NEWSLETTER VOL. 8, NO. 1 FALL 2006

HVIS

HYPERVELOCITY IMPACT SOCIETY

INSIDE THIS ISSUE

We want to hear from you regarding HVI-related news in your life.

Send news to:
Publications Committee Chair
Bill Schonberg
wschon@umr.edu

Message from the President

Dear Colleagues and Society Members,

Welcome to our Summer / Fall 2006 – Newsletter!

As the new HVIS-President, I would like to address you with a few words of greeting, inform you about some organizational news, and extend my sincere and heartfelt thanks to our very active and successful society officers whose contributions have been highly beneficial for our Society.

In this newsletter you will find:

a. Who are the BoD members and officers through HVIS2007
b. Who are the Committee Chairs through HVIS2007 and what they have been up to since HVIS2005
c. Some interesting information about HVIS2005
d. Some information about the next Symposium, HVIS2007
e. A list of the Alex Charters Student Scholars from HVIS2005
f. Information about the next ACSS competition

Lalit Chhabildas, Dennis Orphal and the IAT Team led by Janet Monaco have done a fantastic job in chairing and organizing the HVIS2005 Symposium in Squaw Creek/ Lake Tahoe. Besides the high quality of presentations, I would like to point out the perfect organization of the event, and the outstanding scenery around the venue place. Thanks again to all who helped making the Symposium such a great event.

We are also grateful to all HVIS members who were able to attend HVIS2005, and are looking forward to seeing you all next year for HVIS2007 in Williamsburg, Virginia. We would like to hear from you, as the members of the Society, any HVI related news out of your personal research activities as well as from the international hypervelocity impact community in general. Bill Schonberg will also be happy to receive your comments and suggestions concerning HVIS matters.

With my best wishes for an interesting and successful HVIS term, I remain

Sincerely yours,

Michel Lambert
(President)

Committee Charges and Reports

AWARDS COMMITTEE

The Awards Committee administers awards on behalf of the Society in recognition of distinguished service and activity in the field of hypervelocity impact. In general, a Best Paper Award and the Distinguished Scientist Award are presented at every Hypervelocity Impact Symposium.

The Distinguished Scientist Award is given to a single individual or to a research team of two or more individuals for significant and lasting contributions to the field of hypervelocity science. The award consists of a plaque citing the accomplishments of the award winner and a monetary remuneration set by the Board of Directors.

Formal letters of nomination are now invited from the HVIS Membership and anyone who has been involved in hypervelocity impact science and engineering. In preparing the letter of nomination, which should include supporting information about the candidate, nominators should include supporting information about the candidate, address the candidate's technical recognition within the community, the importance of their work and its contribution to hypervelocity science and their personal contribution and service to the Society.

Previous recipients of this award are:

1989: . . . .Alexander C. Charters
1992: . . . .Alois J. Stilp and Volker Hohler
1994: . . . .James R. Asay
1996: . . . .Burton G. Cour-Palais
1998: . . . .Hallock F. Swift
2000: . . .Charles E. Anderson, Jr.
2003: . . . .Dennis Orphal
2005: . . . .Lalit Chhabildas

Written nominations can be emailed to Ian Cullis (the Chair of the Awards Committee) at the following email address: igcullis@qinetiq.com. The committee would like to see the widest participation from the Membership in nominating the Distinguished Scientist that recognises the talents of researchers across the world. The closing date for nominations is May 30th 2007.

The Best Paper Award recognizes the best paper presented at a Hypervelocity Impact Symposium and is given at the start of the meeting. The selection criteria are:

- Originality of research
- Importance of Research
- Difficulty of Research
- Excellence of the Written Paper

The selection of the beast paper award will be made following the HVIS2007 manuscript review meeting. If you have any queries about this award, please do not hesitate to contact any of the Awards Committee members listed above.

EDUCATIONAL OUTREACH COMMITTEE

The Educational Outreach Committee administers the HVIS Alex Charters Student Scholar Program, whose purpose is to provide travel reimbursement support for students to attend the Hypervelocity Impact Symposia. Reimbursement is provided for transportation and lodging during attendance at Symposia up to a limit specified by the Board of Directors. Alex Charters Student Scholars are provided complimentary registration and a copy of the proceedings, and are scheduled for a short introductory meeting with the HVIS Board of Directors and the Educational Outreach Committee members at the Symposium. This program is aimed

BOARD OF DIRECTORS, MEMBERS & OFFICERS

President . . . . . Michel Lambert (michel.lambert@esa.int)
Past-President . . . . . Eberhard Schneider (Schneider@emi.fhg.de)
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Member . . . . . Bill Schonberg (wschon@umr.edu)
Member . . . . . Dennis Orphal (dorphal@aol.com)
Member . . . . . Stephan Bless (Stephan_bless@iat.utexas.edu)
Member . . . . . Charlie Anderson (canderson@swri.edu)
Member . . . . . Tim Holmquist (tjholm@networks.com)
Member . . . . . Lalit Chhabildas (lcchhab@sandia.gov)

primarily at graduate students who are enrolled in an academic institution at the time of the conference, although currently enrolled undergraduate students may also apply. The nomination consists of a letter of recommendation, on University letterhead, from the student's academic advisor. The committee is currently soliciting nominations for the HVIS2007 Alex Charters Student Scholars Program. A copy of the Call for Nominations can be found elsewhere in this newsletter. Society members are invited to post the call for nominations and to encourage eligible students to apply, through their academic advisors, as detailed in the call for nominations. Please send applications to Frank Schaefer, the Chair of the Awards Committee, at the following address:

