SAVE
SHOCK & VIBRATION EXCHANGE

ABSTRACTS

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UNDEX I

UNDERWATER SHOCK WAVE PROPAGATION IN A LITTORAL ENVIRONMENT

Dr. Giovanni Fusina, Defence R&D Canada
Dr. Craig Burrell, Defence R&D Canada
Dr. Julian Lee, Defence R&D Canada

Underwater blast trials were conducted in the falls of 2013 and 2014 in a littoral environment with relatively small explosive charges having nominal masses between 0.1 kg and 4.54 kg. The charges were suspended and detonated at depths of 7.6 m and 3 m. A number of blast sensors and hydrophones were deployed at various distances between 20 m and 1000 m from the explosion to record the propagation of the underwater blast wave. The pressure histories of the waves were recorded at the measurement locations, and preliminary estimates were made of the peak pressure, impulse, and energy flux density. These measurements provide insight into the near-field and far-field characteristics of the underwater blast, and were compared to propagation models based on deep-water scaling relations by Aarons and Rogers. In general, models using Aarons and Rogers relations provided good predictions for the measured values of peak pressures. Fairly large and unanticipated differences between the 2013 and 2014 peak pressure measurements in the far-field were observed. This suggests that blast wave properties are sensitive to details of bathymetry and thermocline.

Generally, impulse is defined as the integral over time of the pressure profile. The “impulse A-duration” is defined as the integral of the pressure profile over time with the limits of the integration set between the shock front and the first zero-crossing of the pressure waveform. This zero-crossing occurs when the reflection of the shock from the water’s surface, reaches the measurement location. Calculating the “impulse A-duration” from pressure profile measurements in the trials that were conducted in 2013 and 2014 did not always yield good agreement with values from the model. In addition, “impulse A-duration” cannot be determined effectively for a far-field pressure profile because the “zero-crossing” is not well defined. Different methods to estimate impulse were devised yielding better agreement with models in both near-field and far-field.

BUBBLE-INDUCED WHIPPING MOTION IN A FLOATING STRUCTURE

Dr. Julian Lee, Defence R&D Canada
Mr. MJ Smith, Defence R&D Canada
Mr. E. Van Daelen, TNO
Mr. D. Roseveare, Defence R&D Canada

This paper presents an experimental study of the dynamic response of a free-floating structure when subjected to an underwater explosion (UNDEX) beneath it. This behavior is analogous to the hogging, sagging, and whipping motion of a ship impacted by the loading from a close-proximity explosive charge. The target structure has a simple elongated-box shape, and its overall fundamental vibrational mode was designed to match the frequency of the UNDEX bubble pulsation. The interaction between the shock and bubble collapse produces a strong resonant response comprising several bending and torsional modes. Digital Image Correlation (DIC) techniques were used to measure the motion of the entire air-side surface of the structure, while simultaneous underwater video showed the complex interaction between the bubble and the structure. This study provides insight into the inter-dependent bubble and structure behavior and leading to damage caused by whipping-like motion.

COMPARATIVE STUDY ON SHOCK RESPONSE ANALYSIS WITH UNDEX EXPERIMENTAL DATA USING DOWN SCALE SHIP MODEL(II)

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Many simulation program with hydrocodes using a combined Euler-Lagrange model for surrounding water and ship structure is used for the analysis of the effects of an underwater explosion on their own naval ship. But to enhance the reliability of these analysis results, the validation course should be needed basically by the process of comparison with the calculated responses and measurements from the full or down scale shock trials of real naval vessel. For this purpose, this paper discusses that shock analysis calculation data was investigated using well known analysis program and compared with UNDEX experimental data using down scale ship model of ROKN frigate.

INTERACTION TOOLS FOR UNDERWATER SHOCK ANALYSIS IN NAVAL PLATFORM DESIGN

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In order to satisfy the need for good quality UNDerwater EXplosion (UNDEX) response estimates of naval platforms, TNO developed two 3D simulation tools: the Simplified Interaction Tool (SIT) and the hydro/structural code 3DCAV. Both tools are an add-on to LS-DYNA. SIT is a module of user routines for generating the UNDEX loading and accounts for the strong fluid-structure interaction on the wet hull of a 3D finite element model of the platform structure by means of sophisticated physical approximation. This eliminates the need for a 3D modelling of the surrounding water, such as necessary for advanced coupled finite element/hydrocode simulations. Both the shock wave stage with reflections and cavitation and the subsequent gas bubble loading are modelled in SIT. The SIT was tuned and validated using experimental data from full-scale surface ship shock trials. 3DCAV is a module of user routines which uses LS-DYNA's Lagrangian fluid elements as a hydrocode for performing UNDEX simulations with less physical approximations. The results from 3DCAV simulations are used for tuning and validating the more efficient SIT for new applications like submarines and non-standard UNDEX scenarios for surface ships. A typical simulation of a detailed 3D finite element model of a naval platform takes only hours for a SIT simulation of the shock wave stage against days for a comparable 3DCAV simulation. Nevertheless, 3DCAV is still much more efficient compared to coupled Eulerian-Lagrangian hydrocodes. Its simulation efficiency has made SIT a prime UNDEX simulation tool for use in platform design, while 3DCAV remains highly useful for verification, validation and further SIT development. This paper provides a short overview of the physical backgrounds of SIT and 3DCAV, a comparison of their performance and examples of applications.

MIL-S-901 LAND BASED SHOCK TESTING MACHINE SIMULATION FOR ELASTICALLY SUPPORTED EQUIPMENT

Mr. Claude Prost, Vibro Dynamics

The MIL-S-901 Navy shock standard is unique in that it specifies the shock testing machine on which the equipment is qualified, whereas most European Navies define the shock input in terms of acceleration time history, which simplifies the analytical procedure. MIL-S-901 defines three testing machines: the

LWSM, MWSM, and FSP. In order to numerically simulate these tests, the Socitec Group and its US subsidiary, Vibro/Dynamics, have developed and used numerical models of each machine with the proprietary SYMOS software package for many years. The advantage of this approach is to select the optimal wire rope or elastomeric mountings for the job and go to final qualification with a much better chance of success. Conducting many simulation studies is relatively inexpensive and can be implemented at the design stage, even if the equipment is still under development. The Navy has recently developed a new land based shock testing machine as a less expensive potential replacement for the MWSM and FSP. The shock input of this new machine, like the other machines, is not specified and the above arguments in favor of a preliminary numerical simulation remain.

This article will briefly summarize the previous models of LWSM, MWSM, and FSP and discuss the numerical model of the new land based shock testing machine, which will be part of the upcoming MIL-S-901 revision. Numerical models and actual test results will be compared where applicable.

SUBMARINE COMPONENT DESIGN TOOL TO ASSESS RELATIVE RESISTANCE TO SHOCK LOADING

Mr. Justin Caruana, Cardinal Engineering
Mr. David Batol, Cardinal Engineering
Dr. Jeff Cipolla, Thornton Thomasetti

In this presentation, Cardinal Engineering, with team member Thornton Thomasetti - Weidlinger Associates Inc, showcases their solution in response to a Navy SBIR which sought an innovative, cost and time efficient design tool that can evaluate new Navy Submarine equipment designs for shock survivability to mitigate non-recurring engineering (NRE) hours. This new, automated software tool termed Comparative Design Assessment Tool (CDAT) will allow users to determine if a newly designed and non-tested component is as resistant to high intensity shock loadings as a previously designed and MIL-S-901 qualified component without the need for high cost testing or a candidate item Finite Element Analysis. When successfully demonstrated, CDAT will provide assurance to the component designer that the low-cost shock qualification by extension process is achievable. Perhaps even more powerful, when the results of CDAT indicate that a component is not as resistant to previously designed and qualified units, the designer can focus on redesigning the indicated weaknesses of the component and iterate again through CDAT.

INSTRUMENTATION

EMBEDDED SURFACE MOUNT TRIAXIAL ACCELEROMETER

Mr. Robert Sill, PCB Piezotronics

Field results are presented of triaxial acceleration measurements in high velocity impact and penetration environments using an on-board shock recorder. Three accelerometer signals were provided by a single surface mount package embedded in the circuitry of the recorder. This configuration replaced the mounting of three discrete conventional single axis packages, routing and handling their individual cables, and attempting to get shockproof connections. Development is now complete on this ceramic package configuration, which is a hermetic leadless chip carrier housing three orthogonally mounted MEMS sensors.

AN AUTOMATED METHOD TO IDENTIFY OUTLIER SENSOR RESPONSE

Ms. Angela Montoya, Sandia National Laboratories
Mr. Vit Babuska, Sandia National Laboratories
Mr. Jason Booher, Sandia National Laboratories

Accurately capturing the dynamic response of a test body during flight experiments is necessary for asset design development and eventual qualification for use in the field. Often the testing schedule requires near real-time decisions about data quality and the general health of the test body based on an assessment of the data quality. The current method relies on the manual identification of patterns by labor-intensive visual examination of channel outputs. Manual analysis of large amounts of information is inefficient and can be prone to errors. A solution to this problem would not only save analysis time and effort during flight tests, but an efficient method to identify changing patterns with a minimal amount of information would have broad applicability.

Although not a complete replacement for expert analysis, a fast automated method has been developed to identify channels on a flight test body that are responding in an anomalous manner. In this method, a pattern is defined using the relative GRMS of each channel to another for an array of external inputs (flight test events). Pattern change for different channel parings is ranked by the amount of information entropy contained in the pattern. Channels that have an anomalous response will have a higher amount of entropy across different parings relative to others. This paper introduces the method, derives the underlying mathematical model, demonstrates its utility with real data examples, and follows with a discussion on the assumptions and limitations of using this method in the field.

CROSS AXIS CORRECTION OF ACCELERATION DATA

Dr. Jon Yagla, NSWCDD

We fired a projectile in a 57mm gun that attained a muzzle velocity of 1020 meters/second. The projectile contained tri-axial accelerometers that measured accelerations along the axis of the projectile and in two transverse directions. There was an on board recorder. The projectile was recovered. The data were processed to provide acceleration versus time from each accelerometer. The axial acceleration data looked perfectly normal as expected from the pressure time traces measured in the same gun. Upon further analysis, the data presented two perplexing problems. First, integrations to compute the velocity showed a velocity much greater than 1020 m/s. The sensitivity of the transducer adjusted down until the known velocity of 1020m/s at the muzzle of the gun was obtained. This led to 32 kG for the peak acceleration, rather than the 35 kG recorded in the projectile. At this point the velocity was correct, and the accelerometer sensitivity was in question.

The corrected velocity was integrated to obtain the displacement versus time. There was a pressure transducer at the end of the barrel from which the arrival time of the projectile at the barrel could be determined. However, the displacement obtained by integration put the displacement of the projectile well downrange from the pressure transducer at the muzzle at the measured arrival time. A further "correction" of the sensitivity made the velocity to low.

The second perplexing problem was found in the radial acceleration measurements. The orientations of the accelerometers in the projectile were positive for positive acceleration in the radially outward direction. The projectile achieved a spin angular velocity of 770 revolutions/second due to rifling in the barrel. The centripetal accelerations are therefore negative, regardless of the spin direction (clockwise or counter clockwise). However, the data showed a period of positive centripetal acceleration (impossible), then progressing to negative values near ones expected from rigid body dynamics theory as the projectile approached the muzzle.

The problem was solved by considering the cross axis sensitivity of the instruments. Computer experiments assuming approximate cross axis acceleration sensitivities of the accelerometers lead to a complete reconciliation of both perplexing problems. The manufacturer of the accelerometers said the cross axis sensitivities could be 5%. Indeed, a 5% sensitivity correction caused the radial acceleration to be negative and agree exactly with the rigid body spin calculated from the speed and twist of the barrel. The projectile was then put in a spin stand. The axial accelerometer showed an axial acceleration proportional to the angular rate, even though no axial motion was possible. It was then assumed the clock in the projectile was also sensitive to acceleration. A simple model with the clock frequency shift being proportional to the axial acceleration showed a significant difference between the assumed one microsecond time step and the computed time step as the acceleration increased. When the computed instantaneous time step was used rather than one microsecond in the integration, walla, the raw data from the accelerometer, integrated, and double integrated, provided perfect agreement with measured velocity and displacement!

SIX DEGREE OF FREEDOM SHOCKWAVE MONITORING

Dr. Laura Jacobs, Sandia National Laboratories
Dr. Avery Cashion, Sandia National Laboratories

Accelerometer data collected during a recent underground explosive shock test indicates potentially added value from measurement of shock acceleration in 6 degrees of freedom (DOF). An explosive package was placed in a central borehole with accelerometers installed and grouted at various depths in a separate borehole 20 meters away. At each depth, two triaxial accelerometers were mounted in diametrically opposed positions within their respective installation canisters. Data analysis suggests the existence of rotational acceleration of the canisters following the initial shockwave, which cannot be captured using the standard of practice for subsurface explosive instrumentation. The two-gauge installation was originally intended to simply mitigate potential failure of one device but disparities between the acceleration records after the initial shockwave triggered further investigation. From a 6-DOF analysis perspective, a limitation of the using only two diametrically opposed gauges is that only two of the three rotations can be calculated. A second shock test improves upon the sensor design, allowing for the calculation of all three rotations. Treating the system as a 6 DOF sensor, signals appear above the noise floor that correspond with known phenomena (slap down of upper weathered granite), which is not discernable from translation measurements alone. Additionally, mounting and recording the gauges in a 6 DOF orientation can be used to remove the influence of the rotations on the translational measurements. Therefore, a 6 DOF sensor may allow for a more complete understanding of the response of the geology to a high shock event. Test details, analysis and assessment of 6 DOF shockwave monitoring are presented.

EQUIPMENT QUALIFICATIONS FOR DYNAMIC MATERIALS TESTING TO BLAST TESTING

Mr. Mike Hoyer, HBM Test and Measurement

Whether performing dynamic materials testing in a Split Hopkinson Bar application, drilling and blasting a river bed in a environmentally-sensitive area or testing warheads, munitions, explosives or rockets, it is imperative that appropriate equipment and procedures are used to reliably, accurately and safely acquire all necessary data plus efficiently produce calculated results and reports within a timely manner.

Three applications will be examined to show how vital appropriate equipment and analysis software comes into play to; reliably record data during a $75 million rocket test, help limit any possible damage to fish using controlled blasting methods and improve US manufacturing through better characterization of material properties and tools plus account for vibration during the manufacturing process.

ULTRA MINIATURE SHOCK AND VIBRATION PRODUCT DEVELOPMENT TESTING

Mr. Kevin Westhora, Dytran

The need for small triaxial accelerometers in this industry is key and an important feature when determining which sensor utilizes the correct technology. Additionally, there has been a tremendous need for a low out gassing accelerometer with small dimensions and low weight for a multitude of applications. Dytran uses quartz single crystal in the 3133D2 that is a non-aging material perfect for space applications. With other sensors, temperature can affect the units making it impossible for recalibration whereas the quartz single crystal does not need to be recalibrated. Because of quartz' high Q factor, other piezoceramics suffer from low Q factor, exacerbated amplitude slope versus frequency, pyroelectric response and thermal transient response. There is need for accelerometers of small dimensions, light weight, and low outgassing characteristics that are been unmet by the vibration sensor community especially shock and vibration testing. When designing a piezoelectric dynamic sensor of small dimensions, the design team will focus in utilizing a piezoelectric material with higher sensitivity, as the reduce dimensions of the envelope, will limit the weight of the seismic mass that can be used to get signal from the instrument. Therefore, normally piezoceramic materials that have high piezoelectric sensitivity response, like PZT Lead Zirconate Titanate ceramics and others, are incorporated in the manufacturing of small accelerometers.

BLAST TESTING

SOIL EFFECTS ON BLAST INTENSITY

Dr. James Eridon, General Dynamics Land Systems

The blast survivability of ground combat vehicles is often specified in terms of kilograms of TNT, indicating the size of the mine blast that the occupants can withstand without injury. Because of the importance of soil conditions on the magnitude of blast effects, this is a very incomplete specification. Data indicates that the blast impulse delivered by a buried charge can change by more than a factor of two owing to simple changes in the moisture content of the soil. As a consequence, the description of soil conditions is very important in evaluating the blast survivability of a given vehicle.

Recently, the Army Test and Evaluation Command decided to change the soil conditions used for blast testing of combat vehicles. The new soil will have a higher compaction and much lower air-filled volume than that used previously. This should more accurately reflect real-world conditions. The soil specification also includes more detail on density, moisture content, and specific gravity, which should provide better reproducibility and control in live-fire testing. One of the interesting questions concerns the expected difference in blast intensity produced by the new soil compared to the legacy soil. This paper will summarize much of the publicly available test data on the effect of soil conditions on blast intensity. Examination of this data shows that a simple analytical fit to the air-filled volume does a good job of explaining the variation in blast intensity in widely varying soil conditions. This is likely due to the simple fact that air is compressible and can absorb a fair amount of blast energy, while water and soil solids are largely incompressible. The model can be used to estimate the expected difference in blast intensity between historical soil, new ATEC "roadbed" soil, and AEP-55 "Stanag" soil. In addition, the model allows an estimate of the variability to be expected given the range of acceptable soil test parameters in the new specification.

