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Hypervelocity Impact Technology and Applications: 2007

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Hypervelocity Impact Technology and Applications: 2007

Summary to Naval Surface Warfare Center (NSWC) Dahlgren: HVIS 2007, Williamsburg VA, September 23-27, 2007

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ABSTRACT

The Hypervelocity Impact Society is devoted to the advancement of the science and technology of hypervelocity impact and related technical areas required to facilitate and understand hypervelocity impact phenomena. Topics of interest include experimental methods, theoretical techniques, analytical studies, phenomenological studies, dynamic material response as related to material properties (e.g., equation of state), penetration mechanics, and dynamic failure of materials, planetary physics and other related phenomena.

The objectives of the Society are to foster the development and exchange of technical information in the discipline of hypervelocity impact phenomena, promote technical excellence, encourage peer review publications, and hold technical symposia on a regular basis. It was sometime in 1985, partly in response to the Strategic Defense Initiative (SDI), that a small group of visionaries decided that a conference or symposium on hypervelocity science would be useful and began the necessary planning. A major objective of the first Symposium was to bring the scientists and researchers up to date by reviewing the essential developments of hypervelocity science and technology between 1955 and 1985. This Symposia – HVIS 2007 is the tenth Symposium since that beginning. The papers presented at all the HVIS are peer reviewed and published as a special volume of the archival journal *International Journal of Impact Engineering.* HVIS 2007 followed the same high standards and its proceedings will add to this body of work.

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1. INTRODUCTION

The symposium, HVIS 2007, was a very successful conference. At this international venue, over two-hundred attendees from 16 countries provided an update on hypervelocity impact technology and science. Nearly 80 papers were presented at HVIS 2007 bestowing the most current research and state-of-the-art update on recent hypervelocity impact technology. Beginning in 1986, ten symposiums will have been published in the International Journal of Impact Engineering, which continues to update the growing knowledge and progression of hypervelocity science.

1.1 HYPERVELOCITY IMPACT SYMPOSIUM

The 2007 Hypervelocity Impact Symposium (HVIS 2007) was held September 23-27, 2007 at the Williamsburg Lodge, Williamsburg VA. The symposia co-chairs were Leonard Wilson and David Dickinson from Naval Surface Warfare Center, Dahlgren, VA. A technical committee was established to assist with the organization of the symposia. The make up of the technical committee was diverse and consisted of well-reputed international scientists who are experts in the fields associated with hypervelocity science. A list of the technical committee is provided in Appendix A.

One hundred twenty-nine (129) abstracts were received and accepted. Eighty-nine papers were received and peer-reviewed by the technical committee and 52 were recommended for publication in the archival Journal - *International Journal of Impact Engineering* (IJIE). The guidelines used to select the manuscripts include the relevance, quality, and the originality of research representing hypervelocity impact phenomena. This special IJIE volume constitutes the Proceedings for HVIS 2007, and thus the HVIS 2007 presented papers are archived for future reference. The special volume of the IJIE journal containing the papers from HVIS 2007 is expected to be published in the fall of 2008.

Total attendance at HVIS 2007 was 207 from 16 different countries. HVIS 2007 participants are listed in Appendix B. The society makes a significant effort to involve quality students as an investment in the future research and development of the technology. And this year was no exception as nineteen students presented their work to the society. Half of these students were supported by the Alex Charter's student outreach program, while the other half were given discounted registration rates. By this encouragement and help with expenses, we endeavor to provide the students with an incentive and a motivation for further career development in this discipline

Nearly eighty papers were selected for presentation for HVIS 2007. The symposia have a policy that if the publishable journal article is not received on time, the authors are not allowed to present it at the symposia. Of the nearly eighty papers, 52 were presented orally and 25 were presented as posters. All oral papers are presented to ensure maximum exposure; the poster talks also get full exposure by scheduling them for a special afternoon session and maintaining the display throughout the entire symposium. In addition, four keynote lectures, including the HVIS Distinguished Scientist Award lecture, representing either a review of the literature and/or the current state of the art were also presented at the symposia.

