ABSTRACTS

SAVE
SHOCK & VIBRATION EXCHANGE

92nd Shock & Vibration Symposium

September 18 - 22, 2022
Denver, Colorado

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SESSION 1: CHARACTERIZATION OF MECHANICAL SHOCK

Development of In-Structure Shock Test Motions for Shake Table Qualification of Critical Equipment

Mr. James Wilcoski, US Army ERDC

In September 2021 ERDC-CERL developed shake table shock qualification motions for testing critical equipment that will be installed at a particular site. The design shock hazard was defined by broad-frequency range shock response spectra (SRS). Tests conducted in September 2021 showed that the ERDC-CERL Triaxial Seismic and Shock Simulator (TESS) met the SRS very well. The achieved SRS met the required at frequencies up to 180 hertz in the horizontal axis and 250 hertz in the vertical axis. These limits are well above the fundamental frequencies of the critical equipment to be tested, demonstrating that the TESS can be used to qualify the customers equipment. The achieved test motions are much longer in duration than normal shock motions, but longer duration motions can effectively be used to fill out broad frequency range SRS. ERDC-CERL will present the assumptions, and methods used to develop these test motions. The TESS is a hydraulic shake table capable of producing the large forces at high frequencies, needed to qualify heavy equipment against in-structure shock motions.

Analyzing Shock Response of Simple Structures to Investigate Relationships between Shock Spectrum and Physical Response Parameters

Mr. Jason Sammut, Penn State Applied Research Laboratory
Dr. Matthew Lear, Penn State Applied Research Laboratory

Misconceptions of shock fundamentals often leads to the development of inappropriate system requirements for naval shock qualification. This results in a significant disconnect between the intended environments that a system must survive and the loading environments used for testing or analysis of that system. A more thorough understanding of how to determine the equivalency of various shock profiles will greatly aid in the consistency between shock environments encountered in service, during testing, and those used for simulation.

This research aims to further develop the relationships between time domain parameters of a shock input, shock spectra of the input, and physical responses of a given system by observing how a simply supported beam responds to different shock inputs with equivalent shock spectra. A shock synthesis script was used to generate a variety of shock profiles with unique time domain parameters, e.g. maximum acceleration, pulse width, or temporal moments, and nearly identical shock spectrum values at the natural frequencies of the beam. These profiles were then used as a base excitation input to the beam. The shock response of the beam, i.e. dynamic motion and axial stresses, was then computed from an analytical solution for Euler-Bernoulli beam dynamics and corresponding finite element explicit dynamic analyses.

A critical result of this case study is that shock profiles with nearly identical shock spectra do not necessarily produce identical responses in a structure, as significant differences in physical response parameters were observed across the various input profiles. However, profiles with similar shock spectrum as well as time domain characteristics are shown to produce much more consistent physical responses in the beam. Among other conclusions, this leads to the recommendation that a combination of time domain parameters and shock spectrum curves be used in the development and application of shock specifications. Additionally, general guidelines on the quantification of relative severity between shock profiles from this combination of time and frequency domain information can be made from the results of this study.

THE RELATIONSHIP BETWEEN PSEUDO DISPLACEMENT AND SHOCK SEVERITY

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

A shock event's net displacement drives the low frequency characteristics of the pseudo-velocity shock spectra (PVSS). The typical accepted shape, of a PVSS when plotted on tripartite graph, is rising along constant displacement, plateaus at a constant velocity, and falls at a constant acceleration. This study examines the relationship between net displacement and shock severity of a test item. Shock severity using the PVSS will be compared to strain measurements for free-fall and spring-assisted drops at various drop heights. Shock severity will also be examined during shaker shock tests. The results will address whether matching the low-frequency PVSS is critical in matching the shock severity between two different shock events.

SHOCK RESPONSE CALCULATION – AN OVERVIEW

Prof. Kjell Ahlin, Xielalin Consulting

In the 1970's, many people used the digital impulse invariant filter to calculate the response to the SDOF system in the SRS calculation. That method has an aliasing problem. In 1981 Dave Smallwood, Sandia, suggested the use of another filter, ramp invariant. That method mitigates the aliasing, at the cost of a bias error. That was described by the author in a paper at S&V Symposium in Albuquerque 1999. In 2007 an ISO standard for SRS calculation was published, using the Smallwood algorithm. The author was project leader, Smallwood did the final proof reading.

Here an overview of different calculation methods is given. Today's computers have virtually unlimited memory capacity so we may as well use simple DFT to calculate the SDOF response without any errors.

AN EXPERIMENTAL COMPARISON OF FORCE RECONSTRUCTION TECHNIQUES

Mr. Jacob Lewton, University of Colorado
Dr. Curtis Rasmussen, University of Colorado
Dr. Massimo Ruzzene, University of Colorado
Mr. Johnathan Hower, Kansas City National Security Campus
Dr. Washington DeLima, Kansas City National Security Campus

Force reconstruction problems are a type of inverse problem where an applied load must be determined based on the response of a system. While there exist numerous definitions of dynamic loading, this work will focus on reconstructing transient loads and may be applied to mechanical shock events including impacts and drops. Force reconstruction is often essential for this type of problem, as the applied load is an important design parameter, but can be very difficult to measure directly. Once loads are determined, they may be input into a model to aid in the design of structures undergoing dynamic loading. In this talk we will compare different techniques for force reconstruction. The first technique, known as the Sum of Weighted Accelerations Technique (SWAT), is a method for reconstructing an externally applied force based on the vibrational response of a linear system. Measuring applied forces directly can be difficult in many practical situations, and the appeal of SWAT is that it only requires acceleration measurements and knowledge of a system's mode shapes. An extension of this technique, known as SWAT-TEEM (Sum of Weighted Accelerations Technique-Time Eliminated Elastic Motion), has the advantage of not requiring knowledge of the system's mode shapes. Finally, the Load Confluence Algorithm (LCA) is an iterative process where the response of a finite element model with a guessed force is compared to the response of the actual model, and the error between the two is minimized. We will present results from finite element simulations and experiments with transient loads applied to an aluminum block.

SESSION 2: VIBRATION TEST SPECIFICATIONS & ENVIRONMENTS

PROGRAM DEVELOPMENT APPROACHES FOR MIL-STD-167-1A BASED EXTERNAL VIBRATION TESTING

Mr. Neil McRae, Thornton Tomasetti

Many test house client requests refer to vibration test spectra which entirely consist of pre-determined values, with each test having a pre-set duration. Test specifications are chiefly selected according to product type, field service requirements and mounting position on the service platform.

By contrast, the durations and frequencies required to apply MIL-STD-167-1A externally generated (type I) vibration tests to a product can see a high degree of variation. Firstly, there is the potential impact of particular platform information on the useability of the standard tables and the maximum platform frequency that should be applied. Secondly, once a test program begins, there is a large potential impact on overall program duration, driven by the results of initial testing. We will explore the various sides of program development, covering test specification finalisation, batch handling considerations, fixture design implications and product monitoring requirements, plus the commercial approach typically needed to best address tests to this marine equipment standard.

ASPECTS OF LABORATORY VIBRATION TEST SPECIFICATION DEVELOPMENT

Dr. Ronald Merritt, SAALEX Solutions

This paper outlines a comparison of two independent measurement environments based upon aspects that could be part of the development of separate LVTS's for both environments. In short, what aspects of LVTS development can be used to compare two independent measurement environments. For the illustration in this paper, measurements from an "outboard" mounting of an EMV (Environmental Measurement Vehicle) are to be compared to measurements from an "inboard" mounting of the EMV. The implications of this can be substantial if a given materiel must be qualified separately for two platform mounting locations. Comparison is made on the basis of two approaches. First, the comparison is based upon random vibration Autospectral Density (ASD) comparison and measurement "upper limit assessment". Second, the comparison is based upon Single-Degree-of-Freedom (SDOF) modeling employing the Extreme Response Spectrum (ERS) and the Fatigue Damage Spectrum (FDS). As a statistical based comparison the ASD, ERS and FDS results either as amplitudes as a function of Fourier frequencies (ASD) or amplitudes as function of SDOF Natural frequencies. In both cases a simple Analysis-of-Variance (ANOVA) assessment can be applied. Because of the "non-robustness" of test acceleration procedure application the test acceleration is considered from a distributional point of view. This paper outlines all the means of assessment from reliable sources and can serve as a reference in areas of LVTS development and environment comparison.

USE OF THE DAMAGE POTENTIAL SPECTRUM AS A COMPARISON DESCRIPTOR FOR MULTIPLE-DEGREE-OF-FREEDOM RANDOM VIBRATION SPECIFICATIONS

Dr. Michael Hale, Trideum Corporation
Mr. William Barber, US Army Redstone Test Center
Mr. Jesse Porter, Hill Technical Solutions

Multiple-Degree-of-Freedom (MDOF) vibration specification development (VSD) is still a relatively new process. The MDOF VSD technique described in Mil-Std-810H yields a fully populated 6x6xd Spectral Density Matrix where d represents the number of spectral lines and the diagonal terms of each 6x6 matrix are the traditional rigid body degrees-of-freedom [X,Y,Z,Rx,Ry,Rz]. The Damage Potential Spectrum will be used as a comparative descriptor to analyze the MDOF VSD results. Examples based on a tactical 6-DOF VSD are provided.

DUAL RIGIDLY COUPLED MDOF VIBRATION SYSTEM

Mr. Matthew Forman, NSWC Dahlgren
Dr. Luke Martin, NSWC Dahlgren
Mr. Shawn Schneider, NSWC Dahlgren
Dr. Bryan Joyce, NSWC Dahlgren
Mr. Robert Ponder, NSWC Dahlgren

Multi-degree-of-freedom (MDOF) vibration testing is typically accomplished using one of two methods:

- Small components can be tested using relatively small commercial-off-the-shelf (COTS) MDOF vibration systems like a Team TENSOR™ or Team CUBE™.
- Large components and combined systems are often tested using expensive and complex one-off vibration systems such as the Team LC6DOF at Redstone Test Center or the Team MVF at NASA’s facility in Plum Brook, OH. These large and one-off vibration systems are very costly and present a barrier to smaller budget testing.

NSWC Dahlgren is in the process of standing up a large capacity MDOF vibration system utilizing two COTS MDOF vibration systems. The Team CUBE™ is capable of 6-DOF vibration for small to medium sized payloads but has limited mounting space to accommodate larger test item footprints. NSWC Dahlgren has designed hardware that will rigidly couple the CUBE™ shakers together and software to mitigate over actuation. This system will result in a combined 14,000 lbf in each axis and allow for payloads up to 20ft x 12ft. This novel approach holds the potential of executing large component testing in a more cost-efficient manner.

This presentation will review the overall system design, work completed to date, and path forward to system completion. The authors will detail specific fixture and design challenges, additional complexities that may arise once installation and preliminary testing commence, and the potential benefits of combining COTS shakers to expand MDOF test capabilities.

SESSION 2: SHOCK ANALYSIS IMAGING

SCHLIEREN TECHNIQUES FOR SHOCK ANALYSIS WITH HIGH-SPEED IMAGING
Mr. Wayne Carlson, Vision Research

Scientists use schlieren imaging, a non-invasive testing method, to visualize density gradients within otherwise invisible flows. Schlieren imaging is a practical method of visualizing air movement around an airfoil in a wind tunnel or gas interactions within a combustion chamber. Over the past decade, significant improvements in the speed and sensitivity of cameras have greatly increased the quality of schlieren images and the speed at which images can be acquired. Although this advanced imaging technique can now deliver detailed images of highly dynamic processes, obtaining high-quality data requires choosing the best high-speed camera for the application and careful optimization of the optical setup.

SESSION 3: WEAPON EFFECTS MODELING

COMPARISON OF DAMAGE DETECTION RESULTS FOR FINE AND COARSE MARK 84 FINITE ELEMENT MODELS USING PENCURV/EPIC PROGRAM
Mr. Logan Rice, US Army ERDC
Dr. Mark Adley, US Army ERDC
Mr. David Lichlyter, US Army ERDC
Mr. Ernesto Cruz, US Army ERDC

The Mark 84 general purpose bomb is designed to support a variety of mission objectives including the ability to perforate targets of interest. As part of the mission planning it critical that designers have the ability to accurately predict the response of both the terminal effects on the target and the response and/or survivability of the weapon system during impact and penetration. In order to save time and money, simulations are used to quickly determine the response of the warhead during the terminal event. Finite element models can be used to predict behaviors for objects when subjected to certain conditions, such as projectiles impacting targets. During the model creation process, a decision is required as to whether time or accuracy is a priority. Models can be comprised of millions of elements, giving a high degree of accuracy for prediction when used in simulations, but this can cause exceedingly long runtimes even on high end computers. The runtime can be lowered by creating coarser meshes with fewer elements, but this can reduce the quality and accuracy of the results. The USACE Engineer Research and Development Center (ERDC) was tasked with developing a coarse finite element model of the Mark 84 that accurately predicted case failure while also running relatively quickly to support fast running weaponeering programs. These coarse models developed under this program were compared to the results of a high fidelity models to evaluate accuracy and runtime. The models were generated using CUBIT 15.4 and run in PENCURV/EPIC using the Virtual Penetration Laboratory (VPL) driving model. The models were run through simulations impacting 6 ksi concrete targets varying the target thickness, initial velocity, pitch angle, and angle of attack. The models were tested with the fill and case merged and with cohesive elements present that simulate a slideline in the projectile. This presentation provides an overview of models and methods used in the analysis, the results obtained and a comparison of damage accuracy to the simulation runtime.

MODELING OF BLAST-ENHANCING, LOW-DENSITY REACTIVE MATERIALS

Mr. Gustavo Emmanuelli, US Army ERDC
Dr. Greg Bessette, US Army ERDC
Dr. Alan Ohrt, US Army ERDC
Dr. Kyle Overdeep, US Army ERDC

A numerical effort was undertaken to assess the accuracy of a first-principles code for modeling the enhanced blast environment resulting from the detonation of cased explosives internally lined with low-density reactive materials (LDRM). The inclusion of LDRM contributes to a post-detonation energy deposition produced by the additional combustion happening during early-time particle fly-out and late-time impacts with a reflecting surface. The overall effect of this phenomenon is an increase in the integrated blast impulse. The Second-order Hydrodynamic Automatic Mesh Refinement Code (SHAMRC) was used to model a test series involving two LDRM compositions integrated into high-explosive cased weapons and detonated inside a multi-room structure that allowed room-to-room propagation of detonation products and blast overpressures. Cased charges with no LDRM on-board were also tested, providing a baseline for gauging the effectiveness of using SHAMRC for modeling cased explosives. In all cases, the initial detonation was modeled using a fine, two-dimensional cylindrical mesh with results mapped into a coarser three-dimensional grid containing the multi-room layout. This study explores the general procedure for calibrating the LDRM models and reproducing the experiments with a focus on code features that facilitated the work, challenges, comparisons with measured data, computational requirements, and code variables having a first-order effect on the calculated output. Validation of this work would allow for the generation of high-fidelity virtual data to be fed into a fast-running code like BlastX for its own reduced-order modeling of enhanced blast from LDRM combustion.

MODELING ENHANCED BLAST FROM LOW-DENSITY REACTIVE MATERIALS IN THE BLASTX FAST-RUNNING MODEL

Dr. Gregory Bessette, US Army ERDC
Mr. Gustavo Emmanuelli, US Army ERDC
Dr. Alan Ohrt, AFRL Eglin AFB
Mr. Brian Taylor, AFRL Eglin AFB
Dr. Kyle Overdeep, AFRL Eglin AFB
Dr. Suhithi Peiris, AFRL Eglin AFB

The incorporation of low-density reactive material (LDRM) with traditional cased munition concepts can lead to a significant enhancement in blast effects for internal detonations. In particular, secondary combustion of the LDRM can lead to a significant increase in the overall impulse within the detonation room. Secondary combustion of the LDRM occurs during the initial fly out of the particles following case breakup. Additional energy release can arise due to particle impact with neighboring walls. A new model has been developed for the BlastX engineering-level code to capture the enhanced blast arising from LDRM combustion. The model supports two types of LDRM of interest. The BlastX model relies on virtual data developed using the high-fidelity Second-order Hydrodynamic Automatic Mesh Refinement Code (SHAMRC). A series of SHAMRC calculations were carried out to assess the particle burn rate during the initial particle fly out. Additional SHAMRC calculations were conducted to capture enhanced combustion arising from particle impact with walls at varied standoffs from the explosive source. Simplified fits were developed to the SHAMRC-generated data to assess the amount of LDRM combustion as a function of time and location of the particle front. In turn, this information is fed into the combustion model embedded within BlastX to assess the enhanced energy release from the burning LDRM. This paper describes the new LDRM model and its implementation within BlastX. Comparisons are drawn against

recent experiments conducted by the AFRL involving internal detonations of cased LDRM charges within a multi-room structure.

ENDGAME FRAMEWORK AND SHOCK EFFECTS APPLICATION DEVELOPMENT
Ms. Michelle Leblanc, AFRL

Abstract not available.

EVALUATION OF TACTICAL BALLISTIC MISSILES (TBM) AIRBLAST SURROGATES
Ms. Shelby Buckley, US Army ERDC
Ms. Jessica Fulk, US Army ERDC
Mr. John Hoemann, US Army ERDC
Dr. Genevieve Pezzola, US Army ERDC

Tactical ballistic missiles (TBMs) have been increasingly observed in recent attacks in Ukraine, Al Asad Airbase in Iraq, and Erbil, Iraq. These weapons effects must be characterized to develop adequate protective positions for a range of standoffs. The U.S. Army Engineer Research and Development Center has conducted high-fidelity modeling and simulation (M&S) to develop engineering-level modifiers to predict airblast outputs of TBMs. An initial series of experiments was conducted to evaluate TBM airblast surrogates and validate high-fidelity M&S. This included comparing the pressure and impulse outputs of cylindrical and conical charges to hemispherical charges. Various weapon aspect ratios and heights of bursts were studied. Validated modifiers can be used with common airblast prediction tools, such as ConWep, to predict the airblast output of TBMs. This presentation will discuss the results of this study and provide an example case using the validated modifiers.

SESSION 4: DYSMAS I

MEASUREMENT RESULTS FROM UNDEX SHOCK WAVE PROPAGATION TESTS IN THE SEA BOTTOM
Mr. Roger Ilamni, NSWC Indian Head
Mr. Brad Klenow, NSWC Indian Head
Mr. Tobias Timm, WTD-71
Mr. Swen Metzler, WTD-71
Mr. Greg Harris, ATR

The current U.S.-Germany DYSMAS Project Agreement objective is to enhance the capabilities of the DYSMAS code to model sea bottom effects to support Buried Mine Neutralization and Buried Mine Effectiveness studies. To accomplish this, a combination of UNDEX tests, material characterization, material model development, and DYSMAS simulation efforts are underway. The major challenge for these UNDEX tests is the accurate positioning of pressure gages in the sea bottom by divers while keeping the bottom as undisturbed as possible. This talk will present an improved pressure gage design and emplacement procedure to address these issues as well as results from recent UNDEX tests conducted at the WTD-71's test facility in Elpersbüttel, Germany.

CHARACTERIZATION OF SEA BOTTOM MATERIAL AND DYSMAS CONSTITUTIVE MODEL DEVELOPMENT

Dr. Tom McGrath, NSWC Indian Head
Dr. Jeff St. Clair, NSWC Indian Head
Mr. Norman Herzig, Nordmetall
Mr. Swen Metzler, WTD-71

This work describes both material characterization tests and constitutive model development of sea bottom soil material. Characterization tests were carried out at the WTD-71's test facility where the UNDEX tests discussed previously were performed. The resulting characterization data is reviewed, followed by a discussion of EOS and strength models commonly used within DYSMAS for soil modeling and how agreeable they are to the acquired data. The process used for material model development is described. An example UNDEX sea bottom simulation is employed to understand the sensitivity of UNDEX results to the fitted parameters built from the different characterization tests.

DYSMAS SIMULATION OF RECENT UNDEX SHOCK WAVE PROPAGATION TESTS IN THE SEA BOTTOM USING DEVELOPED SEA BOTTOM MODEL

Mr. Brad Klenow, NSWC Indian Head
Dr. Tom McGrath, NSWC Indian Head

The work presented highlights DYSMAS simulation results of recent underwater explosion (UNDEX) shock wave propagation tests in a sea bottom using constitutive models developed from a sea bottom material characterization effort. The setup of the simulations and comparisons of the simulation results to pressure measurements made both in water and in the sea bottom will be discussed for multiple test scenarios. The specific objective of this task is to use the comparisons between the DYSMAS simulation results and the test measurements to evaluate the quality of the developed sea bottom constitutive models in order to guide future sea bottom material characterization efforts.

MULTI-CYCLE BUBBLE UNDEX SIMULATIONS USING DYSMAS BUBBLE ENERGY LOSS CAPABILITY

Mr. Martin Heuvers, WTD–71 Engineer and Scientist Exchange Program
Dr. Tom McGrath, NSWC Indian Head
Mr. Greg Harris, ATR

During multicyclic bubble dynamics of underwater explosions (UNDEX) the bubble energy abates from cycle to cycle. To improve the accuracy of UNDEX simulations for long duration bubble problems, a bubble energy loss capability was implemented in DYSMAS. The energy loss parameters were quantified by detailed simulations by Dynaflow, Inc., resulting in recommended values as a function of charge weight and depth. This study exercises the new energy loss capability against test data. Results are shown for bubble pulse pressures and impulses.

NEAR-FIELD UNDEX RESPONSE OF SHIP GRILLAGES (FVEY)

Dr. Ken Nahshon, NSWC Carderock
Mr. Andrew Glass, NSWC Carderock

Results from recent UNDEX testing of ship grillages extracted from the Canadian destroyer HMCS Iroquois will be presented. The tests are focused on examining bubble-target interactions and seek to generate high-quality validation data on bubble jet loadings coupled with structural response. The tests are conducted using a newly fabricated test frame and include extensive instrumentation to measure grillage response. Comparisons between velocity meters and photogrammetric analysis and high-speed string potentiometers and laser displacement gages will be presented along with comparisons to pre-test modeling and simulation results.

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

USING DIC TO MEASURE THE SHAPE OF SOUND AND VIBRATION
Mr. Bluejay Robinson, Correlated Solutions

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

Over the last 10 years, the VIC-3D HS FFT system has carved out a unique position amongst other ODS measurement techniques, especially those involving accelerometers and lasers. This is largely due to the fact that more data in available less time and at less expense to the customer with a DIC system. The VIC-3D HS FFT system can measure full-field vibrations from a single transient event such as a door slam or single wing flap. Furthermore, the system concurrently computes valuable 3D strain and displacement data that can be displayed alongside the vibration data.