BLAST EFFECTS ON CONCRETE PERIMETER BARRIERS

Cpt. Geoff Dinneen, US Army Engineer Research and Development Center
C. S. Stephens, US Army Engineer Research and Development Center
O. G. Flores, US Army Engineer Research and Development Center
W. Vanadit-Ellis, US Army Engineer Research and Development Center

Concrete barriers used as standoff enforcement and perimeters can be subjected to blast loads in the event of an attack. Due to the inherent risk that would be caused by a breach in a secured perimeter or the standoff enforcement barriers, a need exists to rapidly assess the effects of blasts on barriers. The objectives of this study were to investigate the effects of blasts on concrete perimeter barriers using full-scale experimentation, scaled experimentation in a centrifuge, and computational modeling. Full-scale experimentation was completed using hemispherical bare charges against interlocking Alaska barriers and Texas t-walls. The scaled experiments were conducted in the U.S. Army centrifuge at 1/100 scale with three-dimensionally printed barriers weighted to represent the full-scale concrete barriers. The full-scale experiments were simulated using finite element analysis. Both the scaled experiments and the computational model were validated by the full-scale experimentation.

BLAST-RESISTANT RESPONSE OF NAIL-LAMINATED TIMBER

Mr. Mark Weaver, Karagozian & Case, Inc

Massive timber is an increasingly popular structural solution in North America due to its environmental and constructability advantages. One form of massive timber is nail-laminated timber (NLT), which essentially is constructed by nailing together 2x material to form solid floor and wall sections. As part of an effort to demonstrate the blast-resistant capability of massive timber structural systems, a series of quasi-static and dynamic tests were conducted on NLT panels. The objective of the quasi-static testing was to test and document the post-peak response of 2x4 and 2x6 NLT when subjected to an ever increasing uniform load, including making notes concerning failure patterns and overall panel ductility. Based on this quasi-static testing series, several shock tube tests were performed on 2x4 and 2x6 NLT specimens. The purpose of this paper is to introduce and describe the results obtained from these two testing efforts. Furthermore, the test results are compared with: (1) existing design methodologies that compute peak strength and stiffness of independent 2x timber members and (2) computations created using high-fidelity finite element modeling tools.

HIGH SPEED FIBER OPTIC FBG STRAIN SENSOR SYSTEM FOR ACQUIRING HIGH SHOCK STRAIN RESPONSE

Dr. Vincent Chiarito, US Army Engineer Research and Development Center

No abstract available.

MULTIPLE DEGREE OF FREEDOM BLAST EFFECTS SIMULATOR (MDOF-BES)

Mr. Robert Kargus, ARL
Justin Pritchett, Army Research Laboratory

A new, state-of-the-art underbody blast effects experimental facility has been jointly designed and devleoped by the Army Research Laboratory, Office of Naval Research and Lansmont Corporation. The

Multiple Degree of Freedom Blast Effects Simulator (MDOF-BES) is a laboratory apparatus which simulates an end-to-end ground combat vehicle (GCV) kinematic response, subjected to an underbody blast event. The MDOF-BES possesses a unique capability to simultaneously replicate the rigid body response and localized structural response of a GCV. Moreover, the system overcomes current limitations of tradional drop towers and ARL's Crew Seating Blast Effects Simulator (CSBES), with its multiple degree of freedom loading capability. The MDOF-BES is capable of reaching rigid body velocites up to levels that are obtained in real world main blast events. Powered by pneumatic pistons, elastomeric pads are used to shape and tune pulses with the desired rigid body amplitudes and durations.

STRUCTURAL DYNAMICS TESTING & ANALYSIS

SIMULATING PENETRATION AND PERFORATION OF DIFFERENT CONCRETE TARGETS

Dr. Jennifer Cordes, U.S. Army Picatinny Arsenal
Mr. David W. Geissler, U.S. Army Picatinny Arsenal
Mr. Pavol Stofko, U.S. Army Picatinny Arsenal

A series of numerical simulations were completed for projectiles penetrating or perforating different concrete targets. The targets were not reinforced with steel bar. Results were compared to experimental results generated by the U.S. Army Engineer Research and Development Center and Sandia National Laboratory. The simulations were completed with different material models and different target configurations. Concrete models included conventional strength concrete, high strength concrete, and ultra-high strength concrete. For most of the examples using conventional strength concrete, penetration depth or exit velocity was within 10% of experimental values. Comparisons include predicted high-g accelerations using different material models.

DYNAMIC FATIGUE TESTING OF BREECH ASSEMBLIES WITH LOW PLASTICITY BURNISHING

Mr. David Alfano, Jr., Benet Labs - ARDEC

Dynamic fatigue testing is performed to certify the safety of armament systems. Laboratory fatigue testing consists of imposing ballistic equivalent pressure loads onto the components in order to simulate live-fire. To achieve the desired pressure impulse for testing, a specialized hydraulic oil medium is compressed inside a shortened version of the gun tube and breech assembly. The ultra-high pressure test impulses are achieved through use of a free falling mass that impacts the upper components and compresses the fluid volume. The resulting energy is transferred through the lower chamber plug, acting as a stub case, into the breech block and other assembly components to replicate the stress-strains observed during live-fire. Pressure is monitored through a transducer designed, fabricated, and calibrated in-house and located within the lower chamber plug.

An modified impact system was utilized in order to provide fatigue testing on large caliber cannon breech assemblies that underwent post-processing in an attempt to extend the fatigue life. The system breech assembly was chosen as the demonstration platform for utilizing low plasticity burnishing (LPB) to enhance fatigue life. Based upon results from finite element analysis and previous fatigue testing of the system, critical areas were identified and low plasticity burnishing was applied at those locations to impart compressive residual stresses to delay crack initiation. The objective was to enhance the fatigue life as a prove-out for the process.

Testing was performed on a total of six specimens, each until catastrophic failure was achieved. This presentation will cover the method and results of recent testing performed to demonstrate that an average fatigue life extension of approximately two times was achieved.

SIMULATION OF HIGH-VELOCITY PENETRATOR INTO ULTRA-HIGH-PERFORMANCE CONCRETE USING THE LAGRANGIAN FINITE ELEMENT CODE PARADYN

Mr. Robert Browning, US Army Engineer Research and Development Center
Dr. Jesse Sherburn, US Army Engineer Research and Development Center
Dr. Jason Roth, US Army Engineer Research and Development Center
Dr. Michael Hammons, US Army Engineer Research and Development Center

Concrete continues to serve as a standard construction material in military applications. Therefore, researchers continue to explore options to improve the performance of concrete. Ultra-high-performance concrete (UHPC) offers the added benefits of a much higher compressive strength, as well as greater energy absorption. This makes it very attractive for hardening existing structures and designing new structures to withstand high-velocity penetrators.

Because of the complex nature of the problem, the analysis and design of UHPC for penetration often utilizes advanced numerical methods, such as Lagrangian solid mechanics codes or Eulerian codes capable of simulating structural materials. The accurate simulation of these events is highly dependent on the constitutive models, which can often require considerable input from the user. One constitutive model that requires minimal input is the K&C model in ParaDyn.

Recently, the U.S. Army Engineer Research and Development Center had the opportunity to assess the ability of ParaDyn to model penetration into UHPC using the K&C model. This presentation will discuss the basic approach taken in the model as well as the calibration procedure for the erosion criteria of the UHPC. The results will be compared to experimental data, and recommendations will be made where further research may be needed to improve the accuracy of the model.

M&S OF PROBABLE EFFECTS MODELING OF INFRASTRUCTURE COMPONENTS

Dr. George Lloyd, ACTA Inc.
Mr. Ryan Schnalzer, ACTA
Mr. Randy Anderson, ARA
DiaMs. ne Verner, ARA

Functional Kill of buildings and below-ground structures is becoming an increasing area of concern for war fighters. The term “functional kill” refers to the process of defeating a target by rendering it or its contents (collectively the infrastructure) functionally incapable of performing the overall mission for which the building was designed. In this paper we outline the development of several innovative methods for modeling the probable effects of munitions on building infrastructure. Some of these innovations include scoping the huge inventory of building infrastructure into several useful classes of generic components, developing simple but physically justified scaling laws which map between these generic classes of infrastructure components at the building specification level and the detailed properties of the components themselves, and leveraging existing infrastructure munitions-effects modeling paradigms so that faults associated with bulk displacement, fragment perforation, equipment dismounting, and/or crushing are clearly distinguished from internal fault modes that are critical to model but difficult to quantify. The difficulties associated with modeling the fragility of the physical response models are addressed in a hierarchical manner, ranging from IMEA-compatible severity levels and also the use of modified fragility data from comprehensive and well-documented shock tests. The overall goal is to develop and validate a set of Fast Running Models (FRM's) which capture important response degrees of freedom that can in turn be used together with compatible fragility information to, in the end, provide estimates of the "probable effects," given the loads from a particular munition in a STMG building.

FINDING AND DEFINING MECHANICAL ENVIRONMENT REQUIREMENTS FOR GROUND PENETRATING WEAPONS

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

For the US inventory, the current design for penetrating weapons has not changed appreciably since the mid 1980's. Incremental changes to weapon and fuzing has provided incremental improvement in warfighter capability. As these systems evolve into the 21st century, the design requirements and subsequent metrics measuring the effectiveness of design changes are growing more difficult to define, measure, and evaluate.

This paper outlines the approach that Applied Research Associates has taken to define the structural "survivability envelope" for current inventory, or legacy penetration munitions. This analysis uses more than a decade and millions of dollars' worth of test data to benchmark the high-fidelity structural dynamic models, engineering level modeling to explore a million possible scenarios for weapon-target penetration environmental combinations, statistical distributions for weapon delivery parameters, to weight the probability of occurrence of these scenarios, and high-fidelity modeling of the structural dynamic response of the penetrator, to estimate the survivability limits of these legacy weapons. Armed with this information, the warfighter can now measure the current system survivability limits, as well as set mechanical requirements for new systems, and measure the resultant changes for emerging penetration weapon systems.

CHARACTERIZATION OF FRAGMENT IMPACTS FROM PROPELLED MUNITIONS

Dr. Kyle Crosby, US Army Engineer Research and Development Center
Mr. Cameron D. Thomas, US Army Engineer Research and Development Center
Dr. Jay Q. Ehrgott, Jr., US Army Engineer Research and Development Center
Mr. Denis D. Rickman, US Army Engineer Research and Development Center

Weapon attacks against armor are an ongoing problem for deployed U.S. Forces. Accurate identification of propelled munitions, such as RPGs and recoilless rifles, employed in attacks is of critical importance, both in terms of identifying the exact nature of the threat and for use in designing protection schemes. In order to address this need, the National Ground Intelligence Center and the U.S. Army Engineer Research and Development Center (ERDC) conducted a series of weapon-armor interaction experiments to gather critical forensic data. This test series includes the firing, under strict conditions, of selected weapon systems against various types of armor and the collection of fragment impact data from those firings. An analysis was preformed to correlate the various weapon systems with the fragment impact data. This analysis led to the development of a model that can be used to determine fragment impact patterns for various propelled munitions and angles of attack. This model will be used to develop

forensic tools and technologies to enable the Army to quickly identify weapons and munitions used in attacks on tactical vehicles.

STRUCTURAL RESPONSE TO MECHANICAL SHOCK OR VIBRATION WITH SPECIAL APPLICATIONS

MODELING AND SIMULATION OF AN ELECTRONICS ASSEMBLY RESPONDING TO DROP TEST

Mr. Miroslav Tesla, ARDEC
Dr. Jennifer Cordes - ARDEC US ARMY
Dr. Janet Wolfson - AFRL USAF

Modeling and simulation was used to predict accelerations in a printed wiring boards (PWBs) during drop test. Predicted accelerations were compared with experimental results from MTS drop tower. The PWBs are a part of a Hardened Miniature Fuze Technology (HMFT) as the instrumented test surrogate. There were four accelerometers placed on four PWBs. The objective is to accurately predict the response of fuze components to a known input. The finite element software Abaqus Explicit was used for the predictions.

COMPLEXITIES OF PERFORMING COORDINATE TRANSFORMS ON DYNAMIC STRUCTURES

Mr. Prenn Tran, NSWC Dahlgren

Physical lab testing results are often used to verify and improve modeling and simulation results. In order to accomplish this, response measurement sensors are placed at specific points of interest that correlate to measurement locations in simulation models. However, in some cases it is not possible to position the response measurement sensors at the points of interest due to physical or environmental impediments. In the case of a rigid body, it may be appropriate to position the response measurement sensors in alternate locations and afterwards perform a coordinate transformation to synthesize the apparent response at the desired points of interest. However, in the scope of a dynamics test lab, it is understood that the assumption of a rigid body is never valid.

This presentation will briefly review the math and considerations for performing a coordinate transform. The presentation will include discussion on the considerations required to perform such a calculation on a dynamic structure. Results will be discussed from a recent test event of an encanistered missile, where the canister prevented accelerometers from being mounted at the desired points of interest. The methodology used to reduce the measured data, considerations used when performing the coordinate transform, and the derived utility of the results will all be presented.

SHIP FOUNDATION OPTIMIZED FOR DDAM SHOCK CONDITIONS

Mr. Leo Jeng, Altair Engineering

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

This paper presents a case study of a ship foundation optimized for DDAM early in the design phase to validate and optimize the structural integrity of a ship foundation subject to underwater shock conditions. The optimization and validation is performed using OptiStruct, a commercially available simulation software that not only validates structures using DDAM (Dynamic Design Analysis Method), but has unique built-in optimization capabilities for maximizing performance while reducing weight, cost, and design cycle times. Optimized results will be compared to the baseline model and optimization methods and definitions will be discussed.

VIBRATION ANALYSIS & SOLUTIONS

PERFORMANCE CHARACTERISTICS OF A VIBRATION INTEGRATED SHOCK ISOLATION SYSTEM

Mr. Mark Downing, ITT Enidine
Mr. Eric Peiffer, ITT Enidine
Mr. John Paner, ITT Enidine

Missile container launch systems experience high g-load shock impulses and need to utilize hydraulic shock isolators to dissipate this shock energy from the system. The shock isolation systems are designed to control the system dynamics, provide large amounts of energy absorption (damping), and lower the transmitted shock g-load levels to the fragility limits of the isolated equipment. This paper analyses a novel hybrid system approach of a shock/vibration isolation system in the form of an elastomeric vibration isolator integrated to a hydraulic shock isolator. The vibration isolator will provide vibration attenuation at high frequency levels, provide additional energy absorption to the system, and allow a shift in system natural frequency to circumvent undesired frequency bands. Since the low, mid and high frequency filter characteristics of the vibration isolator are mounted in series with the traditional shock isolator, there is some ambiguity on how the dynamic model will react to a shock input condition. For example, the shock isolation assembly is spring loaded with a preload force to provide support to the system and a return force for the shock isolator piston assembly. Therefore the shock input compresses the vibration isolator first, before the shock isolator moves in compression. The dynamic system model is a 2DOF system which contains two different restoring forces and two different viscous damping forces for the shock isolator and vibration isolator respectively. Understanding how the isolation system reacts in a shock event will help with the design of future systems. The authors present a displacement-zone, linear calculation method for shock response simulation and then a comparison is made to drop test results. The paper concludes with a review of the benefits that a hybrid system approach can provide to an overall system design for shock/vibration isolation.

TEN YEAR CASE STUDY ON THE LONG-TERM PERFORMANCE OF HERMETICALLY SEALED FLUID VISCOUS DAMPERS UNDER NEARLY CONTINUOUS FORCED VIBRATION IN AN UNPROTECTED MARINE ENVIRONMENT

Mr. Alan Klembczyk, Taylor Devices

In 2001, Taylor Devices Inc. developed special Viscous Dampers for use on the Millennium Bridge in London, England. These dampers were specified and designed to be used for mitigating the dynamic response of the bridge due to pedestrian traffic. Prior to the integration of the dampers, the bridge had experienced unacceptable movements, especially during periods when larger crowds of people were on the bridge. The result was that the bridge had to be closed until a solution was found. Much research was done and several papers were published about the nature of that problem and the ensuing solution. After successful component level testing and the installation of 37 Taylor Viscous Dampers, the bridge was re-opened to the public in February, 2002. Tests with approximately 2000 people demonstrated a

much improved dynamic response. Since that time, the dampers have been subjected to almost constant dynamic input, some more than others. Due to the location of the bridge in central London, there has been nearly constant pedestrian traffic on the bridge each day and even throughout the night. Situated over the River Thames, the dampers have also been subjected to a highly corrosive marine environment including precipitation, bird excrement, and caustic exhaust fumes from the constant flow of boats immediately below the bridge. However, because of the specialized nature of the damper design, no degradation in damper performance or in the dynamic response of the bridge itself has been experienced. This paper will outline the specifics in quantifying the continued damper performance through an intermediate inspection after seven years, followed by a successful comprehensive inspection after eleven years. This included the removal, dynamic testing, and re-installation of three selected dampers.

