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SESSION 1: "THE BEST OF SAVE" *HENRY C. PUSEY BEST PAPER AWARD-WINNING PRESENTATIONS*

A SIMPLIFIED FINITE ELEMENT MODEL FOR DESIGN OF A RESONANT PLATE

Angela Patterson, Sandia National Laboratories
Dr. Vit Babuska, Sandia National Laboratories
David Soine, Sandia National Laboratories
Daniel Lee, Sandia National Laboratories

Accurate finite element models are often very complex and can take a long time to develop. The goal of the work described in this paper was to create a model for design that is as simple as it can be and no more complicated than it must be. This paper focuses on the creation of a simplified model for a resonant plate. Resonant plates are used in mid-field pyroshock testing environments. During these tests, components are mounted to one side of the plate, and the other side of the plate is struck by a projectile or hammer. Damping bars are mounted along the plate's edges to damp the response of the plate and avoid problematically long ring down times.

The 1kHz resonant plate was selected to be modeled because an abundance of test data was available and because a more complex model of this plate had already been developed and validated. The simplified model was created using Ansys Mechanical. Ansys was chosen as the modeling software because it is a trusted, widely available, commercial product.

The 1kHz plate has a thickness to length ratio of approximately 1:10, so the first simplification made was to model the plate using two-dimensional plate elements. The accuracy of Ansys plate elements was assessed by comparing the results of modal analyses of models using two-dimensional and three-dimensional elements for plates of varying thicknesses. Plates with thickness to length ratios from 1:40 to 1:2 were modeled. It was found that Ansys plate elements are very robust and can provide results within 1.5% of three-dimensional solid elements even for plates whose thickness is approximately half of its length – well beyond normal plate assumptions. A similar comparison between plate and solid elements was conducted in Sierra SD, but the results were not as promising.

Since Ansys plate elements provided such accurate results, a model consisting purely of plate elements and point masses was produced. These point masses were needed to represent the mounting blocks along the edge of the plate and the impact block in the middle of the plate. The model of the plate with point masses produced natural frequencies within 3.5% of the test data. Next, a simplified model of the plate with damping bars was created. This model consisted of the bare plate model connected to four bars that were modeled using plate elements. Two rows of beam elements were used to connect each bar to the plate which represented the steel rods used to attach the bars to the plate. The natural frequencies produced by this model were within 5% of the frequencies found during a modal test of the plate with damping bars. Modal assurance criteria (MAC) were computed to compare the mode shapes of the models to the test data and identify matching modes for frequency comparison.

Deriving Best SDOF Shaker Inputs from 6 DOF Base Input Payload Models

Randall Mayes, Consultant

We assume here that sufficient field vibration measurement data have been gathered on the base mounted payload. Given that, we show how a 6 DOF base input payload model can reproduce the field response on the payload. This is performed through a sum of the rigid body modes and a relatively small number of fixed base payload modes. Since most qualification testing is done on SDOF vibration machines, we utilize the payload model to determine the best input for the SDOF test as well as the associated uncertainty in matching the field data. The required portions of the 6 DOF payload model can be directly extracted from random surveys of the payload on either 6 DOF or SDOF machines. The structural strain damage potential can be quantified in the potential energy of each fixed base mode which provides significant mechanical insight.

A Technique to Develop a Spectral Density Matrix with Synthesized Rotational Degrees-of-Freedom

Dr. Michael Hale, Trideum Corporation

Reference criteria for a multiple degree-of-freedom (MDOF) random vibration test is generally provided in terms of an acceleration based spectral density matrix (SDM). It is common practice that a SDM is developed in terms of the auto-spectral densities (ASD's) and cross-spectral densities (CSD's) computed from the time histories acquired from an appropriately placed and oriented set of linear accelerometers. A reference SDM in terms of the accelerations associated with the six classical motion degrees-of-freedom as defined at an arbitrary point of origin will be denoted as SDMmotion. In a situation in which it is desired to expose a test article to 6-DOF excitation and there is a lack of appropriately placed transducers, one must exercise caution in the synthesis of a reference SDM to ensure the reference criteria remains physically realizable. The objective at hand is to demonstrate a technique to synthesize a physically realizable reference SDMmotion given only predefined translational spectral shapes.

On the Nature of Spectral Density Matrices used to Characterize Vibration Environments

Dr. Luke Martin, NSWC Dahlgren
Shawn Schneider, NSWC Dahlgren

Multiple exciter vibration testing has been addressed by MIL-STD-810 since 2008 with the inclusion of Method 527, "Multi-Exciter Testing". This method begins the dialog and documentation of the added complexities associated with multiple degree of freedom testing (MDOF) when compared to traditional single degree of freedom (SDOF) testing. One added complexity in MDOF testing is the requirement to define a spectral density matrix (SDM).

This presentation will review families of SDMs computed from real-world measured field data. A given SDM is comprised of auto-spectral densities (ASDs) and cross-spectral densities (CSDs). The author will explore the ASDs and CSDs that comprise the SDM from real-world data. Insight, intuition, and physical relationships gained from analyzing the data will be discussed. This presentation is a prequel to the SDM correction work presented in the recent past at SAVE and ESTECH.

SESSION 2: SHOCK TESTING METHODOLOGY I

DEVELOPMENT OF A MAST MOUNTED ANTENNA TESTING CAPABILITY (PART I)

Sloan Burns, NSWC Dahlgren
Garrett Wiles, NSWC Dahlgren
Robert Ponder, NSWC Dahlgren
Dr. Bryan Joyce, NSWC Dahlgren

Naval mast-mounted antennas must be shock-tested and qualified like all shipboard materiel; however, the velocity in the mast environment is greater than any other shipboard location. Therefore, standard Military Detail (MIL-DTL) 901E shock machines are insufficient for imposing adequate damage potential to mast-mounted antenna and a tailored shock test is required.

This presentation overviews the theory of operation, proof of concept, and application of a mast-mounted antenna test platform that utilizes mechanical resonance to generate severe shock environments. Leveraging resonance amplifies the excitation from a hydraulic shaker to generate the necessary dynamic environment. Models of the resonant fixture are developed and validated by sub-scale testing.

DEVELOPMENT OF A MAST MOUNTED ANTENNA TESTING CAPABILITY (PART II)

Sloan Burns, NSWC Dahlgren
Garrett Wiles, NSWC Dahlgren
Robert Ponder, NSWC Dahlgren
Dr. Bryan Joyce, NSWC Dahlgren

Naval mast-mounted antennas must be shock-tested and qualified like all shipboard support materiel; however, the shock response severity in the mast environment is greater than that elsewhere. Therefore, performing standard Military Detail (MIL-DTL) 901E shock testing on a mast-mounted antenna is not sufficient for imposing adequate damage potential and a tailored shock test is required.

This presentation overviews the mechanical design and operation of a full-scale resonant fixture actuated by a hydraulic shock machine for use in mast-mounted antenna shock testing. Examples of successful operation will be presented. Limitations, lessons learned and future improvements will be discussed.

COMMON PITFALLS IN ENVIRONMENTAL TESTING

Roger Bunce, NTS Technical Systems
Calvin Milam, NTS Technical Systems

This session will give a brief overview of common errors in the testing process. Topics included will be determining the correct test for the article, better defining the Statement of Work, planning a coherent schedule, developing sensible test procedures and common avoidable failure modes during the conduct of shock testing. The primary focus will be centered on heavyweight shock testing although many of the concepts will be applicable to various other tests.

DYNAMIC ENVIRONMENT TEST FIXTURE RESPONSE UNDER SHOCK LOADING

Cora Taylor, Michigan Technological University
Dr. James DeClerck, Michigan Technological University
Dr. Jason Blough, Michigan Technological University
Charles VanKarsen, Michigan Technological University
Raymond Joshua, Department of Energy's Kansas City National Security Campus

The Process to Design, Analyze, and Build Dynamic Environment Test Fixtures (PDADyE) is intended to be used for any type of dynamic environment, such as vibration and shock. In order to validate the PDADyE process the test fixture developed using the process must be tested with both shock and vibration inputs. For this validation procedure truth data was collected using two BARC assemblies, one with and one without the component. This work discusses the replication of the field shock environment in the lab and uses a dynamic test fixture to replicate the component of interest's field response as it experiences a shock event.

TWR PULSE DEVELOPMENT FROM MULTIPLE TEST RECORDS

Sloan Burns, NSWC Dahlgren
Dr. Bryan Joyce, NSWC Dahlgren

Time waveform replication (TWR) of shock test records affords replication of the shock severity of an environment by all metrics of assessment and is therefore preferential for laboratory testing. When multiple test records exist but only one shock pulse is desired for testing, TWR cannot be directly executed. This presentation overviews methods used to derive a single TWR shock pulse from multiple test records. In cases where a large data set exhibiting similar spectral content existing (i.e. gunfire shock), methods to determine or develop a time history which best approximates the desired test level (i.e. envelope or 95/50) is presented. For cases where few test records exist and exhibit different shock severities and/or spectral content (i.e. barge shock), methods of digital signal processing to modulate an original test record to approximate the desired test level will be presented.

SESSION 3: BLAST RELATED DAMAGE

SHAKE & BAKE: INVESTIGATING THE HIGHLY COUPLED AND EXTREME NEAR-FIELD THERMOMECHANICAL ENVIRONMENT OF ROCKET FIRINGS

Dr. Jason Foley, AFRL/RXEB
Dr. W. Jacob Monzel, AFRL/RXNP
Dr. Ming Chen, AFRL/RXNC
Dr. Malissa Lightfoot, AFRL/RQRC
Stephen Danczyk, AFRL/RQRC
Dr. Robert Jensen, Sierra Lobo, Inc.
Kathryn Rutherford, UES, Inc.
Dr. Jeroen Deijkers, UES, Inc.

The Space Force has identified Space Mobility & Logistics (SML) as a core competency in its Spacepower doctrine. AFRL and its R&D partners (AFCEC, ERDC, NASA, and commercial space providers) are correspondingly executing multiple science and technology (S&T) programs to explore the landing and delivery capability of reusable liquid rocket systems. One of the key technical challenges common to all of these programs is understanding the landing surface degradation mechanisms when exposed to the extreme environment of directly-impinging rocket plumes. Unique features of the liquid-fueled rocket plumes will be discussed and some ranges for the thermal and mechanical environments will be given with an emphasis on the transient and highly coupled nature of the loads. The superset of extreme environments provides context for another key research activity: understanding the dominant degradation and/or failure modes observed in laboratory, field, and full scale testing. Results from various experimental and computational tests with a variety of damage mechanisms will be shown. Finally, this presentation will also provide a brief overview into the practical difficulties of collecting data in these tests and comments on the state-of-the-art in extreme environment sensing and data acquisition.

CHARACTERIZATION OF SIMPLIFIED SURROGATE MUNITION

Marcus Barksdale, USACE ERDC
Austin Hopkins, USACE ERDC
Bradley Foust, USACE ERDC
Bowen Woodson, USACE ERDC

The capability to assess terminal effects against targets rapidly for munition design innovations is essential for modern warfare. During munition developmental stages, weapon developers aim to ensure significant lethal effects while minimizing cost and time. Continued development of advanced weapon systems creates capability gaps in the current weapons effects analysis tools. This technology gap necessitates evolutionary development of enhanced modeling and simulation capabilities. These innovations are required to formulate fast-running prediction methods to predict weapon terminal effects across a broad range of velocities and impact conditions that ensure engineering tools are in step with innovations in munitions and materials. By enhancing these capabilities, the effectiveness and lethality of new munition capabilities and their effects against advanced high-performance target materials can be assessed. However, these advanced tools are not possible without validation from physical experiments. Thus, the Engineer Research and Development Center (ERDC) has conducted multiple series of full-scale blast and fragment experiments. A previous experimental series consisted of two arena experiments designed to characterize the fragment distribution and velocities of a simplified surrogate munition that resembles an M107 155 mm. Subsequently, the ERDC conducted another series of seven arena experiments to examine the cumulative damage effects of surrogate munitions against steel and concrete targets. These experiments were discussed at the 92nd Shock and Vibration Symposium in Denver, CO. However, in recent months the ERDC performed a sequel to the previous experiments by conducting six additional arena experiments. The purpose of these experiments was to gain additional insight into the lethality of the simplified surrogate munition against steel and concrete targets and provide the ERDC's numerical modeling team and code developers additional data to fill gaps from previous experimental series. The data from these experimental series consisted of blast overpressures, blast side-on pressures, peak midspan deflection, maximum residual midspan deflection, target perforation areas, fragment velocities, and concrete spall and crater measurements. This presentation provides an overview of the latest test series, compares results to previous experimental series, and highlights the importance of high-fidelity experimental data in development of new tools critical to the Army's mission.

DYNAMIC BLAST EFFECTS

Dr. Brian Taylor, AFRL

No abstract available.

SESSION 4: DYSMAS I

PARADYN PARTICLE COUPLING FOR FRAGMENTATION APPLICATIONS

Dr. Jeff St. Clair, NSWC Indian Head
Jim Warner, NSWC Indian Head
Dr. Tom McGrath, NSWC Indian Head

This work introduces a new capability within the DYSMAS coupled hydrocode that is under development to support ongoing efforts of high fidelity modeling of reactive fragments. While modeling fragments and particles is nothing new within the realm of finite element analysis, capturing the tightly coupled physics of these particles interacting with the fluid around them in a reactive state has been demonstrated by few. A new data-light particle formulation within ParaDyn will be described, as well as the coupling mechanism it utilizes to pass needed information to and from the fluid solver Gemini. Test cases showing capability will be presented, followed by comparisons against experimental data acquired through Vented Calorimetry Chamber (VCC) tests.

HIGH SPEED FUZE IMPACT TESTING AND EVALUATION

Horacio Nochetto, NSWC Indian Head
Erin Ruiz, NSWC Indian Head
Noah Schaeffer, NSWC Indian Head
Kevin Cochran, NSWC Indian Head
Dr. Jeff St. Clair, NSWC Indian Head
Chris Cao, NSWC Indian Head
Ryan Barretta, NSWC Indian Head

Certain target sets for high-speed strike weapons, particularly in the maritime arena, require a delayed fuze function after one or several impacts to ensure the warhead detonates in the desired location within the target. This work describes ballistics tests and accompanying high-fidelity simulations that were conducted by NSWC Indian Head Division to investigate the loading incurred upon and hence the survivability of a fuze within a high-speed weapon during a multi-plate penetration event. The surrogate test vehicle was gun launched against three steel plates perpendicular to the ballistic trajectory. A soft catch was located behind the target plate array for retrieval of data and vehicle remains. Description of the test design, including the vehicle's geometry, terminal impact speed, and target plate array is provided. Results of the test are also presented, including the survivability of candidate fuzes subjected to similar loading. Following the ballistic tests, high fidelity modeling and simulation (M&S) of the test was executed using the Navy's DYSMAS hydrocode. Results of the experiment and M&S efforts are compared, including velocity and resulting g-loading on the surrogate fuze as well as target plate damage. The comparisons are favorable and show promise for using the M&S capability for predictive modeling of tactical scenarios that produce similar loading during a multi-plate penetration event.

DYSMAS-BASED AUTOMATION FOR MACHINE LEARNING OF LETHALITY EFFECTS

Dr. Frank VanGessel, NSWC Indian Head
Dr. Cameron Stewart, NSWC Indian Head

High-fidelity coupled hydrocode simulations of fluid-structure interactions provide the gold-standard in computational predictions of weapon effects. However, these highly accurate models are hampered by significant computational cost and an engineer-in-the-loop paradigm. These challenges restrict typical lethality and survivability assessments to a single, or a handful, of scenarios requiring high-performance computing resources. We present an approach to autonomously perform weapon effect simulations for an arbitrary charge location within a standard threat scenario. This automated framework allows one to rapidly sample the threat parameter space, perform the corresponding high-fidelity simulations, and extract the relevant lethality or survivability effect. The dataset generated by this framework is subsequently applied to training a machine learning surrogate model. This surrogate model capably predicts weapon effects in 6 orders of magnitude less time than the hydrocode model and requires only a fraction of the computational cost. Our multi-tiered approach lays the groundwork for ameliorating traditional modeling challenges associated with high-fidelity M&S, offering high-accuracy predictions in near-real time.

ARCTIC ICE MODELING IN GEMINI

Dr. Brad Klenow, NSWC Indian Head
Anna Czerepak, NSWC Indian Head

To explore the ability to conduct Naval operations in non-traditional environments, an effort has been undertaken to model conventional underwater weapon effects under Arctic sea ice using high-fidelity modeling and simulation tools. This presentation provides a background on relevant approaches to modeling sea ice, and an overview of the development and implementation of an initial sea ice model for use in DYSMAS. Lastly, simulation results from the application of the developed DYSMAS sea ice model to a set of sample underwater weapon effects cases and plans for validation of the model are discussed.

WATER ENTRY MODELING FOR AIR-DELIVERED, UNDERWATER WEAPONS

Horacio Nochetto, NSWC Indian Head
Dr. Jeff St. Clair, NSWC Indian Head
Dr. J. Alan Luton, NSWC Indian Head

There is a growing interest in high-speed maritime strike weapons within the DOD, particularly those that could be utilized underwater to provide both blast and bubble damage mechanisms to the target. This work provides an update on the high fidelity, high-speed water entry modeling efforts that have been ongoing at NSWC Indian Head and have been shown in previous years. The focus of this effort has been on warhead component survivability during the water entry and subsequent dive to depths of interest. As such, results for various weapon concepts investigated will include fuze accelerations, plastic deformation and damage to the structure, among others.

VENDOR SESSION A: EXHIBITOR PRESENTATIONS: CASE STUDIES, NEW DEVELOPMENTS, TESTING & PRODUCTS

PRESSURE SENSOR THERMAL SHOCK MITIGATION

Bob Metz, PCB Piezotronics

Piezoresistive pressure sensors have been used successfully in many blast test situations. Not to be confused with temperature compensation, protection from thermal shock is recommended to eliminate photoflash sensitivity, delay heat flux, and provide particle impingement protection. This presentation will provide practical knowledge of thermal errors associated with pressure measurement in a blast environment, and offer best practices to minimize these influences.

SENSORS WITH BUILT-IN ESD PROTECTION
Jennifer MacDonnell, Endevco

Every year, we learn more about how the test environment impacts the accuracy of our measurements and the longevity of the sensors. Lessons learned include how damping in a sensor can protect against over-loading data acquisition and damaging the sensor, and how low noise cable construction can limit spurious triboelectric output. One difficult to diagnose threat to sensors is Electrostatic Discharge (ESD) and how it may impact the signal fidelity. This paper will explore shock sensors which have this protection built-in and how we achieve that protection.

IEPE SHOCK SENSORS FOR HIGH-G MEASUREMENTS
Kevin Westhora, Dytran Instruments

When measuring high-g shock events, engineers must ensure they are using robust accelerometers that can withstand harsh conditions and deliver accurate data. The presence of high-frequency energy causes signal saturation in applications with high amplitude and high frequency mechanical impacts. Dytran successfully designs and manufactures single axis and triaxial accelerometers in various configurations that deliver accurate data and avoid signal saturation. Series 3099AXT-XX and 3603AXT feature electrical filters that keep the mechanically filtered signal flat throughout the usable bandwidth, thus preventing zero shift from corrupting typical SRS plots. In addition, combining mechanical and electrical filters results in a flat frequency response and reduced signal ringing. For applications requiring ultra-miniature sensors, Dytran offers model 3284A1. The sensor design exhibits a very high natural frequency that prevents saturation and allows users to see the unfiltered data and measure all frequencies of interest.

