ABSTRACTS

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88TH SHOCK AND VIBRATION EXCHANGE
ABSTRACT BOOK
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SUBMARINE COMPONENT DESIGN TOOL TO ASSESS RELATIVE RESISTANCE TO SHOCK LOADING

Mr. Justin Caruana, Cardinal Engineering
Mr. Connor Way, Cardinal Engineering
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Dr. Abilash Nair, Thornton Thomasetti
Dr. Heather Reed, Thornton Thomasetti

In this presentation, Cardinal Engineering, with team member Thornton Thomasetti, showcases their solution in response to a Navy SBIR which sought an innovative, cost and time efficient design tool that can evaluate new Navy Submarine equipment designs for shock survivability to mitigate non-recurring engineering (NRE) hours. This new, automated software tool termed Comparative Design Assessment Tool (CDAT) will allow users to determine if a newly designed and non-tested component required to satisfy MIL-S-901D IC#2 is as resistant to high intensity shock loading as a previously designed and MIL-S-901 qualified component through a strength and environment comparison. When fully developed, CDAT will provide assurance to the component designer that the low-cost shock qualification by extension process is achievable, and also highlight weaknesses of the component so the user can iterate their design. In cases where testing must be done, CDAT will also provide a feature that allows the determination of the appropriate shock test will also identify design changes that could lead to cheaper testing methods.

INFLUENCE AND ENHANCEMENT OF THE DAMPING OF WIRE ROPE ISOLATORS FOR NAVAL APPLICATIONS

Mr. Claude Prost, Vibro/Dynamics SOCITEC
Mr. Bruno Abdelnour, Vibro/Dynamics SOCITEC

Wire rope isolators (WRI) are widely known and used in naval applications, typically for shock and vibration protection of a variety of shipboard equipment such as cabinets, console, missile launchers, and electronic boxes.

All such equipment must be approved prior to shipboard installation, meaning it has to pass the corresponding tests of MIL-STD-167 and MIL-S-901D. In many cases, shock is the most demanding criterion. The equipment must be tested on one of the various shock testing machines as defined in MIL-S-901: the LWSM, MWSM, FSP, and the new DSSM. It is critical that isolation systems utilized to support naval equipment have sufficient levels of damping in order to pass these validation tests.

It has often been mentioned that elastomeric isolators such as Socitec's VBF45 series and other designs perform better dynamically than WRI by virtue of exhibiting more linearity, particularly in the tension phase. This is partially true for standard WRI, but there are methods to minimize this effect, such as changing the WRI aspect ratio in order to move away from the displacement asymptote, or to increase the damping properties of the WRI, which has been recently pioneered by Socitec. All-metal WRI's are preferred over elastomeric designs because of their longer life and better resistance to heat, ozone, and chemicals. The objective is to reduce the shock transmitted to less than 10 g's, which is the current requirement for COTS equipment.

More linear WRI's are ideally suited to naval applications. This presentation will include numerical simulations of the various shock testing machines using the special high damped linear WRI's.

MANAGING EXCURSIONS FOR A LIGHTWEIGHT PAYLOAD SUBJECTED TO MIL-S-901D

Mr. Neil Donovan, Shock Tech
Mr. Gary Melone, Shock Tech

MIL-S-901D is broadly applied to many different types of systems. Over the years the modelling and performance predictions for large systems has become well understood. Smaller and lighter weight payloads remain difficult.

There are many techniques employed to meet the specification while controlling transmitted accelerations in a limited excursion envelope. The paper will discuss techniques such as non-linear spring response, mount orientations, and system stiffness and damping tuning.

This paper presents data from recent shock and vibration tests. Measured results show well-controlled levels of peak acceleration and relative displacement. Comparison of test results with pre-test calculations is given. Simulation models are described.

NONLINEAR SINGLE DEGREE-OF-FREEDOM (SDOF) FLUIDIC SHOCK ISOLATOR MODEL

Dr. J. Edward Alexander, BAE Systems

A general nonlinear SDOF shock isolator model was developed to predict the response of an isolated mass subjected to a transient base acceleration input. This model can be used for a shock isolator that has either linear or nonlinear characteristics. Nonlinear shock isolator parameters include a bi-stiffness spring in parallel with an exponential fluidic damper. The transient model uses a predictor-corrector approach to address nonlinearities and achieve equilibrium within each time step.

An incremental predictor time stepping method is used for the relative displacement, velocity and acceleration of the mass, marching forward in time. z(n) is the relative displacement between the mass and the base at time t(n) , where t(n) = nΔt. The incremental relative displacement, velocity and acceleration are given by,

$\Delta z = z(n+1) - z(n)$
$\Delta zd = zd(n+1) - zd(n)$
$\Delta zdd = zdd(n+1) - zdd(n)$

The Newton-Raphson corrector procedure was used within each time step to assure equilibrium, by reducing the residual force below a prescribed tolerance, where the residual force is given by:

Residual force = inertial force + damping force + spring force

This procedure was validated with test data from the response of a liquid spring shock isolator subjected to a known base acceleration. A matlab function has been developed to execute this procedure.

SHOCK FAILURE ANALYSIS AND ISOLATION OF ELECTRONIC COMPONENTS USED ON ANTENNA STRUCTURES IN MILITARY APPLICATIONS

Mr. Mehmet Emre Demir, Aselsan A.S.
Dr. Mehmet Caliskan, Middle East Technical University

Antenna structures constitute vital parts of electronic warfare systems. Electro-mechanical design considerations are as crucial as electromagnetic design of antenna structures for proper functioning and

meeting high system performance demands. Failure of electronic components operating under shock loading is a common occurrence in military electronic warfare applications, while shock and vibration produces dynamic stresses which can be the main cause of electronical component failure because of the fatigue. Shock analysis of an dipole antenna subjected to various shock disturbances that must withstand during military applications is performed in this study to understand and estimate adverse effects of mechanical shock phenomena on the structure in order to achieve successful electromechanical design process. These adverse effects are mainly caused by the bending stress experienced by means of solder joints and lead wire. In order to foresee these adverse effects beforehand following study is performed.

Previously validated multi-degree-of-freedom theoretical model based on RFR Method is used to calculate transient responses of antenna structure. Input shock loading are pre-defined military requirements or/and synthesized from assessed shock specification to classical shock input. Making use of the theoretical model results, shock severity limits of antenna structures are calculated. Yield stress-derived pseudo velocity limits for mechanical structures, and relative displacement shock severity limit for electronic components are used based on Steinberg's Theory. The pseudo velocity limit and the relative displacement limit are also found from constructed theoretical model. These found limits are used to determine whether component qualification shock testing is necessary for a given shock input or not. In other words, it is checked that how safe electromechanical design is to withstand shock disturbances. In order to satisfy and validate shock severity theoretical limits for critical parts, qualification tests are also performed. After experimental verification of the model by these qualification and fatigue experiments, for the components that are tend to fail from test shock and vibration isolation procedure is performed. For isolation process mathematical model and finite element model are used to select suitable isolator properly by means of the decrease in displacement(or velocity) responses for proper functioning. Thus, complete shock analysis of electronic components are performed and possible failures of these components are prevented by means of proposed isolation procedure.

INSTRUMENTATION

DYNAMIC CALIBRATION OF PRESSURE TRANSDUCERS

Mr. Thomas Platte, SPEKTRA
Mr. Martin Iwanczik, SPEKTRA
Mr. Michael Mende, SPEKTRA

Measuring pressure is an essential task in almost every fluidic application. Therefore statically calibrated pressure sensors are available with very high accuracy. To calibrate these sensors, traceable, primary calibration methods, like the well-known dead-weigh calibration apparatus, are used. However, pressure sensors are mostly used to measure dynamic pressures and as every sensor they have a frequency response. Thus the dynamic response of the sensor S(f) must be taken into account.

Little work has been done yet to investigate the dynamics of pressure sensors and therefore no traceable dynamic calibration method exists. Thus one of the authors designed a dynamic pressure calibrator based on a vibrating piston that allows to excite a fluid medium in a frequency range up to 12 kHz. The design of the exciter allows on the one hand comparison calibration of a device under test (DUT) against a (statically) calibrated reference pressure transducer. The frequency response of this reference transducer is assumed to be flat. On the other hand the exciter allows to measure the

dynamic volume change of the pressure chamber and thus to get a measure for the dynamic pressure change. Since the dynamics of the piston can be measured with traceable calibrated devices, this method should offer a certain traceability of the pressure calibration as well.

The paper will show first measurement results with this pressure exciter and will discuss the questions that these results rise. Furthermore, an outlook regarding another more primary method by means of laser refraction vibrometry will be given that can also be employed with this pressure exciter.

TESTING OF THE ENDEVCO 7274 AND 7284 TRIAXIAL HIGH-G SHOCK ACCELEROMETERS TO THE MIL-STD-810G, CN1 CROSS-AXIS REQUIREMENTS

Mr. James Nelson, Meggitt Sensing Systems
Dr. Vesta Bateman, Mechanical Shock Consulting

At the 87th Shock and Vibration Symposium, cross-axis evaluations of the Endevco 7270A and 7280A High-g shock accelerometers were presented. This paper continues these cross-axis evaluations with evaluations for these same accelerometers but in triaxial mechanical packages intended for use in shock (method 516) and pyroshock (method 517) testing MIL-STD-810G, CN 1. The new results will be compared with previous cross-axis evaluations of three Endevco 7270A mechanical packages mounted to a 0.625 in. cube. Both in-axis and cross-axis laser Doppler vibrometer measurements will be used in these evaluations.

INNOVATION IN ULTRA MINIATURE PIEZOELECTRIC ACCELEROMETER DESIGN

Mr. David Change, Dytran Instruments

Across industries, there is a pressing need for high quality miniature and ultra miniature triaxial accelerometers for use in testing environments which has been historically unmet by the sensor community. This is particularly true within aerospace which requires low out gassing accelerometers with small dimensions and low mass for a multitude of applications, as well as shock and vibration testing. Dytran designed its 3133D ultra miniature accelerometer series with these needs in mind. When designing a piezoelectric dynamic sensor of small dimensions, the design team focused on utilizing a piezoelectric material with higher sensitivity than industry norms, reducing the dimensions of the envelope, and limiting the seismic mass. The 3133D's quartz single crystal sensing element is composed from a non-aging material perfect for space and other applications. With many sensors on the market, temperature variants can affect units making recalibration impossible. Typical piezoceramic's low Q factor exacerbate amplitude slope versus frequency, pyroelectric response and thermal transient response. The quartz single crystal within the 3133D series possess a high Q factor whose design eliminates the need for temperature related recalibration. Piezoceramic materials are the natural design choice for manufacturing ultra miniature accelerometers as they have high piezoelectric sensitivity response (PZT Lead Zirconate Titanate ceramics and others being good examples). This paper explores the design process….(more needed to complete this sentence) which resulted in the versatile 3133D's single quartz, ultra miniature, low base strain sensitive, low outgassing design.

CHARACTERIZATION OF DEBRIS FIELDS USING DRONE PHOTOGRAMMETRY

Dr. Wije Wathugala, ACTA Inc.
Mr. Jacob Maarek, ACTA Inc.
Mr. Timothy Wang, ACTA Inc.

Rapid and economical methods to characterize debris fields are necessary after accidents, natural disasters, and explosions. The gold standard for characterizing debris fields after explosions has been to individually survey each and every debris using traditional surveying methods and/or survey grade GPS devices. Since this involves substantial amount of manual labor, time and money, many investigators only collect debris information from selected sectors of the debris field. Due to accessibility and time constraints, many debris fields are not characterized. The drone based photogrammetry methods developed here overcome all these issues and provide rapid, economical ways to characterize debris fields even in difficult terrains.

In this paper, we present results of novel techniques developed to obtain debris field information rapidly using drone based photogrammetry. Unlike accidents, we can characterize the background scene before the event for experiments. For experiments, we developed special methods where we can subtract the back-ground scene before the event from the scene with debris after the event to facilitate automated debris characterization capabilities.

BLAST

BLAST EFFECTS WITHIN EMBANKMENTS

Ms. Alyson Armstrong, USACE - Engineer Research and Development Center
Mr. Denis D. Rickman, USACE - Engineer Research and Development Center
Dr. Ramon J. Moral, USACE - Engineer Research and Development Center

The potential magnitude of consequences resulting from the breach of an earthen embankment has led to investigations of the effects of explosive attacks. Research is underway to evaluate several attack methods and determine the potential damage that might be produced. The U.S. Army Engineer Research and Development Center (ERDC) has begun a research program looking specifically at explosive detonations inside embankment structures through intrusions, such as observation wells. The damage occurring in this scenario is largely dependent on the geometry and location of the intrusion. As part of this effort, a series of numerical simulations and validation experiments are underway to investigate combinations of intrusion parameters and determine how these affect the resulting damage. The non-dimensional treatment of results and the application to a wide range of embankments and intrusions will be discussed.

EXPERIMENTS TO STUDY SECONDARY DEBRIS FROM BURIED EXPLOSIONS UNDER BRICK PATIOS

Dr. Wije Wathugala, ACTA Inc.
Dr. George Lloyd, ACTA Inc.

Most of the experimental data on buried explosions at shallow depths are derived from weapon penetration, fuzing effectiveness, and ground shock evaluation tests that are conducted on bare soil. As a result, very little information regarding the properties of the secondary debris ejected from the crater are collected or unavailable. These data are important for evaluating hazardous debris densities and containment distances in order to minimize collateral damage. As part of a program to systematically

collect such data, with the goal in mind to develop numerical methods that can eventually predict this complex phenomenon under different conditions, a series of experiments were planned with various levels of cased explosives buried at different depths under brick/concrete patios. In this paper, we present some of our observations from the experiments performed so far.

PREDICTING SECONDARY DEBRIS FROM BURIED EXPLOSIONS UNDER BRICK PATIOS USING NUMERICAL SIMULATIONS
Dr. Wije Wathugala, ACTA Inc.
Dr. Wenshui Gan, ACTA Inc.

Understanding how to model explosions in soil is important in many military and civilian applications such as in predicting the consequences of mines/IEDs/munitions buried in soil and excavations using explosives in the mining industry. In general, rapidly expanding explosion products (gases) push surrounding medium away from the explosion, causing the breakup of the medium and creating cracks through which gases can escape. Explosions in soil involve additional complexities due to the porous nature of soil. The amount of porosity and the size of pores through which gas can escape affect the rate of dissipation of high pressures generated in the explosion. Fast moving gases through soil pores can cause breakup of the medium. There is additional complexity in modeling the secondary debris generated from whole or broken up bricks thrown up in the air due to a shallow underground explosion.

In this paper we present details of numerical simulation of secondary debris generated from brick patios using CartaBlanca. Those results are then compared to experimental results. CartaBlanca is a multi-phase coupled code developed by the Los Alamos National Laboratory using the Material Point Method (MPM) for solid phase and the Arbitrary Lagrangian Eulerian (ALE) method for the fluid phase.

FAST-RUNNING TOOLS FOR BLAST PREDICTION AND LOAD MAPPING TO FINITE ELEMENT MODELS
Dr. Gregory Bessette, USACE - Engineer Research and Development Center
Mr. Micael Edwards, USACE - Engineer Research and Development Center
Mr. Gustavo Emmanuelli, USACE - Engineer Research and Development Center

A fast-running, engineering level model, termed MineX3D, has been developed to characterize the loading environment on a vehicle when subjected to underbody blast. The code predicts the temporal and spatially varying load on the exposed portion of the vehicle. The load data can be mapped onto a finite element (FE) model for a follow-on structural analysis, a process commonly referred to as a one-way coupling. MineX3D has an embedded capability to automatically map the loads onto either LS-DYNA- or ParaDyn-formatted models. Further, the mapping algorithm allows for the automatic generation of pressure patches/segments without the need to modify the original FE mesh. There has been recent development to extend the blast modeling capability to include loading from aboveground detonations. This has been accomplished by integrating the BlastX engineering level model with MineX3D. BlastX is designed to predict the airblast environment associated with open-air and internal detonations. It has the capability to predict enhanced blast from neighboring reflecting surfaces, as well as the modified blast field in the Mach-stem region. It is important to capture these effects in any analysis of a vehicle's response to a close-in aboveground explosion. In the integration, MineX3D serves as a data manager, making calls to BlastX to generate the load history on the element faces exposed to the explosive source. The approach taken in the integration allows for load prediction from blast originating either from buried or aboveground charges. At present, the load prediction is limited to elements on a direct line of sight to the explosive source. There are plans to include the loading from the diffracted blast in the future. This paper outlines the blast methodology, integration approach, and recent model validation.

TUNNEL CONFIGURATION EFFECTS ON AIR BLAST AND IMPULSE FOR CASED CHARGE DETONATIONS
Maj. Matthew Gettings, DTRA
Dr. Joshua D. Kittle, DTRA
Dr. Eric Rinehart, DTRA

A cased charge is statically detonated within a target constructed to mimic the configuration of a possible deeply buried structure in support of programs conducted by the Defense Threat Reduction Agency (DTRA). The data from these four tests allow comparisons between tunnel configuration, geology at the detonation location on measured air blast and impulse and suggest important conclusions regarding tactics, techniques, and procedures (TTPs) when employing weapons against deeply buried targets.