Adjustment of Vibration Response to Account for Fixture-Test Article Dynamic Coupling Effects

Mr. Jesus Reyes, University of Massachisetts Lowell
Dr. Peter Avitabile, University of Massachusetts Lowell

Physical characteristics of vibration testing systems (hardware, shakers and fixtures) are different from one laboratory environment to another. Using different excitation fixtures leads to different test article deformations even when the same shock response spectrum is obtained due to the dynamic coupling effects. This paper presents a technique that modifies an initial shock response input to cause a desired level of response of a test article attached to an excitation device and fixture. This technique uses the uncoupled dynamic characteristics of the components (bare test fixture and test article) to adjust the vibration response of the test article. At the same time, the technique accounts for the fixture-test article dynamic coupling effects to neutralize the dynamic effects of the fixture differences. The technique is applied to simple finite element models subjected to deterministic and random excitations. These models show how a consistent level of vibration across different excitation fixtures is achieved if the dynamic interaction effects are included.

Use of wire rope isolators for tuned mass dampers on chimneys

Mr. Claude Prost, Vibro Dynamics

Tuned mass dampers (TMD), or dynamic absorbers, have been implemented for many years in various applications such as ships, bridges, and chimneys. Although simple in principle, control of the TMD parameters is paramount to avoid unexpected results.

This article will briefly summarize the basic theory of TMDs and propose some innovative solutions with wire rope isolators for chimneys subject to severe crosswind vibrations due to vortex shedding. As wind flows around a chimney vortices start to form on either side of the chimney, these vortices form periodically and cause a harmonic force on the chimney in the direction transverse to the air flow. When the wind velocity reaches the so-called critical velocity, the vortex shedding frequency approaches the natural frequency of the chimney and causes damaging crosswind vibrations, also known as resonance. These crosswind vibrations are what caused the collapse of the famous Tacoma Narrows Bridge.

The addition of a TMD helps in significantly lowering the magnitude of these crosswind vibrations, partly due to the dissipated energy from the TMD as well as inherently changing the dynamics of the system. The key aspect of proper TMD design resides in optimizing its mass, then fine tuning its stiffness and damping to create the appropriate phase shift between the chimney and the TMD.

A real case model will be presented, which utilizes the Socitec Group's proprietary numerical analysis software, SYMOS. Details on the simulation and optimization process will be shown, and the advantages of wire rope isolators used as a TMD will be discussed.

SIMULATION OF HIGH FREQUENCY RANDOM VIBRATION TEST
Mr. Richard Jones, Honeywell FM&T

Web-based tools, known as virtualConsultants, are being used to deploy mature simulated processing environments for product and process engineers. These solutions cover a breadth of applications including mechanical engineering calculators to full 3D simulations. One of these applications is the simulation of closed-loop random vibration testing. This testing is commonly used to qualify systems that will be submitted to similar vibration load during their life. Numerical modeling of this test provides insight about the robustness and success of the tests. The numerical system identification approach and the use of a virtualConsultant to support actual testing on an electrodynamic shaker with a shaker adapter will be discussed.

UNDEX ANALYSIS: MODELING

THE RESPONSE OF COMPOSITE CYLINDERS SUBJECTED TO NEAR FIELD UNDERWATER EXPLOSIONS
Dr. Erin Gauch, NUWC Newport

No abstract available.

FSP DECK SIMULATOR FIXTURE MODE-1 DESIGN SPECTRA
Mr. Rick Griffen, HII-Newport News Shipbuilding
Dr. Michael Talley, HII-Newport News Shipbuilding

The development of alternatives to MIL-S-901 tests representing a ship deck location using the floating shock platform required an objective description of this test environment. This paper reviews efforts to characterize the composite conditions for a range of deck simulator arrangements commonly used in naval equipment shock tests. Definition of this reference environment began with a survey of available test data to define input levels, weights and damping factors. The survey findings guided use of an optimized 2-DOF model for efficient characterization of equipment vertical response around the range of the primary deck frequency. A companion paper reports the effort to define the additional contribution of a deck's higher "mode-3" frequency. These analysis results are assembled into equipment mass response spectra that include the critical mass interaction effects. These design spectra can inform both the development of these alternative test methods and assessment of equipment to be tested.

FSP DECK SIMULATOR FIXTURE MODE-3 DESIGN SPECTRA
Mr. Rick Griffen, HII-Newport News Shipbuilding

The development of alternatives to MIL-S-901 tests representing a ship deck location using the floating shock platform required an objective description of this test environment. This paper reviews an effort to characterize the composite conditions in deck simulator arrangements commonly used in naval equipment shock tests. This paper reviews use of a detailed Deck Simulator Fixture FEM model to characterize the additive contribution of the higher “mode-3” deck frequency. A companion paper reports the effort to define response to the primary deck mode. These analysis results are assembled into equipment mass response spectra that include the critical mass interaction effects. These design spectra can inform both the development of these alternative test methods and assessment of equipment to be tested.

ANALYSIS OF DISCRETIZATION ERROR ON SHOCK LOADING IN EULERIAN UNDEX ANALYSES USING DYSMAS/FD

Mr. Nicholas Reynolds, NSWCCD
Mr. J Gilbert, NSWCCD
Dr. Erwin T. Moyer, NSWCCD

Analysts are increasingly relying on modeling and simulation to predict the loading that a target structure will experience as a result of weapons effects. As part of understanding the limitations of simulation results, it is important to understand and quantify the error that discretization introduces in such analyses, and whether loading is overly- or underly-conservative, particularly when they must be performed with limited computational resources.

An extensive parametric study was undertaken, involving approximately 2000 multiple-phase underwater explosion (UNDEX) analyses representing twelve scenarios and various degrees of discretization at each phase. Each analysis examined the shock loading severity at specific standoffs from a spherical explosive charge. Analyses were performed using the DYSMAS/FD hydrocode, and the preprocessing, submission, and post-processing were executed in an automated manner using a combination of Python and Bash scripting. Deviations in shock severity metric values from the converged solutions were quantified. It was ultimately determined that shock severity metrics are most sensitive to the discretization in the fluid grid in the final/shock propagation phase of the analyses, and tabularized guidelines were established that specify the minimum grid discretization necessary to limit the error in shock loading metrics to prescribed values.

PROGRESS ON VERIFICATION AND ACCEPTANCE OF THE RESIDUAL MASS DDAM

Mr. Rick Griffen, HII-Newport News Shipbuilding

The standard naval shock analysis methodology for the assessment of equipment and foundations is the Dynamic Design Analysis Method (DDAM). This method is an evolution of the response spectrum analysis technique developed for earthquake assessment. Some procedures for implementing this method set modal mass recovery requirements that are difficult to meet in many common models. A modification of this method, called Residual Mass DDAM (RM-DDAM), was presented at the 83rd Shock & Vibration Symposium that offers to resolve this issue by altering the DDAM such that its evaluation phase always includes the full model mass through the assignment of all unrecovered modal mass to an additional synthetic n+1 “residual mass” mode.

This paper presents the results of an assessment study conducted under a National Shipbuilding Research Program task to verify the utility of the RM-DDAM approach and define a procedure for its implementation.

SIMPLIFIED EXODUS II/ SIERRA SD MODEL GENERATION WITH ALTAIR HYPERMESH V14

Mr. Joshua Pennington, Altair Engineering

Many companies that perform shock and vibration analysis use government and open-source tools and solvers to perform finite element analysis (FEA). Among these tools are the common Exodus II data file (to define geometry) and the Sierra Mechanics code suite (developed by Sandia National Laboratories).
The concept of Exodus II is to have a common database for multiple solver codes rather than a solver code specific format. Sierra Mechanics includes simulation capabilities for thermal, fluid, aerodynamics, solid mechanics, and structural dynamics. One of the challenges analysts face with using Exodus II and Sierra solvers is the narrow options for model generation (mesh, material, property, boundary conditions, and other solver-specific parameters).

Through the use of HyperMesh, a commercially available, high-performance finite element pre-processor, model preparation from the import of CAD geometry to export of a solver run, for various disciplines/solvers are now easily achievable. The open architecture and ability to easily customize, and inherent preprocessing capabilities in HyperMesh, made the interface development to Exodus II and Sierra Mechanics a powerful and user friendly tool.

Employing the open architecture of HyperMesh, the high-quality meshing tools, unlimited model size, geometry-editing tools for CAD model preparation orphan mesh editing capabilities, and convertibility to/from commonly used FEA formats, the preparation of Exodus II models can now be performed without modeling or specific restrictions.

This presentation details the current interface to the Exodus II (Sierra SD) user profile. The result is a vastly improved process for building models in the Exodus II and Sierra formats.

EXPLOSIVE DETONATIONS: TUNNEL & CRATER APPLICATIONS

INSERTING ERDC GEOMATERIAL MODELS INTO SIERRA/SM: APPLICATIONS IN IMPACT SIMULATIONS WITH ZAPOTEC 3

Dr. Ramon Moral, US Army Engineer Research and Development Center
Dr. Laura Walizer, US Army Engineer Research and Development Center
Dr. Stephen Akers, US Army Engineer Research and Development Center
Dr. Jesse Sherburn, US Army Engineer Research and Development Center
Dr. Mark Adley, US Army Engineer Research and Development Center
Dr. Andreas Frank, US Army Engineer Research and Development Center
Dr. Arne Gullerud, Sandia National Labs
Mr. Timothy R. Shelton, Sandia National Labs

Zapotec 3 is software developed at Sandia National Laboratories (SNL) that couples the SNL SIERRA/SM dynamic structural mechanics code with their CTH Eulerian code. The U.S. Army Engineer Research and Development Center (ERDC) has been working under an HPC Application Software Initiative (HASI) project to insert ERDC's geomaterial models into SIERRA/SM. The project also partners ERDC with SNL to place a production version of Zapotec 3 into the SIERRA framework and place the ERDC geomaterial models into the shipping version of SIERRA/SM. The ERDC implemented a modified M4 Microplane Concrete model, the M3 Microplane Concrete model, the Advanced Fundamental Concrete model, and the Hybrid Elastic Plastic soil model into SIERRA/SM. The goal of the project is to provide high fidelity soil and concrete models to the Department of Defense computational structural mechanics community in a modern computational structural mechanics platform. This paper will show the current state of the project along with the verification and validation efforts for the ERDC geomaterial models in SIERRA/SM. The example problems include ground shock and penetration simulations.

NUMERICAL SIMULATION OF BURIED EXPLOSIVES UNDER A BRICK PATIO

Dr. Wije Wathugala, ACTA Inc.
Dr. Wenshui Gan, ACTA Inc.

Understanding how to model explosions in soil is important in many military and civilian applications such as in predicting the consequences of mines/IEDs/munitions buried in soil and excavations using explosives in the mining industry. In general, rapidly expanding explosion products (gases) push surrounding medium away from the explosion, causing the breakup of the medium and creating cracks through which gases can escape. Explosions in soil involve additional complexities due to the porous nature of soil. The amount of porosity and the size of pores through which gas can escape affect the rate of dissipation of high pressures generated in the explosion. Fast moving gases through soil pores can cause breakup of the medium. There is additional complexity in modeling the secondary debris generated from whole or broken up bricks thrown up in the air due to a shallow underground explosion. In previous years we have presented issues related to modeling the interaction of soil and expanding explosive gases. In this paper we present issues and the results of an ongoing study where we simulated secondary debris generated from brick patios using CartaBlanca. CartaBlanca is a multi-phase coupled code developed by the Los Alamos National Laboratory using the Material Point Method (MPM) for solid phase and the Arbitrary Lagrangian Eulerian (ALE) method for the fluid phase.

AN EVALUATION OF COMPUTATIONAL MODELING TECHNIQUES FOR MINE BLAST: DETERMINING THE BEST APPROACH FOR DESIGN

Mr. Timothy Shelton, Sandia National Laboratories
Mr. Sean Willey, Sandia National Laboratories
Dr. Arne Gullerud, Sandia National Laboratories
Dr. Laura Walizer, USACE Engineer Research and Development Center
Dr. Stephen Akers, USACE Engineer Research and Development Center

Design of protection systems against mine blast are costly due to the space of conditions a system can experience, depth of burial, soil conditions, charge size, etc. Addressing the space of conditions with modeling is compounded with the possibility of utilizing multiple modeling techniques. Accurately modeling a mine blast is a challenging task and multiple modeling techniques exist that attempt to capture all relevant physics, full Eulerian simulation, full Lagrangian simulation and a range of coupled Eulerian-Lagrangian simulation methods. Even within the full Lagrangian approach there are multiple element technologies that can be applied in addition to traditional Finite Elements such as Smooth Particle Hydrodynamics (SPH), Peridynamics, and adaptive re-meshing. Sandia National Labs (SNL) offers a suite of codes; Sierra/Solid Mechanics for Lagrangian simulations, CTH for Eulerian simulations, as well as a coupling between the two with Zapotec. Recent additions by the US Army Engineer Research and Development Center (ERDC) to integrate Hybrid Elastic Plastic (HEP) material models into the Sierra and CTH code suites allows for better modeling of soil conditions. This study offers a comparison of multiple modeling techniques with the HEP model against experimental data collected by Anderson, C. E. et al., [“Mine Blast Loading Experiments”, International Journal of Impact Engineering, 38 (2011) 697-706]. Computational cost and accuracy of each modeling approach is presented with the intent of informing decisions about modeling technique to use in design studies.

Explosive Removal of Concrete for Rapid Runway Repair

Mr. Stephen Turner, US Army Engineer Research and Development Center
Dr. Jay Ehrgott, US Army Engineer Research and Development Center
Mr. Denis Rickman, US Army Engineer Research and Development Center

The U.S. Army Engineer and Research Development Center has been conducting research to develop new, expedient concrete pavement repair techniques in an effort to update repair guidance for military airfields. Damaged sections must be repaired quickly in order to return the pavement into service and in a manner to minimize future repairs during wartime scenarios. In the event that runway craters occur due to detonations from enemy explosives on or below the pavement surface, rapid runway repair is required to return the runway into service. One of the major time-consuming steps in the runway repair methodology is the cutting of the damaged areas using mechanical methods such as concrete saws. Research has been conducted to determine if explosives could be used to cut out the damaged sections of concrete. C4 and commercially available shaped charges were studied to determine their effectiveness at removing these sections. The experimental results from this research provide detailed insight into using explosives as a tool to cut concrete.

Lofted Debris Effects on Air Blast and Impulse for Cased Charge Detonations

Maj. Matthew Gettings, DTRA
Major Joshua D. Kittle, DTRA
Dr. Eric Rinehart, DTRA

In this work, a cased charge is statically detonated within a target constructed to mimic the configuration of a possible deeply buried structure in support of programs conducted by the Defense Threat Reduction Agency (DTRA). The data from these four tests (shots 5, 13, 15, and 20) allow comparisons between tunnel configuration, geology at the detonation location, and lofted debris effects on measured air blast and impulse and suggest important conclusions regarding tactics, techniques, and procedures (TTPs) when employing weapons against deeply buried targets.

VIBRATION: TRANSPORTATION & FLIGHT

Creating a More Realistic Transport Handling Profile

Mr. Andy Cogbill, Vibration Research
Mr. Jade Vande Kamp, Vibration Research

Traditionally, package vibration test protocols have been based on ASTM and ISTA random PSDs designed to represent different transport vibration modes and & handling events to assure package integrity. A major shortcoming is that PSD-based random vibration tests are generated with Gaussian peak probability distributions which average out the extreme events. There are no potholes in a Gaussian random test. Package survivability to the potholes or transient events during transport are traditionally tested separately by drop tests intended for freefall package drops and other handling events.

Vibration control techniques incorporating Fatigue Damage Spectrum (FDS) & Kurtosion® metrics, weight and combine different transport modes and handling events to confirm or improve test protocols. An FDS-based transport profile of different road types, truck suspensions, rail and air exposures can be enveloped with the potholes, rail humping and forklift handling to define tests representing the cumulative damage from the total exposure. The evaluation of the severities of different environments and the combining into a compressed test duration are presented.

ENVIRONMENTAL ENGINEERING APPLICATION IN THE DEVELOPMENT OF AN AIRBORNE SYSTEM

Mr. Uria Heller, RAFAEL

Environmental robustness testing engineering represents the profession that enables the generation of field equivalent loads in the laboratory, under which the product's environmental robustness will be tested, and design weaknesses will be identified and corrected. Testing is required for every system whose purpose is to perform and survive under field conditions."Environmental Engineering" accompanies the design and manufacture of products, by analysis of the life-cycle stages, identification of the relevant environmental loads, planning of laboratory tests, performance of field tests for measurement of the real-life loads, followed by updating of the testing specifications and performing of the testing, to qualify the product for its mission.