The new single-axis 3099A series features built-in mechanical and electrical filters plus quartz sensing elements. Quartz is more homogenous than a ceramic sensing element and provides better stability of the sensitivity value over time when shock is applied. The combination of quartz and an advanced filter design allows the accelerometer to have a very flat frequency response with no zero shift and reduces signal ringing. Specific applications include explosive bolt testing used on rockets for fuel tank separation, high-shock metal-to-metal impact, shaker shock, protective body gear testing, far-field blasts, pyrotechnics, drop- shock vibration, and stage separation testing.

In addition, Dytran offers the 3603AT series of triaxial sensors, which also incorporate electrical & mechanical filters. This series addresses accelerometer saturation induced by applications where secondary high-frequency mechanical vibration or a high-shock, metal-to-metal impact exceeded the bandwidth of the accelerometer. Each sensor contains three piezoceramic planar shear sensing elements that are suspended inside the housing with a set of supports designed to stop high-frequency propagation into the element structure. The sensing elements are isolated from case ground and enclosed by a Faraday shield for better noise immunity. Units are TEDS enabled and are compatible with any IEPE power source. Specific applications for the 3603A series include high shock metal-to-metal impact, simulated far-field pyrotechnic shock testing, package drop-shock testing, and engine NVH – cylinder head vibration testing. For applications with limited installation space, Dytran offers the ultra-miniature 3284A series. The lightweight sensors can measure high-g mechanical shocks and high-frequency data up to 30,000 g. Their small size does not “mass load” the test article or alter its dynamic behavior. They prevent signal saturation due to a very high natural resonant frequency. Engineers performing drop-shock testing on consumer goods will benefit from capturing unfiltered data and the ability to measure all frequencies of interest. Units feature a lightweight silicone integral cable that eliminates strain on the small housing, allowing for excellent flexibility and hassle-free routing.

HIGH SPEED TRANSIENT EVENT CAPTURE – RECENT ADVANCES IN SMALL FORM FACTOR, HIGH FIDELITY BROADBAND MEASUREMENT SYSTEMS

Mark Remelman, MECALC
Rob Eaton, MECALC

High speed transient event capture has historically been an exercise in compromise. Depending on the type of event to be captured one needed to choose between portability (size), required signal conditioning bandwidth, sample rate and desired dynamic range, types of transducers / measurements, ease of use and environmental considerations. Until today, finding a compact system, fast enough to capture ballistic shocks, while preserving broadband content and making robust high fidelity measurements in potentially hostile environments has been the nemesis of testing groups worldwide. Today we will discuss some of the features and capabilities of a turnkey system utilizing the MECALC - ALI25 transient recorder and controlled by the PhoenixKonnect application.

CONTROLLED LONG DURATION 100G TESTING MODULE FOR HIGH INTENSITY VISIBLE SPECTRUM LED LIGHTING

Dr. Josh Loukus, REL Inc.

Multi axial High G LED Lighting is important in crash test research. High G LED lamps allow for the illumination of dynamic events onboard the test fixture during controlled sled crash events. The design of a LED light to survive 100 G event with durations greater that 20 milliseconds is accomplished with an understanding of physics and a testing module that can be controlled and mounted on a precision flat base with an integrated sled track. The testing module used in this current work can accelerate up to a 4-pound load to 60 miles per hour with a controlled tunable deceleration in less than twenty feet. The module is the REL-CS88 with servo control. This module was used in this work to design the lens, mounting, and the forced convection cooling fan that is integral to the LED unit. This presentation will show the testing results along with videos of the testing along 2 axis for a particular LED Lamp.

TRAINING I: SHOCK RESPONSE SPECTRUM PRIMER

SHOCK RESPONSE SPECTRUM PRIMER

Dr. Carl Sisemore, Sandia National Laboratories

The shock response spectrum (SRS) is the most common way of characterizing transient excitation. The SRS is advantageous due to its ubiquity and ability to substantially reduce the shock data complexity to a manageable level. An overview of the origins and methods for calculating the SRS will be provided. The various types of shock spectra will be discussed in detail along with their applications. A comparison of SRS results from both classical and oscillatory shocks will be presented along with a discussion of the important characteristics of each type of shock when transformed to the SRS.

SESSION 5: INSTRUMENTATION DEVELOPMENTS & SELECTION TECHNIQUES

COMPARING PHOTON DOPPLER VELOCIMETRY (PDV) SYSTEMS DEVELOPMENT COST WITH AN OPEN PLATFORM AND MODULAR BASED APPROACH

Ren Hong, Quantifi Photonics

When designing and building PDV systems, there is a wealth of literature on how to build PDV systems and the components to use. However, it is often important to take a broader perspective on solution selection. Beside just considering components costs and the development hours, it is also important to evaluate the hidden opportunity costs, such as the development time for the control system, resources needed in maintenance and calibration. Furthermore, the system needs to be well-packaged and supported in order to reduce often costly unexpected down time, as well as thoroughly documented to ease the impact of end-user training. Here we present and evaluate the overall cost of building a PDV system against a commercial-of-the-shelf (COTS) approach to PDV that leverages an open and modular platform to reduce the hidden cost in developing, using, and maintaining PDV systems.

TOWARDS A NOVEL MICROSYSTEM SHOCK ACCELEROMETER UTILIZING A LIQUID PROOF MASS

Dr. Paul Galambox, Sandia National Laboratories
Josh Dye, Sandia National Laboratories
Alex Chen, Sandia National Laboratories
Cayden Boll, Sandia National Laboratories

Many applications experiencing shock environments could benefit from on-board high-g acceleration sensing. These applications include inertial measurement, mobility assist and gaming consoles. In these applications, low-SWaP (Size, Weight and Power) sensing systems provide advantages in terms of not affecting the shock measurement and allowing flexibility for system integration and sensor location.

These SWaP advantages motivate development of microsystem acceleration measurement systems. Besides being small and low power, microsystems can be made cheaply using batch fabrication and they allow one to take advantage of the unique physics of the microscale. In this case the increase in surface tension forces at the microscale allow very high g-forces to be contained and measured without a complicated and fragile spring mechanisms or hermetic vacuum environment packaging. Our concept utilizes a small volume (droplet) of liquid, either high density liquid metal or a more benign liquid such as water as a proof mass. The drop is positioned in a microfluidic tube or channel. Pressure transducers at each end of the tube measure the differential pressure resulting from an applied shock or vibration and can be calibrated to use this pressure difference as a measurement of shock level (g's). By taking advantage of microfabrication technologies, we can design a microsystem containing a droplet on the order of picoliters (for example 10 microns x 1 micron x 1 micron) or even less with integrated piezoresistive or piezoelectric pressure transducers to measure differential pressure at the same scale.

Our presentation will focus on larger scale first prototype microfluidic microsystems for shock sensing. We will describe the prototypes, first test results, and associated analysis. Lab scale shocks on the order of 10 to 1000 g's with pulse widths on the order 2 to 5 milliseconds were measured effectively using these prototypes when compared to a COTS (Commercial Off the Shelf) Endevco accelerometer measurement of the same shock at the same time. Shock magnitude and pulse width were varied by changing laboratory drop tower height and shock pad thickness. Shocks were also generated by rapping the prototype on a laboratory bench to apply shorter duration pulses (< 1 millisecond to 1 millisecond). Parametric variation of the prototype design liquid containing tube (capillary) diameter and material (glass, PEEK, polyimide) was investigated in terms of their effect on measured differential pressure transducer voltage response to g's applied. The effect of drop length in the tube and what liquid was used was also investigated. Both water and mercury were used as proof mass liquids, and both could effectively measure the g-levels tested.

Future work will focus on shrinking this initial prototype, increasing the g-levels tested while decreasing the pulse width based on parametric modeling of prototype design shock response. Work to improve package robustness and develop a more effective methodology for filling, sealing and fully assembling these devices will also be conducted.

ELECTROSTATIC DISCHARGE (ESD) CONSIDERATIONS IN SHOCK TESTING

James Nelson, PCB Piezotronics
Dr. Ted Diehl, Magic Leap

Accelerometers are a fundamental building block of the data acquisition chain in shock tests. An ideal accelerometer only responds to acceleration input in its sensitive axis. However, a variety of confounding factors can affect the sensor output. These include intrinsic factors like manufacturing imperfections within the sensor, as well as extrinsic factors like ambient temperature fluctuation. Besides the sensor itself, the data acquisition chain consists of fixturing, cabling, and a data recorder. These additional components of the measurement chain may also subtly influence the final recorded data.

SIGNAL CONDITIONER SELF NOISE: CHARACTERIZATION AND SPECIFICATION

Douglas Firth, Precision Filters
Dr. Thomas Gerber, Precision Filters
Alan Szary, Precision Filters

Signal conditioners are commonly used to measure sensor signals with low levels by providing excitation, amplification, and filtering. When analog signal conditioning is implemented correctly, it effectively reduces noise from both the sensor and the external environment. However, it's important to note that the components within the signal conditioner can introduce their own noise into the measurement circuit. Although in most cases, external and sensor noise overshadow this "self-noise" or intrinsic noise, measurement engineers should still understand the level of noise generated by the signal conditioner itself. Characterizing the self-noise in a circuit that includes multiple gain stages and an active filter is a challenging task, as there is no established standard for its specification. In this presentation, we present a framework for specifying self-noise in signal conditioning systems. We begin by introducing electrical noise analysis, providing a foundation for understanding noise modeling and measurement. Subsequently, we delve into noise specifications for signal conditioners and provide simple examples to demonstrate how these specifications can be used to estimate the signal-to-noise ratio (SNR) of a sensor measurement.

Electrostatic discharge (ESD) has long been understood as a risk to electronic components. In the worst case, ESD can permanently compromise an unprotected device. Other times it may only lead to a temporary disruption in functionality. Minor ESD events are invisible and inaudible to an unwitting observer, making for an insidious threat to sensitive devices.

This paper demonstrates an example of surprising results from a 1-meter drop test in which Endevco accelerometers are located inside an ESD-unsafe container. Static charge buildup occurs under normal handling conditions for the container. The charge buildup is verified using an electrostatic field meter. An ESD event occurs when the static buildup discharges at an unpredictable time during the drop. The discharge often manifests in the sensor data as a low-frequency haversine pulse, or as a long-term drift event. Mitigation efforts are explored to reduce ESD effects in this example setup. Furthermore, information is provided on recognizing these harmful patterns in the data via waveform inspection and analysis.

MINIMUM REQUIREMENTS FOR MECHANICAL SHOCK DATA ACQUISITION

David Soine, Sandia National Laboratories

Environmental testing laboratories perform mechanical shock measurements daily for a wide variety of aerospace and defense shock qualification activities. Since shock acceleration measurement has proven to be more challenging than acceleration measurement for typical vibration testing, substantial effort has been expended developing transducers, instrumentation, calibration methods, data validation techniques, and written guidance for all these aspects of the craft.

This work reviews a legacy approach taken by Sandia National Laboratories to specify the minimum end-to-end requirements for a mechanical shock test measurement system. A specification based on the approach is still in use. Recent minor revisions to the specification, based on current measurement needs, are discussed along with gaps identified during the revision process. An alternative, end-to-end approach to specifying the shock test measurement system is suggested, integrating current measurement system guidance from various organizations and sources.

SESSION 6: RANDOM VIBRATION TEST DESIGN

MULTI-AXIS VIBRATION TESTING OF A HIGH ENERGY LASER FOR AIRBORNE APPLICATION

Matthew Forman, NSWC Dahlgren
Dr. Luke Martin, NSWC Dahlgren
Dr. Bryan Joyce, NSWC Dahlgren

Vibration testing plays a crucial role in the development and assessment of directed energy (DE) systems and beam control mechanisms. Beam control mechanisms, such as adaptive optics and precision positioning systems, are integral components of DE systems. These mechanisms require exceptional precision and stability to maintain the desired beam characteristics.

Continuous advancements in vibration testing have significantly enhanced the ability to evaluate DE system performance under realistic operating conditions in a controlled lab environment. In this presentation, recent developmental vibration testing completed by a High Energy Laser (HEL) program will be highlighted, focusing on simultaneous multi-axis vibration and live-fire testing.

This presentation will review the importance of vibration testing as a fundamental tool in evaluating equipment functionality, diagnosing issues, and optimizing performance. It will share lessons learned by the HEL program and highlight successes achieved.

RECOMMENDED GUIDANCE FOR SUBSIDIARY SHIPBOARD VIBRATION TESTING

Dr. Bryan Joyce, NSWC Dahlgren
Shawn Schneider, NSWC Dahlgren
Garrett Wiles, NSWC Dahlgren

Military Standard (MIL-STD) 167-1A provides procedures and requirements for environmental vibration testing of equipment installed on Navy ships. Following a successful shipboard vibration test, a subsidiary component or subassembly of the principal unit may be replaced due to obsolescence or a failure during later tests. There is a need to conduct a suitable shipboard vibration test on the new subsidiary component without the time and expense of re-testing a full principal unit with the new component.

This presentation provides the general procedure for a subsidiary shipboard vibration test (SSVT). This test procedure subjects the new component to an environment replicating what it would have experienced during a principal unit test. Test amplitudes are derived from response data from the original test at the subsidiary component. Special attention is given to reproduce any cross-axis motion of the principal unit in the new, single-axis SSVT. This presentation outlines the steps to determine suitability for a SSVT, develop tailored variable frequency and endurance test levels and frequencies, and conduct a SSVT. Recommendations and best practices based on previous SSVTs at NSWCDD are also noted.

WHY DO WE NEED TO DESIGN DYNAMIC ENVIRONMENT TEST FIXTURES?

Dr. James DeClerck, Michigan Technological University
Cora Taylor, Michigan Technological University
Dr. Jason Blough, Michigan Technological University
Charles VanKarsen, Michigan Technological University
Raymond Joshua, Department of Energy's Kansas City National Security Campus

Vibration qualification testing is a common requirement for components designed for the automotive and aerospace industries. The intention of the in-lab test is to evaluate component life expectancy by exposing the component to a dynamic environment similar to the field condition. Typically, the component is attached to a rigid fixture and a dynamic, amplitude-controlled force is applied to the fixture. This approach commonly results in over-testing or under-testing because the rigid fixture attachment over-constrains the component.

A dynamic substructuring approach is used to demonstrate that robust dynamic environment testing requires a fixture that sufficiently represents the attachment impedance of the next-structure as well as controlled force input. This paper will verify that a rigid fixture is appropriate when the component impedance is significantly less (softer) than the impedance of the next-structure. Additional cases demonstrate what happens when the attachment impedances of the component and next-structure have similar amplitude and when the next-structure impedance is significantly less (softer) than the component impedance.

PROCEDURE FOR GENERATING IMPULSE-ON-RANDOM SHAKER TESTS

Ryan Quellet, Vibration Research Corporation

Some field environments--such as a vehicle with tracks or treads driving over concrete--experience repetitive high random peaks that mimic transient events. These peaks are lower amplitude than shock events but distinct from the surrounding background random vibration. In addition to standard random background vibration, these impulse events create a primarily random environment with repetitive impulse noise throughout.

When engineers use conventional PSD averaging techniques to analyze this field data, it averages the high-G level impulses down toward the random signal levels, hiding the signal from the test while increasing the random root-mean-square (RMS) level to account for these impulses.

This presentation describes and validates a simple procedure for generating an impulse-on-random test using Kurtosion®: a method of kurtosis control. Kurtosis measures the average deviation of a signal from its mean value and is the fourth statistical moment of the probability density function (PDF). Modern vibration controllers assume random control signals have a Gaussian PDF distribution with a kurtosis of 3.

This technique applies to field data recordings that contain repetitive impulse events, resulting in repetitive high kurtosis impulses on top of background random vibration. If the kurtosis of a periodic random event is greater than 15, the engineer should consider an impulse-on-random shaker test instead of a random test.

Attendees of this presentation will learn how to use Kurtosion to create a random test with periodic amplitude pulses. This presentation will validate the process by comparing 1) the fatigue damage spectrum (FDS) of the generated test to the field recording FDS and 2) the shock response spectrum (SRS) of generated test to the field recording SRS to validate the amount of test acceleration.

SESSION 7: GROUND SHOCK AND CRATERS FROM DETONATIONS

EXPLOSIVE REMOVAL OF DAMAGED PAVEMENT FOR AIRFIELD DAMAGE REPAIR

Stephen Turner, USACE ERDC

Researchers at the U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC) are conducting research under the Airfield Damage Repair (ADR) Program to develop new techniques to quickly and expediently repair bomb-damaged airfields. One of the most time-consuming and logistically challenging steps is the cutting and breakup of concrete pavement in the crater damaged area using bulky concrete saws and loaders. ERDC has developed a method of cutting damaged pavement using arrays of commercially-available miniature shaped charges. Results have shown that theses shaped charges will fully penetrate through any typical runway, and, when placed at proper spacing, interconnecting cracking of the concrete will occur to yield a "cut" through the pavement. ERDC is now studying methods of breaking up the residual concrete. Testing in 2019 with pyrotechnic cartridges and select commercially-available shaped charges proved ineffective. Additional research is under way to evaluate alternate explosive means of breaking up the residual concrete pavement. This document provides an overview of this research and results to date.

RESULTS AND ANALYSIS OF CRATERS FROM ABOVEGROUND DETONATIONS ON AN ASPHALT ROADWAYS

Daniel Vaughan, USACE ERDC
Joshua Payne, USACE ERDC
Dr. Jay Q. Ehrgott, Jr., USACE ERDC

Conventional munitions such as rockets, artillery rounds, and mortars have been an area of interest to the US Intelligence Community for decades, and their use has been widely documented in the ongoing conflicts across the globe. The post-blast forensic signatures from attacks using these munitions, such as a ground crater and munition fragments, can give valuable information to trained intelligence analysists. The National Ground Intelligence Center (NGIC) and the U.S. Army Engineer Research and Development Center (ERDC) have developed a fast-running engineering tool, BEAST (Blast and Explosive Aboveground or Surface Tool), for analyzing the craters from aboveground detonations under the Forensic Encyclopedia Program (FEP). The BEAST tool uses field data collected during several series of aboveground detonations to predict crater size when given inputs for munition, height-of-burst, and soil conditions. The BEAST tool can predict craters over a limited set of testbed surfaces, Intermediate Sand and Gravel Roadways, but analysis of roadways such as asphalt and concrete has become a high priority. ERDC conducted an initial series of aboveground detonations over an asphalt roadway to gather baseline data for adding this capability to the BEAST tool. This paper will present an overview of the experimental series, an assessment of the results, comparisons to previous research, and a list of priority experiments needed to add asphalt roadway crater predictions to the BEAST tool.