STRUCTURAL RESPONSE I / MATERIAL PROPERTIES

DETERMINATION OF JOHNSON-COOK MATERIAL PROPERTIES FROM TAYLOR IMPACT TESTING
Mr. Mehmet Emre Demir, Aselsan A.S.

In this paper, identification of Johnson-Cook parameters from Taylor Impact Test simulations is presented. Taylor Impact Test phenomena is aimed to be performed by finite element analysis tool and the corresponding results are presented and discussed. In order to check the reliability of the results of analysis, these results are validated by using experimental results. Having validated the finite element analysis results, the identification of material properties of unknown material and optimization of the final material properties are presented.

This study introduced and briefly described the basic elements of Taylor Impact Test with experimental and numerical analysis point of view. For high strain rate applications it is one of the problems encountered that the correct modelling of the material. Making use of Taylor Impact Testing one can both verify own numerical model along with the material characteristics (Johnson-Cook parameters) from the presented details and examples that are very easy and clear to apply. The main advantage of this method that it needs only Taylor impact test for the whole identification procedure. The objective was to provide a detailed enough introduction of Taylor Impact Testing and numerical simulations which are compatible with the experimental results. Furthermore, making use of these results unknown material characterization becomes possible.

STRUCTURAL HEALTH MONITORING OF COMPOSITE STRUCTURES IN AN UNDEX ENVIRONMENT
Mr. Bill Gregory, Applied Physical Sciences
Mr. Chris Key, Applied Physical Sciences
Dr. Mike Yeager, vScenario
Dr. Michael Todd, University of California, San Diego

The use of composite structural materials continues to expand across US Navy shipbuilding programs as advancements in design, analysis, and research provide viable alternatives to current baseline metallic material systems. Beneficial properties of composites include minimal corrosion concerns, weight reduction, reduced lifecycle costs, good thermal insulating properties, and improved acoustic performance. Implementation of composite structures onboard Navy platforms is hampered by the limited amount of legacy performance data. To overcome the lack of legacy data, the application of composite structures onboard both Navy surface ships and submarines can be facilitated by the

implementation of a Structural Health Monitoring (SHM) system that can assess the integrity of the structures in real time without the use of destructive inspection techniques.

This paper demonstrates the application of an SHM system to identify the presence of damage in a composite component subjected to an UNDEX-representative load generated using the medium weight shock machine (MWSM). Fiber Bragg gratings (FBGs) implemented in a fiber optic array are used as the SHM sensors for collecting data. Fiber optic sensors and in particular FBGs have gained considerable traction as an attractive sensing option because they are light weight, corrosion-resistant, impermeable to liquid absorption, immune to electromagnetic interference and are compatible with the composite materials being used by the Navy. These optical fiber arrays are embedded directly into a composite structure during fabrication, allowing for integrated, internal sensing of material strain states.

A glass-reinforced plastic (GRP) panel with embedded FBG sensors is subjected to varying degrees of shock input that yielded responses ranging from purely elastic (undamaged) response up through increased delamination response. The sensor data was converted into features whose evolution with damage was quantified by statistical difference metrics. The results of the test series demonstrates a high level of success for the SHM system illustrating 1) the survivability of the sensors under shock including robust ingress/egress fiber connection design, and 2) the potential for using a SHM system based on FBG sensors to monitor the integrity of a Naval composite structure during its life cycle.

SIMPLIFIED FINITE ELEMENT MODEL GENERATION FOR EXODUS II AND SIERRA SD/SM
Mr. Joshua Pennington, Altair

Many companies that perform shock and vibration analysis use government or open-source tools and solvers to perform finite element analysis (FEA). Among these tools are the common Exodus II model and the Sierra Mechanics solvers – developed by Sandia National Laboratories.

The concept of employing Exodus II is to build a common database for multiple solver codes rather than a solver code specific format. Sierra solvers provide simulation capabilities for thermal, fluid, aerodynamics, solid mechanics, and structural dynamics. One of the challenges analysts face with using Exodus II and Sierra solvers is the narrow options for model generation (mesh, material, property, boundary conditions, and other solver-specific parameters).

Through the integration of a commercially available high-performance finite element preprocessor, HyperMesh, model preparation from the import of CAD geometry to the export of a solver run, for Sierra SD/SM disciplines/solvers, is now easily achievable.

Expansion of Structural Dynamics features, the addition of Solid Mechanics support, and an improved process centric interface, has resulted in a more intuitive, innovative, efficient and powerful preprocessing tool.

This presentation details the current interface to the Exodus II (Sierra SD/SM) user profile and an improved process for building models in the Exodus II and Sierra formats.

MARGIN ASSESSMENT USING ENERGY QUANTITIES

Dr. Vit Babuska, Sandia National Laboratories
Mr. Troy Skousen, Sandia National Laboratories
Mr. Matthew Raymer, Sandia National Laboratories
Mr. Carl Sisemore, Sandia National Laboratories

Most systems, be they satellites, submarines, or weapons require that component designers understand the true capability of the component. The term “margin assessment” means quantifying a component’s capability to survive and/or operate in mechanical environments that exceed the qualification environments. The results from the margin assessment provide programs with information to evaluate the robustness of components to off-nominal environments. For example, the use environment may evolve over the deployed life time of the component because the delivery or transportation environment increases in intensity or duration. Another example comes from component testing. If a component is tested incorrectly (e.g., the environment intensity is higher than specified; the duration of the test is longer than specified; or the wrong environment is applied), the program will need to know whether the incorrect test was likely to be damaging and whether the component is still has adequate life remaining so that it can be returned to duty.

In order to make an environmental margin assessment, a metric is required to relate environment severity to damage accumulation and life consumption. For random vibration, the fatigue damage spectrum is one avenue toward quantifying margin. Another avenue uses modal energy and defines margin based on Miner’s hypothesis adapted for energy quantities of interest.

This paper will develop a fatigue damage metric based on energy and discuss the pros and cons of such an approach. Numerical examples form a spring-mass system and a circuit board like structure will illustrate the concepts.

VIBRATION I

VIRTUAL PLATFORM FOR VIBRATION TEST IN SHAKER

Mr. Eric Dodgen, Honeywell Federal Manufacturing & Technologies
Mr. Washington J. DeLima, Honeywell Federal Manufacturing & Technologies
Mr. Richard Jones, Honeywell Federal Manufacturing & Technologies

Random vibration test in an electrodynamic shaker is a common test used to qualify systems and their components that will be submitted to similar vibration load during their life. Numerical modeling of this test provides support for the design of the test and give a good insight how the systems may respond during test. A virtual shaker platform is proposed and its effectiveness is validated using experimental test.

PREDICTING SHAKER DISPLACEMENT DURING RANDOM VIBRATION

Dr. Benjamin Shank, Thermotron Industries

Deficiencies in the vibration industry standard "3 Sigma" method to calculate the maximum displacement of a random vibration are outlined. An alternative method based on test duration and expectation value is proposed.

CONTROL OF MULTI-SHAKER, STATIONARY RANDOM VIBRATION VIA MEAN SQUARE

Dr. Thomas Paez, Thomas Paez Consulting
Dr. Norman Hunter, Sandia Laboratories Consultant

Multi-shaker random vibration testing offers the capability to simulate environments more accurately than single-shaker testing; it is likely that some version of multi-shaker testing will someday be the laboratory standard. Yet, there are sometimes difficulties connected to the accomplishment of specific multi-shaker tests. Some of those difficulties are associated with:

(1) Use of a different test article in the laboratory than the one used during measurement of the environment in the field.
(2) Smoothing and enveloping of test autospectral densities.
(3) System nonlinearities.

We propose, in this paper, a method to alleviate multi-shaker testing difficulties associated with item 1. Our approach is an extension of the current approach to multi-shaker test control. Currently, multi shaker test control specifies the auto spectra at a set of control points. Typically these points are selected to define motions in several degrees of freedom (X, Y, and Z, for example). Once the auto spectra are defined, the cross spectral densities between the control points are derived either from field data or through judicious use of smart control algorithms based on minimum or nearly independent drives. The technique maps frequency-distributed mean squares in drive signals into frequency-distributed mean squares in control motions. The autospectrum is typically defined over narrow frequency intervals so the mean square control motions are specified over small bandwidths. Our technique relaxes this high-resolution frequency, narrow bandwidth requirement. We seek to specify a sequence of drive signals that excite control point motions whose mean squares (autospectra) and quadratic mean cross-products (cross-spectra) are controlled over frequency intervals that are wide relative to the usual frequency increment used in single- or multi-shaker random vibration testing. There are several ways to accomplish our objective; we explore a few of them. Some examples are provided.

FIBER OPTIC ULTRA HIGH TEMPERATURE ACCELEROMETER (1000°C)

Mr. Nicholas Burgwin, FIBOS

Increasingly, accelerometers used to monitor component vibration are being placed in challenging and harsh environments. Condition monitoring, such as turbine blade or exhaust vibration, requires measurements to be made in elevated temperatures that exceed the acceptable operating conditions of traditional electronic accelerometers. Fibos has developed the world's first ultra high temperature accelerometer that can operate up to 1000°C (~1800°F) utilizing a fiber optic sensor. This presentation will dive into the details of how the accelerometer was designed and tested while describing its performance characteristics and application opportunities.

UNDEX I

DDAMX: EXTENSION OF DDAM METHODS TO EXTERNAL ITEMS

Dr. Jeffrey Cipolla, Thornton Tomasetti
Mr. Alex McVey, Thornton Tomasetti
Mr. Mahesh Bailakanavar, Thornton Tomasetti
Mr. Corbin Robeck, Thornton Tomasetti

DDAM remains in widespread use for UNDEX QBA and QBE in the US Navy community. DDAM owes its longevity less to its physical resolution than to the consistency of results and the confidence that NAVSEA places in its use. External components, however, are not supported by current DDAM theory; an external-DDAM using 'stagnation pressure' is not widely accepted. This talk will describe progress in extending a DDAM workflow familiar to current practitioners to the case of an item exposed to the water. Physically, the new effects considered include the direct loading to the item due to the charge, and the reactive loading due to the item's motion interacting with the fluid. We retain the linearity and base-motion assumptions of DDAM, resulting in a method by which the user still uses a spectrum of shock design values for each mode of the item under consideration. We want to minimize user errors and minimize the requirements for experience to achieve success in DDAMX. This talk will therefore also discuss new implementations of the method in mode space which facilitate analysis.

MODCHK - FINITE ELEMENT PREPROCESSOR FOR SHOCK APPLICATIONS

Mr. Corbin Robeck, Thornton Tomasetti
Mr. Abilash Nair, Thornton Tomasetti

As computational power has grown and finite element code bases have become more mature - offering an ever-increasing array of numerical simulation options - high fidelity models are increasingly pushed into the range of hundreds of millions of elements. These large models can be unwieldy, making manual error checking intractable. To complicate things further, each simulation code regards modeling violations in non-standard ways: some violations are regarded as warnings that will allow the simulation to proceed, some are "fatal" simulation ending errors, and some will not be reported at all. Developed with funding from NSWCCD, Modchk is a software whose intent is to standardize finite element preprocessing, outside of a specific code environment, allowing code agnostic error checking. In addition to various model checking routines included in most commercial finite element packages (duplicate elements/nodes, element quality, etc.) Modchk has implemented additional advanced error checking algorithms including: a priori contact/intersection detection, initial time step reporting, and model translators for numerous popular simulation codes. Modchk is fully parallelized and has been tested and verified for problems involving hundreds of parts and over 100-million elements on multi-core computing platforms. This paper documents the new features of Modchk and progress in incorporating it into the NESM code base.

SIMULATION OF UNDEX-INDUCED IMPLOSION FOR LOW-DUCTILITY METALLIC AND COMPOSITE UNSTIFFENED CYLINDERS

Mr. Adam Dick, Thornton Tomasetti
Mr. Ryan Anderson, Thornton Tomasetti
Mr. Alex McVey, Thornton Tomasetti
Dr. Pawel Woelke, Thornton Tomasetti
Mr. Adam Hapij, Thornton Tomasetti

Following the ONR sponsored FNC research, Thornton Tomasetti has been pursuing enhancements in numerical simulation of hydrostatically-induced and UNDEX-induced implosions of low-ductility metallic and composite unstiffened cylinders. The numerical analyses described in this paper were conducted as finite element simulations in EPSA, using the VistaDam fracture mechanics constitutive model for metallic EVs and the Hashin composite damage model for composite EVs. The simulations present the results of two approaches for modeling the fluid field; the first includes uncoupled fluid-structure interaction (FSI) using the Doubly Asymptotic Approximation (DAA) and the second employs coupled EPSA-Gemini simulation technology. The modeling and simulation procedures used in this effort build on the software development employed within the WAI Implosion Evaluator (WAIie) technology. This paper highlights the VistaDam material model, a three invariant phenomenological damage model that accounts for the influence of stress triaxiality and Lode angle on the fracture strain. Additionally, this paper spotlights some of the compelling features of the implosion phenomenon that are pertinent to fracture-sensitive materials and the differences in the resulting field response when compared with more ductile materials.

VULNERABILITY AND MITIGATION OF RADIAL SPILLWAY GATES TO BLAST EFFECTS

Mr. Matthew Murray, USACE - Engineer Research and Development Center
Mr. Stephen Rowell, USACE - Engineer Research and Development Center

Catastrophic failure of a spillway gate has the potential to cripple the critical operations of dams, such as power generation, river navigation, irrigation, and flood control. The typical location of spillway gates leaves them exposed to underwater explosive (UNDEX) attacks from the upstream reservoir. Loads generated by an UNDEX event have the potential to buckle or collapse the gate's radial structural support arms. These radial arms hold the gates in place between the pier walls on the spillway. A system of catcher posts anchored into the pier walls along the downstream sides of the gates comprise a potential mitigation system. The catcher post system (CPS) limits the downstream displacement of the gate in the event that the structural integrity of one or both radial arms is compromised. The U.S. Army Engineer Research and Development Center (ERDC) conducted UNDEX experiments on spillway gates scaled down from a typical 50- by 45-ft radial spillway gate in order to evaluate the effectiveness of the CPS. A baseline for the gate's response to a specific UNDEX load was identified by conducting an experiment on a gate without the CPS installed. A second gate, with an identical design, was evaluated with the CPS installed. Results of the experiment incorporating the CPS characterized the system's ability to limit the downstream displacement of the gate without catastrophic damage to either the gate or catcher posts. A third gate, with a significantly weaker radial arm design, was then evaluated with the CPS. The CPS resisted the downstream displacement of the "weak-arm" gate; however, failure of the radial arm connections allowed the gate to displace significantly upstream due to negative pressure on the upstream surface of the skin plate that can occur with an UNDEX event. It was determined that the CPS adequately increases a radial spillway gate's resilience against upstream UNDEX loads by limiting the downstream displacement.

DEDICATED SESSION: GROUND SHOCK & BURIED BLAST

THE EFFECT OF DISPERSION ON THE MEASUREMENT OF PRESSURE FROM BURIED BLAST

Dr. David M. Fox, USACE - Engineer Research and Development Center

Methods for measuring and predicting global underbody buried blast effects, such as the total momentum imparted to the center of mass of a rigid body, have shown significant advances in recent years. However, techniques for determination and modeling of the temporal and spatial evolution of pressure and impulse produced from a buried explosive charge require further refinement in order to ensure that the most accurate mine blast loads are applied to the design and optimization of protection systems for ground vehicles and dismounted soldiers.

One approach to improved characterization of the pressure field involves the use of arrays of cylindrical Kolsky bars to measure buried blast pressure vs. time data at various spatial locations within the evolving blast field. Theory indicates that the geometry of the bars can be adjusted to minimize pressure signal distortion caused by dispersion effects due to variation of the speed of sound within the bars at higher frequencies.

To this end computational predictions of local pressure signals as measured by Eulerian tracers placed near the measurement faces of simulated Kolsky bars are compared, for different charge sizes, with the pressures observed at various axial distances away from the faces of Kolsky bars of several diameters in order to examine the effects of geometry and length scale on the pressure signals. These results will inform more accurate experimental methods for the characterization of the spatially and temporally evolving pressure loads caused by explosive charges buried in soil.

FULL-SCALE UNDERBODY BLAST EXPERIMENTS THAT QUANTIFY EFFECTS OF HOMEMADE-EXPLOSIVE TYPES ON ABOVEGROUND IMPULSE

Mr. Garrett Doles, USACE - Engineer Research and Development Center
Dr. Neil Williams, USACE - Engineer Research and Development Center
Dr. Jay Ehrgott, USACE - Engineer Research and Development Center

Abstract not provided.