2. TECHNICAL PAPERS

This report is an attempt to provide a brief summary of the technical findings and advances represented in the papers presented at HVIS 2007. The combination of this brief summary, along with the abstracts and the complete proceedings copy will constitute a review of the current state-of-the-art of hypervelocity science circa 2007. In addition to the regular technical sessions, four keynote lectures, including the distinguished scientist award, representing either a review of the literature and/or the current state of the art were also presented at the symposia.

The technical sessions for the HVIS 2007 were organized around the following technical topic areas. The number of papers in each topic area is given in parenthesis. The title of each paper is given in Appendix C.

- Launchers and Diagnostics (9)
- Impact and Penetration (8)
- Material Response (13)
- Analytical and Numerical Computations (12)
- Shielding (17)
- Fracture and Fragmentation (6)
- Planetary and Space (5)
- Phenomenology (10)

Dr. Gordon Johnson from Southwest Research Institute received the HVIS Distinguished Scientist Award for 2007. The title of Dr. Johnsons' Distinguished Scientist Award Lecture was: **Numerical Algorithms and Material Models for High-Velocity Impact**

The titles of the three other keynote addresses were as follows:
- **Low–Altitude Airbursts from Small Asteroid Impacts**, *Dr. Mark Boslough*, Sandia National Laboratories, USA
- **To Question What is Known….A Survey of Tenuous Assumptions in the Solid Mechanics of High-Rate Fracture and Failure**, *Professor Rebecca M. Brannon,* University of Utah Mechanical Engineering, USA
- **Probing Planetary Surfaces with Hypervelocity Impacts**, *Peter Schultz*, Brown University

3. SUMMARY/HIGHLIGHTS OF THE SYMPOSIUM

Hypervelocity impact technologies have been motivated by space applications and have been discussed at this symposium since the beginning of this venue. However, it is not limited to just that aspect of the phenomena. Though strong interest of high-velocity launchers is still paramount in the field, such as launchers developing velocities >30 km/s, two & three stage guns launching plates and particles to 12 and 19 km/s respectively, now the drive is to use these tools for understanding the impact phenomenology. Papers were presented offering new concepts, such as techniques in understanding impact-flash signatures and observing expanding debris clouds. Diagnostics to identify materials as well as estimating temperatures and the physics of the associated rapidly expanding and cooling of multi-phase debris cloud were presented.

Improved and new launching techniques are always being pursued. Six papers in this area were presented in this meeting. These papers focused on increasing performance in two-stage light gas guns by changing the working conditions between the breech and the acceleration reservoir, adding a third stage to a two-stage gun and utilizing multi-shock compressions of light gas, and varying piston mass without exceeding the engineering limitations of the gun hardware.

Launcher developments have been used to investigate orbital debris impact on spacecraft shielding. Properties of new shielding materials need to be quantified by testing and results input into new models. The common approach over the years of study regarding hypervelocity impact on spacecraft has assumed that the orbital debris is spherical in shape. It is now realized that debris is more likely to be irregular in shape. Twelve papers investigated the shielding aspect utilizing hydrocode modeling and ballistic limit equations to characterize irregular shaped impacts.

Planetary science research tends to include a blend of astronomy, space exploration, and meteorite work (based on Earth). However hypervelocity impact is ever-present in this topic. Papers presented discussed near-earth objects being deflected, hypervelocity impacts of asteroids/comets on earth. Recently the Deep-Impact mission established a new ‘strategy” for probing planetary surfaces. This mission was a man-made hypervelocity impact collision into a comet. The results from this mission provided critical data into numerical modeling of the excavated crater, the ejecta spreading backwards from the impact site, impact flash and the dynamics of the debris. It also provided insight into the porosity and the strength variations within the upper surface of the comet. These details could only be realized from the standards provided from hypervelocity impact research. Three papers and special keynote speakers once again enlightened the attendees to the unlimited challenges of hypervelocity impact.

An ever increasing interest in how materials behave under hypervelocity impacts is growing within this community. Material behavior forms the baseline for the remaining topics at HVIS; Material modeling, fracture/fragmentation, and impact and penetration. Concrete, glass, fibrous sheets, ceramics and metals are some of the materials that are intimately touched by hypervelocity impacts. Very little is known or established of the material behavior when impacted at very high-velocities resulting in extremely high pressures. Researchers continue to provide state-of-the-art knowledge of hypervelocity science.