Influence of Pavement on Ground Shock and Aboveground Overpressure from Buried Detonations

Will Myers, USACE ERDC
Dr. Jay Q. Ehrgott, Jr., USACE ERDC

The U.S. Army Engineer Research and Development Center is participating in a multi-year effort under the Enhanced Weaponeering and Collateral Damage Estimation Program to obtain experimental data to better quantify the effects of burial on weapon performance and to improved methods for predicting collateral damage. As part of this research effort a series of well characterized experiments was conducted comparing the effects of surface pavement on buried detonations. Experiments were conducted with two different munitions and were performed under concrete or asphalt pavement and compared to experiments with no pavement. The ground shock was measured at different radiuses at the depth of the charge using soil stress gauges and soil accelerometers. The aboveground blast overpressure was measured at several ranges using ground surface overpressure gauges and elevated side-on overpressure gauges. This paper summarizes the results of these experiments and compares the effects of pavement on ground shock and aboveground blast overpressure.

Development of the Generic Munition Crater Assessment Tool (GMCAT)

Daniel Vaughan, USACE ERDC
Joshua Payne, USACE ERDC
Dr. Jay Q. Ehrgott, Jr., USACE ERDC

Conventional munitions such as rockets, artillery rounds, and mortars have been an area of interest to the US Intelligence Community for decades, and their use has been widely documented in the ongoing conflicts across the globe. The post-blast forensic signatures from attacks using these munitions, such as a ground crater and munition fragments, can give valuable information to trained intelligence analysists. The National Ground Intelligence Center (NGIC) and the U.S. Army Engineer Research and Development Center (ERDC) have developed a fast-running engineering tool, BEAST (Blast and Explosive Aboveground or Surface Tool), for analyzing the craters from aboveground detonations under the Forensic Encyclopedia Program (FEP). The BEAST tool uses field data collected during several series of aboveground detonations to predict crater size when given inputs for munition, height-of-burst, and soil conditions. This method an analyst to assume a threat munition, perhaps based on recovered fragments or knowledge of the threats in an area, but this information is not always available. For instances where the threat weapon cannot be determined, ERDC has developed several methods for predicting the cratering behavior of a Generic Cased

Munition. This paper will present the development process for these methodologies, an assessment of how they perform against our dataset, and a path forward for implementing them into the BEAST tool.

THE EFFECT OF SOIL COVER ON EARTH-COVERED MAGAZINE LOADING
Joshua Payne, USACE ERDC

Earth-covered magazines or ECMs are critical to the U.S. Army's ability to supply warfighter with ammunition and explosives around the world. These magazines are designed with a minimum of 2 feet of earth cover, as specified in the Defense Explosives Safety Regulations (DESR 6055.09). However, over time erosion may occur resulting in an earth cover that is less than the required 2-foot thickness. This reclassifies the ECM as an aboveground magazine (AGM) and significantly reduces the allowable storage capacity. To address this issue, the U.S. Army Technical Center for Explosives Safety (USATCES) requested support from the U.S. Army Engineering and Support Center (CEHNC) and the U.S. Army Engineer Research and Development Center (ERDC) to research and evaluate the effects of varying earth covers for ECMs. A research effort, code-named Magazine Earth Cover Update/Reassessment Study (MERCURY), was developed to investigate the effects of earth-cover thicknesses for donor and acceptor ECMs. This paper provides an overview of the research effort and a summary of key findings.

SESSION 8: DYSMAS II

MULTI-COMPONENT STRENGTH IMPLEMENTATION FOR SEA-BED MODELING
Dr. Brad Klenow, NSWC Indian Head
Dr. Tom McGrath, NSWC Indian Head

The work presented is a continuation of efforts presented in 2022 on the DYSMAS simulation of recent underwater explosion (UNDEX) shock wave propagation tests in a sea bottom using constitutive models developed from a sea bottom material characterization effort. In the current work, sea bottom material parameters obtained from improved characterization efforts and the implementation of a novel, multi-component strength constitutive model in DYSMAS are discussed. The setup of the simulations and comparisons of the current simulation results to pressure measurements from the 2022 testing and previous simulation results are given.

INFLUENCE OF SEA-BED PROPERTIES ON UNDEX EFFECTS
Rachael Busby, NSWC Indian Head
Dr. Brad Klenow, NSWC Indian Head
Otto Quinones-Melendez, NSWC Indian Head
Dr. Tom McGrath, NSWC Indian Head

The influence of a sea-bed on underwater explosion (UNDEX) effects can be divided into two categories: shock wave propagation effects and underwater bubble effects. To model these effects in DYSMAS requires a sea-bed constitutive model that can be populated with parameters obtained from material characterization testing. In this work, DYSMAS simulation results of multiple UNDEX scenarios are analyzed to determine how the parameters of the sea-bed constitutive model influence shock wave propagation and underwater bubble effects for an UNDEX event in proximity to a sea-bed. This effort is a culmination of a multi-year DYSMAS effort to support the simulation of underwater explosions in proximity to a sea bottom using sea bottom material characterization and UNDEX test data.

UNDEX TESTING AND M&S OF COMBAT RUBBER RAIDING CRAFT

Otto Quinones-Melendez, NSWC Indian Head
Ron Zitzman, NSWC Indian Head
Roger Ilamni, NSWC Indian Head
Kent Rye, NSWC Carderock
Bill Lewis, NSWC Carderock

The Naval Surface Warfare Center Indian Head is actively seeking improvements to risk decision-making tools to better estimate safe operating distances for small craft and crew when in close proximity to underwater explosion (UNDEX) events. The existing estimates take into consideration UNDEX shockwave effects and UNDEX plume effects but are perceived as conservative. To address this, an UNDEX test series on Combat Rubber Raider Craft were conducted to address gaps in the existing data. Test data collected included UNDEX shock pressure, acceleration, and velocity data as well as response from Hybrid III Manikin. Additionally, DYSMAS was used to predict safe range estimates to ensure test object survivability during test. This talk will present initial comparisons of DYSMAS simulations and test data.

SIMULATING THE UNDERWATER SHOCK RESPONSE OF HUMAN LUNG SIMULANTS

Dr. Emily Guzas, NUWC Newport
Brandon Casper, NUWC Newport
M. Babina, NUWC Newport
Dr. Eugenia Stanisauskis Weiss, NUWC Newport

This presentation covers computational model development for a series of physical experiments performed with mechanical simulants of human lungs to better understand diver lung response to underwater explosions (UNDEX). Researchers at the Naval Submarine Medical Research Laboratory (NSMRL) have developed several variations of instrumented mechanical simulants of the human thoracic region and subjected these to UNDEX loading in tank test experiments at the University of Rhode Island (URI). Analysts at the Naval Undersea Warfare Center, Division Newport (NUWCDIVNPT), have developed computational models of a subset of these experiments using the Navy fluid-structure interaction code DYSMAS. This presentation discusses model development and validation to test data.

VENDOR SESSION B: EXHIBITOR PRESENTATIONS: CASE STUDIES, NEW DEVELOPMENTS, TESTING & PRODUCTS

INDUCTION RING SHAKERS IN AEROSPACE APPLICATIONS

Luis Infante, ETS Solutions

When you need to perform vibration testing with accelerations of over 100gRMS for aerospace applications, your options are very limited. At ETS Solutions, we have the shaker design and amplifier technology to support aerospace testing, with proven performance and legacy. In this brief talk, we are proud to present our I-Series, induction ring shaker systems, performance capabilities and application experience.

ADVANCED TECHNOLOGIES FOR SINGLE AND MULTI DEGREE OF FREEDOM SHOCK AND VIBRATION TESTING
Thomas Reilly, NVT Group

NVT Group will present advanced technologies developed by its member companies Data Physics Corporation and Team Corporation for single and multi degree of freedom testing. The presentation will include the following topics:

- Air-cooled and water-cooled electrodynamic shakers
- Slip tables and guided head expanders
- High intensity shock test systems
- High channel count vibration controllers and data acquisition systems
- Multi shaker test systems
- Multi shaker single axis testing
- Multi degree of freedom testing
- Advanced safety systems for protection of high value test articles

IMPROVEMENTS IN VISUALIZING DIC FFT RESULTS AND IN DATA PROCESSING SPEEDS
Bluejay Robinson, Correlated Solutions

VIC-3D HS FFT is a three-axis, non-contact, full-field measurement system that measures the amplitudes and phase changes of operational deflection shapes (ODSs) in the frequency domain using the Digital Image Correlation method.

Vibration measurements to obtain ODSs generally require thousands of image pairs to be analyzed per test, which may take upwards of one or more hours to process, depending on the efficiency of the source code. This talk will explain a new method that stores image files in a way that improves the speed of the DIC algorithms, decreasing processing time, without altering the images in any way.

Animating the in-plane and out-of-plane ODS' components is not a trivial task, because this generally requires two-dimensional (in-plane) amplitudes to be displayed as an exaggeration within the image or in the 3D environment in order to visualize the behavior of the vibration. Moving the collected data to a dedicated workspace within the program allows the user to easily visualize and understand the behavior of the ODS. An overview of the new workspace will be explained using example data.

HIGH SPEED IMAGING WITH SENSOR DATA IN SMALL SPACES
William Spinelli, Photron

Photron will be presenting the challenges and constraints of high frequency image acquisition in constrained spaces with focus on unique hardware solutions that the MH6 multi camera Hi-G platform offers. As well as other Fastcam product line examples. Synchronized Data Acquisition with camera data options will also be covered.

PROANALYST 2023 BY XCITEX THE NEXT GENERATION OF MARKERLESS MOTION ANALYSIS SOFTWARE
Shane Fitzgerald, Xcitex

Xcitex is known worldwide for ProAnalyst, the industry-leading motion analysis software. For more than two decades, ProAnalyst has been used in a variety of motion analysis applications, ranging from frequency analysis to sports performance and product testing. Today, we are proud to announce

ProAnalyst 2023, which improves upon ProAnalyst's interface and user experience with a new framework, new tools, and upgraded tracking algorithms. ProAnalyst 2023 is available now with new licensing options to fit any budget or use case.

TRAINING II: CLEAR GUIDELINES FOR IMPROVING SPACECRAFT SHOCK ANALYSIS AND TESTING

CLEAR GUIDELINES FOR IMPROVING SPACECRAFT SHOCK ANALYSIS AND TESTING

Monty Kennedy, MK Engineering
Dr. Jason Blough, Michigan Technological University

Based upon shock research performed over the last 2 ½ years it has become obvious that there is a need in the aerospace industry for clear guidelines due to the much more complex aspect of shock loads and the subsequent significantly more challenging shock analysis and testing of spacecraft. Shock analysis is typically glossed over in typical vibration and structural dynamics college classes. There is much more uncertainty in spacecraft shock analysis predictions and obtaining accurate shock test levels, much more than analyzing and testing for other vibration loads like sine and random vibration loads. Additional significant knowledge is required for performing accurate shock analysis and obtaining accurate shock test levels, much more so than that required for sine and random vibration testing, the two most common and routine vibration analysis and testing performed in the aerospace industry.

Typical experienced structural analysts have much more experience and routinely perform most types of vibration analysis and testing like sine and random vibration testing. They typically have much less experience in performing shock analysis, the methodology used, and the spacecraft subsystems that are most vulnerable to shock failures. Larger model uncertainty factors should be used for shock analysis, much higher than the value typically used for random vibration analysis. Furthermore, it is necessary to account for shock wave propagation and attenuation that does not occur in sine and random vibration analysis. That is best accomplished by performing FRF (frequency response function) correlation from tap testing into a shock resonant plate tuned to the SRS (shock response spectrum) knee frequency (typically around 1 kHz). This requires knowledge of digital signal processing, which most structural analysts are probably not familiar with.

SESSION 9: SIGNAL AND DATA ANALYSIS

A ROBUST METHOD FOR ESTIMATING THE TRANSIENT DURATION OF COMPLEX SHOCKS

Dr. Carl Sisemore, ShockMec Engineering LLC

Estimating the duration of a mechanical shock or transient vibration event is important for translating measured field data into realistic laboratory test specifications. For simple shocks, estimating the transient duration is relatively straightforward. However, for complex shock transients, the definition has historically been subjective. Military specifications currently define the shock pulse termination by the engineer's perception. Spacecraft design guidance offers an alternative, simplistic definition that is highly dependent on the signal processing technique. Subjective definitions or definitions that rely heavily on unique signal processing techniques are not appropriate for requirements documents or qualification test specifications. Historically, a measurement of shock pulse duration has been one of the most requested data additions to the shock response spectra, and yet the definition remains subjective and inconsistent. This paper presents a numerical method for estimating shock pulse duration based on a cumulative zeroth-order temporal moment. Integrating the measured acceleration data as a temporal moment smooths the response and allows for a consistent interpretation of the shock pulse termination. The method is detailed using analytical data and is demonstrated on measured acceleration data from several resonant plate shock tests. The method will be shown to work on data corrupted with electrical noise spikes, multiple impact test data, and data with variations in signal processing.

Enhancing Signal Accuracy and Bandwidth Extension in Transient Shock Measurements Using Transfer Function Compensation

Strether Smith, Strether Smith Consulting
Dr. Ted Diehl, Bodie Technology, Inc.

Data acquired from real-world events using measurement systems always suffer from distortions caused by a variety of nonidealities. These distortions can arise from transducer characteristics, signal conditioning, antialias filter limitations, data-cable filtering, and other factors, leading to distorted results and limited measurement bandwidth.

This paper introduces a technique that employs the frequency domain characteristics of the measurement system to mitigate these distortions and provide a more accurate representation of the signal. Furthermore, this technique enables extending the measurable frequency range beyond the nominal limits of the measurement system and facilitates upsampling for improved time-domain representation.

The application of this approach is demonstrated using transient shock accelerometer data. The results showcase how the technique compensates for distortions that result from the distortions listed. Additionally, it demonstrates the effectiveness of transfer function compensation in enhancing the correlation of measurements obtained from different testing facilities using different acquisition and sensor hardware. Finally, the paper highlights the use of the transfer function technique for signal upsampling, leading to improved estimation of signal peaks and other signal details in the time domain.

The Effects of Dropout in Telemetered Data on Shock Response Spectra

Dr. Vit Babuska, Sandia National Laboratories
Angela Patterson, Sandia National Laboratories
David Soine, Sandia National Laboratories
Daniel Lee, Sandia National Laboratories

In laboratory experiments, connections between the instrumentation and the data acquisition system are usually hard-wired. However, during field testing—particularly flight testing—the measured signals are transmitted via telemetry, often leading to dropouts from signal degradation due to aircraft maneuvers or radio-frequency interference.

The goal of this paper is to investigate the effects of dropouts in field test data on Shock Response Spectra (SRS). The SRS is often used to characterize the shock experienced by a test article during a field test. The effect of the dropout on the SRS depends on its duration and location with respect to the actual shock event.

In this study, dropouts of varying length and location were applied to common shock signals such as decaying sinusoids, resonant plate shock data, and flight test data. The SRS was computed for each of the signals, both with and without dropouts. Through this comparison, it is possible to find the parts of a signal that are the most important to the accuracy of the SRS. For example, if dropout occurs a certain number of cycles after the shock event, its effect on the SRS is minimal and the dropout may not be of concern.

This paper also explores techniques for filling in data that were lost during a dropout to minimize the effect on the SRS. If a dropout occurs in an area of the signal that was identified as influential, is there anything that can be done to still get a reasonable SRS?

Acknowledgments
Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SESSION 10: BLAST

METHODOLOGY FOR NATO AEP-55 STANAG-COMPLIANT MINE EXPLOSION SIMULATIONS (PARTS I AND II)

Giri Prasanna, Altair Engineering

Explosive hazards pose a significant threat to military operations, particularly in conflict zones where buried mines can cause devastating consequences. To mitigate these risks, the NATO Standardization Agreement (STANAG) provides guidelines for the development and testing of military equipment, including measures for simulating buried mine explosions.

In this presentation, we explore a comprehensive methodology for simulating mine explosions in accordance with the NATO AEP-55 STANAG regulation. We will discuss the process of creating complex terrain models, incorporating soil properties, and accurately representing explosive devices. Thus, enabling the optimization of vehicle structures and countermeasure strategies to enhance survivability and minimize injuries.

SMALL SCALE AIRBLAST TESTING FOR THE ASSESSMENT OF MULTIPLE BARRIERS ON SHOCK WAVE PROPAGATION

Kellan Sullivan, USACE ERDC
Dr. Hussam Mahmoud, Colorado State University
John Hoemann, USACE-ERDC
Dr. Genevieve Pezzola, USACE-ERDC

Blast assessment of structural systems has traditionally been explored using experimental or analytical methods. Though analytical and numerical methods have grown in popularity over the years because of their accurate and rapid evaluation capabilities, in many cases, experimental testing remains a popular and necessary method for verifying these models. Issues of scale, equipment capacity, and availability of research funding continue to limit full-scale testing of subassemblies or complete structures under blast loads. In addition, full-scale blast testing can be time-consuming, allowing only a handful of tests to be conducted. Small-scale air blast experiments offer an economical alternative, in terms of material and labor requirements, to full-scale testing that can be performed rapidly with repeatable results. This study presents small-scale air blast experiments that were completed to validate the results of a numerical model ran in the well-validated hydrocode CTH on the effect of multiple perimeter wall barriers focusing on shock wave propagation. In these small-scale tests, air blast effects such as pressure and impulse from the scaled experiments are presented and compared to the hydrocode predictions.

NUMERICAL MODELING OF FULL-SCALE RC SLABS TO CLOSE IN BLAST, COMPARISON BETWEEN SPH - LSDYNA & VIPER::BLAST – OPENRADIOSS

Dr. Peter McDonald, Viper Applied Science

No abstract available.

SESSION 11: PROJECTILE PENETRATION TOOL DEVELOPMENT

JOINT AFLCMC/AFRL/DTRA HIGH-VELOCITY ROCK PENETRATION EXPERIMENTS

Mark Green, Geomechanics Research and Analysis
Dr. James Cargile, J Donald Cargile Consultancy
Ernie Staubs, AFRL
Keri Bailey, USACE ERDC
Dr. Bradley Martin, US Air Force Life Cycle Management Center
Koby Kennison, Integrated Solutions for Systems
Dr. Danny Frew, DSR
Dr. Brian Plunkett, AFRL

The AFLCMC, AFRL, and DTRA jointly performed a series of scaled high-velocity penetration tests against intact (non-jointed) rock targets withs seven different rock types tested: Sandstone, Limestone, Dolomite, Granite, Tuff, Gneiss, and Schist. All rock blocks used to construct the targets were obtained from various rock quarries. A total of 33 tests were performed to obtain advanced penetration data for use in developing new rock penetration resistance algorithms. The projectiles were launched out of a smooth-bore powder gun with impact conditions and penetration depth measured. In addition, an instrumentation package (developed by Dynamic Systems Research, Inc.) was compression mounted inside the projectile internal cavity to measure and record axial deceleration during the impact and penetration of the target. This paper provides an overview of the test setup and results.

UPDATE OF CAPABILITIES OF PENCURV+ COMPUTATIONAL SOFTWARE FOR ANALYSIS OF PROJECTILE PENETRATION EFFECTS

Logan Rice, USACE ERDC
Ernesto G. Cruz, USACE ERDC
Dr. Mark Adley, USACE ERDC

Projectile penetration research is an area of extreme importance in the areas of military defense and offense. This area allows for effective design and analysis of defensive infrastructure. The U.S. Army Engineer Research and Development Center (ERDC) has conducted research to develop a fast-running penetration analysis software, called PENCURV+. PENCURV+ is a computational tool which utilizes a suite of penetration algorithms to quickly and effectively analyze the effects a projectile will have against an array of defensive structure. The software essentially allows the user to design a projectile impact scenario and quickly retrieve a depth of penetration, exit velocity, or several other results of interest. The program includes the capability to run both rigid body and finite element projectiles as well as targets. This paper will present the updates made to the PENCURV+ software, particularly the forcing functions and target materials capable of being tested.