MODELING HOMEMADE EXPLOSIVE'S EFFECT ON UNDERBODY BLAST IMPULSE AND SOIL MOTION

Dr. Neil Williams, USACE - Engineer Research and Development Center
Mr. Garrett Doles, USACE - Engineer Research and Development Center
Dr. Stephen Akers, USACE - Engineer Research and Development Center

In the last twenty years, research has been conducted to determine the predominant factors affecting impulse imparted by a buried charge to an overhead structure. The U.S. Army Engineer Research and Development Center (ERDC) has investigated the relationship between a buried charge, the geologic/soil material, and explosive-induced impulse. Most of the tests focused on the soil material and as such, used ideal explosives. The present work expanded on the past efforts by including homemade explosives' effects on impulse as well as confinement with those tests and compared the results using cast TNT. The soil was characterized and tested in the laboratory at the field conditions, and a Hybrid-Elastic-Plastic model fit was generated from these data. The homemade explosive tests provided

impulse and soil velocity measurements for modeling and simulation purposes. This work presents the efforts to model these test results.

HYBRID LAMINATED METAL COMPOSITE STRUCTURES FOR UNDERBODY BLAST

Dr. Ken Nahshon, Naval Surface Warfare Center Carderock Division
Dr. Jessica Dibelka, Naval Surface Warfare Center Carderock Division
Dr. Nicholas Reynolds, Naval Surface Warfare Center Carderock Division

Abstract not provided.

MECHANICAL SHOCK II

MONTE CARLO OPTIMIZATION OF A HYBRID SPECTRAL / TEMPORAL SINGLE INPUT MULTIPLE OUTPUT (SIMO) INPUT DERIVATION FOR AN OSCILLATORY DECAYING SHOCK

Mr. Jerome Cap, Sandia National Laboratories
Mr. Chad Heitman, Sandia National Laboratories
Mr. Matthew Raymer, Sandia National Laboratories
Mr. Trevor Hunt, ATA Engineering

The ability to achieve a given acceleration level associated with a transient shaker test (i.e., a shaker shock) is really a function of the peak amplifier voltage and current. For tests having spectral content within the frequency range for which the shaker behaves like a rigid body, minimizing the table acceleration is generally sufficient to maximize the ability to perform the test. However, for tests having spectral content in the frequency range where shaker dynamics come into play, there is no longer a direct linear relationship between the table acceleration and the amplifier performance. This case provided the motivation for developing a methodology for generating a table input that has the minimum amplifier response while still achieving the desired Shock Response Spectra (SRS). A previous study [Heitman, et.al., 2016] demonstrated the value of using Monte Carlo techniques to derive the minimum inputs for a Single Input Multiple Output (SIMO) system. That paper was interested in the case where the responses at multiple points were defined in terms of their SRS. Such an approach is not applicable when considering both spectral and temporal responses. This paper will present a methodology in which Monte Carlo techniques were successfully employed to create the shaker table input that matches a desired SRS while minimizing the peak temporal amplifier voltage.

DISPLACEMENT PREDICTIONS OF OSCILLATORY DECAYING SHOCKS

Mr. Chad Heitman, Sandia National Laboratories
Mr. Jerome S. Cap, Sandia National Laboratories
Dr. Garrett Nelson, Sandia National Laboratories
Mr. Randy Hielo, Sandia National Laboratories

When specifying oscillatory decaying shock tests on a shaker it is important to be determine if the shaker to be used for the test has the velocity and displacement capability to execute the test. If the shaker does not have the required velocity or displacement needed to run the test either the test may not run correctly with the potential to break equipment or the test will be altered. This paper discusses the reasons why it is difficult to predict displacement of an oscillatory decaying shock in general and on the Spectral Dynamics Jaguar control system specifically. Test data is also analyzed in which displacement of the shaker is measured and compared with the displacement predicted by the control

system and the analytical solution of oscillatory decaying sine tones. Methods are discussed that improve the displacement prediction.

USING TEMPORAL MOMENTS TO DETECT INTERACTIONS DURING SIMULTANEOUS SHOCK TESTING OF MULTIPLE COMPONENTS

Dr. Carl Sisemore, Sandia National Laboratories
Dr. Vit Babuška, Sandia National Laboratories
Mr. Jason Booher, Sandia National Laboratories

Small components are often tested in groups with several components mounted to a common test fixture and tested simultaneously. This test method is frequently used to reduce the time spent in the test laboratory. There is an inherent problem testing multiple identical components simultaneously since the overall fixture-component system will possess a number of closely spaced vibration modes. This is a direct result of the components all having nearly identical mass and stiffness. The ramifications of this is that the shock applied to the fixture may not be evenly distributed to all components, resulting in some being tested more severely than others. This is possible even with a well-designed fixture. This paper presents a novel application of temporal moments for detecting and quantifying the interaction between multiple components from a single shock test. The paper also presents a series of experimental results showing how the temporal moments shift as damage progresses through the multi-component system.

SHOCK ATTENUATION WITH DISTANCE: A COMPARISON OF TEST DATA WITH NASA CURVES

Mr. Alexander Hardt, Orbital ATK

Shock attenuation with distance curves for a cylindrical shell were established with the publication of NASA CR 116406 in March of 1970. These are the same curves presented in NASA-HDBK-7005 and MIL-STD-810. This presentation reviews the test data used to establish these curves and then compares them with Orbital ATK test data. Additionally it compares test data for a pyroshock on simple plate.

STRUCTURAL RESPONSE II

AXIAL IMPACT OF A FLUID-FILLED DEFORMABLE PIPE

Dr. Catherine Florio, US Army ARDEC
Mr. Adam L. Foltz, US Army ARDEC
Mr. Lyonel Reinhardt, US Army ARDEC

The dynamic behavior of a water-filled standard black pipe with one closed end and one open end and the free fluid surface subjected to an impact load was examined experimentally and computationally. Experimentally-measured fluid pressure variations were correlated to the timing of the resulting deformation and failure behavior of the pipe captured with high speed video. Metallurgical analysis indicated the failure modes of the pipe material. To gain a better understanding of the experimentally-observed phenomena, computational modeling methods were developed to simulate the experimental conditions. The simulations successfully predicted fluid pressure magnitudes and variations with time, the timing and location of initial pipe failure, and the likely failure mode. Through the combined experimental and computational studies, distinct phenomena were identified for seamed and seamless pipes, and trends were identified as a function of pipe wall thickness. This work can assist in the study

and prediction of the phenomena associated with dynamic pressure wave propagation through a non-flowing fluid in a deformable pipe and the resulting structural response of the pipe.

STRUCTURAL RESPONSE OF REINFORCED CONCRETE SLABS TO BLAST LOADING: THE ROLE OF MATERIAL STRENGTH
Dr. Tarek Kewaisy, Louis Berger

This paper reports on the findings of a comprehensive study that involved various numerical simulations of blast-loaded Reinforced Concrete (RC) slabs of different strength classes. The study investigated response characteristics associated with the application of bilinear shock loading of varying intensity and energy levels to one-way RC slabs of various material strengths and boundary conditions. Three strength classes of RC concrete were investigated; Normal Strength (5,000 psi concrete and 60,000 psi rebar), Medium Strength (10,000 psi concrete and 75,000 psi rebar), and High Strength (15,000 psi concrete and 100,000 psi rebar). Nine shock loading profiles were considered by pairing various levels of peak pressure (30 psi for Low, 45 psi for Medium, 60 psi for High) and duration (10 ms for Short, 20 ms for Medium, 40 ms for Long). Two numerical techniques were implemented to simulate strain-rate effects, materials nonlinearities, and damage patterns and extents typically encountered in blast applications: Single Degree Of Freedom- SDOF using RCBlast program and Finite Element Analysis- FEA using LS-DYNA Software. Primary simulation parameters for various RC slab configurations were calibrated using response measurements obtained from testing. The blast testing program was funded by the National Science Foundation (NSF), administered by the University of Missouri – Kansas City (UMKC) and completed at the Blast Loading Simulator (BLS) of the Engineering Research and Development Center (ERDC) at Vicksburg, MS. The effects of considering different strength classes of concrete and reinforcement on the blast response of RC slabs were evaluated. Valuable insights were obtained, and useful conclusions were drawn regarding the appropriateness of use of various material strengths to achieve optimized and enhanced performance of RC slabs subjected to varying levels of blast loading.

A METHODOLOGY FOR SCALING SHOCK RESPONSE SPECTRA
Dr. Arup Maji, Sandia National Laboratories
Mr. Matthew Raymer, Sandia National Laboratories

Shock testing is typically done based on a specified Shock Response Spectra (SRS). The SRS captures how Single Degree of Freedom (SDOF) structures of differing frequency would respond to the shock; the SRS therefore no longer contains the complete time history of the shock. This loss of information along with lack of original system test data makes shock response scaling a challenging proposition. Component SRS specifications are usually derived from Systems level shock tests where acceleration response at various component locations are obtained and then converted into SRS specifications. This specification is used both for component design as well as for component testing. An important and recurring need is to assess how component-level design or safety margins may change when the specification at the system level changes (new or modified system, new operation of existing system, etc.). Most often new test data is not available especially in the early design phase to provide the answer component designers need and shock specifications cannot be directly scaled from old specifications. A process for specifying component-level SRSs with associated safety margins was developed based on underlying theory and available data. The old component SRS specifications are first linearly scaled according to the new System-level SRS specifications. Adjustments are then made accounting for differences in structural damping and interdependency of one frequency on another. Original test data, if available, can be used to make the specifications more accurate. Different SRSs were used as test cases along with different transfer functions between system and component to determine the accuracy of the proposed method.

SURVEY OF THE NUCLEAR WEAPON EFFECTS EXPERIMENTAL DATABASE
Dr. Eugene Sevin, ESCS

This paper surveys the U.S. experimental nuclear weapon effects database consisting of 1030 nuclear events conducted in the atmosphere, at high altitude, under water and underground during the period 1946 to 1992. Of these, 58 were designated as weapons effects tests; each of which contained numerous individual experiments of potential relevance to the Shock and Vibration community. Database compilations reviewed include LLNL's recent declassification of over 750 nuclear test videos and posting of many to YouTube, and DTRAs Nuclear Weapons Effects Technical Information project emphasizing guides to the experimental data on aboveground, shallow-buried and deeply-buried structures. Examples are cited as to how this trove of information can be utilized for simulation code development and verification.

SHANFO CYLINDER TESTS
Maj. Matthew Gettings, DTRA
Dr. Eric Rinehart, DTRA,
Mr. D. Rand, ARA

A methodology is developed for obtaining the Jones-Wilkins-Lee (JWL) parameters for Sensitized Heavy Ammonium Nitrate Fuel-Oil (SHANFO). Four cylinder tests are conducted without the need for ultra-high speed optics. While pin gages have proven effective recording case expansion, more data points improve resolution of the case expansion velocity. A novel approach is implemented using high-frequency radar as a cost-effective means for determining case expansion and a continuous set of data.

SRS AND PIEZOELECTRIC ZERO SHIFT

COMPARISON OF INPUT LEVELS ON THE SHAPES OF SRS FUNCTIONS
Mr. William Larsen, Michigan Technological University
Dr. Jason R. Blough, Michigan Technological University
Dr. James DeClerck, Michigan Technological University
Mr. Charles VanKarsen, Michigan Technological University
Mr. David Soine, Honeywell
Mr. Richard Jones, Honeywell

This paper will compare the Shock Response Spectra (SRS) calculated from shock acceleration responses measured on a set of experimental test plates using different types of shock inputs and input force levels. The experimental plates were constructed with different damping mechanisms integrated in the plate assemblies. Differing force levels have the potential to excite non-linearities in the experimental test plate assemblies. All data is from a set of test plates developed at MTU to evaluate factors that impact shock response in the plates and the corresponding shape of the SRS. Numerical simulations will also be used to estimate the shock response for comparison to experimental data.

VELOCITY AND OTHER LOW FREQUENCY SRS SHAPE MODIFIERS

Dr. Jason Blough, Michigan Technological University
Mr. William Larsen, Michigan Technological University
Dr. James DeClerck, Michigan Technological University
Mr. Charles VanKarsen, Michigan Technological University
Mr. David Soine, Honeywell
Mr. Richard Jones, Honeywell

The goal of this paper is to fully understand and explain what shapes the Shock Response Spectrum (SRS) below the "knee frequency" where the shape of the SRS distinctively transitions from a positive slope rising with frequency to a more constant valued function as frequency increases. There are multiple contributors to the shape of the SRS below the "knee frequency." These effects include a non-zero residual velocity being present in the acceleration response of the shock response plate and fixture. This paper will demonstrate those effects as well as present an approach to remove the residual velocity. Additionally, this paper will investigate how the shape of the SRS changes for different input functions such as Haversine vs. a square pulse vs a delta function. Additionally, the effect of the SDOF systems which make up the SRS calculation beating with the natural frequencies of the plate/fixture will be shown. All examples will be presented using analytical data so as not to confuse issues such as unknown boundary conditions and sensor response issues.

RECOMMENDED PRACTICES TO MINIMIZE ACCELEROMETER ZERO SHIFT UNDER SEVERE SHOCK; PART 1

Dr. Patrick Walter, Texas Christian University
Mr. Anthony Agnello, PCB Piezotronics
Mr. Jeff Dosch, PCB Piezotronics
Mr. Robert Sill, PCB Piezotronics
Mr. Strether Smith, Independent Consultant

This work first reviews the evolution of accelerometer technology to minimize errors that can occur when integrating accelerometer records to acquire velocity measurements during severe mechanical shock. Specifically, in pyrotechnic shock, the ability of an accelerometer record to return to zero is one metric used to assess the quality of the resultant computed shock spectra. In spite of significant advances in accelerometer technology, under the environments being considered small offsets are still observed in recorded data. While troublesome, these offsets are often small enough that it is not apparent that the accelerometer is the singular or even the most significant cause of them. After looking at potential offset contributors associated with the accelerometer, additional contributors that can occur within the instrumentation system are identified and recommendations are made to minimize their effect.

RECOMMENDED PRACTICES TO MINIMIZE ACCELEROMETER ZERO SHIFT UNDER SEVERE SHOCK; PART 2

Dr. Patrick Walter, Texas Christian University
Mr. Anthony Agnello, PCB Piezotronics
Mr. Jeff Dosch, PCB Piezotronics
Mr. Robert Sill, PCB Piezotronics
Mr. Strether Smith, Independent Consultant

This work first reviews the evolution of accelerometer technology to minimize errors that can occur when integrating accelerometer records to acquire velocity measurements during severe mechanical shock. Specifically, in pyrotechnic shock, the ability of an accelerometer record to return to zero is one

metric used to assess the quality of the resultant computed shock spectra. In spite of significant advances in accelerometer technology, under the environments being considered small offsets are still observed in recorded data. While troublesome, these offsets are often small enough that it is not apparent that the accelerometer is the singular or even the most significant cause of them. After looking at potential offset contributors associated with the accelerometer, additional contributors that can occur within the instrumentation system are identified and recommendations are made to minimize their effect.

DEDICATED SESSION: VEHICLE BORNE IED RESEARCH & TESTING I

EXPERIMENTAL TESTING OF POTASSIUM CHLORATE-DIESEL IN VEHICLE-BORNE IMPROVISED EXPLOSIVE DEVICES

Mr. Daniel Vaughn, USACE - Engineer Research and Development Center
Mr. Joshua Payne, USACE - Engineer Research and Development Center
Dr. Kyle Crosby, USACE - Engineer Research and Development Center
Dr. Jay Ehrgott, Jr., USACE - Engineer Research and Development Center
Mr. Denis Rickman, USACE - Engineer Research and Development Center

Vehicle-borne improvised explosive devices (VBIEDs) are a worldwide threat to U.S. and Allied forces, which can cause significant human casualties as well as serious infrastructure damage. Post-blast forensic analysis of VBIED events can provide valuable information for both characterizing the events and mitigating future attacks. The National Ground Intelligence Center (NGIC) and the U.S. Army Engineer Research and Development Center (ERDC) created the Forensic Encyclopedia Program (FEP) to better understand a variety of weapon effects and improve our ability to collect evidence for characterizing attacks. Homemade explosives (HMEs), such as potassium chlorate mixed with diesel fuel (PCD) used in VBIEDs, have been recognized as a growing threat by the intelligence community; however, little test data representing these events are available. To address this need, the U.S. Department of Homeland Security (DHS), NGIC, ERDC, and the U.S. Naval Surface Warfare Center's (NSWC) Indian Head performed a series of controlled experiments with PCD charges ranging from 200 to 10,000 lbs. Information such as the airblast pressure/impulse fields, ground crater measurements, and damage to witness items was collected during these tests for use in VBIED forensic analysis tools. This paper presents an overview of those experiments.