Improved material models, the faster/quicker super-computers, and advanced hydrodynamic codes have added motivation to comparing results to the experimental data. As new numerical techniques evolve, so does the confidence of the computational results. Some of these examples are shown in the simulations of penetrator-to-target interaction, the response of complex fabrics to hypervelocity impacts, impacts to spacecraft and the dynamic response of the entire structure, and advancements of analytical models of spherical cavity expansion within brittle materials. The topics where numerical tools are applied are both diverse and varied and are and indication of an enormously greater level of maturity than what had existed in years gone by. This is shown in the nine papers along with keynote talks presented on this subject.

Impact and penetration phenomenology is extremely varied and investigations need to probe not only velocities typically found in the space environment but those within the earth's atmosphere. At the somewhat lower 'hypervelocities', material strength becomes an extremely import aspect to be studied. This topic area includes investigations tailored to address penetration phenomena in a variety of targets including metals, ceramics, composites, and geo-materials. The long rod penetrators used in the four papers that were presented investigate how the strength of the penetrator affects depth of penetration. Additionally a presentation investigated how a materials basic material properties change with temperature under impact loading.

Fracture and fragmentation is a broad topic as it will overlap many other areas which has been shown by the many of the papers on damage, material phenomenology, and debris shielding and penetration behavior. This topic is quite informative and is extremely important to assess weapons effectiveness. To be able to describe the effects of fragmenting metals, one needs information of mass distribution of the fragments. Four papers address these complex processes of violent phenomena leading to destruction/fragmentation.

4. CLOSURE

Hypervelocity impact research is an important area of modern physics touching topics including geosciences, high pressure physics, planetary physics, space research, material science as well as defense research and technology. The contribution to these fields as well as the topics included in this symposium shows that considerable progress is still being made for continuing development of hypervelocity science.

HVIS 2007 clearly succeeded in the objectives set forth by the society. Over two hundred attendees from 16 countries presented their current research and the state of the art hypervelocity science. Test laboratories are obtaining higher and higher velocities. Diagnostics are more precise and diverse then ever before providing the data necessary for advancement in computer and modeling technology. The continuous advancement of science and technology relevant to hypervelocity impact is without a doubt evident for HVIS 2007

Summarizing HVIS 2007 and the nearly 10,000 pages of technical papers for these 10 symposiums, the ever increasing body of knowledge continues to grow and advance the understanding of hypervelocity phenomenology and corresponding applications.

APPENDIX A: MEMBERS OF THE TECHNICAL COMMITTEE FOR HVIS -2007

Conference Co-Chairmen

Leonard Wilson	Naval Surface Warfare Center, Dahlgren, VA
David Dickinson	Naval Surface Warfare Center, Dahlgren, VA

Conference Coordinator

Catherine Quinn	Naval Surface Warfare Center, Dahlgren, VA

Technical Committee Co-Chairmen

Lalit Chhabildas	Sandia National Laboratories
Bill Schonberg	University of Missouri at Rolla

Technical Committee

Yasuhiro Akahoshi	Thilo Behner
Tod Bjerke	Rebecca Brannon
Mike Burkett	Philip Church
Randy Coates	Datta Dandekar
Mehdi Eliasi	Alessandro Francesconi
Mike Giltrud	Gene Hertel
Bryn James	Kenichi Kondo
Dave Lambert	Nick Lynch
Thomas McCarthy	Jeffrey Lawrence
Nicholas Nechitailo	Ted Orzechowski
Nigel Park	Brad Pedersen
Raj Rajendran	K. T. Ramesh
John Remo	Werner Riedel
Eric Rinehart	Jean-Marc Sibeaud
Brett Sorensen	Douglas Templeton
Kirk Vanden	Stephen White