Advancing Runway Damage Assessment: A Comprehensive Overview of RW-CRATER+ Hybrid Tool

Ernesto Cruz, USACE ERDC

The understanding of ground shock behaviors resulting from buried high explosives holds immense value in predicting potential damage to critical structures, particularly airfields that are frequently targeted by a variety of ground- and air-delivered weapon systems due to their strategic significance. These weapon systems are designed to perforate runways and generate large ground shock loads to maximize damage, rendering the runway unusable until repairs can be made. To address the need for assessing runway damage caused by such attacks, the U.S. Army Engineer Research and Development Center (ERDC) is developing the next-generation hybrid tool, "RW-CRATER+" an advanced software package that includes multiple new analysis capabilities including the RW-CRATER reduced-order-model that combines non-linear finite element analysis with sophisticated engineering loads models. This tool aims to improve runway crater predictions by providing a rapid assessment tool and higher fidelity capability, enabling accurate estimation of potential runway damage. The RW-CRATER+ software package includes the rapid assessment tool RW-CRATER fast as well as the higher fidelity capability RW-CRATER reduced-order model to provide accurate estimations of potential runway damage. By combining a finite element model of the runway with a ground-shock loads model, RW-CRATER provides detailed estimates of the level of damage inflicted on runways, becoming an invaluable resource for assessing damage from various threat weapon systems and assisting in mission planning and sustainment evaluations at crucial military assets. This paper provides a general summary of the current state of development of RW-CRATER+, highlighting its current capabilities and new features, aiming to enhance the understanding and application of this advanced software package for assessing runway damage.

Multi-Surface Splash Ring (MSSR) Analysis and Prediction Tool Development for High Explosive Anti-Tank (HEAT) Munition

Jasiel Ramos-Delgado, USACE ERDC
Keila Estevez-Cruz, USACE ERDC

Upon the impact of High Explosive Anti-Tank (HEAT) munitions on armored fighting vehicles, fragments of fractured explosives can leave behind strike signatures that, when analyzed, can further allow engineers and analysts to predict and determine which kind of threats were deployed. Amongst the various projects existing within the Forensics Enciclopedia Program (FEP) is the Multi-Surface Splash Ring (MSSR) analysis and prediction tool which allows the identification of attributes that point towards the correct muntion. The current interface for the MSSR tool is however not intuitive for users who are not familiar with working on low-level computer environments giving way to inefficient use of the tool. As a result, the goal of this project is to create a simple Graphical User Interface (GUI) for the MSSR tool by optimizing the previously existing code and creating a native application that users can easily install and run within any other environment.

SESSION 12: INNOVATIVE SHOCK TEST ANALYSES

A Metric for Comparing Psuedo-Velocity Shock Response Spectra

Matthew Stevens, NSWC Carderock

The Pseudo-Velocity shock response spectra (PVSS) is a tool frequently usedto characterize shock environments. For this reason, PVSS is a keyparameter used when comparing shock environments. Since the PVSS is a function of frequency, it is often difficult to quantify the similarities ordifferences between two PVSS. This presentation discusses the developmentof a metric which calculates the error between two PVSS in terms of both a magnitude and shape error.

DATA DRIVEN METHOS TO PREDICT CONFINED IMPLOSION

Caleb Penner, Thornton Tomasetti
Dr. Abilash Nair, Thornton Tomasetti
Adam Hapij, Thornton Tomasetti
Benjamin Medina, NSWC Carderock
Dr. Joseph Ambrico, NUWC Newport
Dr. Emily Guzas, NUWC Newport

Conducting rapid predictions using multi-degree of freedom methods, high fidelity calculations (and/or physical tests) for the implosion phenomenon is not always feasible due to the large overheads and computational resources that might not be easily accessible. Data driven technologies are becoming central for rapid loading predictions for implosions. In this work a data-driven Machine Learning (ML) model is developed for predicting loading resulting from the confined implosion phenomena. The implosion of the confined volume creates a highly coupled and non-linear fluid response that would ordinarily take several days of calculations on a High Performance Computing (HPC) platform. In the work presented here, the nature of the implosion signal is examined to create parameterized time histories, which are then driven through a ML algorithm to generate the predictive models. Two predictive models are created in this work. It is shown that running simulations (with lower overheads) enables quick generation of ML models that can quickly provide reliable loading predictions. We will also demonstrate the usage of the Implosion Database Utility (IDU) to create the data pipelines required to train the ML models for confined implosions.

ENABLING QUICK GENERATION OF PREDICTIVE MODELS USING THE IMPLOSION DATABASE UTILITY (IDU)

Dr. Abilash Nair, Thornton Tomasetti
Caleb Penner, Thornton Tomasetti
Adam Hapij, Thornton Tomasetti
Benjamin Medina, NSWC Carderock
Dr. Joseph Ambrico, NUWC Newport
Dr. Emily Guzas, NUWC Newport

In this work we develop pipelines for automatic ML model generations within the Implosion Database Utility (IDU). The IDU is a comprehensive database of Implosion data with sources that include Physical tests and Virtual simulation data. The majority of this work is focused on leveraging the colocation of data & computational resources to generate fast running, data driven predictive models "on the fly". The workflow with the IDU will allow for user to trigger an update of the predictive implosion model whenever new data becomes available within the IDU database. Within IDU, the data is maintained and organized such that the user can query, export, design and train a predictive data-driven ML model all within the same environment. In this work, an application of the database to create ML model for confined implosion phenomena is presented. The case-study will demonstrate the usage of the IDU framework to design & train ML models with diverse data sources (that could be either experimental or simulation-based). Also presented in this work is a roadmap to identify the sparsely sampled regions of the data to generate new datasets to enhance performance of the predictive models.

INCORPORATION OF VALIDATION-DERIVED ERROR TO IMPROVE SURVIVABILITY PREDICTIONS
Dr. Russel Miller, IDA
John Przybysz, IDA

IDA is currently investigating the incorporation of modeling and simulation (M&S) uncertainty, as determined by verification and validation (V&V), into survivability assessments of naval vessels. The importance of understanding a ship's survivability is emphasized by the combat damage events experienced by USS Princeton, USS Stark, and USS Samuel B. Roberts. The Navy uses various M&S tools to predict structural damage, equipment and system failures, mission loss, and personnel casualties caused by threat weapon encounters. IDA is exploring the use of statistical methods to determine confidence intervals and prediction intervals that quantify M&S uncertainty based on comparisons with data from live tests and simulations. The objective of this work is to develop a practical method for applying the V&V-determined statistical error distributions to derive meaningful uncertainty bounds for damage, mission loss, and probability of kill given a hit prediction. The initial approach is outlined using Monte Carlo simulation across the error bounds of selected damage modules. The paper also addresses the uncertainty resulting from additional user-defined criteria.

VENDOR SESSION C: EXHIBITOR PRESENTATIONS: CASE STUDIES, NEW DEVELOPMENTS, TESTING & PRODUCTS

DESIGN, INSTALLATION, AND COMMISSIONING OF LARGE MIMO SYSTEM TESTING
Deepak Jariwala, Spectral Dynamics

The paper discusses a case study of two identical large water cooled ED shakers interfaced in a MIMO configuration to generate double the force of each shaker. The shaker is rated for 44,000 lbf. The ED shakers run in vertical configuration to drive a common head expander with a mounted device under test (DUT) of 7,735 lbs to generate a vertical force of 88,000 lbf. Also, the shakers run in horizontal configuration to drive a common slip table with a mounted DUT of 7,735 lbs to generate a horizontal force of 88,000 lbf. The paper also shows interesting pictures of the installation, and plots of the MIMO Control in Swept Sine and Random modes.

DIGITAL TWIN: BACK TO THE FUTURE
Ray Deldin, Altair Engineering

The idea of a digital twin that is a virtual model of the product produced is nothing new - or is it? What makes the digital twins of today different from what built in the past? Altair will present a vision and prescription for taking the digital twins of the past into the future facilitating the achievement of a true "digital twin".

RESONANT PLATE TESTING: ROUND OR SQUARE PLATES
Dr. Carl Sisemore, ShockMec Engineering

Resonant plate shock testing is frequently used to simulate pyrotechnic shock events in the laboratory. The method is a proven technique for the evaluation and qualification of small components. Most resonant plate shock test machines make use of square plates for testing. The square plate is sized such that its lowest bending mode corresponds to the primary test specification frequency, the unit under test is attached to the front, and a shock excitation is applied to the rear. However, there have been several recent research efforts experimenting with round resonant plates. Resonant plate theory does not require the plate to be a particular shape, only that it can be rung. This naturally leads to the question of whether one configuration is better than another. Numerical and experimental results are presented on two comparatively sized resonant plates, round and square, examining their similarities and differences. Consideration is also given to how the use of differently shaped resonant plates could impact the development and application of test specifications and component qualification.

CHARACTERIZING SHOCKWAVE PROPAGATION & MECHANICAL VIBRATIONS USING HIGH-SPEED DIGITAL IMAGES
Dr. Kyle Gilroy, Vision Research

Over the last two decades there has been tremendous progress in the development of high-speed CMOS sensor technologies. This advancement in digital imaging has subsequently provided scientists and engineers with innovative tools for characterizing tough experiments that were previously reliant on single-point contact sensors (i.e., strain gauges and accelerometers). In this talk, we will explore this progress in imaging technology along with some of the advanced imaging techniques utilized in the field. Focused examples will include Schlieren imaging for shockwave characterization; template matching for kinematic analysis; digital image correlation (DIC) for full-field material deformation-, strain- and vibration-mapping; and growth in real-time vibration measurements with high-throughput image streams.

TRAINING III: BLAST SCALING

BLAST SCALING
Denis Rickman, USACE ERDC

The explosive testing community routinely utilizes scaling to relate the effects produced by explosions of differing energy levels. Scale-model testing is also used by the weapons effects community to reduce the time/cost to conduct certain experiments.

Sachs and cube-root scaling are most frequently used for blast testing. These techniques provide functional scaling relationships for the various explosion effects. Other scaling methods are sometimes utilized. In some cases, non-cube-root scaling is used to account for observed trends that don't appear to follow cube-root scaling laws.

SESSION 13: SHOCK & VIBRATION ISOLATION DESIGN AND ANALYSES

INTERPRETATION OF ELASTOMERIC FINITE ELEMENT ANALYSIS
Robert Sharp, Hutchinson

During isolator design, elastomeric Finite Element Analysis (FEA) is generally performed first to validate that the Load versus Deflection (LD) and performance of the section meet the system requirements. Further analysis is then performed to confirm suitability of the section to deflection driven stress and strain and to optimize the section details. This presentation and paper focuses on the interpretation of those stress and strain results.

Interpretation of the results of elastomeric FEA is significantly different, more subjective, and more nuanced than that of metallic or composite structures. A detailed understanding of the application, the inputs causing the deflections, and the desired system response is required. Completely different interpretations could be made from results at the same deflection for a static response than to a vibration, shock, or impact. Elastomers respond differently to compression than to tension and can survive much higher compressive stress. They are also highly strain and rate sensitive which influences the apparent elastomeric modulus and stress scaling.

Historical rules of thumb carried over from traditional design evaluation apply more to global averaging of stress and strain over the section than to the extremely focused element level evaluation afforded by modern FEA. Elevated stress or strain in single elements or in small concentrations could be benign if related to large deformation or bulge, or serious fatigue indications in critical areas. The experienced elastomeric engineer takes all of this into account when developing the design and when presenting the results, but it is extremely helpful for the end user to have an understanding in place beforehand. This paper is presented not as an engineering manual for interpretation, but as a background guide for the customer to understand the methods used and reasoning behind the recommendations.

THE USE OF HIGH DAMPING WIRE ROPE ISOLATORS AND SYMOS SOFTWARE FOR UNDEX APPLICATIONS

Ali Shehadeh, Socitec US
Osadolo Irowa, Socitec US
Cyril Coquet, Socitec France

Wire Rope Isolators (WRI) are well known and used for the protection of sensitive equipment against non-contact underwater explosions (UNDEX) on board Naval Ships, amongst others, which are extremely destructive and can completely impair the ship’s combat capability and functionality.

Traditional WRI exhibit a number of definite advantages, such as large deflection capability, modularity and insensitivity to aggressive environment when proper materials are used. However, in some specific cases, their inherent nonlinearity does not always provide the best solution possible in terms of shock attenuation. (Stiffening tension characteristics).

Fortunately, there are ways to overcome this problem, namely increasing their damping and/ or changing their aspect ratio by using high damping cable. It is the purpose of this presentation to show how Socitec’s proprietary software, SYMOS, is used to select the proper isolation system for UNDEX and other applications and compare results from HDWRI (high damping wire rope isolators) vs. conventional WRI in specific applications.

WIRE ROPE ISOLATORS FOR TRANSPORT CONTAINERS

Robert Filec, Socitec US
Liron Fridman, Socitec US

The Socitec Group has been known for more than 40 years as a worldwide leader in wire rope isolators (WRI) as well as related engineering services, including numerical simulations. The US branch is based just outside of Chicago and provides the same engineering and production capabilities upon which the Socitec Group has built its reputation.

Rugged components and assemblies used in defense and aerospace often require isolation and protection during transport. Static and dynamic inputs such as quasi-static forces, shock and vibration, as well as handling hazards are all factors that could damage equipment during transport. While rugged components can be designed to resist loads of 10 G's or more, even a minor 10” drop may induce a short duration shock of tens, if not hundreds of G's, causing damage to the equipment. Wire Rope Isolators are commonly used in shipping containers to significantly reduce shock loads and harmful vibrations. While field testing is not always an option, numerical methods allow for the simulation of road conditions, predicting loads, and selecting optimal isolators for each case.

In this presentation, we will take a closer look at what needs to be considered when using Wire Rope isolators for transportation applications. This includes a review of inputs and specifications, advantages and disadvantages of using Wire Rope Isolators, as well as a closer look at simulations done to estimate the shock event response.

EXPECTED TRENDS IN MODAL RESPONSE SENSITIVITY OF A VIBRATION ISOLATED RIGID BODY SUBJECTED TO SINUSOIDAL BASE EXCITATION IN 3 ORTHOGONAL AXIS UNDER TWO VARYING CONDITIONS
Dr. Christopher Merrill, CM&A Engineering

Dynamics analysis will be performed on a vibration isolated Rigid Body of constant mass and isolator base plate connection geometry subjected to sinusoidal base excitation between 4 and 50 Hz along 3 orthogonal axis to determine the modal response (modes and mode shapes) function M at given ratio: α – a selected geometric ratio of CG elevation to the fixed horizontal separation of base plate isolator connections, and given ratio: β – a selected isolator stiffness ratio between the isolator systems horizontal stiffness to a selected system vertical stiffness, in order to generate a modal response function data point set M (α, β). Set M (α, β) will be determined by investigating a small number m+n of selected values of interest I = 1,m and j = 1,n used to evaluate the modal response function at m+n specific M (αi, βj) data points. The resulting modal response function data point set will used to build a trade space to determine whether hypothetical trends in the modal response function occur where expected and to evaluate and further identify trends of system modal response over the data space.

Expected behavior hypothesis: 1) At $\alpha = 0$, $\beta \geq 1$, varying, the vertical and horizontal modal response will be driven by the rigid body mass and the vertical and horizontal stiffnesses; 2) At $\alpha > 0$, $\beta >>1$ the large horizontal stiffness will lock base plate horizontal motion and the vertical and horizontal modal response will become controlled by the rigid body mass and the vertical stiffnesses due to rocking motion of the rigid body mass causing out of phase vertical motion on the isolators on either side; and 3) At $\alpha > 0.5$ and $\beta \geq 1$, varying, the vertical and horizontal modal response will tend to become controlled by the rigid body mass and the vertical stiffnesses due to rocking motion of the rigid body mass causing out of phase vertical motion on the isolators on either side.

EXPECTED TRENDS IN TRANSIENT RESPONSE SENSITIVITY OF A VIBRATION ISOLATED RIGID BODY SUBJECTED TO TRANSIENT SHOCK BASE EXCITATION IN 3 ORTHOGONAL AXIS UNDER TWO VARYING CONDITIONS
Dr. Christopher Merrill, CM&A Engineering

Dynamics analysis will be performed on a vibration isolated Rigid Body of constant mass and isolator base plate connection geometry subjected to transient shock base excitation similar to MWSM inputs along any 2 of 3 orthogonal axis to determine the transient shock response (modes and mode shapes) function T at given ratio: α – a selected geometric ratio of CG elevation to the fixed horizontal separation of base plate isolator connections, and given ratio: β – a selected isolator stiffness ratio between the isolator systems horizontal stiffness to a selected system vertical stiffness, in order to generate a transient shock response function data point set T (α, β). Set T (α, β) will be determined by investigating a small number m+n of selected values of interest I = 1,m and j = 1,n used to evaluate the transient shock response function at m+n specific T (αi, βj) data points. The resulting transient shock response function data point set will used to build a trade space to determine whether hypothetical trends in the transient shock response function occur where expected and to evaluate and further identify trends of system transient shock response over the data space.

Expected behavior hypothesis: 1) At $\alpha = 0$, $\beta \geq 1$, varying, the vertical and horizontal transient shock response will be driven by the rigid body mass and the vertical and horizontal stiffnesses; 2) At $\alpha > 0$, $\beta >> 1$ the large horizontal stiffness will lock base plate horizontal motion and the vertical and horizontal transient shock response will become controlled by the rigid body mass and the vertical stiffnesses due to rocking motion of the rigid body mass causing out of phase vertical motion on the isolators on either side; and 3) At $\alpha > 0.5$ and $\beta \geq 1$, varying, the vertical and horizontal transient shock response will tend to become controlled by the rigid body mass and the vertical stiffnesses due to rocking motion of the rigid body mass causing out of phase vertical motion on the isolators on either side.

SESSION 14: RANDOM VIBRATION CHARACTERIZATION AND SPECIFICATION DEVELOPMENT

A Proposed Update to the Common Carrier Vibration Specification

Dr. Michael Hale, Trideum Corporation
William Barber, Redstone Test Center
Jesse Porter, Redstone Test Center
Dr. Bryan Joyce, NSWC Dahlgren
Dr. Luke Martin, NSWC Dahlgren
Shawn Schneider, NSWC Dahlgren

The default Common Carrier vibration specification defined in MIL-STD-810H dates to the 1983 release of MIL-STD-810D. While test duration and associated mileage are provided, there is no meta-data provided to address issues such as applied time compression, trailer types, and payload weights. In addition, the wide variation in spectral shapes between the lateral degrees-of-freedom in the current specifications is suspect. This paper takes advantage of a comprehensive set of field measurements acquired by the US Navy on multiple vehicles to propose an updated common carrier specification. Multi-Axis options and examples are also provided.

