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

THE DART MISSION: A BIG, FAST, TERMINAL BALLISTICS EXPERIMENT,

In the last 60 years, a number of spacecraft have been intentionally impacted into celestial bodies.

During the Apollo program of manned exploration of the Moon, nine spacecraft were intentionally impacted into the Moon to provide seismic signals for the seismometers left on the surface by the astronauts: five Saturn IV upper stages (massing around 14,000 kg, impact speed 2.55 km/s) and four lunar ascent modules, after returning the moonwalking astronauts to the command module (2,350 kg at 1.68 km/s). The Lunar Prospector spacecraft was intentionally impacted into the Moon in 1999. In 2009, the LCROSS spacecraft watched as its Centaur upper stage impacted the Moon (2,250 kg at 2.5 km/s). Data collected from observing the plume argued that there was water in the impacted lunar soil. There have been many impacts into the Moon; these ones directly gathered data at the time of impact.

In 2005, the comet Tempel 1 was struck by the Deep Impact spacecraft and the resulting plume was imaged by a companion fly-by spacecraft (372 kg, 10.2 km/s). In 2019 the Hayabusa2 ("Peregrine Falcon 2") mission used an EFP to produce a crater on the asteroid Ryugu (the EFP had 30 cm base diameter, copper liner mass 2.5 kg, 4.5 kg HMX with a plastic binder, speed around 2.1 km/s). Both Hayabusa missions used impactors (5 gram tantalum balls, 300 m/s) to launch material from the surface into a sample return container.

This year we had an exciting addition to this work in impact and large-scale terminal ballistics.

→

Issue #12, December 2022

CONTENTS

GET INVOLVED!

Don't just be a name on a list – be an active part of the scientific community!

See the website www.ballistics.org for a list of committees & projects with contacts.

A spacecraft mission was launched specifically to impact an asteroid and determine how much deflection the impact caused. On November 23, 2021, the DART (Double Asteroid Redirection Test) was launched from Vandenberg Space Force Base (located north of Los Angeles along the California Pacific Coast). The spacecraft was launched by a SpaceX Falcon 9 rocket. It was put on trajectory to arrive at the binary asteroid system of Didymos and Dimorphos on September 26, 2022. Both pervious IBS president Sidney Chocron and myself and our families were fortunate to be there to witness the launch (we are both members of the DART Investigation Team).

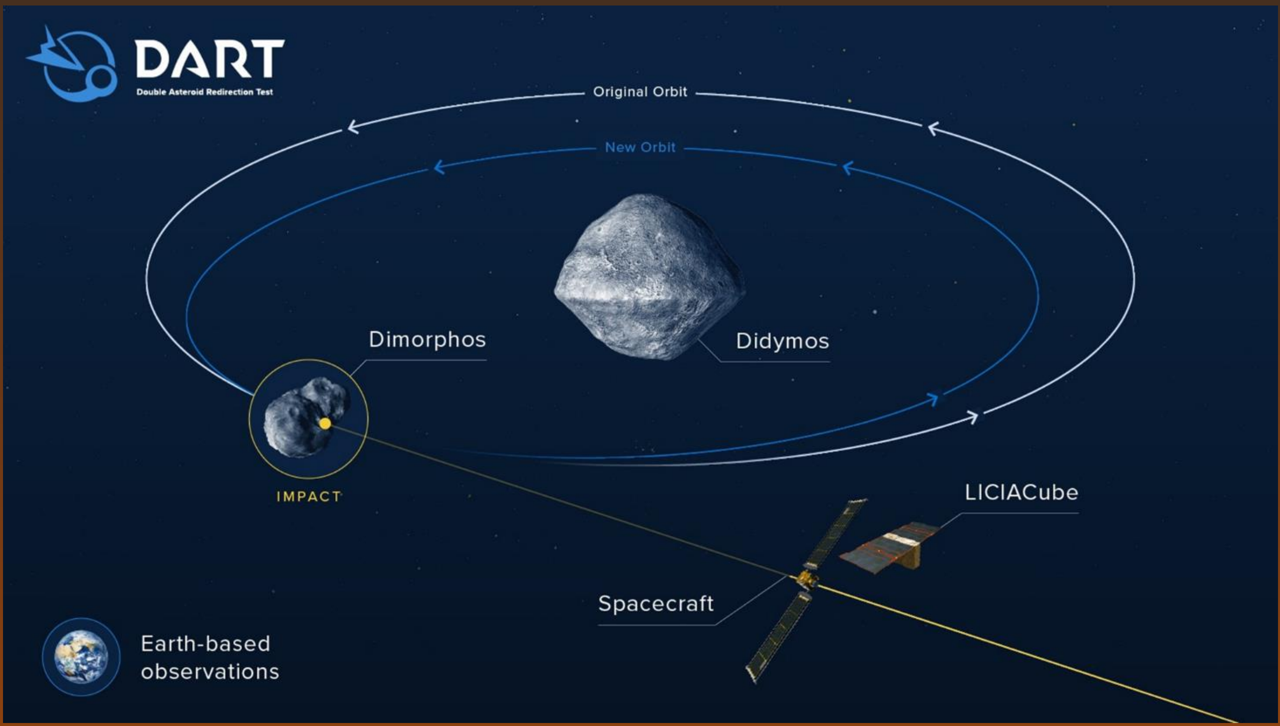


Fig. 1. Schematic of impact experiment plan.

Ten months later, the spacecraft struck Dimorphos at 6.14 km/s. Coincidentally, occurred at 6:14 p.m. Central Time in the US, making it easy for Sidney and I to remember, as we live in Texas. The impact was observed by the Hubble Space Telescope, the new James Webb Space Telescope, and a variety of ground-based telescopes.

Why impact a double asteroid? The moonlet Dimorphos is around 160 meters across and is in an orbit around Didymos, which is around 780 meters across, with a separation of their centers of roughly 1200 meters. It is possible to determine the orbital period from ground telescopes by watching the variation in light intensity as the moonlet passes behind and in front of the asteroid. The moonlet is too small to be seen separately from the asteroid from a distance, but the fact that the period could be determined by the light curve meant that it was not necessary to rendezvous with the asteroid to obtain the results of the impact. The orbital period before the impact was 11 hours and 53 minutes. The change in Dimorphos' orbital period due the impact has been determined to be between 32 and 33 minutes. →

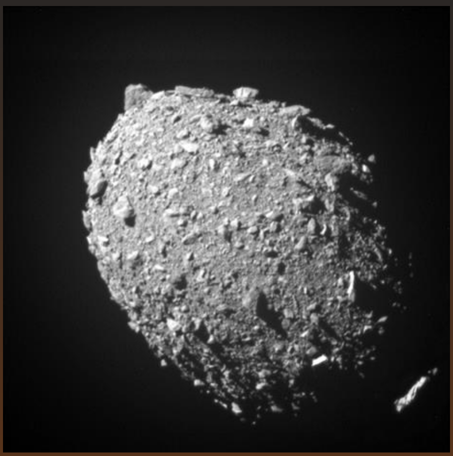


Fig. 2. Photograph of Dimorphos by DART from a distance 68 km, 11 sec. before impact. Image courtesy of NASA/JHU/APL. (Johns Hopkins University Applied Physics Laboratory led the DART mission).

Fig3. Last complete photograph of Dimorphos, taken 2 seconds before impact at a distance of 12 km. The image is 31 meters by 31 meters. Image courtesy of NASA/JHU/APL.

Fig. 4. Post-test image from LICIACube, a cubesat set loose by DART two weeks before impact, showing Didymos (upper) and Dimorphos (lower) with with ejecta liberated by the impact. Courtesy Italian pace Agency (ASI) / NASA.

Beyond this the results are still in an embargo period, but I can outline what is being done to obtain the final results. It is necessary to make some assumptions about the shape of the orbit before and after the impact. The simplest is to assume circular before and elliptical afterward, but in any case it is discovered that the change in orbital speed of Dimorphos is in the low millimeters per second. Lower average orbital speed corresponds to reduced period because the average distance separating Didymos and Dimorphos is less. Next, efforts are being made to estimate the mass of Dimorphos based on the observed shape of the moon and an estimate of its density. Only one side of the Dimorphos was observed, but it is roughly ellipsoidal and a volume is being worked on by the team. Currently the density estimate is coming from assuming a similar density to Didymos: the shape of Didymos was known by radar and the mass of Didymos is known due to it having a satellite.

Once we have the change in speed of Dimorphos and its mass, and the impact speed of the spacecraft (6.14 km/s) and it mass (somewhat over 550 kg), it is then possible to compute momentum enhancement beta, which is the change in momentum of Dimorphos divided by the incoming momentum of the spacecraft. The DART Investigation Team hopes to have an official estimate before the end of the year. Momentum enhancement beta is a measure of how effective and efficient a hypervelocity impact is at deflecting a potentially hazardous asteroid or comet nucleus. The large beta is the better.