In this presentation, a guitar and an aluminum plate will be used to demonstrate how the VIC-3D HS FFT system obtains ODS's. The aluminum plate data will show how the system is primed for FRF measurements and how accelerometers can be used to verify DIC data authenticity.

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

When measuring high-g shock events, engineers must ensure they are using robust accelerometers that can withstand harsh conditions and deliver accurate data. The presence of high-frequency energy causes signal saturation in applications with high amplitude and high frequency mechanical impacts. Dytran successfully designs and manufactures single axis and triaxial accelerometers in various configurations that deliver accurate data and avoid signal saturation. Series 3099AXT-XX and 3603AXT feature electrical filters that keep the mechanically filtered signal flat throughout the usable bandwidth, thus preventing zero shift from corrupting typical SRS plots. In addition, combining mechanical and electrical filters results in a flat frequency response and reduced signal ringing. For applications requiring ultra-miniature sensors, Dytran offers model 3284A1. The sensor design exhibits a very high natural frequency that prevents saturation and allows users to see the unfiltered data and measure all frequencies of interest.
The new single-axis 3099A series features built-in mechanical and electrical filters plus quartz sensing elements. Quartz is more homogenous than a ceramic sensing element and provides better stability of the sensitivity value over time when shock is applied. The combination of quartz and an advanced filter design allows the accelerometer to have a very flat frequency response with no zero shift and reduces signal ringing. Specific applications include explosive bolt testing used on rockets for fuel tank separation, high-shock metal-to-metal impact, shaker shock, protective body gear testing, far-field blasts, pyrotechnics, drop- shock vibration, and stage separation testing.

In addition, Dytran offers the 3603AT series of triaxial sensors, which also incorporate electrical & mechanical filters. This series addresses accelerometer saturation induced by applications where secondary high-frequency mechanical vibration or a high-shock, metal-to-metal impact exceeded the bandwidth of the accelerometer. Each sensor contains three piezoceramic planar shear sensing elements that are suspended inside the housing with a set of supports designed to stop high-frequency propagation into the element structure. The sensing elements are isolated from case ground and enclosed by a Faraday shield for better noise immunity. Units are TEDS enabled and are compatible with any IEPE power source. Specific applications for the 3603A series include high shock metal-to-metal impact, simulated far-field pyrotechnic shock testing, package drop-shock testing, and engine NVH – cylinder head vibration testing.

For applications with limited installation space, Dytran offers the ultra-miniature 3284A series. The lightweight sensors can measure high-g mechanical shocks and high-frequency data up to 30,000 g. Their small size does not "mass load" the test article or alter its dynamic behavior. They prevent signal saturation due to a very high natural resonant frequency. Engineers performing drop-shock testing on consumer goods will benefit from capturing unfiltered data and the ability to measure all frequencies of interest. Units feature a lightweight silicone integral cable that eliminates strain on the small housing, allowing for excellent flexibility and hassle-free routing.

ADVANTAGES OF A SOLID ARMATURE SHAKER
Mr. Graham Carmichael, ETS Solution

To prepare the basis of understanding for why a wireless shaker is superior to a wired shaker.

LIVE REMOTE VIBRATION MONITORING
Mr. Ed Okurn, Scantek, Inc.

No abstract available.

PROPER STRAIN RELIEF TO AVOID CABLE DAMAGE
Mr. Bob Metz, PCB Piezotronics

During shock testing, an accelerometer cable must be properly strain relived to avoid damage. Specifically the cable-sensor interface is the weakest link and most likely to fail. Strain relief guidelines will be presented as best practice to avoid damage, noise and low frequency zero offsets common to shock testing.

TRAINING I: DEVELOPING EXODUS II AND SIERRA SD/SM FORMAT MODELS

DEVELOPING EXODUS II AND SIERRA SD/SM FORMAT MODELS
Mr. Kory Soukup, Altair Engineering

The training session will be a presentation of the process involved to develop an Exodus II model using Altair's preprocessor - HyperWorks. The session will be based on the Technical Presentation introducing the Exodus/ Sierra SD interface. Within the interface CAD import, geometry modification/creation, model meshing, and potential for model optimization will be demonstrated. Editing of existing Exodus II/Sierra formatted models to incorporate design changes will also be illustrated.

TRAINING I: A PRACTICAL INTRODUCTION TO FEA ANALYSIS

A PRACTICAL INTRODUCTION TO FEA ANALYSIS
Mr. Bart McPheeters, Gibbs & Cox

A short introduction some typical techniques and issues with FEA analysis. Theory will be kept to a minimum and the class will focus of things that can be used immediately and that will help users understand some basic assumptions of FEA analysis and interpretation of results. (This will be a new class that has some elements of my old Intro class, but more focused on practical concepts and less on the theory).

SESSION 5: SHOCK AND VIBRATION ISOLATION

COMPARING THE PERFORMANCE OF WIRE ROPE ISOLATORS AND ELASTOMER MOUNTS UNDER CHANGING TEMPERATURES
Mr. Liron Fridman, Vibro/Dynamics

The properties of Wire Rope isolators are generally known to be unaffected by changing temperatures. This is an advantage over elastomeric isolators that can have drastic changes in their performance when temperature conditions are either high or low. The Socitec group ran temperature-controlled tests for both Wire Rope and Elastomer Isolators. Load deflection data is collected under ambient, cold, and hot temperatures. This brief presentation will compare the collected test data from both types of isolators under the changing temperatures. The results from each isolator will be compared to understand how the properties of each mount are affected and which isolator should be used.

ROBUST ISOLATION FOR VIBRATION ABATING (RIVA): A TECHNOLOGY TO INCREASE LASER BEAM STABILITY
Dr. James Rall, ShockTech RED
Mr. David Frank, ShockTech RED

Since the discovery of lasers in the early 1960s, they have been used for many applications including recent advances in directed energy (DE) defense systems and optical communication (OC). Both of these applications require high precision and stability of the laser beam to be effective. RIVA was designed to stabilize laser beams in OC systems aboard deep space satellites through the suppression of spacecraft vibration to the OC device.

Traditional radio-frequency (RF) communication technology has dominated the communication market for over 100 years. Although RF is heavily reliable, it also has significant issues including limitations on transferring large amounts of data, large footprints, weight, and power consumption. NASA has been transitioning from Apollo-era RF communication systems to optical communication, with its first demonstration in 2013. To maintain a high bandwidth link, these optical communication systems require additional measures to ensure precise pointing accuracy and stability. Therefore, the reduction of any vibration, even micro-vibrations, to the optical device is paramount for stability of the optical link. Robust Isolation for Vibration Abating (RIVA) is designed for deep space satellites using an optical communication device and reduces micro-vibrations from the host satellite.

RIVA is a dual-function isolator. The first function allows it to reduce micro-vibrations from the host spacecraft to the optical communication device or other optical instrument requiring high stability. The second function protects itself and the optical communication device from launch loads. Preliminary designs indicate a reduction of micro-vibrations by 99.5% (100 Hz). RIVA also reduces launch load from 1500 g to 7 g, a 99.5% reduction. When put into an assembly with 4 RIVAs and an optical device, a 150 micro-radian disturbance is reduced to 1.5 micro-radians (100 Hz).

THE UNDERWATER BUBBLE EFFECT ON ON-BOARD EQUIPMENT SUSPENSIONS ON SURFACE VESSELS AND SUBMARINES

Mr. Jean-Michel Courzereaux, Vibro/Dynamics
Mr. Ali Shehadeh, Vibro/Dynamics

Underwater explosion specs never take into account the bubble effect that follows the primary shock. This may have the consequence of underestimating the deflection of the suspensions of the equipment subjected to these shocks. And this is most severe in the case where there is coupling between one of the excitation frequencies of the bubble and one of the modes of suspension.

To reduce suspension deflection, one solution is to increase damping by using damping devices that are not dependent on the strain velocity.

LIQUID CRYSTAL ELASTOMERS (LCES): A NEXT-GENERATION DISSIPATIVE, RATE DEPENDENT, AND DIRECTIONAL MATERIAL FOR IMPACT PROTECTION AND VIBRATION ISOLATION

Mr. Chris Yakacki, Impressio.tech

Liquid-crystal elastomers (LCEs) combine the self-organization of liquid crystals into the elasticity of rubbery networks to create extraordinary multifunctional materials. They are most known for their reversible muscle-like actuation and have been proposed for soft robotic applications; however, their soft-elastic behavior and a high degree of dissipation mimic natural tissues, which also makes them attractive for energy absorbing devices that can span from impact protection, vibration and noise isolation, and even biomedical devices. The first portion of this talk will focus on the properties of these materials, such as their elevated dissipation factor (i.e., tan delta), high degree of soft elasticity, rate dependence, and anisotropy (i.e., directionality). For example, materials were tested across a broad spectrum of impact speeds ranging from quasi-static to 3,000 per second in terms of strain rate. The LCE materials demonstrated an increase in stress by 2 orders of magnitude and retained their soft elastic response. The second portion of this talk will focus on how these properties can be applied to specific applications. LCE pillars were manufactured and embedded within a 3D printed lattice structure to create protective liners for helmets. Drop testing was performed on both square pads and a complete helmet prototype. The results show that LCEs prevented the lattices from bottoming out at higher energies and were more consistent at repeated impacts. Lastly, this talk will demonstrate the vibration attenuation response of LCE-coated aluminum and composite panels compared to control samples.

SESSION 5: SHOCK AND VIBRATION HUMAN EFFECTS

A REVIEW OF SHOCK DYNAMICS EXPERIENCED BY A PARARESCUEMEN (PJ) DURING A MILITARY TETHERED TANDEM BUNDLE (MTTB) JUMP

Dr. James Rall, ShockTech RED
Mr. David Frank, ShockTech RED

Guardian Angel squadrons and other DOD special operations units rely on aerial delivery of personnel and supplies to a battlefield for combat search, rescue, and recovery operations. Although pararescuemen (PJs) may carry limited supplies during a jump using a rucksack, it is more common to use Military Tethered Tandem Bundles (MTTBs) for critical supplies in excess of 300 pounds and up to 1000 pounds. The increase in supplies delivered with a PJ (MTTB Master) through MTTBs allows for expedited recovery of operational supplies without the need for tracking and traveling to aerial delivery bundles on a battlefield.

Although PJs utilizing MTTBs provide increased capabilities, it has greater potential for injury, or even death, to a PJ. An airman experiences two extreme shocks during the jump: (1) snatch force and (2) parachute opening shock (POS). The snatch force occurs due to a bundle completely extending the length of the tether and inducing the PJ with a burst of momentum and energy. These two shock events are often the cause of minor or severe injury. The most experienced MTTB Masters can reduce but not eliminate the risk of injury entirely. Specific dynamics of a MTTB jump will be presented with emphasis relating to the risk of injury to a PJ.

SESSION 6: MECHANICAL SHOCK: NUMERICAL APPLICATIONS

MECHANICAL SHOCK ANALYSIS AND TESTING FOR SEISMO-GEODETIC ICE PENETRATOR

Mr. Alex Miller, MIT
Mr. Michael J. Brown, MIT
Mr. Aaron Makikalli, MIT
Prof. Jeffery Hoffman, MIT
Dr. Pedro Elosegui, MIT
Mr. Christopher Eckert, MIT
Mr. Chester Ruszczyk, MIT

The Seismo-Geodetic Ice Penetrator (SGIP) is a proposed air-dropped penetrator for deploying a seismometer and GPS receiver in Antarctic ice shelves. These in-situ instruments will measure oscillations in the infragravity (< 1 Hz) range to safely study ice shelf dynamics and better understand causes of ice shelf calving. The 90 kg SGIP must impact an ice shelf at 42.5 m/s to exceed the minimum penetration depth of 2 meters required for scientific measurements. However, the resulting impact creates a severe mechanical shock that can damage shock sensitive components, such as SGIP's seismometer. We present a preliminary dynamic model and finite element model used to predict the seismometer's structural response to this severe ice shelf impact. We discuss initial results that define the shock protection requirements for the seismometer. We present shock testing plans and future work to validate the SGIP structural model using a mass simulator. Results from small-scale (2 kg penetrator) impacts into sand and snow are used to support the full-scale (90 kg penetrator) testbed design.

OPTIMIZING MOUNTING TECHNIQUES FOR PCB COMPONENTS SUBJECT TO HIGH G TESTING

Mr. Richard Clayson, Sandia National Laboratories
Mr. Josh Dye, Sandia National Laboratories
Mr. Shane Curtis, Sandia National Laboratories

Large and brittle ceramic materials (i.e., capacitors) are a known weakness in high-g shock environments. To better understand and mitigate capacitor failure in these environments, a variety of capacitor types and mounting structures were encapsulated into a test fixture and tested on a drop tower at increasing shock levels. Capacitor types included both large and small Multi-Layer Ceramic

Capacitors (MLCCs), as well as newly developed, custom Polymer Multilayer (PML) capacitor. Some components were mounted directly on the board, others on lead frames, and others on copper standoffs. The experiments, which have been conducted in collaboration with the Air Force Research Laboratory (AFRL) and Applied Research Associates (ARA), revealed component failures that indicate optimal material type and mounting techniques as well as encapsulation failures that provide process improvement insights. In addition, modeling was performed using Sierra Solid Mechanics to quantify and better understand the experimental results.

PRESSURE TESTING ENCLOSURE PROJECTILE IMPACT ANALYSIS

Mr. Jonathan McConnell, University of Central Florida
Mr. Andrew Hicks, LSU/ Sandia National Laboratories
Dr. Kimberly Haulenbeek, Sandia National Laboratories
Dr. Neal Hubbard, Sandia National Laboratories
Dr. Thomas Ivanoff, Sandia National Laboratories

High pressure experimentation poses a significant hazard in the event of structural failure, as rupturing vessels and test articles can propel high velocity shrapnel into surrounding areas. Thorough analysis is therefore necessary to design and implement proper safety enclosures for the protection of experimenters and neighboring equipment. We explore the effects of design parameters such as material, thickness, and boundary conditions in reaction to a projectile impact with differing velocities and orientations. A nonlinear failure criteria model is implemented for analysis of: A36 steel and polycarbonate safety enclosures, multiple barrier thicknesses for each of these materials, and fixed and gasket-supported enclosure panels. Comparison of modeled barrier performance yields insight into optimal design parameter selection for future creation of similar pressure testing enclosures.

FAST STATISTICAL MODELS OF SHOCK PROPAGATION AT MID AND HIGH FREQUENCIES

Mr. Ed Heyd, 3DS SIMULIA

This talk will discuss new simulation methods that have been recently developed by Dassault SYSTEMES for modeling the propagation of transient shocks through large complex structural-acoustic systems across a broad frequency range. The methods have been implemented in the commercial vibro-acoustic software package wave6. The talk will illustrate some of the physics of shock propagation in built up structures and discuss how direct and reverberant wavefields contribute to the development of a Shock Response Spectra (SRS) over time. The effects of uncertainties in the properties of a system on SRS responses will be demonstrated numerically and used to illustrate why statistical modeling approaches are essential at mid and high frequencies (for both steady state and transient applications). Some new statistical wave based methods for modeling steady state noise and vibration will be reviewed along with their extension to transient problems. Various validation examples will then be presented ranging from simple test structures to separation events on flight hardware.

SESSION 6: NAVY SHOCK QUALIFICATION

SHOCK QUALIFICATION METHODOLOGIES AND CHALLENGES FOR SUBMARINE PAYLOADS

Ms. Teresa Gangi, NUWC Division Newport

The Naval Undersea Warfare Center Division Newport (NUWCDIVNPT) has successfully qualified several Temporary Alteration (TEMPALT) systems for Grade B shock. Various methods have been used to accomplished Grade A and Grade B qualification, however these methods have come with challenges. This presentation will discuss the recent methodologies used for shock qualification, as well as potential challenges that can arise and approaches to overcome those challenges.

BLOCK V VIRGINIA CLASS SHOCK ENVIRONMENT SELECTION FOR TOMAHAWK ALL-UP-ROUND (AUR) QUALIFICATION

Mr. Michael Warnock, NUWC Newport
Mr. Kevin Behan, NUWC Newport
Ms. Stacy Canepari, NUWC Newport

When utilizing Finite Element Analysis (FEA) to support shock qualification of submarine payloads, proper inputs need to be determined and utilized. However, determining the proper inputs for transient shock analyses can be a challenging problem. This presentation describes procedures developed and utilized by the Naval Undersea Warfare Center Division Newport (NUWCDIVNPT) for determining the proper inputs for FEA models to support the shock qualification of the Block IV Tomahawk All-Up-Round (AUR) in the Block V VIRGINIA shock environment.

SESSION 7: WEAPON EFFECTS TESTING

OVERVIEW OF JOINT WEAPON EFFECTS RESEARCH

Mr. Ernie Staubs, AFRL
Dr. Holger Sohn, German Ministry of Defense
Mr. Jason Angel, CCDC-Army Research Lab

The purpose of this joint testing program was to collect empirical data needed to develop and improve predictive codes used for strike planning, post-strike damage, and collateral hazard assessments in urban areas. Eight joint live fire test campaigns have been conducted to date to gather data critical to weapon effects model development. Test objectives are to obtain data for the purpose of developing, improving, and validating predictive analytic tools to estimate structural response, air blast propagation, secondary debris generation, and the resulting damage to critical equipment and infrastructure. This paper gives an overview of the joint testing conducted under the project which ended last summer and provides background information for companion papers presented at this symposium.

SECONDARY DEBRIS IMPULSE MEASUREMENTS FROM FAILING CMU AND RC WALLS

Dr. George Lloyd, ACTA, Inc
Dr. Tom Paez, ACTA,
Mr. Jake Allyn , ACTA

Secondary debris generated by munitions effects on urban targets can be the dominant cause of damage to building infrastructure outside the charge room. This phenomenon results because airblast effects attenuate rapidly through failing surfaces, as does the density of primary fragments, while the net impulse imparted by secondary debris can *increase* in conjunction with the concomitant increase in the density of secondary debris impacts which occurs.

The available experimental data for loads and damage to equipment generated by secondary debris is sparse. In this paper we present an analysis of several impulse measurements that were performed in conjunction with tests performed on CMU and RC walls in multiple buildings which contained a variety of equipment. In the case of CMU walls, both unreinforced and reinforced walls were studied, at varying charge densities. The results for RC walls include replicate measurements. The suite was designed such that CMU and RC tests at the same charge density were done, allowing for one-for-one comparisons of blast effects on airblast and secondary debris impulse. Multiple impulse measurements were fielded in each building, which enabled the studies of differential effects and measurement variability to be made.

The impulse measurement apparatus was instrumented to record high-fidelity motions, and also to make a permanent record of individual debris impacts using a witness plate approach. The dynamic data that were obtained are analyzed to decouple the secondary debris effects from airblast-induced effects. The data for the aggregate impulse time histories and the evolution of debris strikes during wall breakup are analyzed to deduce realistic load models that can be applied for functional kill assessment.

AN ANALYSIS OF THE GROUND CRATER PRODUCED ON THE SHIELD 2019 TEST

Mr. Denis Rickman, US Army ERDC
Dr. Kyle Crosby, US Army ERDC
Mr. Daniel Vaughan, US Army ERDC

The Super Heavy Improvised Explosive Loading Demonstration (SHIELD) test performed at Älvdalen, Sweden in summer 2019 provided a very large scale blast loading environment for the evaluation of protective structures and retrofit methods. The explosive charge used on SHIELD was an elongated arrangement of commercial ammonium nitrate/fuel oil (ANFO) placed on a tractor-trailer rig. Although explosive charges used in commercial and military applications and employed in terrorist attacks are created in a variety of shapes, spherical or hemispherical charges are assumed for many of the calculations used to predict blast effects from these threats. Numerous studies have shown that charge shape, soil type and conditions, and subsurface geology can have a significant effect on the ground crater produced by the blast.

The SHIELD test produced a very unique and asymmetric ground crater. The US captured the size and shape of the SHIELD blast crater using photogrammetry and LIDAR measurement techniques. The presentation presents detailed measurements of the crater and a summary of the local soil type and subsurface geologic conditions. Comparisons of the SHIELD crater profiles are then made to the craters produced by similar tests with varying soil conditions. In all cases, the data from other tests are scaled upward to the relative explosive yield of the SHIELD test. A comparison is also made to the crater from an accidental detonation with somewhat similar subsurface geology to the SHIELD test field.

THE GHOST OF THE NEGATIVE PHASE: AN INTRODUCTION TO BLAST-INDUCED CONDENSATION CLOUDS

Mr. Denis Rickman, US Army ERDC
Dr. Kyle Crosby, US Army ERDC

Given favorable atmospheric moisture conditions, explosion-induced blast waves may produce a short-lived condensation or “Wilson” cloud. When present, this condensation cloud is often perceived by observers as being the airblast shock wave. In reality, it is an artifact of the negative overpressure phase of the airblast wave. This paper presents an overview of the process by which blast-induced condensation clouds form and addresses the required negative blast overpressure and ambient atmospheric moisture threshold for cloud formation.

GROUND SHOCK PREDICTIONS FOR BURIED CONVENTIONAL MUNITIONS

Dr. Jeffrey Honig, Protection Engineering Consultants
Mr. Matt Barsotti, Protection Engineering Consultants
Mr. Frank Holiman, Applied Research Associates
Dr. Young Sohn, Defense Threat Reduction Agency

When a buried, cased munition detonates within the vicinity of a structure, predictions of ground shock and soil velocity are needed to calculate the dynamic loads that act upon the structural elements in contact with the soil such as footings, foundations, basement walls, etc. Predictive models for bare explosives exist, but there is room for improvement for conventional cased weapons. The goal of this research is to develop a fast running model (FRM) for shock and velocity predictions for detonation of buried cased munitions.

To develop a database from which to derive the FRM, numerical simulations were performed across a wide parameter space, including charge weight, depth of burial, casing thickness, and soil type. The data set includes measured outputs such as soil stress, soil velocity, time of arrival, and various decay parameters. Modeling of detonations of cased munitions in air is still a challenging problem; modeling detonation within soil is even more complicated, particularly if after-burning explosives are employed, due to the limited availability of oxygen to complete the burn. These challenges and solutions are discussed.