Defining Multi-axis Vibration Test Control Matrix

Barak Deutscher, Rafael
Zachi Katzir, Rafael
Gal Rubinstein, Rafael

In the recent decade, the rapid increase awareness for a multi-axis vibration test is evolving, yet there is much room to improve when in it comes determining the control matrix specification. During a MultiInput Multi-Output (MIMO) test, the user must define the required Power Spectral Density (PSD) for each channel as well as the cross terms between them, known as CPSD that are usually defined as Coherence and Phase. While for single exercise the PSD and CPSD are well defined as they are taken from an actual field measurements, for multiple exercises defining the full control matrix specially the cross terms is quite a challenge and far from being a well defined method.

Some companies and organizations have implemented several algorithms in their control systems while not all of the considerations and algorithms are revealed to the end user. The common practice to MILSTD-

810H method 527 suggests the user should conduct an uncorrelated test with near zero values in the cross terms.

Our multi-axis MIMO vibration test example includes a payload exited by 6 shakers and controlled by 9 acceleration sensors. The current work focuses on the process of analyzing measured field data from several environments and defining one test specification to envelop them all while utilizing familiar methods from the literature such as minimum drive, buzz test and phase-pivot algorithms.

ARTIFICIAL INTELLIGENCE FOR ANOMALY DETECTION IN VIBRATION TESTING AND SCREENING

Dr. Charles Hull, Lockheed Martin

Artificial intelligence methods have numerous potential applications within equipment vibration testing and screening. This study shows how convolutional neural networks (CNNs) can be trained to identify and categorize variations in vibration signatures. The concept and process is illustrated with an idealized multi-mass, spring, damper system in a random vibration environment. Simulation results suggest CNNs can effectively discriminate differences in dynamic behavior despite modest sensor noise.

SESSION 15: PROJECTILE IMPACT AND CRATERING

AN OVERVIEW OF SOIL CRATERING DATA AND MODELS FOR BURIED DETONATIONS AND KINETIC ENERGY IMPACT

Dr. Kyle Crosby, USACE ERDC
Denis Rickman, USACE ERDC
Logan Callahan, USACE ERDC

Considerable damage to a target can result from cratering from a near miss of a weapon penetrating and detonating or impacting with significant kinetic energy adjacent to the target. This paper examines three buried explosive cratering models used in ConWep, CALDERA, and the Holsapple cratering tool and the underlying data used to generate these models. The underlying data analysis includes comparisons of the explosive types, soil types, and depths of burial in the experimental data used as the basis for these models. Then, the Holsapple kinetic energy cratering model and underlying data is analyzed to determine if any relationships for crater size and shape exist between buried explosive cratering and kinetic energy cratering.

SOIL CRATERING FROM PROJECTILES IMPACTING AT HIGH VELOCITIES

Logan Callahan, USACE ERDC
Dr. Zane Roberts, USACE ERDC
Reid Bond, USACE ERDC
Dr. Kyle Crosby, USACE ERDC
Dr. Jay Q. Ehrgott, Jr., USACE ERDC

Soil cratering from projectile impact is an important phenomenon to understand for applications with terminal ballistics. However, there is a lack of projectile impact cratering data into well characterized soils. In support of the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME), the U.S. Army Engineer Research and Development Center (ERDC) conducted tests to determine the effect of different projectiles and impact velocities on ground cratering over a range of soil types and conditions. The impact tests were conducted with ERDC’s 152mm Mobile Ballistic Research System (MBRS) and utilized three projectiles, a 3.0-Caliber Radius Head (CRH) ogive projectile and two cylindrical nylon projectiles of different sizes and masses. The ogive projectiles were fired into a well prepared clayey sand testbed, and the nylon cylinders were fired into an in-situ silty sand testbed. Impact velocities were varied from 1000 to 5000 ft/s. Both photogrammetry and surveying techniques were used to characterize the pre- and post-impact crater dimensions. This work includes an overview of the testing setup, experimental test matrix, results, and comparison of projectile kinetic energy and crater geometry. These data provide a baseline to calibrate predictive cratering models for the determination of the effects of projectile characteristics and soil conditions on resultant crater geometry.

High Velocity Perforation of Steel and Reinforced Concrete Targets with a Multi-Component Projectile

Dr. Zane Roberts, USACE ERDC
Dr. Kyle Crosby, USACE ERDC
Reid Bond, USACE ERDC
Logan Callahan, USACE ERDC
Dr. Jay Q. Ehrgott, Jr., USACE ERDC

The ERDC conducted perforation tests investigating the target damage and spall from impact by a thin-walled, multi-component projectile in support of numerical modeling efforts. The 2.5 in. diameter aluminum projectiles had three main internal components consisting of a tungsten cone, steel cylinder, and aluminum cylinder. The projectiles were fired into 5/8 in. A36 steel plate and one or two layers of 4 in. rebar-reinforced conventional strength concrete slab targets with nominal impact velocities of 1000, 2000, and 3000 ft/s using an 83-mm-bore powder gun (with sabot). High-speed digital video was used to measure the projectile break-up and trajectory (pitch and yaw), debris field cone angle, and the residual velocities of the projectile components and debris after target perforation. Photogrammetric software was used to reconstruct three-dimensional target front- and back-faces to analyze the damage. This data will be used to validate numerical models and improves our understanding of the damage caused by impact of a high velocity thin-walled body multi-component projectile.

Perforation and Penetration of 3MR Ultra High Performance Concrete

Reid Bond, USACE ERDC
Dr. Kyle Crosby, USACE ERDC
Dr. Bill Heard, USACE ERDC

The U.S. Army Engineer Research and Development Center (ERDC) conducted testing against Ultra High Performance Concrete (UHPC) with and without fiber reinforcement. The purpose of this testing was to observe the effects of fiber reinforcement on concrete penetration resistance and to provide data for validation of PENCURV+ and an analytical projectile penetration model. Ogive nose projectiles were fired at targets using ERDC's 83-mm smooth bore powder gun. Residual velocities were measured using high speed video, and photogrammetry was utilized to analyze the dimensions of the target impact and exit craters. On-board instrumentation packages were used to collect projectile deceleration data. The experimental results showed that the fiber-reinforced UHPC yielded greater penetration resistance than non-fiber-reinforced UHPC. Results from the analytical model, PENCURV+ simulations, and the empirical data were compared and analyzed.

EVALUATION OF PENETRATION RESISTANCE OF CONVENTIONAL CONCRETE SLABS REPAIRED WITH SPRAYABLE ULTRA-HIGH-PERFORMANCE CONCRETE

Cameron Thomas, USACE ERDC

A rapid repair method for damaged concrete structures is a desirable technology for protecting soldiers in conflict zones. To address this, the U.S. Army Corps of Engineers Engineer Research and Development Center (USACE ERDC) has been tasked with an effort to evaluate the projectile penetration resistance of conventional-strength concrete targets repaired with a sprayable High-Performance Concrete (HPC). This study will assess the resistance concrete targets to penetration from a projectile fired from an 83mm smooth bore powder gun located at the USACE ERDC. As part of the evaluation, a set of controlled experiments were conducted by launching 3-in. diameter, 17.7 in long 4340 steel projectiles into conventional concrete targets using predetermined muzzle velocity and impact conditions. The baseline for comparison will be the pristine conventional concrete slabs. After firing, the damaged concrete targets will be sprayed with a HPC material using a rapid repair method for which results will be compared to the baseline concrete targets. Parameters for comparison will include perforation hole size and residual velocity. Residual velocities were measured using high-speed video, and photogrammetry was utilized to analyze the dimensions of the target impact and exit craters. In addition, digital photography and measurement tools documented the effects of munition(s) and response of the target materials. This paper presents an overview of the experiment design and the results from this effort.

SESSION 16: MECHANICAL SHOCK: TEST CHARACTERIZATION, ANALYSIS, SOLUTIONS

VALIDATION OF THE DYNAMIC FEA MODELING OF AN ARMAMENT SYSTEM TO EMPIRICAL TEST RESULTS USING ACCELEROMETERS AND STRAIN GAUGES

Blace Jacobus, US Army
Dr. Catherine Florio, US Army
David Geissler, US Army
Ryan Hanc, US Army
Russell Jones III, US Army
Steven Manole, US Army
Thomas Ziegler, US Army

Gun launch is well known as a highly dynamic event as a result of accelerating a projectile to high speeds over a short distance. However, the dynamics also apply to the gun tube recoil, which may be overlooked due to the lower acceleration magnitudes relative to those of the projectile. These accelerations, though, are still quite high at about +/- 300 G's and frequencies around 200Hz. This necessitates a robust design coupled with a rigorous modeling approach. The use of Finite Element Analysis (FEA) offers an unobstructed window into nearly every aspect of the system during the event. Although FEA is a powerful tool, it must be well-validated to have confidence in the results.

Typical model validation consists of a handful of sensors and post-firing inspection, at most. A rare opportunity was presented to instrument a gun system with over forty strain gauges and accelerometers. The sensors were located based on the areas of interest for each component, such as expected high strain or stress regions. The test included firings at different quadrant elevations and charge levels. A test firing matrix was constructed using design of experiments methods to provide the most data rich results with a limited number of firings. This ensured the model could capture the full range of scenarios the gun system may encounter.

The recorded gun breech acceleration data from the was then passed through a low-pass filter and used to drive the FEA model. The final step was comparison of the physical strain gauges to results of the FEA. A close alignment was achieved for first recoil spikes of the system in both time and amplitude. Subsequent spikes in the strain gauge data appeared to match temporally but were miss aligned in amplitude. This misalignment is currently believed to be caused by inaccurate friction, lack of damage modeling for all components, and not damping on the FEA system.

SUPPORTING PIPE FOUNDATION FLANGE SHOCK ANALYSIS TOOL FOR SIMULTANEOUS LARGE QUANTITY FLANGE ANALYSIS – IMPROVEMENTS

Mackenzie Wilson, HII - Newport News Shipbuilding
Chris Campbell, HII - Newport News Shipbuilding

This paper describes the further development of the supporting pipe foundation flange shock analysis tool, which was presented at SAVE 2022. The supporting pipe foundation flange shock analysis tool was developed for evaluating flanges in a cost effective manner before a more cost prohibitive finite element analysis would need to be performed. However, further development of the tool has resulted in the following functional changes and additions: 1) evaluation of flange orthogonal direction load capacities; 2) adjustment of assumptions to improve balance of conservatism and reality with regards to more accurately distributing loading between multiple foundation flanges and connecting piping; 3) and exploration of additional hand calculation avenues prior to requiring FEA in the event the tool yields undesired results. Example analyses of the pipe foundation flanges are also presented and discussed. This project is an example of leveraging Excel for engineering shock analysis and demonstrates how spreadsheet applications can be a valuable tool for engineering work.

INVESTIGATION OF SHIPBOARD FIRE DETECTOR RESPONSE TO NON-MIL-DTL-901 SHOCK

Daniel Provenzano, NSWC Philadelphia
Brian Moore, NSWC Philadelphia

Daniel Provenzano is a Mechanical Engineer working in the NSWCPD Code 333 Shock and Vibration Lab. He graduated from Lehigh University in 2011 with a BS in Mechanical Engineering. From 2011 to 2021 he worked in NSWCPD Code 324 Acoustics and Machinery Silencing, specializing in laboratory and shipboard vibration measurement and analysis. After a 6 month rotation as an Electrical Engineer in the NSWCPD Code 333 Electromagnetic Compatibility Lab, he began working in the NSWCPD Code 333 Shock and Vibration Lab where he develops test procedures, reports, and executes MIL-STD-167 and MIL-DTL-901 testing.

PRINTED HYBRID ELECTRONIC (PHE) ASSEMBLIES ON HEMISPHERICAL DOMES SUBJECT TO EXTREME (100,000 G) ACCELERATION LEVELS: MECHANICAL PERFORMANCE AND OPERATIONAL APPLICATIONS

Major Hayden Richards, University of Maryland, College Park
Dr. Abhijit Dasgupta, University of Maryland
Andres Bujanda, US Army Research Lab
Dr. Harvey Tsang, US Army Research Lab
Dr. Jian Yu, US Army Research Lab

The Center for Advanced Life Cycle Engineering at the University of Maryland, in partnership with the US Army Research Lab, employs an on-site 100,000-G accelerated drop tower to perform performance evaluation and reliability assessment of various Printed Hybrid Electronic (PHE) assemblies. Current research efforts are focused on the evaluation of both printed and injection molded hemispherical domes. These domes are overlaid with electronic components interconnected with printed traces deposited by a variety of extrusion and aerosoljet printing techniques. Ongoing work is evaluating, for many permutations of these assemblies, both 1) the first-drop survivability and 2) the long-term reliability for both the dome substrates and the electronic components. Accelerations range from 10,000 G to 100,000 G with pulse durations of 0.05-0.1 ms and impact velocities of 6.5-20.5 m/s. Consistent with established electronics reliability methodology, degradation is assessed based on changes in electrical resistance within circuits of interest over time. This resistance is measured real-time, in-situ during the drop event and incrementally over the course of many drops. In combination with high-speed video and strain measurements, this resistance data offers insight into the behavior of these PHE assemblies during the impact event and supports the generation of computer models that can predict specimen performance.

Catastrophic failures of compliant additively manufactured ABS domes at relatively low acceleration levels (10,000-30,000 G) has motivated the use of molded polycarbonates, which withstand hundreds of drops at over 100,000 G. Trace degradation from the as-printed condition to complete open-circuit failure takes as few as 1-2 drops at 100,000 G to hundreds of drops at 10,000-40,000 G. Prior to complete trace failure, circuit resistance can instantaneously spike during the ~.05 ms duration of the acceleration pulse, which would jeopardize any PHE system that can't handle a momentary discontinuity. Additionally, resistance measurements for traces progressively increase with number of drops, at rates proportional to acceleration magnitude. Complete trace failure occurs at approximately 10^6 cumulative impact energy for various acceleration levels. Future work will 1) further expand our knowledge of material and component combinations to determine ideal pairings for a given task or application, 2) mature the dome and component models to better assess stress, strain, and the implications thereof, and 3) perform drop testing at elevated temperatures. Ultimately, these studies inform Army Research Lab efforts and help direct developmental work on operationally-relevant applications for these technologies.

How to Fail a Shock Test

Dan Moran, NSWC Philadelphia

No abstract available.

VENDOR SESSION D: EXHIBITOR PRESENTATIONS: CASE STUDIES, NEW DEVELOPMENTS, TESTING & PRODUCTS

Design, Characterization, and Refinement of a Multibody Shock Isolation System

Alan Klembczyk, Taylor Devices

Deriving an optimized shock and vibration isolation system in 6DOF can be complex due, in part, to the interaction of the isolation system components, the isolated mass, and the support structure. This presentation will demonstrate how a rigid body analysis coupled with flexible body elements were used to obtain optimized shock mitigation with a non-linear isolation system.

COMPOUNDING CUSTOM ELASTOMERIC FORMULATIONS TO INCREASE SERVICE LIFE
Neil Donovan, Hutchinson
Adam Meyer, Hutchinson

Hutchinson solves shock and vibration problems for the majority of our customers through the application of molded elastomeric materials. The ability to design, mix, and test our own custom compounds allows us to tailor solutions to our customer's needs.
In this presentation, we will present some recent advancements in elastomeric materials, and discuss the common process of "compromise and material properties tradeoffs" in a practical sense while focusing on developments in elastomers that can increase the service life and performance of components.

IDC AND THE JES GROUP – YOUR RESOURCE FOR SHOCK AND VIBRATION SOLUTIONS
Eric Jansson, Isolation Dynamics Corp.

No abstract available.

BENEFITS OF USING BAND-LIMITED DAMPING IN EXPLICIT DYNAMICS FEA SIMULATIONS
Dr. Ted Diehl, Bodie Technology

Modeling severe impact and other complicated dynamic events is often accomplished via an explicit dynamics FEA model, either Abaqus/Explicit, LS-Dyna, or another explicit solver. While such models can handle many complex aspects of the physics involved, they traditionally have limited options for representing material damping compared to linear modal dynamics simulations (which of course have their own limitations). As a result of this, most users of explicit dynamics make no effort to include material damping in their models; they rely on effects from default algorithmic damping, plasticity, and/or other mechanisms to represent overall damping effects. We show that this approach can lead to simulation inaccuracies causing noticeable discrepancies between FEA and physical testing. Moreover, for SRS calculations derived from transient FEA model output, insufficient damping in simulations can lead to significant over-estimation of the SRS spectra magnitudes which in-kind may lead to over-testing specimens in physical testing. Fortunately, a new approach for representing material damping called band-limited material damping (BLMD) has become available in the last couple of years in at least two of the major explicit dynamics codes – Abaqus/Explicit and LS-Dyna. BLMD allows simulation users to specify by material (or other groups up to and including the whole model) a critical damping ratio over a band of frequencies. While BLMD itself is not perfect and has limitations, its proper use often yields significant improvements in transient FEA results, including their use in SRS spectra calculations. To demonstrate this, two very different severe transient events are presented with and without the use of BLMD. One event is an elastically dominated event and the other is an event that has significant plasticity. Post-processing and organizing of the various results will be demonstrated via Kornucopia® ML™.

MOTION AMPLIFICATION MEETS MODAL ANALYSIS: WHAT'S SO "SHOCKING" ABOUT THAT?
Jeff Hay, RDI Technologies

The paper discusses a case study of two identical large water cooled ED shakers interfaced in a MIMO configuration to generate double the force of each shaker. The shaker is rated for 44,000 lbf. The ED shakers run in vertical configuration to drive a common head expander with a mounted device under test (DUT) of 7,735 lbs to generate a vertical force of 88,000 lbf. Also, the shakers run in horizontal configuration to drive a common slip table with a mounted DUT of 7,735 lbs to generate a horizontal force of 88,000 lbf. The paper also shows interesting pictures of the installation, and plots of the MIMO Control in Swept Sine and Random modes.

TRAINING IV: SHIP SHOCK INSPECTIONS

SHIP SHOCK INSPECTIONS

Michael Poslusny, Gibbs & Cox

This training details the ship shock inspection process for Navy surface ships, including the utilization of 3D model assessments during detail design and physical checks conducted during the construction phase. The presentation will provide a brief synopsis on shock as it affects a ship, its systems and their components, compartment inspection procedures and what to look for, commonly found discrepancies, and shock damage prevention measures.

SESSION 17: SHOCK TESTING METHODOLOGY II

A COMPARISON OF THE NON-LINEAR DYNAMIC FORCE-DISPLACEMENT CHARACTERISTICS OF SHOCKMOUNTS WITH BOTH STATIC MEASUREMENTS AND VENDOR PROVIDED CHARACTERISTICS

Dr. Bernard Heinemann, Helmut Schmidt University/University of the Federal Armed Forces Hamburg
Dipl.-Ing. Jan Dreesen, Bundeswehr Technical Center for Ships and Naval Weapons, Maritime Technology and Research
Prof. Dr.-Ing. Delf Sachau, Helmut Schmidt University/University of the Federal Armed Forces Hamburg

In naval applications, shockmounts are used to delay the flow of shock energy in the event of underwater explosions, in order to protect equipment and personnel. Underwater explosions typically induce structural excitation within a few milliseconds, with peak accelerations reaching several hundreds of g. In contrast, the force-displacement-characteristics of shockmounts are commonly determined through static measurements. For naval engineers, having reliable information on the dynamic behavior of shockmounts is essential. Therefore, this paper presents the dynamically measured force-displacement characteristics of shockmounts and compares them with vendor data, as well as with statically self-measured characteristics. The data from three different types of elastomer shockmounts and three wire rope shockmounts are evaluated, considering excitation in both axial and radial directions as well as varying shock loadings. Depending on the shockmount type, strength and load direction, the comparison results range from almost no difference to a significant difference between the dynamically and statically measured force-displacement characteristics.