→

ESA is planning a mission, named HERA, to go to the Didymos/Dimorphos system to accurately determine the mass of Dimorphos and examine the crater produced by the impact. This mission is scheduled to arrive in 2026.

It is an exciting experiment. In our laboratory, in preparation for this impact we performed an experiment where we impacted a pile of rocks at 5.44 km/s with a 3-cm-diameter aluminum sphere. The rocks were held in place in our vertical pendulum by cement. Though not an exact analog, our measured momentum enhancement beta was 3.4 (+0.1, -1.0). In other words, the crater ejecta exiting the crater added another 240% to the momentum transferred to the target above and beyond the momentum of the impacting spacecraft. If you are interested, the details of our experiment were published before the DART impact in an open access article that can be seen at this link: https://iopscience.iop.org/article/10.3847/PSJ/ac854f/meta

Fig. 5. Target preparation (left), target setup (middle) and impact image from the test with SwRI's large two-stage light gas gun (right). Images courtesy of SwRI (from James D. Walker et al. 2022 Planet. Sci. J. 3 215).

It is an exciting time to be involved in impact and ballistics. Hopefully you will attend the 33rd International Ballistics Symposium next year in Bruges (October 2023) where this and other topics in the broad range of interior, exterior, and terminal ballistics will be presented and discussed. I encourage you to invite colleagues and students who may be interested in our fields of study.

James D. Walker

President, International Ballistics Society

THE ISB IN RENO

by Frederick Rickert II and Thelma Manning

32nd ISB Chairs

The 32nd International Symposium on Ballistics was held in Reno, Nevada, USA at the luxurious Peppermill Reno Resort from May 09 through 13, 2022. The symposium was co-chaired by Dr. Thelma Manning, US Army DEVCOM Armaments Center Propulsion Research and Development Branch and Mr. Frederick Rickert II, US Army DEVCOM Ground Vehicle Systems Center Survivability Research and Development Branch. A total of 168 technical paper were submitted from 24 countries to determine poster and oral presentations. The co-chairs would like to say a huge Thank You to all of the volunteers for reviewing the technical abstracts, reviewing technical paper submissions, and chairing sessions, without their hard work the event would not have been the success it was.

Peppermill Resort and Casino Reno

The Education Committee Chair Dr. Markus Graswald lead the organization of the tutorials on May 9th. The morning sessions covered TB101: Introduction to Terminal Ballistics by Dr. James Walker, SwRI, USA and EB101: Introduction to Exterior Ballistics by Dr Pierre Wey, ISL, France. The afternoon sessions covered EM101: Introduction to Explosion Mechanics by Dr Meir Mayseless, Retired, Israel and IB101: Introduction to Interior Ballistics and the Propellant Charge Design Process by Dr Sebastian Wurster, Fraunhofer ICT, Germany. Thank you to all of the tutorial leads and participants!

Coffee break in the exhibitor hall

ASMII organizers team

Next the symposium Oral and Poster Sessions began on May 10th concluding on May 13th. Dr. Sidney Chocron, SwRI, USA, the Immediate Past President of the society, kicked off the Oral sessions by welcoming all the participant and thanking the many sponsors. The Keynote Address was provided by Dr. Michael Zellner from the US Army DEVCOM Army Research Laboratory providing an in-depth talk titled "Proton Radiography for Electromagnetic Field Visualization: A Multi-Probe Technique to Study Materials at Extreme States while Immersed in Electromagnetic Fields". Dr. Zellner provided a great start to the oral session and it was followed by the General Session that spanned topics from Interior Ballistics, Exterior Ballistics, Launch Dynamics, Vulnerability and Survivability, Terminal Ballistics, Explosion Mechanics, and Emerging Technologies. Another General Session provided the conclusion of the Oral Session to conference. While the Oral Sessions were running the Poster Sessions were also in full swing covering the same topic areas as the Oral Sessions. Overall, very high caliber presentations and posters were provided. These gave the basis for very fruitful discussions on advancing the state of the art for the ballistics community. Thank you to all of the participants in the Oral and Poster sessions!

Symposium Dinner

Ernie Baker at the award presentation

The symposium concluded with the presentation of awards. Congratulations to all.

Finally, we would like to invite you to the 33rd International Symposium on Ballistics (ISB) that will be taking place in Bruges, Belgium, during 16-20 October 2023.

Thank you for making the 32nd International Symposium on Ballistics a memorable experience.

AWARD WINNERS

The International Ballistics Society assisted by QinetiQ and the South African Ballistics Organization awards the best authors in different categories during the International Symposium on Ballistics.

JACK RIEGEL STUDENT AWARDS

The Jack Riegel Student Award is awarded to the best papers from students presenting their work at the ISB (full eligibility requirements can be found on the IBS website).

At the 32nd ISB in Reno the following students were awarded:

- **Sebastian Göhler**, Germany (not present)

Category: Explosion Mechanics

Title of Paper: *Numerical and experimental investigations on behind armor effects by shaped charges*

University: University of Applied Sciences Koblenz, Germany

- **Mohamed Dhouibi**, Tunisia

Category: Interior Ballistics

Title of Paper: *Quantification of the wear effects on the performance of small calibre guns*

University: Royal Military Academy, Belgium

Jack Riegel Student Award presented to Mohamed Dhouibi (right) by Markus Graswald and Roxy Riegel

- **Abdelhafidh Moumen**, Belgium

Category: Launch Dynamics

Title of Paper: *On the Quantitative Investigation of the Intermediate Ballistics: Velocity Measurement of the Muzzle Flow*

University: Université Libre de Bruxelles, Belgium

Jack Riegel Student Award presented to Abdelhafidh Moumen (right) by Markus Graswald and Roxy Riegel

LOUIS AND EDITH ZERNOW AWARD

The Louis and Edith Zernow Award in Ballistics is presented to the author(s) of the paper containing the best advancement made in the fundamental nature of ballistics and presented within the proceedings of the International Symposium on Ballistics.

At the 32nd ISB in Reno the award went to

M. Becker, A. Klavzar, T. Wolf and M. Renck

for their paper

Data-Driven Prediction of Plate Velocities and Plate Deformation of Explosive Reactive Armor

Louis and Edith Zernow Award presented to Anreaa Klavzar (middle) by Ernest Baker and Thelma Manning

ROSALIND & PEI CHI CHOU AWARD

The Rosalind and Pei Chi Chou Award for Young Authors is given to authors 35 years of age or younger at the time of the Symposium for the best original contribution to the ballistic sciences (full eligibility requirements can be found on the ISB website).

At the 32nd ISB in Reno the award was presented to

C. Franzmann

for his paper

Experimental Determination of Pitch Damping Coefficients Using a Wire Suspension

Rosalind and Pei Chi Chou Award presented to Christian Franzmann (right) by Paul Locking

NEIL GRIFFITHS AWARD

The Griffiths Award is presented to the author(s) of the paper judged to have made the most significant contribution to a shaped charge technology at the International Symposium on Ballistics.

At the 32nd ISB in Reno the award was presented to

A. Collé, J. Limido, S. Dalle Piagge and F. Paintendre

for their paper

Innovative Meshless Approach for Shaped Charges Modelling vs Explosive Reactive Armor

Neil Griffiths Award presented to Anthony Collé (right) by William Huntington-Thresher

SABO AWARD

The South African Ballistics Organisation (SABO) Award gives recognition to the author(s) of the best poster as displayed and presented at the International Symposium on Ballistics.

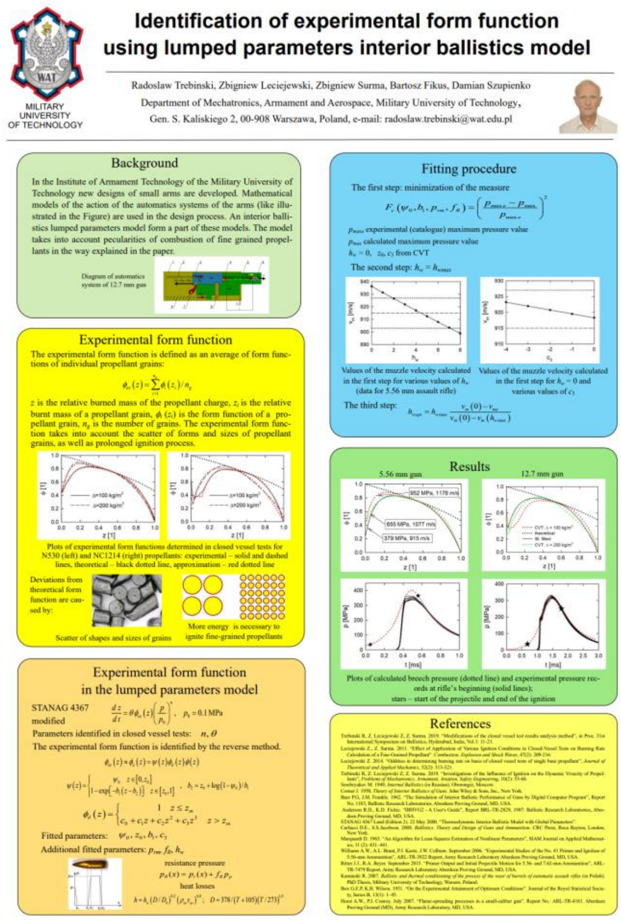
At the 32nd ISB in Reno the award was presented to

R. Trebinski, Z. Leciejewski, Z. Surma, B. Fikus and D. Szupienko

for their poster titled

Identification of experimental form function using lumped parameters interior ballistics models

SABO Award presented to Radoslaw Trebinski (right) by Rudolf Gouws



Award-winning poster by R. Trebinski et. al.; click on the photo to open the poster as .pdf on the IBS website.