This paper describes the application of the Environmental Engineering methodologies and technologies in the development of an airborne store. Following a brief introduction, the in-flight data acquisition and the ground analysis processes are described. Next an Experimental Modal Analysis (EMA) performed on the in-flight accumulated data is presented. Following this the results of the flight data's EMA, are compared to those of an EMA performed in the laboratory, revealing a good fit between the results of the two. The results of the EMA were supplied to the numerical simulation personnel, to update the product's numerical model. The flight data's analysis results were used also to update the product's laboratory vibration testing specifications, based on data from similar systems. The paper also shows a use of the EMA technology leading to an improvement of the classical process, applied in the vibration environment characterization and its laboratory simulation for an airborne system. Several summarizing remarks conclude the paper. STI software is company proprietary having excellent presentation and reporting format including random vibration, shock and multi-axis response displays to oblique loads. We describe the iterative process for calculation and how the software was used at several design stages of the project. Especially useful was to describe (model in the software), the magnetic assembly and its components as a group of coupled masses whose geometry and layout can significantly affect the dynamics of at the equipment. This is especially important when equipment layout (or weight and geometry) is changed and the placement of isolators has already been established. . Multi-axis stiffness and hysteretic curves of the arch mounts are presented and calculated response to sea state 3 is reviewed. Drop testing of the complete unit validated the selection of mounts and the design of the isolation system.

HELICOPTER VIBRATION MEASUREMENT ANALYSIS AND GENERATION OF LABORATORY VIBRATION SIMULATION PROGRAMS BASED ON ENERGY CONSIDERATIONS

Dr. Zeev Sherf, RAFAEL
Y.Cohen, RAFAEL
P. Hopstone, RAFAEL
I. Sofer, RAFAEL
A. Elka, RAFAEL

Vibrations measured on a helicopter carried store, were analyzed to identify their spectral content. The spectral analysis was performed using parametric analysis. The analysis revealed once again the combination of harmonic with random vibrations that characterize the vibration measured in a helicopter environment. The harmonics were separated from the random part to generate a laboratory simulation program. The parabolic relation between GRMS and flight speed was identified once again. A vibration simulation regime was generated, based on energy equivalence considerations.

ASPECTS OF STATIONARY AND NON-STATIONARY FLIGHT VIBRATION ANALYSIS, WITH APPLICATION TO THE FORMULATION OF VIBRATION SIMULATION PROGRAMS

Dr. Zeev Sherf, RAFAEL
Y.Cohen, RAFAEL
P. Hopstone, RAFAEL
I. Sofer, RAFAEL
A. Elka, RAFAEL

Vibration data measured during stationary and non-stationary flight exercises on an airborne store were analyzed with the intention to use the analysis results in the formulation of vibration simulation programs. GRMS time history, Auto Regressive (AR) parametric models and Power Spectral Density (PSD) functions were evaluated for the various flight exercises, and for the different measurement locations. The relations were evaluated between the GRMS values and the location along the airborne store and between the GRMS values and the dynamic pressure. Methods for evaluating the accumulated damage under different flight conditions were also described and applied. The use of the analysis results in the generation of simulation conditions is also presented.

STRUCTURAL RESPONSE & TESTING

DEVELOPING, VERIFYING, AND VALIDATING VARIABLE AXIAL LOADING IN THICK WALLED PRESSURE VESSELS

Mr. Lucas Smith, Benet Laboratories

Traditional hydraulic fatigue testing is performed quasi-statically on open ended cylindrical sections of pressure vessels to establish their fatigue life. Typically, only hoop loading of the pressure vessels is required to determine fatigue life. However for some specific geometries and service conditions a more complex test is required. This has been confirmed, whereby, certain geometries have experienced circumferential cracking because of combined, nearly equivalent axial loading and hoop loading. Consequently, a test fixture was engineered, designed, built and tested by US Army – Benét Laboratories / ARDEC to replicate the service loading condition and verify the finite element analysis (FEA) modeling of the system. Simultaneous axial / hoop fatigue testing in a lab environment can validate the FEA model to ensure the test fixture design is a realistic representation of loading conditions.

Thick walled pressure vessels subject to high axial loads were instrumented with strain gages during field loading conditions, and the resulting strain output has shown the axial and hoop components are equivalent in certain sections. These sections have specific geometric design constraints. After various design iterations through FEA and review, a test fixture was manufactured to test thick walled pressure vessels in a laboratory environment in order to duplicate field loading conditions. To verify the test fixture in the laboratory environment, strain gages were applied to representative sections as done in field loading. Upon review of the test sections at test pressure, the strain gage data was able to validate the FEA as well as ensure the representative field loading could be duplicated.

High-Strain Rate Testing of Ultra-High Performance Concrete with Flow-Induced Fiber Orientation

Mr. Andrew Groeneveld, Michigan Technological University
Dr. Tess Ahlborn, Michigan Technological University
Dr. C. Kennan Crane, US Army Corps of Engineers, ERDC

Ultra-high performance concrete (UHPC) incorporates fiber reinforcement to increase tensile strength and improve crack resistance. When casting structural components with UHPC, the fibers tend to orient in the direction of material flow. Thus, fibers are not randomly oriented, and assuming isotropic properties may not be justified. This work examines the effect of fiber orientation on dynamic compressive properties of Cor-Tuf UHPC. A beam was cast to provide a representative structure, and cores were drilled from the beam in three orthogonal directions for testing. Fiber orientation in cored specimens was determined using x-ray computed tomography and image processing techniques. The perpendicular orientation number was used to describe fiber orientation. For a specimen loaded in compression, cracks are generally bridged more effectively by fibers that are oriented perpendicular to the applied load. The fiber orientations for specimens in the three directions were significantly different at a 95% confidence level. Dynamic tests were performed using a split-Hopkinson pressure bar (SHPB) and achieved strain rates of 130-200 1/s. Dynamic compressive strength ranged from 38.1 ksi to 58.5 ksi, but fiber orientation had no clear effect on strength. Ductility was measured using the strain at peak stress, which ranged from 0.0105 to 0.0131. Ductility increased with the perpendicular orientation number, though the correlation was somewhat weak. Overall, the degree of fiber alignment that occurs in a typical beam does not clearly affect strength, though ductility does vary somewhat with fiber orientation.

The dynamic tensile behavior and dynamic residual strength after fatigue of 321 austenitic stainless steel at intermediate strain rate

Dr. Yilei Liu, Nuclear Power Institute of China

The effect of strain rate on stress-strain behavior of austenitic steel 321 is investigated. Tensile tests are conducted at room temperature at strain rate ranging from 0.1s-1 to 200s-1. The experiment data show that the yield strength and tensile strength of 321 stainless steel rise with the increase of strain rate. Further studies show that the stacking of faults/dislocations and partial phase change from austenite to α-martensite are prior to heat softening. The dynamic residual strength after fatigue of 321 stainless is also researched. It shows that the dynamic yield strength of 321 stainless decreases with increase of the ratio of cycle number(n/N). But the dynamic tensile strength of 321 stainless steel remains nearly constant until the ratio of cycle number increases to certain value, and it drops rapidly with the ratio of cycle number keeping increase.

Bolt Behavior under Combined Tension and Shear: Tests

Dr. Emily Guzas, NUWC Newport
Mr. Wesley Trim, US Army Engineer Research and Development Center

A collaborative effort between NSWC-CD and NUWCDIVNPT has been undertaken to (1) carry out a test series of threaded fasteners in combined shear and tension, and (2) develop computational models of the tested fasteners, to support the development of standard bolt shock analysis methods. This paper covers the performed test series, which investigated the load limits of single threaded fasteners under various combinations of tension and shear loading. Testing was performed in accordance with National Aerospace Standard Method (NASM) 1312-2 for 0.25-in, 0.375-in, and 0.5-in K-Monel K500 and Grade 8 steel threaded fasteners, where each fastener was tested to failure for three different preloads. Test

results taken using a NSASM 1312-2 test fixture include recorded load-displacement data and the derived fastener interaction diagram for each unique test specimen configuration (bolt diameter, material, preload). Computational models of the experiments using the Abaqus finite element (FE) software package are currently under development.

Measurement of Dynamic Stiffness and Damping of Electric Cables for Shipboard Use

Mr. Joseph Donovan, Northrop Grumman

Interfaces to shipboard equipment often include small gauge (large diameter) electric cables such as those defined by MIL-DTL-24643C. These cables can significantly influence the dynamic behavior of the equipment. Thus, a dynamic model which is intended to provide accurate predictions of the equipment's response to dynamic excitation such as MIL-S-901D shock requires accurate representations of these cables. Values of dynamic stiffness and damping are not generally available either from the manufacturer or elsewhere.

Determination of the dynamic stiffness by analytical methods would be challenging and would require extensive correlation with measured data to be trusted. There is no known analytical method for determining the damping. Thus, empirical methods are preferred for both quantities.

This paper provides a test method for measuring the dynamic stiffness and damping of cables. It describes the setup consisting of commonly available test equipment. Recommendations are made for improvements to the test method. Measured results for several cables are also provided.

Finally, this paper makes recommendations for incorporating measured data into dynamic models. The dynamic stiffness can be represented as constant flexural rigidity Euler–Bernoulli beams. The damping can be represented as element damping in those same beams or as overall damping applied to the model. Such models are useful not only for determining the response of the equipment but also for optimizing the routing of the cables, locating cable clamps, and determining the forces and moments applied to the equipment by the cables.

BLAST: NEAR-FIELD

Near-Field Airblast Characterization of Homemade Explosives

Dr. Andreas Frank, US Army Engineer Research and Development Center
Mr. Garrett Doles, US Army Engineer Research and Development Center
Dr. Jay Ehrgott, US Army Engineer Research and Development Center

The threats from Improvised Explosive Devices (IEDs) continue to grow around the world. The threats range from shallow-buried IEDs to personnel IEDs and large vehicle-borne IEDs, all utilizing various existing and new homemade explosive (HME) formulations. There is a significant need to expand the current capability to characterize the loads and loading distributions from the detonation of emerging HMEs and non-ideal explosives used in IEDs to improve our understanding of these threats and advance our ability to model these loads in the development of protective systems. The U.S. Army Engineer Research and Development Center is conducting research under the Adaptive Simulation to Characterize Emerging Non-Ideal Threats Program to improve our understanding of the physics, scalability, and spatial loading distributions of various non-ideal explosives. The research is focused on developing and improving constitutive models for non-ideal explosives in shock-physics codes. The goal is to improve the accuracy and flexibility of explosive models used for these current and emerging HME threats to account for significant differences in the burn rate, shock front, and confinement effects when compared to current ideal explosive models. Well-characterized and highly instrumented experiments were conducted using widely proliferated HME explosive mixtures to capture the explosive environment with varying conditions such as shape, confinement, and mass. The experimental layout, test results, and results from CTH hydrocode calculations compared with the experimental data will be presented in this paper. The CTH calculations were conducted using an "ideal" Cheetah-generated Jones-Wilkens-Lee equation of state for the reacted products with an ideal programmed burn detonation velocity, thereby evaluating the departure from ideal explosive burning behavior for the near-field blast wave.

VALIDATION OF THE MINEX3D CODE FOR PREDICTING LOADS FROM UNDERBODY BLAST

Mr. Micael Edwards, US Army Engineer Research and Development Center
Mr. Greg Bessette, US Army Engineer Research and Development Center
Mr. Gustavo Emmanuelli, US Army Engineer Research and Development Center

MineX3D is a fast running, engineering level code for modeling the loading environment on the underbody of a vehicle from a close-in detonation. The code predicts the spatial and temporal loading on the underbody and is capable of considering variations in explosive type and configuration, depth of burial, soil composition, and vehicle geometry. The underbody geometry can be imported from LS-DYNA node, element, or segment cards. The predicted loads can be exported to LS-DYNA as either load or set segment format for use in a follow-on higher fidelity structural analysis. In an effort to validate the code, several existing experimental data sets were simulated in LS-DYNA using MineX3D generated load curves. For comparison, these data sets were also simulated using the *INITIAL_IMPULSE_MINE card available in LS-DYNA. The results of these simulations are presented in this paper along with a brief description of the MineX3D load prediction methodology.

FULL-SCALE UNDERBODY BLAST EXPERIMENTS FOR COMPONENT TESTING AND COMPUTATIONAL SIMULATION VALIDATION

Mr. Garrett Doles, US Army Engineer Research and Development Center
Dr. Neil Williams, US Army Engineer Research and Development Center

A significant amount of research has been conducted to evaluate and understand the key influence factors affecting the impulse imparted to an overhead structure from a buried improvised explosive device (IED). It has been shown that the blast loading environment is a function of many factors including the explosive type, configuration, mass, and depth of burial, the soil characteristics, and the distance between the ground surface and the target structure. The U.S. Army Engineer Research and Development Center (ERDC) has focused considerable attention on understanding the relationship between a buried explosive charge and the surrounding geologic/soil material and advancing our ability to capture these soil/explosive phenomena in high performance calculations. To expand on the available data, ERDC designed, built, and utilized three rigid test devices in a series of underbody blast experiments to determine how the factors of the soil, explosive, and target affect the imparted impulse. The modeling of these experiments involved significant mixing interactions of soils, explosive detonation products, air, and metal components. The experimental and calculation results from this research provide detailed insight into the blast load environment created in a shallow-buried underbody blast condition and also provide much needed critical validation experimental data that can be utilized to gain confidence in the modeling to predict the loading and deformation from a realistic underbody blast test event.

EXPLOSIVE COUNTERMEASURES

ANALYSIS OF CABLE STAYED BRIDGE CABLE PROTECTIVE COUNTERMEASURES

Mr. Christopher Rabalais, US Army Engineer Research and Development Center
Dr. C. Kennan Crane, US Army Engineer Research and Development Center
Mr. David Miller, US Army Engineer Research and Development Center

Landmark bridges are believed to be among the most attractive targets to terrorist organizations wanting to harm the United States. Apart from their symbolic importance, these structures could cause numerous casualties and catastrophic economic harm. In the past decades, many organizations have directed significant resources to determine the effects of attacks as well as to develop physical countermeasures to defeat possible threats. This research sought to expand the limited data available for the behavior of cable stays of cable-stayed bridges under “real world” tension loads.

Previous research indicated that the two most likely types of terrorist weapons were a contact charge and a kinetic energy penetrator (KEP). Baseline tests were completed on two cable stay configurations, i.e., 19-cable bundle, the most common small cable configuration used in cable-stayed bridges, and 61-cable bundle, the median number of cables for typical cable-stay configurations. Each cable configuration was tensioned to approximately 40% of the guaranteed ultimate tensile strength (GUTS), the industry standard “real-world” tension load, and tested using selectively formed contact charges and KEPs. The KEP caused a majority of the cables to be cut in the 19-cable bundle and the 61-cable bundle, whereas the contact charge cut significantly less cables based on visual data. The KEP was determined to be the most significant threat to the cable bundles, and a countermeasure was developed to defeat the KEP.

Numerical modeling and conceptual tests showed that a layered mitigation had the greatest effect on stopping the KEP; therefore, a countermeasure was designed and fabricated using ultra-high performance concrete confined by ASTM A36 plate and tube steel. Each cable configuration had a countermeasure surrounding the bundle, was tensioned to 40% of GUTS, and tested by a KEP charge. The countermeasures performed markedly well by drastically reducing the number of cables cut in the 19- and 61-cable bundles.

This research series proved that the cable stays from cable-stayed bridges face a significant threat from the KEP, but a layered countermeasure will drastically reduce the damage to the cable bundles. Future research will optimize the countermeasure design by using deflector plates, reducing the size and thickness of the layers, and using higher strength steel.

INTERNAL RETROFIT EXPLOSIVE THREAT FOR LANDMARK BRIDGES

Mr. Richard Bennett, US Army Engineer Research and Development Center
Dr. Charles K. Crane, US Army Engineer Research and Development Center
Mr. Bob E. Walker, US Army Engineer Research and Development Center

Of the 43,997 terrorist attacks identified by the U.S. Department of State to have been perpetrated worldwide between 2012 and 2015, transportation systems were targeted 1,210 times. Explosives were used in 56.3% of the attacks during this time period, making this the most commonly used tactic.1 Violent extremists have demonstrated a trend toward attacking targets that present an opportunity to disrupt the economy of a region, demoralize the populous, and maximize the loss of life. The economic importance and proximity to heavily populated urban areas of many U.S. landmark bridges make them attractive targets to terrorist organizations and lone wolf actors seeking to compromise the Nation's infrastructure. Hardening a landmark bridge against an explosive threat presents unique challenges, as many of these bridges were built in the first half of the 20th century and are not suited to conventional explosive hardening methods. Additionally, bridge owners may want to avoid altering the aesthetics of a nationally recognized iconic structure with the application of external armor plating. There is a need, then, to provide bridge owners with an internal retrofitted security measure capable of minimizing the damage of a close-in blast that might otherwise cause catastrophic failure, resulting in the extended disruption of commerce and the loss of life.