IMPROVED DIGITAL CONTROL OF SHOCK WAVEFORMS WITH SHAKERS

Dr. Mattia Dal Borgo, Siemens Industry Software
Umberto Musella, Siemens Industry Software NV
Eddy Faignet, Siemens Industry Software NV
Dr. Bart Peeters, Siemens Industry Software NV

Shock is defined as an abrupt change in the state of a system that causes a transient response. Standards specify several types of shocks directly in time domain, based on classical waveforms, such as half-sine, terminal peak sawtooth or trapezoid. Alternatively, the shock response spectrum (SRS), which is commonly used to estimate the severity of a shock event, can also be used to synthesize a time waveform via a summation of fundamental transient responses, such as wavelets or damped sines. The replication of shock responses in a controlled laboratory environment using shakers has been an item of interest for test centres since the mid-1950s. Shakers have a number of advantages over traditional shock machines, among them the possibility of replicating diverse shock waveforms, the use of the same facility for both vibration and shock tests, and the direct replication of an acceleration signal via closed-loop control to better represent the real environment. The purpose of the controller is to guarantee that the correct excitation is applied to the device under test. If a control sensor measures a deviation with respect to the specified waveform, then the controller updates the shaker driving signal to reduce this error. In practice, non-ideal behaviour of the exciters, such as uncertainties, nonlinearities, external disturbances and interaction with the test object, can affect the performance of the controller.

This paper presents the development of improved control algorithms that minimise the errors introduced by these effects in order to achieve accurate and robust replication of the target waveform. The results of this development are demonstrated on both single axis and multi-axis exciters.

GENERATION OF SYNTHETIC SHOCK DATA USING GAN'S

Victor Neverez, Sandia National Laboratories
Jingyu Chen, Sandia National Laboratories

Machine learning (ML) and Artificial intelligence (AI) solutions to target detection problems are limited by the current available testing datasets. The cost and time constraint that each of these destructive tests demand significantly limit the usability of complex ML and AI techniques. Simulation data typically has the issue of not being able to properly capture damping effects from experimental testing data, which limits its usability for ML and AI techniques. Instead, we are looking in producing synthetic datasets from already existing high quality shock environments using Generative Adversarial Networks (GANs). GANs are neural networks that uses a generator, which produces the fake data, and a discriminator, which determines whether the synthetic data passes or not compared to real data. Using these networks, we have been able to successfully recreate simple elastic collisions, drop tower shocks, and hard target environments. Using various shock profiles, we explored implement physics constraints into the cost function to improve the accuracy and quality of the data. We found that these physics constraints improve the issue of over constrained solutions. We have now been able to generate synthetic data for hard target datasets limited to 3 datasets. The GAN synthetic datasets are similar in response to the original datasets and have similar velocity, position, and shock response spectra (SRS) that would pass a physics check for these tests. Using these GAN synthetic data methods, it is possible to take a smaller available testing dataset and expand it to a quantity where more ML and AI techniques can be used.

A NEW APPROACH FOR SYNTHETIZING MULTI-AXIS SHOCKS FROM SRS SPECIFICATIONS

Umberto Musella, Siemens Industry Software
Dr. Mattia Dal Borgo, Siemens Industry Software
Dr Alberto Garcia De Miguel, Siemens Industry Software
Dr. Bart Peeters, Siemens Industry Software
Eddy Faignet, Siemens Industry Software

The Shock Response Spectrum (SRS) was originally developed in 1930 by the Belgian physicist Maurice Biot to quantify a seismic event with a generic curve that could represent the rapidly varying transient nature of an earthquake and the potential effects on an elastic (undamped) building. Due to its simplicity, flexibility, and possibility to include frequency-domain margins, the SRS was largely adopted to describe not only seismic events, but any shock event. However, the SRS represents an incomplete, non-unique and irreversible transformation. Because of this, deriving suitable inputs for shaker testing starting from

SRS specifications can be extremely challenging. The main reason is the impossibility to consider a-priori physical limitations of the testing setup or the shape and nature of the synthetized acceleration waveforms that need to be replicate at the interface between the shaker and the device under test. The problem scales up in case of multi-axis shock testing on shakers because of the need to include a degree of cross-correlation that may exist between the real-life responses between different axes of excitation. The goal of this work is to show a methodology that aims to overcome these challenges and illustrates the results and the benefits of the implemented algorithms on a high-performance biaxial seismic table.

SESSION 18: BALLISTICS

SIMULATING AIR BURST THREATS AND ASSESSING SURVIVABILITY

Giri Prasanna, Altair Engineering

In the realm of defense and security, understanding the potential threats posed by air bursts is crucial for ensuring the survivability of critical infrastructure and military assets. The ability to accurately assess the effects of air bursts and design appropriate countermeasures is paramount for strategic planning and risk mitigation.

This presentation explores a case study which demonstrates the use of Radioss, an advanced simulation tool, in the emulation of air burst scenarios and the assessment of targeted system survivability. Emphasis is placed on the meticulous modeling of blast waves and mapping techniques; which are critical components in the optimization and accurate simulation of such events.

RESISTANCE OF FEBR GLAZING AGAINST INDIRECT FIRE THREATS

David Senior, USACE ERDC
Craig Ackerman, US Department of State

The protection levels of ballistic resistant glass against direct fire projectiles has been extensively studied and can be well-defined through numerous testing protocols. These include standards such as the Underwriter's Laboratory or the National Institute of Justice standards in the United States (U.S.), or the NATO Standardization Agreement (STANAG) testing standards used across the international community. However, correlation between these standardized penetration resistance levels and protection against the fragmentation effects of indirect fire weapons such as rockets and mortars is an open issue for the protective research and design community. In support of U.S. Department of State protective designs, the U.S. Army Engineer Research and Development Center is conducting experimental research to investigate the correlation between standardized ballistic glass protection levels and the fragmentation effects at-range from indirect fire weapon detonations. Fragment simulating projectiles are used to define V50 penetration resistance of glass rated to various standardized protection levels. This experimental data will then be used as a basis for correlation between ballistic ratings for specific glasses and safe standoff from certain indirect fire threats. This research is ongoing; the proposed presentation will provide an overview of the background and motivation for the research and will present results of experimentation and analyses to-date.

ELECTRONIC SURVIVABILITY AND RESPONSE OF MICROBEADED ENCAPSULANTS UNDER SHOCK

Alex Chen, Sandia National Laboratories
Cayden Boll, Sandia National Laboratories
Dr. Dan Stefan Bolintineanu, Sandia National Laboratories
Dr. Dr. Robert Andrew Buraque de Macedeo
Dr. Jeff Hill, Brigham Young University

In harsh shock environments, electronics are traditionally packaged in a thermoset polymer encapsulant. The encapsulant supports the electronics during impact, mitigates damaging high frequency mechanical vibration, and prevents high voltage breakdown between components. However, these traditional encapsulants present their own challenges. During the thermal cure cycle, an elevated temperature for a prolonged period is required for the polymer to fully cure. This contributes to a residual stress state in the device. A coefficient of thermal expansion (CTE) mismatch between the electrical components (circuit board, capacitors, etc.) and the encapsulant can cause additional stresses, before the device is even under shock. Additionally, if there are electronic components that need to be recovered, or parts that need repair, the process is difficult, time consuming, and irreversible.

Using glass beads as a cureless shock mitigation media as an alternative to polymer encapsulants could address some of these issues. These packaged glass beads, or microbeaded encapsulants, have been shown in literature to mitigate shock and vibration. Microbeaded encapsulants require no thermal cure, no vacuum processing requirements, and allows for easy disassembly of packaged electronics. The CTE of these glass beads match electronic components much better than the polymer encapsulants, reducing both residual stresses during packaging, and during varying thermal conditions.

This work broadly explores the design space including physics based modelling of microbeaded encapsulant systems in the Large-scale Atomic/Molecular Massively Parallel Simulator (LAMMPS) software, physical packaging methodology, different bead sizes and materials, and experimental data evaluated against a range of acceleration profiles using a drop tower. This goal of this project is to explore the practical use of beaded encapsulants in shock environments.

SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

SHOCK MITIGATION EXPERIMENTS WITH A SIX-INCH DIAMETER GAS GUN

Mr. Chad Heitman, Sandia National Labs
Joshua Nowlin, Sandia National Labs
Dr. Nancy Winfree, Sandia National Labs
Chad Heitman, Sandia National Labs

Several materials were examined for their shock-mitigating capability when used in a particular configuration around a test unit during a 40,000 g impact with a duration of approximately 0.5 ms, achieved in reverse-ballistic impact tests with a 6”-diameter gas gun. The materials tested were SAE F-3 felt, Sorbothane-30A, silicone 50A, ultra-high molecular weight polyethene, an epoxy material with glass micro-balloons (828/DEA/GMB), and a polyurethane of durometer 75D. Both high-speed video and accelerometer data were used to evaluate the shock isolation effect of the materials.

SESSION 19: WEAPONS EFFECTS MODELING & SIMULATION

MODELING FRAGMENTING MUNITIONS AND THEIR EFFECT ON STRUCTURES

Dr. T. Neil Williams, USACE ERDC
William M. Furr, USACE ERDC
Christopher M. Shackelford, USACE ERDC
Dr. John Q. Ehrgott, Jr., USACE ERDC

The ERDC Terminal Weapons Effects (TWE) program, which supports the Army's Long Range Precision Fire (LRPF) cross-functional team, is developing a fast running tool that predicts structural target response with a tighter coupling of the blast and fragmentation effects. This presentation provides an update on the high fidelity method the TWE program is investigating to create some of the synthetic blast and fragmentation data. This presentation will show predicted fragmentation results determined using Zapotec, which couples CTH with Sierra/SM, the resulting interaction between the fragments and structures, and compare the simulations with recent ERDC test results.

FRAGMENTATION AND BLAST EFFECTS LIBRARY (FABEL)

William Furr, USACE ERDC
Christopher M. Shackelford, U.S. Army ERDC
Dr. T. Neil Williams, U.S. Army ERDC
Dr. John Q. Ehrgott, Jr., U.S. Army ERDC

This work describes the Fragmentation and Blast Effects Library (FABEL), a code establishing a suite of tools allowing an automated methodology for running high-fidelity combined blast-fragment loading simulations. This work was conducted under the U.S. Army Engineer Research and Development Center Terminal Weapons Effects Program. Seeking to address capability gaps in terminal weapons effects predictive capabilities, this program is in direct support of the Army's Long-Range Precision Fires modernization priority. Weapon developers and the warfighter need the capability to predict terminal effects quickly and accurately from modern long-range, high-velocity weapons, which often utilize both explosive air blast and fragments to defeat targets. However, combined loading is a complex phenomenon to model, and parametric studies using arena testing can be cost prohibitive. A modeling methodology for the process of blast loading, fragment formation, fragment flight, and target loading should leverage available data and simulation capabilities. The FABEL code automates these simulations, providing a wide range of user inputs to establish the appropriate fragment characteristics from the standardized munition characterization file format, ZDATA. FABEL automates the input file generation, running calculations, and harvesting relevant terminal effects results.

STRUCTURAL RESPONSE PREDICTIONS OF STEEL AND CONCRETE TARGETS USING THE FRAGMENTATION AND BLAST EFFECTS LIBRARY (FABEL)

Christopher Shackelford, USACE ERDC
William M. Furr, USACE ERDC
Dr. T. Neil Williams, USACE ERDC
Dr. John Q. Ehrgott, Jr., USACE ERDC

A primary initiative of the U.S. Army Engineer Research and Development Center's Terminal Weapons Effects (TWE) program is to support and enhance the capabilities of the warfighter through the development and improvement of fast running weapons effects codes and tools to accurately predict a weapon's terminal performance and lethality against structures and other critical targets. Part of this initiative is the development of a methodology to take munition fragmentation data obtained through either arena tests or high-fidelity modeling and run combined blast load and fragment impact calculations on structural targets. Using data obtained from ERDC arena tests, the ERDC developed Fragmentation and Blast Effects Library (FABEL) creates a virtual fragment environment which is superimposed on targets of interest. The work presented here focuses on using the FABEL generated fragment environment and Sierra/Solid Mechanics to predict the structural response of steel and concrete targets at various radial distances subjected to combined blast-fragmentation loading conditions and comparing the calculated responses with recent experimental data.

MODELING AND SIMULATION OF DEFORMABLE PROJECTILES INTO CONCRETE TARGETS USING EPIC

David Lichlyter, USACE ERDC
Dr. T. Neil Williams, USACE ERDC
Dr. Z. Kyle Crosby, USACE ERDC
Dr. John Q. Ehrgott, Jr., USACE ERDC

As part of the ERDC's Terminal Weapons Effects (TWE) program, research is currently underway to evaluate and improve high-fidelity modeling and simulation capabilities for materials and structural response to predict weapons effects against structures and critical assets. As part of this effort, the TWE program has conducted an experimental series of a scaled surrogate artillery round impacting reinforced concrete targets. The Elastic Plastic Impact Computations (EPIC) code has been previously validated for penetration/perforation into steel and concrete targets and this effort focuses on evaluating the capability of EPIC in modeling these tests with a deformable projectile. The work presented here compares EPIC calculation results with the test results focusing on the projectile damage and exit velocity seen in tests. This work is expanded by exploring and comparing two different modeling methods of predicting depth of penetration with the deformable projectile.

PRE-DAMAGED HIGH-PERFORMANCE CONCRETE TARGETS SUBJECTED TO PENETRATION TESTING TO OBSERVE RESIDUAL VELOCITIES

Justin Gilliland, USACE ERDC
Andreas Frank, USACE ERDC
Jason Roth, USACE ERDC

The U.S. Army Engineer Research and Development Center (ERDC) has been conducting research on protective systems to defeat multi-hit precision strike weapons. Part of this effort involves developing a better understanding of the penetration resistance of damaged high-performance concrete. Several phases of experiments have been executed to evaluate penetration into high performance concrete targets previously loaded using the 5M-lb universal testing machine (UTM) at United States Bureau of Reclamation (USBR) Denver to introduce various damage states damage. Preliminary experiments were conducted to evaluate the optimized dimensions of the targets based on limiting parameters. The main constraints for optimizing the targets were the capabilities of the UTM at USBR Denver and that the penetrators perforated the target to record residual velocities. The set up and results from the final phase of this testing will be presented, along with a comparison to previous penetration tests of non-damaged high-performance concrete.

SESSION 20: UNDEX

UNDERWATER EXPLOSION RESPONSE OF CANTILEVERED BEAMS AT VARIED SPACING

Rebecca Grisso, NSWC Carderock
Sara Fisher, NSWC Carderock
Matthew Stevens, NSWC Carderock

When exposed to an underwater explosion (UNDEX) loading, structures willcollect loading and respond to the excitation in a combination of forced and free response. In this talk, the predicted response of a single cantilevered beam subjected to an UNDEX load is compared to that of the same beam, subjected to the same UNDEX load, when it is located at various distances to a secondary beam. The effects and response trends from the presence of a secondary beam with varied proximity and boundary conditions are presented.

SHOCK QUALIFIED STOWAGE SOLUTIONS FOR SUBMARINE APPLICATIONS

Teresa Gangi, NUWC Newport
Monica Blanchard, NUWC Newport

Naval Undersea Warfare Center Division, Newport (NUWCDIVNPT) developed shock qualified stowage solutions are used on various classes of United States submarines to safely store electronics, spare parts, and Temporary Alteration (TEMPALT) equipment in the torpedo room. Flat stowage solutions exist for SSN 688 and 21 CLASS submarines. NUWCDIVNPT has also developed a flat stowage solution for the VA CLASS torpedo room, which has recently been shock qualified. Additionally, electronics enclosure racks were developed for stowage of electronics on SSN 688 and VIRGINIA Class submarines. TEMPALT hardware developers leverage these existing solutions to integrate new capabilities onto submarines while maintaining shock qualification. This paper describes available stowage solutions and their shock qualification approaches.

DEVELOPMENT OF A MIL-DTL SUBSIDIARY COMPONENT SHOCK TEST INFORMED BY 6 DOF SIMULATIONS

Lee Yung Chang, NSWC Carderock

This presentation discusses development of a subsidiary (Type B) shock test to meet MIL-DTL-901 specifications. Simulation of potential Medium Weight Deck Simulating Shock Machine (DSSM) environments was conducted using the Shock Isolation Mount Predictions & Loading Estimates (SIMPLE) program, a 6DoF solver. Two potential Type B test arrangements were simulated, with the environments being assessed via comparison to the dynamic characteristics of the principal unit. This effort is presented to the community as a case study for use of simulation software in informing development of a Type B test.

HYBRID-SCALED WHIPPING MODEL TESTS: OVERVIEW

Dr. Ken Nahshon, NSWC Carderock
A. Burr, NSWC Carderock
Matthew Strawbridge, NSWC Carderock
David Umansky, NSWC Carderock

Results from recent Underwater Explosion (UNDEX) tests on two 100’ long hybrid-scaled whipping models will be presented. The tests have been conducted in order to generate high-quality data on both elastic,

inelastic, and combined holing and inelastic whipping effects. The talk will provide an overview of model design, testing arrangements, and test results.

HYBRID-SCALED WHIPPING MODEL TESTS: DATA PROCESSING
David Umansky, NSWC Carderock
Dr. Ken Nahshon, NSWC Carderock

Data processing efforts performed during recent tests on two 100' long hybrid-scaled whipping models will be presented. Topics covered will include comparisons of pre and post-damage 3D laser scans, processing of story pole data measuring displacement during whipping tests, and workflows for fully automatic data processing using UERD Tools and Python.

PANEL: MULTI-DEGREE-OF-FREEDOM VIBRATION TESTING CURRENT CAPABILITIES, HURDLES, & PATH FORWARD FOR WIDESPREAD ADOPTION

MULTI-DEGREE-OF-FREEDOM VIBRATION TESTING CURRENT CAPABILITIES, HURDLES, & PATH FORWARD FOR WIDESPREAD ADOPTION

Panelists:
Matthew Forman, NSWC Dahlgren
Troy Skousen, Sandia National Labs
Dr. Bryan Joyce, NSWC Dahlgren
Dr. Chris Roberts, UK MOD
William Barber, Redstone Test Center
Dr. Pablo Tarazaga, Texas A&M

This panel discussion will brief out current lab technologies used to accomplish multi-degree-of-freedom (MDOF) tests and survey the audience to gather perspective on obstacles which have held up the community from more widespread adoption. Feedback will be incorporated to assist in development of a "MDOF Roadmap" to continue adoption efforts.