VIPER TOOL - VEHICLE BORNE IED POST-BLAST FORENSIC DATA COLLECTION AND ANALYSIS TOOLS

Mr. Joshua Payne, USACE - Engineer Research and Development Center
Dr. Kyle Crosby, USACE - Engineer Research and Development Center
Mr. Daniel Vaughan, USACE - Engineer Research and Development Center
Mr. Ernesto Cruz, USACE - Engineer Research and Development Center
Mr. Jasiel Ramos Delgado, USACE - Engineer Research and Development Center
Dr. Jay Ehrgott, USACE - Engineer Research and Development Center
Mr. Denis Rickman, USACE - Engineer Research and Development Center

Vehicle-borne improvised explosive devices (VBIEDs) are a well-documented and proliferated threat to U.S./Allied forces. VBIEDs have the potential to cause large amounts of casualties as well as catastrophic damage to nearby structures. Accurate comparative forensic analyses of such attacks are of high importance in order to assist the warfighter and senior decision makers in mitigating these threats. However, analysis is hampered by the lack of precise correlations of the observed levels of structural damage, size of the blast crater, and the visual damage seen to "witness items", e.g., vehicles and road

signs, to the explosive net equivalent weight (NEW). In addition, fast-running software tools are not available to directly estimate explosive yield given post-blast forensic data. In order to address this need, the National Ground Intelligence Center and the U.S. Army Engineer Research and Development Center (ERDC) initiated the VBIED Post-Blast Forensic Program. The objective of this program is to develop VBIED post-blast collection methodologies and assessment algorithms to assist with the post-blast analysis of a VBIED event. The VBIED Post-Blast Data Collection Guidebook will document expedient collection techniques and methodologies. A post-blast data collection and analysis software code (named VIPER) is under development to evaluate forensic data and provide estimated NEW assessments. This paper will present an overview of the VBIED post-blast collection guidebook and the VIPER Tool.

VEHICLE-BORNE IMPROVISED EXPLOSIVE DEVICE CRATER TEST DATA AND ANALYSIS TECHNIQUES

Mr. Ernesto Cruz, USACE - Engineer Research and Development Center
Mr. Joshua Payne, USACE - Engineer Research and Development Center
Mr. Jasiel Ramos Delgado, USACE - Engineer Research and Development Center
Dr. Kyle Crosby, USACE - Engineer Research and Development Center
Dr. Jay Ehrgott, USACE - Engineer Research and Development Center
Mr. Denis Rickman, USACE - Engineer Research and Development Center

Vehicle-borne improvised explosive devices (VBIEDs) are a significant threat to U.S and Allied forces in areas of conflict worldwide. The detonation of these devices has the potential to cause significant casualties as well as severe damage to structures and support facilities. Accurate estimates of the net explosive weight (NEW) employed by these VBIEDs are of critical importance in terms of both threat identification and mitigation. One of the primary methods of estimating the NEW utilized in a VBIED attack is to examine the size of the soil crater. However, analysis is hampered by the lack of precise correlations of the size of the blast crater to the explosive yield. In order to address this need, the National Ground Intelligence Center (NGIC) and the U.S. Army Engineer Research and Development Center (ERDC) initiated the VBIED Post-Blast Forensic Program. One goal of this program is to develop a scientific method to estimate NEW based on the observed crater size. To develop this capability, a series of well-controlled experiments were conducted on gravel and asphalt roadways to develop correlations between crater size and NEW. These correlations may be used to provide an estimated NEW based on crater size, thus assisting with the post-blast analysis of a VBIED event. This paper will present an overview of the data used in the analysis and the developed crater analysis procedures.

CIVILIAN VEHICLE DAMAGE ANALYSIS FROM VEHICLE BORNE IED DETONATIONS

Mr. Jasiel Ramos Delgado, USACE - Engineer Research and Development Center
Mr. Joshua Payne, USACE - Engineer Research and Development Center
Dr. Kyle Crosby, USACE - Engineer Research and Development Center
Mr. Ernesto Cruz, USACE - Engineer Research and Development Center
Dr. Jay Ehrgott, USACE - Engineer Research and Development Center
Mr. Denis Rickman, USACE - Engineer Research and Development Center

Vehicle-borne improvised explosive devices (VBIEDs) are a significant threat to U.S and Allied forces in areas of conflict worldwide. The detonation of these devices has the potential to cause significant casualties as well as severe damage to structures and support facilities. Accurate estimates of the net explosive weight (NEW) employed by these VBIEDs are of critical importance, both in terms of threat identification and mitigation. VBIEDs typically produce levels of damage to common “witness items”, such as vehicles and signs, that are dependent upon both the distance from the VBIED and the VBIED

explosive yield. However, analysis of witness item damage is hampered by the lack of precise correlations of the observed levels of damage to blast pressure and impulse. An area of great importance is accurate correlation of the level of visual damage to civilian vehicles to blast loading, since these vehicles are commonly present near VBIED events. In order to address this need, the National Ground Intelligence Center (NGIC) and the U.S. Army Engineer Research and Development Center (ERDC) initiated the VBIED Post-Blast Forensic Program. One of the objectives of this program is to generate experiment data that will assist with the development of a civilian vehicle post-blast damage collection and analysis procedures to rapidly assess civilian vehicle damage and use the observed damage level, along with the distance to ground zero, to estimate NEW. This paper will present an overview of this procedure.

AN INTRODUCTION TO THE SUPER HEAVY IMPROVISED EXPLOSIVE LOADING DEMONSTRATION (SHIELD) TEST PROGRAM

Mr. Denis Rickman, USACE - Engineer Research and Development Center
Mr. Anders Persson, Swedish Fortifications Agency
Mr. Markus Jaun, Federal Department of Defence, Civil Protection and Sport DDPS
Mr. Tor Knutsen, Norwegian Defence Estate Agency,
Mr. Hans Dirlewanger, Bundeswehr Technical Center for Protective and Special Technolog

Vehicle-borne improvised explosive devices (VBIEDs) continue to be a threat world-wide. Due to the pervasive nature of the threat and shared interests in developing means of protection, a common interest was identified between the partner countries of Sweden, Germany, Switzerland, Norway, and the United States to conduct a very large blast test as a means of assessing force protection methods and determining VBIED forensic signatures. The Super Heavy Improvised Explosive Loading Demonstration (SHIELD) Test is a multinational project aiming to conduct a very large full-scale blast test at Älvdalen shooting range, Sweden in 2018. The overall aim is to contribute to a safer environment for both civilian and military interests. This will be accomplished by verifying and validating physical protection solutions and fortified constructions, and by improving and expanding forensic data collection and assessment methodologies. This paper presents an overview of the SHIELD Project, including the types of structures to be evaluated and the data which will be collected by the partner countries.

DEDICATED SESSION: EXPERIMENTAL TESTING METHODS & INSTRUMENTATION IN HIGH-G ENVIRONMENTS

BULLETS WITH BRAINS: EVALUATING INTEGRATED CIRCUIT MEMORY IN ULTRA HIGH-G ENVIRONMENTS

Mr. Shane Curtis, Sandia National Laboratories
Mr. Rus Payne, Sandia National Laboratories

In packaging electronics to survive traditional high-g environments (>10,000 g's), two mechanisms are generally believed to be responsible for component failures: Printed Circuit Board (PCB) flexure and inertial forces. Packaging methods in this regime most often include encapsulating the assembly in a thermoset epoxy to both dampen high frequency shock and support the electronics. However, in ultra high-g environments (>100,000 g's), other failure methods and packaging schemes must be considered due to the intensity of the shock load. For example, failures in the components themselves due to spalling, material phase changes, piezo electric effects, or other mechanisms could be present in addition to material yielding and fracture due to high inertia loads. In this study, we look at the survivability of two Integrated Circuit (IC) memory packages in ultra high-g environments: an Ultra-Thin

Small Outline No-Lead Package (USON) and a Small Outline Integrated Circuit Package (SOIC). Several packaging concepts are presented involving 9mm and .44 caliber custom bullets to encase and protect the memory chips while being shot out of a powder gun at high velocities into a soft catch. Results from Finite Element Analysis (FEA) and experimentation are presented.

PRESSURE TRANSDUCER DYNAMIC RESPONSE TO EXTREME PRESSURE AND MECHANICAL SHOCK

Mr. Curtis McKinion, Air Force Research Laboratory
Dr. Jacob Dodson, Air Force Research Laboratory,
Dr. Alain Beliveau, Applied Research Associates

The Air Force Research Laboratory is evaluating the latest Fuze technologies embedded in the fill material of a weapon. Compared to conventional hard-mounted conditions, the embedded environment experiences both high-g mechanical shock and large dynamic pressures. Pressure transducers capable of surviving the shock and measuring these high pressures are being investigated. The sensor must be packaged in a small form factor as well as be insensitive to acceleration. Piezoresistive pressure transducers from two different manufacturers are evaluated. The transducer performance to mechanical shock and extreme pressure determined from experiments are discussed in this paper.

DISPLACEMENT MEASUREMENT OF THE FILL MATERIAL IN SUB-SCALE PENETRATOR

Dr. Alain Beliveau, Applied Research Associates

AFRL Munitions Directorate research activities in firesets embedded in fill material includes efforts in measuring the movement of an embedded system in the explosive simulant for sub-scale penetrator impacting hard target. Very high deceleration level (thousands of Gs), large pressure (ten thousands of psi) and rapid movement of the fill material are present during hard target penetration. Commercial magnetic displacement sensors were evaluated for this application. The Honeywell SPS-L225-HALS SMART position sensor performed well under laboratory dynamic load but had some limitation for the application of interest. An in-house magnetic displacement sensor was assembled to improve the response. We report laboratory measurement of the performance of both sensors and discuss their usage in measuring the fill material displacement in hard target attack by sub-scale penetrators.

FORWARD ASSEMBLY TEST PROTOCOL FOR FUNCTIONAL VALIDATION (FATP-FV)

Ms. Hayley Chow, University of Dayton Research Institute
Dr. Jacob C. Dodson, AFRL/RWMF
Dr. Janet C. Wolfson, AFRL/RWMF
Dr. Alain Beliveau, ARA

The Air Force Research Lab is conducting testing to explore and evaluate the survivability and functionality of an embedded fuzing system. As part of this endeavor, it is critical to understand the forces at play in the embedded environment and their impact on the operation of the fuze. In order to test the survivability and functionality of various embedded firesets (also known as forward assemblies or FA's), researchers at AFRL's Fuzes Branch have developed the Forward Assembly Test Protocol for Functional Validation (FATP-FV), a standardized testing method developed to check out FA's efficiently and effectively. The FATP-FV requires a series of electrical check-out tests, low shock drop tower tests, quasistatic pressure testing, and hard target subscale cannon testing, to verify that the FA meets its design requirements. Also, included in the FATP-FV is a series of tests to the determine the envelope of survivability of the FA through additional high-G drop tower testing, high level quasistatic pressure testing, and dynamic pressure testing. Results will be presented on several different embedded FA

designs as they are subjected to the FATP-FV experimental series. This presentation will discuss the current status and future work on the testing of FA designs for operational functionality.

CHARACTERIZATION OF EXPLOSIVE FILL DYNAMICS FOR HARD TARGET MUNITIONS

Mr. Phil Marquart, Applied Research Associates
Mr. Justin Bruno, Applied Research Associates
Mr. Dan Chitty, Applied Research Associates
Mr. Drew Malechuck, Applied Research Associates
Mr. Craig Doolittle, Applied Research Associates
Mr. Dave Truncellito, Applied Research Associates
Mr. Alma Oliphant, Applied Research Associates
Mr. John Perry, Applied Research Associates
Mr. Edwardo Freeman, Air Force Lifecycle Management Center
Mr. Jamie Conley, Air Force Lifecycle Management Center

Current efforts to develop embedded smart fuzing for hard target munitions rely on the explosive fill for shock mitigation. At the same time, the fuze must be able to derive information about the target without being confused by the dynamic response of the fill. To help understand the environment of embedded systems, the Recorder for Explosive Acceleration and Pressure Response (REAPR) was developed to measure the explosive fill response during hard target penetration test events. The embedded instrumentation was deployed on several full-scale sled tests. Data from these tests demonstrate how the embedded fuzing environments differ from those of aft mounted fuzing systems. Comparison between test data and computational modeling aids in refining and validating explosive fill material models. This provides confidence that analytical tools can be used to guide further development of embedded smart fuzing solutions.

STRUCTURAL RESPONSE III

EVALUATING THE USE OF ENERGY RESPONSE SPECTRA FOR DETERMINING THE RELATIVE SEVERITY OF MACHINING OPERATIONS

Dr. Carl Sisemore, Sandia National Laboratories
Dr. Vit Babuška, Sandia National Laboratories

Energy response spectra have been used to quantify the severity of mechanical shock and vibration events for some time. Recently, the energy response spectra have been used to quantify the severity of shock and vibration induced from machining operations. There has been a recent interest in harvesting sub-components from larger assemblies for testing, inspection, and potential reuse. Recovering these components often requires multiple machine shop operations including: cutting, sawing, grinding, and prying. There is an interest in understanding and quantifying the damage inducing effects of these operations on the sub-components of interest. Energy response spectra are normally calculated by integrating over the event time; however, the machining environment is both very long and nonstationary. This paper presents a series of analyses on measured machining data and compares several different methods for determining the relative severity of a machining operation.

DDAM-COUPLED OPTIMIZATION METHODS FOR SHIP STRUCTURES

Mr. Leo Jeng, Altair

The traditional design process for structural components often involves many iterations between the designer and the analyst. If the structure is being designed to withstand specific shock conditions, the iterative process can be much more involved. Historically, design validation for structural integrity occurs near the end of the design lifecycle. By incorporating structural design that has been optimized for DDAM shock analysis, the iterative design cycle can be dramatically reduced. Optimization driven design brings validation and performance optimization early into the design phase.

This paper presents a case study using DDAM-coupled optimization methods to improve the structural performance of a ship component. DDAM-coupled optimization methods allow engineers to account for shock loading early in the design phase to generate structural designs that can improve the performance of the structure and/or result in weight savings. The case study used in this paper will demonstrate a complete optimization process beginning with concept level design optimization tools then design fine tuning tools. The optimization and validation is performed using OptiStruct, a commercially available simulation software that not only validates structures using DDAM, but has unique built-in optimization capabilities for maximizing performance while reducing weight, cost, and design cycle times. Optimized results show an improvement in the structural performance of the part and will be compared to the baseline model.

2D FE AND 2DOF SIMULATIONS OF GROUND SHOCK EXPERIMENTS – REFLECTION PRESSURE TIME HISTORY DEPENDENCY DUE TO THE CHARGE´S AND STRUCTURE´S PROPERTIES

Prof. Leo Laine, LL Engineering AB
Prof. Morgan Johansson, Chalmers University
Mr. Ola-Pramm Larsen, ANKER-ZEMER Engineering AS

This paper analysis by using 2D Finite Element (FE) with Autodyn the structural response of a well-defined structure; a suspended piston-spring system buried in sand subjected for ground shock from an explosive charge. The parameters varied in the simulations were charge size, charge distance, reflection area of the piston, piston mass, and spring stiffness. Earlier experiments by experiments from 1980s conducted by S. Hultgren, FORTF, where Hultgren studied showed that the reflection pressure over time was dependent on the mass and stiffness of the structure. Here, some more parameters were varied in simulations to see how well a two degree of freedom model can capture the main behaviour of the structural response. The first aim of the FE simulations was to better understand the physics of the observed experimental results. Based on this, the second aim was to find a methodology that can use simplified relationships for ground shock prediction, from e.g. ConWep, in combination with simplified models such as 2DOF, to predict the structural response of e.g. a buried concrete wall.

The FE simulation models were generated in Autodyn-2D, where the sand was modelled with Euler cells and the piston, spring, and cylinder were modelled with Lagrange element. The sand was modelled with an Equation of State (EOS) designed for porous soils. The simple 2DOF model confirms some of the main behaviour found in the FE results and experiments, such as the initial collision effect only depends on mass and that total spring deflection gave reasonable agreement with simulations.

UNDEX II

COMPARISON OF THE NONLINEAR SHOCK RESPONSE OF STRESSED-SKIN MODULES
Mr. Matthew Tilley, Newport News Shipbuilding
Mr. Matt Davis, Newport News Shipbuilding

Stressed-skin panels have been proposed as a lower cost alternative for submarine internal structures. An alternate design approach for these T-stiffened plate structures is used and the response of this type of module to full-scale transient shock analysis is evaluated. This paper describes the results of the analysis compared to legacy structural design approach for isolated deck modules. This is done with the intention of supporting future use of T-stiffened panels in isolated deck modules.

ON THE TORPEDO TUBE-LOADED SHOCK ASSESSMENT OF NAVY PAYLOADS
Dr. Emily Guzas, NUWC Newport
Mr. Kevin Behan, NUWC Newport

Recent Navy projects have allowed the investigation and development of technical alternatives to meeting shock requirements for torpedo tube-loaded hardware. These innovations, along with traditional methods, for evaluation of torpedo tube-loaded hardware will be presented and discussed.