Dr. Frank Schaefer
Fraunhofer Institute for High-speed Dynamics
Ernst-Mach-Institute (EMI)
Eckerstrasse 4
D-79100 Freiburg
Germany

MEMBERSHIP COMMITTEE

The primary responsibility of the Membership Committee is promoting membership in the Society. The Committee also has responsibility for ensuring that membership dues are collected each year and for keeping the Secretary-Treasurer informed of the current membership of the Society. In recent months, the Committee has been working on a detailed statistical analysis of preference conference attendances. The Committee plans to work closely with the HVIS2007 Organizing Committee to better gather membership data.

NOMINATIONS COMMITTEE

The Nominations Committee is responsible for nominating candidates for election to the Board of Directors of the Society. Diversity on the Board of Directors is encouraged with respect to such criteria as country of origin, organization or employment, gender, race or ethnicity, and area of specialization in the general area of hypervelocity impact (i.e., space shielding, high pressure equation of state measurements, launcher technology, etc.). It is desired that the Board of Directors reflect and represent the membership and interests of the Society to as great a degree as possible with a limited number of members.

PUBLICATIONS COMMITTEE

The Publications Committee assists in the preparation and dissemination of materials for the benefit of the Society. The Publications Committee Chair serves as editor and publisher the HVIS Newsletter and is responsible for compiling the proceedings of the Symposia.

SITE SELECTION COMMITTEE

The Site Selection Committee is charged with developing prospective hosts for future Symposia. If you or your organization is interested in hosting a Symposium, please contact the Committee Chair. We are always on the lookout for new locations and organizations to host our Symposia!

GET INVOLVED! If you would like to participate on any of these Committees, please contact the appropriate Committee Chair. This is your Society… we welcome and encourage your participation!

HVIS COMMITTEE CHAIRS

Awards . . . . . Ian Cullis (igcullis@qinetiq.com)
Educational Outreach. . . . . Frank Schaefer (Frank.Schaefer@emi.fraunhofer.de)
Membership. . . . . Emma Taylor (e.a.taylor@open.ac.uk)
Nominations. . . . . Jerry Yatteau (jyatteau@ara.com)
Publications . . . . . Bill Schonberg (wschon@umr.edu)
Site Selection. . . . . Lalit Chhabildas (lcchhab@sandia.gov)

HVIS 2005 — Alex Charters Student Scholars

The following is a list of students who were selected as Alex Charters Student Scholars for the 2005 Hypervelocity Impact Symposium.

Please remember that these students and others like them are the future of our profession and our Society. The Board of Directors and the Program Selection Committee works very hard to send as many deserving students as possible to our Symposia. If you or your organization wish to get involved in by sponsoring qualified students or if you know about funding opportunities that can be leveraged to secure additional support for deserving students, please contact the Committee Chair… the Society can always use additional financial support for this program!

2005 Alex Charters Student Scholars

NAME	INSTITUTION	COUNTRY
Julian Gomez	Auburn University	USA
Shannon Ryan	Fraunhofer-EMI	Germany
Shinya Fukushige	Kyushu Institute of Technology	Japan
Takayuki Harano	Kyushu Institute of Technology	Japan
Masumi Higashide	Kyushu Institute of Technology	Japan
Andrew Lloyd	Marquette University	USA
Emily Baldwin	University College London	England
Daniel Milner	University of Kent	England
Noah Bergeron	University of Louisiana at Lafayette	USA
Alberto Bettella	University of Padua-Italy	Italy
Robert Rabb	University of Texas Austin	USA
Masayoshi Tadaoka	Kyushu Institute of Technology	Japan

Alex Charters Student Scholars Program
CALL FOR NOMINATIONS

The Hypervelocity Impact Society is pleased to announce a call for nominations for the Alex Charters Student Scholars Program. This program provides travel reimbursement support to selected students for attendance at the 2007 Hypervelocity Impact Symposium. Students are selected through a competitive evaluation of nominations submitted by their academic advisors. The symposium will be held the week of September 23rd, 2007 at the Williamsburg Lodge in Williamsburg, Virginia, USA.

ELIGIBILITY

Students enrolled in an academic institution at the time of the conference and interested in hypervelocity impact phenomena are eligible for nomination to the Alex Charters Student Scholars Program. This program is aimed primarily at graduate students, although undergraduate students may apply.

AWARD PACKAGE

Students selected as Alex Charters Student Scholars will receive travel reimbursement support for attendance at HVIS 2007 (transportation and lodging expenses only), up to a limit of one thousand dollars ($1,000 USD) per student. Alex Charters Student Scholars will receive complementary conference registration and a copy of the conference proceedings.