APPENDIX B: MEETING PARTICIPANTS: HVIS 2007

Ted	Blaney	Northrop Grumman
Stephan J.	Bless	Institute for Advanced Technology, University of Texas at Austin
Scott	Blouin	Applied Research Associates, Inc.
April L.	Bohannan	University of Texas
John P.	Borg	Marquette University
Mark B.	Boslough	Sandia National Laboratories
Rebecca	Brannon	University of Utah
Timothy L.	Brown	Sandia National Laboratories
Claude A.	Bryant	ESCB - Johnson Space Center
Murat	Buyuk	George Washington University
Akbulut	Cakmakci	Undersecretariat for Defence Industries
James	Cazamias	University of Alabama at Birmingham
Nicholas R.	Chambers	Mississippi State University
Wai	Chan	Specialised Imaging
Thomas D.	Chase	Hamilton Sundstrand
Lalit C.	Chhabildas	Air Force Research Laboratory
Eric L.	Christiansen	NASA Johnson Space Center
Randolph	Coates	US Army Research Laboratory
David L.	Cole	Sandia National Laboratories
Steven L.	Collignon	Naval Surface Warfare Center
William L.	Cooper	Air Force Research Laboratory
Ian G.	Cullis	QinetiQ Ltd
Dattatraya P.	Dandekar	US Army Research Laboratory
David L.	Darg	Redlake, Inc.
William E.	Davidson	ESCB - Johnson Space Center
Bruce A.	Davis	ESCB - Johnson Space Center
Anthony M.	Dawson	Institute for Advanced Technology, University of Texas at Austin
Douglas J.	Day	AWE plc
Michael H.	Denigan	Air Force Research Laboratory/MNMW
David L.	Dickinson	Naval Surface Warfare Center
Heinrich G.	Dorsch	IABG mbh
Jason T.	Drotar	Naval Surface Warfare Center
Milan K.	Dutta	US Army SMDC
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Erick A.	Fahrenthold	University of Texas at Austin, Mechanical Engineering
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James L.	Foster	SAIC
Alessandro	Francesconi	CISAS - University of Padova
Peter	Frankl	QinetiQ Ltd
Michael D.	Furnish	Sandia National Laboratories
Bence	Gerber	ANSYS, Inc.
Majid	Ghassemi	KN Toosi University/New Mexico Tech
Michael	Giltrud	Defense Threat Reduction Agency
Dennis E.	Grady	Applied Research Associates
Michael	Greenfield	US Army Research Laboratory
Brenden	Grove	Schlumberger

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Toshiya	Hanada	Kyushu University
Wayne	Harrison	AWE plc
Donald	Henderson	NASA JSC-Whtie Sands Test Facility
Eugene	Hertel	Sandia National Laboratories
Tetsuyuki	Hiroe	Kumamoto University
Kevin A.	Hoffman	ESCB - Johnson Space Center
William A.	Hollerman	University of Louisiana at Lafayette
Timothy J.	Holmquist	Southwest Research Institute
Michael	Hopson	NAVSEA Dahlgren
Jack K.	Horner	Science Applications International Corporation
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Clark S.	Ince	Lockheed Martin
Gordon R.	Johnson	Southwest Research Institute
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Yegor	Kartuzov	Institute for Problems in Materials Science
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Sari	Katz	SOREQ
Nobuaki	Kawai	Tokyo Institute of Technology
Anthony T.	Kearsley	The Natural History Museum
Megan E.	Kern	University of Alabama at Birmingham
Geremy J.	Kleiser	Air Force Research Laboratory
Ken-ichi	Kondo	Tokyo Institute of Technology
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Michel	Lambert	ESA-ESTEC
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Dana	Lear	NASA Johnson Space Center
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Seung	Lee	Defense Threat Reduction Agency
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Katarina	Miljkovic	The Open University
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Willis	Mock, Jr.	Naval Surface Warfare Center
Robert J.	Moore	University of Louisiana at Lafayette
Yasuko	Motoyashiki	JAPAN Aerospace Exploration Agency (JAXA)
Henry K.	Nahra	NASA - Glenn Research Center
Tomoya	Nakamura	Kyushu Institute of Technology
Sidney	Nebeker	Cordin Company, Inc.
Nicholas	Nechitailo	Naval Surface Warfare Center
Masahiro	Nishida	Nagoya Institute of Technology
Michael J.	Normandia	Ceradyne, Inc.