Congratulations to all award winners!

Introducing the Communications Committee

by Thomas Hartmann

Chair of the Communications Committee

The Communications Committee is a standing committee that is responsible for producing the newsletter and handling press releases, conference advertisements, etc.

While for the last two years all the work had been done by Amy Pullen and myself, we have gained two additional members at the Reno symposium. Hence, it seems about time to briefly introduce ourselves to the readers.

The Communications Committee, i.e. the people who must be blamed for this newsletter, currently consists of:

Thomas Hartmann
(NUMERICS, Germany)

- Committee Chair -

Amy Pullen
(New Zealand Defence Force)

David Reinecke
(CSIR, South Africa)

Andreas Klavzar
(ISL, Germany / France)

However, I have to point out that while we are the ones that put together the pieces, it is mainly the contributions of others that actually make a newsletter. We depend on the committee chairs' inputs and especially on those members, who write symposium reports, lab reviews, technical notes, etc. We would therefore like to take this opportunity to express our special thanks to all the contributors to the past and to the present issue(s) of the IBS Periodic Bulletin.

In order to keep the IBS newsletter alive, we will also need such contributions in the future. So, do not hesitate to bring yourself in. Lab reviews, symposium side stories, book reviews and of course technical notes are welcome at any time. It is not for us – it is for the entire community and the entire community will thank you.

Finally, let me pose you a riddle: What is the shortest word in the English language that contains the letters: a, b, c, d, e, f?

The answer is: "feedback". Please don't forget that communication is not a one-way process and that feedback is one of the essential elements of good communication.

For contributions, feedback and suggestions, but also if you want to become a member of our team, please send an email to communications@ballistics.org.

Definition of a Member of Good Standing

by Clive Woodley

Chair of the Membership Committee

The Constitution of the International Ballistics Society (IBS) refers to a member being of "good standing". However, there is no definition of the meaning of "good standing". The Member ship Committee (MC) was tasked by the Board to propose a suitable definition and the following was agreed by the Board at the 32nd International Symposium on Ballistics at Reno in May 2022.

A member of good standing:

- Must have logged in to the IBS website.
- Follows and supports the objectives and principles of the IBS.
  - Actions which are construed to be against these principles include the following:
    - Bringing the IBS or the International Symposia on Ballistics (ISB) into disrepute
    - Defaming either the IBS or the ISB
    - Committing the IBS or ISB to any actions or expenditure without authorisation.
- Must be fully paid-up and have no outstanding invoices.

For the purposes of eligibility to vote on any IBS matters then the person must have been a member of the IBS for a minimum of 12 months.

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

THE NEIL GRIFFITH AWARD

by Ian Cullis

Chair of the Griffith Award Committee

The Griffiths Award is presented to the author(s) of the paper judged to have made the most significant contribution to a shaped charge technology at the International Symposium on Ballistics. It was created in memory of Neill Griffiths who was head of the Explosives Technology Department at the Royal Armament Research and Development Establishment at Fort Halstead in the UK, the fore runner of Dstl and QinetiQ.

Neill Griffiths started his career working in explosives and was awarded an Order of the British Empire (OBE) for his work on the warhead systems to defeat Improvised Explosive Devices (IEDs) that the British Army had to cope with during the troubles in Northern Ireland in the 1970s. He later led much of the early work in shaped charges and was a keen supporter of the introduction of numerical simulation, which I was tasked with introducing to Fort Halstead in 1978. A Welshman he was great fun to work with had a disarming sense of humour.
Neill was a keen supporter of the International Symposium on Ballistics from its inception and was a founding member of the International Ballistics Committee. He was one of the first to recognise the need for a more formal organisation that became the Society.
Sadly, Neil died not long after he had retired, and he is still very much missed at Fort Halstead. The Award was created in his memory in recognition of his pioneering work in the UK in shaped charge technology. He was central to the development of the first tandem warhead to defeat the complex armours that began to appear on tanks and armoured vehicles in the late 80s.

The Griffiths Awards, from the first made at Jerusalem at the 15th ISB in 1995 with a paper by Karpp et al entitled "A Technique for Estimating the Strength of Materials in Stretching Shaped-Charge Jets", to the most recent in 2022 at the 32nd ISAB in Reno by Collé et. al., entitled "Innovative Meshless Approach for Shaped Charges Modelling vs Explosive Reactive Armor", cover the full range of experimental and simulation methods to understand and design shaped charges for all kinds of applications in both the military and civilian fields. The titles of

the award-winning papers clearly show that the technology of shaped charges is constantly developing and evolving. As the challenges posed by the constant evolution of threats and targets continues to increase, the demand for ever more sophisticated weapons technologies to defeat them will continue to require clever applications of multiple shaped charge concepts.
Have a look on the website at the titles of the winners of the Griffiths Award and you will quickly see that this is not a dead-end research area! Far from it!
If you are working in shaped charge technologies, then think about submitting a paper to the next ISB and you never know you might be the next Griffiths Award winner!

CHOU AWARD COMMITTEE CHAIR STATEMENT

by Paul Locking

Chair of the Chou Award Committee

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 ISB by encouraging young authors in all fields of ballistics to submit papers and to attend the symposium.

To be eligible for the Award, 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 significant contribution to the paper. Further, the Young Author must register at the Symposium and must present the paper (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.

Can all Bruges authors please consider if your proposed paper is open for this valued award.

Award application forms need to be submitted shortly after submission of the final paper.

Please contact myself for more details at:
ChouAward@ballistics.org

SITE SELECTION COMMITTEE

by Dennis W. Baum

Chair of the Site Selection Committee

The venue for the 34th ISB to be held in North America in spring of 2025 has yet to be determined. Candidate venues are now being considered and a recommendation to the IBS board is planned for October of this year. A decision at that time will be shared with the IBS membership.

Also, looking forward to seeing everyone in Bruges, 16-20 October 2023.

NOMINATIONS COMMITTEE CHAIR STATEMENT

by Paul Locking

Chair of the Nominations Committee

At the Reno Symposium, we had three members elected to the IBS Main Board, these being: Prof. Pengwan Chen, James Walker and Clive Woodley.

We have at the forthcoming symposium at Bruges, Belgium, 16-20 October 2023, two Main Board positions open for election.

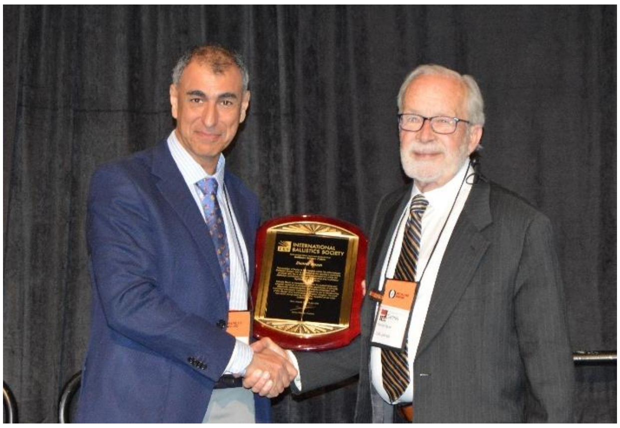
Election voting will be open to members as usual, by E-Voting beforehand and also by Voting in person at the symposium itself.

So I am calling for all members to consider if they are interested in standing for this Main Board position or to be nominated by another to stand.

If this is the case can you please send me details by email to: nominations@ballistics.org

PROMOTION TO BALLISTIC SCIENCE FELLOW

The Ballistic Science Fellow is awarded to those individuals who have distinguished themselves within the ballistics community. At the last ISB, the Board of Directors decided that this honor goes to **Dennis Baum**.



Dennis W. Baum (right) receiving his promotion to Ballistic Science Fellow from Sidney Chocron

LAB REVIEW

EXPLOSIVES ENGINEERING PROGRAM AT NEW MEXICO TECH

by Seokbin Lim
New Mexico Tech, USA

Energetic materials are highly useful to a broad sector of our society. These materials may be dangerous and destructive. However, more often, energetic and explosive materials are used to support society, to defend the nation, and to advance scientific inquiry.

New Mexico Tech's explosives engineering program is one of the most unique explosives engineering programs in the US. This program is specially designed to train prospective students who wish to study commercial explosives-related, fundamental extreme physics or national defense research fields. While many explosives engineering programs in the nation are designed to serve the mining or mineral extraction industries, the explosives engineering program at New Mexico Tech differentiates from them by emphasizing the theory, experimental, science/engineering, and physics behind the energetic materials and the associated extreme dynamic environment.