NOMINATION PROCEDURE

The nomination must be submitted by the student's academic advisor, on the letterhead of the academic institution, by mail to the postal address shown at the right under "Schedule". The nomination is limited to a maximum of three (3) pages, and must include the following items: (1) name, address, email address, and telephone number of both the student and the advisor; (2) a brief overview of the student's academic background and record; (3) a description of future academic work to be pursued by the student; and (4) a discussion of why the symposium would be helpful to the student. Nominations submitted by electronic mail or exceeding the three page limit will not be considered.

SCHEDULE

The nominations must be received not later than January 1, 2007, at the mailing address shown at right. Announcement of the Alex Charters Student Scholars for HVIS 2007 is expected to occur six months prior to the start of the conference.

Dr. Frank Schaefer
Fraunhofer Institute for High-speed Dynamics
Ernst-Mach-Institute (EMI)
Eckerstrasse 4
D-79100 Freiburg
Germany

Alex Charters Student Scholars will be selected based on a review of the nominations by the HVIS Educational Outreach Committee.

Questions on the program may be directed to the committee chair, Dr. Frank Schaefer (Frank.Schaefer@emi.fraunhofer.de).-

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Please post “Call for Nominations” on reverse
on a bulletin board.

HVIS 2005 — *A Fantastic Symposium!*

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. The objectives of the Society are to foster the development and exchange of technical information in the discipline of impact phenomena, promote technical excellence, encourage peer review publications, and hold meetings on a regular basis. It was sometime in 1985, and partly in response to the Strategic Defense Initiative (SDI, also often referred to as the STAR WARS) 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.

As such, 2005 Hypervelocity Impact Symposium (HVIS2005) marked the 20th anniversary for the seeding of the Hypervelocity Impact Symposia under the auspices of the Hypervelocity Impact Society. All papers presented at the HVIS are peer reviewed and published as a special volume of the archival journal International Journal of Impact Engineering. The eight previous HVIS proceedings contain nearly 7,000 pages of peer reviewed hypervelocity research articles.

HVIS 2005 was the ninth in the "modern" series and was held October 9–13, 2005 at the Resort at Squaw Creek in California. Total attendance at HVIS 2005 was 191 from 13 different countries, including 12 students who received "Alex Charters Student Scholarships" (ACSS) of up to $1,000 to help reimburse some of their travel expenses. In addition, these students also received fully paid registrations and access to all social functions. In addition to the 12 ACSS students, 13 additional students attended at a reduced student registration rate. All students will receive the special volume of the archival journal International Journal of Impact Engineering that will contain the proceedings of the symposium.

A total of 148 abstracts were initially received by the Society for presentation consideration from 15 different countries. The Technical Committee recommended 100 abstracts for further consideration, and 100 manuscripts were subsequently received. These manuscripts were peer-reviewed for publication in the International Journal of Impact Engineering. As a result of the review, only 84 papers were ultimately selected for presentation at HVIS2005 and publication in the International Journal of Impact Engineering. The 84 papers presented at HVIS2005 fell into the following topical areas:

- Launchers and Diagnostics (12 papers)
- Impact and Penetration (14 papers)
- Material Response (17 papers)
- Analytical and Numerical Computations (8 papers)
- Debris Shielding (6 papers)
- Fracture and Fragmentation (11 papers)
- Planetary and Space (12 papers)
- Phenomenology (4 papers)

The opening keynote talk of HVIS2005, following the tradition that was started in 1989, was given by the recipient of the Society's Distinguish Scientist Award, **Dr. Lalit Chhabildas**. Lalit's talk was entitled, *Material EOS/ Properties Measurements to Hypervelocity Launchers.* Plenary talks leading off the other days of the Symposium were given by **Marcus Knudson** of Sandia National Laboratories *(The Fastest Magnetic Launcher — Macroscopic Plates to Over 30 km/s – EOS Development and other Applications),* **Peter Schultz** of Brown University *(The Deep Impact Mission),* and by **Dennis Grady** of Applied Research Associates *(Fragmentation and Sir N.F. Mott).*

The Hypervelocity Impact Society is grateful for the support provided by the Army Research Office as well as the Army Research Laboratory. The support provided by these organizations allowed for active and meaningful participation by the students, and helped ensure the overall success of the symposium!

SOCIETY Awards

According to the Society's Constitution,

"The Board of Directors may establish an Awards Committee to administer awards and recognition for service to the field of hypervelocity impact. In general, an award for best paper and the Distinguished Scientist Award are presented every two to three years at an HVIS meeting."

Here is some more information about these two important awards and how they are determined and administered.

Best Paper Award

An award for the best paper presented at the Hypervelocity Impact Symposium and published in the proceedings is given at each Hypervelocity Impact Symposium. The selection criteria for this award are:

- originality;
- difficulty of research;
- importance of research; and,
- excellence of the written paper.

Candidates for the Best Paper Award are nominated by the Chairs of the technical sessions to be held at the upcoming Symposium. This is typically done at the manuscript review meeting. The nominations are presented to the Awards Committee for final selection. The Committee members rank order each of the nominees and identify a final selection for the Best Paper Award. Once a selection is made, the Society President is notified for concurrence, but the authors of the paper are not notified until the Award is actually announced at the Symposium.