UNDEX INITIATED IMPLOSION IN SHALLOW WATER OF CYLINDERS IN A CONFINED ENVIRONMENT
Dr. Joseph Ambrico, NUWC Newport
Dr. Ryan E. Chamberlin, NUWC Newport

Typically, underwater implosion is a concern only at deep depths where there is significant hydrostatic pressure. At shallow depths, there is much less potential energy in an implodable volume since there is little pressure to drive the implosion. Additionally, at shallow depth adjacent structures are at a smaller fraction of their collapse strength, so they have greater reserve strength and can withstand greater loading without damage. However, a shallow implosion initiated by a nearby underwater explosion (UNDEX) has the potential to be amplified by the UNDEX pressure. The overpressure from the UNDEX shock wave can accelerate the collapse and produce a significant implosion pressure pulse, even at shallow depth. An additional factor controlling the resulting implosion pressure pulse is whether the implodable volume is in a free-field or confined by surrounding structure. Confining structure affects water flow around the collapsing volume, and can significantly alter the implosion pressure pulse. A specific case of shallow, UNDEX initiated, confined implosion will be presented. The level of confinement and the material ductility of the implodable cylinder are investigated.

FINITE ELEMENT MODELING OF ISOLATION MOUNTS
Ms. Janet Bivens, NUWC Newport
Dr. Emily Guzas, NUWC Newport

Shock isolation mounts are used throughout Navy platforms as a means to mitigate shock and vibration effects to sensitive equipment. In order to determine shock isolation mount viability on changing components, recent Finite Element Analysis (FEA) was conducted on a component shock mounted with spring isolation mounts. This paper covers the efforts required to effectively model shock mounted hardware and validate the findings using high impact shock testing. Details include the development of the FEA model, actual shock testing of the modeled component, and comparative results.

ISOLATION

EVALUATION OF ELASTOMERIC ISOLATORS' PROPERTIES IN BROAD TEMPERATURE RANGE AVIONICS APPLICATIONS
Mr. Neil Donovan, Shock Tech
Mr. Kevork Kayayan, Shock Tech

Elastomeric Isolators are used for shock and vibration isolation in modern guidance systems. These isolators need to exhibit constant properties over the broad temperature range of the expected applications. Special elastomeric compounds are developed which exhibit flat performance with temperature change. Over time modern applications of these mounting systems have required performance at higher and higher frequencies. Understanding dynamic properties and damping at these higher frequencies, and correctly modelling them, is critical to control program cost and schedule.
This paper presents data from recent tests, reviews performance characteristics of guidance and avionics mounting systems, and presents vibration results at different temperature ranges. Measured results show well-controlled levels of peak acceleration and relative displacement. Comparison of test results with pre-test calculations is given. Simulation models are described.

A USE OF WIRE ROPE ISOLATORS FOR SEISMIC APPLICATIONS
Mr. Claude Prost, Vibro/Dynamics SOCITEC
Mr. Bruno Abdelnour, Vibro/Dynamics SOCITEC

An initial article was presented during SAVE 2015 in which wire rope isolators were applied to circuit breakers and generating sets. A comparison with restrained-spring isolators was also discussed. The present article is a narrative of further developments to seismic protection of various sub-station equipment.

Case studies will be presented for circuit breakers, surge arresters, and transformers, all of which are composed of fragile equipment incorporating porcelain insulation material. Applying this successful approach with wire rope isolators to the support of full substations will be explored considering the recent extension of Socitec's product line to isolators composed of 2" diameter wire rope.

Numerical simulations using Socitec's proprietary nonlinear, multi-body SYMOS package will be presented, including animations and comparisons with measured results on a 3D seismic table where applicable.

NUMERICAL METHODS / MODELING

M/S TOPIC: IMPROVING MODEL QUALITY AND ACCURACY THROUGH AUTOMATED LINKS TO DESIGN INFORMATION
Mr. Michael Boddie, General Dynamics - Bath Iron Works

As shock and dynamic analysis capacity continues to expand, dynamic system models become increasingly detailed. Without tools tailored to verify and manage design information, the volume of data can soon become overwhelming and can lead to errors and lack of traceability (verification). Engineers and developers will trend to the development of industrial standards requiring greater integration of Computer Aided Design/ Computer Aided Engineering (CAD/CAE). Looking forward, it is likely that details formerly 'smeared' (or analogous simplifying assumption) may routinely be modeled explicitly. Managing this volume of data and the need to verify model accuracy can be enhanced

through automation. In addition to increased accuracy, using design information in an automated sense to develop this framework within an engineering database provides a level of increased efficiency that affords more time for analysis and the ability to meet project schedule objectives for models of all sizes.

DAMAGE BASED ANALYSIS: THEORY, DERIVATION AND PRACTICAL APPLICATION USING BOTH AN ACCELERATION AND PSEUDO-VELOCITY APPROACH

Mr. Vince Grillo, AI Solutions/NASA

The objective of this presentation is to give a brief overview of the theory behind the Damage Based Analysis (DBA) method including the derivation and practical application of the theory using the Python computer language. The Theory and Derivation will use both Acceleration and Pseudo Velocity methods to derive a series of equations for processing by Python. The results will compare both Acceleration and Pseudo Velocity methods and discuss implementation of the Python functions. Also, we will briefly discuss the efficiency of the methods and the amount of computer time required for the solution. In conclusion, DBA offers a powerful method to evaluate the amount of energy imparted into a system in the form of both Amplitude and Duration during flight and compare those results to the ground test qualification environments. Many forms of steady state and transient non-stationary vibratory motion can be characterized using this technique. DBA provides a more robust alternative to traditional methods such as Power Spectral Density (PSD) using a maximax approach.

DESIGN & MODELING OF TESTS

DESIGNING HARDWARE FOR THE BOUNDARY CONDITION ROUND ROBIN CHALLENGE

Mr. David Soine, Honeywell
Mr. Richard Jones, Honeywell
Ms. Julie Harvie, Sandia National Laboratories
Mr. Tyler Schoenherr, Sandia National Laboratories

Qualification of products to their vibration and shock requirements in a laboratory setting consists of two basic steps. The first is the quantification of the product's mechanical environment in the field. The second is the process of testing the product in the laboratory to ensure it is robust enough to survive the field environment. The latter part is the subject of the "Boundary Condition for Component Qualification" challenge problem. This presentation describes the challenges in determining the appropriate boundary conditions and input stimulus required to qualify the product. This presentation also describes the steps and analyses that were taken to design a set of hardware that demonstrates the issue and can be used by round robin challenge participants to investigate the problem.

FATIGUE BASED TECHNIQUE TO COMPENSATE FOR IMPERFECT TEST FIXTURES

Mr. William Barber, US Army Redstone Test Center

One of the primary goals of fixture design for laboratory vibration testing is to replicate the dynamic characteristics of the fielded configuration such that an equivalent fatigue can be applied for the intended dynamic environment in a controlled laboratory setting. When this goal is not fully achievable, analysis may be performed to understand the implications and to define corrective actions required to ensure a quality test. This papers discusses analysis tools and techniques that have been implemented at Redstone Test Center to minimize the risk of unrealistic results in the laboratory vibration test.

Analysis and vibration data from a recent test case are presented to demonstrate the effectiveness and limitations of these techniques.

EXPERIMENTAL OPTIMIZATION OF A STRUCTURAL ELEMENT'S VIBRO-ACOUSTIC ROBUSTNESS-PT I AND II
Mr. Zeev Sherf, RAFAEL
Mr. Philip Hopstone, RAFAEL

This is a series of two papers that describe the application of Design Of Experiments (DOE) methods in the experimental optimization of a structural's element vibro-acoustic robustness. After several introductory notes ,the DOE methodology is elucidated, followed by the description of the acoustic excitation's structural element interaction principles. Models of this interaction are used in the simulation of a set of experiments in which the values of the structural parameters(stiffness and damping) that assure the lowest vibratory response to the acoustic excitation are identified. The identification is performed by application of appropriate data analysis methods (Analysis of Means, Analysis of Variance) to the data accumulated during the experiments. Several summarizing remarks conclude the presentation.

NAVY ENHANCED SIERRA MECHANICS (NESM) I

NAVY ENHANCED SIERRA MECHANICS (NESM) VERSION 5.0
Mr. Jon Stergiou, Naval Surface Warfare Center Carderock Division
Mr. Ray DeFrese, Naval Surface Warfare Center Carderock Division
Dr. John Gilbert, Naval Surface Warfare Center Carderock Division
Mr. Michael Miraglia, Naval Surface Warfare Center Carderock Division
Dr. Erwin Moyer, Naval Surface Warfare Center Carderock Division
Mr. Nicholas Reynolds, Naval Surface Warfare Center Carderock Division
Dr. Najib Abboud, Thornton Tomasetti
Mr. Paul Hassig, Thornton Tomasetti
Dr. Badri Hiriyur, Thornton Tomasetti
Mr. Garth Reese, J. Thomas, Sandia National Labs

Navy Enhanced Sierra Mechanics (NESM) is the DoD HPCMP CREATE Ships Shock/Damage software product providing massively parallel computational tools for ship shock and structural vulnerability predictions due to threat weapon engagements. NESM is designed to take full advantage of High Performance Computing (HPC) systems allowing for solution of models needed for high physical fidelity. The newer capabilities in NESM v5.0 include acoustic shock enhancements, coupled software scalability enhancements, and progress toward automated remeshing. Significant verification and validation efforts led to endorsement from NAVSEA 05P technical warrant holders. Upcoming capabilities are also highlighted, and the program's roadmap is discussed.

ACOUSTIC SHOCK CAPABILITIES FOR DEEP SUBMERGENCE

Dr. Nicholas Reynolds, Naval Surface Warfare Center Carderock Division
Mr. Jon Stergiou, Naval Surface Warfare Center Carderock Division
Dr. Scott Miller, Sandia National Laboratories
Dr. Garth Reese, Sandia National Laboratories

Under specific ambient conditions, underwater explosion (UNDEX) phenomena may be solved using acoustic fluid approximations which decrease time to solution and are less computationally expensive when compared to Eulerian hydrocodes. Sierra Strucutral Dynamics (Sierra/SD) includes such an acoustic fluid capability and uses an infinite element domain truncation approach. Over the past year, this capability has been extended through implementation of additional emperically-based load routines as well as a cavitating acoustic fluid capability. The acoustic fluid can provide loads to Sierra/SD via monolithic coupling, as well as to Sierra Solid Mechanics (Sierra/SM) via the Navy Standard Coupler (NSC) communication API. This talk presents an overview of the aforementioned work as well as recent acoustic verification and validation studies.

PERFORMANCE ENGINEERING IN NAVY ENHANCED SIERRA MECHANICS

Dr. John Wohlbier, U.S. DoD High Performance Computing Modernization Program
Dr. John Gilbert, Naval Surface Warfare Center Carderock Division
Mr. Jon Stergiou, Naval Surface Warfare Center Carderock Division
Mr. Michael Miraglia, Naval Surface Warfare Center Carderock Division
Mr. Paul Hassig, Thornton Tomasetti
Dr. Badri Hiriyur, Thornton Tomasetti
Dr. John Linford, ParaTools

Navy Enhanced Sierra Mechanics (NESM) is a toolbox developed by the U.S. Navy for the prediction of ship response, ship damage, and shock environments transmitted to vital ship systems due to a threat weapon encounter. NESM couples the shock capturing fluid code Navy Energetic Modeling Oracle (NEMO) with Sierra Mechanics from Sandia National Laboratory to solve fluid structure interactions (FSI) using a multiple program, multiple data (MPMD) parallel model. Production NESM calculations can contain millions of structure elements, billions of fluid elements, and span across thousands of MPI ranks. We describe the parallel coupling mechanism, and analyze code performance characteristics. We demonstate that code performance is largely determined by MPMD load balancing, mixed cell equation of state phenomena, and strided load effects. We document several code changes that have lead to nearly a factor of two improvement in the code run time.

VERIFICATION AND VALIDATION OF COUPLED FLUID STRUCTURE ANALYSES USING EPSA-NEMO

Dr. Abilash Nair, Thornton Tomasetti
Mr. Corbin Robeck, Thornton Tomasetti
Dr. Badri Hiriyur, Thornton Tomasetti
Mr. Adam Hapij, Thornton Tomasetti
Dr. Najib Abboud, Thornton Tomasetti

NEMO is a massively parallel Eulerian hydrocode that can model shock and explosive effects in fluid domains. EPSA is an explicit finite element code that can model dynamic response and failure of shell structures. EPSA and NEMO have been coupled using the Navy Standard Coupler (NSC) to solve coupled fluid/structure problems involving the impact of shock on naval structures. In this talk, we present the results of preliminary verification and validation studies that have been carried out using EPSA-NEMO.

DEDICATED SESSION: VEHICLE BORNE IED RESEARCH & TESTING II

VEHICLE BORNE IED HME AIRBLAST EQUIVALENCY TESTING AND ANALYSIS

Dr. Jay Ehrgott, USACE - Engineer Research and Development Center
Mr. Joshua Payne, USACE - Engineer Research and Development Center
Dr. Kyle Crosby, USACE - Engineer Research and Development Center
Mr. Daniel Vaughan, USACE - Engineer Research and Development Center
Mr. Denis Rickman, USACE - Engineer Research and Development Center
Dr. Jon Windham, USACE - Engineer Research and Development Center

Vehicle-borne improvised explosive devices (VBIEDs) are a significant threat to U.S and Allied forces in areas of conflict worldwide. The detonation of these devices has the potential to cause significant casualties as well as severe and catastrophic damage to structures and support facilities. How this threat is used in an attack and the explosive charge utilized in these devices continue to evolve. These devices are commonly packed with some form of easily accessible Homemade Explosive (HME) mix that is detonated using a wide range of methods/mechanisms. In order to improve our understanding and characterization of these HME VBIED threats, the National Ground Intelligence Center (NGIC), the Department of Homeland Security, the U.S. Army Engineer Research and Development Center (ERDC) and the U.S. Naval Surface Warfare Center's (NSWC) Indian Head conducted carefully controlled experiments with some of the common HMEs used in these events. As part of this research, a series of airblast equivalency tests were conducted using several of the widely proliferated HME explosive mixtures including fertilizer-based ANFO, a potassium chlorate diesel mix, and a urea nitrate mix. This paper presents the test layout and test results and compares the airblast environments captured in these equivalency tests for these HMEs ranging in charge mass from 15 to 200 lbs. Comparisons of the airblast environments captured from several of the larger VBIED HME test events with charge masses ranging from 200 to 10,000 lbs are also presented.

NEAR-FIELD AIRBLAST CHARACTERIZATION OF UNCONFINED HOMEMADE EXPLOSIVES

Dr. Andreas Frank, USACE - Engineer Research and Development Center
Dr. Jay Ehrgott, USACE - Engineer Research and Development Center
Mr. Steven Turner, USACE - Engineer Research and Development Center
Mr. Donny Guynes, USACE - Engineer Research and Development Center
Mr. Sonny Johnson, USACE - Engineer Research and Development Center
Mr. Neill Stephens, USACE - Engineer Research and Development Center
Mr. Jim Hall III, USACE - Engineer Research and Development Center
Mr. Billy Bullock, USACE - Engineer Research and Development Center
Mr. Tom Carriveau, USACE - Engineer Research and Development Center

The threats from Improvised Explosive Devices (IEDs) continue to grow around the world. The threats range from shallow-buried IEDs to personnel IEDs and large vehicle-borne IEDs, all utilizing various existing and new homemade explosive (HME) formulations. There is a significant need to expand the current capability to characterize the loads and loading distributions from the detonation of emerging HMEs and non-ideal explosives used in IEDs to improve our understanding of these threats and advance our ability to model these loads in the development of protective systems. The U.S. Army Engineer Research and Development Center is conducting research under the Adaptive Simulation to Characterize Emerging Non-Ideal Threats Program to improve our understanding of the physics, scalability, and spatial loading distributions of various non-ideal explosives. The research is focused on developing and

improving constitutive models for non-ideal explosives in shock-physics codes. The goal is to improve the accuracy and flexibility of explosive models used for these current and emerging HME threats to account for significant differences in the burn rate, shock front, and confinement effects when compared to current ideal explosive models. Well-characterized and highly instrumented experiments were conducted using widely proliferated HME explosive mixtures including Anfo, AN/Al, and KCL. The experimental layout, test results, and results from CTH hydrocode calculations compared with the experimental data will be presented.

SPHERICAL EQUIVALENCY OF ELLIPSOIDAL CHARGES IN FREE AIR

Dr. Kyle Crosby, USACE - Engineer Research and Development Center
Dr. Andreas Frank, USACE - Engineer Research and Development Center
Mr. Denis Rickman, USACE - Engineer Research and Development Center
Mr. Joshua Payne, USACE - Engineer Research and Development Center
Mr. Daniel Vaughan, USACE - Engineer Research and Development Center
Dr. Jay Ehrgott, USACE - Engineer Research and Development Center

Although explosive charges used in commercial and military applications and employed in terrorists' attacks worldwide are created in a variety of shapes, spherical or hemispherical charges are assumed for almost all of the calculations used to predict blast effects from these threats. Several studies have shown that charge shape can have a significant effect on the peak incident overpressure and impulse generated from an explosion. However, all of the studies investigating the effects of charge shape have focused on cylindrical-shaped charges, which have very complex blast-wave patterns that make it difficult to quantify a spherical equivalency for pressure and impulse. This work investigates ellipsoidal charges of different length-to-width ratios using the shock physics code CTH. Like spherical charges, ellipsoidal charges have only gradual changes in geometry that promote less turbulent blast waves that are simpler to analyze. The results of the numerical simulations are used to determine spherical equivalencies for incident overpressure and impulse. The results are also compared to experimental data from a series of vehicle-borne improvised explosive device (VBIED) tests conducted by the National Ground Intelligence Center (NGIC), the Department of Homeland Security (DHS), and the U.S. Army Engineer Research and Development Center (ERDC) that measured incident overpressures from a variety of charge configurations.