The purpose of this presentation is to discuss the ongoing development of a novel explosive threat mitigation to be made available as an internal retrofit to landmark bridges. A series of tests conducted by the U.S. Army Engineer Research and Development Center (ERDC) for the Department of Homeland Security (DHS) seeks to identify and categorize the physical characteristics of steel cable blasting mats in order to determine their suitability to perform as inertia dampers for large fragments produced by an explosive blast against a tower wall. Test data collected regarding elongation under tension, the effects of load on the catenary of the mat, shear capacity, and the response under modal vibration will be utilized to construct a simplified, multiple degree-of-freedom, physics-based computational model. This model will be compared against results of future explosive testing and will serve as the basis for more advanced numerical models.

VIBRATION AND MECHANICAL SHOCK TESTING (INCLUDING FIXTURE DESIGN)

PAYLOAD INTEGRATION MWSM SHOCK TESTING: FIXTURE DESIGN

Dr. Emily Guzas, NUWC Newport
Ms. Monica Black, NUWC Newport
Mr. Kevin Behan, NUWC Newport

A collaborative effort between NSWC-CD and NUWCDIVNPT has been undertaken to (1) carry out a test series of threaded fasteners in combined shear and tension, and (2) develop computational models of the tested fasteners, to support the development of standard bolt shock analysis methods. This paper covers the performed test series, which investigated the load limits of single threaded fasteners under various combinations of tension and shear loading. Testing was performed in accordance with National Aerospace Standard Method (NASM) 1312-2 for 0.25-in, 0.375-in, and 0.5-in K-Monel K500 and Grade 8 steel threaded fasteners, where each fastener was tested to failure for three different preloads. Test results taken using a NSASM 1312-2 test fixture include recorded load-displacement data and the derived fastener interaction diagram for each unique test specimen configuration (bolt diameter, material, preload). Computational models of the experiments using the Abaqus finite element (FE) software package are currently under development.

PAYLOAD INTEGRATION MWSM SHOCK TESTING: TEST CONDUCT

Ms. Monica Black, NUWC Newport
Mr. Kevin Behan, NUWC Newport

No abstract available.

REFURBISHMENT, IMPROVEMENT, AND CALIBRATION OF THE WOX-7B SHOCK MACHINE WITH THE DAHLGREN SHIPBOARD SHOCK SIMULATOR FIXTURE

Mr. Sloan Burns, NSWC Dahlgren

The WOX-7B, a MIL-Spec-901 Alternative Vehicle shock machine, was developed for testing weapons such as torpedoes or missiles. The addition of the Dahlgren Shipboard Shock Simulator (DS3) fixture to the WOX-7B allows the shock testing of Vertical Launch Systems (VLS) missiles. This fixture is designed to employ a single blow to excite all axes, in the proportions similar to those observed shipboard during a Under Water Explosive (UNDEX) event.

The work presented here will review recent improvements to both the WOX-7B and DS3. It will also outline the process used to calibrate the DS3 prior to testing and how the calibration data is compared to classic test and measured shipboard data. It will also detail many of the challenges faced when calibrating, including extreme variations in climate between test and calibration series and changes in dynamic response of different inert calibration assets.

EQUIPMENT ON DECK FIXTURE RESPONSE PREDICTION WITH A 2-DOF MODEL

Mr. Rick Griffen, HII-Newport News Shipbuilding
Mr. Matt Davis, HII-Newport News Shipbuilding

Prediction of the peak response acceleration expected for an equipment under test on the Deck Simulator Fixtures used with the MIL S 901D Floating Shock Platform is a frequent point of interest. Response prediction is more accessible if the test arrangement can be reduced from a large complex FEM model of the DSF to a simple two degree of freedom particle model. Multiple models of simulated equipment attached to a uniform pinned-end beam driven by a measured FSP inner bottom motion were analyzed to establish a set of reference responses. Iteration of a 2-DOF model established parameter selection rules that predict equipment peak response acceleration with less than 10% error for equipment frequencies of 50% to 150% of the deck frequency.

FIXTURE DESIGN FOR IMPROVED MECHANICAL SHOCK AND VIBRATION TESTING

Mr. Troy Skousen, Sandia National Laboratories
Mr. Ronald N. Hopkins, Sandia National Laboratories
Dr. Brian C. Owens, Sandia National Laboratories

Test fixture design is an important part of vibration and shock test planning. Of first import is constraining the test article so that it stays where it should be. A better approach is to attach the test article with boundary conditions (bolts, welds, etc.) representative of how it is used. In addition to boundary conditions, an even better approach is to attach the test article in a way to preserve the test article modes and damping so that they are representative of the next level of assembly. This will allow the test article to have similar stress states and thus failure mechanisms as seen when fielded. This talk will discuss why it is important to maintain test article modal frequencies, mode shapes, and damping in testing as seen in field use. Poor fixture design can cause failures due to incorrect amplifications that may drive costly test article redesigns that are not necessary. Poor fixture design may also eliminate vibration modes from a test that would cause failure in the field. This would engender insufficient qualification tests putting the system at risk for costly failures in the field. Examples of improper fixture design and redesign efforts will be discussed. An idea is also provided that could enable design of fixtures that maintain fielded dynamic boundary conditions.

TORQUEING STRATEGIES FOR FIXTURE DESIGN INCLUDING UNIT PLACEMENT AND TEMPERATURE AFFECT

Mr. Matthew Raymer, Sandia National Laboratories
Mr. Thomas Bosiljevac, Sandia National Laboratories

The key to any test fixture is to efficiently couple the excitation motion from the test equipment to the test article. There are numerous variables that are important to ensure this objective is completed. This research study focuses on torque and the variables that are introduced during testing. These variables include torqueing scheme, test article placement, torqueing strategies, and temperature affects. There is not a clear understanding of the temperature effects on preload. Depending on the sensitivity of the load path to temperature the preload could either become too low or hence allow the test article to decouple from the fixture or become too high and risk damaging the test unit. Therefore, testing was completed to assess the effects of temperature (hot and cold) on the preload. A Sandia data acquisition system was used to record the data. The preload was recorded using load washers from Omega Engineering. The load washers were used as a washer, sensing compression force, or compression load. The torque load in each bolt was measured using an interface torque wrench/transducer.

EVALUATION OF ACCELEROMETERS FOR PYROSHOCK PERFORMANCE IN A HARSH FIELD ENVIRONMENT

TECHNOLOGIES, MANUFACTURERS, AND MODELS EVALUATED WITH MOUNTING DETAILS

Mr. Anthony Agnello, PCB Piezotronics

This session presents the results of a comprehensive study of the comparative performance of the more common accelerometer types, manufacturers, and models routinely used in pyroshock testing. Every effort was made to provide objectivity in the evaluation of the resultant data, which were acquired in an extremely harsh testing environment. Because of the extent of this study in detail and analysis the summary report (below) is broken down into five (5) separate presentations.

TEST CONFIGURATION, STIMULI, AND OBSERVATIONS

Mr. Robert Sill, PCB Piezotronics

This session presents the results of a comprehensive study of the comparative performance of the more common accelerometer types, manufacturers, and models routinely used in pyroshock testing. Every effort was made to provide objectivity in the evaluation of the resultant data, which were acquired in an extremely harsh testing environment. Because of the extent of this study in detail and analysis the summary report (below) is broken down into five (5) separate presentations.

SIGNAL CONDITIONING AND DIGITAL RECORDING CONSIDERATIONS

Dr. Patrick Walter, Texax Christian University / PCB Piezotronics

This session presents the results of a comprehensive study of the comparative performance of the more common accelerometer types, manufacturers, and models routinely used in pyroshock testing. Every effort was made to provide objectivity in the evaluation of the resultant data, which were acquired in an extremely harsh testing environment. Because of the extent of this study in detail and analysis the summary report (below) is broken down into five (5) separate presentations.

General Overview of Signal Conditioning Considerations for Pyroshock Measurements

Mr. Alan Szary, Precision Filters

This presentation will expand on Presentation #3 with a broader and more rigorous treatment of the practical considerations required when selecting the analog signal conditioning required for pyroshock experiments. The paper will describe the proper selection of filter characteristics which will provide faithful reproduction of in-band pyroshock data while attenuating accelerometer resonance and preventing aliasing artifacts in the digital record. The paper will also discuss the amplifier stage characteristics crucial for use with energy rich, transient pyroshock data. In addition, it will describe usability features that assist in quick setup verification and validation of the measurement channel.

Data Analysis Technique and Compilation

Mr. Strether Smith, Consultant
Dr. Patrick Walter, Texas Christian University / PCB Piezotronics

This session presents the results of a comprehensive study of the comparative performance of the more common accelerometer types, manufacturers, and models routinely used in pyroshock testing. Every effort was made to provide objectivity in the evaluation of the resultant data, which were acquired in an extremely harsh testing environment. Because of the extent of this study in detail and analysis the summary report (below) is broken down into five (5) separate presentations.

Conclusions of the Testing

Mr. Anthony Agnello, PCB Piezotronics
Dr. Patrick Walter, Texas Christian University / PCB Piezotronics, Mr. Bob Sill, PCB Piezotronics, Mr. Strether Smith, Consultant

This session presents the results of a comprehensive study of the comparative performance of the more common accelerometer types, manufacturers, and models routinely used in pyroshock testing. Every effort was made to provide objectivity in the evaluation of the resultant data, which were acquired in an extremely harsh testing environment. Because of the extent of this study in detail and analysis the summary report (below) is broken down into five (5) separate presentations.

MIMO/SIMO TESTING

Advances in MIMO Testing over the past 2 Decades; From MIL-STD-810G to a Recommended Practice, RP

Dr. Marcos Underwood, Spectral Dynamics
Mr. Russ Ayres, Spectral Dynamics, Inc.
Mr. Tony Keller, Spectral Dynamics, Inc.

Serious vibration testing has been taking place in the U.S. and around the world for over 7 decades. However, it is only in the past 2 decades that the use of multiple shakers for testing many kinds of structures, large and small, has been seriously developed. This has required simultaneous development of couplings and fixtures; test specifications such as MIL-STD-810G, Method 527; Recommended Practices such as DTE-022, Multi-Shaker Test & Control; and modern Control Systems which can implement the many new concepts and functions which have been developed.

This paper looks at many of these developments in light of the currently available MIMO RP and the current MIL-STD which covers MIMO testing and suggests ways in which the current RP can be strengthened and expanded to include recent developments.

ON THE NATURE OF SPECTRAL DENSITY MATRICES USED TO CHARACTERIZE VIBRATION ENVIRONMENTS

Dr. Luke Martin, NSWC Dahlgren

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

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

DEFINING THE ERROR OF SINGLE AND MULTI-AXIS VIBRATION TESTS: A MOVE FROM QUALITATIVE TO QUANTITATIVE METRICS

Dr. Garrett Nelson, Sandia National Laboratories
Norman Hunter, Sandia National Laboratories
Kevin Cross, Sandia National Laboratories

As equipment and methods continue to evolve in the areas of experimental vibration testing and analysis, it is becoming increasingly critical to develop a rigorous set of metrics by which the performance of laboratory vibration tests can be assessed. When comparing the results of a vibration test conducted in the lab against its specification or against the field data from which those specifications may have been derived, a simple binary (pass/fail) metric often provides insufficient information to make an intelligent decision on future design changes, alternate control approaches, or modified test specifications. If the deviations between these two datasets is significant, it is routinely left to an engineer to judge the severity of these differences. In large scale tests, with multiple response locations and/or multiple control objectives (e.g. degrees-of-freedom), the comparison of performance between different data sets is often not possible with these qualitative or ad hoc analysis techniques. By establishing a set of well-defined, informative metrics to assess vibration test performance, a greater move towards standardization in this area can be achieved. Discussed are a series of vibration performance metrics which were explored to quantify the agreement between two different datasets based on both frequency and time domain characteristics by incorporating data features such as response energy levels, correlation, and structural similarity. These have been applied to both simulated and experimental data from single and multi-axis test environments. Guidance is given on the limitations of each metric and their applicability for analyzing the different types of vibration test data.

DEVELOPMENT OF A SINGLE INPUT MULTIPLE OUTPUT (SIMO) INPUT DERIVATION ALGORITHM FOR OSCILLATORY DECAYING SHOCKS

Mr. Chad Heitman, Sandia National Laboratories
Mr. Dylan Murpy, Sandia National Laboratories

During shaker shock testing of a complex system it may be desirable to match a Shock Response Spectra (SRS) at one location while controlling the test at a different location. Further, it may be desirable to match SRS at multiple locations. This paper builds on an algorithm for deriving an optimum shaker shock input such that a weighted combination of the responses for multiple locations is matched with respect to the field data measured at those locations. Due to the inherent nonlinearities of the SRS, the initial Single Input Multiple Output algorithm (SIMO) was based on David Smallwood's decayed sine synthesis algorithms. Currently, the SIMO algorithm only optimizes the amplitude of the sine tones. This method can result in unrealistic and untestable inputs when the chosen frequencies of the sine tones are close to the transfer function poles or zeros. If the sine tones happen to fall at a transfer function zero where the transfer function is very low, the algorithm will derive a high input, with the inverse being true at a transfer function pole. The new algorithm developed in this paper will optimize the frequencies of the sine tones so that they are away from the poles and zeros by a certain amount while retaining a consistent spacing from point to point. This will allow for a more realistic and testable input and more accurate prediction of SRS across multiple datasets.

DERIVATION OF TESTING CONDITIONS FOR MULTI AXIS , MULTI SHAKER LABORATORY VIBRATION SIMULATION

Dr. Zeev Sherf, RAFAEL
Y.Cohen, RAFAEL
P. Hopstone, RAFAEL
I. Sofer, RAFAEL
A. Elka, RAFAEL

Using data measured on a system operated in the field, at several locations, the process of testing specification generation for a multi shaker multi axis vibration testing setup is demonstrated. A spectral analysis of the measured data enables the derivation of PSDs (Power Spectral Densities) and CSPs(Cross Spectra) that are ensemble into the control matrix. The Spectral analysis of the data is performed using parametric modeling methods (ARMA). The presentation starts with the description of the system and the testing setup. The data acquisition process and data acquisition system are presented next, followed by the discussion of the ARMA modeling process. Its application to the data analysis in terms of PSDs and CSPs is described after that, followed by the presentation of the building of the control matrix. Several summarizing remarks conclude the presentation.

PYROSHOCK & BALLISTIC SHOCK

UNDERSTANDING SENSOR LIMITATIONS, TIME DATA QUALITY CHECKS, AND TEST BOUNDARY CONDITIONS DURING PYROSHOCK TESTING APPLICATIONS

Mr. Giann Cornejo, Harris Corp.
Dr. Erik J. Wolf, Harris Corporation

An acceleration sensor with a crystal resonance in mid-20 KHz was used on a test article in a pyroshock event at a location where the detonation energy from the pyrotechnic device drove sensing element into resonance. The time response measured with this accelerometer resulted in signal clipping and zero

shift. This condition was simulated in the laboratory and a series of exercises were spawned to demonstrate accelerometer limitation, to implement shock data quality validation practices, to understand known data recovery techniques, and to characterize time data acquisition systems. Finally, a benchmark study was conducted to evaluate performance of several pyroshock accelerometers from various manufactures. The results from this study are presented and discussed.

Cylindrical Structure Pyroshock Test Data

Mr. Alex Hardt, Orbital ATK

Pyroshock testing was conducted on a cylindrical structure to simulate a separation event. Shock responses were simultaneously measured using accelerometers and a laser vibrometer. Response due to acoustic effects are presented in addition to comparing mounting block configurations.

Reusable Rapid Prototyped Blunt Impact Simulator

Mr. Douglas Petrick, U.S. Army Research Laboratory

Advancements in component fabrication using Rapid Prototyping (RP) have recently begun to revolutionize the field of projectile development. RP components have been successfully used in wind tunnel mock-ups, internal electronics packaging and sabot applications to name a few. The ability to produce highly detailed geometry in very short manufacturing lead times, often less than 24 hours, is being utilized in the early stages of projectile development to accelerate schedules and save cost.

The U.S. Army Research Laboratory (ARL) Guidance Technologies Branch (GTB) recently utilized RP technology to create a custom, reusable projectile for air cannon launched impact research. Several projectile configurations with varying frontal impact area geometries were manufactured utilizing Selective Laser Sintering (SLS) RP technology. These projectiles were launched with a compressed air cannon developed by ARL's Survivability/Lethality Analysis Directorate (SLAD) and Weapons and Materials Research Directorate (WMRD) for the Behind Helmet Blunt Trauma (BHBT) research initiative. The projectiles contained a commercial-off-the-shelf (COTS) on-board recorder (OBR) in conjunction with a 3-axis accelerometer to measure impact forces between the projectile and target. The projectiles were subsequently recovered and the recorded impact data was downloaded via an embedded connector interface for analysis.