Distinguished Scientist Award

This award is given to a single individual or to a research team of two or more individuals for significant and lasting contributions to the field of hypervelocity science. The award consists of a plaque citing the accomplishments of the award winner and a monetary remuneration set by the Board of Directors. The recipient also receives free registration at future meetings of the HVIS.

The process for selection is based on a list of candidates that has been generated by members of the Board of Directors and by the Awards Committee. The Chair of the Awards Committee also solicits input from the HVIS membership at large. This can be done through a formal mailing or through the HVIS Newsletter and is typically done about a year before the award is made. Each nomination must consist of a formal letter of nomination with supporting information about the candidate.

Once a complete set of candidates is identified, the Awards Committee goes through several rounds of voting to identify the winner. The criteria for selection include:

- technical recognition;
- importance of work;
- scope of work;
- current work and level of activity; and,
- service to the Society

The selection of the Distinguished Science Award recipient is typically completed at least three months prior to the next HVIS meeting in order to give the recipient sufficient time to prepare an acceptance keynote speech at the Symposium.

Hypervelocity Impact Symposium

September 23–27, 2007
Williamsburg Lodge Conference Center
Williamsburg, Virginia

The Hypervelocity Impact Symposium is a biennial event that is dedicated to enabling and promoting an understanding of the basic physics of high velocity impact and related technical areas. This international event provides a forum for researchers to share and exchange a wealth of knowledge through oral and poster presentations and commercial exhibits.

HVIS 2007 will be the tenth symposium in the modern series and will be held at Williamsburg Lodge Conference Center located in historic Williamsburg, Virginia.

Williamsburg Logde & Conference Center

HVIS 2007
P.O. Box 207
Sealston, VA 22547-0232

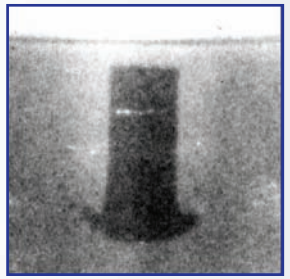
10th HVIS Symposium

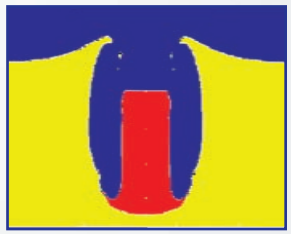
Hypervelocity Impact Symposium

First Call for Abstracts

Abstracts Due December 15, 2006

Check the HVIS 2007 link
at HVIS.org
for the latest information





Symposium Chairs

David L. Dickinson
Naval Surface Warfare Center Dahlgren Division
E-mail: dickinson@hvis2007.org

Leonard T. Wilson
Naval Surface Warfare Center Dahlgren Division
E-mail: wilson@hvis2007.org

Symposium Coordinator

Catherine C. Quinn
Strategic Insight, Ltd.
E-mail: quinn@hvis2007.org

Williamsburg, Virginia

Williamsburg is centrally located between Richmond (the capital of Virginia) and Virginia Beach (located on the Atlantic shore). Williamsburg is part of Virginia's Historic Triangle which includes Jamestown and Yorktown.

Hypervelocity Impact Symposium

September 23-27, 2007

Williamsburg Lodge Conference Center
Williamsburg, Virginia

Topics include:

- Hypervelocity Phenomenology Studies
- High Velocity Launchers and Diagnostics
- Spacecraft Meteoroid/Debris Shielding and Failure Analyses
- Spacecraft Shielding
- Spacecraft Studies Space Debris Environment
- Material Response (including EOS)
- Fracture and Fragmentation
- High Velocity Penetration Mechanics and Target Response
- Armor/Anti-Armor
- Impact and Penetration
- Analytical and Numerical Techniques
- Asteroid Impact and Planetary Defense Technology
- Penetration Mechanics of Shaped Charges and Explosively Formed Penetrators

Images courtesy of Colonial Williamsburg and Jamestown Settlement

Submission of Abstracts

Abstracts of proposed papers are solicited from those interested and involved in hypervelocity impact. The preferred method of submitting abstracts is using e-mail. This can be done through the HVIS 2007 link at the Society web site at www.hvis.org or postal mail to:

HVIS 2007
P.O. Box 207
Sealston, VA 22547-0232
USA

Abstract Guidelines

- Abstracts should be limited to 1,000 words plus figures and references.
- The official language is English.
- Abstracts must be unclassified and cleared for public release with unlimited distribution.
- Include name, address, affiliation, phone number, fax number, and e-mail address of primary author.
- Indicate author's preference for oral or poster presentation.

Schedule

December 15, 2006 . . . . . .Abstracts Due
February 2, 2007 . . . . . .Notification of Authors
April 2, 2007 . . . . . .Papers Due for Review
June 28, 2007 . . . . . .Final Papers Due
September 23, 2007 . . . . . .HVIS 2007 Starts

International Symposium on Ballistics

By Stephan Bless

The 22nd International Symposium on Ballistics (ISB) was held in Vancouver, British Columbia, 14–18 November 2005. These conferences are overseen by the International Ballistics Committee.

The American conferences are run by the Ballistics Division of the National Defense Industrial Association (NDIA), for which Bill Flis of DE Technologies and Brian Scott of ARL served as Chairs.