To develop the FRM, a proprietary artificial intelligence (AI) solver using evolutionary algorithms was employed to conduct symbolic regression of high dimensionality data sets. The AI solver yields simple, human-readable, multi-variable equations that model the underlying data set with a high degree of accuracy. The user may insert aspects of the physics of the actual problem where known, e.g., symmetry can be enforced, gravity effects can be applied, proportionalities can be included, etc. Unlike other ML models (e.g., neural networks, etc.) which tend to over-fit the data, these genetic programming solutions are stable across the whole domain and can be effective even with sparse data. The application of the AI solver to the synthetic data set is described and the resulting FRMs for ground shock and soil velocity are presented.

A GREEN'S FUNCTION METHODOLOGY FOR HIGHER-FIDELITY SURROGATE MODELS

Dr. George Lloyd, ACTA, Inc
Dr. Tom Paez, ACTA,
Mr. Jake Allyn , ACTA

The benefits to weaponeers of HFPB-based surrogate models (i.e., fast-running models or "FRMs") are widely recognized. They have been applied extensively in modeling and simulation environments to capture the responses of building structural components to weapons effects, for example, as well as to model human vulnerability and equipment fragility. The miniscule computational burden of an FRM, compared with that associated with the HFPB calculations used to train the FRM, enables complex scenario sets and parameter studies to be examined to an extent not achievable in any other fashion.

The traditional path that is followed to develop a surrogate model has been to calibrate and validate an appropriate HFPB model, identify the input and output parameter spaces which span the domains of the system and excitations and the range of the desired response metric (such as penetrability, residual capacity, or human injury criterion), and then establish by some means a finite set of training data which covers the system, excitations, and response. The FRM is then trained using this set of data.

This path is straightforward and adequate when the response can be reduced to a scalar or low dimensional vector. However, in many cases the response information needed for decision making for a multi-degree of freedom physical system under spatially distributed and transient excitations is not generally reducible to a scalar. Often, both spatial and temporal information at multiple degrees of freedom is needed in order to, for example, identify and rank the locations and times where failure is most likely to be initiated or occur in the system. The training data requirements under the traditional approach rapidly become prohibitive.

In this paper the authors will introduce concept of a Green's function based surrogate model. This approach extends previous work in which surrogate models have been trained to approximate the stochastic operator that evolves the probabilistic response of a system. In the present case the approach is applied to train the kernel or impulse response function of the system dynamics. The use of this methodology will be illustrated using a simple demonstration problem and a more complex application in the realm of infrastructure fragility.

SESSION 8: DYSMAS II

DYSMAS COUPLING UPDATES IN SUPPORT OF COMPLEX, ERODING GEOMETRIES

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

The coupling methodology for the DYSMAS hydrocode was originally developed for modeling the response of naval vessels to underwater explosion (UNDEX) phenomena. This legacy capability permits the simulation of holing of thin-walled structures that are modeled with shell elements. In the subsequent years DYSMAS has been applied to other loading scenarios besides UNDEX including buried blast, air blast, and penetration. In addition, the structural models have greatly increased in size and complexity, with the use of solid elements becoming much more common. This has led to the need for simulating the coupled response of complex structures discretized with solid and/or shell elements and subjected to extensive damage due to a variety of loading conditions.

Enhancements to the Standard Coupling Interface (SCI) of DYSMAS now allow for the modeling of coupled erosion. This is accomplished by a coupling interface that adapts to the changing connectivity and shape of the structure as Lagrangian elements (both solid and shell) are deleted due to material failure. First an overview of the adaptive SCI capability will be presented. Strategies for modeling coupled erosion, including multiple structural components with contact, will then be discussed in conjunction with simulations that highlight the new capability.

CALIBRATING AND VALIDATING DYSMAS MATERIAL MODELS VIA OPTIMIZATION

Dr. Frank Vangessel, NSWC Indian Head

The DYSMAS hydrocode is capable of simulating a wide array of weapon effects. Specifically, underwater explosions, metal fragmentation, reactive material dispersal and burning, and nuclear explosions are all explosive phenomena that can be simulated by DYSMAS. To ensure predictive weapon effects models, hydrocode simulations require accurate material models as inputs. Among the critical constitutive material models are equations of state, strength and fragmentation models, and non-ideal burn rate models. We present a framework for calibrating, and ultimately validating, DYSMAS material models using an optimization framework. This framework interfaces optimization routines directly with DYSMAS to iteratively update model parameters in an automated fashion, ensuring accurate prediction of experimental data. We demonstrate the utility of this optimization approach to an array of weapon effects scenarios. Namely, we demonstrate calibration of water EOS for UNDEX wavebending prediction, non-ideal energy release models for modeling novel explosive formulations, strength models for reactive material breakup, and nuclear fireball model for nuclear explosion modeling.

FLUID-STRUCTURE INTERACTION OF COLLAPSING VOLUMES IN CONFINED ENVIRONMENTS

Mr. Craig Tilton, NUWC Division Newport
Dr. Joe Ambrico, NUWC Division Newport
Dr. Joe Ambrico, NUWC Division Newport
Mr. Ryan Chamberlin, NUWC Division Newport
Mr. Arun Shukla, NUWC Division Newport
Mr. Anton Spirkin, NUWC Division Newport

Implosion occurs when a pressure vessel reaches a critical pressure, causing an instability and the rapid collapse of the structure. The collapsing structure, known as an implodable volume, has the potential to emit large pressure waves during its collapse, which in turn have the potential to damage nearby structures. An implosion occurs in a confined environment when structures near the implodable volume significantly change the physics of the implodable's collapse. The collapsing of volumes in confined environments is not well understood. This work seeks to understand the relationship between the parameters of a confining environment and the physics of collapse of the implodable volume. It is also of particular interest to understand how the severity of an implosion changes with the parameters of a confined environment. The work presented will highlight recent advances in understanding using both simulations and testing.

IMPLOSION OF PRESSURE VESSELS WITHIN CONFINED ENVIRONMENTS

Dr. Joe Ambrico, NUWC Division Newport
Mr. Craig Tilton, NUWC Division Newport
Dr. Joe Ambrico, NUWC Division Newport

Pressure vessels exposed to external depth pressure in water have the potential to collapse. The resulting implosion can create a high-pressure wave that radiates outward in the water. When a pressure vessel is located within some sort of confining structure, that structure can restrict or affect the water flow that drives the implosion. This effect can either mitigate or enhance the implosion magnitude, depending on several factors. This study investigates a particular configuration of a confining structure, and creates an upper-bound estimate of pressure vessel implosion within it. The estimate is based on detailed fluid-structure interaction simulations. The upper-bound is characterized by approximating the pressure vessel as a similarly shaped air bubble. Numerous simulations are run to characterize the implosion for different combinations of pressure vessel length, diameter, and collapse pressure. Several key trends are described, some of which are counter-intuitive.

Simulated Hydrostatic Implosion of a Cylinder within a Closed Box

Dr. Emily Guzas, NUWC Division Newport
Dr. Joe Ambrico, NUWC Division Newport
Mr. Craig Tilton, NUWC Division Newport
Mr. Ryan Chamberlin, NUWC Division Newport

This paper covers a series of numerical experiments performed to investigate the effect of the presence of a closed water-backed confining structure (rectangular box) on the hydrostatic implosion dynamics of a cylindrical pressure vessel (implodable volume) located inside the box structure. We present DYSMAS simulation results for the hydrostatic implosion of a small cylinder for various combinations of box dimensions and plate thicknesses. Additionally, we investigate the implosion dynamics for various sizes of rigid boxes, to isolate the effect of relative volume of confining structure to implodable volume. As a reference point, we compare select time histories from confined implosion cases to simulated hydrostatic implosion results at the same sensor locations for the same cylinder at the same depth in an unconfined (free-field) environment. Additionally, we propose a method to characterize the confining box's influence on the implosion.

Simulating the Underwater Shock Response of Soft Biomimetic Structures

Dr. Emily Guzas, NUWC Division Newport
Dr. Joe Ambrico, NUWC Division Newport
Mr. Nick Valm, NUWC Division Newport
Mr. Brandon Casper, Naval Submarine Medical Research Laboratory
Mr. Matt Babina, Naval Submarine Medical Research Laboratory

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

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

The Importance of Using Proper DSP when Correlating Physical tests and Numerical Simulations

Dr. Ted Diehl, Bodie Technology

One of the most common causes for poor, to outright terrible, correlations between transient responses from physical tests and numerical simulations of mechanical shock/impact is unintended DSP-related mistakes made during data capture and further data processing. There a several places in such a workflow where critical DSP mistakes are made. A few of these types of mistakes include aliasing data during initial data capture or later decimation manipulations and making unfair comparisons due to the dissimilar bandwidth potential of the different sources of data (physical tests and simulation). These are just a few of the many mistakes that will be described. On top of these issues, it is likely that the DSP expertise and experience of the test engineer and simulation analyst are vastly different, and that the DSP challenges of each of their respective domains (physical testing and numerical simulation) is more different than either would ever suspect. This presentation describes these various challenges and more for such correlation efforts, and then demonstrates proper workflows (with examples) of how to properly apply DSP techniques to ensure you have aliased-free data, and how one can fairly process data to ultimately judge correlation in both the time-domain and frequency domain for transient mechanical shock/impact data.

MEMS Gas Damped Sensors Replacing Strain Gage Fluid Damped Sensors
Ms. Jennifer MacDonell (Endevco)

For decades, we have relied on fluid damped piezoresistive sensors to damp out unwanted sensor resonances. While this technology has served us well, the high cost of making tiny strain gages, matching them, setting mechanical stops for them and then filling the package with fluid while enforcing a hermetic seal, is no longer sustainable. With the advent of MEMS, we can more efficiently form the strain gages, match them, include mechanical stops and introduce gas damping during the wafer bonding, eliminating hours of costly manual labor. Data will be shared comparing fluid damped sensors to gas damped sensors in a series of tests demonstrating their equivalent performance.

Sirius XHS for High Bandwidth Recording (Sample Rate – 15 MS/s)
Mr. John Hiatt, DEWESoft

The Sirius XHS is an innovative new data acquisition module that allows users to acquire data at 15 MS/s with hybrid ADC technology and several user-controlled filtering options to ensure high bandwidth, quality data. The Sirius XHS was designed for high frequency shock/blast testing as well as power analysis. The maximum sample rate does not decrease with the number of channels.

Seeing is Believing in Dynamic Events
Dr. Josh Loukus, REL Inc.

Real time video at 1 million frames per second and beyond has helped explode the dynamic testing space. Capturing events happening in 100’s of nanoseconds gives greater depth to the understanding of high strain rate physics. Seeing inertial effects in real time helps the community as a whole to understand Newton’s laws more clearly and allows for better material models to help fuel the next generation of products designed and built for industry, government, and outer space!

The Influence of High Damping Cable Wire Rope Isolators on Naval Applications
Mr. Ali Shehadeh (Vibro/Dynamics)

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

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

Fortunately, there are ways to overcome this problem, namely increasing their damping and/ or changing their aspect ratio. It is the purpose of this presentation to show how to overcome this problem and through analysis, by use of validated models of the shock testing machines. The existing technology will be briefly presented and HDWRI (high damping wire rope isolators) vs. conventional WRI responses will be compared on the US Navy shock testing machines of MIL-S-901D.

THE QUEST FOR A DIGITAL TWIN

Mr. Ray Deldin, Altair Engineering

Altair is at the forefront of the evolution toward a smarter, more connected world. Our comprehensive, open-architecture solutions for data analytics & AI, computer-aided engineering, and high-performance computing (HPC), enable design and optimization for high performance, innovative, and sustainable products and processes.

TRAINING II: NONLINEAR MECHANICAL SYSTEMS – IDENTIFICATION AND SIMULATION USING MATLAB

NONLINEAR MECHANICAL SYSTEMS – IDENTIFICATION AND SIMULATION USING MATLAB

Prof. Kjell Ahlin, Xielalin Consulting

Linear mechanical systems with localized nonlinearities are studied. The nonlinear forces may be functions of displacement and/or velocity at the involved degrees-of-freedom. The training gives basic background of nonlinear systems, such as determination of nonlinearity, harmonic balance calculation and different examples of nonlinearities. It then concentrates on effective simulation routines built on digital filters implemented in MATLAB. Many different types of nonlinearities are treated, such as nonlinear springs and dampers, friction such as stick-slip, coupled nonlinear systems as for nonlinear bridge cables, etc. System identification using Bendat's method of "Reverse Path" is introduced and used in different applications. Finally, an efficient general method for nonlinear system simulation is introduced. The linear system may be characterized by a Finite Element Model, a lumped mass-damper-spring system, an analytical expression (as for beams) or from Experimental Modal Analysis. Any number of simultaneous forces may be applied, any number of localized nonlinearities may be added. Any number of responses as displacement or velocity may be calculated

SESSION 9: PYROSHOCK

FEASIBILITY OF USING LIGHTWEIGHT GAS GUNS FOR HIGH-G RESONANT PLATE SHOCK TESTING

Dr. Carl Sisemore, ShockMec Engineering LLC

Resonant plate shock testing is frequently used to simulate pyrotechnic shock events in the laboratory. The method has been used for many years and is a proven technique for evaluation and qualification of small components. In recent years, there has been a trend towards resonant plate testing at higher acceleration levels and at a wider range of test frequencies. This has often resulted in poor quality tests at the capability extremes. While resonant plate testing has always required unique plates designed for specific test frequencies, the gas guns used to provide the shock impulse are almost always the same. Often the projectile weight will be varied while the gun and bore are fixed. This paper investigates the feasibility of using smaller bore, lightweight gas guns to obtain high-energy shock excitation in resonant plates. The paper further investigates the relationship between bore diameter, projectile weight, and resonant plate frequency.

SHOCK MODEL AND TEST CORRELATION FOR STRUCTURAL RESPONSE PREDICTION

Mr. Sean Pham, NASA Jet Propulsion Laboratory
Dr. Ali Kolaini, NASA Jet Propulsion Laboratory

When defining hardware shock environments, it is typical to assume a reduction of shock through structural joints – nominally, a 30% reduction per joint up to a maximum of three joints. However, review of shock test data from a flight-like test article demonstrates that attenuation across interfaces is not always realized. Across a single joint, significant amplification is observed at various locations on the test article throughout the entire frequency range, with maximum amplification of ~12dB. Responses across a second joint still shows low frequency amplification coupled with mid to high frequency attenuation. While empirical scaling of shock inputs may be appropriate for most applications, its failure to account for potential amplification may result in an underestimate of a hardware's shock environment. An analytical framework for deriving shock environments from system-level specifications would be beneficial to accurately qualifying hardware for flight loads. Modeling and test data correlation of a flight-like test article in NX Simcenter is being conducted to determine if finite element analysis is sufficiently robust to capture the complexities of shock transmission through interfaces in the 20-1500Hz frequency range. Careful consideration is given to capturing interface impedances and uncorrelated inputs during the modeling process to closely replicate the testing configuration, which were investigated using coupon-level tap testing. In this paper, we discuss measured structural responses to shock loading with an attempt to correlate them to FEM-based predicted responses. We only cover low to mid-frequency predicted structural responses and defer higher frequency prediction to future work.

GUIDELINES FOR REDUCING UNCERTAINTY IN SHOCK ANALYSIS AND TESTING

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

The average aerospace structural analyst is very familiar with performing various types of dynamics analysis (sine vibration, random vibration, transient) but much less familiar with dealing with shock analysis defined by SRS (shock response spectrum) dealing with very high acceleration levels (1,000-2,000 g's) and high frequency limits (10 kHz). Likewise the average aerospace engineer performs a lot of sine and random vibration testing at the system and subsystem levels and feedback from those tests are readily compared to analysis predictions.

In contrast typically very little SRS related analysis and subsequent shock testing is performed either at the system or subsystem level and rarely would shock analysis predictions be compared with shock test results. Typically going into sine and random vibration test a structural analyst will know expected responses at accelerometer locations. For a typical shock test many times a dynamics engineer is a bystander and watches the test lab use their shock test method to achieve the SRS tolerance levels in each axis and typically no shock analysis predictions of the shock test setup are performed.

Sine and random vibration tests at the system level are common, but shock testing at the system level is much rarer (sometimes the customer will waive the system shock test requirement – that can't happen!) as it is much more difficult test to perform. To reduce uncertainty in shock analysis predictions it is essential that shock testing at the system level become as common as sine and random vibration testing and much less difficult to do. As such, adaptive mechanical shock devices need to be developed that can readily dial in a shock pulse at the base of the system that will satisfy SRS test tolerance requirements. To reduce uncertainty in shock analysis it is necessary to feed back the shock testing responses at the system level into a system level shock FEM such that reasonable correlation is achieved between shock testing and shock analysis predictions accounting for structural dynamics effects, shock propagation, and shock attenuation with distance from the shock source and through joints.

The purpose of this paper is to provide clear guidelines and helpful references that will benefit the average aerospace engineer performing shock analysis that will reduce uncertainty that is typically associated with shock analysis because of the complex nature of shock loads. To accomplish this objective will require more shock analysis and testing knowledge and a commitment and more attention to address shock analysis and testing throughout the development program such that shock predictions and proposed testing at the system level and subsystem levels can be routinely addressed at CDR (Critical Design Review) and thus readily apparent to the customer that shock analysis and testing is being properly addressed. This type of engineering detail required for shock analysis and testing is currently not being done – and is one of the reasons why there is still significantly more uncertainty in shock analysis predictions than sine and random analysis predictions.

SESSION 10: UNDEX SHOCK TEST SIMULATION

DP_VITS/MECHANICAL SHOCK FOR UNDEX LABORATORY SIMULATION, PART I

Mr. Kevin Gilman, Lansmont Corp

In the presentation, I detail the design, development, and implementation of a unique testing machine to meet the Pseudo Velocity Shock Response Spectra (PVSRS) requirements specific to the German Navy. The requirement specifies a "Double pulse" impact requirement that simulates the effects of underwater explosions with test specimen weighing up to 1000 kg. The machine can produce initial half sine peak accelerations up to 300g at 3.3 to 10 ms durations followed by reverse impact half sine accelerations up to -150g at 9 to 32 ms durations. These impacts are produced using a combination of Lansmonts proprietary elastomer impact modules arranged strategically to achieve the desired time domain characteristic transient that yields the desired PVSRS shape. Based on Lansmonts extensive history and experience in producing high quality impact testing machines, we were uniquely suited to develop a robust machine meeting these difficult requirements. The design approach and principles of operation will be presented along with considerations employed in the design to meet the unusual COVID restrictions encountered during assembly in Germany.

ON-SITE ACCEPTANCE TESTING OF NEW VERTICAL SHOCK TESTING SYSTEMS AT WTD 71

Mr. Alexander von Bluecher, Bundeswehr - WTD 71

German Naval Standards describe shock load references by a three-line polygon in the Pseudo-Velocity Shock Spectrum (NATO Standardized Level, PVSS). Shock testing machines approach these PVSS best by generating "Double Pulses". In 2022 a new Vertical Shock (Impact) Testing System from Lansmont Corp., "DP-VITS", has been commissioned at Bundeswehr Technical Center for Ships and Naval Weapons, Maritime Technology and Research, WTD 71, in Kiel, Germany. Acceptance (tolerance) criteria were taken from the draft of STANAG 4549. Furthermore, the DP-VITS' requirements asked for a wide bandwidth of PVSS, which ought to be covered by this shock testing system and a good repeatability in achieving the required PVSS.

An overview of the DP-VITS at WTD 71 in Kiel will be given, emphasizing the results from the on-site acceptance testing, demonstrating the different shock levels which were achieved as well as the accurate repeatability of the PVSS. The DP-VITS main operating parameters will be introduced and typical test settings for various PVSS will be discussed. For extending its shock testing capabilities and in addition to the DP-VITS a new Horizontal Shock Testing System, DP-HITS, has been ordered by WTD 71 in 2020. An initial overview on the DP-HITS design and the requirements will be provided.

SESSION 11: BLAST & BALLISTICS MEASUREMENT

INTERIOR BALLISTICS HARDENING FOR SENSOR PACKAGE DEVELOPMENT

Mr. Ryan Hanc, US Army CCDC - Armaments Center
Mr. Russell Jones, US Army CCDC - Armaments Center
Mr. Adrian Sanchez, US Army CCDC - Armaments Center
Mr. Arhum Mirza, US Army CCDC - Armaments Center
Mr. Ervin Beloni, US Army CCDC - Armaments Center
Mr. Alfred Rotundo, US Army CCDC - Armaments Center

The interior ballistics environment of large caliber gun systems represents a particularly unique challenge for the survival of electronics and sensor packages used to provide empirical data to support the external validity of small scale testing, modeling, and simulation. Elevated static pressures, temperatures, and unique effects of propellant ignition generate considerable stressors for sensitive electronic components, all of which require the cognizant designer to incorporate various methods of protection to ensure a robust assembly. This study describes the development and design decisions encompassed in the development of a novel sensor package capable of measuring and recording accelerations and strain gauge data from inside the sealed combustion chamber of a large caliber artillery cannon. Several aspects of the experimental development are discussed, including sensor selection, electronics integration, structural protection, and high pressure sealing methods. Finite Element Analysis and Computational Fluid Dynamics results for the optimization of key features are also presented. The work presented demonstrates a preliminary achievement for the enhancement of data capture abilities for applied science on full-scale, large caliber gun systems, which shows significant promise for future development and growth.

STRAIN GAGE RESPONSE OF LARGE CALIBER STUB BASES

Mr. Russell Jones, US Army DEVCOM Armaments Center
Mr. Ryan Hanc, US Army DEVCOM Armaments Center
Mr. Brian Peterson, US Army DEVCOM Armaments Center
Mr. Adrian Sanchez, US Army DEVCOM Armaments Center
Mr. Arhum Mirza, US Army DEVCOM Armaments Center

The harsh and rapidly changing interior ballistics environment of large caliber artillery systems presents unique challenges for the temporal measurements of instrumentation for the validation of dynamic mechanical behavior of internal components. Historically, data capture has been limited to ported pressure gages or post-mortem observations, which must often be augmented by modeling and simulation to infer time-dependent behavior during the ballistic cycle. In this study, novel methods of strain gauge instrumentation and interior ballistics hardening are presented for an expanding single-sided open ended cylinder that constitutes the high pressure seal for the system. Data reduction and

interpretation is discussed in the context of simple stress-strain mechanics and cylinder stress equations. Conclusions may be inferred from the quantitative data about seal timing, contact settling, tensile strain oscillations, and ovalization. The work presented demonstrates a marked improvement in the capabilities for instrumenting the interior ballistics environment to better understand the coupled structural dynamics of the system.