Nestor	Nsiampa	Royal Military Academy
Daiju	Numata	Tohuku University
Kazunori	Ohkubo	National Defense Academy
Gregory D.	Olsen	Mississippi State University
Erick A.	Ordonez	ESCB - Johnson Space Center
Dennis L.	Orphal	International Research Associates.
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Kevin L.	Poormon	University of Dayton Research Institute
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Robin	Putzar	Fraunhofer Institut-EMI
Martin N.	Raftenberg	US Army Research Laboratory
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Norman	Robertson	Century Dynamics Limited
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Paul	Roehrenbeck	Photo-Sonics, Inc.
E. Torsten	Rönn	BAE Systems Bofors AB
Todd	Rumbaugh	DRS Technologies - DIS
Shannon	Ryan	Ernst-Mach Institut
Tei	Saburi	National Institute of AIST
Tsutomu	Saito	Muroran Institute of Technology
Kousuke	Sakuraba	Kyushu University
Sikhanda	Satapathy	Institute for Advanced Technology, University of Texas at Austin
Yasuhisa	Sato	Tohoku Gakuin University
Frank K.	Schäfer	Fraunhofer Institut-EMI
Volker	Schirm	French German Research Institute
Eberhard E.	Schneider	Fraunhofer Institut-EMI
William P.	Schonberg	University of Missouri-Rolla
Peter	Schultz	Brown University
Dan	Shaine	Israel Military Industries, Central Laboratory
Jean-Marc	Sibeaud	DGA - Centre d'Etudes de Gramat
Wayne	Smethurst	Specialised Imaging
Brett	Sorensen	US Army Research Laboratory
Doug	Squires	The Cooke Corporation
Jerome	Stofleth	Sandia National Laboratories
Valery	Sultanov	Institute of Problem Chemical Physics
Anne J.	Sunwoo	Lawrence Livermore National Laboratory
Richard	Sutherland	Redlake, Inc.
Pazhayannur,K.	Swaminathan	The Johns Hopkins University
Koichi	Tanaka	Nagoya Institute of Technology
Patrick	Thiot	Thiot Ingenierie
Klaus	Thoma	Fraunhofer Institut-EMI

Thomas F.	Thornhill	Ktech Corporation / Sandia National Laboratory
Christer	Thuman	BAE Systems Bofors AB
David	Touati	Israel Military Industries, Central Laboratory
Kirk	Vanden	Air Force Research Laboratory
Jean-Baptiste	Vergniaud	EADS Astrium
Tracy J.	Vogler	Sandia National Laboratories
James D.	Walker	Southwest Research Institute
Kenneth C.	Walls	University of Alabama at Birmingham
Joseph M.	Weiderhold	AFRL Munitions Directorate
Stephen J.	White	AWE plc
Matthias	Wickert	Fraunhofer Institut-EMI
Markus	Wicklein	Fraunhofer Institut-EMI
James S.	Wilbeck	ITT Industries
Joel	Williamsen	Institute for Defense Analysis
Leonard T.	Wilson	Naval Surface Warfare Center
Jerome D.	Yatteau	Ballistic Impact Engineering, LLC
Manabu	Yokoo	Tokyo Institute of Technology
Qingming	Zhang	Beijing Institute of Technology

APPENDIX C: TITLES AND AUTHORS OF ALL ORAL PRESENTATIONS AT HVIS 2007

C.1 Keynote Lectures:

Numerical Algorithms and Material Models for High-Velocity Impact- Distinguished Scientist, Dr. Gordon Johnson, *Sourthwest Research Institute*

Low–Altitude Airbursts from Small Asteroid Impacts- Dr. Mark Boslough, *Sandia National Laboratories*

To Question What is Known….A Survey of Tenuous Assumptions in the Solid Mechanics of High-Rate Fracture and Failure- Professor Rebecca M. Brannon, *University of Utah Mechanical Engineering*

Probing Planetary Surfaces with Hypervelocity Impacts- Peter Schultz, *Brown University*

C.2 Fracture and Fragmentation:

Explosively Driven Facture and Fragmentation of Metal Cylinders and Rings- D.M. Goto, R. C. Becker, T. J. Orzechowski, H. K. Springer, A. J. Sunwoo, C. K. Syn**,** *Lawrence Livermore National Laboratory, USA*