The inception of the formal Explosives Engineering program at New Mexico Tech was driven by an agreement between Sandia National Laboratories (SNL) and New Mexico Tech in 2000. Many of the explosive experts in the SNL weapons complex were retiring and there was a need to educate a new workforce. The program was designed to address the needs of both SNL and Los Alamos National Laboratory, which needed employees with extensive knowledge on how to handle/test energetic materials and to understand the dynamics in the extreme environment. Since the national labs do not operate a formal education program and they are not degree-awarding institutes, building a formal education program to provide explosives education to potential students (and staff members) was critically important.

This agreement between the two organizations was pivotal in expanding the capacity and increasing the quality of New Mexico Tech's explosives program. Prior to that point, the Explosives Engineering program was not nearly as robust and was not specifically geared towards national defense-related applications.

Over the years, the Explosives Engineering program in the Department of Mechanical Engineering at New Mexico Tech has continued to expand by hiring more full-time faculty specializing in explosives-related research, and by adding more advanced degree programs ranging from the undergraduate minor program to the PhD program specialization in intelligent energetic systems. Over 150 advanced degrees with specialization in the Explosives Engineering have been awarded since 2002, and currently,

over 40 students from both in and out of state, including the national lab staff, are enrolled in this program and pursuing their academic goals.

Explosives engineering is an intellectually rich area for scientific and engineering inquiry. Explosives detonation by its nature begs for improved mathematical modeling and sophisticated analytical advancement. Explosives are used in a wide range of applications, ranging from launching spacecraft to sources of quantum energy for micro-electro-mechanical devices. The demand for professionals in the area of explosives engineering has therefore increased notably, and includes the need for personnel with expertise in many topics. Since most of these fields are inherently multi-disciplinary, to develop a strong curriculum in the area of explosives engineering, collaborative effort between scholars of different disciplines is essential.

New Mexico Tech's explosives program is afforded unique potential for synergistic activities with the Energetic Materials and Research Test Center (EMRTC) on campus.

EMRTC is one of the numerous research divisions of New Mexico Tech. This facility has over 70 years of expertise in explosives research and testing, and specializes in the analysis of energetic materials for corporate, government, and university clients. It houses a 40-mile^2 field laboratory in the mountains adjacent to the New Mexico Tech campus, including over 30 test sites comprising explosives storage, sled track, shock-tube, large gun range, melt-casting facilities, etc., and other research facilities, allowing for a complete spectrum of research and testing activities in the field of explosives science and technology.

Seokbin (Bin) Lim, PhD
Pete V. Domenici Endowed Associate Professor

Department of Mechanical Engineering
New Mexico Tech, 801 Leroy Place, Socorro, NM 87801

On Brittle Fracture Conoid Angles

by Z. Martinez-Guo
Idaho National Laboratory, Idaho Falls, USA

Introduction

The angle of ceramic conoid fracture is a matter of ongoing debate. Earlier works analyzed the fracture response of brittle materials under quasi-static normal indentation via Hertzian contact analysis [1–5]. The maximum principal tensile stresses under indentation were shown to occur along an approximate 65° trajectory to the surface normal, concurring with experimental observations on brittle substrate indentation. To this end, glass is a good choice of transparent material for examining the crack propagation and fracture response without catastrophic failure of the entire specimen.

With the advent of ceramics as candidates for ballistic protection systems, later studies began focusing on their impact response. Florence and Wilkins provided extensive studies on the ballistic response of ceramic-faced light armor systems [6–12]. In what is now known as the Florence model, a constant conoid angle of 63° was sufficiently accurate in predicting ballistic limit velocities of ceramic-faced bicomponent systems. Subsequent studies used 63–68° conoid angles with varying degrees of success [13–16].

In later works studying the spherical impact of brittle materials [17–20], this conoid angle was found to be dependent on the impact velocity V_s, decreasing from a quasi-static Hertzian angle of 63° to about 25° at ballistic velocities above 300 m/s. Some works have hypothesized that a rate-dependent change in Poisson's ratio was the reason for a decrease in fracture conoid angles [20,21]. However, a rigorous mathematical analysis of surface waves by McDonald & Satapathy [22] showed that, under compressive loading by a flat punch, the angle decreases from 67° under quasi-static indentation to 55° under dynamic impact, even with a rate-independent Poisson's ratio.

On the other hand, Fellows & Barton [23] developed a model for flat projectile impact on ceramics, using a linearly-increasing conoid angle from 34° to 68° at high impact velocities above 1000 m/s. These trends were collated from prior works by Hetherington et al.

These experimental results, while enlightening, were often complicated by the multitude of interactions between the projectile and the ceramic target. Notably, plastic deformation and projectile erosion during the initial phase of impact result in complex stress states that are often difficult to solve from a pure mechanics standpoint. Moreover, the broad range of projectile geometries and projectile-target pairs, along with the dearth of ballistic experimental data in open literature, make it difficult to extract discernible and quantifiable trends for performance prediction.

Recent works have sought to isolate the dependence of conoid angle on impact velocity [24–26]. However, these conclusions are often complicated by the influence of free-surface boundary conditions on their post-mortem fracture patterns and brittle failure response. Computational simulations themselves are also sensitive to solver algorithms, material models, and mesh geometries [25,27].

The problem of a velocity-dependent fracture conoid angle is still not fully resolved, and conclusions of prior studies by their respective authors are somewhat in disagreement. In this bulletin, we briefly summarize the velocity-dependent trends of fracture conoid angles as collated from past experimental works. A simplified closed-form equation for a velocity-dependent conoid angle is used to solve the modified Florence model as presented by Ben-Dor et al [28]. Ballistic limit predictions were performed for experimental data by Wilkins [29] and Mayseless [30].

PRIOR EXPERIMENTAL STUDIES

Quasi-static conoid angles from prior studies were compiled for several glasses [31–40] and ceramics [41–46] loaded by indenters of different materials and geometries. The average angle θ_0 across all brittle materials tested was 64.3±4.8°.

Fracture conoid measurements under dynamic loading are less common in open literature. Chaudhri [20] used steel, tungsten carbide (WC), soda-lime glass, and sapphire spheres to impact silica glass. Similarly, Knight et al [17] used steel spheres to impact Pyrex® glass targets. Janotti et al [47] impacted borosilicate glass with conical-nosed brass rods at different angles of obliquity.

For ceramics, Akimune [18] shot steel and partially stabilized zirconia (PSZ) spheres on silicon carbide (SiC) targets. Iyer [48] used WC spheres to impact SiC targets. Oh & Shin [19] tested steel and SiC spheres on SiC plates. Aydelotte et al [49] shot boron carbide (B_4C) targets with WC spheres. LaSalvia [50] provided data for spheres impacting PAD B_4C. Toussaint et al [24] impacted free-standing alumina tiles (99.5% purity) with steel spheres. Only data for the angle at the contact region (i.e. β in Ref. [24]) was collated. Angles collated from the above studies are given in Figure 1.

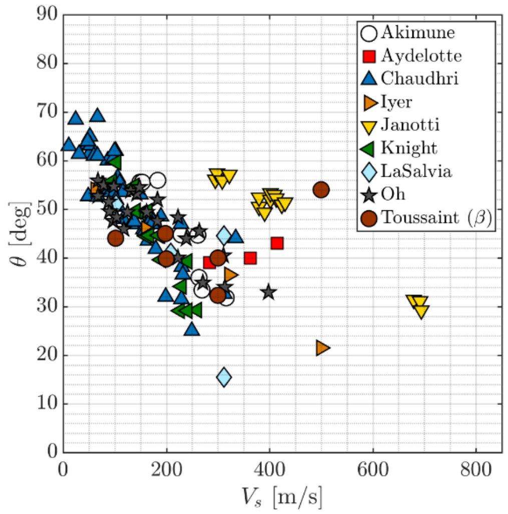


Figure 1: Conoid angle θ against impact velocity V_s as compiled from prior experimental studies.

CLOSED-FORM EQUATION

Ben-Dor et al modified the Florence model to include the ceramic fracture effects based on momentum and energy conservation:

$$V_{bl} = \gamma_1\sqrt{2\pi h_1(R_p + a)/(m_p \cos\theta)} + \gamma_2\sqrt{\pi a^2 h_2(m_p + m_1 + m_2)/m_p}$$

$$a = R_p + h_1 \tan\theta$$

$$m_1 = \frac{1}{3}\pi h_1(R_p^2 + aR_p + a^2)\rho_1$$

$$m_2 = \pi a^2 h_2 \rho_2$$

$$\gamma_2^2 = \varepsilon_2\sigma_2/0.91$$

In the above set of equations, R_p is the projectile radius, h is the component thickness, and σ and ε are the failure stress and strain respectively. Subscripts 1 and 2 denote the ceramic face and the ductile backing, respectively. In their model, Ben-Dor et al used a constant 45° angle for θ based on a best-fit regression to Wilkins' data [29], and fitted a γ_1 value of 865 $(N/m)^{1/2}$. For an Al6061-T6 backing, γ_2 has a value of 15,797 $Pa^{1/2}$.