SESSION 12: BLAST EFFECTS ON CONCRETE MATERIALS

A FUNCTIONAL ASSESSMENT OF THE REPAIR OF CONCRETE ELEMENTS

Ms. Katelyn Polk, US Army ERDC
Mr. Stephen Turner, US Army ERDC
Mr. Cameron Thomas, US Army ERDC
Dr. Jay Ehrgott, US Army ERDC
Mr. Denis Rickman, US Army ERDC

There is a continuous need in the military for the development and application of advanced materials for the protections and support of our forces around the world. High performance concrete (HPC) shotcrete materials exhibit rapid strength gains and high bonding characteristics, which could be utilized to perform rapid repairs of structures and structural elements. Consequently, HPCs have potential application for deployed military forces in remote locations for the expedient repair of damaged concrete structural and protective elements. The use of HPCs that are simple to deploy, cure quickly, and achieve high bond strength with minimal to no surface preparation have been tested to evaluate their effectiveness for repairing various common concrete elements. The ERDC has performed a series of experiments to evaluate the functionality and performance of the HPC shotcrete rapid repair methods for damaged concrete elements including Alaska barriers, reinforced concrete boxes, concrete structural walls, and others subject to various blast loading conditions. In addition, an evaluation of the durability of the material and hazardous secondary fragment production from HPC-repaired elements has been conducted. Data analysis is used to understand the suitability of HPC shotcrete for the repair of concrete elements as a rapid method, and to quantify the effect of the repairs on the secondary fragment hazards produced by repaired elements subjected to blast loading conditions. This paper is focused on presenting the results of a series of experiments comparing HPC repaired elements to conventional concrete elements subject to blast loading, as well as concepts for future applications.

The data collected in the experimental events included structural performance, durability, and secondary debris hazards created when this HPC material is subjected to these harsh conditions. These results were compared to pristine concrete elements subjected to similar conditions. This paper will present the experimental layout, comparison of the results, and future plans and applications of this material.

High Performance Concrete Shotcrete Rapid Repair and Enhancement of Concrete Barriers

Mr. Stephen Turner, US Army ERDC
Mr. Katelyn S. Polk, US Army ERDC
Mr. Cameron D. Thomas, US Army ERDC
Mr. Chris M. Moore, US Army ERDC
Dr. Jay Q. Ehrgott, US Army ERDC
Mr. Denis D. Rickman, US Army ERDC

The US military uses a significant number of concrete barriers (such as Alaska barriers) to support expeditionary operations, including construction and maintenance of forward operating base defensive perimeters. The defensive posture of deployed forces may be impacted due to damage or destroyed concrete barrier walls from various attack vectors. There are currently no deployable and expedient methods for repairing these walls in the field to restore or enhance their useful function. ERDC has been evaluating a High-Performance Concrete (HPC) shotcrete material to expediently repair damaged concrete barriers in the field. This HPC has shown to have quick setting time, high bond strength, and requires minimal surface preparation. This effort has determined this HPC technology can provide an acceptable repair of concrete barriers under austere conditions. Also this HPC can provide enhanced blast performance of repaired Alaska wall barriers. This presentation will cover an overview of the program, background on the product, design of the experiment, collection of test data, and a comparison of the results.

Comparative Study of UHPC and HSC One-Way Slabs Subjected to Far-Field Blast Loads

Mr. Bowen Woodson, US Army ERDC
Dr. Bradley W. Foust, US Army ERDC
Mr. Micael Edwards, US Army ERDC
Dr. Serdar Astarlioglu, US Army ERDC
Dr. Carol F. Johnson, US Army ERDC

Ultra-high-performance concrete (UHPC) and high-strength concrete (HSC) have gained popularity in recent years for protective applications due to their enhanced compressive strength and toughness when compared to normal-strength concrete (NSC). Furthermore, new UHPC mixtures are being developed throughout the world that incorporate different materials to reduce costs. It is necessary to fully characterize the behavior of structural elements consisting of these newly-developed materials before they are utilized in protective design. The U.S. Army Engineer Research and Development Center (ERDC) has conducted extensive research in recent years to investigate the performance of multiple UHPCs and HPCs. The research discussed herein will focus on the flexural response of one-way panels subjected to far-field blast loads for two UHPCs and two HPCs. Numerical simulations were conducted to analyze the behavior of the slabs against far-field blast loads. Additionally, a comprehensive set of far-field blast experiments was conducted using ERDC's Blast Load Simulator Facility to validate numerical results. This paper will discuss the structural response of all four materials and compare them to a baseline NSC.

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

HIGH SPEED IMAGING WITH SENSOR DATA IN SMALL SPACES

Mr. Bill Spinelli, Photron

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

SHOCK & VIBRATION TEST RESULTS FOR A NEW, HIGH CAPACITY PUMPKIN MOUNT

Mr. Alan Klembczyk, Taylor Devices

This presentation will outline the results of comprehensive testing of a new 6 DOF shock & vibration isolation mount, with an isolated mass capacity of approximately 2,000 lbs. that is currently being deployed as another product manufactured by Taylor Devices. At last year's SAVE Symposium, preliminary results were shared that provided the impetus to continuing substantial R&D efforts to qualify the mounts for naval use. Shock and vibration testing at SUNY Buffalo's Structural Engineering and Earthquake Simulation Laboratory verified outstanding results. Barge testing at Thornton Tomasetti's test facility in Scotland demonstrated superior shock mitigation ability. MIL-STD-167 vibration testing at HI-TEST was conducted with results as expected. Component-level static, dynamic and environmental tests at Taylor Devices demonstrated excellent performance. During this presentation, test results will be presented covering all phases of testing.

GIBBS & COX SURVIVABILITY CAPABILITIES

Mr. Michael Poslusny, Gibbs & Cox

Gibbs & Cox, Inc., a Leidos Company, relies on an experienced team of marine and engineering specialists to provide quality design and technical services. The work we do involves a wide range of activities, beginning with concept and feasibility ship design and continues through detailed design, construction support, life-cycle support, and ship-alt design for service-life extensions. Under this breadth of support, there is a dedicated team at G&C who incorporate survivability strategies at each stage of design / construction. Our presentation will focus on G&C's survivability capabilities which includes environmental qualification testing and a brief overview of our current projects; including analysis, shock, vibration, and EMI support for multiple ship programs.

TRAINING III: AN INTRODUCTION TO DYNAMIC ANALYSIS

AN INTRODUCTION TO DYNAMIC ANALYSIS

Mr. Bart McPheeters, Gibbs & Cox

A short introduction to the different methods of FEA analysis that center around dynamics. The class will discuss what makes a problem dynamic and the different types of dynamic analyses can be done within the framework of FEA. (I've done variations of this class before and it is usually popular).

SESSION 13: MODELING & VALIDATION OF RESONANT PLATE

A SIMPLIFIED FINITE ELEMENT MODEL FOR DESIGN OF A RESONANT PLATE

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

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

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

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

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

DEAD ENDS AND CHALLENGES IN SIMPLIFIED FINITE ELEMENT MODELING OF A RESONANT PLATE

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

This is intended to be the 2nd paper in a trilogy describing a simple finite element modeling of a resonant plate suitable for designing resonant plates with specific properties. The first paper described the development of a simple model of a 1kHz resonant plate with damping bars using Ansys Mechanical.The focus of this paper is on the process of creating this simplified model, so that similar methods can be applied in other situations, emphasizing modeling approaches that were dead ends and did not work.

The initial finite element model for the resonant plate without damping bars was constructed with two-dimensional plate elements. Considering how extremely simple this model was, it produced reasonable results. The natural frequencies of the modes in this model were within 10% of the modes found during modal testing, with all of the model frequencies being higher than the test frequencies. Therefore, it was determined that other details needed to be included. These were the mounting blocks along the edge of the plate and the impact block in the middle of the plate. These blocks primarily provide mass, and accounting for their mass lowered the natural frequency. The blocks were modeled as point masses, and this model produced natural frequencies within 3.5% of the test data.

Next, damping bars were introduced to the plate model. First, modal analyses of the damping bars using one-dimensional beam elements, two-dimensional plate elements, and three-dimensional solid elements were run and compared. Both the beam and plate element representations of damping bars produced natural frequencies that were within about 1% of the solid element model. Therefore, either simplified element type could be used in the model. The beam element model was used initially because it was simpler and more accurate than the plate element damping bar. Next, it was discovered that Ansys's built-in contact tools were not as compatible with plate elements as they are with three-dimensional solid elements. Problems arose from the fact that, in reality, the top surface of the plate is connected to the bottom surface of the damping bar, but these surfaces are not modeled by the two-dimensional elements. Instead, there is a gap between the plate and bars. We attempted to span this gap using spring elements located where bolts connect the plate and damping bars. By tuning the spring constant, it was possible to match a few mode shapes and frequencies in the model with the test data. However, modes involving damping bar torsion were not modeled well. The spring elements were replaced with steel beam elements, so that the connection would provide stiffness in all directions. This improved the result, but there were still problems with the first saddle mode of the plate. Ultimately, two rows of seven beam elements to connect each damping bar to the plate were required to produce a model that had modal frequencies within 5% of the test data and consistent mode shapes.

VALIDATION OF A FINITE ELEMENT MODEL OF A RESONANT PLATE IN THE SHOCK DOMAIN

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

This is intended to be the 3rd paper in a trilogy describing a simple finite element model of a resonant plate suitable for designing resonant plates with specific properties. The focus of this paper is on how the model behaves in a shock environment with an emphasis on simple methods for modeling damping. Additionally, the model was adapted to match the dimensions of another resonant plate to evaluate its accuracy for different resonant plates.

The first paper described the development of a simple model of a 1kHz resonant plate with damping bars using Ansys Mechanical. The final version of this model used plate elements to model the plate and four damping bars. Each damping bar was connected to the plate using two rows of beam elements, and point masses were added to the plate to represent blocks attached to the plate. The second paper described the simplification process for creating this model, with a focus on modeling approaches that did not work. However, both papers focus on modal analyses of the resonant plate model and compare to modal test data. Since the resonant plate is meant for use in shock tests, it is important to determine how accurately the model portrays the plate's behavior in the shock domain.

Extensive shock testing on the 1kHz resonant plate was performed. To compare the results of these tests with the model, the SWAT-TEEM (Sum of Weighted Acceleration Technique – Time Eliminated Elastic Motion) method was used to calculate the input force experienced by the plate. This force data were applied to the center node of plate in a Modal Transient Structural analysis in Ansys. Modal damping values were tuned in the model so that the ring down time, SRS (Shock Response Spectrum), and FFT (Fast Fourier Transform) of the model matched the test results.

Finally, the applicability of this simple modeling approach was assessed by modifying the model to match the characteristics of another resonant plate. The dimensions and locations of components in the model were adjusted to represent the setup of the new plate. Modal and Modal Transient Analyses of the model for the new plate were performed in Ansys. The results of these analyses, compared to test data for the new plate, will be presented in the paper.

RESONANT PLATE SHOCK TEST AND DATA VALIDATION CHALLENGES

Mr. David Soine, Sandia National Laboratories
Mr. Forrest Arnold, Sandia National Laboratories
Mr. Florentino Arias, Sandia National Laboratories
Mr. Kevin Brenner, Sandia National Laboratories
Mr. Dillon Neeley, Sandia National Laboratories

Data validation is a critical step in mechanical shock testing, especially for pyroshock. This work presents data validation and post-test evaluation activities performed during an experimental resonant plate shock test series. Resonant plate shock events are considered a mid-field pyroshock, and piezo-resistive MEMS transducers were selected to perform the measurement due to their high resonant frequency, flat response, and phase linearity. The data acquisition system was appropriate for these transducers. Data validation steps performed on the measured shock data produced unexpected results, leading to additional investigation.

EVALUATION OF THE RC FILTER CABLE MODEL WITH PR ACCELEROMETER RESONANT RESPONSE

Mr. Forrest Arnold, Sandia National Laboratories
Mr. David Soine, Sandia National Laboratories
Mr. Florentino Arias, Sandia National Laboratories
Mr. Kevin Brenner, Sandia National Laboratories
Mr. Dillon Neeley, Sandia National Laboratories

When planning a shock test where piezo-resistive (PR) MEMS accelerometers may be utilized, the RC filter model can be applied to estimate the effect of the measurement cable on the frequency (or rise time) performance of the data acquisition system. Understanding the attenuation due to the measurement cable on the frequency range of interest can help ensure that the measurement uncertainty and test results ultimately meet the expectations of the organization requesting the test. Additionally, the cable can also influence the measurement of the transducer resonant response, often considered to be outside of the frequency range of interest. Mechanical shock tests are conducted to examine this effect, and the results are compared to estimated cable attenuation from the RC filter model for PR accelerometer cable performance.

SESSION 14: INSTRUMENTATION: PERFORMANCE VALIDATION

TESTING OF VIBRATION IMMUNITY OF MEMS SENSORS WITH EXCITATION UP TO THE MHZ RANGE

Mr. Michael Mende, SPEKTRA GmbH

MEMS sensor structures are getting smaller and smaller and the sensors are packed more and more densely with other components on circuit boards. Therefore, the question of how immune these sensors are to high-frequency spurious vibrations is becoming more and more important. Such oscillations can be induced, for example, by surrounding components such as DC-DC converters as well as by shock-like excitations on the structures or housings in which the sensors are mounted.

The paper presents a novel piezoelectric vibration exciter that can be used to precisely generate both translational vibrations and tilting motions up to the MHz range. The design of the exciter thereby suppresses unwanted transverse motions that occur in classical piezo-electric exciters based on a stack of piezo plates. The basic idea on which the new exciter is based and measurement results on prototypes with a 3D scanning laser vibrometer are shown.

APPLICATIONS OF PDV IN LFT&E

Mr. Brandon Hepner, US Army Aberdeen Test Center

In recent years, Photon Doppler Velocimetry (PDV) has grown in popularity in the explosives research community for its ability to provide high temporal resolution measurements of extreme velocities. Less frequently, PDV is used to measure smaller velocities (sub 200 m/s) and small displacements as other instrumentation such as accelerometers are traditionally used. However, there are applications in LFT&E when PDV measurements are ideal due to the destructive nature of testing. A small, inexpensive ($35) collimating probe can be sacrificed to make a measurement in an environment that would otherwise destroy a $2,000 accelerometer. This presentation focuses on the development, basic system principals and operational examples of the US Army Aberdeen Test Center’s PDV system used in LFT&E.

VALIDATION TESTING OF MANUFACTURING CHANGE TO LEGACY ACCELEROMETER

Mr. Julian Richards, Aberdeen Test Center
Mr. Brandon Hepner, Aberdeen Test Center

Throughout its tenure as the Army's premiere vehicle vulnerability/survivability test center, the US Army Aberdeen Test Center has employed a commercial, oil damped, 2,000g accelerometer to make various measurements in Live Fire Test and Evaluation of military vehicles. This legacy sensor, (dubbed sensor A for the purposes of this report) was often utilized for its robustness and its nonsusceptibility to artifacts often found in strain-based accelerometers used in the ballistic shock environment. Unfortunately, due to an acquisition of the OEM, sensor A is now obsolete and has been replaced with a similar (albeit different) sensor dubbed type B for this report. Sensor B has similar performance specifications but several key differences, mechanical overrange stops, squeeze film damping, and output impedance needed to be validated before the sensor could be used in testing. A frequency response sweep performed on each sensor revealed similar amplitude response within their given frequency range. Sensor B displayed slightly better results with a lower deviation percentage from nominal sensitivity. At high frequencies the results showed both sensors with similar roll-off and attenuation with sensor B providing slightly better results. An amplitude overmatch characterization was created for the Type A and Type B to determine how the sensors reacted when they were in scenarios outside their specified range. This test was administrated using a smack bar to simulate high impact scenarios of up to 10,000g. Type B maintained a similar linearity and accuracy as the Type A up to 2,000g. Both sensors were able to survive inputs of higher than 10,000g. It was discovered that Type B had a soft mechanical damping system which caused the data to tail off at 2000g and plateau at 3000g. In comparison the Type A was able to maintain linearity up to 6000g before it experienced a late time velocity drift at 8,000g.

SESSION 14: ACOUSTICS

MULTIPLE-INPUT MULTIPLE-OUTPUT ACOUSTIC TESTING OF TURBOPROP FUSELAGE STRUCTURES

Dr. Mattia Dal Borgo, Siemens Industry Software
Mr. Umberto Musella, Siemens Industry Software
Mr. Luigi Staibano, Lead Tech
Mr. Pasquale dell'Aversana, Lead Tech
Mr. Mariano Alvarez Blanco, Siemens Industry Software
Mr. Raffaele Bianco, Lead Tech
Mr. Bert Pluymers, KU

Advanced turboprops are currently at the forefront of the research in sustainable aviation for regional transport, offering higher fuel efficiency compared to conventional turbofans. However, propeller driven aircraft are commonly perceived as being noisy, thus limiting their widespread adoption. The reason is that the interior noise in turboprops is not only generated by the excitation of the outer skin due to random pressure fluctuations in the turbulent boundary layer (TBL), but also by the periodic pressure fluctuations caused by the propeller blades passing near the fuselage.

Cabin noise attenuation has been an active field of research for over 40 years and it still is. Different solutions have been developed targeting both the TBL excitation and the blade passage excitation. However, evaluating their effectiveness by measuring the fuselage responses usually requires either flight tests or low noise wind tunnel tests. Although accurate, both these approaches are extremely expensive, especially during the initial development phases of a noise attenuation technique. This paper presents an alternative approach, where a near-field array of loudspeakers is used to synthesize a pressure field on the fuselage surface similar to the loads generated by both the TBL and the propeller blade passages, simultaneously.

In the framework of the CleanSky2 CONCERTO project (GA886836), novel cabin noise testing equipment is developed that will be used to evaluate the interior noise of regional aircraft and to aid the development of noise reduction solutions. The innovative noise generation system consists of three modular frames that hold evenly distributed loudspeakers at a given distance around the fuselage circumference. The frames can be adjusted to accommodate fuselages of differing diameters. The sound pressure is measured by a certain number of microphones placed around the fuselage surface. The number and location of the microphones used in the control loop are selected using a pre-test optimisation analysis, which aims to reduce the time and cost of the test set-up. An iterative learning approach is then used to minimise the error between the target and the measured pressure fields. Preliminary tests on a small-scale electroacoustic demonstrator were used to validate the multiple-input multiple-output control strategy. In this paper, the implementation of such an approach on the full-scale realisation of the system will be discussed. The test results will be presented in terms of accuracy of the pressure field reproduction.

FULL-FIELD MONITORING DURING MULTIPLE-INPUT MULTIPLE-OUTPUT ENVIRONMENTAL ACOUSTIC TESTS

Dr. Alberto Garcia de Miguel, Siemens Digital Industries Software
Dr. Mariano Alvarez Blanco, Siemens Digital Industries Software
Dr. Onur Atak, Siemens Digital Industries Software
Mr. Jan Blockx, Siemens Digital Industries Software
Mr. Werner Brughmans, Siemens Digital Industries Software
Dr. Umberto Musella, Siemens Digital Industries Software

This work discusses the introduction of a solution for the visualization of virtual spectral responses in multiple-input multiple-output (MIMO) vibro-acoustic environmental tests. The method is applied to the generation of full-field outputs in direct field acoustic noise testing (DFAN). This testing approach is increasingly being employed in the space industry to qualify payloads against the extreme acoustic loadings during the launch, presenting several advantages in terms of cost and risk management with respect to standard environmental acoustic tests performed in large reverberant chambers. Using the proposed method, a full multi-physics model, which simulates the electro-acoustic frequency response functions (FRFs) of the test system, is directly accessible online during the DFAN test. The model can be updated onsite using the experimental FRFs obtained in the system identification step, which are mapped to the corresponding virtual sensors. During the online test, virtual solutions are computed and updated at each iteration of the MIMO controller, and can be compared to the physical responses in the same graphical interface. Such capability allows test engineers to monitor the system responses, e.g. pressures or accelerations, in locations where no physical sensors are installed. Moreover, the visualization of full-field responses provides better insights on certain physical phenomena which are difficult to foresee based on the observations at a limited number of sensors, such as standing waves and vibro-acoustic couplings, as well as on areas of the structural specimen which might be at risk during the test.

SESSION 15: UNDEX SIMULATIONS

GENERATION OF UNDEX LOADS AT THE FLUID-STRUCTURE INTERFACE USING MACHINE LEARNING

Dr. Nicholas Reynolds, NSWC Carderock
Mr. Ari Bard, NSWC Carderock Division
Mr. Eric Miller, NSWC Carderock Division

Accurate prediction of UNDEX loads is critical to capturing structural and equipment response.
Current approaches rely on expensive computational fluid dynamics calculations. Fast-running load generation techniques, which are available to deep submergence structures due to UNDEX and above-water structures due to AIREX, have been overlooked for surface structures due to the complexity of cavitation phenomena. A dataset of histories at the fluid-structure interface (FSI) across the relevant parametric space has been populated using high fidelity analyses. Using machine learning, this dataset has been used to develop a transfer function that maps freefield loads and FSI structural velocity to FSI pressures. This transfer function forms the basis for a fast-running approach for applying UNDEX loads to shallow structures.

SHOT SELECTION METHODOLOGY FOR VULNERABILITY STUDIES INVOLVING NUMEROUS ANALYSES

Dr. Nicholas Reynolds, NSWC Carderock
Mr. T.W. Shaw, NSWC Carderock Division
Mr. Ryan Anderson, Thornton Tomasetti
Mr. Adam Hapij, Thornton Tomasetti

Answering questions pertaining to the response of structures to underwater explosions (UNDEX) is increasingly reliant on modeling and simulation, as it provides a means to solve problems that would be impractical to solve solely through traditional testing. Until recently, only a limited number of shot geometries could be evaluated using high-fidelity, coupled, large structure shock simulations due to their computational expense. As the price for computing resources continues to drop, the ability to perform numerous scenarios becomes more tractable. In this presentation, a heat-map driving methodology for selecting shot geometries to encompass an entire large structure is presented. Aided by parameterization and automation, analysts are further equipped with the capability to perform and post-process all the analyses from the established run-matrix in a “just-press-go” format. Such a workflow is discussed in the context of generating data for usage by other assessment programs.

TAYLOR FLAT PLATE ANALYSIS VERIFICATION WITH ABAQUS EXPLICIT AND NAVY ENHANCED SIERRA MECHANICS

Mr. Matt Davis, Newport News Shipbuilding
Mr. Chris Joseph, Newport News Shipbuilding

Abaqus Explicit and Navy Enhanced Sierra Mechanics (NESM) were used to conduct verification analyses of both the air-backed and fluid-backed Taylor Flat Plate problems. The analysis codes evaluated acoustic element approaches to predict the proper response for each case and compared to the analytical equations. Acoustic fluid mesh discretization was evaluated to determine proper discretization to capture the proper plate response. Comparisons of approaches and important findings are discussed.