The objective of this report is to inform the audience of a novel use of RP technology to fabricate projectiles for a non-classical gun experimental application.

Instrumentation for Local Accelerative Loading

Mr. Christopher Monahan, US Army Aberdeen Test Center
Mr. Brandon Hepner, U.S. Army Aberdeen Test Center
Mr. Jake Hawkins, CORVID Technologies
Mr. Robert Spink, U.S. Army Research Lab
Ms. Anne Purtell, MCSC SIAT

To properly evaluate blast effects on armored vehicles subjected to live-fire mine and improvised explosive device (IED) tests, appropriate instrumentation is required. Whether the evaluation consists of test-to-test or test-to-simulation comparisons, it requires instrumentation capable of surviving harsh mechanical loads without experiencing drift, bias, or saturation. The inherent value of costly system level tests is greatly enhanced if instrumentation survives and provides accurate measurements that do not have to be discounted in post-test analysis. Furthermore, high fidelity computer modeling is more commonly used in vehicle design and test planning, so correlating simulation and test data has become increasingly important. However, it is difficult to collect consistently accurate data that can be used for these purposes with the current instrumentation used during Live Fire Test and Evaluation (LFT&E). Previously, legacy gauges were the best capability achievable at the time of development but do not necessarily cover the broader range of detailed data needed to support additional analysis capabilities that have been evolving.

This project, evaluated legacy instrumentation along with recent advances in accelerometer design and isolation systems in order to identify those best suited for the unique conditions generated during LFT&E. Each accelerometer and isolator combination was characterized with time domain and frequency domain performance properties, such as peak velocity, time-to-peak velocity, and shock response spectrum errors, corresponding to specific loading conditions. The loading conditions were divided into three frequency ranges: low (1 – 10 Hz), medium (10 – 2,000 Hz), and high (2,000 – 10,000 Hz). All of these frequency range loading conditions occur during tactical wheeled vehicle LFT&E, including frequency content higher than 10,000 Hz; however, the limit for this project was set at 10,000 Hz. This approach highlights the benefits of using the appropriate instrumentation for tests with known expected loads.

Ultimately, it was determined that the Endevco 7264D, the Endevco 7280A, and the Tiny BOB are best suited for capturing content in the low, medium, and high frequency ranges, respectively. However, it was also determined that the LOFFI is the most accurate at capturing the extremely low frequency content that contributes to bulk motion. It consistently measured the least amount of velocity drift over all three frequency range loading conditions. In addition, a test protocol has been established to allow for the evaluation of new accelerometers and/or isolators being considered for use in LFT&E. An overview of each test within the protocol and the performance of representative gauge and isolator combinations will be presented.

FREQUENCY RESPONSE CORRECTION OF MEMS PRESSURE TRANSDUCERS & ACCELEROMETERS

Dr. Adam Hurst, Kulite Semiconductor Products, Inc.
Mr. Andrew Bemis, Kulite Semiconductor Products, Inc.
Mr. Steve Carter, Kulite Semiconductor Products, Inc.

We present experimental results demonstrating that the frequency response of a transducer can be extended to the natural resonances of the sensing element by employing an advanced, real-time electrical filtering technique, referred to herein as REZCOMP®. The data presented demonstrate that this resonance compensation scheme not only flattens the response in the frequency domain but also corrects the time response by reducing the settling time of the sensor without adversely impacting the sensor's rise time. We present experimental shock tube, step response results using resonance compensation to extend the bandwidth and improve the time response of a fast responding, piezoresistive pressure transducer. We similarly demonstrate the use of REZCOMP with a piezoresistive MEMS accelerometer exposed to an impulse event.

UNDEX & IMPLOSION ANALYSIS: APPLICATION

DYNAMIC RESPONSE OF MARINE MAMMAL LUNGS TO UNDEX LOADING

Dr. Stephen Turner, NUWC Newport

New models are investigated to assess the effects of underwater explosion on the lungs of marine mammals. Legacy, one-dimensional analysis methods include simplifying assumptions that neglect the shape of the lungs and neglect the influence of tissue and rib structures surrounding the lungs. The DYSMAS fluid structure interaction code is used to evaluate the effects of asymmetric loading, surrounding tissue, and non-spherical lung structure on the response of the lungs. This presentation demonstrates that the DYSMAS analysis is consistent with the legacy analysis method when the same assumptions are made. Further, the DYSMAS tool is used to evaluate the influence of surrounding tissue layers on expansion/contraction of the lung volume, as well as to assess mechanical stress/strain in the surrounding tissue layers.

CHARACTERIZATION OF BLACK POWDER UNDERWATER EXPLOSION OUTPUT

Mr. Gregory Harris, NSWC Indian Head
Dr. Thomas McGrath, NSWC Indian Head
Mr. Kent Rye, NSWC CD
Mr. William Lewis, NSWC CD
Dr. Ken Nahshon, NSWC CD

A series of underwater explosion (UNDEX) tests was conducted to quantify the output of large black powder charges. One set of tests was dedicated to reproducing the shallow charge geometry representative of the Confederate submarine H.L. Hunley's attack on USS Housatonic in the Civil War. A second set was conducted with a deep geometry to characterize the UNDEX shock and bubble output of black powder, which was used to develop an explosive Equation of State for use in advanced numerical simulations. Sample data will be presented to contrast black powder output with conventional high explosive output, and preliminary results from the EOS development and validation will be shown.

UNDERWATER EXPLOSION ANALYSIS OF THE HL HUNLEY SUBMARINE

Dr. Ken Nahshon, NSWCCD

On February 17, 1864, the H.L. Hunley submarine, using a black-powder filed spar torpedo, attacked the USS Housatonic, a Union sloop of war. The resulting explosion sank the USS Housatonic and secured the Hunley's place in history as being the first submarine to sink an enemy combatant. Although the attack was successful, the Hunley was lost at sea with all hands due to unknown circumstances. A previous talk at the 85th SAVIAC described the initial results of a study examining the response of the Hunley to the underwater explosion resulting from the Hunley's torpedo using advanced numerical simulations. Here, an update on current progress in simulation efforts will be presented.

IN-TUBE IMPLOSION: EXPERIMENTS AND SIMULATION

Dr. Joseph Ambrico, NUWC Newport
Mr. Ryan Chamberlin, NUWC Newport

When a structure containing low pressure compressible material (typically air) implodes from depth pressure, a significant pressure wave is created. This pressure wave propagates outward and has the

potential to cause damage to nearby objects. When the same structure implodes within confining, flooded structure (such as a tube), the implosion pressure wave is significantly altered. Detailed fluid-structure simulations and small scale experiments are conducted to characterize implosion occurring within a specific tube. Of particular interest are the pressure waves that propagate outside of the confining tube (which has water on both sides). Several cases are considered, including implodable volume size, restricting water flow into the confining tube, and multiple implodable structures. In all cases, the implosion pressure waves outside of the tube are significantly smaller than inside of the tube, and significantly smaller than from the same structure imploding free-field (i.e. not within a confining structure).

ELECTRONIC COMPONENTS IN EXTREME ENVIRONMENTS

FINITE ELEMENT MODELING AND EXPERIMENTAL EVALUATION OF ELECTRONICS PACKAGING STRATEGIES

Mr. Matthew Neidigk, Sandia National Laboratories
Mr. Jamie Kropka, Sandia National Laboratories
Mr. Shane Curtis, Sandia National Laboratories

Packaging electronic components to survive extreme mechanical environments (thermal cycle and impact) has been the subject of research for decades. In many cases, electronics packaging strategies have been based on experimental trial and error as well as historical lore. Unfortunately, a packaging strategy to maximize resistance to failure in thermal cycle environments may be detrimental in an impact environment or vice versa. With the advent of finite element modeling, a more scientific approach to packaging research has been enabled. New constitutive models can now capture the rate and temperature dependent behavior of nonlinear viscoelastic materials such as potting and underfills or viscoelastic solders. In addition, coupled physics codes such as Sandia's SIERRA have enabled true life cycle modeling including stresses from manufacturing, thermal, and dynamic environments. With these tools, computational parameter studies were performed to develop a fundamental understanding of how materials and design choices for packaging affect electrical components in thermal and dynamic environments. Experiments were performed on simple geometries to validate the conclusions of the predictions.

RECORDER TECHNOLOGY AND INSTRUMENTATION FOR HARD-TARGET PENETRATIONS

Mr. Curtis McKinion, AFRL
Dr. Janet Wolfson, AFRL
Dr. Jacob Dodson, AFRL
Dr. Alain Beliveau, ARA

Fuze systems within many Air Force weapons are required to function in high-g environments. These systems may be hard-mounted or embedded within the explosive fill material. Hard-target penetration events subject fuze components to large accelerations and pressures.

AFRL is improving methods to instrument subscale penetrators in order to characterize these extreme environments. A variety of on-board recorders are evaluated in their ability to capture acceleration and pressure throughout the subscale penetrator. Trade-offs including sampling rate, precision, available channels, and form factor are to be considered with different recorders. The fill material mitigates high frequencies that are present in hard-mounted configurations, however, the embedded environment introduces new challenges to successful measurements. Movement within the fill material can create noise and damage to sensor cables. Existing shock-hardened recorders must be packaged remotely from embedded units due to physical size constraints. AFRL is working to integrate the recorder with the embedded unit to improve measurements, through in-house designs and with outside manufacturers.

MEASURING THE DYNAMIC PRESSURE ENVIRONMENT OF AN EMBEDDED SYSTEM IN EXTREME ENVIRONMENTS

Dr. Jacob Dodson, AFRL/RWMF
Dr. Alain Beliveau, ARA
Mr. Curtis McKinion, AFRL/RWMF
Dr. Janet C. Wolfson, AFRL/RWMF

The understanding of the movement of the inside polymeric composites in complex dynamic systems is critical to gaining insight to the dynamics seen by an embedded electronic components. The movement of the polymeric composites inside systems in extreme loading environments can generate large internal forces and pressures. The understanding of the relative movement is critical for measuring the dynamics that the electrical components experience. While computational models can give some idea about the dynamic state in the polymeric composite, there are only a small number of measurement techniques which give us validated data during a harsh mechanical shock loading.

In order to fully understand the internal dynamics, experimental methods need to be developed to characterize the dynamic states of the polymer composite in the embedded environment. These methods validate dynamic responses seen in computational models in operational loadings and quantify measure the severity of the shock and vibration in the embedded mechanical environment, and identify any damage to the polymer composite due to the extreme shock loading environments. This presentation will discuss the current status, including embedded acceleration and pressure measurements during extreme shock loading environments with polymer composites, and future work on the development of these experimental methods.

UNDERSTANDING THE PRELOADED THREADED INTERFACE: TRANSMISSION OF IMPULSIVE DYNAMIC TENSILE WAVES

Mr. Marc Sanborn, Georgia Institute of Technology
Ms. Aine Mangan, Georgia Institute of Technology
Dr. Lauren Stewart, Georgia Institute of Technology
Dr. Jacob Dodson, AFRL
Dr. Janet Wolfson, AFRL

Efficient and robust modeling and simulation strategies are essential for effective design and analysis of components and structural systems. For structures subjected to impulsive loading conditions, these models rely on the accurate representation of the wave propagation through the various structural members and their connections. In the case of munitions, the dynamics due to interfaces are the least understood and often pose challenges in computational simulations. These challenges are compounded when stress states are complex, such as when an applied preload is coupled with a high-rate transient load. Such complex stress states are common in munitions and other defense systems that are subjected to shock loadings. In a typical penetrator, there are multiple threaded interfaces between the warhead case and the electronics in the fuze, which manages the initiation decision. For full- and sub-scale tests using various fuze components, a static torque preload is applied to the baseplate and lockrings of the weapon system to hold the fuze in place. After the shock loading caused by a hard target penetration, the preloaded torque has relaxed and the baseplate can be removed by hand with no resistance, in many instances. This indicates that at some currently uncharacterized point(s) in time the stored static torque is released during the dynamic event, which is currently uncharacterized.

To better characterize the wave propagation and associated relaxation with threaded interfaces, an experimental technique using a tension Hopkinson bar with combined preload torqueing system was developed. Experiments were conducted at various preload levels and impact velocities to quantify the strain and behavior on various portions of the threaded interface. The established data set was then used to compare to existing modeling techniques as well as to develop new modeling strategies.

ENERGY DISSIPATION THROUGH A THREADED JOINT SUBJECTED TO IMPACT LOADING

Dr. Bo Song, Sandia National Laboratories
Mr. Brett Sanborn, Sandia National Laboratories

Threaded joints have been utilized in many engineering applications to directly connect two or more component parts together. When the component is subject to impact loading, impact energy transmits from one component part to the other through the threaded joint. The impact energy may dissipate through the threaded joints due to possible localized plasticity, friction, etc. In this study, we developed experimental and analytical methods to characterize the impact energy dissipation through a threaded joint. The experiments were performed with split Hopkinson bar (also called Kolsky bar) techniques and the data were analyzed in terms of energy dissipation in both time and frequency domains. The effects of impact speed and pre-torsion load on the impact energy dissipation characteristics will also be presented.

FREQUENCY-BASED IMPACT ENERGY DISSIPATION IN SILICONE FOAM AND RUBBER

Mr. Brett Sanborn, Sandia National Laboratories
Dr. Bo Song, Sandia National Laboratories

Silicone foams and rubber are used in a variety of applications to protect internal components from external shock impact. Understanding how these materials mitigate impact energy is a crucial step in designing more effective shock isolation systems for components. In this study, a Kolsky bar with pre-compression and passive radial confinement capabilities was used to investigate the response of silicone foam and rubber subjected to impact loading. Using the preload capability, silicone foam samples were subjected to increasing levels of pre-strain. Frequency-based analyses were carried out on results from silicone foam and rubber to study the effect of both pre-strain and material processing on the mechanism of energy dissipation in the frequency domain.

TEST MEASUREMENT METHODS

IMPROVEMENTS IN ACCELEROMETER CALIBRATION AT NIST USING DIGITAL VIBROMETERY

Mr. Beverly Payne, NIST
Mr. Richard A. Allen, NIST
Ms. Colleen E. Hood, NIST

Improvements in shaker design and laser vibrometer development has provided more precise calibration of accelerometers. Calibrations are performed at frequencies from 1Hz to 20 kHz with improved uncertainty and improved efficiency. The vibrometer mounting hardware is designed for easier optical alignment at multiple, repeatable, and unique reference positions on the shaker's mounting table. Calibrations using this system, which is now used in the NIST routine calibration service, show excellent agreement with traditional NIST calibrations obtained using the laser interferometer methods that were developed at NIST. The legacy NIST laser interferometer system uses a shaker with a beryllium mounting table insert while the vibrometer-based system uses two shakers to cover the desired frequency range. For high frequencies (10 Hz – 20 kHz), a shaker with a ceramic mounting table which reflects the laser beam without the requiring a mirror is used. For low frequencies (< 10 Hz), a shaker with an aluminum mounting table is used. This system is described and compared with the previous calibration system. Comparison results for two accelerometers are presented using the two measurement systems.

TESTING COMPLIANCE OF HIGH-G SHOCK ACCELEROMETERS TO MIL-STD-810G

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

In the last year, Meggitt Sensing Systems has developed test methods for demonstrating compliance to MIL-STD-810G Change Notice 1, particularly Method 516.7 (Shock) and Method 517.2 (Pyroshock). The compliance tests include linearity, cross-axis sensitivity, and frequency response. A summary of the procedures for each test is provided, as well as example data from tests on Endevco® 7280A and 7270A high-shock accelerometers.

TRACEABLE HIGH-FREQUENCY VIBRATION CALIBRATION OF ACCELEROMETERS IN THE TEMPERATURE RANGE OF -60C TO 90C

Mr. Randy Mendoza, Sandia National Laboratories
Mr. Michael Mende, SPEKTRA

The determination of accelerometer response to temperature variation is well understood in terms of accelerometer design. However, traceable calibration of accelerometers under extreme temperature conditions, particularly at higher frequencies, is a unique challenge. The Primary Standards Laboratory at Sandia National Laboratories, in conjunction with SPEKTRA, has recently implemented a sinusoidal vibration calibration system for the traceable calibration of accelerometers from 10 Hz to 10 kHz in the temperature range of -60C to 90C. This paper includes the following: a brief overview of vibration calibration theory, a description of the calibration system and its configuration, an approach for determining the temperature coefficient of a back-to-back reference standard accelerometer, and a summary of improvements on existing capabilities and measurement uncertainties.