This was a well attended conference with a number of papers that are of interest to the HVIS community. Bound and CD copies of the proceedings were distributed at the conference. Copies of the powerpoint presentations are also available online at:

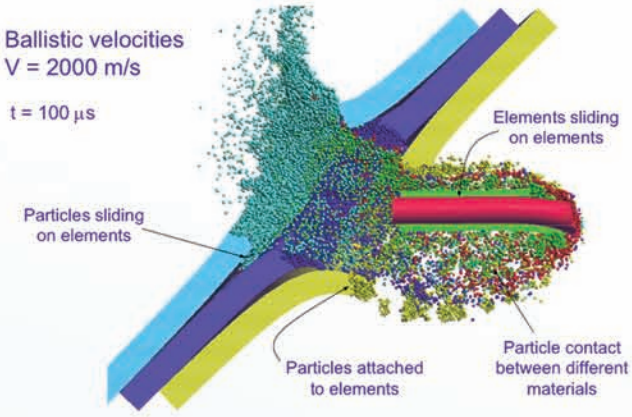
http://www.dtic.mil/ndia/22ndISB2005

The 2005 Symposium included 171 papers on all aspects of ballistics, and are sorted by technical area in the Symposium proceedings. Many of the papers also fall within the scope of typical Hypervelocity Impact Symposia topics.

The next Symposium will be held in Tarrogona, Spain, 16–22 April 2007. The 2008 Symposium will be held in New Orleans and will be chaired by longtime HVIS members **Drs. James Walker and Stephan Bless**.

The following paragraphs summarize some of the highlights of the 2005 ISB that might be of interest to Society members.

In the area of fracture and fragmentation, Lidén showed that fracture during rod yawed impact is repeatable and not stochastic. Bless and his colleagues from IAT presented papers on behind armor debris and fracture of tungsten that extended their work presented at HVIS 2005. They also presented a paper on fracture of alumina in which they found unusually high compressive strength.



In the area of high velocity penetration mechanics, **Th. Behner**, et al, measured failure wave velocities in glass struck by hypervelocity penetrators, and showed an effect on the Tate penetration resistance, R_t. **Strassburger**, et al, also observed failure-wave-like behavior in AlON and fused silica from edge impacts. Penetration and fragmentation of concrete were discussed in two papers from **Armasuisse** (by **Jeanquartier** and **Lampert**). There were also a large number of papers dealing with threshold penetration in brittle materials. **Mullin**, et al, provided data for hypervelocity penetration of DU into metals and ceramics. **Anderson** prevented a rather complete evaluation of hypervelocity tubular projectiles striking armor-type targets, finding that they were very vulnerable to off-axis forces.

Finally, in the area of analytical and numerical methods, progress on their new meshless techniques for carrying calculations beyond fracture and fragmentation was reported by **Johnson** and **Stryk**. The figure above shows some results using this new technique. The **Johnson-Cook** damage model was quantitatively evaluated against data by **Anderson**, et al, and parameters for steel were given.

The Discrete Particle Analysis Method

by Allen J. Richardson

History

At the onset of the Apollo Project in 1964, one of the many engineering tasks undertaken by then North American Rockwell (NAR) was the calculation of the meteoroid hazard to the Command Service Module (CSM) Vehicle. It was contractually established that the probability of no crew loss due to this hazard be 99.3% or greater, and that shielding should be incorporated as necessary to meet this requirement. The vehicle was readily divided into its numerous components based on the allowable damage they could sustain. Component probability of no failure was then determined by use of the familiar Poisson equation, $P_0 = e^{-NAT}$, where N is the meteoroid flux of mass m or greater, A is the component surface area, T is the exposure time, and m is the mass of the meteoroid which will cause component failure. It was the failure mass calculation for which analysis methods were inadequate at that time. Considerable particle impact test data was available, but on single sheet structures and at velocities well below the designated meteoroid velocity of 30 km/sec. Damage predictions using analysis methods for single sheet structures were divergent, and methods for predicting damage to multilayered structures were nonexistent. In the 1964 to 1969 time period the Discrete Particle Analysis (DPA) method was developed for NASA by a NAR team. That method has been in use continually by Rockwell, Boeing, and now is in book form [1].

Method Development and Capability

The DPA method was developed in four stages each documented by a report. In Stage 1, equations were derived for predicting penetration into metal, glass and ablator. This was done by applying regression to all available test data. This included micro-particle data as it extended to higher velocities (15 km/sec). In Stage 2, an equation was developed for predicting the hole size resulting from projectile impact on a thin metal sheet. In Stage 3, equations were derived for predicting damage to a simple, spaced two-sheet metal structure where the projectile and structure material were the same. Damage prediction included hole size in the first sheet and maximum penetration into the second sheet. To accomplish this, two analysis innovations were introduced. First, it was noted from high-speed films that the projectile fragmented on impact with the first sheet. Therefore, an equation was introduced which quantified the extent of particle fragmentation in terms of the number (and thereby the size) of the fragments. Second, the same films indicated that these fragments translated toward the rear sheet in an expanding spherical cloud. Applying basic physics relationships, equations were derived for predicting the velocity vectors for these fragments. Knowing fragment velocity and size, its penetration into the rear sheet was readily predicted by use of the penetration equation developed in Stage 1. This approach