NUMERICAL ANALYSIS OF THE EFFECTS OF BARRIER WALL SHIELDING ON DYNAMIC PRESSURE AND IMPULSE FROM A DETONATION

Dr. Kyle Crosby, USACE - Engineer Research and Development Center
Dr. Andreas Frank, USACE - Engineer Research and Development Center
Mr. Denis Rickman, USACE - Engineer Research and Development Center
Mr. Joshua Payne, USACE - Engineer Research and Development Center
Mr. Daniel Vaughan, USACE - Engineer Research and Development Center
Dr. Jay Ehrgott, USACE - Engineer Research and Development Center

Concrete and earth-filled barriers are commonly used to protect civil and military infrastructure from attacks employing vehicle-borne improvised explosive devices (VBIEDs). Blast barriers provide protection by increasing the standoff distance between the VBIED charge and infrastructure and by providing a physical barrier to impede the blast pressures and vehicle fragments generated from the VBIED charge and host vehicle. The reduction in blast pressures behind a barrier wall is referred to as blast shielding, and a number of studies have addressed the effects of blast shielding on incident pressure and impulse. The effect of blast shielding on dynamic pressure and impulse has largely been

ignored, although it is primarily responsible for vehicle overturning and contributes to the reflected pressure loading on structures. This work investigates the effects of barrier wall shielding on the dynamic pressure and impulse using the shock physics code CTH. The results of the numerical simulations are then compared to experimental data from a series of VBIED tests conducted by the National Ground Intelligence Center (NGIC), the Department of Homeland Security (DHS), and the U.S. Army Engineer Research and Development Center (ERDC) that measured incident and total pressures behind barrier walls of various sizes.

FERRET DATA COLLECTION METHODOLOGIES FOR FORENSIC ANALYSIS OF SMALL ARMS AND PROPELLED MUNITIONS

Mr. Cameron Thomas, USACE - Engineer Research and Development Center
Dr. Jay Ehrgott, USACE - Engineer Research and Development Center
Dr. Kyle Crosby, USACE - Engineer Research and Development Center
Mr. Denis Rickman, USACE - Engineer Research and Development Center

The need for quickly and accurately identifying the weapon systems used in attacks against mounted U.S. and Allied forces is of critical importance both for implementing effective tactics, techniques, and procedures (TTPs) and for designing protection schemes to mitigate the threat. In order to address this need, the National Ground Intelligence Center (NGIC) tasked the U.S. Army Engineer Research and Development Center (ERDC) with developing forensic analysis tools and technologies to enable the Army to quickly identify weapon systems used in attacks based on post-blast forensic signatures. The Forensic Encyclopedia Results Retrieval and Evaluation Tool (FERRET) program addresses this task by performing carefully controlled firings of various weapon systems against armor targets. Data collection consists of all the weapon signatures, including munition and target photographs, residual munition fragments, and chemical and paint samples. The collected data are stored in a searchable, network-accessible database. This paper presents the data collection methodologies developed under the FERRET program, which are used to collect data during controlled experimental conditions or at an attack scene.

VIBRATION II

STATISTICAL COMPILATION OF SOUNDING ROCKET FLIGHT VIBRATION ENVIRONMENTS

Dr. Ricky Stanfield, Northrop Grumman Technology Services

Sounding rocket class vehicles offer a low-cost option for access to space. However, they generate intense flight vibration environment for instruments and systems to endure and survive. Vibration loads and spectral content differ between the thrust and lateral axes and one's relative location in the vehicle. They also vary in intensity proportionally with the flight dynamic pressures of the rocket. For new sounding rocket vehicle configurations, one can estimate the potential overall flight vibration conditions by comparing the relative dynamic pressures of vehicles with similar geometry, and scaling up the known spectra by the resulting ratio. While overall root mean squared vibration levels tend to trend with flight dynamic pressure, the spectral content is usually unique to the vehicle configuration. The task of anchoring the reference spectrum is complicated. In many sounding rocket applications, payload configurations differ from mission to mission, even if the motor stack is common to a set of vehicles. This is especially true for scientific rockets. In these cases, the spectral content can vary quite widely, even though the overall power in the signal will be consistent with like vehicles. In other applications, the payloads and the vehicles have been sufficiently similar to show very consistent spectral features between multiple rockets. Two sets of sounding rockets have been studied for their flight vibration spectra and levels. The first is a set of NASA Terrier – Black Brant rockets, which had a common motor

stack, but where the payloads were similar though not identical. More recently, a new set of Navy Terrier – Oriole rockets has been studied. These vehicles have been practically identical in motor stack and payload geometry. This paper discusses the process of identifying the maximum and mean Power Spectral Density (PSD) of the flight vibration environment from spectrogram results, the use of Normal Tolerance Level (NTL) processes for statistically combining the PSD profiles from different missions into a aggregate PSD profile, the combination of thrust and lateral spectra to define a single PSD for test definition purposes, and the scaling up of the resulting spectra to introduce margins into acceptance and qualification test levels. Processing these two sets of vehicle vibration signatures helps highlight the role that vehicle geometry plays in flight vibration spectra. This process has also results in a robust description of the vehicle flight environment, the ability to substantiate test levels based on flight results, and the flight data needed to continue trending the relationship between flight vibration loads and the aerodynamic environment.

A NEW METHOD OF PSD ESTIMATION

Mr. Philip Van Baren, Vibration Research
Mr. Joel Minderhoud, Vibration Research
Mr. Jacob Maatman, Vibration Research

It is vital that a random test consistently meets power spectral density (PSD) requirements throughout the test. By nature, random averaging requires time to present in-tolerance and smooth spectral lines. This article discusses Vibration Research's newly developed method of PSD estimation, iDOF®, which provides an accurate and smooth PSD estimate without requiring traditional averaging time. This is the best method available to ensure that a random vibration test meets PSD requirements throughout the test.

VIBRATION SPECIFICATIONS OF A SUPERSONIC MISSILE

Mr. Matan Mendelovich, RAFAEL

Building vibration specifications for a laboratory simulation of a supersonic missile's free flight phase is complicated for some reasons. In contrast to subsonic flight, where the maximal vibration level (caused by the turbolent flow) is reached at the maximal dynamic pressure, when the missile's speed crosses the supersonic (and transonic) point, the flow-induced vibration level decrease significantly (up to 2000[Hz]).

When a light-weight supersonic missile is launched from a ground launcher, it goes through the subsonic stage for a very short time, and then through the supersonic stage.

Since the vibration measurements are not always taken at the most "violent" launch scenario, it is difficult to estimate how to simulate the most violent conditions in the flight envelope, based on the measured scenario. The estimation becomes more complicated since a major part of the flight is at supersonic speed.

The presentation contains a short introduction about the missile, modal analysis of the missile and how the information about the modal behavior of the missile helped building the vibration test specifications, in order to demonstrate the missile's durability under vibration test in the laboratory.

REVISED NAVY SHOCK TEST REQUIREMENTS

BASIC STRUCTURE AND FEATURES OF MIL-DTL-901E FOR USE ON SURFACE SHIPS, CARRIERS, AND SUBMARINES

Dr. Christopher Merrill, NAVSEA

MIL-S-901D has been the basic requirements document for all equipment high impact shock testing performed on Navy submarines and surface ships since issued in 1989. In the 28 years since, gaps have been identified due to advancements in new technologies, process clarification, and efficiencies based on lessons learned. Navy organizational structure, terminology, and shock test practices have changed as well. For these reasons, MIL-S-901D has been revised to MIL-DTL-901E. 901E reflects current Navy needs and shock test technology by integrating Navy cost reduction strategies from submarine shock testing 901D interim change documents, Navy cost reduction initiative clarification letters and cost reduction strategies, and additional cost reduction provided by the Deck Simulating Shock Machine (DSSM) into a Navy shock test requirements document. 901E is consistent with Navy current organization structure, accepted Navy terminology, and approved Navy shock test practices tailored to meet Navy Joint Forces document instructions. This paper provides a brief description of 901E, a summary comparison of new features and returning processes, and potential 901E use with current Navy documents.

BASIC STRUCTURE AND FEATURES OF T9072-AF-PRO-010 FOR USE ON SURFACE SHIPS AND CARIERS

Dr. Christopher Merrill, NAVSEA

NAVSEAINST 9072.1A is a document that was published in 1989, and redefined responsibilities and technical policy for shock hardening of surface ships in accordance with OPNAVINST 9072.2. OPNAVINST 9072.2 was published in 1987, and was modernized and released by OPNAV as OPNAVINST 9072.2A in February 2013. OPNAVINST 9072.2A is consistent with current Navy terminology and organizational structure and recognizes various analytical process improvements, test method improvements, ship shock certification, and cost reduction processes developed in equipment qualification, ship shock testing, and ship shock hardening certification methods since 1987 . T9072-AF-PRO-010 establishes processes for execution of OPNAVINST 9072.2A policies, including processing of equipment shock qualifications, management of shock qualification non-compliances, shock risk assessment strategies, and technology advances in item shock qualification processes. This paper provides a brief description of T9072-AF-PRO-010 for use in surface ship and carriers, a summary comparison of new features and returning processes from the NAVSEAINST, and potential use of T9072 with current Navy documents.

MECHANICAL SHOCK III

SUBSIDIARY SHCOK TESTING OF A CIRCUIT CARD ASSEMBLY UTILIZING AN ELECTRODYNAMIC SHAKER

Mr. Sloan C. Burns, NSWC Dahlgren

A specialized case of MIL-S-901 shock qualification by extension utilizing subsidiary shock testing will be presented. A structurally similar but modified circuit card assembly (CCA) underwent theoretical and experimental modal analysis to identify the frequency range of interest. Modal analysis was used to justify a limited frequency subsidiary shock test. Data captured on the CCA foundation during Floating Shock Platform qualification testing was filtered to produce a shock pulse capable of replication on an

electrodynamic shaker, while preserving the shock severity at frequencies of interest identified by modal analysis.

The work presented will review caveats which allow subsidiary shock testing for this specialized case. Results of the modal analysis study will highlight the technical justification for conducting a limited frequency subsidiary shock test. The filtering scheme used to attenuate non-damaging frequencies will be presented. The filtering scheme allows for the shock severity in the frequency range of interest to be preserved while attenuating frequencies which contribute to the large displacement quasi-static response.

NSRP SHOCK AND VIBRATION QUALIFICATION TESTING OF FLEXIBLE INFRASTRUCTURE BULKHEAD TRACK
Mr. Mike Poslusny (Huntington Ingalls Industries)

Flexible Infrastructure is a system of foundations that provide capabilities for rapid space changes without the use of "hot work." These systems will maximize time for technology development prior to equipment installation during construction outfitting, eliminate cost and schedule impacts associated with the traditional conflicts from re-work and change orders during new construction, and ease compartment reconfiguration to support changing missions and lifecycle refresh of electronic components.

The concept for Flexible Infrastructure (FI) started as part of the early design studies for the new CVN 78 class of Aircraft Carriers. In 2003, NAVSEA tasked Newport News Shipbuilding (NNS) to explore concepts for compartment modularity to support the design of the warfare system for the new class. During this stage of ship and system design, the Operational Requirements Document (ORD) for the CVN 78 class was developed and contained requirements for reconfigurable spaces for warfare systems. These requirements drove the need for an interface between warfare systems and the ship that allowed quick equipment relocation and new technology insertion. Newport News Shipbuilding has qualified multiple configurations of Flexible Infrastructure systems for 8Hz, 14Hz and 25Hz applications aboard CVN class ships. By recognizing extendable configurations that were previously qualified and testing unique FI configurations; this NSRP project, with team members of HII-Ingalls Shipbuilding and HII-Newport News Shipbuilding, intends to qualify FI for use aboard DDG, LPD and LHA class ships.

Shock testing was performed at NTS in 2015. Successful outcomes from the shock test determined stud spacing, installation techniques and attachment methods. Successful attachment configurations were initially vibration tested in Spring, 2016. Several failures occurred. Ingalls personnel modified attachment methods and ruggedized several test configurations, along with changing the range to 4 – 25Hz. A retest was performed in February, 2017. Results from the vibration tests and final bulkhead track / attachment methods will be discussed in this presentation.

MEDIUM WEIGHT SHOCK TEST OF A SUPERBOLT EXPANSION BOLT: MODELING AND DESIGN
Mr. Matthew Davis, Newport News Shipbuilding
Dr. Michael Talley, Newport News Shipbuilding
Mr. Jeremy Tucker, Newport News Shipbuilding
Mr. Kevin Lafountain, Newport News Shipbuilding

The use of expansion bolts in commercial industry has been a mainstay for decades. Expansion bolts provide diametric fit through a mechanical wedging effect, that occurs as the bolt assembly is torqued across a connection. Typically, this bolt design allows for a greater relief in the required bolt and hole

tolerances because of the ability of the mechanical wedge to make up the difference. This is particularly true when compared with traditional fitted bolt connections, which require a tedious drilling and installation process that can be costly and time consuming. It has been shown that due to the ease of installation, the use of expansion bolts can provide significant cost benefits for traditional fitted bolt machinery foundation applications. The purpose of this effort is to evaluate the shock performance of the SuperBolt expansion bolt in shear, in order to add to the body of knowledge and address existing NAVSEA concerns for use in Navy applications. Part I provides an overview of the concerns, the development of a non-standard fixture for testing a single SuperBolt in shear on the Medium Weight Shock Machine, and an overview of the test plan. Part II provides an overview of the shock test and the nondestructive and destructive post-test examinations that were conducted by Newport News Shipbuilding. Insights, conclusions, and recommendations are provided.

MEDIUM WEIGHT SHOCK TEST OF A SUPERBOLT EXPANSION BOLT: FINDINGS AND RECOMMENDATIONS

Mr. Matthew Davis, Newport News Shipbuilding
Dr. Michael Talley, Newport News Shipbuilding
Mr. Jeremy Tucker, Newport News Shipbuilding
Mr. Kevin Lafountain, Newport News Shipbuilding
Mr. Steve Arturo, Newport News Shipbuilding

The use of expansion bolts in commercial industry has been a mainstay for decades. Expansion bolts provide diametric fit through a mechanical wedging effect, that occurs as the bolt assembly is torqued across a connection. Typically, this bolt design allows for a greater relief in the required bolt and hole tolerances because of the ability of the mechanical wedge to make up the difference. This is particularly true when compared with traditional fitted bolt connections, which require a tedious drilling and installation process that can be costly and time consuming. It has been shown that due to the ease of installation, the use of expansion bolts can provide significant cost benefits for traditional fitted bolt machinery foundation applications. The purpose of this effort is to evaluate the shock performance of the SuperBolt expansion bolt in shear, in order to add to the body of knowledge and address existing NAVSEA concerns for use in Navy applications. Part I provides an overview of the concerns, the development of a non-standard fixture for testing a single SuperBolt in shear on the Medium Weight Shock Machine, and an overview of the test plan. Part II provides an overview of the shock test and the nondestructive and destructive post-test examinations that were conducted by Newport News Shipbuilding. Insights, conclusions, and recommendations are provided.

HIGH IMPACT SHOCK TESTING OF LITHIUM ION BATTERIES

Ms. Janet Bivens, NUWC Newport
Ms. Monica Black, NUWC Newport

Lithium ion (Li-ion) batteries provide a high-endurance energy source for a variety of naval applications. Several Li-ion battery modules were tested at the Naval Undersea Warfare Center Division, Newport (NUWCDIVNPT) on a Medium Weight Shock Machine (MWSM). This paper covers the efforts required to safely and accurately test Li-ion battery modules for high impact shock sensitivity. The test unit was designed to create a representative environment for the battery modules, and used a combination of actual and dummy hardware. Details include the development of the test plan and safety procedures, as well as the actual test conduct, results, and lessons learned.