DESIGN OF A MITIGATION MEASURE FOR NAVAL INFRASTRUCTURE EXPOSED TO UNDERWATER UNEXPLODED ORDNANCE (UXO)

Dr. Eric Hansen, Thornton Tomasetti
Mr. John Mould, Thornton Tomasetti
Mr. Adam Hapij, Thornton Tomasetti
Mr. Ross Cussen, Thornton Tomasetti
Mr. Jason Yang, Thornton Tomasetti
Mr. Jamie Anderson, Cape Environmental Management Inc.
Ms. Kimberly Markillie, NAVFAC Pacific

The U.S. Navy owns and maintains critical infrastructure assets to construct and dock naval vessels for maintenance and repairs. These assets are used extensively which results in the need for repairs on a regular basis. In addition, the adjacent harbor that allows access to vessels requires dredging.

Recently, the Navy Facilities Engineering Systems Command (NAVFAC) Pacific initiated a dredging process next to a similar existing asset. One of the challenges facing the dredging team is the possibility of exposing and unintentionally detonating an over 80-year-old unexploded ordnance. This presentation will summarize the evaluation of this infrastructure asset in a shallow underwater explosion environment. It will also cover the design of mitigation measures for the planned dredging operations. An explanation of the role of detailed computational fluid dynamics and structural mechanics simulations in the design and optimization of the mitigation solution involving closed-cell foam and bubble screens.

ACOUSTIC FLUID STUDY OF THE SUBMERSIBLE BOX TEST SERIES

Mr. Timothy McGee, NAVSEA
Lauren Evoy, NSWC Carderock/University of Maryland College Park

A test series of a fluid filled submersible box was conducted at Aberdeen test center (ATC) in March of 2016 to improve/validate modeling methods for transient shock analysis (TSA) of structures containing entrained fluid volumes. In the second half of 2019, simulations of this test series were executed using the acoustic shock capability in the Navy Enhanced Sierra Mechanics (NESM) suite of codes. This white paper is the documentation of the results of NESM applied to a problem with entrained fluid and doubly wetted shells, as well as acoustic calculations that account for cavitation.

SESSION 16: BLAST: CRATERING EFFECTS AND TOOL DEVELOPMENT

AN OVERVIEW OF THE EFFECT OF WEAPON CASING ON GROUND CRATERING

Mr. Josh Payne, US Army ERDC
Mr. Daniel L. Vaughan, US Army ERDC
Mr. William V. Pratt, US Army ERDC
Mr. Denis Rickman, US Army ERDC
Dr. John Q. Ehrgott, Jr., US Army ERDC

Understanding the effect of weapon casing on ground cratering is critically important for the accurate prediction of craters from aboveground or near surface detonations of cased munitions. The differences in cratering from bare charges versus equivalent cased munitions vary depending on charge position relative to the ground surface. When weapons are fully buried below the ground surface, the effect of casing is limited and prediction methodologies often use the total bare charge mass (in terms of TNT-equivalence) for crater predictions. As the charge becomes elevated, there is limited research that directly relates the crater formation size/shape to munition casing. Recent testing of elevated near surface munitions have shown that ground crater formation depends on variables such as charge position, casing thickness, warhead shape, angle of impact, and initiation point. Since the relationship between some of these variables and soil type and condition are complex, empirical curves based on test data are often used to account for any differences observed between cased munitions and bare charges. This paper will investigate current methods for predicting ground craters from aboveground detonation of cased weapons and evaluate their performance against well-controlled test data.

EVALUATION OF CURRENT FORENSIC ASSESSMENT CAPABILITIES FOR CRATERS FROM ABOVEGROUND DETONATIONS

Mr. William Pratt, US Army ERDC
Mr. Daniel L. Vaughan, US Army ERDC
Mr. Joshua E. Payne, US Army ERDC
Dr. John Q. Ehrgott, Jr., US Army ERDC
Mr. Denis D. Rickman, US Army ERDC

The identification and utilization of forensic evidence remaining after a combat incident can provide vital clues to the type or size of threat and in cases, the actual weapon system employed in the attack. The resulting ground crater is one piece of post blast forensic evidence that may be used to help identify the attack munition or relative charge mass used in the event. The correlation between crater characteristics (depth, diameter, and shape) and the height-of-burst, soil conditions and munition class/type or charge mass are all key parameters that need to be understood in order to properly utilize the post blast crater to support analysis techniques. Crater modeling tools, currently under development, are developing these correlations and identifying specific input data to predict a dimensional representation of the ideal corresponding crater. Controlled experiments and evaluations of prediction capabilities are necessary to determine measures for improving the crater models for forensic applications. An ongoing program at ERDC has examined currently available aboveground detonation crater prediction capabilities and assessed their performance and limitations against test data. This paper will present an evaluation of various methods used to predict the craters from aboveground detonations and their potential for use in forensic assessments.

DEVELOPMENT OF CRATER PREDICTION EQUATIONS FOR ABOVEGROUND DETONATIONS OF INDIRECT-FIRE MUNITIONS

Mr. Daniel Vaughan, US Army ERDC
Mr. Joshua E. Payne, US Army ERDC
Mr. William V. Pratt, US Army ERDC
Dr. John Q. Ehrgott, Jr., US Army ERDC

Conventional munitions such as artillery rounds, rockets, and mortars have been an area of concern in the U.S. military for decades, as their use has been proliferated across the globe. Their potential for causing human casualties and severe infrastructure damage has become widely publicized through recent conflicts. Studying the forensic signatures such as ground crater, weapon fragments, and fragment strike patterns left by these munitions after detonation can give valuable information to trained intelligence analysists. The National Ground Intelligence Center (NGIC) has tasked the U.S. Army Engineer Research and Development Center (ERDC) to develop a fast-running engineering tool for analyzing the craters from aboveground detonations of conventional munitions, building upon previous research efforts under the Forensic Encyclopedia Program (FEP). To develop the BEAST (Blast and Explosive Aboveground or Surface Tool) program, ERDC performed several series of aboveground detonations using conventional munitions as well as cased and uncased high explosive charges while varying parameters such as impact angle, height-of-burst, and testbed soil conditions. The crater data collected during these experiments is processed and investigated, and the resulting trends form the basis for crater predictions in the BEAST program. This paper will present the methodology used to develop the prediction equations for aboveground detonations of conventional munitions and bare charges.

UPDATE ON FINITE ELEMENT/EMPIRICAL MODEL FOR RUNWAY CRATER PREDICTIONS AND GROUND SHOCK FROM BURIED HIGH-EXPLOSIVE DETONATIONS

Mr. Ernesto Cruz, US Army ERDC
Mr. Mark Adley, US Army ERDC
Mr. Logan Rice, US Army ERDC
Mr. Daniel Rios-Estremera, US Army ERDC
Ms. Dorothy Boswell, Applied Research Associates
Mr. Steve Akers, US Army ERDC
Dr. Jay Ehrgott, US Army ERDC

Understanding the behaviors of the ground shock generated by a buried high explosive is of great value in predicting the level of damage that could potentially affect critical structures and military assets, such as airfields. Runways in particular are frequently targeted by militaries using a variety of ground- and air-delivered weapon systems due to their strategic value. Many of the weapon systems are designed to perforate the runway and detonate in the subgrade below in order to generate large ground shock loads and maximize damage. Depending on the level of damage caused by the threat weapon, the runway may become unusable until repairs can be made. In order to understand the potential damage to runways caused by these attacks, the U.S. Army Engineer Research and Development Center (ERDC) is updating their hybrid tool “RW-CRATER” to improve runway crater predictions, developing a rapid assessment tool “RW-Crater Fast” to enable rapid estimates of potential runway damage and is in the process of developing the next generation “SABER NX” codes to provide enhanced, fast-running ground shock predictive capabilities. These codes combine finite element models to simulate the ground shock behavior in the sub-grade and to predict the level of damage inflicted on the runway. These tools are an invaluable resource for assessing possible damage from various threat weapon systems to assist in mission planning and sustainment evaluations at these vital military assets. The purpose of this paper is to give a general summary and understanding of the current state of development of the RW-CRATER, RW-Crater Fast, and SABER NX codes as well as their new and updated features.

SESSION 17: COMPUTATIONAL BLAST AND FRAGMENTATION

GENERATING FRAGMENT DISTRIBUTIONS USING ZAPOTEC FOR A GENERIC PIPE BOMB

Dr. T. Neil Williams, US Army ERDC
Mr. William M. Furr, US Army ERDC
Mr. Christopher M. Shackelford, US Army ERDC
Dr. Gregory Bessette, US Army ERDC
Dr. John Q. Ehrgott, Jr., US Army ERDC

Fast running weapons effects tools are utilized in the DoD weaponeering community to predict the response of critical targets to fragmenting weapons. The current weapon effects tools commonly treat the airblast and fragment impact from the weapon as independent events. This decoupled approach can result in under predicting cumulative damage effects. The ERDC Terminal Weapons Effects (TWE) program, which supports the Army's Long Range Precision Fire (LRPF) cross-functional team, is developing a fast running tool that predicts structural target response with a tighter coupling of the blast and fragmentation effects. This presentation provides an overview of the different fidelity methods the TWE program is investigating to create the synthetic blast and fragmentation data. The presentation will also show fragmentation results determined using Zapotec, which couples CTH with Sierra/SM, and compare the Zapotec calculation to recent test results.

ZONAL FRAGMENT DISTRIBUTION PREDICTIONS WITH THE GRADY-KIPP MODEL

Mr. William Furr, US Army ERDC
Dr. T. Neil Williams, US Army ERDC
Dr. Gregory C. Bessette, US Army ERDC
Dr. John Q. Ehrgott, Jr., US Army ERDC

The warfighter and weaponeering community depend on the capabilities of terminal weapons effects codes and tools to accurately predict the response of critical targets to both the explosive airblast and fragment impact. Current fast running tools treat the airblast and fragment impact as independent events, potentially underpredicting cumulative damage effects. A primary goal of the ERDC Terminal Weapons Effects (TWE) program, which supports the Army's Long Range Precision Fire (LRPF) cross-functional team, is to develop a fast running tool that predicts a tighter coupling of the blast and fragmentation effects against structural targets. In an effort to inform and support the development of this tool, work is underway to predict zonal fragment distributions using a first principles code and the Grady-Kipp post-processing methodology. The literature has thoroughly validated the Grady-Kipp model as a simple analytical relationship between material properties and strain-rate to predict an average fragment size. This work will present an overview of the Grady-Kipp model as implemented, discuss enhancements to extend its use to zonal predictions, discuss validation metrics chosen for this problem, and compare against available data.

BREACH AREA PREDICTIONS WITH AN INSTANTIATED FRAGMENT ENVIRONMENT

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

A primary initiative of the U.S. Army Engineer Research and Development Center's Terminal Weapons Effects (TWE) program is to support and enhance the capabilities of the warfighter through the development and improvement of fast running weapons effects codes and tools to accurately predict the weapon's terminal performance and lethality against structures and other critical targets.. Part of this initiative is the development of a methodology to take munition fragmentation data obtained through either arena tests or high-fidelity modeling and run combined blast load and fragment impact calculations on structural targets. Through the use of data obtained from recent ERDC arena tests, an in-house developed fragment instantiation tool, and ConWep blast loading calculations, a fragment environment is created and superimposed on targets of interest to obtain a structural response using Sierra/Solid Mechanics. Additional post processing tools were created to increase automation of the process. The work presented here focuses on using both historically available data and data gathered from a recent surrogate pipe bomb arena test with target plates located at various radial distances to evaluate the new calculated fragment environment methodology.

MODELING M107 155 MM SURROGATE ROUNDS IN CTH

Mr. Zoran Nadzakovic, US Army ERDC
Dr. Gregory C Bessette, US Army ERDC

A series of arena tests were conducted simulating an M107 155 mm artillery round with a cylindrically shaped cased charge surrogate. Multiple blast pressure and fragment velocity measurements were taken from a vertically standing surrogate in contact with the ground. In addition to seven vertical tests, one air burst horizontal arena experiment was conducted. The tests were modeled using the high-fidelity code CTH and compared with the collected test data. Different surface boundary conditions were investigated to get the best data match.

CHARACTERIZATION OF SIMPLIFIED SURROGATE MUNITION

Mr. Marcus Barksdale, US Army ERDC
Mr. Austin Hopkins, US Army ERDC
Dr. Bradley Foust, US Army ERDC

The capability to rapidly assess terminal effects against targets for munition design innovations is essential for modern warfare. During munition developmental stages, weapon developers aim to ensure significant lethal effects while minimizing cost and time. The continued design and development of advanced weapon system is is creating capability gaps in the current weapons effects tools. This technology gap necessitates continued development of enhanced modeling and simulation capabilities to formulate engineering tools for rapid predictions of weapon terminal effects across a broad range of velocities and impact conditions to ensure engineering tools are up to date with innovations in munitions and materials. By increasing these capabilities, the effectiveness and lethality of new munition capabilities and the effects against advanced high-performance target materials can be assessed. To support this requirement, the Engineer Research and Development Center (ERDC) conducted a series of full scale blast and fragment experiments. The series consisted of two arena experiments (horizontal and vertical shots), consisting of both flash panels for fragment velocities and fragment collection media for capturing surrogate fragments for characterization. Following this experiment, the ERDC also conducted another series of seven arena tests to examine the cumulative damage effects of surrogate munitions against steel and concrete targets. The data from this test series consisted of blast overpressures, deflection, fragment velocity, and fragment mass distribution. Once the data were collected and processed, they were given to the modeling and computational team in order to validate the numerical model. This presentation provides an overview of the test series, the test setup, data collected, and high-speed blast videos.

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

VIDEO-BASED MOTION ANALYSIS

Mr. Eric Frederick, Xcitex

No abstract available.

The Rest of the Story: Vibration Controllers and Electro-Dynamic Vibration Test Systems
Mr. Steve Wood, Spectral Dynamics

The presentation will focus on giving viewers an understanding of the inner workings of Vibration Controllers and Electro-Dynamic Vibration Test Systems. It will weave in notable highlights of technological advancements in past history with notable Mil-Standard specification requirements that created the present-day Vibration Test Systems.

Comparing Steel and Aluminum Plates for Resonant Plate Shock Testing
Dr. Carl Sisemore, ShockMec Engineering

Resonant plate shock testing is often used to simulate pyrotechnic shock in the laboratory. The method traditionally uses hanging aluminum plates with free boundary conditions with the shock excitation provided by an air-driven hammer. While aluminum plates are convenient, their lighter weight creates a situation where heavier test articles have the potential to unreasonably influence the resonant plate's response. Steel plates are substantially heavier than aluminum plates and provide significant margin against test articles unduly driving the plate's response. Steel plates have been traditionally avoided due to the apparent difficulty of exciting the desired shock test levels. The research and case studies presented here show that heavy steel plates can be used quite well for modest shock test levels and can be easily rung with a judicious choice of hammers.

Acquire, Analyze, and Act: Shock and Vibration Solutions from enDAQ and Hutchinson
Mr. Chris Ludlow, Mide Corporation
Mr. Neil Donovan, Hutchinson

Hutchinson Defense and Mobility Systems have a 75-year record of solving shock, vibration, and motion control problems for customers in all industries. enDAQ (part of MIDE) is a recent acquisition of Hutchinson corporation. Working together these two sister companies can "acquire, analyze, and act" to solve customer shock, vibration, and noise control problems in many industries. The presentation will cover general skill sets and tools which enDAQ and Hutchinson employ to provide value to our customers.

Mechanical Shock Testing Methods
Mr. Roger Rutz, Experior Laboratories

Mechanical shock testing helps determine whether a component, device or system can remain functional when subjected to sudden, abrupt motion changes associated with service environments like product handling, shipping/transportation, rocket stage separation, weapon firing, etc. Experior Laboratories will discuss mechanical shock testing options, types, test setup differences and application range.

SESSION 18: UNDEX I

THE EFFECTS OF NON-CONTACT UNDERWATER EXPLOSIONS ON NAVAL COMPOSITE STRUCTURES: DESIGN NUMERICAL ANALYSES AND EXPERIMENTAL VALIDATION

Mr. Francesco Mannacio, University of Genova/Italian Navy
Mr. F. Di Marzo, Italian Navy
Mr. M. Venturini, Italian Navy,
Mr. M. Gaiotti, University of Genova
Mr. C.M. Rizzo, University of Genova

Even if the non-contact underwater explosion phenomenon has been studied for decades and various numerical methods have been provided in open literature, its effects on naval structures, especially those made by composite materials, are, even nowadays, a matter of research. Actually, a fully coupled fluid-structure interaction model for underwater shock explosion analyses is extremely complex to set, computationally demanding and certainly not suitable for everyday design practice. In this paper, a simple finite element (FE) model including both, the structure and the fluid, accessible and easy to use in an early design phase, is proposed. Within a commercial FE software environment, an approximate fluid-structure interaction model is outlined by simplifying the fluid behaviour, in which the problem of combining computational fluid dynamics (CFD) and FE domains and equations is overcome as long as also the fluid is modelled using elements defined as Fes. Thus, reducing the computational time and numerical efforts.

As a test-case, a typical minehunter ship parallel body block is modelled, using two-dimensional multi-layered shell elements and therefore properly accounting for the characterization of composite materials. Three dimensional volumetric elements are used for the fluid instead, directly coupled to the structural elements.

The results achieved applying the numerical model are compared with the structural response measured on board of a composite ship during a full-scale shock test. Satisfactory agreement was obtained allowing the validation of the model. In any case, the procedure proposed is an approximation of the real phenomenon, therefore differences in the comparison are discussed, allowing a better understanding of the phenomena.

Eventually, the modelling strategy has been considered useful for the concept and preliminary design of composite structures subject to underwater explosion phenomena.

SHAPE EVALUATOR – A NOVEL METRIC FOR ASSESSING SIMULATION PERFORMANCE FOR SPECTRAL QUANTITIES

Mr. Brian Lang, NSWC Carderock

Shape evaluator is a novel metric was developed to automate evaluation of spectral comparisons between simulations and measured test data. Shape evaluator allows for fast comparisons of trhe data sets and avoids using subjective expert opinion on a comparison-by-comparison basis. Shape Evaluator is intended to compare the characteristic shape of one shock response spectra to another, although any spectral quantity could be used. It is intended to asses whether a simulation identifies the same key response frequencies as measured test data. Therefore, the absolute magnitude of the spectra curves is not of concern and does not appear. A nice feature of Shape Evaluator is that it allows some meaningful comparison of scores amongst different simulation-to-data comparison sets. Results are shown several

notional spectral quantities and demonstrate that the Shape Evaluator algorithm appears rational and provides useful insight into a simulation's performance.

Verification of Abaqus Import Methods for Determination of Permanent Set for Nonlinear Transient Problems

Mr. Matt Davis, HII-NNS

For transient analysis with nonlinear material with damage, either due to underwater explosion, shock, or conventional weapons effects, it is often necessary to determine the post-event permanent deformation. This short study compares the preferred static analysis method for determining permanent material set with an explicit transient method using Abaqus. This effort verifies results between the two methods for a simple conventional weapons loading (CONWEP) problem involving contact and nonlinear material.

Fast Pre-design Assessment of Underwater Explosion using Boundary Element Method

Mr. Kory Soukup, Altair Engineering
Mr. Carlos de Lima, Altair Engineering

Designing military aircrafts and naval vessels is a complex task that presents many challenges to the structural engineering teams. One of the challenges is to assess the performance of these structures under blast and shock loads. Physical tests are not a viable alternative due to prohibitive costs. With new technologies and advancements in super computers, simulation has been consolidated in the last decades as a fundamental step in the design cycle of airplanes and ships. Finite Element Methods (FEM) has been proved to be accurate for underwater explosion simulations using ALE formulation. But the run times and complexity prevent it from being used more often and broadly to drive design decisions. It is used as a pass/no pass check in most cases.

This presentation will review different methods to model BLAST and discuss the use of Boundary Elements Method (BEM) and Double Asymptotic Approximation (DAA) for Underwater Explosion using the commercial explicit solver RADIOSS. The idea is to show how this method can be faster than traditional ALE and be used early in the design cycle to evaluate different parameters, assess overall response of the structure, and more importantly help the engineers to make impactful design decisions.

JASSO: A year of Testing and Development

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

Warships are designed to be robust against underwater explosions, and in order to demonstrate that a warship has met the required standard of shock capability, a number of shock qualifications on equipment and systems are normally undertaken. The shock qualification tests undertaken cover range from individual equipment's and systems to tests covering the entire vessel. Shock machines are used to carry out some of these tests where the equipment size and desired levels are suitable or if it is not cost effective to carry out explosive or airgun shock barge testing.

In addition, all naval ordnance is required to withstand levels of shock to ensure safety and safety and serviceability when embarked on ships. This may also be extended to other weapons as there is a strong possibility that they may be sea transported at some point during their life where there may be a risk from UNDEX shock.

The JASSO machine was developed by Thornton Tomasetti Defence to address some of these limitations with the aim of developing a machine that could serve as general UNDEX shock machine but which also could be deployed to test ordnance of a variety of sizes and weights with a meaningful shock pulse.
This paper and provides an overview of the last years work associate with the further development and testing of the JASSO Shock test machine particularly covering the following:

- A recap and overview of the design principals and how it works
- A review of the wide range of commissioning tests completed over the last year in particular concentrating on typical environmental/ transportation shock levels and large displacement shock levels coupled with mass dependencies.
- A look into future developments will also be briefly covered.

SESSION 19: TEST METHODS AND DATA VALIDATION

CALIBRATION OF DIGITAL ACCELEROMETERS AND ANGULAR RATE SENSORS

Mr. Michael Mende, SPEKTRA GmbH

Most sensors that we use for measurements in laboratories, technical investigations or other applications still have an analog output today. We have established calibration methods for such sensors and developed calibration systems that support these methods. However, for consumer or automotive products, sensors with a pure digital output instead of an analog signal output have been developed in recent years. These sensors are now so good that they are increasingly being used in other areas, such as laboratory measuring equipment or in military applications.

Some transducers, such as special geophones, even turn out to be complete measurement systems that automatically transfer their measurement results to an Internet cloud service. Since the A/D conversion of the signal and perhaps even some data pre-processing now becomes part of the sensor, our old calibration standards and calibration systems no longer fit into this new digital sensor world.

The paper shows an approach for the architecture of a calibration system that can adapt to very different digital interfaces as well as communicate on a logical level with the different DUTs. It also addresses challenges in determining measurement uncertainties of the calibration system with respect to digital DUTs.