CTH Simulations of an Expanding Ring to Study Fragmentation- J.P. Meulbroek, K.T. Ramesh, P.K. Swaminathan, A. M. Lennon, *The Johns Hopkins University, USA*

Fragment Mass Distribution of Metal Cased Explosive Charges- W. Arnold[*] and E. Rottenkolber[**] [*]*MBDA-TDW Gesellschaft für verteidigungstechnische Wirksysteme mb H, Hagenauer Forst, Schrobenhausen, GERMANY*

Size Distributions in Hypervelocity Fragmentation- Dennis E. Grady**,** *Applied Research Associates, USA*

C.3 Material Response:

Towards Predictive Modelling for Concrete- M Hinton, S Gilbert, I Cullis, P Church, D Porter, T Andrews, M Hamblin, B Proud, A Pullen, *QinetiQ, UNITED KINGDOM*

Changes to the Shock Response of Fused Quartz Due to Glass Modification- Douglas W. Templeton,* C. Scott Alexander**, Lalit C. Chhabildas, and W.D. Reinhart, **U.S. Army Tank-Automotive Research, Development and Engineering Center, USA, ***Sandia National Laboratories, Albuquerque, NM, USA*

Experimental Study on the Effectiveness of Fiber Sheet Reinforcement on the Explosive-resistant Performance of Concrete Plates- K.Ohkubo, M.Beppu, T. Ohno* , and K.Satoh**, **Department of Civil and Environmental Engineering, National Defense Academy Hashirimizu, JAPAN, ** Maeda Kosen Corporation, JAPAN*

The Influence of a Steel Rear Barrier on the Detonation Response of a Steel Covered Explosive Struck by a Steel Projectile- Nicholas Lynch, *QinetiQ, UNITED KINGDOM*

Characterizing the Transient Response of CFRP1A1 HC Spacecraft Structures Induced by Space Debris Impact at Hypervelocity- S. Ryan,*&** F. Schafer,* M. Guyot,*** S.

Hiermaier,* and M. Lambert****, **Fraunhofer-Institut für Kurzzeitdynamik, Ernst-Mach-Institut (EMI), Freiburg, Germany, **School of Aerospace, Mechanical & Manufacturing Engineering, RMIT University, Melbourne, Australia, ***EADS Astrium SAS, France and ****ESA-ESTEC, Noordwijk, The Netherlands*

Dynamic Deformation and Fracture of Mullite ($3AI_20_3 \cdot 2Si0_2$) Ceramics Under Hypervelocity Impact- Nobuaki Kawai*, Yosuke Harada,** Manabu Yokoo,** Toshiyuki Atou,** Kazutaka G. Nakamura,** and Ken-ichi Kondo**, **Center for Urban Earthquake Engineering & **Secure Materials Center, Materials and Structures Laboratory, Tokyo Institute of Technology, Yokohama, Japan*

Temperature Measurements of Expansion Products from Shock Compressed Materials Using High-Speed Spectroscopy- W.D. Reinhart, T.F. Thornhill, L.C. Chhabildas, W.G. Breiland, and J.L. Brown, *Sandia National Laboratories, Albuquerque, NM, USA*

Debris Cloud Distributions at Oblique Impacts- M. Higashide, T. Koura, Y. Akahoshi, and S. Harada, Department of Applied Science for Integrated System Engineering, Kyushu Institute of Technology, Fukuoka, Japan

C.4 Hypervelocity Phenomena:

Triboluminescence Properties of Zinc Sulfide Phosphors Due to Hypervelocity Impact- N.P. Bergeron*, W.A. Hollerman**, S.M. Goedeke, and R.J. Moore,*** **Department Of Physics, University Of Louisiana, USA, Current Affiliation: Institute For Micromanufacturing, Louisiana Tech University, USA, **Engineering Science and Technology Division, Oak Ridge National Laboratory,USA, Current Affiliation: McHale and Associates, Incorporated, USA, ***Department of Physics, University of Louisiana at Lafayette, USA*