In order to reconcile the measured θ_0 of 63° with an impact velocity-dependent fracture conoid angle i.e. $\theta = \theta(V_s)$, the following conditions have to be satisfied:

i) A quasi-static Hertzian angle θ_0;
ii) A constant dynamic angle θ_d at high V_s;
iii) A defined transition regime from θ_0 to θ_d.

Prior studies [23,51,52] used piecewise functions of impact velocity V_s; we opt instead for a sigmoidal function

$$\theta(V_s) = \frac{(\theta_0 - \theta_d)}{1 + \exp[X_1(V_s - X_2)]} + \theta_d$$

As presented in its current form, the same curve can increase or decrease depending on the relative values of the quasi-static angle θ_0 and the dynamic angle θ_d. Based on the ensemble of experimental data (Figure 1), we assume that the conoid angle decreases with impact velocity.

Using $\theta_0 = 63°$, $\theta_d = 45°$ (as per [28]), and $\gamma_1 = 835\ (\mathrm{N/m})^{1/2}$, the predicted versus experimental V_{bl} values [29,30] are given in Figure 2.

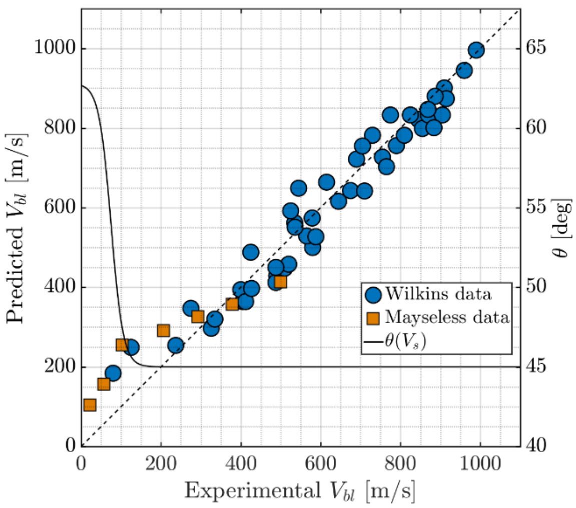


Figure 2: V_{bl} prediction with a velocity-dependent conoid angle vs. experimental data. Solid line shows sigmoidal $\theta(V_s)$ function.

Compared to Ref. [28] where a constant fracture conoid angle of 45° was used, the closed-form equation gives a 3% improvement in prediction accuracy (metric being residual sum of squares). This improvement is marginal but should be considered with the context of Ben-Dor et al's model using best-fit regression values for ballistic limit predictions.

In essence, the closed-form equation presented captures the experimentally observed behavior of an impact velocity-dependent change in fracture conoid angle. The same sigmoidal form of $\theta(V_s)$ further allows for more flexibility in modeling either an increase or decrease in the fracture conoid angle.

ACKNOWLEDGMENT

Work was supported through the INL Laboratory Directed Research & Development (LDRD) Program under DOE Idaho Operations Office Contract DE-AC07-05ID14517.

REFERENCES

[1] F.C. Frank, B.R. Lawn, On the theory of Hertzian fracture, Proc. R. Soc. London. Ser. A. Math. Phys. Sci. 299 (1967) 291–306. doi:10.1098/rspa.1967.0137.

[2] B.R. Lawn, T.R. Wilshaw, N.E.W. Hartley, A computer simulation study of Hertzian cone crack growth, Int. J. Fract. 10 (1974) 1–16. doi:10.1007/BF00955075.

[3] K. Zeng, K. Breder, D.J. Rowcliffe, The Hertzian stress field and formation of cone cracks—I. Theoretical approach, Acta Metall. Mater. 40 (1992) 2595–2600. doi:10.1016/0956-7151(92)90328-C.

[4] K. Zeng, K. Breder, D.J. Rowcliffe, The Hertzian stress field and formation of cone cracks—II. Determination of fracture toughness, Acta Metall. Mater. 40 (1992) 2601–2605. doi:10.1016/0956-7151(92)90329-D.

[5] C. Kocer, R.E. Collins, Angle of Hertzian cone cracks, J. Am. Ceram. Soc. 81 (1998) 1736–1742. doi:10.1111/j.1151-2916.1998.tb02542.x.

[6] A.L. Florence, T.J. Ahrens, Interaction of projectiles and composite armor (AMRA CR 67-05F), 1967.

[7] A.L. Florence, Interaction of Projectiles and Composite Armor Part II (AMMRC CR 69-15), 1969.

[8] M. Wilkins, C. Honodel, D. Sawle, An Approach to the Study of Light Armor (UCRL-50284), Livermore, CA, 1967.

[9] M.L. Wilkins, Second Progress Report of Light Armor Program (UCRL-50349), 1967.

[10] M.L. Wilkins, Third Progress Report of Light Armor Program (UCRL-50460), Livermore, CA, 1968.

[11] M.L. Wilkins, C.F. Cline, C.A. Honodel, Fourth progress report of light armor program (UCRL-50694), (1969) 56. doi:10.2172/4173151.

[12] M.L. Wilkins, R.L. Landingham, C.A. Honodel, Fifth Progress Report of Light Armor Program (UCRL-50980), 1970.

[13] R.L. Woodward, A simple one-dimensional approach to modelling ceramic composite armour defeat, Int. J. Impact Eng. 9 (1990) 455–474. doi:10.1016/0734-743X(90)90035-T.

[14] J.G. Hetherington, The optimization of two component composite armours, Int. J. Impact Eng. 12 (1992) 409–414. doi:10.1016/0734-743X(92)90145-J.

[15] I.S. Chocron Benloulo, V. Sánchez-Gálvez, A new analytical model to simulate impact onto ceramic/composite armors, Int. J. Impact Eng. 21 (1998) 461–471. doi:10.1016/S0734-743X(98)00006-2.

[16] M.M. Shokrieh, G.H. Javadpour, Penetration analysis of a projectile in ceramic composite armor, Compos. Struct. 82 (2008) 269–276. doi:10.1016/j.compstruct.2007.01.023.

[17] C.G. Knight, M. V. Swain, M.M. Chaudhri, Impact of small steel spheres on glass surfaces, J. Mater. Sci. 12 (1977) 1573–1586. doi:10.1007/BF00542808.

[18] Y. Akimune, Hertzian cone crack in SiC caused by spherical particle impact, J. Mater. Sci. Lett. 9 (1990) 659–662. doi:10.1007/BF00721795.

[19] S.Y. Oh, H.S. Shin, Effect of Particle Impact Velocity on Cone Crack Shape in Ceramic Material, Key Eng. Mater. 297–300 (2005) 1321–1326. doi:10.4028/www.scientific.net/kem.297-300.1321.

[20] M.M. Chaudhri, Dynamic fracture of inorganic glasses by hard spherical and conical projectiles, Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 373 (2015). doi:10.1098/rsta.2014.0135.

[21] D. Bahat, M.R. Sharpe, Dependence of Hertzian fracture angle on Poissons ratio and indentation techniques, J. Mater. Sci. 17 (1982) 1167–1170. doi:10.1007/BF00543537.

[22] J. McDonald, S. Satapathy, Surface Wave Effects on the Ballistic Response of Brittle Materials, Procedia Eng. 103 (2015) 538–545. doi:10.1016/j.proeng.2015.04.070.

[23] N.A. Fellows, P.C. Barton, Development of impact model for ceramic-faced semi-infinite armour, Int. J. Impact Eng. 22 (1999) 793–811. doi:10.1016/S0734-743X(99)00017-2.

[24] G. Toussaint, I. Polyzois, Steel spheres impact on alumina ceramic tiles: Experiments and finite element simulations, Int. J. Appl. Ceram. Technol. 16 (2019) 2131–2152. doi:10.1111/ijac.13318.

[25] E.C. Simons, J. Weerheijm, G. Toussaint, L.J. Sluys, An experimental and numerical investigation of sphere impact on alumina ceramic, Int. J. Impact Eng. 145 (2020) 103670. doi:10.1016/j.ijimpeng.2020.103670.

[26] M.K. Khan, M.A. Iqbal, V. Bratov, N.F. Morozov, N.K. Gupta, An investigation of the ballistic performance of independent ceramic target, Thin-Walled Struct. 154 (2020) 106784. doi:10.1016/j.tws.2020.106784.

[27] M.R.I. Islam, J.Q. Zheng, R.C. Batra, Ballistic performance of ceramic and ceramic-metal composite plates with JH1, JH2 and JHB material models, Int. J. Impact Eng. 137 (2020) 103469. doi:10.1016/j.ijimpeng.2019.103469.