NAVY ENHANCED SIERRA MECHANICS (NESM) II

NAVY ENERGETIC MODELING ORACLE (NEMO) IMPROVEMENTS

Dr. John Gilbert, Naval Surface Warfare Center Carderock Division
Mr. Paul Hassig, Thorton Tomasetti
Dr. Badri Hiriyur, Thorton Tomasetti
Mr. Michael Miraglia, Naval Surface Warfare Center Carderock Division
Mr. Jon Stergiou, Naval Surface Warfare Center Carderock Division

The Navy developed and released a new hydrocode, the Navy Energetic Modeling Oracle (NEMO), last year as part of the CREATE Ships Shock/Damage toolkit. NEMO is a robust, scalable Eulerian hydrocode which couples to Sandia National Laboratories' Sierra Mechanics suite (Sierra/SM and Sierra/SD) for fluid-structure interaction (FSI) problems via an embedded boundary methodology developed at Stanford University. This paper presents an update on the technical capabilites offered in the current release of NEMO, improvements in algorithms and methods, and discusses future planned efforts related to the development and deployment of NEMO as a component of the Navy Enhanced Sierra Mechanics (NESM) toolkit.

NAVY ENHANCED SIERRA MECHANICS (NESM) AUTOMATED REMESHING TOOL

Mr. Michael Miraglia, Naval Surface Warfare Center Carderock Division
Mr. Ray DeFrese, Naval Surface Warfare Center Carderock Division
Dr. John Gilbert, Naval Surface Warfare Center Carderock Division
Dr. Erwin Moyer, Naval Surface Warfare Center Carderock Division
Dr. Nicholas Reynolds, Naval Surface Warfare Center Carderock Division
Mr. Jon Stergiou, Naval Surface Warfare Center Carderock Division
Dr. Garth Reese, Sandia National Laboratories
Dr. Jesse Thomas, Sandia National Laboratories

The Navy Enhanced Sierra Mechanics (NESM) team is working on an Automatted Remeshing capability (ARM) that aims to reduce the laborous process of model refinement. A succesful ship shock analysis or structural vulnerability prediction is contingent on Finite Element Models that provide a good description of structural response caused by weapons effects loading. Unfortunately the modeling requirements depend strongly on the type of analysis performed. For example, the required refinement for predicting shock environments is generally less than the required refinement for predicting severe damage environments. FEMs therefore need to be tailored to meets the needs of each analysis they are used for and the process of FEM construction is laborious and expensive. The ARM software tool is aimed at reducing these expenses by automating parts of the refinement process. The ARM tool will be released as a Beta capability as part of NESM 6.0 (April 2018).

FRAMEWORK FOR A STREAMLINED WORKFLOW AND THE FUTURE ROLE OF THE ANALYST

Dr. Nicholas Reynolds, Naval Surface Warfare Center Carderock Division
Mr. Michael Miraglia, Naval Surface Warfare Center Carderock Division
Mr. Jon Stergiou, Naval Surface Warfare Center Carderock Division

With the existance of queryable model databases, the development of codifiable best modeling practices, and the availability of scripting languages and high performance computing platforms, the present is rife with opportunities to streamline common workflows in the world of modeling and

simulation for shock testing. This talk presents a possible framework for automating modeling and simultion for these applications. It addresses steps that would be required to migratie in this direction. It also highlights technical, logistical, and existential considerations for the community of analysts.

MULTIPLE PROGRAM MULTIPLE DATA FSI COUPLING OF STRUCTURAL DYNAMICS (SIERRA-SD) AND UNDEX (NEMO)
Dr. Lynn Munday, Sandia National Labs
Dr. Gregory Bunting, Sandia National Laboratories
Dr. Scott Miller, Sandia National Laboratories
Mr. Jon Stergiou, NSWC Carderock

Sierra/SD is a production structural dynamics code developed and maintained at Sandia National Laboratories. NEMO is a production underwater explosion (UNDEX) simulation code developed and maintained at NSWC Carderock Division. A fluid structure interaction (FSI) algorithm was implemented to facilitate coupling communication between the codes. The algorithm is based upon communication flags which permit each code to request certain actions, e.g., time step advancement, information passing, or output generation, from the other. Communication is done in an all-to-all pattern via MPI in a multiple program, multiple data (MPMD) model. Results presented include a 465-processor coupled analysis run of a large U.S. Navy surface ship with over 3 million structural elements and nodes and 25 million fluid elements.

STRUCTURAL RESPONSE OF GROUND AND MECHANICAL STRUCTURES

MODELING NONLINEAR ROLLER-SPRING KINEMATICS WITH A HYPERELASTIC MATERIAL
Dr. Emily Guzas, NUWC Newport

This presentation discusses the development of a numerical model of a roller and spring assembly that exhibits nonlinear load-displacement response. The hardware includes a roller, roller bracket, leaf spring, leaf spring supports, and an adjusting bolt that works as a mechanical stop for the leaf spring. The load-displacement response of the entire assembly is bilinear, with an initially very stiff response that quickly transitions into a softer response. As a way of achieving the desired load-displacement response without introducing unnecessary model complexity (contact, adjusting bolt preload, explicit modeling of numerous small parts, etc.), the combined action of the leaf spring and roller adjusting bolt is modeled using a hyperelastic material for the leaf spring. The presentation discusses model development and calibration to desired nonlinear load-displacement data.

RESPONSE OF ADOBE STRUCTURES SUBJECTED TO INTERNAL BLAST LOADS
Dr. Bryan Bewick, AFRL Munitions Directorate
Mr. Brandon Taylor, AFRL/RWML
Mr. Ernie Staubs, AFRL/RWML

The response of fixed target structures subjected to the synergistic loading of airblast and fragmentation from cased munitions is of great interest for targeting and munition development efforts. Adobe and brick structures account for 30.5% of existing structures worldwide. However, methodologies for predicting structural response of adobe structures are not well-validated for internal detonation loading scenarios. The highlighted effort discusses a set of validation experiments performed on adobe walls in a replica bunker with an internally placed explosive charge. The test articles were instrumented for response metrics (deflection, debris velocity, etc.) and tested for residual load-bearing capacity post-blast loading. Test results are presented and compared against the existing approaches for predicting

structural response adobe walls including SDOF, engineering level fast-running models (FRMs), and finite element (FE) analyses.

MULTI-STRIKE BREACH AND SPALL PREDICTION IN REINFORCED CONCRETE WALLS

Dr. George Lloyd, ACTA Inc.
Dr. Wije Wathugala, ACTA Inc.
Mr. Ryan Schnalzer ACTA Inc.
Mr. Casey Meakin, Karagozian & Case Inc.
Mr. Joe Magallanes, Karagozian & Case Inc.
Mr. Joseph Abraham, Karagozian & Case Inc.

Lethality assessment and vulnerability analysis of above ground and buried reinforced concrete hard targets is a standard weaponeering problem. The problem is complex since damage can occur from close-in coupled shock effects, large gas pressures from confinement, and from primary fragment impacts. Important damage consequence metrics include localized spall (tensile failure induced by reflected stress waves), and the development of local or disseminated venting and breaching. Capturing this large range of damage phenomenology in a reduced parameter space is difficult, but existing correlations based upon a large number of tests over the years adequately address the problem. However a methodology to address the effects of multiple strikes and hits is needed. Several developments pertaining to RC hard targets have taken place during the last two decades that can potentially lead to new and important insights for this damage prediction problem. First, the capabilities of high-fidelity physics-based (HFPB) codes to comprehensively simulate the wall and slab responses have improved to the point where such codes can be considered "validated" for many applications. Indeed, for specialized weaponeering applications, where the time and cost of performing dedicated HFPB simulations is not a concern, predictions can be based solely on such codes. Second, and related, a number of fast running and/or reduced-order models have been formulated and trained using HFPB results as "virtual" experiments. These "FRMs" are capable of improved predictions for an increased number of degrees of freedom. In this paper we examine the use of these new capabilities for rapid predictions for multi-strike scenarios.

EXPERIMENTAL DOOR RESPONSE RESULTS FROM MULTIPLE CHARGES

Mr. Roosevelt Davis, AFRL
Capt. Brian Lagrange, AFRL

Door response can be important when the need arises to gain entry to a facility or within the facility. The capability currently exists to overcome multiple door designs that could be encountered inside structures of interest. Current options typically involve large munitions with the ability to completely overwhelm doors. This discussion will investigate using much smaller charges, with obvious limitations, in an effort to achieve the desired door responses to aid in facilitating access into or throughout structures of interest.

A one room test structure has been designed and constructed to conduct both external and internal testing of door. It has been used for execution of blast experiments. The one room structure is robust enough to provide confinement of airblast while rigidly holding a selected door in place. There are five experimental configurations consisting of single or multiple charges at different orientations with respect to the door. Detonations of multiple charges are simultaneous. An experiment is also conducted with single charge sequential detonations for cumulative damage. Measurements of pressure are collected throughout the structure during experiments. The one room structure is outfitted with

reference measurement positions meant to determine airblast loads the chosen door would experience. There is also the capability to deploy high speed cameras observing the structural response for the door. Discussions will consist of a review of the experiments coupled with experimental results. Details of the experiments relative to charge placement, charge size, and charge type will be provided. Pressure data from the experiments will be analyzed and evaluated. High speed camera data capturing the transient door response will also be discussed.

EXPLOSIVE REMOVAL OF UPHEAVAL USING SHAPED CHARGES

Mr. Stephen Turner, USACE - Engineer Research and Development Center
Dr. Jay Ehrgott, USACE - Engineer Research and Development Center
Mr. Denis Rickman, USACE - Engineer Research and Development Center

Researchers at the U.S. Army Engineer Research and Development Center (ERDC) have conducted research under the Airfield Damage Repair (ADR) Modernization Program to develop new, expedient concrete pavement repair techniques and to update repair guidance for military airfields. The time that a damaged runway is removed from service must be reduced using fast methods and durable materials to reduce lost operational time and subsequent maintenance time. In the event that runway craters occur due to the detonation from enemy ordinances, rapid runway repair is required. One of the major time-consuming steps in the runway repair methodology is cutting the damaged concrete area using mechanical methods such as concrete saws. The Air Force Civil Engineer Center tasked ERDC to investigate if these mechanical methods could be replaced with explosive methods. A literature review was conducted to determine typical runway design and crater dimensions. After C4 experiments were conducted with inadequate results, commercially-available shaped charges were tested and proved more promising. Results showed that these shaped charges will penetrate through a typical runway, and, when placed at proper spacing, interconnecting cracking of the concrete and minimal surface spall will occur.

DEDICATED SESSION: MECHANICAL SHOCK – INSTRUMENTATION, MODELING, & SIMULATION I

THE EFFECT OF POTTING MATERIAL ON THE MECHANICAL RESPONSE OF THE ELECTRONIC COMPONENTS OF THE PINE FIRESET TO AN IMPACT LOAD

Dr. Catherine Florio, US Army ARDC
Dr. Jennifer Cordes, US Army ARDEC

The PINE fireset is part of a family of firesets intended to be embedded within the explosive fill of a warhead. With its small size and potential need to withstand the loads induced by target impact, the selection of a potting material that allows for ease of manufacturing while providing the necessary support to the electronics can be challenging. In this work, comparisons are made of the mechanical response of the electronic components a PINE fireset under an impact-type load when filled with viscoelastic, hyperelastic, or porous foam potting materials. Insight is provided into the reasons behind the observed differences and the potential effects on the function of the device.

COTS RECORDER ADAPTED FOR USE IN HIGH-G EMBEDDED ENVIRONMENT
Mr. James Scheppegrell, AFRL Fuzes Branch / ARA ECD

AFRL's research activities in embedding firesets into the explosive material require measurement of the embedded environment during hard target attack. Current approaches in sub-scale tests use hard wiring between the embedded unit and a high-G recorder in the aft end of the penetrator. In harsher environments (higher impact velocities, harder target) such an approach is not reliable. It has become clear that embedding the recorder with the fireset would solve many issues. In this paper we discuss an approach to shock harden a small COTS recorder with excellent performance, and the design to mount it in the embedded assembly. Results for both survivability and accuracy are discussed.

UNDEX III

COMPARATIVE STUDY ON SHOCK RESPONSE ANALYSIS WITH UNDEX EXPERIMENTAL DATA USING DOWN-SCALED SUBMERGED SHIP MODEL
Dr. Jeong-Il Kwon, Korea Institute of Machinery and Materials
Dr. Seok-Jun, Moon, Korea Institute of Machinery & Materials
Dr. Jung-Hoon, Chung, Korea Institute of Machinery & Materials
Mr. Jin-Woo, Park, Korea Institute of Machinery & Materials

Many Modeling & Simulation code is used for the analysis of the effects of an underwater explosion on their own naval ship. But to enhance the reliability of these analysis results, the validation course should be needed basically by the process of comparison with the calculated responses and measurements from the real shock experiment using real or down-scaled naval vessel. For the purpose of this research, last year we conducted a study on underwater explosion test using down-scaled surface ship model. In this study, we present the results of a real UNDEX test using down-scaled submerged ship model and the comparative analysis result.

THE CHARACTERISTICS OF LOADING OF THE CONTACT UNDEX OF TNT
Prof. Jianhu Liu, China Ship Scientific Research Center

The contact UNDEX is one of the most disastrous threats to a naval architecture. As the huge high pressure that causes very strong nonlinearity and of very different characteristics compared with the medium and far field UNDEX, the loading characteristics of that is not very clear to the most naval architecture designer that has badly impeded the advancing on the technology of the protection structure. In this paper, the investigations on the characteristics of the contact UNDEX of TNT explosive were executed by the numerical and experimental method. The loading model was proposed and the driving effect to the steel plate was analyzed. The pressure value, and the time decaying constants from the loading model were well coincident with the loading model and the velocity of flying fragments predicted by the loading model was also of good precision compared with the test results. The results can be used to the design and evaluation of the naval protection structure.

FLUID-STRUCTURE INTERACTION ON AN AIR-BACKED PLATE SUBJECTED TO STRONG SHOCK WAVE BY CLOSE-IN UNDERWATER EXPLOSION

Mr. Zhangtao Zhou, China Ship Scientific Research Center

Fluid-structure interaction of strong shock wave and plate is investigated by theoretical method. Considering the fluid and structural material compressibility, the reflected wave front parameter and reflection coefficient are obtained by introducing state of equation of water and structural material. Then, according to the law of conservation of momentum, the motion equation of the plate is established, then the wet-surface pressure and velocity history of the plate are obtained. Finally the theoretical approach on the fluid-structure interaction is verified with underwater explosion experiment and numerical calculation. The results show that the theory method is in good agreement with the experimental and numerical results. The method provides the theory basis for the research on the loading and dynamic damage problems of the naval underwater protection structures to the close-in underwater explosion.

RESEARCH ON THE COUPLING DAMAGE OF SURFACE SHIP STRUCTURES TO UNDERWATER EXPLOSIONS

Dr. HaiKun Wang, China Ship Scientific Research Center

When a surface ship is attacked by a nearby underwater explosion, a severe damage may be caused including the local and the whole one. The local damage can be presented by a hole or a huge deformation that usually can't cause sinking for a ship of design excellent of floodability. However, the whipping motion of hull girder, defined as whole damage, induced by underwater noncontact explosion can cause hull girder buckling, tearing, or even loss of whole strength, the serious consequences can be catastrophic. Also the local and the whole damage of a surface ship to UNDEX had been widely investigated for a long time, the coupling effects were not deeply concerned yet. In the paper, based on the Taylor plate theory and the rigid-plastic material model, the local damage of hull structure was investigated. The classical two-dimensional hull girder method by considering the modified damping model was adopted to research the whipping responses and damage caused by a nearby UNDEX. On this basis, the coupling characteristics of local damage and whole damage of hull structures were presented. It was shown that the local damage seriously affected the whole damage that mainly caused by bubble of UNDEX. The research results can provide references for the optimizing of attack modes of underwater weapons and the improving of damage effects to targets.

THE COUPLING DAMAGE EFFECT OF YIELD AND BUCKLING OF A RING-STIFFENED CYLINDER TO UNDERWATER EXPLOSIONS

Dr. Jun Wang, China Ship Scientific Research Center

The damage of the ring-stiffened cylindrical shell structures to underwater explosion (UNDEX) is one of the most major problems which submarine designers concerns about. Sever damage models such as shell rupture, shell sunken and local or whole buckling will occur for the ring-stiffened cylindrical shell structures under the combined loads of the hydrostatic pressure and the underwater explosion pressure. In above damage models, every single damage model was widely investigated, and the coupling effect on the damage models were seldom deeply investigated. In this paper, the coupling effect of structural yield and bulking damage was investigated through theoretic method to reveal the damage mechanism of the ring-stiffened cylindrical structures to the UNDEX. The results can be used for better prediction and evaluation of the damage of the deep sea structures to noncontact UNDEX.

DEDICATED SESSION: DYSMAS & UNDEX LOADING

DYSMAS STATUS, RECENT ACCOMPLISHMENTS, AND PLANS (DISTRO D)
Mr. Greg Harris, NSWC Indian Head EOD Technology Division

DYSMAS is a fully-coupled hydrocode for the simulation of underwater explosion phenomena and their effects on nearby structures. It is the most extensively validated tool for this application. This talk will provide an update on recent features added to DYSMAS for Navy, Army, and critical national infrastructure programs. The impact on several recent major DoD programs, including the LCS full ship shock trials and the Army Blast Protection Institute, will be highlighted. Finally, ongoing code development work and near term plans will be described.