A STUDY OF THE EFFECTS OF THE DIGITAL NOISE FLOOR ON FLIGHT DATA MEASURED USING A UNIFORM RESOLUTION ANALOG TO DIGITAL CONVERTER

Mr. Jerome Cap, Sandia National Laboratories
Ms. Melissa C' de Baca, Sandia national Laboratories
Ms. Angela Cork Montoya, Sandia National Laboratories

Flight data must be digitized prior to transmission to the ground station using a Pulse Code Modulated (PCM) telemetry system. Part of that process includes passing the analog signals through an Analog to Digital Converter (ADC). A traditional uniform resolution N-bit ADC introduces quantizing noise that is proportional to the bit resolution of the ADC. This study will look at how the noise floor varies as a function of the ADC bin stagger relative to the mean and the effect of the quantizing error on random, sinusoidal, and shock environments.

HAMPEL FILTERING OF PSDS TO REMOVE SPURIOUS SINE TONES IN RANDOM VIBRATION DATA

Dr. Vit Babuska, Sandia National Laboratories
Mr. James Woodall, Sandia National Laboratories

During a recent test, the data acquisition system introduced spurious signals that had the potential to corrupt measurements at specific frequencies. Prior to the test, data were collected to characterize the noise floor of the instrumentation chain. The spurious signals appeared as very narrow band spikes in the PSD of the noise floor data. They were large enough to be observable in the PSDs of the accelerations collected during the test.

Two frequency domain methods were investigated to remove the spurious signals. Both methods applied a Hampel filter to the PSDs. The first method computed the simple difference between the original noise floor and the filtered noise floor and subtracted it from the PSDs of the measured data: $PSD_C = PSD_M - (PSD_N - \widehat{PSD}_N)$ where PSD_C is the cleaned up measured PSD, PSD_M is the measured PSD with the spurious tones, PSD_N is the PSD of the noise floor and $\widehat{PSD}_N$ is the noise floor PSD with the spikes removed with the Hampel filter. This cleaned up PSD was unaltered at the frequencies without the spurious sine tones, while mitigating their effects where they appeared. This correction left residual sine tone peaks, but their amplitudes were small and generally only distinguishable when there was no other energy content in a signal.

The second approach was a variation of the first method, but instead of simply subtracting the PSD spikes, the spikes were removed using the amplitudes (i.e., the square-root of the PSD):
$PSD_C = [PSD_M^{1/2} - (PSD_N^{1/2} - \widehat{PSD}_N^{1/2})]^2$

A third method in which the noise floor PSD was simply subtracted from the PSDs of the test. This method was the baseline against which the Hampel filter methods were benchmarked. The first method worked remarkably well and was adopted to clean up the measured PSDs.

The paper and the presentation will discuss Hampel filtering of PSDs. The two methods summarized will be discussed in detail. Additional Hampel filtering methods may be discussed as well. Test data will be used to assess the methods and identify the strengths and weaknesses of each one.

IMPACT DYNAMICS WORKFLOW FOR SEISMO-GEODETIC ICE PENETRATOR (SGIP)

Alex Miller, MIT
Michael J. Brown, MIT
Aaron Makikalli, MIT
Daniel Poe, MIT
Christopher Eckery, MIT
Dr. Chester Ruszczyk, MIT
Dr. Pedro Elosegui
Prof. Jeffery Hoffman, MIT

The Seismo-Geodetic Ice Penetrator (SGIP) is an air-dropped penetrator with a seismometer and GNSS sensor to measure resonant forcings of the Ross Ice Shelf caused by atmospheric and ocean waves, thus gaining better understanding of ice shelf health and ice shelf dynamic events. SGIP unit is comprised of two sections, a “body” frontal section approximately 1 meter in length, followed by a semi-conical “flare” section to hold antennas, regulate a stable terminal drop velocity, and act as a snow brake. The body and flare stay connected during flight, and separate during impact, causing the body to penetrate ice shelf while the flare stays at the surface. The top of the aft body of SGIP must be >1 meter from the surface after the drop event, to achieve coupling between the seismometer and the ice shelf and to mitigate wind vibrational noise. To determine SGIP’s cross sectional area, nose cone shape, and snow break shape, as well as to understand the shock that each component must withstand, we model the impact dynamics of the penetrator system. Snow, ice and firn exhibit several different types of energy absorption, and thus have a wide range of nonlinear impact behaviors. We present a workflow that first uses a small-scale drop testbed (3kg penetrator), data from core samples, and a sensitivity analysis between various snow conditions to validate an explicit dynamics finite element model, which is then scaled to model the full size penetrator system (90kg). Results are compared to canonical impact dynamics methods, and contextualized with a “squeeze model” which uses the material properties of snow and firn under compression to estimate penetration depth. Implications of modeling towards SGIP systems design are also discussed. The modeling workflow is further extended to incorporate future learnings from higher energy drop tests, and further physical validation methods.

Multiple Shakers to Generate Large Force Needed for Massive DUT’s and High Acceleration

Mr. Deepak Jariwala, Spectral Dynamics, Inc.

Conventional Testing is MISO (Multiple Input Single Output) using a single Electro Dynamic Shaker, Slip Table and a Head Expander. But do you when the DUT is too massive to be accommodated on a single shaker or the high acceleration calls for a larger force which a single shaker cannot generate? The solution is multiple shakers (MIMO: Multiple input Multiple output) to add the Force vectors of the shakers. The paper details a case study of two water-cooled shakers adding up the forces in the Vertical or the Horizontal direction pushing a common Head Expander or a common slip table respectively. Each shaker could also be used on individual smaller slip tables by a 180 degrees rotation. Indeed, a superior MIMO Controller does this job effectively.

By utilizing this methodology, an organization achieves:

- Improved laboratory throughput
- Improved fidelity
- Cost savings

SESSION 20: SCALED PROJECTILE PENETRATION AND PERFORATION TESTING

Projectile Nose-Shape Effects on Steel Plate Perforation with On-Board Accelerometers, Post-Test Photogrammetry, and Residual Velocity Measurements

Dr. Zane Roberts, US Army ERDC
Mr. Reid Bond, US Army ERDC
Dr. Kyle Crosby, US Army ERDC
Dr. Jay Ehrgott, US Army ERDC

Projectile perforation of steel targets is of critical interest to the military, but there are limited well-characterized deceleration test data available to develop and validate numerical analysis and prediction tools. Under the Terminal Weapons Effects program, the ERDC conducted perforation tests investigating the effect of target thickness and projectile nose-shape geometry on the residual velocity and deceleration response of projectiles. Perforation tests were conducted using 4340 steel projectiles and three projectile nose-shapes: 3.0 Caliber Radius Head (CRH) ogive, hemispherical, and truncated-conical. The 1.563 in. projectiles were fired at velocities from 750 to 1800 ft/s using an 83-mm-bore powder gun (with sabot) normally into A36 target plates with thicknesses measuring 0.25 to 2.0 in. High-speed digital video with image correction and tracking software were used to measure the striking velocity, residual velocity, and projectile trajectory (pitch and yaw) before and after target perforation. Photogrammetry was used to generate 3-dimensional target front-face and back-face point clouds to capture high resolution details of post-test target damage. On-board accelerometers were used in certain tests to determine their suitability for steel target impact and to capture the deceleration of the projectile. Acceleration time records for all three nose-shapes were compared for 1000 ft/s shots through 0.5-in.-thick targets, and for ogive projectiles at two different velocities against 0.5 in. and 1.0-in.-thick targets. The data generated from this series of tests informs our fundamental understanding of the perforation process and will be used to calibrate and validate metal perforation predictive models.

Characterizing Metal Target Response to Projectile Nose Shape and Impact Velocity Utilizing Photogrammetry

Mr. Logan Callahan, US Army ERDC
Dr. Zane A. Roberts, US Army ERDC
Mr. Reid R. Bond, US Army ERDC
Dr. Z. Kyle Crosby, US Army ERDC
Dr. Jay Q. Ehrgott, US Army ERDC

Metal target response to projectile perforation is of high interest in military research, but current literature lacks large data sets of three-dimensional, post-impact deflection data. Under the Terminal Weapons Effects program, the ERDC conducted tests to determine the effect of different projectile nose shapes and impact velocity on metal target deflection. Three different nose shapes were tested: 3.0 Caliber Radius Head (CRH) ogive, truncated conical, and hemispherical. The projectiles were all 1.563 in. diameter of hardened 4340 steel. The targets utilized for this effort were A36 mild steel with thicknesses ranging from 0.25 in. to 2 in. thick. Impact velocities ranged from 860 ft/s to 1800 ft/s. Photogrammetry techniques were used to generate high-resolution, three-dimensional point clouds of the front and back faces of the target, post-impact. Measurements were then taken of the global and local target deflections, including target thickness dependent effects, such as petaling. High speed video on the impact and exit sides of the targets captured plugging and fragmentation of the plate, as well as the projectile residual velocities near the ballistic limit. This work includes an overview of the testing set up, experimental test matrix, results, and comparison of the effect of each variable on target deflection. This data can be used to calibrate and validate metal perforation numerical models for the terminal ballistic effects on target response. This test series also helps elucidate the perforation mechanisms present throughout different impact regimes.

Modeling and simulation of the ballistic behavior of steel projectiles with different nose shapes against steel targets

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

There are efforts underway across the DOD to develop and improve fast-running tools and high-fidelity computational capabilities to predict weapon's terminal performance against critical targets of interest. The ERDC Terminal Weapons Effects (TWE) program is supporting this effort under the Army Long Range Precision Fires (LRPF) cross-functional team. One objective of this program is to evaluate and understand munition nose effects on target interaction during a penetration event and validate numerical simulation capabilities that can be used to accurately predict this weapon/target interaction and support the development of faster running weapon effects tools. The TWE program has conducted an extensive experimental series evaluating three penetrator nose shapes against steel targets of varying thickness. The Elastic Plastic Impact Computations (EPIC) code has been validated extensively for penetration and perforation. This effort focused on determining the capability of EPIC to reliably represent the effect of nose geometry in steel-on-steel penetration and/or perforation event. The work presented here describes the high fidelity calculations methods utilized in this effort and compares EPIC calculation results using the Johnson-Cook strength and fracture model with the steel test series results.

Penetration experiments with 1018 steel targets and ogive-nose steel projectiles at striking velocities up to 4500 ft/s

Dr. Kyle Crosby, US Army ERDC
Mr. Reid Bond, US Army ERDC
Dr. Zane Roberts, US Army ERDC
Mr. Logan Callahan, US Army ERDC
Dr. John Ehrgott, Jr., US Army ERDC

A series of depth-of-penetration (DoP) experiments was conducted using 0.50-inch-diameter, 3.25-inch-long, ogive-nose steel projectiles and 10.00-inch-diameter, 1018 steel targets. The projectiles were made from A2 tool steel (60-62 HRC) and had a nominal mass of 0.16-pound. The projectiles were launched using a powder gun to striking velocities up to approximately 4500 ft/s. High-speed digital video with image correction and tracking software was used to measure the striking velocity and projectile trajectory (pitch and yaw) before target impact. A FaroArm coordinate measuring machine was used to generate a 3-dimensional point cloud of the target front face. The post-test targets were cross-sectioned using a water jet to obtain the final projectile orientations in the target. The goal of this test series was to gather rigid body penetration data into steel targets that will further our understanding of the steel penetration process. This data will be used to calibrate and validate metal penetration predictive models in support of ERDC's Terminal Weapons Effects program under the Long Range Precision Fire cross-functional team.

Perforation Testing and Simulation of Half-Scale Artillery Surrogates with Instrumentation Packages

Mr. Reid Bond, US Army ERDC
Dr. Zane Roberts, US Army ERDC
Dr. Z. Kyle Crosby, US Army ERDC
Dr. Jay Ehrgott, US Army ERDC

Under the Long Range Precision Fires (LRPF), the U.S. Army's top modernization priority, research is underway to develop the next generation 155 mm cannon artillery. This modernization effort has led to the development of several new artillery rounds including the XM1113 Rocket Assisted Projectile (RAP). Assessing the penetration capabilities of new projectile designs such as the XM1113 RAP is crucial in determining their effectiveness against targets of interest such as structural targets constructed from reinforced concrete. This study assesses the penetration capabilities of the XM1113 artillery round against reinforced concrete of varying thicknesses. Half-scale XM1113 rounds were fired at targets using an 83 mm smooth bore powder gun located at the US Army Corps of Engineers Engineer Research and Development Center (USACE ERDC). Residual velocities were measured using high speed video, and photogrammetry was utilized to analyze the dimensions of the target impact and exit craters. Previous research efforts at USACE ERDC were conducted for a legacy artillery ordnance, the M107 155 mm cannon artillery. The results of this study were used in a comparative analysis with the M107. Results from the study were also compared to results generated from PENCURV+ simulations in order to validate the fast-running, computational tool.

SESSION 21: MECHANICAL SHOCK TESTING & ANALYSIS

Mechanical property evaluation of Silicon for High G Micro-electromechanical systems (MEMS)

Dr. Vasant Joshi, NSWC Indian Head
Dr. Salil Mohan, NSWC Indian Head
Mr. Colin Qualters, NSWC Indian Head
Mr. Efrem Perry, NSWC Indian Head
Mr. Sean Tidwell, NSWC Indian Head
Mr. Chris Cao, NSWC Indian Head

Large silicon based micro electro mechanical system (MEMS) devices of the order of millimeter are used in multi-functional sensors. Silicon metal is known to be very brittle, with very low strain to fracture. Although some generic mechanical properties of silicon have been published, high-strain rate and flexural failure data is unavailable. Machining of silicon samples required for high-strain rate test is very difficult and required unique method development. Accurate measurement of failure strain in compression requires longer and cylindrical sample, which cannot be obtained from wafers. Unique methods in sample preparation and experiments conducted for characterization of silicon provided stress vs. strain at low strain rate using precision compression testing, high-strain rate using split Hopkinson pressure bar (SHPB) equipped with very high strength bars, and a four-point bend test using a custom fabricated test setup. While low and high strain rate tests were performed on a monocrystalline silicon rod from a commercial source, four-point bend tests were performed using single crystal wafers from a different commercial source. Data generated from these tests were used in generating a material model suitable for simulations of High G MEMS device. In this presentation, experimental methods and results for obtaining data for silicon combining above methods will be presented.

CHAIN KEEPER ASSEMBLY: A CASE STUDY ON TAKING INTO ACCOUNT SHIP STRUCTURE FOR DDAM FEA VS. DDAM WITH FIXED BASE

Mr. Adarsha Sapkota, Newport News Shipbuilding

Often DDAM analysis is performed with an assumed fixed base. A recent project highlighted the issues with this assumption and how shipboard structure can have a major effect on analysis results which can only be found if modeled appropriately. The Chain Keeper Assembly is an important component present on the foundation of the Powered Drive Unit (PDU) for the Aircraft Elevator. The purpose of this paper is to elaborate on the findings or issues discovered from the shock related Finite Element Analysis (FEA) performed with fixed base assumptions vs. a model developed taking into account the ship structure i.e. deck structure. The FEA was performed on the above assembly using Dynamic Design Analysis Method (DDAM). It was found that although a fixed base model indicated little to no stress in an item joining two PDUs together, an FEA performed with representative ship structure revealed overstresses and a need for re-design.

SEATED HUMAN INJURY CRITERIA FOR VERTICAL SHOCK

Dr. Russel Miller, Institute for Defense Analyses
Mr. John Przybysz, Jr., Institute for Defense Analyses

IDA is currently investigating ship shock human injury criteria to be applied to surface ship and submarine survivability assessments. Our initial work provides an update to the Hirsch criterion and a probabilistic criterion for human injury due to vertical shock when seated. The updated threshold levels for injury are based on the work of the ground vehicle community, who teamed with a number of university laboratories. We discuss the use of human cadaveric specimens (e.g., lumbar test specimen) and whole body human specimens. To support the new criteria, we present the demographics, test conduct, and post-test analysis of the test results. A sigmoidal curve based on logistic regression defines the mean probabilistic criterion, and we derive and include confidence intervals on the sigmoidal curve. We present an approach for applying the human injury criteria to survivability modeling and simulation results, and outline future work for assessing injury to both unrestrained seated humans and standing humans, as well as injury due to shock in other directions than vertical.

DIGITAL TRANSFORMATION OF THE SHOCK QUALIFICATION PROCESS

Mr. Justin Caruana, Cardinal Engineering
Mr. Michael Ros, Cardinal Engineering
Mr. Barry Mapen, Cardinal Engineering
Ms. Amanda Capasso, Cardinal Engineering
Mr. Steve Adams, Cardinal Engineering
Mr. Keith Kanoun, Cardinal Engineering
Mr. Doug Algera, Cardinal Engineering
Ms. Annaliese Nardi, Cardinal Engineering

Under a Navy sponsored SBIR, Cardinal Engineering has been developing a cloud-based software tool to reduce the required experience, time, and cost associated with equipment shock qualification. By embedding the requirements contained in MIL-S-901D IC#2 and MIL-DTL-901E in a user-friendly collaborative web application, the qualification requirements can be consistently applied, all qualification options can be rapidly evaluated, and the most cost-effective approach identified. Using equipment and installation information provided by the user through a guided, intuitive, browser-based user interface, ShockIQ applies the decision logic defined in the applicable qualification specification to identify suitable qualification methods and provide insight into the factors limiting the suitability of others. The innovation of ShockIQ is rooted in the translation of the shock qualification requirements into advanced digital logic implemented in a secure collaborative tool based on digital engineering principles. This translation addresses all cases, conditions and paths through the applicable shock qualification specification. When completed, ShockIQ will support the full range of users, from novice to master, and organizations, from equipment designers and Shipyards to government organizations, involved in the design and qualification of shipboard equipment. ShockIQ provides a Subject Matter Expert force multiplier and a collaboration environment enabling cost avoidance and time saving.

In this presentation, Cardinal illustrates the digital innovation in coding shock requirements and demonstrates an example of how ShockIQ can aid in the shock qualification process.

SESSION 22: COMPUTATIONAL & EXPERIMENTAL METHODS FOR ORDNANCE TECHNOLOGY

HIGH SPEED FUZE AND EXPLOSIVE SYSTEM DESIGN

Dr. Jacob Dodson, AFRL

Abstract not available.

EXPERIMENTAL EVALUATION OF THE DYNAMIC RESPONSE OF STRUCTURAL INTERPENETRATING LATTICE AS SENSOR

Dr. Adriane Moura, Applied Research Associates
Mr. Michael Davies, AFRL
Dr. Alain Beliveau, Applied Research Associates
Mr. Zachary Jowers, Applied Research Associates
Dr. Jacob Dodson, AFRL

Abstract not available.

IMPACT DETECTION USING A NOVEL RF SENSOR FOR SMART FUZING APPLICATIONS

Mr. Philip Randall, Sandia National Laboratories
Mr. Daniel Gutierrez, Sandia National Laboratories
Mr. Alex Chen, Sandia National Laboratories
Mr. Ian Sobering, Sandia National Laboratories
Mr. Shane Curtis, Sandia National Laboratories
Mr. John Borchardt, Sandia National Laboratories

A new target detection sensor for penetrator weapons is being developed where RF waves are transmitted and received inside a weapon body, unlike traditional radar applications where RF is emitted externally. Traditional inertial sensing technologies such as accelerometers and g-switches are limited to the speed of mechanical and acoustic waves within the medium (e.g., explosive fill, weapon body, etc.), while RF will move near the speed of light and provide much lower latencies. This technology would also eliminate the need for any cabling, reducing the risk of disconnection during impact as the RF signal can pass through certain homogenous materials. The feasibility of this technology was assessed by putting a homodyne radar in the base of a waveguide and mechanically changing the length of the waveguide with a piston to simulate longitudinal deformation. The received signal is phase modulated by the moving waveguide, and an output signal is generated that accurately matches the displacements at the other end. The results show that this technology could potentially be

used for smart-fuzing applications with further processing and analysis, as well as vibration monitoring in laboratory settings.

TOWARDS ONLINE STRUCTURAL STATE-ESTIMATION WITH SUB-MILLISECOND LATENCY

Mr. Austin Downey, University of South Carolina
Dr. Jason Bakos, University of South Carolina
Dr. David Andrews, University of Arkansas
Mr. Miaoqing Huang, University of Arkansas
Dr. Adriane Moura, Applied Research Associates
Dr. Jacob Dodson, AFRL

The online state estimation and tracking of a structure's health is an important consideration of next-generation control schemes for structures that experience extreme dynamic events. Examples of such structures include hypersonic vehicles, space infrastructure, active blast mitigation, and hard target penetrating munitions. Due to the nature of the dynamics these structures experience, the estimated structural state should be updated on a time-scale of 1 ms or less. This work presents recent progress on the use of long short-term memory (LSTM) recurrent neural networks for the tracking of structural states for structures with a continuously changing state-of-health. To enable the required sub-millisecond latency, a coupled hardware-software approach was taken in the development of the proposed structural health tracking system. This introductory work investigates the effects of limiting various computational resources on system performance. Here, limits on computation time, field-programmable gate array (FPGA) resources, and embedded memory are all investigated while adhering to the strict 1 ms latency constraint. Validation of the proposed structural health tracking system is performed using publicly available data collected on the Dynamic Reproduction of Projectiles in Ballistic Environments for Advanced Research (DROPBEAR) initially developed at the Air Force Research Laboratory. DROPBEAR consists of a beam that is fixed at one end with a movable pinned support to simulate a change in its structural state (i.e. damage) that slides along the beam. The movable pinned support is monitored with a position sensor while the free end of the beam is instrumented with an accelerometer. Performance metrics of latency and precision are analyzed and comparisons to the state estimation obtained using a real-time physics-based model updating technique are discussed.

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

PYROSHOCK EVENT CAPTURE – RECENT ADVANCES IN HIGH FIDELITY BROADBAND MEASUREMENTS

Mr. Rob Eaton, MECALC
Mr. Mark Remelman, MECALC

No abstract available.

STATE-SPACE MODEL CREATION IN SIMCENTER TESTLAB

Mr. Chris Sensor, Siemens Digital Industries Software

Simcenter Testlab now supports the creation of state-space models from experimental modal data. Real-time state-space models are linear dynamic models that can be used to predict system responses to a given shock or vibration input, increasing the accuracy and reliability of test predictions and therefore the safety of the device under test.

MARINE MACHINERY ASSOCIATION
Mr. John Rhatigan, Marine Machinery Association

No abstract available.