[28] G. Ben-Dor, A. Dubinsky, T. Elperin, Improved Florence model and optimization of two-component armor against single impact or two impacts, Compos. Struct. 88 (2009) 158–165. doi:10.1016/j.compstruct.2008.02.015.

[29] M.L. Wilkins, Mechanics of penetration and perforation, Int. J. Eng. Sci. 16 (1978) 793–807. doi:10.1016/0020-7225(78)90066-6.

[30] M. Mayseless, W. Goldsmith, S.P. Virostek, S.A. Finnegan, Impact on ceramic targets, J. Appl. Mech. Trans. ASME. 54 (1987) 373–378. doi:10.1115/1.3173022.

[31] F.C. Roesler, Indentation Hardness of Glass as an Energy Scaling Law, Proc. Phys. Soc. Sect. B. 69 (1956) 55–60. doi:10.1088/0370-1301/69/1/307.

[32] J.P.A. Tillett, Fracture of Glass by Spherical Indenters, Proc. Phys. Soc. Sect. B. 69 (1956) 47–54. doi:10.1088/0370-1301/69/1/306.

[33] J.J. Benbow, Cone Cracks in Fused Silica, Proc. Phys. Soc. 75 (1960) 697–699.

doi:10.1088/0370-1328/75/5/308.

[34] A.G. Mikosza, B.R. Lawn, Section-and-Etch Study of Hertzian Fracture Mechanics, J. Appl. Phys. 42 (1971) 5540–5545. doi:10.1063/1.1659977.

[35] T.R. Wilshaw, The Hertzian fracture test, J. Phys. D. Appl. Phys. 4 (1971) 316. doi:10.1088/0022-3727/4/10/316.

[36] J.S. Nadeau, Hertzian Fracture of Vitreous Carbon, J. Am. Ceram. Soc. 56 (1973) 467–472. doi:10.1111/j.1151-2916.1973.tb12525.x.

[37] H. Conrad, M.K. Keshavan, G.A. Sargent, Hertzian fracture of Pyrex glass under quasi-static loading conditions, J. Mater. Sci. 14 (1979) 1473–1494. doi:10.1007/BF00549324.

[38] M.M. Chaudhri, P.A. Brophy, Single particle impact damage of fused silica, J. Mater. Sci. 15 (1980) 345–352. doi:10.1007/BF02396782.

[39] R. Mouginot, D. Maugis, Fracture indentation beneath flat and spherical punches, J. Mater. Sci. 20 (1985) 4354–4376. doi:10.1007/BF00559324.

[40] M.M. Chaudhri, C. Liangyi, The orientation of the Hertzian cone crack in soda-lime glass formed by oblique dynamic and quasi-static loading with a hard sphere, J. Mater. Sci. 24 (1989) 3441–3448. doi:10.1007/BF02385722.

[41] N.P. Padture, B.R. Lawn, Toughness Properties of a Silicon Carbide with an in Situ Induced Heterogeneous Grain Structure, J. Am. Ceram. Soc. 77 (1994) 2518–2522. doi:10.1111/j.1151-2916.1994.tb04637.x.

[42] N.P. Padture, B.R. Lawn, Contact Fatigue of a Silicon Carbide with a Heterogeneous Grain Structure, J. Am. Ceram. Soc. 78 (1995) 1431–1438. doi:10.1111/j.1151-2916.1995.tb08834.x.

[43] L. An, H.M. Chan, N.P. Padture, B.R. Lawn, Damage-resistant alumina-based layer composites, J. Mater. Res. 11 (1996) 204–210. doi:10.1557/JMR.1996.0025.

[44] M. Belmonte, S.K. Lee, Contact damage in alumina reinforced with silicon carbide platelets, J. Mater. Sci. Lett. 16 (1997) 379–381. doi:10.1023/A:1018554629979.

[45] C. Evci, M. Gülgeç, Effective damage mechanisms and performance evaluation of ceramic composite armors subjected to impact loading, J. Compos. Mater. 48 (2014) 3215–3236. doi:10.1177/0021998313508594.

[46] S.K. Lee, S. Wuttiphan, B.R. Lawn, Role of Microstructure in Hertzian Contact Damage in Silicon Nitride: I, Mechanical Characterization, J. Am. Ceram. Soc. 80 (2005) 2367–2381. doi:10.1111/j.1151-2916.1997.tb03129.x.

[47] P. Jannotti, B. Aydelotte, B. Schuster, Time-Resolved Terminal Ballistic Response of Glass, in: Proc. 30th Int. Symp. Ballist., 2017.

[48] K.A. Iyer, Relationships between multiaxial stress states and internal fracture patterns in sphere-impacted silicon carbide, Int. J. Fract. 146 (2007) 1–18. doi:10.1007/s10704-007-9108-z.

[49] B. Aydelotte, P. Jannotti, M. Andrews, B. Schuster, A Comparison of Damage in Glass and Ceramic Targets, in: 2017: pp. 1–12. doi:10.1002/9781119321682.ch1.

[50] J.C. LaSalvia, M.J. Normandia, H.T. Miller, D.E. MacKenzie, Sphere Impact Induced Damage in Ceramics: II. Armor-Grade B4C and WC, in: n.d.: pp. 183–192. doi:10.1002/9780470291276.ch21.

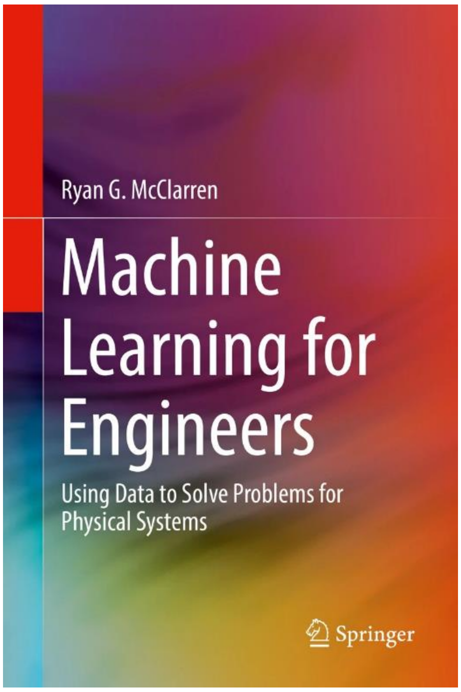
[51] S. Feli, M.H. Yas, M.R. Asgari, An analytical model for perforation of ceramic/multi-layered planar woven fabric targets by blunt projectiles, Compos. Struct. 93 (2011) 548–556. doi:10.1016/j.compstruct.2010.08.025.

[52] H. Shanazari, G. Liaghat, S. Feli, H. Hadavinia, Analytical and experimental study of high-velocity impact on ceramic/nanocomposite targets, J. Compos. Mater. 51 (2017) 3743–3756. doi:10.1177/0021998317692658.

BOOK REVIEW

by A. Klavzar
French-German Research Insitute of Saint-Louis, Germany

In this issue we present a book about the possible applications of machine learning methods for engineering problems.



AUTHOR: **Ryan G. McClarren**

PUBLISHER: **Springer Cham**

PAGES: **247**

FORMAT: **Hardcover, Softcover, eBook**

ISBN (Hardcover): **978-3-030-70387-5**

It is the first edition of a book published in 2021 by Prof. Ryan McClarren, Associate Professor of Aerospace and Mechanical Engineering at the University of Notre Dame. Amongst other positions Prof. McClarren was research scientist at the Los Alamos National Laboratory in the Computational Physics and Methods group.

As written in the preface is the aim to show engineering and science students how machine learning methods can be applied to their field of research, as his connection is often not seen. I can say as a rather experienced scientist in terminal ballistics with minor knowledge in machine learning methods during reading the book I found a lot examples which I considered to be applicable to our scientific discipline.

The book is separated in three main parts, Fundamentals, Neural Networks and Advanced topics plus appendices with implementation examples. Each chapter starts with an abstract and keywords, what makes it easy to scroll through the book searching for a certain problem. After each sub-chapter a summary is given.

The "Fundamentals" part of the book is divided in 4 sub-chapters:

- The general concepts of supervised and unsupervised learning.
- Linear models for regression and classification, which comes with the interesting examples of an object in free fall or how to determine governing equations from data.
- Decision trees and random forests for regression and classification with the (especially for me) interesting example how the result of a numerical simulation can be predicted. The example is the simulation of a laser driven shock launched into a beryllium disc.
- Finding structure within a data set – for sure helpful for anyone analyzing big data sets

In the second part ("Neural Networks") the theory and applications of feed forward neural networks is developed and at the end explained with an application example. For the theoretical explanation for sure maths is needed, still, one can read the chapter without trying to comprehend all the formulas and will still understand at the end the basic concept.

The example at the end explains how neural networks can for example be used to predict the strength of concrete as a function of age and ingredients from a data set with the help of a neural network.

In the "Advanced Topics" part different methods for certain problems are explained:

- Recurrent neural networks which are tailored to solve problems where the inputs are time serious data. As an example, it is shown how the frequency and shift of an oscillating signal can be found.
- Long short-term memory networks, used in the example to determine the behavior of a cart mounted pendulum.
- Autoencoders used for example for data reduction from a physics simulation and finally reinforcement learning with policy gradients, applied to control the cooling of glass in an industrial process.