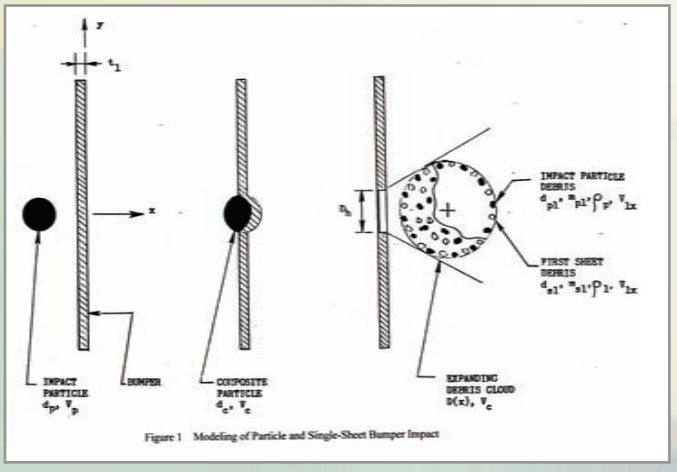


Figure 1 Modeling of Particle and Single-Sheet Bumper Impact

Figure 1

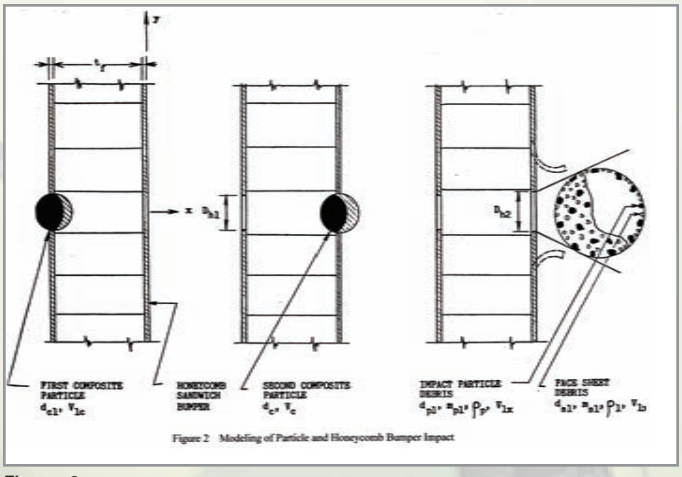


Figure 2 Modeling of Particle and Honeycomb Bumper Impact

Figure 2

was designated as the Discrete Particle Analysis (DPA) method, presented at the 1969 AIAA Hypervelocity Impact Symposium, and subsequently published in the AIAA Journal [2].

Analysis of the Apollo CSM structures required a more sophisticated method. Therefore, in Stage 4 the DPA method was extended, (1) to consider projectile and first layers composed of different materials and account for both projectile and first layer fragments (see Figure 1), (2) to allow the first structure layer to be a single sheet or a honeycomb sandwich (see Figure 2), and (3) to account for the shielding effect of any low density layer (e. g. thermal insulation) located anywhere behind the first layer (see Figure 3). The resulting methodology was programmed for computer solution and its accuracy was confirmed by test (a typical verification is presented in Figure 4). The DPA method as developed over 40 years ago predicts (1) penetration into the bumper for particles too small to perforate it, (2) hole size in the bumper when perforated, (3) size and velocity of the fragments exiting the bumper, (4) reduction in fragment velocity due to passage through any low density layer between the bumper and rear sheet, (5) maximum penetration of the fragments into the rear sheet, and (6) all the preceding information for the case where the bumper is a honeycomb sandwich structure.