Selecting a Best-Fit Temperature-Dependent Regression Model for Thin Target HVI Data- B. Myers Corbett, *University of Denver, USA*

Damage Evaluation of Concrete Plates by High-velocity Impact- Masuhiro Beppu,* Koji Miwa,* Masaharu Itoh, Masahide Katayama,** and Tomonori Ohno*, **De*partment of Civil and Environmental Engineering, National Defense Academy Hashirimizu, JAPAN,**Impact Dynamics & Material Science Team, Energy & Industrial Systems Dept., Science & Engineering Systems Div., ITOCHU Techno-Solutions Corporation , JAPAN*

Z- Pinch Source Irradiation and Equation-of-State Measurement ofMeteorite Materials- John L. Remo, * **and Michael D. Furnish,** **Department of Astronomy, Department of Earth and Planetary Sciences, and Harvard Smithsonian Center for Astrophysics USA, **Sandia National Laboratories, USA*

Hypervelocity Impact Penetration Mechanics- C. McFarland,* P. Papados,** and M. Giltrud***, **SAIC Inc., Engineer Research and Development Center, U.S. Army Corps of Engineers, ** and ***Defense Threat Reduction Agency*

Composite Materials Behavior Under Hypervelocity Debris Impact- S. Katz,*&** E. Grossman,* I. Gouzman,* M. Murat,* E. Wiesel,**and H.D. Wagner**, **Space environment Section, Soreq NRC, Yavne, Israel, **Department of Materials and Interfaces, The Weizmann Institute of Science, Rehovot, Israel*

The Influence of the Asymmetries in Shaped Charge Performance- Oguzhan Ayisit, *TUBITAK-SAGE, Ankara, Turkey*

C.5 Shielding:

A Comparison of NASA, DoD, and Hydrocode Ballistic Limit Predictions for Spherical and Non-spherical Shapes Versus Dual- and Single-Wall Targets, and Their Effect on Orbital Debris Penetration Risk- J. E. Williamsen,[*] W. P. Schonberg,[**] H. Evans,[***], and S. Evans,[****] **Institute for Defense Analysis, USA, **University of Missouri-Rolla, Civil Engineering Department, ***University of Denver Research Institute, USA, ****NASA Marshall Space Flight Center, USA*

Influences of Space Debris Impact on Solar Array Under Power Generation- Yasuhiro Akahoshi[1)], Tomoya Nakamura[1)], Shinya Fukushige[1)], Naomi Furusawa[1)], Shuhei Kusunoki[1)], Yu Machida[1)], Takao Koura[1)], Keiko Watanabe[2)], Satoshi Hosoda, Tatsuhito Fujita[3)], and Mengu Cho[1),] *1) Kyushu Institute of Technology, 1-1Sensui Tobata-ku Kitakyushu, JAPAN, 3) JAPAN Aerospace Exploration Agency, JAPAN*

Ballistic Limit Equation for Equipment Placed Behind Satellite Structure Walls- Frank K. Schäfer*, Shannon Ryan,*&** Michel Lambert,*** Robin Putzar,* **Ernst-Mach-Institut - Fraunhofer Institut für Kurzzeitdynamik, Germany, **School of Aerospace, Mechanical & Manufacturing Engineering, RMIT University, Australia ***ESA-ESTEC, The Netherlands*

Micrometeoroid Impact on Ceramic Thin Components for Interplanetary Probe- Yasuko Motoyashiki, Sunao Hasegawa, Kyoko Okudaira, Eiichi Sato, *Institute of Space and Astronautical Science, JAPAN Aerospace Exploration Agency, JAPAN*

Hypervelocity Impact on CFRP: Testing, Material Modelling, and Numerical Simulation- Darren M. White,*&** Markus Wicklein,[**] Richard A. Clegg,* Hartwig Nahme,[**] *[*]Century Dynamics Ltd., England, [**] FhG - Ernst-Mach-Institut, Germany*

A Comparison of Ballistic-Limit and Adaptive-Mesh Eulerian Hydrocode Predictions of One-and two-Plate Aluminum Shielding Protection Against Millimeter-Sized FE-NI Space Debris- Jack K. Horner, *Science Applications International Corporation, Santa Fe, NM, USA*

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