ADVANCED TECHNOLOGIES FOR VIBRATION TESTING OF LARGE, HIGH VALUE, TEST ARTICLES
Mr. Thomas Reilly, NVT Group

NVT Group will present advanced technologies developed by its member companies Data Physics Corporation and Team Corporation for vibration testing of large, high value, test articles like the James Webb Space telescope and Orion spacecraft. The presentation will include the following topics:

- Slip tables and guided head expanders for test articles with large overturning moments
- High channel count vibration controllers and signal analyzers
- Advanced safety systems for protection of high value test articles
- MDOF tables and control systems

DSF MASS RATIO AND HEAVYWEIGHT SHOCK TESTING
Mr. Travis Kerr, HI-TEST Laboratories

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

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

SESSION 23: SHOCK PULSE SHAPING & MITIGATION

REUSABLE ENERGY ABATEMENT PAD (REAP): A REPLACEMENT TO HONEYCOMB FOR AIRDROP TRAINING
Dr. James Rall, ShockTech RED
Mr. David Frank, ShockTech RED

The US Air Force is experiencing shortages of protective cardboard honeycomb for aerial delivery, causing disruption to aircrew and pilot certification. As such, an alternative material to honeycomb would be advantageous to continue certification missions while reducing unnecessary damage to bundles that can occur with one layer of honeycomb or no energy dissipation material. It has been reported by some bases that payload damage occurs at an increased rate of 5 – 10 times with only one layer of honeycomb compared to the traditional 2. That is, one base was replacing 50-gallon water barrels at a rate of 1-2 per week with 3 layers of honeycomb but now replaces 1-2 per day with only one layer of honeycomb. Reusable Energy Abatement Pad (REAP) has been developed over the past three years, prior to any honeycomb shortage, and its designs and laboratory tests were presented at previous conferences including 91st Shock and Vibration Symposium.

REAP has been tested in an operational environment at four (4) Air Force Bases and deployed to several others. The first operational test was held at a test squadron in Tucson, AZ and demonstrated similar ground impact and performance between CDS bundles utilizing honeycomb and those using REAP. Based on these results, a unilateral airdrop training (UAT) authorization was given to REAP in December 2021 to allow for further operational testing across the entire Air Force. Based on operational data gathered, REAP reduces the acceleration on a payload by as much as 30% when compared with honeycomb. Additionally, REAP shows a decrease in rebound energy by as much as 20% from bundles with honeycomb. Continued operational testing is being performed on REAP to determine its performance over its lifetime and in varying environmental conditions.

MICRO-BEADED ENCAPSULANTS FOR ELECTRONICS PACKAGING

Dr. Jeff Hill, Brigham Young University
Mr. Josh Stanfield, Brigham Young University
Mr. Alex Chen, Sandia National Laboratories
Mr. Cayden Boll, Sandia National Laboratories

In order to protect electronics during harsh vibration and shock environments, the standard method for protection is to use a hard encapsulation, providing structural support to circuit boards and their components. There are many drawbacks to this encapsulation method, including a large mismatch between the coefficient of thermal expansion (CTE) of the materials. This paper explores bead encapsulation as an alternate method of circuit board protection. This approach utilizes small microbeads (60-900 µm) of a hard material to replace the hard encapsulation. Computer modeling is done using the molecular dynamics simulator LAMMPS and preliminary experimental work is done by placing instrumented circuit boards in an aluminum enclosure and then encapsulating them with various beads. The enclosure is then dropped to simulate shock impacts. Various bead sizes and material characteristics are compared to determine which one best reduces the impulse experienced and protects the circuit board.

EXPERIMENTAL INVESTIGATION OF IMPACT PULSE SHAPING IN ELASTIC METAMATERIALS

Mr. Greg Dorgant, Georgia Institute of Technology
Dr. William Johnson, Savannah River National Laboratory
Dr. Washington DeLima, Kansas City National Security Campus
Dr. Michael Leamy, Georgia Institute of Technology

A procedure is presented to design, fabricate, and verify elastic metamaterial pulse shapes under impact excitation as applied in the Split Hopkinson Pressure Bar (SHPB) test. The SHPB test, a fundamental dynamic test for over 70 years, often incorporates pulse shaping. Herein we re-examine pulse shaping through the use of elastic metamaterials. Elastic metamaterials hold promise for enhancing conventional pulse shaping abilities and improving capabilities of the SHPB test. An elastic metamaterial pulse shaper based on a combination of a phononic crystal and local resonator is first numerically optimized with finite element analysis. Pulse shaper candidates are then fabricated and tested to validate the procedural efficacy. The procedure incorporates an iterative element to correct for inaccuracies in input force and material properties and converge on an appropriate pulse shaper. This procedure is carried-out for pulse shapers fabricated from 3D-printed polylactic acid (PLA) to achieve an extended dwell acceleration pulse shape. The procedural efficacy is effectively confirmed through experimental impact tests resulting in rise, dwell, and fall behaviors comparable to that predicted and desired.

SESSION 23: PROTECTIVE STRUCTURES

BALLISTIC EFFECTS ON 3D PRINTED CONCRETE

Mr. Ryan Salter, Battelle Memorial Institute
Mr. John Lindquist, Battelle/AFCEC
Mr. Kevin Wise, AFCEC
Mr. Michael Newberry, Battelle/AFCEC

3D Printed Concrete, or 3DPC, is a developing method of construction whose advantages over conventional methods include the ability to reduce or eliminate the need for formwork, the ability to fabricate complex geometries, and has the potential for expedited construction with future advancements in the technology. There is a sparsity of studies in the literature, however, on the material properties and performance characteristics of 3DPC in relation to ballistic threats. It is well established that 3DPC has inherent issues in adhesion between layers, and ballistic analysis demonstrated that weakness of these cold joints is exacerbated as samples failed at interfaces between filaments layers as well as infill interfaces. Penetration resistance varied with test article design as testing was conducted with four variations of targets that each performed differently. Results from studies conducted at AFCEC on ballistics testing of 3DPC will be presented, in respect to understanding lack-of-fusion considerations and a comparison of the ballistic response of 3DPC and the expectations based on the ballistic response of cast samples.

SESSION 24: VIBRATION TEST METHODS & STRUCTURAL RESPONSE

TOWARDS MULTI-AXIS VIBRATION TEST METHODOLOGY

Mr. Barak Deutscher, RAFAEL
Mr. Zachi Katzir, RAFAEL
Mr. Gal Rubinstein, RAFAEL
Mr. Yuval Dekel, RAFAEL

These days during a product design, development and manufacturing processes the dynamic testing plays a significant factor. While there are already common methods of performing single-exciter single-axis vibration tests, this field is greatly evolving towards multi-exciter multi-axis tests. The benefits of Multi-input Multi-Output (MIMO) test control are well known for a long time by the environmental engineering community. The major guidelines for MIMO tests methods are defined in the well-known MIL-STD-810H method 527, as it suggests test facility, test fixtures, sensor locations and control methodology guidelines for defining the Multi-Input Multi-Output (MIMO) test. However, the definition of the full control matrix is not strictly defined.

The user must define a Power Spectral Density (PSD) for each sensor location which specifies the vibration spectrum level, as well as the Cross Power Spectral Density (CPSD) which contains data about the dynamic relation between the measurement points.

Our work considers two approaches; The first tries to match simultaneously both the control lab PSD and the CPSD to the field measurements; The second approach utilizes the PSD definition from measurements and defines a new unique CPSD for the lab test.

Our current work focuses on the first approach and will include demonstration of multi-axis vibration of payload in our unique multi-axis platform. We will share our experience of designing the fixtures, test setup and accelerometers locations taking into account the requirement to converge to unique spatial and spectral vibration profiles.

MULTIPLE-INPUT MULTIPLE-OUTPUT RANDOM CONTROL OF STRAIN RESPONSES: A NEW POSSIBILITY TO ENHANCE THE REPLICATION OF OPERATIONAL ENVIRONMENTS

Mr. Umberto Musella, Siemens Industry Software
Dr. Mattia Dal Borgo, Siemens Industry Software
Dr. Alberto Garcia De Miguel, Siemens Industry Software
Dr. Raphael Hallez, Siemens Industry Software
Dr. Bart Peeters, Siemens Industry Software

Main goal of a successful environmental vibration control test is ultimately to replicate in the laboratory the same load path and stress responses that the test article experiences when subjected to operational vibrations: poor replications can lead to an unacceptable time to failure estimation for the unit under test and different failure modes. Constraints of test setups lead to the challenge of facing unavoidable differences between real-life and testing boundary conditions and excitation mechanisms. These differences can lead to the introduction of over-testing factors in order to compensate for uncertainties on the failure mechanism of the unit under test. In case of in-flight random vibration environments, this limitation becomes particularly critical due to the distributed nature of the aerodynamic loads. Multi-Input Multi-Output (MIMO) random vibration control is a technology that allows to explore new possibilities. It has been demonstrated that increasing the number of inputs, increasing the number of acceleration control channels on the structure, and trying to match the operational mechanical impedance resulted in a better replication of acceleration responses to in-service distributed excitation. The main goal of this work is to add a new unexplored possibility to the MIMO random control testing practice: the simultaneous control of multiple strain responses instead of traditional accelerations. The underlying idea is to directly target the replication of stress propagation mechanisms while making making use of the well-known advantages of MIMO random control at the same time.

REPLICATION OF MIMO RANDOM VIBRATION ENVIRONMENTS: LATEST SOFTWARE AND HARDWARE DEVELOPMENTS

Mr. Umberto Musella, Siemens Industry Software
Dr. Mattia Dal Borgo, Siemens Industry Software
Mr. Joris Janssens, Siemens Industry Software
Dr. Raphael Hallez, Siemens Industry Software
Ms. Lydia Bemol, SEREME
Mr. François Decobert, SEREME
Dr. Bart Peeters, Siemens Industry Software

The benefits of Multiple-Input Multiple-Output (MIMO) control, as compared to Single-Input Single-Output (SISO) control, in dynamic environmental testing are widely recognized by the environmental engineering community ever since 1958. However, this practice is still considered as pioneering by the majority of test engineers and it has not been fully adopted yet as a standard in industry. Originally, the low uptake of MIMO control tests was due to the technological shortcomings of the excitation mechanisms. Consequently, numerous failed attempts, the general complexity of the control problem and the hefty computational power required to run such controllers, postponed the interest of the testing community in MIMO control until the early 2000s. However, the recent rise in complexity, as well as sizes and costs of the articles to be tested, led to increased concerns about replicating as close as possible the operational environment of the test articles, which therefore contributed to the resurgence of the MIMO control testing technology.

The objective of this presentation is to give a detailed insight on the latest developments in MIMO control technology for the purpose of reproducing more realistically the random vibration environments that the test article will be exposed to during operation. The main goal is to highlight how the software and hardware advancements in recent years are focusing not only on enhancing the capabilities of MIMO control in terms of realizability of random operational environments, but also on overcoming the stigma of overcomplex testing practices.

Improved Vibration Testing with a New Approach to Optimal Vibration Control and Analysis and a Modern Inductive Powered Vibration Shaker

Mr. Stewart Slykhous, Spectral Dynamics

A new modern powerful inductive powered shaker presents both advantages and disadvantages depending on the specific application for vibration testing. The specifics of shaker construction and the requirements for the power amplifier will be explained. Looking at each specific application including the effects of new optimal control solutions utilizing the Underwood technology addressing both narrowband and wideband processing for both MISO and MIMO applications will be contrasted to the Smallwood algorithm and the popular Lincoln convolution approach. Details of a new modern solutions-based control architecture maximizing the benefits of distributed specialized computer processing as well as enhanced data acquisition speed and accuracy will be presented.

Development and Testing of Thick Shock Resistant GFRP-Steel Adhesive Bond

Mr. Roelof (Sander) Dragt, TNO
Ms. J.H.A. Schipperen, TNO
Mr. C.P.R.J. Verhaeghe, Damen Naval
Ms. A. Ruitenberg, Damen Naval
Mr. J.A.A. Vaders, Defense Materiel Organisation

For future naval ship designs, Glass Fibre Reinforced Plastics (GFRP) structures are regarded possible options for structural parts of the ship. This means there is a need for shock resistant GFRP-steel joints, for example in case of a composite superstructure connected to a steel hull. This paper shows that, when properly designed and built, adhesive bonds provide a feasible alternative to conventionally bolted connections and show good shock resistant capabilities. This paper describes the development of a shock resistant GFRP-steel adhesive bond. First, suitable adhesives are selected and material tests are performed, both under quasi-static and highly dynamic conditions. Next, an extensive set of small scale shock experiments are performed, to investigate the behaviour of the adhesive bonds, both in tension and in shear. Finally, this knowledge is used to design a true scale joint, which is tested according to naval standards. These tests are designed as qualification tests and experiments show that an adhesive bond is capable of withstanding very severe shock loading. This makes this adhesive bond a true alternative for traditionally bolted connections. The work described in this paper is the result of a research project executed by TNO and Damen Naval, for the Netherlands Defence Materiel Organisation.

SESSION 25: SCALED AIRBLAST

CONSIDERATIONS FOR SCALED AIRBLAST EXPERIMENTS

Mr. John Hoemann, US Army ERDC
Dr. Genevieve Pezzola, US Army ERDC
Mr. David Senior, US Army ERDC
Mr. Kyle Moss, US Army ERDC
Mr. Thomas Carriveau, US Army ERDC
Dr. James Davidson, Auburn University

Scaled airblast experiments are an efficient and effective way to execute parametric studies. Research currently using scaled airblast models, on the order of 1/25- and 1/15-scale, on a steel table to investigate the effects of various explosive shapes and configurations. The steel table top test allows for multiple subscale experiments in a single day. Several challenges arise when performing scaled experiments, including the inability to scale (1) instrumentation systems and (2) the explosive ignition source (i.e., exploding bridge-wire (EBW) initiators, which are a fixed sizes). To address these issues, a series of subscale studies were performed to ensure that the physical models were obtaining reliable data. These studies included a series of laboratory procedures that isolated each component of the instrumentation system to investigate its unique electronic and physical responses. A series of subscale explosive experiments paralleled with computational modeling were used to validate the limits of the EBW and EBW-explosive interaction to confirm symmetric output from the steel table. This multi-step process ensures that data obtained from the scaled experiments are valid and allows comparisons between the physical scaled model and the computational model. Lessons learned at the subscale level are presented with their influence on designing of full-scale experiments.

EFFICIENT HYDROCODE MODELING OF AIR BLAST PROPAGATION AT LARGE SCALED RANGES

Ms. Kellan Sullivan, US Army ERDC
Dr. Genevieve Pezzola, US Army ERDC
Dr. Jesse Sherburn, US Army ERDC
Dr. Catherine Stephens, US Army ERDC
Dr. Hussam Mahmoud, Colorado State

Understanding the effects of air blast over a large variation of scaled ranges is of interest to the U.S. Army as well as other military and civil communities. Many prediction methods are known to be accurate for relatively simple charge geometries and setups such as a hemisphere on the ground or a sphere in free air. Charge shape, initiation configuration, and charge orientation have a substantial impact on the blast wave and corresponding air blast parameters. Accurate and efficient modeling of various charge configurations for a range of scaled distances provides insight into blast loading scenarios from a variety of threats. Modern computational capabilities have allowed numerical simulations and hydrocodes to become popular tools in blast analysis. High-fidelity numerical models can accurately capture the high-energy wave propagation phenomena associated with blast analysis. However, high computational cost limits their application for large scaled ranges in three dimensions. Automatic mesh refinement (AMR) is a common technique used in some hydrocodes to reduce computational cost while maintaining accuracy; however, user-defined choice of AMR can affect the model's accuracy. This study presents an analysis procedure that uses AMR with the CTH hydrocode to efficiently model two- and three-dimensional air blast simulations at large scaled distances for hemispherical and cylindrical charges. In this procedure, AMR is used as a timed rezoning switch for a designated region of the

domain around the explosive. The AMR procedure, the CTH models, and the comparisons of the numerical simulations against a data rich experimental environment are presented.

SESSION 25: STRUCTURAL RESPONSE: NUMERICAL METHODS

VERIFICATION OF APPLYING MODAL PROJECTION METHODS TO TRANSIENT DATA AS AN ANALYSIS FILTER

Dr. Jeff Cipolla, Raytheon
Mr. Matt Davis, Newport News Shipbuilding

Modal transient analysis methodologies provide a convenient and efficient way to solve linear systems dynamically in time. Modal transient approaches in many finite element analysis solvers, however, are often limited in allowable load types. Because of this, dynamic responses can include modal content that is not desired for a particular solution that would have otherwise been solved by a modal transient method with a reduced set of included modes. Modal projection methods are applied to direct transient analysis to provide post-analysis filtering of the transient data by individual modes post analysis. The approach uses standard modal dynamic methods to dissect the transient results by each individual mode, and then rebuilds the transient response based on desired modes only. The process is recorded and implemented in Matlab, and is verified using an example beam whipping analysis using Abaqus.

SIERRA/SD FEATURES FOR SHOCK AND VIBRATION APPLICATIONS

Mr. Michael Miraglia, NSWC Carderock
Dr. Nicholas Reynolds, NSWC Carderock
Mr. Jonathan Stergiou, NSWC Carderock
Mr. Rohan Bardhan, NSWC Carderock
Mr. Ari Bard, NSWC Carderock
Mr. Meredith Blanco, NSWC Carderock
Mr. Raymond Defrese, NSWC Carderock

Sierra Structural Dynamics (Sierra/SD) is a Lagrangian implicit solver developed at Sandia National Laboratories and part of the Navy-Enhanced Sierra Mechanics (NESM) suite of tools. Beyond its ability to compute the solution to large-scale models due to its massively-parallel computing capabilities, it has several features that make well-equipped for the equipment shock problem space. This talk highlights several of the tool's capabilities of interest to the shock community, including user-programmed mounts, DDAM, super elements, modal damping, and modal analysis of floated/submerged structures.

SESSION 26: NUMERICAL APPLICATION FOR STRUCTURES

AUTOMATED DAMAGE ASSESSMENT OF T-STIFFENERS USING MACHINE LEARNING

Dr. Nicholas Reynolds, NSWC Carderock

A study was undertaken to develop a machine learning algorithm that would be capable of assessing damage in T-stiffeners based on their deformed shapes. Such an algorithm would have applicates to damage assessments performed as part of modeling and simulation as well as to structural health monitoring. This study was undertaken in two phases. In the first, phase, a dataset was populated from the manual damage assessment of T-sections in an extensive parametric stud. In the second phase, candidate machine learning algorithms were trained, optimized, and tested against the dataset in order to determine their accuracy at detecting the onset of damage, and further categorizing the damage based on the deformation pattern. The final Multi-Layer Perceptron Neural Network machine learning algorithm out-performed other algorithms considered, achieving accuracies in excess of 99%. This study is the first step for automated damage assessment of maritime structures, addressing component-level damage. Further efforts would aim at assessing assembly-level structural damage.

DYNAMIC STRAIN EFFECTS IN PRESSURE VESSELS

Dr. Andrew Littlefield, US Army DEVCOM Benet Labs
Mr. David Alfano, US Army DEVCOM AC WSEC Benet Labs
Dr. Michael Macri, US Army DEVCOM AC WSEC Benet Labs
Dr. Xin-Lin Gao, Southern Methodist University

When an object moves down a cylinder it sends a strain wave ahead of it through the wall of the cylinder. As the object speed increases, the speed of this wave increases, and can increase greatly over static predictions because the wall material cannot deform fast enough. In thin walled cylinders this can lead to the failure of the cylinder. This phenomenon is called dynamic strain and the speed at which the strain increases asymptotically is called the critical velocity. This phenomenon is well understood and analytical solutions were developed in the 1980's. It has been observed that an orthotropic jacket can reduce this effect. Previous solutions looked at the aggregate orthotropic properties but not any lower scales. New analytical work has been performed to extend the previous work by developing closed-form formulas for critical velocities of anisotropic cylinders under a high-velocity moving pressure are derived using the Love-Kirchhoff thin shell theory incorporating the rotary inertia effect.

GROUND SHOCK RESPONSE PREDICTIONS FOR BURIED CONVENTIONAL MUNITIONS

Dr. Jeffrey Honig, Protection Engineering Consultants
Dr. George Kantrales, Protection Engineering Consultants
Dr. Alexander Mieloszyk, Applied Research Associates
Dr. Young Sohn, Defense Threat Reduction Agency

The detonation of a buried cased munition creates a crater as well as ground shock and soil velocity waves that will load nearby structural elements, such as footings, foundations, basement walls, etc. Craters will directly remove the vertical load-carrying elements within the crater region. Impact of ground shock and soil velocity waves on footings and foundations outside of the crater will compromise their ability to support the structure; this is referred to as "Ground Shock Response". Predicting the damage and residual capacity of structural elements outside the crater is important for estimating the potential for structural collapse, both intentional and collateral. Currently, pressure-impulse curves or single degree of freedom models are used; these simple models do not handle ground shock loading and a better technique is needed.

To predict structural damage and collapse potential, a new approach has been developed, using open-source structural engineering software to create "mid-fidelity" finite element models of key portions of the building. With a finite element model, localized response can be predicted, material nonlinearities can be tracked, and residual capacity can be estimated. The dynamic load histories from the soil can be directly input into the finite element model; development of a separate FRM for estimating the ground shock and soil velocity is presented in a separate presentation.

There were a number of challenges to overcome in developing this Ground Shock Response FRM. Computational efficiency was critical, as this FRM will be used in mission-planning tools that require fast turn-around. This was accomplished with careful modeling choices to reduce the degrees of freedom while capturing relevant phenomena. Ground shock loading on the foundational element was dynamically corrected to consider soil-structure-interaction effects. The finite element model is not high-fidelity nor highly meshed, so transition from damage to failure at the element and component levels had to be assessed with established structural failure criteria.

The development of the Ground Shock Response FRM is described in this paper; comparisons to high-fidelity numerical simulations are provided. Suggestions for future developments are given.

TRAINING III: INTRODUCTION TO HEAVYWEIGHT SHOCK TESTING

INTRODUCTION TO HEAVYWEIGHT SHOCK TESTING

Mr. Travis Kerr (HI-TEST Laboratories)

This training will cover the necessary background information relative to heavyweight shock testing. This session is intended for engineers and product developers who are unfamiliar with the heavyweight shock testing process. Subjects covered include pre-test planning, procedure preparation, fixture design, test setup, test operations, instrumentation interpretation, and reporting. Construction and use of the floating shock platforms (FSP, IFSP, and LFSP) will be covered. Shock test requirements applicable to heavyweight shock testing will be discussed.