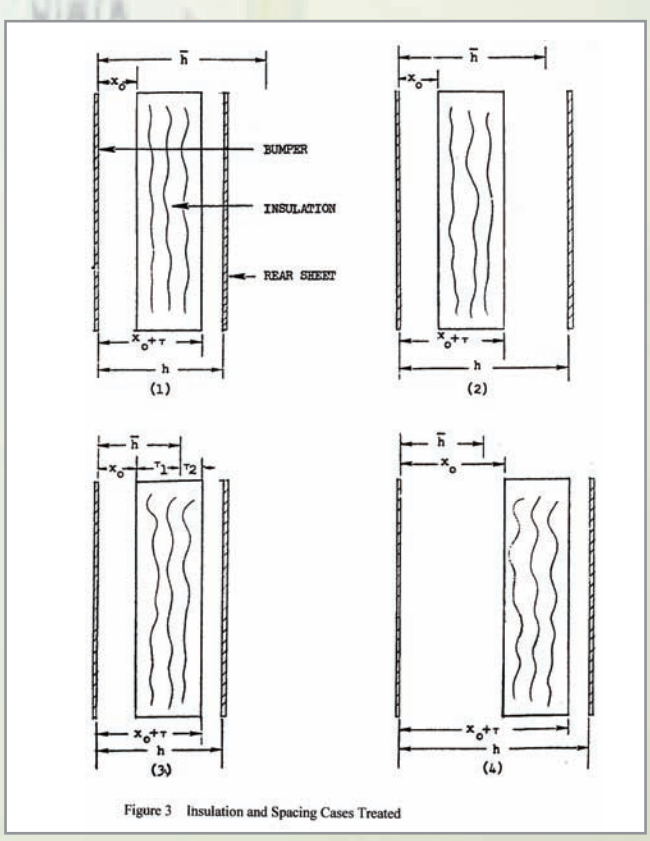


Figure 3 Insulation and Spacing Cases Treated

Figure 3

Application to Appollo Spacecraft

The sole impetus for development of the DPA method was to calculate the meteoroid hazard to the Apollo CSM during the trans-lunar mission. This analysis was completed as outlined above, and the probability of no crew loss due to meteoroid impact was found to exceed the required 99.3% value. This was without any meteoroid shielding added to the vehicle. Early in the project, meteoroid shielding had been specified for the Service Module but after application of the finalized DPA method it was deleted. The writer received the NASA Snoopy award for the development of the DPA method and completion of the CSM meteoroid hazard analysis.

Application to the Space Shuttle

During 1975 to 1990, Rockwell engineers completed several Space Shuttle studies to determine the hazard posed by impact of hypervelocity particles, including both meteoroids and space debris. The DPA program was applied again to determine the failure particle mass for numerous Space Shuttle components. It was found that the typical Space Shuttle wall construction of Figure 5 could be represented in terms of the models shown in Figures 1-3. The fourth and definitive hazard analysis was completed by Rockwell engineers in 1991 [3] during which the new directional meteoroid flux was introduced, and supporting hypervelocity particle impact tests were conducted for Rockwell by NASA. The major findings were that the particle environments posed a significant but acceptable hazard, and that the hazard could be significantly reduced by proper on-orbit orientation. It was also found that the test results supported the DPA calculations, indicating again the versatility of the DPA program.

Current Applicability

The NAR reports on the DPA method were distributed to the NASA centers in the early 1970s upon their completion. It is understood from recent communications

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with HVIS personnel that Cour-Palais, Wilbeck, and Hermann presented papers on much of that information in the years immediately following. Learning of this, a preliminary internet review of recent HVIS and AIAA publications dealing with methodology similar to the DPA was conducted. The information obtained suggests that the DPA method or variations of it were adopted early on by NASA as well as the DOD and are still in use (see, e.g., [4] and [5]).

When the meteoroid hazard analysis of the Apollo CSM was completed by the NAR team, the writer and a colleague were sent by NAR to seek funding for extension of the DPA method as a separate contract. Various NASA centers were visited and the documentation passed along. The extension recommended was to systematically identify the fragmentation factors for a full range of projectile materials, as was done by NAR for beryllium and aluminum. These factors could then be incorporated into the DPA method which any engineer could then utilize to compute hypervelocity particle damage to spacecraft structures. The author is pleased to note that fragmentation continues to a topic of interest to the HVIS community as evidenced by the eleven papers presented on this topic at HVIS2005. This leads to the observation

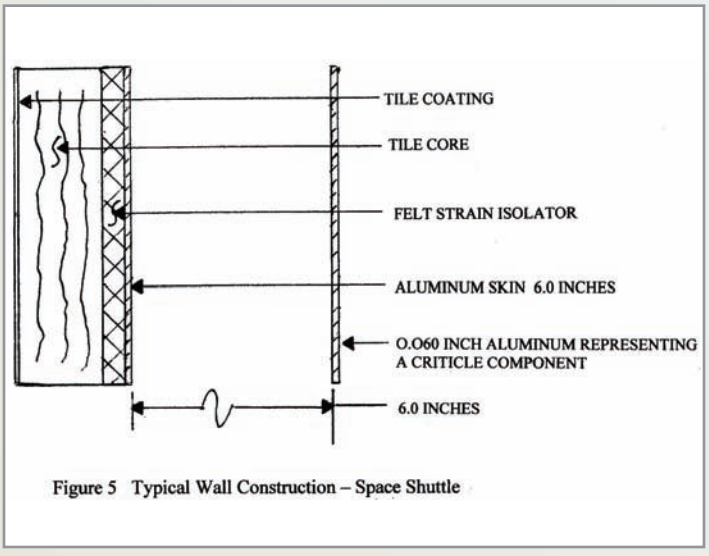

Figure 5 Typical Wall Construction – Space Shuttle

Figure 5

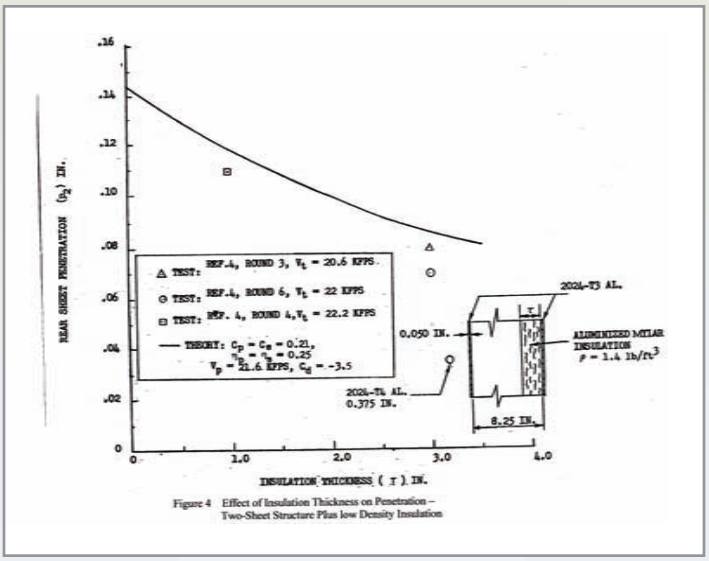

Figure 4 Effect of Insulation Thickness on Penetration – Two-Sheet Structure Plus low Density Insulation