To summarize, all the applications and examples in the book are related to engineering problems, and I guess anyone working experimentally or with numerical simulation will find an example which can is related to his work.

Still, reading the book once gives only an overview on the possible applications and explains the general methods how the machine learning method works.

After each chapter references are given for those who want to dig deeper in a certain subject.

DID YOU KNOW…?

…that in 2005, the UK Ministry of Defence issued soldiers special antimicrobial underwear that can be worn up to three months at a time without needing a change?

The antimicrobial underpants had been introduced by the Ministry of Defence as part of a new desert uniform for soldiers. They were the first undergarments issued to British troops, who traditionally had to supply their own.

British Army Unisex Pelvic Protective Anti-Microbial Underwear (Image: https://www.ebay.co.uk/itm/262933851071)

"Support for the modern serviceman or woman starts from the skin out", said the then Armed Forces Minister Adam Ingram.

If anyone ever tried to challenge the promised continuous wearability of 3 three months is unknown, though…

However, the UK is not the only country that put some effort in the development of special underpants. In 2011, the U.S. military sent out versions of silk underwear to its soldiers as the latest in protective military armoury. The 'ballistic boxers', which were made from heavy silk were specially designed to protect soldiers' genitals from damage when sand shoots up at them after an explosion. Along with the boxers, troops were sent two types of 'cups' to wear beneath their pants - one metal and one made from high-molecular-weight polyethylene.

While the cups were found to be rather uncomfortable and the soldiers did not want to use them, the (antimicrobial) silk underwear passed the field test. And even though the heavy silk cannot protect soldiers' genitals from bullets or shrapnel, it can limit the damage caused by small particles and keeps wounds clean, which makes them easier for medics to treat.

…good to know that someone cares about our privates' privates…

33RD INTERNATIONAL SYMPOSIUM ON BALLISTICS

BRUGES, BELGUIM OCTOBER 2023

MARK YOUR CALENDAR!

The 33rd International Symposium on Ballistics will be held from October 16 to 20, 2023 in the Bruges Meeting and Convention Center just next to the historic city center of Bruges, Belgium.

The Department of Weapon Systems and Ballistics of the Royal Military Academy is proud to announce that it will be hosting the 33rd International Symposium on Ballistics (33ISB) in the city of Bruges, Belgium. The 33ISB is the prime international scientific event in the field of ballistics, traditionally covering the following topics:

- Exterior ballistics
- Interior ballistics
- Terminal ballistics
- Explosion and warhead mechanics
- Launch dynamics
- Vulnerability and survivability

Next to this, the 33ISB also encourages other papers and presentations on emerging Technologies, including directed energy, hypersonics, and other new technologies related to ballistics.

Next to offering the opportunity to present novel research in the field of ballistics, the 33ISB will also be an excellent opportunity to meet researchers and professionals working in the field of ballistics from all over the world. Networking with other ISB participants will be greatly encouraged during the coffee and lunch breaks, as during the social events. Additionally, a special DIY touristic program has been prepared for all participants to the Symposium and their companions.

The Department of Weapon Systems and Ballistics is looking forward to giving you a warm welcome at the next International Symposium in Bruges!

WHAT IS IT?

The symposium gives access 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 an international group of professionals and experts. 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. Next to this, a number

of high-quality tutorials in the field of ballistics will be given at the start of the Symposium.

VENUE

The symposium will be held at the Bruges Meeting & Convention Centre (BMCC), which is the perfect venue for special events, conferences and trade fairs. In addition to the impressive 4500m² ground floor — perfect for trade fairs, larger public events and concerts — there is the conference area on the upper floors. The BMCC is easily accessible on foot from the city centre and the railway station. It also has all the necessary amenities for persons with disabilities.

The Symposium scientific sessions will take place in the large conference theatre, while catering will be served on the top floor of the BMCC, including an outdoor terrace with view on the old Bruges town centre.

No dedicated hotels were earmarked for the event. Sufficient accommodations are available in the heart of Bruges at walking distance from the BMCC.

CALL FOR ABSTRACTS

Abstracts for papers to be included in the Symposium Proceedings can now be submitted through the website of the IBS:

[Abstract submission]

Linked to the Symposium, there will also be a Special Issue of the open-access, peer-reviewed international journal Defence Technology. Submissions for this Special Issue can be submitted through the following link:

[Paper submission]

MORE INFORMATION

Additional information on the upcoming symposium, e.g. on the tentative symposium agenda, the social events and on the companion program, can be found on the official website and on LinkedIn. For specific questions, please send us an email.

www.ballistics.be

ISB33@LinkedIn

ISB33@dymasec.be

EXHIBITION & SPONSORING

The 33rd ISB also offers opportunities to companies and organizations to showcase their capabilities and products. Have a look to the website or contact us directly through the email address above for more information!

“THE DIFFERENCE”

TDW Gesellschaft für verteidigungstechnische Wirksysteme mbH,

a 100% subsidiary of MBDA Germany, is experienced in the design and manufacture of warheads systems including the associated fuzes and safe and arm devices. TDW was founded in 1958. Since then, more than two million warhead systems have been produced at and delivered from its site in Schrobenhausen, located in the Greater Munich Metropolitan area. With approximately 150 employees, TDW operates as an essentially autonomous full-service company at one integral site. Our product portfolio includes all kinds of warhead systems such as shaped-charge, blast/fragmentation-, and penetrators and their combinations in single-, tandem-, or multiple-charge systems for MBDA Group as well as other missile, torpedo, and precision-guided munition system houses worldwide.

TDWs value creation chain encompasses all of the following activities to their full extent:

- **Concepts, Designs, and their Assessment,**
- **Development and Qualification,**
- **Manufacture and Integration,**
- **Testing and Verification &Validation.**

An own manufacturing, integration and testing area located nearby the development and all other supporting departments represents a major asset in terms of time and value for money for a development / qualification and series production program. It includes high explosives processing (mixing, casting or pressing), mechanical workshops, inert assembly lines, warhead final assembly lines, a chemical lab, as well as an environmental testing lab and the test range. TDW is in the fortunate position owning a test site of approx. 21 ha, where we can perform almost every static test for warheads and environmental testing for even complete missile systems. A rocket sled track is available to conduct dynamic warhead and missile tests.

Available key technologies include flexible response, target adaptive, and low collateral damage warheads, insensitive explosive charges with outstanding safety under extreme mechanical and thermal threats which provide nonetheless ultimate destructive performance, as well as intelligent highly shock-resistant fuzing systems.

Thanks to governmental-funded and self-funded research and development, TDW is today at the forefront of technologies for future warhead systems comprising:

- **Scalable Effects Warheads (Dial-a-RADIUS®)**
- **Multi-Effects Warheads (Dial-an-Effect)**
- **Reactive Materials Warheads (Dial-a-Blast)**

For further information, please visit our website at www.tdw-warhead-systems.com/en/ or contact michael.korte-weich@mbda-systems.de.

Phone: +49 8252 99 6694

QinetiQ

- **We employ more than 13,000 people worldwide.**
- **Our scientists and engineers solve some of the world's most important problems.**
- **We are the UK's largest research and technology organization.**
- **We are the world's leading supplier of military robotics.**

More than 75% of our workforce carry high-level national security clearances.

NEXTER GROUP is a leading actor in the land-defence industry. Today it is the principal partner of the French Army, and its equipment is used in over 100 countries.

In a world of constantly changing threats, the Group's 2,700 employees listen carefully to customers to provide the solution best adapted to their specific needs. Innovation, protection and adaptability are the key guidelines by which NEXTER designs its products and services.

With nearly 11% of annual sales dedicated to research and development, NEXTER introduces increasingly innovative and high-quality products onto the world market while meeting customers' deadlines and budgets.

Descending from Giat Industries, NEXTER is continuing a long tradition that could be considered to start in the XVIIth century, during the reign of Louis XIV in France, when the Royal Arsenal was created at the Bastille.

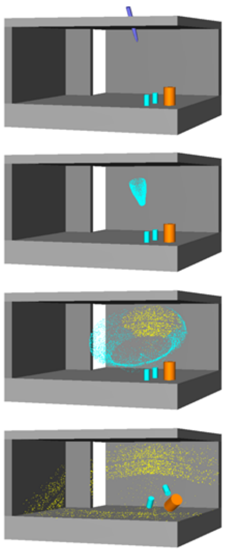
For more information visit https://www.nexter-group.fr/

Southwest Research Institute (SwRI®) is a nonprofit engineering R&D center. The main facility is a 1200-acre campus in San Antonio, Texas where over 3000 employees perform contract research for both government and industry. SwRI's Engineering Dynamics Department in the Mechanical Engineering Division works on armor and impact physics.