TRAINING IV: SHOCK RESPONSE SPECTRUM PRIMER

SHOCK RESPONSE SPECTRUM PRIMER

Dr. Carl Sisemore (Sandia National Laboratories)

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

SESSION 27: UNDEX II

CHARACTERIZATION OF A PETN-BASED EXPLOSIVE UNDERWATER BUBBLE COLLAPSE STUDIES

Dr. Julian Lee, Defence R&D Canada
Mr. L. Gagné, Defence R&D Canada
Mr. C.R. Marshall, Defence R&D Canada

A plastic-bonded explosive comprised of pentaerythritol tetranitrate (PETN) and a silicon-based elastomer (SylgardTM) has been developed for the study of close-proximity underwater explosion (UNDEX) effects on targets. Because these effects involve the collapse of explosion bubbles against rigid and semi-rigid structures, water clarity improves the visualization and diagnostic measurements of the bubble dynamics. PETN is a reference explosive that has a better oxygen balance than other common explosives such as trinitrotoluene (TNT) or cyclotrimethylene trinitramine (RDX), and produces lower amounts of opaque combustion products such as solid carbon, leading to higher-quality imaging of the bubble collapse process. It was consequently chosen as the main component in a clean explosive formulation for UNDEX studies.

The development of a new PETN-based explosive mixture is described in this study, as well as experimental tests to characterize its performance. The underwater blast pressures were measured, and underwater imaging of the free-field bubble collapse was captured. Similitude equations for both the blast properties such as peak pressure and impulse, and the bubble parameters such as maximum radius and bubble oscillation period were also found. Finally, Jones-Wilkins-Lee (JWL) equation of state parameters were also calculated for the new mixture.

Numerical simulations of the experimental tests were also performed using the calculated JWL parameters. The simulated peak shock pressures were compared with the test data. High-speed underwater video recorded during the tests allowed for a comparison of the bubble size and the bulk cavitation shapes resulting from interactions between the shock and bubble with the water surface.

THE PHASE CHANGE AND THERMAL EFFECT ON THE BUBBLE DYNAMICS: FIRST, SECOND AND THIRD BUBBLE PULSATIONS

Mr. Seonghak Kim, Seoul National University
Mr. Kyungjun Choi, Seoul National University
Prof. Chongam Kim, Seoul National University

Bubble dynamics have been an interesting research field because it is related to cavitation erosion and structural damage from an underwater explosion. Thus, there has been a lot of effort to understand bubble dynamics for predicting the lifespan of underwater structures and preventing the risk of damage. The structural damage results from the shock wave emission and jetting when the bubble collapse. These effects occur not only in the first bubble period but also in the following bubble pulses (second, third, etc.). Therefore, the multiple pulsations of the bubble have to be considered for more realistic and accurate bubble dynamics. However, the bubble dynamics include the complex flow characteristics involving largely deforming motion near the solid wall (jetting and splitting of the bubbles) and the phase change effect at the bubble collapse. In addition, due to the high temperature developed inside the bubble at the end of the bubble collapse, the phase change process that occurred in hot water is no longer considered to be isothermal; thus, a thermal effect must be included in the simulation. For these difficulties, there is little numerical research on multiple bubble dynamics near the solid wall, and the thermal effect at the moment of bubble collapse has never been dealt with.

In this study, the phase change and thermal effect on the bubble dynamics are thoroughly investigated by applying the isothermal phase change model (the Schnerr-Sauer model known as the representative form of the isothermal process) and the non-isothermal phase change model (the physics-based model developed in this research group). The physics-based model is based on the classical bubble growth theories, in which the bubble generated by phase change is limited by the smaller value between inertial-controlled growth rate and heat diffusion-controlled growth rate. This non-isothermal model includes both growth rates and thus can reflect the thermal effect properly.

Without a phase change, the expansion and contraction in the first bubble period can be captured, but the bubble over-expands during the second bubble period. On the other hand, when the phase change is considered, the bubble motion corresponds to the experimental data for not only the first but also the second bubble period. However, the thermal effect observed at the collapse brings about different behavior in the following bubble period. The isothermal phase change model is based on the inertial-controlled growth rate only, which causes excessive condensation at the second bubble collapse and leads to the demise of the vapor bubble. The non-isothermal phase change model, on the contrary, appropriately calculates the phase change rates by employing both inertial and heat diffusion-controlled regimes. The computations show that consideration of the thermal effect during the phase change is critical to resolving the bubble dynamics up to the third period.

Computations on the Entire Stage of Underwater Explosions: Single and Double Detonations

Mr. Kyungjun Choi, Seoul National University
Prof. Chongam Kim, Seoul National University

Underwater explosion (UNDEX) refers to the detonation of explosive charges immersed in water. While the UNDEX scenario is seemingly simple, actual physical phenomena beneath the water's surface are highly complex and can be categorized into three stages. The massive energy released by the initial explosion causes the propagation of a spherical blast wave (Stage I). Rarefaction waves are reflected after the shock wave reaches the free surface, while a weak shock is transmitted to the air due to an impedance mismatch between air and water media. As the expansion waves propagate in the water, cavitation bubble clusters are formed in the low-pressure region beneath the free surface (Stage II). The moment the cavity clusters collapse, a bulk cavitation load arises that could reach a comparable magnitude to Stage I. Meanwhile, the explosion gas bubble expands and contracts periodically, emitting a large amount of pressure pulses (Stage III). The actions of these multiple dynamic loads by shock, bulk cavitation collapse, and bubble pulses damage any structures near the explosion.

Investigations on UNDEX have been conducted since the nature of these phenomena is intricate and can potentially be applied to safety purposes as well. Historically, theoretical and experimental studies on UNDEX have been continuously carried out, but detailed examination on the flow physics has largely relied on numerical approaches. A number of numerical studies adopted a boundary integral method (BIM); however, BIM has limitations in predicting the whole flow fields with shock and phase change due to the potential flow assumption. Other numerical studies, based on more realistic Euler or Navier-Stokes equations, still have limitations since they mostly used simplified equation of state (EOS) and pressure-cut or mechanical cavitation model. In addition, most of the previous computations have focused on each stage of the UNDEX scenario separately, such as capturing the shock wave propagation or the explosion bubble behavior itself. Since physical phenomena of UNDEX take place consecutively (Stage I -> III), the possible interactions between stages must be considered by a continuous simulation of the entire process, especially in the case of an explosion close to the boundary or multiple detonation situations.

This research group proposed a high-fidelity computational framework and extensively validated; ACTFlow_MP (All-speed Compressible Turbulent Flow_Multi-Phase) has accurately resolved the major flow physics of the entire three stages of UNDEX. More emphasis has been placed on accurate thermodynamic aspects, which are the sophisticated equation of state and thermodynamic cavitation process. In this study, a continuous simulation of the entire stage of single and double underwater explosions is conducted. Especially the double explosions at successive time instants show highly nonlinear physics and strong interactions between explosion bubbles. The flow characteristics of bubble deformation, jet formation, and interaction of shocks and cavitation regions will be discussed in detail.

SESSION 27: VIBRATION: SPECTRAL DENSITIES

SPECTRAL DENSITIES: STATISTICS AND PROBABILITY IN THE FREQUENCY DOMAIN

Mr. Neil Loychik, Los Alamos National Laboratory

Statistical behavior is often characterized by a probability density (e.g. a bell shaped curve). Simplified descriptors of the probability density are: variance being the relative width, skewness being the asymmetry of the distribution, and kurtosis being the extremes at the tails of the distribution. Of these, variance is the only statistical parameter to have a frequency-domain decomposition through the power spectral density (PSD). This presentation derives spectral densities of higher-order statistics (skewness, kurtosis, probability density), applies the transform to cases of interest, and investigates the uncertainty of estimate.

This presentation first discusses the proposed higher-order spectral densities in the context of existing tools like the PSD, response spectrum, and the wavelet in order to orient the audience. Next, we derive the analytical expressions for a spectral density that can compute variance in addition to higher-order statistics with emphasis on the skewness spectral density (SSD), kurtosis spectral density (KSD), and the probability density spectral density (PDSD). The new transform aims to behave similarly to the PSD by being 1) Physical and statistical, 2) Convergent, 3) Integrable and obey a Parseval-like relationship, and 4) be differentiable. By retaining these behaviors, it is expected that the transforms can support Newtonian mechanics problems for sound, vibration, turbulence, etc.

Second, this presentation demonstrates the capabilities of the higher-order spectral densities (SSD, KSD, and PDSD) through a series of case studies analyzing simulation and experimental data. The cases are examples of foundational problems in sound and vibration that can be enhanced through higher-order spectral densities: 1) mass-spring-damper transmissibility, 2) fluid turbulence energy cascade, 3) sound recognition (timbre), 4) machine health monitoring.

Last, this presentation derives a means to bound error to asses transform accuracy and repeatability. A functional form to error bounds is proposed that accommodates both the bias and random error inherent to the signal. The functional form is tested through a convergence study that estimates the dispersion of an estimate though repeated simulation spectral densities.

SPECTRAL DENSITIES: STATISTICS AND PROBABILITY IN THE FREQUENCY DOMAIN (PART 2)

Mr. Neil Loychik, Los Alamos National Laboratory

Statistical behavior is often characterized by a probability density (e.g. a bell shaped curve). Simplified descriptors of the probability density are: variance being the relative width, skewness being the asymmetry of the distribution, and kurtosis being the extremes at the tails of the distribution. Of these, variance is the only statistical parameter to have a frequency-domain decomposition through the power spectral density (PSD). This presentation derives spectral densities of higher-order statistics (skewness, kurtosis, probability density), applies the transform to cases of interest, and investigates the uncertainty of estimate.

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Last, this presentation derives a means to bound error to asses transform accuracy and repeatability. A functional form to error bounds is proposed that accommodates both the bias and random error inherent to the signal. The functional form is tested through a convergence study that estimates the dispersion of an estimate though repeated simulation spectral densities.

SESSION 28: NUMERICAL METHODS FOR VIBRATION

COORDINATE TRANSFORMATION OF VIBRATION AUTOSPECTRAL DENSITY (ASD)

Dr. Arup Maji, Sandia National Laboratories

Autospectral Density (ASD), also referred to as Power-Spectral Density (PSD) is the most common way of quantifying vibration for archival of test data and specifications for laboratory tests. The original acceleration vs. time history is no longer available, especially as the ASDs are used in subsequent mathematical processes such as probabilistic assessments leading to test specifications. Later on, it is necessary to determine ASDs in coordinate systems that are oriented at an angle w.r.t. the original coordinate system. For instance, tests need to be run in component coordinate axis vs. system coordinate axis in which data was collected and propagated.

This paper summarizes the necessary theoretical background of ASD transformation, as it relates to both correlated and uncorrelated (random) vibration data. Equations are provided to allow the user to calculate relevant ASDs in a transformed coordinate system. Also, the consequence of alternative methods that are often used (such as enveloping the 2 orthogonal specifications or sum of ASDs as upper limit) are explored and compared with more accurate methods and equations. Finally, simulations with various angle of transform and relative phase of vibration in the two axes are used to understand the implications and to quantify the levels of conservatism.

COMPARISON OF POWER FLOW THROUGH INTERFACE MODE SETS

Mr. Jon Young, Pennsylvania State University Applied Research Laboratory
Dr. Kyle Myers, The Pennsylvania State University Applied Research Laboratory

Power flow between source and receiver structures is a means of quantifying the vibratory response of coupled structures using a single scalar quantity. For structures with many degrees of freedom (DOFs) on their coupling interfaces, the calculation of power flow can become computationally expensive, particularly if it is evaluated using a fine frequency resolution. Two methods for reducing the number of interface DOFs are shown and compared; namely, through the use of Characteristic Constraint (CC) modes and Local Interface (LI) modes. CC modes are obtained by means of performing an eigenanalysis on the assembled interface mass and stiffness matrices, and LI modes are obtained from performing an eigenanalysis on the individual substructure interface matrices. The number of interface modes needed to accurately predict natural frequencies, mode shapes, and power flow spectra of the assembled source-receiver structures are compared for both interface mode sets. The effects of different size interface mode basis sets were compared on plate structures with continuous interfaces, as well as panel structures that are connected along discrete interface points. It is shown, in general, that fewer CC modes are required to accurately predict the natural frequencies, mode shapes, and power flow spectra due to the eigenanalysis being performed on the assembled interface mass and stiffness matrices.

SESSION 28: STRUCTURAL RESPONSE: NUMERICAL APPLICATIONS

TRULY CURVED CONTACT IN HIGHER-ORDER LUMPED-MASS EXPLICIT METHODS FOR HIGH-RATE APPLICATIONS

Dr. Kent Danielson, US Army ERDC

Higher-order finite elements have proven to provide significant advantages for lumped-mass explicit methods in nonlinear solid dynamics and have increasingly become available in popular codes. They inherently include curvature and especially perform well in flexural modes and with material incompressibilities in unstructured meshes without locking problems or the need for artificial hourglass control, incompatible modes, or other ad hoc procedures. Contact is substantial in many explicit applications, such as for high-rate blast and fragment impact simulations. Methods for contact with higher-order elements have been developed, but they are generally less mature than for first-order ones, especially in lumped-mass explicit software. The innate curvature of higher-order elements can also be quite beneficial, but implementations frequently make simplifying approximations (e.g., piecewise bilinear) to reduce complexity and computational costs. In this presentation, basic lumped-mass explicit capabilities are demonstrated for three-dimensional contact that rigorously include arbitrary-order elemental curvature. Deformable-to-deformable surface contact/impact is considered with both triangular and quadrilateral faces for large deformation/sliding. Double-pass node-to-face contact searching and enforcement approaches are used for general three-dimensional C0 higher-order Lagrange type elements in nonlinear solid dynamics using typical lumped-mass central difference time integration. Typical friction models used in similar first-order node-to-face contact methods are generally applicable. Treatment of even only modest amounts of curvature demonstrates improved performance in benchmark and practical high-rate contact-impact applications using various elastic, hyperelastic, and elastic-plastic material models.

A METHOD TO EXPAND SPARSE SET ACCELERATION DATA TO FULL SET STRAIN DATA

Mr. Jonathan Hower, Honeywell FM&T
Mr. Raymond Joshua, Honeywell FM&T

Expansion methods are commonly used to compute the response at locations not measured during physical testing. The System Equivalent Reduction Expansion Process (SEREP) produces responses at finite element degrees of freedom through the mode shapes of that model. Measurements used for expansion are often acceleration, strain, and displacement and operate only on like sets of data. For example, expanding acceleration data produces only additional acceleration data and does not provide insight into the test article's stress or strain state. Stress and strain are often desired to evaluate yield limits and create fatigue models. The engineer may have acceleration measurements available, but desire a component's stress and strain state. This work evaluates a physical experiment from which acceleration is measured and a full set of strain, stress and displacement data is obtained through SEREP and integration.

SIMPLIFIED FINITE ELEMENT MODEL GENERATION FOR EXODUS II AND SIERRA SD/SM

Mr. Kory Soukup, Altair Engineering

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 solverspecific parameters). Through the integration of a commercially available high-performance finite element preprocessor, HyperWorks, 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.

SESSION 29: IMPACT & PENETRATION EFFECTS

MODELING THE BALLISTIC LIMIT OF FRAGMENT SIMULATING PROJECTILES IMPACTING A36 MILD STEEL SPACED ARMOR CONFIGURATIONS

Mr. Daniel Rios-Estremera, US Army ERDC
Dr. Matthew W. Priddy, MSU
Dr. Jesse A. Sherburn, US Army ERDC

Terminal ballistics describes the multivariate behavior and aftermath of projectile and target interactions. While tests and models are often based on monolithic armors, layered and spaced armors are common in real world applications. Such configurations add complexities that require research to understand their effects on terminal ballistics. The protection ballistic limit velocity (V50) represents the speed where armor perforation probability is 50%. It is used for quantitative comparison of protection capabilities for different armors. This study developed a new methodology for estimating the V50 of spaced and layered A36 steel armors against fragment simulating projectiles (FSPs) by leveraging the Monte Carlo method. The methodology offers significantly increased accuracy relative to literature methodologies.

JOINT US/GE PENETRATION EXPERIMENTS AGAINST HIGH-STRENGTH FIBER REINFORCED CONCRETE

Mr. Mark Green, GmRA
Ms. Keri Bailey, US Army ERDC
Mr. Ernie Staubs, AFRL
Mr. Thorsten Sarrach, WTD-9
Mr. Martin Bucksch, TMS
Dr. Danny Frew, DSR
Dr. Bradley Martin, AFLCMC

In 2020, the US and Germany jointly performed a second series of scaled penetration experiments against advanced high-strength concrete (HSC) targets under different impact conditions and target thicknesses used in the first test series conducted in 2019. The objective of these experiments was to obtain advanced penetration and perforation data for use in developing new penetration resistance and layer sensing algorithms for this specific class of concrete. The projectiles were launched out of a smooth-bore powder gun. In addition to measuring penetration depth and perforation velocities, two instrumentation packages (one developed by the US and one by Germany) were placed inside the projectiles to measure and record axial deceleration during penetration/perforation of the target. This paper provides an overview of the experimental setup and test results along with comparisons with post-test simulations.

FAST-RUNNING MODEL FRAMEWORK FOR CONCRETE PENETRATION USING VIRTUAL DATA

Mr. Jean Santiago Padilla, US Army ERDC
Mr. David Failla, US Army ERDC
Mr. Daniel Rios-Estremera, US Army ERDC

The Ballistic Resistance Assessment Tool (BRAT) was developed by the U.S. Army Engineer Research and Development Center as a decision support tool to provide the Warfighter the capability to quickly determine the level of protection provided by existing structures against ballistic threats and to improve the level of protection with suggested expedient retrofit solutions. The first release of the application leveraged historical experimental data to develop a fast-running model to predict terminal ballistic effects. For the next generation of BRAT, a new, cost-effective framework is proposed using numerical simulations to create a synthetic database. For this work, the Lagrangian explicit dynamics code, Elastic Plastic Impact Computation (EPIC), is used to simulate penetration effects at ordnance velocity for various concrete materials using surrogate projectiles representing ball rounds and armor-piercing rounds, as well as fragment simulating projectiles (FSPs). Empirical equations derived from the synthetic data are validated using available experiments.

SESSION 30: RESPONSE OF CONNECTIONS UNDER SHOCK LOADS

FIXTURE DESIGN FOR THE LIGHTWEIGHT SHOCK MACHINE TESTING OF BACKGOUGED AND NONBACKGOUGED WELDS

Mr. Matt Davis, Newport News Shipbuilding
Mr. Steve Elder, Newport News Shipbuilding
Mr. Kevin Arden, Newport News Shipbuilding

A novel test apparatus was created in order to dynamically test material samples with various weld imperfections on the light weight shock machine. A finite element analysis representation of the light weight shock test machine and nonlinear transient analysis were used to evaluate various revisions of

the test apparatus to ensure the design provided ample strain energy to the test coupons. With the goal of incrementally loading the test coupon up to 5% strain or failure, the fixture was designed to include variable test mass and allow for sufficient increase or decrease in energy based on machine hammer heights should changes be required during testing.

LIGHTWEIGHT SHOCK MACHINE TESTING OF BACKGOUGED AND NONBACKGOUGED WELDS

Mr. Matt Davis, Newport News Shipbuilding
Mr. Steve Elder, Newport News Shipbuilding
Mr. Kevin Arden, Newport News Shipbuilding

A series of backgouged and nonbackgouged welds samples were performance tested on the light weight shock machine to determine loss in strength of weld performance due to various imperfections. The test coupons were incrementally loaded up to 5% strain or failure using a novel test apparatus. The dynamic testing of the test coupons at shock level strain rates provided insight into the effect of the various imperfections tested. These results are presented to the community for information on weld performance in a shock environment.

COMPARATIVE QUASI-STATIC AND DYNAMIC SHOCK BOLTED JOINT TESTING: PART I - TESTING AND HIGH-LEVEL CONCLUSIONS

Mr. Randall Goodnight, NSWC Carderock
Mr. Thomas Bruno, NSWC Carderock
Mr. Jacob Mason, NSWC Carderock
Ms. Anna Bethel, NSWC Carderock

Bolted connections are ubiquitous on ship and submarine platforms, and are complex in their dynamics and failure modes. It is well known that bolted connections perform differently under dynamic and static loading. This talk will describe a test series that was conducted to demonstrate the relationship between failures in bolts loaded quasistatically and dynamically via the Lightweight Shock Machine. The test series included testing of 3/8" Grade 8 and Grade 5 steel bolts tension, shear, and 45° combined loading. This talk will present the results of test series and the high level conclusions drawn from the test.

COMPARATIVE QUASI-STATIC AND DYNAMIC SHOCK BOLTED JOINT TESTING: PART II – DATA AND FINITE ELEMENT ANALYSES

Ms. Rebecca Grisso, NSWC Carderock
Mr. Tam Nguyen, NSWC Carderock
Mr. Ryan Hegarty, NSWC Carderock

The testing described in the preceding talk resulted in a significant data repository from a wide variety of instrumentation types over a wide range of loading. The first objective of this talk is to present data analysis conducted with the recorded instrumentation and conclusions developed from that analysis. The second objective of this talk is to review approaches to take the recorded data to load and correlate with finite element (FE) models of the test with varied levels of model fidelity and extent. Finally, conclusions and areas for continued investigation will be discussed.

SUPPORTING PIPE FOUNDATION FLANGE SHOCK ANALYSIS TOOL FOR SIMULTANEOUS LARGE QUANTITY FLANGE ANALYSIS
Mr. Mackenzie Wilson, Newport News Shipbuilding
Mr. Chris Campbell, Newport News Shipbuilding

This paper describes the supporting pipe foundation flange shock analysis tool that was developed for both verifying finite element analysis (FEA) model results and to have the capability for evaluating flanges in a cost effective manner. The analyses performed included the following: 1) assess a varied range of flange mounting orientations; 2) evaluate of pipe-to-flange and flange-to-foundation fasteners due to shock loading; 3) evaluate both flange areas local to fasteners and flange cross-section due to shock loading; 4) and accomplish these analyses for a large assorted quantity of flanges simultaneously. Example analyses of the pipe foundation flanges are also presented and discussed. This project is an example of leveraging Excel for engineering shock analysis and demonstrates how spreadsheet applications can be a valuable tool.

TRAINING V: INTRODUCTION TO UERDTOOLS

INTRODUCTION TO UERDTOOLS
Mr. Brian Lang, NSWC Carderock

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

TRAINING VI: INTRODUCTION TO MEDIUM WEIGHT SHOCK TESTING

INTRODUCTION TO MEDIUM WEIGHT SHOCK TESTING
Mr. Jeff Morris, HI-TEST Laboratories

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