VERIFICATION AND VALIDATION STUDIES USING ABAQUS/GEMINI
Dr. Chris Abate, General Dynamics Electric Boat

Abstract pending public release

DYSMAS MODELING OF BURIED BLAST AND STRUCTURAL RESPONSE
Dr. Thomas McGrath, Naval Surface Warfare Center Indian Head
Mr. Roger Ilamni, Naval Surface Warfare Center Indian Head
Dr. Alan Luton, Naval Surface Warfare Center Indian Head
Mr. James Warner, Naval Surface Warfare Center Indian Head
Mr. Jeff St. Clair, Naval Surface Warfare Center Indian Head
Mr. Cameron Stewart, Naval Surface Warfare Center Indian Head

Blast weapons used against vehicles and dismounted personnel are a leading cause of casualties during recent operations. The Blast Protection for Platforms and Personnel Institute (BP3I) is filling software gaps to enhance the ability of modeling and simulation software to accurately predict buried blast loading and platform response in a high performance computing environment. DYSMAS is a major component of the BP3I software suite. This presentation will introduce the usage of DYSMAS for buried blast applications. The software and solution methodology, including the application of an Eulerian material strength model, will be briefly discussed. Buried blast experiments conducted by the Aberdeen Test Center (ATC) and the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) will be introduced. Applications of DYSMAS to these tests will be discussed and comparisons of computational and experimental results will be presented.

PRE-TEST PREDICTIONS OF NEAR-FIELD BUBBLE LOADS ON STIFFENED PLATE STRUCTURES
Dr. Ken Nahshon, Naval Surface Warfare Center Carderock Division
Mr. Nicholas Reynolds, Naval Surface Warfare Center Carderock Division
Mr. Georges Chahine, Dynaflow Inc.
Mr. Gregory Harris, NSWC IHD
Mr. Roger Ilamni, NSWC IHD
CT Hsiao

Testing on near-field bubble loads on stiffened plate structures will be conducted in the near-future as part of a US-Canadian program testing structure that is to be extracted from the EX-IROQUOIS. Here, initial high-fidelity calculation results will be presented comparing different numerical methods and

analyzing fixture response. These calculations support the development of a suitable fixture and positioning of instrumentation. The goal of this upcoming test series is to generate high-quality validation data on bubble jet loadings coupled with structural response of ship panels.

DYNAMIC RESPONSE OF MARINE MAMMAL LUNGS TO UNDEX LOADING
Dr. Stephen Turner, NUWC Newport
Dr. Emily Guzas, NUWC Newport
Mr. Tom Fetherston, NUWC Newport
Mr. Glenn Mitchell, NUWC Newport

New models are investigated to assess the effects of underwater explosion on the lungs of marine mammals. Legacy, one-dimensional analysis methods include simplifying assumptions that neglect the shape of the lungs and neglect the influence of tissue and rib structures surrounding the lungs. The DYSMAS fluid structure interaction code is used to evaluate the effects of asymmetric loading, surrounding tissue, and non-spherical lung structure on the response of the lungs. This presentation demonstrates that the DYSMAS analysis is consistent with experimental testing of an elastomeric air-filled lung-like structure subjected to UNDEX within a pressure tank.

DEDICATED SESSION: MECHANICAL SHOCK – INSTRUMENTATION, MODELING, & SIMULATION

REPACKAGING FUZE ELECTRONIC COMPONENTS FOR ENHANCED RELIABILITY AND SURVIVABILITY
Mr. Curtis McKinion, Air Force Research Laboratory

Solid-state electronics are becoming more pervasive in modern fuze technologies. Fuzes utilizing a capacitive discharge unit contain commercial electronics not designed for the survivability requirements of penetrating weapons. A common approach to improve survivability is to encapsulate these components in a potting material. There are disadvantages to potting, including reduced thermal cycle life as well as limited diagnostics after potting. Additively manufactured supports are investigated as an alternative packaging scheme for electronic components in harsh thermal and mechanical environments. A functional circuit board and engineered support structures were designed and manufactured for experimental evaluation. Finally, this paper will discuss experiments performed to evaluate the performance of this assembly in these harsh environments.

MAPPING LEGACY PENETRATOR FUZING SYSTEM LIMITS WITH MODELING AND SIMULATION
Mr. Alma Oliphant, Applied Research Associates
Mr. Russ Klug, AFLCMC/EBD
Mr. Justin Bruno, Applied Research Associates
Ms. Ericka Amborn, Applied Research Associates
Mr. Daniel Fajardo, Applied Research Associates

Continuum mechanics and finite element analysis methods can be used with relative ease to providing a high-fidelty risk assessment for structural components in penetration events. Structural successes and failure of assemblies during penetration events can be tracked with classical metrics such as component stresses and strains, identifying the structural limits of these components. But, when electronic fuzing systems are included in the penetrator assembly, success and failure of the All-Up-Round system, or the risk to survivability of the full system level assembly, is not as easily identified by simple structural stress

or strain metrics. Electronic success and failures may be more nuanced, and not necessarily tied to stress and strains of adjacent structural components.

This paper outlines the approach that Applied Research Associates has taken to explore and define the Structural and Electronic survivability envelope for several legacy penetration munition fuzes. This approach utilizes high-fidelity continuum mechanics models of the fuze to determine the structural dynamic capability of the system, combined with known test results and data points to benchmark these models, and correlate the model behavior to know electronic survivability of the system. This process builds on the Legacy Weapon Improvement Program process of evaluating the penetrator for edge of envelope survivability, adding the fuze to the risk evaluation process.

DEFINING STRUCTURAL DYNAMIC ENVIRONMENTS FOR PENETRATOR FUZES

Mr. Alma Oliphant, Applied Research Associates
Mr. Russ Klug, AFLCMC/EBD
Mr. Justin Bruno, Applied Research Associates
Ms. Ericka Amborn, Applied Research Associates
Mr. Craig Doolittle, Applied Research Associates
Mr. Drew Malechuk, Applied Research Associates

The Legacy Weapon Improvement Program has mapped the system level survivability limits for legacy penetrating munitions. A product of this program is test and modeling and simulation derived structural dynamic shock environments for fuzing systems, at the edge of envelope limits for legacy penetrating munitions. These environments represent the maximum level shock loading a fuzing system should experience in legacy penetrators. This paper reports on these shock environments, their development, strengths and limitations, and briefly discusses the path forward for developing ground testing methods to meet these environments. The primary goal of this environment definition is to define ground testing methods to reduce cost and risk for penetrating fuzing systems.

WAVE PROPAGATION IN POLYMER COMPOSITES UNDER HIGH-G LOADING WITH EMBEDDED INSTRUMENTATION

Dr. Bryan Joyce, University of Dayton Research Institute
Ms. Hayley Chow, University of Dayton Research Institute
Dr. Jacob Dodson, AFRL/RWMF
Dr. Janet Wolfson, AFRL/RWMF
Ms. Aine Mangan, Georgia Tech

Operation of next generation fuzing systems depends on understanding the relative motions and pressures of the explosive fill inside a weapon system in severe dynamic environments. Explosive fill and other polymer composites exhibit complex dynamic behavior which poses challenges for both modeling and experimental efforts. This presentation discusses continuing work by AFRL Fuzes Branch in developing experimental techniques for characterizing these materials in high-g loading. Externally bonded strain gauges and embedded accelerometers and thermocouples inside samples of polymeric composites capture the material response in high-g, operational conditions. This response data can be used to determine the severity of the mechanical shock, study how energy propagates through the material, and calculate wave dispersion and attenuation coefficients.

SIMULATION OF A REINFORCED CONCRETE WALL SUBJECTED TO BLAST EFFECTS USING MARS AND LDPM

Mr. Micael Edwards, USACE - Engineer Research and Development Center
Dr. James Baylot, USACE - Engineer Research and Development Center
Dr. James O'Daniel, USACE - Engineer Research and Development Center

Researchers in the Geotechnical and Structures Laboratory at the U.S. Army Engineer Research and Development Center (ERDC) and engineers at ES3 used the Multiscale-multiphysics Analysis of the Response of Structures (MARS) code, utilizing the Lattice Discrete Particle Method (LDPM) to model the response of an air-backed, reinforced concrete wall loaded by an internal, vented detonation.

This is the largest simulation conducted to date by ERDC using MARS and LDPM. The model consists of over 500,000 nodes and over 3 million tetrahedral LDPM elements. The LDPM is a discrete meso-mechanical model for concrete that simulates the concrete meso-structure with discrete particles randomly positioned within the structure according to the given aggregate size distribution (Cusatis et al. 2011). The LDPM material model for concrete uses the physical mix design and the static strength parameters of the target material. The LDPM material model was calibrated in MARS using simulations of compression tests to match the recorded data for the physical test specimen. The steel reinforcement was modeled using beam elements and an elastic-plastic material model.

Three load cases were applied to the wall, one distributed pressure-time history simulating the physical experiment data and two uniform, triangular pressure-time histories of different peak values. The response of the wall was compared to the physical experiment results (Steed and Dallriva 2009).

This work was conducted in parallel with other recent efforts assessing the accuracy and effectiveness of several finite element codes for simulating concrete response to blast (Lawrimore et al. 2017).

BLAST MODELING AND TESTING

MODELING AND SIMULATION OF COMBINED BLAST AND FRAGMENT MUNITIONS BENCHMARKED AGAINST EXPERIMENTAL DATA

Mr. Andrew Barnes, USACE - Engineer Research and Development Center
Mr. Robert S. Browning, USACE - Engineer Research and Development Center
Dr. James L. O'Daniel, USACE - Engineer Research and Development Center

When designing structures to protect against combined blast and preformed fragment munitions, conducting full-scale arena characterization experiments to define the threat environment is often cost prohibitive. In such situations, the ability to predict the combined blast and fragment environment via modeling and simulation is necessary to ensure that the threat environment is correctly defined. High-fidelity coupled Eulerian and Lagrangian numerical codes may be employed for this purpose. However, studies must be performed to determine the ability of coupled codes to accurately predict such environments. In this study, ALE3D and DYSMAS were investigated to determine their ability to predict the threat environment generated by a representative large scale combined blast and preformed fragment munition. A series of experiments and simulations was conducted for this purpose. First, a series of blast pad experiments were conducted to determine the blast environment from both an uncased and a cased representative preformed fragment munition to investigate the equation of state for the explosive, the ability of the codes to predict the blast environment, and how the blast environment was affected by the presence of the preformed fragments. Next, a historical set of data

from a small-scale simplified preformed fragment munition was simulated and compared to the experimental results. Finally, a representative full-scale combined blast and preformed fragment munition was tested experimentally and simulated. The resulting predictions of fragment velocities and trajectories were compared against the experimental results and showed good agreement.

PRELIMINARY ASSESSMENT OF FINITE ELEMENT CODES FOR SIMULATING CONCRETE SUBJECTED TO BLAST EFFECTS

Dr. William Lawrimore, USACE - Engineer Research and Development Center
Dr. James Baylot, USACE - Engineer Research and Development Center
Mr. Robert Browning, USACE - Engineer Research and Development Center
Dr. James O'Daniel, USACE Engineer Research and Development Center

Analysts at the U.S. Army Engineer Research and Development Center (ERDC), as well as engineers and researchers from other government agencies, must often perform numerical simulations to assess the responses of concrete structures subjected to blast effects. Often, the schedule or funding does not permit the analyst to conduct a thorough assessment of which software would be the most accurate and/or effective. Recently, members of the computational team within the Geotechnical and Structures Laboratory at ERDC have begun an effort to assess a set of finite element (FE) codes for simulating these types of events. This presentation will discuss preliminary work that has been conducted to date.

The preliminary assessment focused on explicit Lagrangian FE codes commonly used in DOD applications, two of which will be discussed here, namely, LS-DYNA and ParaDyn (the parallel version of DYNA3D). For the purpose of comparison, the computational team identified a "challenge problem" to be analyzed with each code. The challenge problem represented a reinforced concrete air-backed wall (ABWall) subjected to an internal, vented detonation. Physical blast experiments were conducted on subscale ABWall specimen in 2008, and data from those tests were used to validate simulation results. LS-DYNA and ParaDyn were chosen for the preliminary assessment due to their long history of use in solving these types of problems. Additionally, the similarity between LS-DYNA and ParaDyn facilitated faster model generation and the two codes also serve as a representation of commercial software vs. government-owned software.

In both codes, the K&C Revision 3 constitutive model was used to govern the behavior of the concrete, and a kinematic/isotropic elastic-plastic model was used for the reinforcing steel. The concrete was meshed using 8-noded hexagonal elements, while the reinforcement was meshed with 3-noded beam elements. Thus far, the codes have been used to simulate the ABWall under a realistic blast load as well as two uniform triangular pulse loads. For each of the three load cases, maximum deflection and maximum strain were calculated and compared across both codes.

APPLICATION OF THE AFRL BLASTPAD TO LOW HEIGHT OF BURST CONFIGURATIONS

Ms. Michelle Barreto, AFRL/RWML
Dr. Alan Ohrt, AFRL
Dr. Catherine Stephens, USACE ERDC

Obtaining blast propagation data is of great importance in order to develop effective blast loading computational models. The layout of the AFRL blastpad currently allows us to gather this data simulating an open air field detonation, allowing blast to flow in all directions. However, we recently performed a series of air blast tests, in collaboration with ARMY ERDC, which required us to gather Height of Burst (HoB) data. This required us to modify the current design of the blastpad and develop a

blast resistant steel plate to cover the airblast replaceable detonation area. A charge was then be suspended at a specific height over the plate, effectively simulating a low HoB.

The objective of this effort was to obtain blast pressure data from blast tests in order to characterize the blast environment from specified test items for use in computational model validation and development of force protection technologies.

Twenty four blastpad tests were conducted with this low HoB configuration, consisting of: a) One hemispherical charge, and b) seven explosive cylinders/rectangular prisms of varying length-to-diameter ratios/widths. This paper will discuss the details in the modified blastpad design and summarize the results of selected tests.

GENERATING A BLASTX EXPLOSIVE SOURCE MODEL

Mr. Gustavo Emmanuelli, USACE ERDC

BlastX is a fast-running, engineering-level code developed jointly by the U.S. Army Engineer Research and Development Center and the U.S. Air Force Research Laboratory that is used to predict the airblast environment resulting from the detonation of an explosive. Users can simulate a variety of airblast problems including free-air bursts, internal room-to-room detonations, and external arenas, such as a height-of-burst test. Common inputs include the definition of one or more rigid structures and the selection of an explosive model, while typical output consists of pressure-time histories at prescribed spatial points. The explosive models available in BlastX, denominated as tabular source models, are essentially free-air detonation blast effects databases of unique combinations of explosive composition, weight and geometry that have been scaled to a 1-kg standard. Each of these tabular models has been developed using several tools. First, an equilibrium thermodynamics calculator, such as Cheetah by Lawrence Livermore National Laboratories, is used to investigate the reaction chemistry and quantify key parameters such as its heat of formation, its molecular formula and elemental molar weight fractions, a Jones-Wilkins-Lee equation of state fit for the burned explosive, and a balance of available fuels within the detonation products that might trigger additional secondary burns. Second, a first-principles computational fluid dynamics code, such as SAGE, CTH or SHAMRC, is employed to model the explosive charge of interest and calculate hydrodynamic data as a function of time at different ranges and azimuths around the charge. This step requires selecting and evaluating a burn model that suitably describes the transition from an initially unburned state to a fully reacted one following the detonation, and calibrating such a model through an iterative process if the modeling parameters are not readily available in the literature or if results are not satisfactory. Finally, the explosive model is evaluated within the BlastX code and validated against available experimental data. This paper examines each of these steps and details the complete methodology for developing a tabular explosive source model for use in BlastX.

BALLISTIC PERFORMANCE OF CROSS-LAMINATED TIMBER

CDT Zade Koch, United States Military Academy
CDT Andrew Valkenberg, United States Military Academy

This project studies the ballistic performance of Cross-Laminated Timber (CLT). The desired endstate is to demonstrate that a structural material, with its proven advantages in terms of cost, weight, ease of use, and renewability can also provide protection from ballistic impact. The study features multiple ballistic impact tests, measuring striking and residual velocities as well as the depth of penetration of non-perforating impacts. Additionally, we tested three types of “Hybrid” Cross-Laminated Timber which

featured a layer of one-quarter inch of Hi-Hard steel, fiberglass-concrete composite, and ten sheets of Kevlar, respectively. These hybrid specimens were laminated in the center of the CLT blocks. Ballistic performance was characterized by the specimen's V50: the specimen's threshold between full perforation and partial penetration, in relation to its areal density. Upon examination of these results, we conclude that CLT, although not as effective as traditional armor materials, has great potential when considering its cost, weight, and ease of use. In addition, the Hybrid Cross-Laminated Timber, demonstrates increased potential because of its improved ballistic resistance, yet remains effective in terms of its cost, weight, ease of use, and renewability.