TRAINING V: INTRODUCTION TO HEAVYWEIGHT SHOCK TESTING

INTRODUCTION TO HEAVYWEIGHT SHOCK TESTING
Travis Kerr, HI-TEST Laboratories

An understanding of both the history and physics of mass ratio are presented. For the layperson, the ratio requirement was introduced into the shock specifications to keep the tail from wagging the dog. Onboard Navy ships, decks are typically relatively massive compared to the equipment installed so that under shock loadings, the deck drives the equipment.

In the shock qualification test world, the goal is to simulate the physics onboard shipboard installations in order to demonstrate the survivability or shock hardness of shipboard equipment during an underwater explosion (UNDEX) event. There are several parameters that affect whether or not a test setup reasonably simulates the shipboard installation. This presentation discusses the impact of mass ratio on heavyweight shock tests and applicable parameters established in MIL-DTL-901E.

SESSION 21: EXPERIMENTAL METHODS FOR SRS

EXPERIMENTAL DETERMINATION OF RESONANT PLATE MODES UNDER HIGH SHOCK LOADS

Dr. Carl Sisemore, ShockMec Engineering LLC

Resonant plate shock testing is a common technique for simulating pyrotechnic shock events in the laboratory. While the method has been in use for some time, and is generally quite repeatable, the plates can still produce unexpected results when not properly rung. Resonant plate research has focused almost exclusively on modal analysis of the plates. Modal analysis, whether experimental or from finite element modeling, is a powerful tool for studying the possible dynamic characteristics of a system. Modal analysis shows what is possible, but it does not show what will actually happen. The actual response of a physical system can only be determined once loads are applied to the structure. In order to determine which modes of a resonant plate are excited during a shock event, it is necessary to apply a high shock load and examine the modal deformation from that particular load. This paper presents the results of multiple resonant plate shock test experiments using Chladni's method to determine the actual high shock vibration modes of the plate. The experiments also show that it is possible to selectively drive energy into higher plate modes with a judicious choice of high shock impact parameters.

RESPONSE LIMITING & OPTIMIZING SHAKER SHOCKS - ALGORITHMS

Dr. Vit Babuska, Sandia National Laboratories
Jerome Cap, Sandia National Laboratories

Force limiting and response limiting are relatively standard practices to reduce over-test risks in random-vibration laboratory tests. These approaches are used because shakers have nearly infinite impedance, which can lead to over-testing and unrealistic failures when controlling base acceleration. Limiting in shaker shocks is done for the same reasons.

For a response limited test, when a measured acceleration and/or spectral content on the unit under test exceeds a threshold, the control is reduced so that the response does not exceed the threshold (limit). Most shaker controller software has built in capabilities for “on-the-fly” limiting during random-vibration testing because those tests are run closed-loop.

Response optimization is similar to response limiting but the objective is to define an input that minimizes the error between test measured responses and specified environments. This can produce a better overall test when the target random vibration or shock environments are known at response locations.

Shocks are short-duration vibration transients, and shocks performed on shakers are open-loop tests using deterministic waveforms. That is, the test engineer specifies the input acceleration waveform directly. Therefore, response limiting and response optimization must be designed into the control waveform a priori.

Algorithms for generating transient vibration waveforms from specified Shock Response Spectra have existed for decades. Many of the algorithms and tools are derived from the work done by David Smallwood in the previous century. Extensions of the fundamental Smallwood algorithm to the response optimization and limiting cases have been developed at Sandia National Laboratories.

This paper presents shaker shock response limiting and optimization in a unified structure. Numerical and experimental results illustrate the application and effectiveness of the approaches.

Acknowledgments
Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Disclaimer
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RESPONSE LIMITING & OPTIMIZING SHAKER SHOCKS - EXPERIMENTS

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Jerome Cap, Sandia National Laboratories

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SHOCK RESPONSE OF RESONANT BARS FOR COMPONENT TESTING

David Soine, Sandia National Laboratories
Tyler Schoenherr, Sandia National Laboratories
Adam Bouma, Sandia National Laboratories

The resonant bar technique was one of several resonant fixture methods developed in the 1980s to perform controlled mid-field pyroshock simulation testing on aerospace components. The technique utilizes a bar with a longitudinal extension mode designed to respond at some desired natural frequency; a test article is attached to one end of the bar, then the opposite end of the bar is struck with a projectile. Ordinarily, the projectile impact and test article center of mass coincide with the longitudinal axis of the bar, which is also the primary shock response direction. The transverse acceleration experienced by the test article is very low.

In recent resonant bar testing, it was found that the transverse acceleration of the test article increased substantially with a relatively small location change of the projectile impact on the end of the bar. This effect is investigated. The increase in transverse acceleration achieved using this technique has the potential to meet a shock response specification in three response directions simultaneously. With an appropriately designed test specification and resonant bar test using this method, an aerospace component could be qualified to shock levels in three directions with a single shock test.

MULTI-AXIS RESONANT PLATE ANGLED FIXTURE

Trevor Turner, Texas A&M University
Dr. Pablo Tarazaga, Texas A&M University
William Zenk, Honeywell Federal Manufacturing & Technologies
Chase Zion, Honeywell Federal Manufacturing & Technologies
Dr. Washington DeLima, Honeywell Federal Manufacturing & Technologies

Resonant plate shock testing is a well-established technique used to evaluate the structural integrity and reliability of various mechanical systems subjected to dynamic loads. A standard resonant plate test acts in one direction, requiring a separate test for each desired axis of measurement. One multi-axis test would be able to test three axes simultaneously, saving time and money, while also more accurately representing in-field environmental conditions of the system. This study investigates the use of an angled fixture on a resonant plate to create an inclined plane at an angle α. With the z-axis being normal to the angled plane, the x- and y-axes are now on the inclined plane, at an angle β from the orthogonal edges of the plane. By altering α and β, the orientation of the axes and the energy transmitted along them will change in relation to the direction of the shock input. The objective of this research is to analyze the influence of these angles on the resulting shock response spectra while also comparing the results of the three axes to the response along the primary axis of shock input. This presentation will showcase the results obtained from testing the plate and fixture.

SESSION 22: NUMERICAL METHODS

A Comprehensive Digital Twin Solution: Revolutionizing Defense Operations

Kory Soukup, Altair Engineering

Digital twin technology has gained significant attention in recent years as a powerful tool for enhancing maintenance strategies across various industries. Whether it's a fleet of ships, an oil rig, or another large assembly; risk mitigation and lifecycle management are paramount. Using real-time data stream analytics and machine learning, a digital twin can deliver ideal maintenance routines, trigger insights through anomaly detection, and estimate remaining useful life (RUL). This capability delivers significant advantages, which include, increased operational efficiency, reduced downtime, improved asset performance, optimized maintenance schedules, and increased safety.

This presentation explores the key components of a digital twin predictive maintenance system, including data acquisition, model creation, and analytics. It examines the importance of accurate and real-time data from sensors, Internet of Things (IoT) devices, and other sources for creating reliable digital twin models. It will showcase how digital twins can support condition-based and predictive maintenance approaches, enabling organizations to shift from reactive to proactive maintenance practices. The Digital Twin Solution can be integrated across all lifecycle stages, from conceptual design to in-service performance, enhancing efficiency, and enabling robust product development.

Streamlining the Design Cycle with a Mesh-Free Approach to Structural Analysis

Kory Soukup, Altair Engineering

Advancements in defense technology demand sophisticated engineering analysis tools that can rapidly and accurately assess the structural integrity and performance of complex systems. Traditionally, finite element analysis (FEA) has been the go-to method for such evaluations. However, FEA often requires time-consuming and computationally expensive meshing processes that hinder efficiency in critical defense applications.

This presentation aims to introduce SimSolid, a cutting-edge simulation technology that provides efficient and accurate analysis on un-simplified geometry, without the need for meshing. SimSolid's unique approach leverages the power of mathematical techniques, like advanced meshless numerical methods and reduced-order modeling, to streamline the analysis process while maintaining exceptional accuracy. Through practical case studies, it has demonstrated ability to handle complex assemblies, provide accurate results, and expedite design iterations; allowing for more rapid evaluation of multiple design variations than standard FEA methods.

Parameterized Friction Model with Optimized User Constructs

Robert Duong, Sandia National Laboratories
Andrew J. Slezak, Texas Tech University/Sandia National Laboratories.
Chris L. Jawetz, Georgia Institute of Technology/Sandia National Laboratories,

There is a dearth of models which can accurately predict the requisite compression to secure components captured via friction interfaces of varying characteristics. To fill this gap, we created a design advisor to accelerate engineering processes that otherwise require many iterations of designing, building, testing, and modification to ensure component and assembly survivability. This paper presents a model capable of simulating various interfacing materials, geometries, temperature ranges, shock and vibration profiles using Cubit alongside Creo and Sierra SM&SD. This model was validated with physical testing of representative geometries with standard equipment used during iterative design practices.

SEMI-ANALYTICAL METHOD FOR PREDICTING ELASTO-PLASTIC WAVE PROPAGATION IN ONE-DIMENSIONAL PERIODIC MEDIA

Greg Dorgant, Georgia Institute of Technology
Dr. Michael J. Leamy, Georgia Institute of Technology
Dr. Washington DeLima, Kansas City National Security Campus

We present a semi-analytical method with which to study the propagation of elasto-plastic waves in a periodic one-dimensional medium. While plastic wave propagation has received considerable attention over the past 80 years, the phenomena of plastic wave propagation in periodic media has remained largely unexplored. The semi-analytical procedure we present formulates the method of characteristics numerically in a one-dimensional variable cross-sectional area rod. We validate this procedure against time-domain finite element results obtained using a commercial finite element code for a variety of input waveforms and area profiles. Lastly, we examine the propagation of these waves in a medium characterized by a periodic area profile. The presented semi-analytical method may provide the groundwork for future studies on plastic waves, to include elasto-plastic wave propagation in phononic crystals and acoustic metamaterials.

SESSION 23: MODELING, TESTING, AND ANALYSIS OF FUZE TECHNOLOGY FOR EXTREME ENVIRONMENTS

DESIGN OF ADDITIVELY MANUFACTURED INTERPENETRATING LATTICE FOR INTEGRATED SENSING

Richard Clayson, Sandia National Laboratories
Joshua Dye, Sandia National Laboratories
Benjamin White, Sandia National Laboratories

Recent developments in additive manufacturing (AM) have opened the door to new mechanical structures that were previously unattainable. One such structure, the interpenetrating lattice, has the potential to provide both mechanical support and an integrated sensing mechanism. As the lattices deform during shock events due to inertial loading and/or dynamic deformation, the distances between the lattices change accordingly, resulting in a change in capacitance across the structure. A circuit converts these small changes in capacitance to a usable correlated output voltage. While the technology has many applications, this project has focused on incorporating the lattice into the penetrator nose for detecting layers and voids in concrete target sets.

This presentation will cover the mechanical design of the AM lattice penetrator nose including finite element analysis (FEA) and topology optimization. The electrical design will also be discussed including lab-scale mock-capacitor dynamic testing. A lab-scale nose cone has been designed and built for drop-tower testing and a sub-scale penetrator nose cone is being designed for subsequent cannon testing.

M&S EVALUATION OF FUZE PACKAGING STRATEGIES UNDER THERMAL AND MECHANICAL SHOCK ENVIRONMENTS

Jared Hammerton, Applied Research Associates

No abstract available.

EXPERIMENTAL EVALUATION OF ELECTRONIC PACKAGING STRATEGIES
Zachary Jowers, Applied Research Associates

No abstract available.

TESTING HARDENED FORWARD ASSEMBLIES FOR FUNCTIONAL VALIDATION
Dustin Landers, Applied Research Associates

No abstract available.

DISCUSSION GROUP

DISCUSSION ON THE MODELING AND SIMULATION OF BOLTED CONNECTIONS WHEN SUBJECTED TO DYNAMIC LOADING
Moderator: Joshua Yates, NSWC Carderock

Discussion will focus on modeling and simulation of bolted connections under dynamic loading. Bolted connections are integral to US Navy equipment and structures; accordingly it is critical that they are designed and assessed properly. Due to the wide variety of bolted connections, different M&S techniques should be used depending on the specific intended use of the analysis. Selecting the proper approach for representing a bolted connection in a dynamic analysis has a meaningful impact on results; however, there are not generally accepted best practices for what modeling constructs should be used in different applications. The objective of this working group is to understand the different M&S approaches used across the shock and vibration community and to discuss the effect that different M&S techniques have on analysis results.

TRAINING VI: INTRODUCTION TO MULTI SHAKER TESTING

INTRODUCTION TO MULTI SHAKER TESTING
Raman Sridharan, Data Physics/NVT Group

This training will cover the basics of multi exciter testing starting with a simple 2 shaker system and expand to include 6 Degree of Freedom (DOF) testing. The training will feature modeling and mode shape animation to reinforce concepts and offer attendees insight into behavior of test items and placement of control points. This training course will cover topics as outlined in the following agenda.

Vibration Fundamentals with practical examples
- Mechanical Resonance, Modeshapes
- Multi Degree of Freedom vibration
- Multiple-input (multiple forces/shakers) vibration
- Rigid Body DoF versus Modal DoF
- Extension to Multi-DoF Control, shaker orientation

Digital representation of a vibrating system
- Analog vs. Digital
- Signal noise and filtering, and FFT
- Frequency Response Function

- Extension to Vibration Control
- Multi-Degree of Freedom Vibration
- MIMO Frequency Response
- Extension to Vibration Control

Single Shaker Control
- Pretest FRF Measurement
- Pretest Report
- Sine, Random, Shock, Replicator

Multi-Shaker Control
- Bearings
- Multi-shaker Considerations
- Degrees of Freedom
- Rigid Body, Non-Rigid Body, Kinematic Transformation
- Pretest MIMO Frequency Response Identification
- Square Control, Overconstrained, Underconstrained
- Extension from 2-DoF to 6+ DoF
- Multi-Shaker Random: Understanding MDoF Random profiles
- Case Study: TEAM Cube
- Hydraulic actuators
- Common control issues, Low Frequency Pretests
- Equalization Time
- Case Study: TEAM Tensor
- Electrodynamic actuators
- Common control issues
- Modeshape Cancellation

TRAINING VII: BLAST DATA PROCESSING & DATA ANALYSIS

BLAST DATA PROCESSING & DATA ANALYSIS
Denis Rickman, USACE ERDC

I developed this material for the purpose of improving the general understanding of data processing methods with specific application to blast data. I have found that most of our researchers manage pretty well with processing and analyzing well-behaved data records, but as Mike Tyson once said, “Everybody has a plan, until they get punched in the mouth”. My goal is to provide the participants with enough of an understanding of blast data processing that when they do get punched in the mouth by their data, they’re ready to punch back. I may not cover every trick in the book, but hopefully enough that you’ll be able to show that unruly data who’s boss!

TRAINING VII: TYPE I VIBRATION QUALIFICATION IN ACCORDANCE WITH MIL-STD-167-1A, COMMON ERRORS AND BEST PRACTICES

TYPE I VIBRATION QUALIFICATION IN ACCORDANCE WITH MIL-STD-167-1A, COMMON ERRORS AND BEST PRACTICES

Thomas Borawski, NSWC Philadelphia

Training explaining the basic concept of MIL-STD-167-1A Type I Vibration Testing, responsibilities during and path to gaining qualification. Additionally, a review of some common pitfalls during the qualification process, and best practices to avoid those pitfalls.

SESSION 24: SRS ANALYSIS METHODS

SHOCK RESPONSE SPECTRUM ANALYSIS AND DATA VALIDATION TOOL

Seth Siddle-Mitchell, National Technical Systems
Dr. Logan McLeod, National Technical Systems

High amplitude pyrotechnic shock tests create a severe multi-axis acceleration environment that can be difficult to measure and quantify with accuracy. Careful consideration and design of the entire measurement chain, from transducer selection to digitization parameters, is critical to maximize the likelihood of success. However, even a well-designed measurement system can experience anomalies and produce corrupt data in the presence of a severe pyroshock environment. To ensure data integrity during pyroshock testing, NTS has developed a data validation software tool for processing shock data immediately after the shock event. This tool contains numerous tunable data processing parameters as well as validation checks capable of detecting potential corruption of the acceleration data. This software development effort has yielded an increased capability to immediately identify anomalous shock test data, while simultaneously improving the efficiency and functionality in test execution and reporting.

The NTS shock data analysis tool features an easy-to-use GUI where the user can tune numerous features specific to shock processing, such custom digital filters for the acceleration profiles, SRS calculation damping coefficient, fractional octave number, frequency range, pre-shock evaluation, variance from tolerance thresholds and nominal values, and more. For each shock event measured, the software employs a series of robust validation checks analyzing the measured transient shock event in the time domain and the corresponding SRS in the frequency domain. The software validates the measured shock event data, providing the test engineer with immediate feedback on pre-shock and post-shock test durations, noise floor levels, shock duration and concentration of energy within the duration, offset removed data, acceleration, and velocity profiles. The SRS is verified in the time and frequency domain with warnings presented if the test equipment settings are insufficient or limiting relative to the test profile or showing signs of corruption.

Capable of applying low, high, or band-pass filters at desired cutoff frequencies, the calculated SRS is analyzed while considering desired tolerance levels and generating a performance statistics report. The program provides a graphical presentation of a transient acceleration, integrated velocity, Maximax SRS and positive and negative SRS in a summary report format, along with any relevant test information useful for the test engineer to validate and generate reports. Each of the verifications provide distinct insight, such that several industry standard concerns can be addressed in real-time at the test facility. The evaluation of the SRS figures and validation checks immediately after a test provides useful information for the test engineer to consider as the next test is configured. As an NTS developed tool, additional features are continuously added, and test engineer requests can be accommodated with updated considerations.

THE RESPONSE OF WELDED STEEL PLATES WITH RESIDUAL STRESS TO CLOSE-PROXIMITY UNDEX LOADING

Dr. Rasmus Wedberg, Swedish Defence Research Agency FOI
Niklas Alin, Swedish Defence Research Agency FOI

Axisymmetric close-proximity UNDEX experiments has been performed on several test objects, each consisting of an air-backed S355J2 construction steel plate welded to a cylinder of the same material. In each experiment, the object is dynamically loaded by a PETN charge detonated vertically above the plate along the axis of symmetry. The response of the plate is measured over time by laser distance meters and strain gauges. This paper reports on a selection of experiments using a plate thickness of 6, 10 and 15 mm and a charge size of approximately 5 g resulting in responses in the elastic to mildly plastic regime. Numerical simulations are carried out using LS-Dyna with a penalty coupling between the Lagrangian and the Eulerian description of water, air and explosive gas products. A simple approach is proposed to account for the initial deformation due to residual stresses from welding and hydrostatic pressure. The predicted plate responses agree very well with the experiments during shock loading and the first gas bubble collapse, due to this approach.

JASSO: A FURTHER YEAR OF TESTING AND DEVELOPMENT

Gavin Colliar, Thornton Tomasetti
Phillip Thompson, Thornton Tomasetti
Nick Misselbrook, Thornton Tomasetti
Brian Ferguson, Thornton Tomasetti
Alex Whatley, Thornton Tomasetti

Warships are designed to be robust against underwater explosions, and in order to demonstrate that a warship has met the required standard of shock capability, a number of shock qualifications on equipment and systems are normally undertaken. The shock qualification tests undertaken cover range from individual equipment's and systems to tests covering the entire vessel. Shock machines are used to carry out some of these tests where the equipment size and desired levels are suitable or if it is not cost effective to carry out explosive or airgun shock barge testing.
In addition, all naval ordnance is required to withstand levels of shock to ensure safety and safety and serviceability when embarked on ships. This may also be extended to other weapons as there is a strong possibility that they may be sea transported at some point during their life where there may be a risk from UNDEX shock.