RUGGED PIEZORESISTIVE BRIDGE SHOCK ACCELEROMETER WITH INTERNAL SIGNAL CONDITIONING

Mr. Randall Martin, Meggitt Sensing Systems
Mr. Alan Stillwell, Meggitt Sensing Systems

An accurate and rugged piezoresistive bridge shock accelerometer with internal signal conditioning is presented. It utilizes the inherent advantages of a DC response piezoresistive bridge type accelerometer closely coupled with programmable integral signal conditioning electronics. It is designed for pyroshock and mechanical shock measurements in flight systems and other applications requiring tighter tolerances and accuracies than available from unconditioned sensors.

DEVELOPMENT OF DIGITAL FILTER METHODOLOGY FOR HOPKINSON BAR DISPERSION CORRECTION

Mr. Craig Doolittle, Applied Research Associates
Dr. Julius Smith, III, CCRMA
Dr. Weinong Chen, Purdue University

The dispersive characteristics of a compressive pulse traveling in a cylindrical rod, such as a Hopkinson Pressure Bar (HPB) or a Kolsky Bar (Split Hopkinson Pressure Bar, SHPB), were developed by Pochhammer in 1876, and independently by Chree in 1889. A method for correcting the dispersion based on Fourier Shifting was developed by Follansbee and Frantz, and independently by Gorham, both in 1982. The Fourier Shift method involves determining the Discrete Fourier Transform (DFT) of the compressive pulse and shifting the phase angles of individual frequencies based on the phase velocity of the specific bar, which is a function of the bar material and geometry. This method is computationally intense and can result in spurious pre-signal noise as demonstrated in both Follansbee's and Gorham's papers.

A new and innovative methodology has been developed based on a digital All-Pass filter with specified phase velocity, which is fundamentally causal (no precursor waves possible) and thus completely eliminates a shortcoming of the Fourier Shift methodology. In addition, the digital filter can be pre-computed for a specific bar, allowing for dramatic savings in computational time as there is no need to obtain the DFT and IDFT of each pulse to be corrected. Because this digital filter is an All-Pass filter which modifies only the phase of the signal, essentially no gain error is introduced at any frequency, and the dispersion error can be made arbitrarily small by increasing the filter order. This digital filter can easily be combined with other digital filters to correct strain gage frequency response, data acquisition system response, etc. The new methodology has applications in material testing (SHPB) and in electronics and accelerometer testing with test items mounted on the end of a HPB. The methodology has been favorably compared to both high-fidelity finite element simulations and test data.

EUROPEAN SERVICE MODULE STRUCTURAL TEST ARTICLE (E-STA) "BUILDING BLOCK APPROACH" MODAL TEST RESULTS

Mr. Vicente Suarez, NASA
Dr. James Akers, US Army Engineer Research and Development Center
Ms. Samantha Bittinger
Mr. Trevor Jones
Mr. Lucas Staab (presenter)
Mr. James Winkel

No abstract available.

SHOCK ISOLATION ANALYSIS & PERFORMANCE STUDIES

USING ANALYSES AND MODELS TO EVALUATE THE SHOCK RESPONSE AND MECHANICAL STRESSES OF AN ISOLATED ENCLOSURE

Mr. Fred Sainclivier, 901 LLC
Mr. Mahmoud Zreik, 901 LLC

Specifications often require complex 'packaging' of equipment within a Navy rack. COTS electronic units and components in an isolated enclosure subjected to barge test can sometimes experience different shock response loads than at the rack itself. Often the rack is considered a 'rigid mass' but its structural

design and placement of equipment creates secondary dynamics that can amplify the response. For example, ’G’ loads can be greater on ‘’sprung’ units than at the base of the enclosure. This is due to a combination of the mechanical design of support brackets, location of the components, distributed masses and the complex load transfer path within the rack. The actual shock input at the electronic equipment within the rack can be different from the measured response directly above the base isolators.

This paper describes typical 901LLC design and simulation methods using FEA and proprietary software to evaluate the expected shock response. A case study is described of an isolated rack. Results from a barge test are reviewed and compared to calculations. The predicted response of the rack was analyzed to evaluate the predominant frequencies, accelerations and SRS levels at components. Isolator data is from Shock Tech’s library of high deflection arch mounts. The shock response above the isolation was used as an input to the enclosure at its cg. Distributed loads and mechanical stresses were calculated at various locations such as equipment support(s) at the frame of the rack.

DESIGNING SHOCK AND VIBRATION ISOLATION SYSTEMS AND COMPONENTS (OR “HOW TO LEARN TO LOVE YOUR MOUNT SUPPLIER”)
Mr. Robert Sharp, Hutchinson

Designing isolation systems is a process of environmental analysis, payload sensitivity analysis, isolator selection, and system integration. It is the preliminary environmental and payload analyses which set the course for the program and can lead to a compromised final design if improperly preformed. Unfortunately it is often this exact information which is missing or incomplete at the start of the project. An experienced isolation system engineer can fill in those blanks based on similar applications, ensuring successful performance.

For most cases a shock or vibration isolator configuration already exists which can be directly applied or adapted to suit the application specifics, and most isolator suppliers have a full catalog of those common configurations. In the rare cases when a custom isolator is required there are established elastomer section design methods that have been published in numerous manuals and guidebooks. Again, an experienced isolator design engineer will be familiar with these methods and have the tools to create a robust solution.

It is imperative to begin working with the isolation system designer as early as possible to determine the critical path of system inputs and sensitivities. Even engineers already acquainted with isolation benefit from the support of an experienced supplier’s familiarity with multiple system and isolator configurations, across disparate industries and applications.

This paper discusses the basics of system and isolator design for shock and vibration, and includes an overview of the most common isolator configurations and their use. It also presents case histories illustrating successful management of evolving or conflicting design requirements.

UK ROYAL NAVY MOUNT SHOCK CHARACTERISATION PROGRAMME - MOUNT CHARACTERISATION PROGRAMME OVERVIEW
Mr. Matthew Brownlow, BAE Systems
Mr Thomas Fairchild, BAE Systems

Resilient mounts and snubbers exhibit highly nonlinear behaviour when subjected to naval shock loadings that generally cannot be fully represented with native elements in finite element codes. In 2012, BAE Systems undertook a Mount Shock Characterisation Programme to develop a series of algorithms for use in transient shock analyses. The algorithms were based on physical drop test data and characterised the response of the mount when subjected to differing impact loads at varying velocities. A variety of mounts and snubbers of interest were tested to provide data over the expected range of shock motions and to investigate the capacity limits. This data was used to develop robust shock characterisations that provide accurate representations of their macro-level responses. The algorithms were implemented as a suite of ABAQUS user elements and used to aid the analyses of mounting arrangements that are subjected to shock scenarios and hence predict the environment that they experience. The programme resulted in improved modelling accuracy, reduced modelling time and modelling errors, and a consistent modelling approach throughout the organisation.

The 2012 programme was undertaken on resilient mounts and snubbers in a 'pre-service' condition. This led to a desire to verify that the response data obtained from the 2012 programme was still appropriate for mounts at the end of their service life and to determine if the current 'service life' is overly cautious. In 2015, a second test programme was undertaken to analyse the response of large resilient machinery mounts at the end of their service life and to determine any significant deviations from their pre-service behaviour.

UK ROYAL NAVY MOUNT SHOCK CHARACTERISATION PROGRAMME - COMPARATIVE STUDY OF SHOCK PERFORMANCE BETWEEN PRE-SERVICE AND POST-SERVICE RESILIENT MACHINERY MOUNTS

Mr. Thomas Fairchild, BAE Systems
Mr. Matthew Brownlow, BAE Systems

The 2015 test programme subjected seven large resilient machinery mounts to physical drop tests. Six of the mounts had completed their service life and the other mount was in a pre-service condition and had been tested during the 2012 programme, enabling the consistency between the two programmes to be measured. The study investigated the effects of in-service conditions on the response of the mounts and determined whether there had been degradation due to ageing in the point at which the mount fails and/or exceeds its excursion limits.

The 2015 programme closely followed the previous programme's test methodology, re-using the test fixtures and apparatus and addressing 'lessons learned'. This resulted in a marked improvement in rig performance and testing efficiency. Physical drop test data was obtained for the mounts in both the axial compressive and axial tensile directions which enabled comparisons to be made with the pre-service mounts tested in the 2012 test series. Comparisons of the test data found that the post-service mount performance was similar to that of mounts in a pre-service condition and found no discernible evidence that mount shock performance had been reduced by service life.

STRUCTURAL RESPONSE & BLAST

BREACH OF URBAN WALLS DUE TO SMALL MUNITIONS DETONATING ON IMPACT OR AFTER PARTIAL PENETRATION: PART 1: HFPB SIMULATIONS

Mr. Joseph Abraham, Karagozian and Case
Mr. Jason Yang, Karagozian and Case
Mr. Pietro Gheorghiu, Karagozian and Case
Dr. Wije Wathugala, ACTA
Dr. George Lloyd, ACTA

In recent years, the US military finds itself more and more involved in urban warfare. In urban warfare, armed forces have to carry out their mission with caution to minimize harm to nearby civilians and friendly forces. These precautions exclude the use of large weapons and therefore the military is interested in the use of more precise small weapons. These small weapons are often used to breach urban walls and can be inert projectiles or explosive projectiles (cased weapons) that a) detonate upon impact or b) fused to detonate after penetration into the target in order to maximize damage.

The physics of the inert or explosive impacts and the resulting breakup and debris generation of these munitions are complex and challenging to predict. The HFPB models that can simulate the complex phenomena involved in the impact of inert/explosive ammunitions require vast computer resources and advanced knowledge of computational solid and fluid dynamics models; which is not suitable for military planners and commanders who need quick answers or to perform "what-if" studies. Therefore, it is necessary to develop FRMs that capture the essence of the HFPB simulations and run very quickly. The FRMs also need to provide information to the analysts/planners on their predictive accuracy (confidence in the results) given the inherent uncertainties in the modeling process.

Results are presented in two papers. In this paper, we present details of HFPB simulations of small munitions impacting and detonating on or inside urban walls such as DRC (doubly reinforced concrete) walls, brick walls, CMU walls, and adobe walls.

BREACH OF URBAN WALLS DUE TO SMALL MUNITIONS DETONATING ON IMPACT OR AFTER PARTIAL PENETRATION: PART 2: FRM DEVELOPMENT

Dr. Wije Wathugala, ACTA Inc.
Dr. George Lloyd, ACTA
Mr. Joseph Abraham, Karagozian and Case

In recent years, the US military finds itself more and more involved in urban warfare. In urban warfare or MOUT (Military Operations on Urban Terrain), armed forces have to carry out their mission with caution to minimize harm to nearby civilians and friendly forces. These precautions exclude the use of large weapons and therefore the military is interested in the use of more precise small weapons. These small weapons are often used to breach urban walls and can be inert projectiles or explosive projectiles (cased weapons) that a) detonate upon impact or b) fused to detonate after penetration into the target in order to maximize damage.

The physics of the inert or explosive impacts and the resulting breakup and debris generation of these munitions are complex and challenging to predict. The HFPB models that can simulate the complex phenomena involved in the impact of inert/explosive ammunitions require vast computer resources and advanced knowledge of computational solid and fluid dynamics models; which is not suitable for military planners and commanders who need quick answers or to perform “what-if” studies. Therefore, it is necessary to develop FRMs that capture the essence of the HFPB simulations and run very quickly. The FRMs also need to provide information to the analysts/planners on their predictive accuracy (confidence in the results) given the inherent uncertainties in the modeling process.

Results are presented in two papers. In the second paper, we present details of developments of prototype FRMs for predicting breach hole size and shape for urban walls based on the HFPB simulations presented in Part 1.

PERIDYNAMIC SOLUTION OF AN ELASTO-PLASTIC PLATE WITH FAILURE

Mr. Michael Miraglia, Naval Surface Warfare Center Carderock Division
Dr. E Thomas Moyer, Naval Surface Warfare Center Carderock Division

Currently numerical modeling of large thin walled structures via the FEM requires the use of structural elements to limit the computational cost of the simulation. These approaches have limitations in handling material failure and discontinuities, which Peridynamics was specifically formulated to address. Peridynamic analogs to traditional structural elements will enable the application of Peridynamics to large scale problems that involve material failure and are of interest to the Navy (i.e. collision, grounding, weapons effects, etc.). A peridynamic formulation of an elasto-plastic plate with failure has been developed. The approach uses a layered two-dimensional Linear Peridynamic Solid material model in conjunction with a shear correction term to produce Mindlin Plate-like behavior. The theoretical framework will be presented and the results will be reported for simple verification problems.

PREDICTING SECONDARY DEBRIS FOR VEHICLES SUBJECTED TO CLOSE-IN OR INTERNAL DETONATIONS

Mr. Joseph Abraham, Karagozian and Case
Mr. Mark Weaver, Karagozian and Case, Inc.
Mr. Joe Magallanes, Karagozian and Case, Inc.
Mr. Ernest Staubs, Air Force Research Laboratory
Mr. Brandon Taylor, Air Force Research Laboratory
Mr. Brandon Whitworth, A-P-T Research, Inc.

A software tool capable of predicting secondary debris deriving from vehicles subjected to internal detonations or external close-in detonations is described. The tool is designed to enable assessment of or analysis of the effects of secondary debris generated from accidental explosions that occur in vehicles during transportation of energetic materials as well as intentional explosions due to improvised explosive devices (IEDs) and weapons detonating inside or near vehicles. The methodology used in the tool has been designed to accept secondary debris data generated from either field tests, high-fidelity physics-based (HFPB) computations, or both test and HFPB data, and to use this data to predict secondary debris characteristics for similar scenarios. An approach for generating secondary debris based on major vehicle components is described for various detonation locations inside or around the vehicle. Outputs generated by the tool can be used to determine secondary debris trajectory as well as the associated debris velocity and momentum as it impacts an adjacent user-defined surface. Furthermore, the secondary debris data generated by the tool is formatted in such a way to facilitate transfer to other analysis programs. As such, the tool can be useful for a variety of purposes, including: vulnerability assessments, explosive safety, and perimeter security planning.

A COMPONENT-BASED FAST-RUNNING MODEL (FRMS) SUITE FOR ESTIMATING WEAPONS EFFECTS ON STRUCTURES

Mr. Joseph Magallanes, Karagozian and Case
Dr. George Lloyd, ACTA Inc.
Mr. Randy Anderson, ARA

A suite of novel component-based fast-running models (FRMs) have been researched, developed, and integrated into existing analysis tools that can be used to estimate weapons effects on structures. Contrary to existing structural response methodologies, which employ simplified empirical relationships (e.g., Pressure-Impulse Diagrams) or Single-Degree-of-Freedom (SDOF) models, these FRMs are formulated using High-Fidelity Physics-Based (HFPB) computations to formulate the FRMs. This affords the FRMs the capability to account for realistic weapon loads, including blast, gas, primary fragment loadings, and most recently, secondary debris loadings from other failed portions of the structure; it is not possible to explicitly account for these combined effects using the existing structural response methodologies. Furthermore, the models account for complex failure modes that are unique and critical to quantify for each of the structural components of interest. The FRMs are designed to estimate probability of failure of the component, including residual capacities for damaged components, and outputs the damage in such a way that is can be used to evaluate the stability of the structural system in its damaged state. Finally, the FRMs estimate secondary debris generated by failed components when they are overwhelmed by the weapon loads. FRMs in this suite have been developed for mass construction components (brick, adobe, and structural clay tile), reinforced concrete construction, concrete masonry block components, and steel framing components. This paper describes the FRMs, their basis, validation examples, a summary of their capabilities as currently integrated into existing analysis tools, and their current integration into a coupled fast-running methodology (CFRM) that affords modeling cascading failure of geometrically complex structures where the response of the structure influences the propagation of the weapon loadings.

BLAST EFFECTS ON STRUCTURES

EVALUATING EFFECTS OF COMMON PRE-DETONATION MATERIALS ON PROTECTIVE STRUCTURE BLAST LOADS

Mr. Omar Esquilin-Mangual, US Army Engineer Research and Development Center
Mr. Donald H. Nelson, US Army Engineer Research and Development Center
Mr. Omar G. Flores, US Army Engineer Research and Development Center

Blast and fragmentation mitigation techniques using layers of soil and concrete have been used to defeat contact burst detonations for Overhead Cover (OHC) structures, which saves the lives of soldiers in theater. However, these systems require high manpower and construction time costs because of the large amount of material and labor required for construction. Due to changing operational requirements, high-mass, logistically expensive materials such as soil and concrete do not fully satisfy protection needs. New protective capabilities are required that combine reduced mass and volume with increased performance characteristics. Recent investigations show that using common materials to pre-detonate a large variety of indirect-fire weapons can significantly reduce the amount of cover material required for blast mitigation, resulting in manpower and time savings of OHC construction. However, more research is required to identify and correlate the parameters necessary to accurately predict the effect of the pre-detonation layer over the shielding layer. To address these evolving requirements, the U.S. Army Engineer Research and Development Center developed a full-scale experimental test matrix to identify key parameters of common pre-detonation materials that significantly affect the performance of protective structures. Full-scale tests were conducted with a spherical, high-explosive

bare charge. The structure was instrumented to obtain time and size of the breach of the pre-detonation layer and the blast pressures on the shielding layer. Numerical modeling was used to simulate the tests in an effort to develop a validated model to further evaluate the relationship between pre-detonation roof breaching and blast propagation onto the shielding layer. This paper presents the experimental procedure and the methodology to determine the most significant parameters and their contributions to protection.