Figure 4

that the quantification of projectile fragmentation inaugurated and recommended by the NAR team apparently continues to be pursued.

Some final observations are as follows: (1) it appears that damage prediction methods currently in use by NASA were derived from the DPA method, which is a credit to the NAR team which pioneered this method, (2) the original DPA method [1] is still applicable and may contain capabilities not present in currently used variations of the method, and (3) the DPA method appears to be ideally suited to analysis of the current Apollo-like trans-lunar vehicle under study at this time.

(1) Richardson, A.J., 2006, Hypervelocity Particle Penetration into Spacecraft Structures, available at AlRichardson2@AOL.COM.
(2) Richardson, A.J., 1970, "Theoretical Penetration Mechanics of Multisheet Structures Based on Discrete Particle Modeling", AIAA Journal of Spacecraft and Rockets, Vol. 7, No. 4.
(3) Hasselbeck, M. J., M. J. Koharchik, et al, 1991, Orbiter Particle Impact Hazard Study, Rockwell International SSD Report 910771.
(4) Wilbeck, J.S., et al, 2001, "Hypervelocity Impact of Spaced Plates by a Mock Kill Vehicle", International Journal of Impact Engineering.
(5) Reimerdes, H.G., et al, 2005, "Modified Cour-Palais / Christiansen Damage Equations for Double-Wall Structures", Proceedings of the 2005 Hypervelocity Impact Symposium, International Journal of Impact Engineering.

HVIS 2007 — Williamsburg, Virginia, U.S.A.

The next Hypervelocity Impact Symposium, HVIS 2007, will occur during the week of 23 September 2007 in Williamsburg, Virginia, USA. The Technical Program Co-Chairs are Lalit Chhabildas (Sandia National Laboratories) and Bill Schonberg (University of Missouri-Rolla).

Williamsburg is located centrally between Richmond (the capital of Virginia) and Virginia Beach (located on the shores of the Atlantic), Virginia. It is part of Virginia's Historic Triangle which also includes Jamestown and Yorktown.

The conference location will be the Williamsburg Lodge. During 2006, the Lodge's conference center, guest rooms, and suites will be new or newly renovated with furnishings inspired by the collections of the Abbey Aldrich Rockefeller Folk Art Museum. Guest accomodations will include all modern amenities, including high-speed internet connectivity. Recreation at the Lodge includes golf, outdoor pools, tennis croquet and lawn bowling.

Included in the conference package will be admission tickets to Colonial Williamsburg. By taking a short walk from the Lodge, you will step back in time to a thriving 18th-century community, the capital of England's largest and most important colony in the new world. America's largest living history museum offers an unparalleled view of daily Colonial life when it was a powerful center of politics, commerce and culture. Over 500 original and carefully reconstructed public buildings, private homes, taverns and shops, and 90 acres of gardens and public greens make up the Historic Area. It is brought to life with tradesmen and historical interpreters in full period costume. A shuttle-bus service around the perimeter is available.

Colonial Williamsburg's Visitor Center is also the official gateway to America's 400th anniversary, marking the establishment of the first permanent English settlement in the New World at Jamestown in 1607. America's evolution from colonial status to nationhood is chronicled through a unique blend of timeline, film, thematic exhibits and outdoor living history at the Yorktown Victory Center. Special events throughout 2007 at both locations celebrate this momentous event and explore its role in the evolution of government, cultural and social institutions that characterize today's United States.

The Williamsburg area offers a variety of other activities, including Busch Gardens Williamsburg an action-packed, European-themed adventure park with 17th-century charm and 21st-century technology and shopping at the area's outlet malls. By taking short drives one can explore America's Civil War history, maritime museums at Norfolk and Newport News, and the shores of the Chesapeake Bay or Atlantic Ocean.

Commercial Exhibits will be on display during the entire symposium giving attendees ample time to emet with company representatives. There will also be an opportunity during the symposium for th erepresentatives to provide a brief oral overview. Companies interested in exhibiting should look for the Commercial Exhibit link on the symposium web page. HVIS Symposium Exhibition Co-Chairs are William Reinhart and Masahide Katayama.

Major airports are located within 45 minutes of Williamsburg. The average temperature range should range from a low of 57°F to a high of 78°F.

Photos courtesy of The Colonial Williamsburg Foundation, Williamsburg, VA.

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Hypervelocity Impact Society
Bill Schonberg, Publications Committee Chair
UMR CArE Engineering Department
1870 Miner Circle • Butler-Carlton Hall
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