1. SwRI maintains multiple indoor, outdoor ballistic, and remote range facilities, where small and medium arms are tested against various armor configurations. Land mines, IEDs, and arena tests can also be performed to assess the survivability of vehicles and structures.
2. Low, medium, and high-strain-rate laboratory testing facilities provide the ability to characterize materials and then develop constitutive models (equation of state, strength, and failure) for use in computational tools.
3. SwRI has extensive experience with the three primary software tools used for ballistics and explosive-loading: CTH, LS-DYNA, and EPIC. SwRI has modified all three for new constitutive models and boundary conditions.

Visit www.engineeringdynamics.swri.org for more information or www.penmech.swri.org for the Penetration Mechanics weeklong course taught every year.

Engineering Services & Software for Defence Industry and Government Agencies



NUMERICS GmbH is a consultancy engineering and software development company located close to Munich, Germany. NUMERICS is serving its customers world-wide with tailored solutions to their problems in the complete field of ballistics: from detonation to terminal effects.

NUMERICS also offers a set of professional COTS engineering software products:

SPEED:	Latest Technology Lagrangian / Eulerian Hydrocode
PS3D:	Penetration Simulation with 3D Trajectories
SPLIT-X:	Fragmentation Warhead Expert System
FI-BLAST:	Analysis of Combined Blast / Fragment Loads on Structures

www.numerics-gmbh.de/en

中国兵工学会
China Ordnance Society

Founded in April 1964 and affiliated with the China Association for Science and Technology, the China Ordnance Society is an academic social group composed of science and technology workers for China Ordnance.

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.

The Society has general members, senior members and fellows and so on. It has all together 22562 members, among which more than 585 are senior members and 34 are fellows.

Earth, Horizon, Space …
WEIBEL Scientifics Reaches Further

WEIBEL
DOPPLER RADARS

Weibel Scientific is the global leader in the market for advanced Doppler radar systems. For over fifty years, we have been designing, manufacturing, and delivering cutting-edge velocity and position measuring instruments to customers around the world. On a daily basis, Weibel radars are used to protect lives on the ground, in flight, and in space.

Ellwood Group, Inc. is a family-owned, privately-held company that has been operating for over 100 years. Through growth and acquisition, EGI has become a major supplier of high-quality, engineered, heavy metal components to customers all over the world. While EGI has grown significantly and now employs over 2,000 employees, the same family values are just as important now and they were 100 years ago.

EGI's leadership team works closely with employees on important topics such as safety and continuous improvement. EGI employees are skilled professionals who are committed to the long term success of the company. EGI business unit companies manufacture and market metal products to customer in industries such as oil and gas, power generation, mining, infrastructure and construction, aerospace, defense, railroad, automotive, industrial machinery, metal processing, gearing/power transmission, and shipbuilding. Over many years of business, EGI has spent millions of dollars for new equipment and to rebuild existing equipment, as well as to expand our manufacturing spaces. We have increased our capacity and enhanced our capabilities to keep pace with our largest and most technically demanding customers.

Our EGI business units are leaders in their field. Combining significant years of experience with the latest technological advances, EGI provides customers with world class products and services they require.

We are proud to be a U.S. manufacturer who helps to support our Government in the defense of our country.

- Tank Breech Components
- Missile Motor Cases
- Helicopter Rotor Shafts and Hubs
- Cannon Suspension Arms
- Navy Nuclear Submarine Components
- Missile Warheads
- Gun Housings
- Cannon Housings
- Navy Nuclear Valve Bodies

For further information, please visit www.ellwoodgroup.com.

Phone: +1 814-779-9145

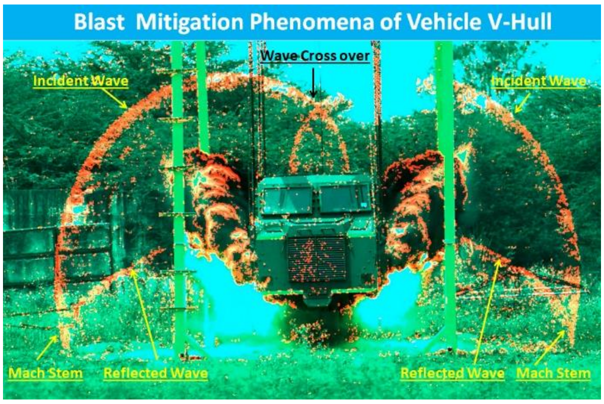
Contact: Dana A Beyeler, DBeyeler@elwd.com

चरम प्राक्षेपिकी अनुसंधान प्रयोगशाला

Terminal Ballistics Research Laboratory

सेक्टर-30, चंडीगढ़-160030 / Sector-30, Chandigarh – 160030

[आई0 एस0 ओ0 9001:2015 प्रमाणित प्रयोगशाला] / [An ISO 9001:2015 Certified Laboratory]



Terminal Ballistics Research Laboratory (TBRL) was envisaged in 1961 as one of the modern armament research laboratories under the Department of Defence Research & Development. The laboratory became fully operational in January 1968. It is actively involved in design, development and testing of ammunition and explosive warheads. The laboratory is also involved in testing of personal and vehicle armour against small arm ammunition and explosive blast. The laboratory has instrumented test infrastructure to generate data on blast, shock, lethality, fragmentation, impact and penetration.

BOGGES is a company focused on research, development, testing and expertise in the field of ballistic and blast protection. Our team is ready to fulfil your requirements for personnel and vehicle survivability development and enhancement based on advanced materials and technologies.

BOGGES's goal is to fulfil your requirements by a combination of high flexibility, skilled team of experts, and utilization of the most recent equipment and testing facilities.

For more information please visit our website: http://www.bogges.eu

E-mail: info@bogges.eu

Phone: +420 777 248 604

Fraunhofer EMI

The Fraunhofer Institute for High-Speed Dynamics, known under the name Ernst-Mach-Institut (EMI) is one of the 60 institutes of the German Fraunhofer society. Fraunhofer is a non-profit organization which specialises in applied research and has close links to German government authorities. It is the biggest research organization in its field in Germany and one of the essential European research organizations.

HEPHAESTUS

Armour, Ballistics, Survivability & Security Consulting Engineers

Armour & Ballistic Advice, Design, Test & Evaluation Services

A unique range of experience in protecting military and civilian personnel

Hephaestus Consulting provides specialist design advice and build services to the European military and civilian protected assets sector. Possessing a unique range of real, practical experience, extending from stab and slash resistant PPE garments through to IED blast and anti-tank munitions, Hephaestus has worked extensively with UK agencies, test houses and universities to deliver client needs.

Hephaestus are specialist subject matter experts in the design, testing and integration of composite armour solutions, vehicle design, and ballistic, blast, IED and RPG testing, as well as in providing civilian security and infrastructure solutions. In addition to this, Hephaestus can also supply advice and threat analysis based on detailed experience of real-world scenarios, including the real limitations of protective equipment.

Past clients include UK and European police forces, MoDs and scientific organisations, as well as bespoke protected vehicle builders for covert policing and cash-in-transit applications. Architectural and critical infrastructure protection agencies are also supported.

Services include design, test and evaluation, threat analysis and advice, third party reviews and expert witness testimonies, as well as full project management of design through to build and installation / integration / production.

✉ Enquiries@HephaestusConsulting.com

💻 www.HephaestusConsulting.com

MS INSTRUMENTS PLC – The Ballistics Centre

MS Instruments PLC – Manufacturers of Ballistic Measuring Instrumentation, Range Design and Live-fire Training Facilities

www.msinstruments.co.uk

SPECIALISED IMAGING

1 billion fps and beyond

Specialised Imaging is a leading Company dedicated to designing and developing specialist High-speed imaging solutions. Our portfolio of solutions includes cameras capable of capturing high resolution images up to 1Billion frames/second and down to 1Million frames/second, all with nanosecond exposure times.

We also provide several Tracker systems to follow either linear or random moving projectiles in flight. To complete all these solutions, we offer a choice of triggering and lighting systems developed for the range environment.

specialised-imaging.com

bsi ISO 9001:2015 Quality Management FM 87429

ABAL : The Department of Weapon Systems & Ballistics of the Belgian Royal Military Academy

The department of weapons systems & ballistics is unique as it is the only place in Belgium to teach courses in ballistics and weapon systems on a university level.
The department is equipped with a modern laboratory featuring a 102-m indoor range.

www.rma.ac.be/en/rma%20-%20weapon%20systems%20and%20ballistics.html

ALSO YOU CAN BECOME A CORPORATE SPONSOR!

Corporate membership is open to all corporations, firms, foundations, institutions, associations, universities, organizations, and components approved by the Board of Directors. Corporate Members have the right to nominate employees to regular individual membership in the Society. The total number of such memberships depends on the sponsorship level (membership dues) of the corporate member. Nominees (delegates) do not have to pay individual membership fees.

Inform yourself now! – It is cheaper that you think…

Lifetime corporate membership is also available – please visit https://www.ballistics.org/membership_info.php or contact the Membership Committee Chair (membership@ballistics.org) for further information.