The JASSO machine was developed by Thornton Tomasetti Defence to address some of these limitations with the aim of developing a machine that could serve as general UNDEX shock machine but which also could be deployed to test ordnance of a variety of sizes and weights with a meaningful shock pulse.
This paper and provides an overview of the developments and activities associated the JASSO Shock test machine particularly covering the following:
O An recap and overview of the design principals and how it works
O A review of the wide range of testing environments the JASSO test machine can be utalised for.
O A look into how JASSO shock testing can be applied in addressing Multi Axis shock specifications.

EXPERIMENT AND NUMERICAL SIMULATION STUDY ON THE NEAR-FIELD UNDERWATER EXPLOSION OF ALUMINIZED EXPLOSIVE

Dr. Yuanxiang Sun, Beijing Institute of Technology

As a kind of high-performance non-ideal explosive, the non-ideal component of aluminized explosive applied to underwater explosion can improve the ratio of shock wave energy and bubble energy in total energy, it is widely used to the charge of underwater weapon warhead. It can enhance the brisance and damage ability of underwater weapons significantly.

In this study, the near-field underwater explosion experiments of aluminized explosive RL_F (RDX/Al/binder:70/20/10) and TNT were carried out using PVDF pressure sensor based on electrical measurement method, and the Coupled Eulerian-Lagrangian (CEL) method was used for numerical simulation. The numerical results agreed well with experiment. The analysis show that CEL method can be used to simulate the propagation process of near-field underwater explosion shock wave of TNT and aluminized explosive accurately if reasonable boundary conditions, calculation parameters and finite element model are adopted.

The following conclusions can be drawn through experiments and numerical simulations:

(1) Based on the electrical measurement method, the peak pressure of near-field underwater explosion shock wave of aluminized explosive RL-F and TNT was measured by PVDF pressure sensor. The experiment overcomes the shortcomings of traditional pressure sensors in measuring near-field shock wave pressure, and the difficult problem of positioning devices is solved. The measured near-field shock wave pressure of underwater explosion has high accuracy.

(2) The comparison between numerical simulation results, experimental results and empirical values shows that CEL method can simulate not only simple explosive such as TNT accurately, but also the propagation process of near-field underwater explosion shock wave of aluminized explosive well by using calculation parameters such as outflow non-reflection boundary condition, suitable state equation, appropriate grid density and reasonable finite element model. And the results show that the near-field underwater shock wave pressure attenuation of aluminized explosive is slower than that of TNT.

(3) On the basis of verifying the validity of numerical model and taking the peak pressure calculated by CEL method as a reference, the empirical formula of aluminized explosive RL-F underwater explosion peak pressure in the range (R is explosion distance, a is explosive radius) is obtained by fitting the simulation results. This empirical formula is very valuable for predicting peak pressure of underwater explosion shock wave of aluminized explosive.

SESSION 25: SPACECRAFT SHOCK TESTING

IT IS ESSENTIAL TO PERFORM SPACECRAFT LEVEL SHOCK TESTING

Monty Kennedy, MK Engineering
Dr. Jason Blough, MTU professor

It is well known in the aerospace industry that performing shock analysis and testing on spacecraft is very difficult to do and the main reason why it is so far behind other types of vibration analysis and testing like sine and random vibration analysis and testing. As such, there is significantly more uncertainty associated with shock analysis predictions and creating accurate shock levels for shock testing than that associated with other vibration loads.

Analysis and ground vibration testing is routine, like sine and random vibration testing on small and medium size spacecraft (300-2,000 lbs) and is typically done to protoqual vibration levels to verify spacecraft structural integrity and that electronic systems can survive launch loads. However, shock testing is not routine, and there is no evidence that any spacecraft level shock testing is being performed on small and medium sized spacecraft. The aerospace industry is very good at accurately predicting peak responses for all the loads using detailed FE (finite-element) models of these spacecraft, except for pyroshock loads because of the complex nature of such loads and the many difficulties associated with shock analysis.

Contrast these sine and random vibration loads and associated controlled protoqual vibration ground tests to complex pyroshock loads, analysis, and testing. The difference is dramatic and is the reason for so much uncertainty involved in shock analysis and testing. A spacecraft is exposed to various pyroshock events during launch: lift-off, 1st stage separation, fairing separation, other spacecraft separation, and spacecraft separation. Pyroshock loads are created from a contained point or line charge explosion that fractures a mechanical interface to separate systems. Pyroshock loads create a very sudden damped oscillating sine transient that decays in about 20 msec, resulting in peak acceleration as high as 1,000-2,000 g about 12-15 inches from a shock source which has a very wide spectral content, from 100 Hz to 10 kHz. It is unlike any other load, it is a complex load, the actual acceleration shock transient is typically not available or specified in a loads document, rather it has to be created (synthesized) from the shock load, the SRS (shock response spectrum), that is specified in a loads document. Many different synthesized shock transients can be created that have different peak values, shape, decay rate, and duration but can all satisfy the SRS, contributing significantly to loads uncertainty compared to sine and random vibration loads, which are exact loads that can be used in analysis and controlled to in testing.

The benefits of performing shock testing at the spacecraft level are significant and include demonstrating design margins. Additionally, feedback from such shock tests can be used to improve and significantly reduce the uncertainty associated with shock analysis, just like the feedback that is common from sine and random vibration testing. Also, a shock testing data base can be created, just like the data base created from sine and random vibration testing, which can help with future spacecraft development.

NASA SPACECRAFT MOCKUP USED TO PERFORM SPACECRAFT LEVEL SHOCK TESTING

Monty Kennedy, MK Engineering
Dr. Jason Blough, MTU professor

NASA-STD-7003A, Pyroshock Test Criteria (2011) states: “Successful pyroshock testing shall be considered essential to mission success.” It is typical to perform pyrotechnic testing at the spacecraft level for large spacecraft that are still separated from the launch vehicle by pyrotechnic charge.

It is not appropriate to do pyrotechnic testing of small and medium size spacecraft (~300-2,000 lbs) since these spacecraft are mostly separated by separation rings and not pyrotechnic charges. Based upon shock research performed over the last 2 ½ years there appears to be no evidence that small/medium size spacecraft shock testing at the spacecraft level is being done. It such shock testing is being done the methodology and the results of such testing are not being shared in the aerospace industry. Part of the reason for doing no such shock testing is because there is no easy, acceptable, standardized method to perform this testing as there is for sine and random vibration testing on a shaker. Due to the complex nature of shock load shock testing cannot be performed on a shaker (acceleration levels too high, frequency levels too high).

NASA has developed a spacecraft (or satellite) mockup called ShockSat to perform shock testing on. NASA presented initial results of their shock testing and analysis in 2022. It is a public domain program, as such, as part of shock research being conducted at MTU (Michigan Tech University), shock testing was performed at UTU (Utah Tech University) over the 2022-2023 academic school year.

An overview of ShockSat and the results of shock testing at UTU are presented. The results of the UTU ShockSat testing are significant and should lead to significant improvements in performing shock analysis and testing, which is severely needed in the aerospace industry:

1. Tap testing using a small calibrated hammer into a circular shock resonant plate bolted to the base of a spacecraft works really well. Tap testing is typically associated with modal testing, however modal testing of a spacecraft for shock loads would be too difficult, too costly, and too time consuming so the recommendation is to use tap testing to perform frequency response function (FRF) correlation between tap testing and FE model shock predictions to reduce the significantly higher uncertainties associated with shock analysis (vs sine and random vibration analysis).
2. Two different prototype mechanical shock adaptive devices were developed and used to qualify ShockSat to typical protoqual shock levels over a frequency band from 100 – 10,000 Hz. These devices work really well, are easy to setup and use, and create repeatable results. So now shock testing for these size spacecraft can be readily performed in several hours (setup to test completion) and become as routine as sine and random vibration testing.

NASA SHOCKSAT UTU SHOCK TEST RESULTS AND RECOMMENDATIONS TO IMPROVE SHOCK ANALYSIS AND TESTING

Monty Kennedy, MK Engineering
Dr. Jason Blough, MTU professor

Additional ShockSat results from shock testing at UTU are presented. Test results show clearly there are much higher errors associated with shock analysis predictions compared to sine and vibration analysis predictions. Shock test results and FE shock analysis predictions indicate:

1. The standard practice of creating shock zones to define shock levels for spacecraft subsystems will most likely create severe over testing for some subsystems. If spacecraft level shock testing and tap testing into a shock resonant plate at the spacecraft base to perform FRF (frequency response function) correlation of a spacecraft become common and routine there it will be possible to eliminate using shock zones, rather it will be possible to determine the correct shock zones for each subsystem vulnerable to shock failures.
2. Empirically derived shock attenuation rules, mostly established in the 1970's should not be used because of the significant errors associated with applying these general shock attenuation rules. Rather, through common and routine spacecraft level shock testing and FRF correlation tap testing it will be possible to determine how shock loads propagate, reflect, amplify, and attenuate with distance from the shock source and across mechanical joints into bulkheads, panels, and other structure for these unique complex spacecraft designs.

Two other main issues that need to be improved in the aerospace industry to reduce the significant amount of uncertainty associated with shock analysis and testing are:

1. The need for clear guidelines for performing shock analysis and testing because shock analysis is glossed over in typical vibration and structural dynamics college classes. Additional knowledge is

required for shock testing, much more so than that required for sine and random vibration testing, the two most common and routine vibration analysis and testing performed in the aerospace industry.

2. The need for clearer shock loads, shock analysis, and shock testing direction and information from the customer procuring the spacecraft and the launch vehicle provider that launches the spacecraft into space. Both the customer and the launch vehicle provider treat shock loads, shock analysis, and shock testing the same as sine and random vibration loads, analysis, and testing. It is not the same and additional, clearer direction and information is needed.

SHOCK TEST AND ANALYSIS LESSONS LEARNED PART 1

Alexander Hardt, Northrop Grumman Space Systems

Ongoing efforts by Northrop Grumman Space Systems have evaluated the Shock Response Spectrum (SRS) for its ability to estimate damage potential and piece part failure. The data has repeatedly demonstrated that the SRS by itself does not correlate with damage potential, is not a good predictor for failure, and results in strain differences for the same SRS of more than an order of magnitude. This presentation will outline simple FEA modeling that can be used to help understand these test results as well as accelerometer dynamics to help with shock test design, setup and execution.

SHOCK TEST AND ANALYSIS LESSONS LEARNED PART 2

Alexander Hardt, Northrop Grumman Space Systems

Ongoing efforts by Northrop Grumman Space Systems have evaluated the Shock Response Spectrum (SRS) for its ability to estimate damage potential and piece part failure. The data has repeatedly demonstrated that the SRS by itself does not correlate with damage potential, is not a good predictor for failure, and results in strain differences for the same SRS of more than an order of magnitude. This presentation will outline test comparisons of input shock SRS, test & fixture mounting effects on shock damage and also outline basic test accelerometer data validation with laser vibrometer comparisons.

SESSION 26: STRUCTURAL RESPONSE & MATERIALS

SOIL RESPONSE TO IMPACT LOADS

Mina Habashy, US Army DEVCOM Armaments Center
Dr. Mike Macri-US.Army-DEVCOM Armaments Center

Researching a numerical technique for analyzing soil response due to impact loading will give engineers the ability to assess soil response and enable design engineers to improve recoil systems for wide array of weapon systems. Modeling soil material poses a significant computational challenge, requiring the capability to implement the material response accurately and efficiently optimizing the computational cost. This requires the need to account for the volumetric and deviatoric stress components of the material response. This study presents an approach to better understand soil response and to calibrate soil parameters in general, focusing on Young’s modulus. Random Finite Element Method approach, RFEM, is used to reach an effective Young’s modulus for the soil. Test data from different soil types has been incorporated to guide finite element development. This presentation will review incorporating RFEM for hyperplastic material properties into the Finite Element Analysis, FEA, framework and compare results with historical data and existing static hyperplastic material properties.

SEISMIC TESTING OF A CROSS-LAMINATED TIMBER SHELTER CONSTRUCTED WITH THERMALLY MODIFIED COASTAL WESTERN HEMLOCK AND CARBON FIBER JOINTS

James Wilcoski, USACE ERDC
Peter Stynoski, USACE ERDC,
Mark O'Brien, Composites Recycling Technology Center
Erik Poulin, Composites Recycling Technology Center

The Composites Recycling Technology Center (CRTC) developed a concept for mass timber building design using cross-laminated timber (CLT) with thermally modified coastal western hemlock. CRTC fabricated a small shelter that can be easily assembled by two people. The structure is flat packable, designed for multiple rapid assemblies and disassembly, which is particularly attractive for Department of Defense applications. It uses several connection systems including thru bolted steel brackets, tongue and groove panel joints, internally routed tensioning cables, and carbon fiber composite splice plates. This shelter was tested with seismic motions on the U.S. Army Engineering Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), Triaxial Earthquake and Shock Simulator (TESS). Supplemental weights were added to the roof of the structure, so that it could be tested at levels that would cause several modes of failure, representative of the failure mechanisms of a larger structure built from these materials. Despite the temporary nature of the structure, and non-traditional use of CLT panels made with brittle materials, the structure responded well to seismic testing, exhibiting ductile failure modes, reasonable overstrength and energy dissipation, which are all important to good seismic performance.

The design concept will be presented and seismic performance of this small structure. The modular design used in this small structure can be expanded and the same construction technology applied to larger scale modular buildings, with similar controlling modes of failure expected. The results of this testing can be used to develop well-proportioned large-scale buildings, using the same modular panel system.

SESSION 27: UPDATES TO BLASTX

IMPROVEMENTS TO ALUMINIZED EXPLOSIVE MODELS IN BLASTX

Gustavo Emmanuelli, USACE ERDC

BlastX is a reduced-order code for airblast prediction that calculates the shock propagation and detonation product expansion in user-defined structures. The code contains an extensive library of explosive models generated from first-principles calculations and validated against experimental data. These models include information on the chemical composition of the explosive, which is used to characterize the detonation product gases and their expansion over time. For aluminized explosives, aluminum is one of the chemical species included and its reaction with oxygen is prioritized over other chemical reactions when evaluating energy release. Traditionally, BlastX allowed all the available aluminum moles to react in the combustion model, granted there was oxygen present. A recent modification calibrated the amount of embedded aluminum permitted to burn and contribute to the gas phase pressure based on limited experimental data. A new methodology bounds the aluminum participation as a function of target characteristics, specifically, the loading density and available venting. This paper describes the approach taken to address the aluminum combustion in different versions of BlastX and demonstrates sample hydrocode calculations intended to track and quantify the amount of aluminum burned following the detonation of an aluminized explosive.

IMPLEMENTATION OF THE ERDC CASED MUNITION MODEL (ECMM) INTO BLASTX

Krystal Rodriguez-Soto, USACE ERDC
Dr. Gregory C. Bessette, USACE ERDC

BlastX is a fast-running model designed to predict the airblast environment associated with both external and internal detonations. The extensive run times of the legacy cylindrical model made it necessary to develop and implement a faster model into BlastX. The new model will be known henceforth as the ERDC Cased Munition Model (ECMM). The ECMM emulates the blast field of a bare or cased cylindrical charge by modifying the base data from a one-dimensional spherical tabular source model to account for the differences in shape and casing conditions. A first principles code was used to produce the virtual data that fed the model for all relevant scaled ranges. Different combinations of length-to-diameter ratios and metal-to-charge ratios were analyzed to explore their effects on the blast field. This paper outlines the development and implementation of the ECMM into BlastX and presents comparisons to experimental data for a range of standoffs from a fixed structure.

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MODELING TIME-DEPENDENT BREACH IN BLASTX

Zoran Nadzakovic, USACE ERDC
Dr. Gregory C. Bessette, USACE ERDC

BlastX is an engineering-level fast-running code designed to predict the airblast environment associated with explosive detonations in complex multi-room structures. The propagation of the blast effects through a structure in BlastX has traditionally relied upon structural openings, such as doors and windows, to serve as pathways for blast propagation. Updates in BlastX are underway to support modeling breach and subsequent blast propagation through the newly failed structural elements. The new time-dependent breach (TDB) model will specifically evaluate failure resulting from the combined blast and fragment loading generated by cased munitions. The TDB model identifies breach size and growth versus time at varying standoff distances for different types of target materials. The initial implementation of the TDB model supports steel targets of varying thicknesses and spans. The first principles code Sierra/SM was used to generate the TDB model data. The Fragmentation and Blast Effects Library (FABEL) suite of codes automates the blast loading, fragmentation, and running of Sierra/SM to speed up data generation. This paper outlines the development of the TDB model for steel plates, its implementation, and comparisons against experimental data.

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VALIDATION OF THE BLASTX CODE FOR CASED AND UNCASED ALUMINIZED EXPLOSIVES

DeBorah Luckett, USACE ERDC
Gustavo Emmanuelli, USACE ERDC
Roosevelt Davis, Air Force Research Laboratory

The Engineer Research and Development Center (ERDC) has traditionally been responsible for the development and maintenance of BlastX. This fast-running model continues to aid with predicting airblast environments associated with both external and internal detonations. In this study, a closer examination of the accuracy of data generated in BlastX is conducted and compared to experimental data utilizing a

Windows-based regression test suite (RTS). The Air Force Research Laboratory (AFRL) provided the experimental data used for this analysis, which are from a series of tests involving both cased and bare aluminized explosive charges performed at its blast pad facility. The analysis discussed in this paper seeks to validate the effectiveness of the BlastX software using empirically based case-reduction formulas, such as Modified Fano, as well as to gain insight into the effects of cased and uncased explosives on the blast field.

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TRAINING VIII: INTRODUCTION TO UERDTOOLS

INTRODUCTION TO UERDTOOLS

Brian Lang, NSWC Carderock

The UERDTools program is a collection of data processing and analysis routines integrated into a single package to provide a comprehensive tool for on-site data analysis. The real-time analysis of acquired test data necessitates a convenient, easy to use package for data processing, plotting, and manipulation routines to support rapid assessment and interpretation of measured test results. This suite of data analysis routines is designed to help standardize the way Navy shock programs analyze and process data. It also facilitates ease of generation of comparison plots of both measured and computed results in support of analytical correlations studies. This training summarizes the UERDTools suite of programs, illustrates its basic features (including curve comparisons), and describes the built in user-defined macro capability. Details of the development, architecture, and resident analysis modules are outlined.

TRAINING IX: INTRODUCTION TO MEDIUM WEIGHT SHOCK TESTING

INTRODUCTION TO MEDIUM WEIGHT SHOCK TESTING

Jeff Morris, HI-TEST Laboratories

This training will cover the necessary background information relative to medium weight shock testing. This session is intended for engineers and product developers who are unfamiliar with the medium weight shock testing process. Subjects covered include pre-test planning, fixture selection, test set-up, test operations, and reporting. Some aspects of medium weight shock machine operation will be covered. Shock test requirements applicable to medium weight shock testing will be discussed.