BLAST EFFECTS ON MODULAR RELOCATABLE BUILDINGS

Mr. David Roman-Catro, US Army Engineer Research and Development Center
Dr. C. S. Stephens, US Army Engineer Research and Development Center
Mr. O. G. Flores, US Army Engineer Research and Development Center
Mr. R. E. Walker, US Army Engineer Research and Development Center
Dr. T. R. Slawson, US Army Engineer Research and Development Center
Dr. L. E. Suárez, UPRM

Intermodal freight shipping containers can be converted into Life Support Areas and Tactical Operations Centers in contingency operations where ease of relocation or modularity for reconfiguration is important. In situations such as contingency operations, the containers used as shelters could be subject to blasts. Therefore, it is important to understand the effects of blast on the containers in order to improve the protection of the occupants. There were two objectives for this research: (1) the characterization of the effects of blast on modular re-locatable buildings (MRLBs) and (2) the development of a computational model for the MRLBs. The characterization was achieved for two different designs of the MRLBs: (i) W-MRLB or wood stud and plywood construction and (ii) S-MRLB or steel stud and sheet metal-backed drywall construction. Both types of MRLBs were subjected to blast loadings from several charge sizes at various standoffs so that both the pressure- and impulse-sensitive responses of the MRLBs could be captured. Blast pressure-time histories inside and outside of the MRLBs and displacement-time histories at the midpoint of the wall closest to the blast were recorded. High-speed photography and real-time videography were used to capture the responses of the MRLBs. The levels of damage to the MRLBs were assessed after the test. The quantitative and qualitative data acquired during the characterization of the MRLB provided the necessary results to validate the computational model. As a result, the compilation of data led to a better understanding of blast effects on the MRLBs and the survivability of its occupants.

BLAST EFFECTS ON ELEVATED EXPEDITIONARY TOWER

Mr. Benjamin Jones, US Army Engineer Research and Development Center
Mr. Aaron Sullivan, US Army Engineer Research and Development Center
Mr. Omar Esquiline - Mangual, US Army Engineer Research and Development Center
Dr. Catherine Stephens, US Army Engineer Research and Development Center
Mr. Omar G Flores, US Army Engineer Research and Development Center
Mr. James Davis, US Army Engineer Research and Development Center

A need exists for designs of guard tower kits especially for small and extra-small basecamps to improve the level of protection, reduce logistics, and simplify construction. The U.S. Army Engineer Research and Development Center has developed a guard tower kit called the Elevated Expeditionary Tower (EET) by adapting a version of the HESCO Elevated Sanger with armor panels in a method similar to the Modular Protective System. The EET consists of a scaffolding system fitted with armor panel sidewall protection and an overhead cover protection system. The overhead cover protection system has a pre-detonation layer to trigger indirect fire weapons above an armor protection layer that stops the fragmentation. The

objective of this research was to characterize the structural response of the EET due to a blast similar to that of an indirect fire weapon. A series of experiments were completed using bare charges to represent only the blast portion of an indirect fire weapon. In each test, a charge was placed on either the overhead cover system or on the sidewall protection. The blast pressures and structural responses of the EET were recorded using pressure transducers, high-speed photography, and real-time videography. The level of damage to the guard tower was assessed posttest, and occupant survivability was determined.

FURTHER STUDY OF THE EFFECT OF BARRIER WALL SHIELDING ON THE RELATIONSHIP BETWEEN OVERPRESSURE

Mr. Denis Rickman, US Army Engineer Research and Development Center
Mr. Joshua E. Payne, US Army Engineer Research and Development Center
Dr. Z. Kyle Crosby, US Army Engineer Research and Development Center
Dr. Jay Q. Ehrgott, US Army Engineer Research and Development Center

The dynamic pressure and impulse produced by a detonation is an important damage mechanism, particularly in terms of blast overturning of vehicles. Relationships exist to accurately estimate the dynamic pressure produced by an above-ground detonation based upon the measured overpressure at a given location. However, these relationships are predicated upon the assumption of free-field conditions. In most real-world scenarios of interest, structural elements such as walls and buildings may significantly disrupt the local airblast field in their wakes. This phenomenon is typically referred to as blast shielding. A study was initiated in 2015 to begin evaluating the effect of blast shielding on dynamic pressure in a vehicle-borne improvised explosive device (VBIED) environment. In this paper, the effect of blast shielding on the relationship between dynamic pressure and overpressure is further explored for the case of taller barrier walls and closer proximity between the wall and the blast source.

SHOCK AND VIBRATION PROJECTS SPONSORED BY THE NATIONAL SHIPBUILDING RESEARCH PROGRAM (NSRP)

WHAT IS NSRP?

Mr. Sean Murphy, HII Ingalls Shipbuilding

No abstract available.

DOOR STANDARDIZATION THROUGH SHOCK EXTENSIONS

Mrs. Jennifer Schilling, HII Ingalls Shipbuilding

No abstract available.

SHOCK TESTING OF FLEXIBLE INFRASTRUCTURE ARRANGEMENTS FOR SURFACE COMBATANTS

Mr. Sean Murphy, HII Ingalls Shipbuilding

No abstract available.

VIBRATION TESTING OF FLEXIBLE INFRASTRUCTURE

Mr. Mike Poslusny, HII Ingalls Shipbuilding

No abstract available.

SHOCK AND VIBRATION TESTING OF ADHESIVE ATTACHMENT METHODS

Mr. Mike Poslusny, HII Ingalls Shipbuilding

No abstract available.

BLAST INVESTIGATION & MODELING

A LAYERED METAMATERIAL FOR BLAST PROTECTION

Dr. Hossein Sadeghi, Karagozian and Case
John Crawford, Karagozian and Case
Zach Smith, Karagozian and Case
Joe Magallanes, Karagozian and Case

Reinforce concrete (RC) structures can be extremely vulnerable under near-contact explosive threats, and most of the techniques for the design of RC structures have shortcomings that need to be addressed with regard to such threats. A near-contact blast load, due to the intensity of the shock front, can generate a dense field of micro cracks in the vicinity of the charge, which pulverizes the concrete allowing it to flow out of the rebar cage. Addressing these shortcomings demands that novel protective materials be developed that are capable of withstanding the extreme loading environment created by near-contact explosives. In this paper, a layered metamaterial is designed which can be placed over the surface of an RC structure that deadens the shock front associated with near-contact detonations and prevents the pulverization of the concrete. Metamaterials are novel composite materials that exhibit shock mitigative properties that cannot be achieved through current protective materials. Preliminary laboratory test results show that metamaterials have an attenuation coefficient more than an order of magnitude higher than current protective materials. The frequency content of a near-contact shock wave is studied and the frequency range that contains the majority of the shock wave is identified. Through proper design of the microstructure of the layered metamaterial, high frequency components of the shock front are filtered (reflected back toward the explosive) and shock peak overpressure transmitted to RC structure is minimized. To evaluate the protective performance of the layered metamaterial finite element simulation of a RC structure, with the layered metamaterial attached to its surface, subjected to near contact explosion is performed. As a reference case, the same RC structures under the same near contact explosion, without the layered metamaterial, is also studied. Contours of displacement and damage (plastic strain) in the RC structure are analyzed for both cases. Residual load carrying capacity of the structure is studied to better understand the protective capability provided by the layered metamaterial.

MODELING THE BLAST LOAD SIMULATOR: EFFECTS OF THE OBLIQUITY ANGLE OF A STRUCTURE ON OVERPRESSURE

Mr. Gustavo Emmanuelli, US Army Engineer Research and Development Center
Mr. Andrew Barnes, US Army Engineer Research and Development Center
Dr. Gregory Bessette, US Army Engineer Research and Development Center
Dr. Carol Johnson, US Army Engineer Research and Development Center
Dr. James O'Daniel, US Army Engineer Research and Development Center
Mr. Mark Hunt, Mississippi State University

The Defense Threat Reduction Agency (DTRA) tasked the U.S. Army Engineer Research and Development Center (ERDC) to perform a numerical validation of airblast data for several first-principles codes (FPC). In order to achieve this objective, a series of experiments were conducted at ERDC's Blast Load

Simulator (BLS) - a shock tube used for blast effects research that is able to reproduce both the positive and negative phases resulting from the detonation of a high explosive with the use of compressed gases. The experiments consisted of releasing air at a pressure of 800 psi and an initial volume of about 7.66 ft3 into the BLS tunnel. An instrumented box structure having a square cross-section had its center point located close to 35.14 ft from the pressurized vessel, a distance where the pressure wave was expected to have developed a planar front profile. The box had each of the five faces exposed to the flow equipped with several gauges that recorded pressure as a function of time. Three experimental configurations were tested, each having repeat shots to account for data scatter. The distinction between the tested configurations was the normal angle of one lateral side of the structure with respect to the flow direction. The angles considered were 0, 45, and 30 degrees of obliquity. Each of these experiments was modeled using the following FPCs: CTH, DYSMAS, Loci/BLAST, and SHAMRC. The selection of these codes represent a wide variety of modeling techniques for solving this problem, including the usage of unstructured and structured meshes, coupled Eulerian-Lagrangian and fully-Eulerian domains, and different integration schemes and remap logic in the solver of each code. This paper examines the use of these FPCs for modeling the BLS. Comparisons are made between the numerical results and experimental data, as well as assumptions made in the model setup of each code.
Permission to publish was granted by the Director, Geotechnical and Structures Laboratory.

A COMPUTATIONAL STUDY ON THE EFFECTS OF CASING PROPERTIES ON CLOSE-IN AIRBLAST

Mr. Joseph Abraham, Karagozian & Case, Inc
Mr. Pietro Gheorghiu, Karagozian and Case, Inc

The effect of material properties on casing fragmentation has been the subject of numerous computational and experimental studies. Most of these studies have focused on the relationships between the material properties with the velocity and mass distribution of the fragments. The casing material properties also have a pronounced effect on the close-in airblast environment but very few studies have focused on analyzing and quantifying this relationship.

To address this gap, this paper presents a numerical study aimed at quantifying the effect of casing material properties on the close-in airblast overpressure. Coupled computational structural dynamics and computational fluid dynamics simulations are employed to model the detonation of the high-explosive fill and the breakup of a cased explosive having a simplified geometry. The study aims to quantify the effect of brittle energetic and non-energetic casing materials on the properties of the close-in incident shock front, i.e. time of arrival, peak pressure, and impulse.

Results from a sensitivity study that considers parameters affecting the brittleness and fracture of the casing are provided. The results show strong correlation between the strength and brittleness of the material on the incident shock wave transmitted into the free air from the detonation of the cased charge. The results of the computations are then used to formulate analytical formulas that can be used to estimate the effects observed in the computations that can be enhanced or calibrated to test data.

EFFECTS OF CHARGE SHAPE ON OVERPRESSURE DISTRIBUTION

Mr. Christopher Price, US Army Engineer Research and Development Center
Mr. Sean R. Wade, U.S. Army Engineer Research and Development Center
Dr. Catherine S. Stephens, U.S. Army Engineer Research and Development Center
Dr. Jesse A. Sherburn, U.S. Army Engineer Research and Development Center
Dr. Robert E. Walker, U.S. Army Engineer Research and Development Center

Charge shape has been shown to cause standoff dependent effects on the blast loading of structures. Improved blast loading in fast-running structural response tools is needed for better predictive capabilities. The objective of this research was to determine the spatial and time variations of the overpressure history for cylindrical charges with varying length-to-diameter (L/d) ratios and a three-point symmetric detonation using computational modeling and experimentation. The well-known hydrocode CTH was used to investigate this problem computationally, and the Air Force Research Laboratory (AFRL) Blastpad was utilized to investigate the problem experimentally. For both computation and experimentation, one (1) hemisphere and seven (7) cylinders with L/d ratios varying from 1 to 7 were investigated. Overpressure data captured at azimuths every 22.5 degrees at various ranges from the AFRL Blastpad were compared to the CTH results for each geometry. A comparison of the overpressure histories from both the experiments and CTH was completed to understand the spatial and time variations produced by the different charge shapes.

ENERGY BASED SHOCK MODELS

6-DOF MECHANICAL SHOCK FAILURE PREDICTIONS OF A CANTILEVER STRUCTURE USING ENERGY RESPONSE SPECTRA METHODS

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

Shock Response Spectra (SRS) and energy spectra are both equally valid for quantifying mechanical shock severity. However, both of these metrics are traditionally applied only in one axis since tests are typically conducted one axis at a time. In contrast, many real world shock events occur in multiple axes simultaneously. This paper describes an analytical, numerical, and experimental study that compares SRS and energy response spectra from 6-DOF shock tests. A test structure holding four 3-D printed cantilever beams was used on a 6-DOF shaker system with three translational and three rotational shocks simultaneously applied at levels predicted to fail the test specimen. The combined 6-DOF test results are compared to single degree-of-freedom shock predictions and drop table test results with a focus on how SRS and energy response spectra failure predictions correlate with failures in the laboratory.

GENERATION OF EQUIVALENT HALF SINE SHOCKS TO MEASURED SHOCKS DURING FREE FLIGHT OF A MISSILE

Dr. Zeev Sherf, RAFAEL
Mr. P. Hopstone, RAFAEL
Mr. I. Sofer, RAFAEL
Dr. A. Elka, RAFAEL

During a free flight test of a missile shock time histories have been measured at a location on the system in the Y (lateral) and Z(vertical) directions. Although the measured time history were available

for the laboratory simulation, some administrative limitations imposed the generation of half sine equivalent shocks.

The purpose of the work described in this paper was the identification of Half Sine shocks "equivalent" to the measured shocks. The equivalence was established in terms of the energy carried by the measured shocks and as much as possible in the spectral content. Namely, Half Sine Shocks that carry the same energy and a similar spectral content as the measured shocks had to be identified. The paper describes the use of the energy equivalence principle in the derivation of the half sine testing shocks. The energy equivalence could be achieved but the spectral content not. The generated half sines are of the same energy but of different spectral content.

A NEW METHOD TO SYNTHESIZE AN SRS COMPATIBLE BASE ACCELERATION WITH ENERGY AND TEMPORAL MOMENTS TO IMPROVE MDOF SYSTEM RESPONSE, PART I

Dr. J. Edward Alexander, BAE Systems

A new method has been developed to synthesize a shock response spectrum (SRS) compatible base acceleration with additional parameters in the synthesis process beyond current practices. Current base acceleration synthesis methods address only SRS compatibility. However, additional information is available to synthesize a base acceleration to improve multi-degree of freedom (MDOF) system response accuracy. Expanding the synthesis procedure to include energy input and temporal information provides more constraints on the development of the synthesized acceleration. Similar to the SRS, an energy input spectrum (EIS) is a frequency based relationship for the peak energy input per unit mass to a series of single-degree of freedom (SDOF) oscillators from a base acceleration. The EIS represents total input energy contributions (kinetic, damped and absorbed energy). Temporal information includes overall shape of the transient shock pulse envelope E(t) (rise, plateau, decay) and five temporal moments. When EIS, E(t) and temporal moments compatibility are added to the synthesis procedure, an improved base acceleration results. To quantify the significance of these quantities, a regression analysis was performed based on linear and nonlinear 3DOF model responses. The regression analysis confirmed that compatibility with SRS, EIS and five temporal moments were significant factors to improve MDOF model response accuracy. To test this finding, a base acceleration was synthesized with the expanded procedure. Four other accelerations were synthesized with current state of the art methods which match the SRS only. The five synthesized accelerations were applied to a 3DOF model based on a US naval medium weight shock machine (MWSM). MWSM model results confirmed that the SRS, EIS, and temporal moment compatible acceleration resulted in improved MWSM model accuracy of peak mass accelerations and displacements in the majority of the cases, and consistently gave more accurate peak energy input to the MWSM model. Energy input to a structure is a significant factor for damage potential. The total kinetic, damped and absorbed energy input represents a system damage potential which the structure as a whole must dissipate.

A NEW METHOD TO SYNTHESIZE AN SRS COMPATIBLE BASE ACCELERATION WITH ENERGY AND TEMPORAL MOMENTS TO IMPROVE MDOF SYSTEM RESPONSE, PART II

Dr. J. Edward Alexander, BAE Systems

A new method has been developed to synthesize a shock response spectrum (SRS) compatible base acceleration with additional parameters in the synthesis process beyond current practices. Current base acceleration synthesis methods address only SRS compatibility. However, additional information is available to synthesize a base acceleration to improve multi-degree of freedom (MDOF) system response accuracy. Expanding the synthesis procedure to include energy input and temporal information provides more constraints on the development of the synthesized acceleration. Similar to the SRS, an energy input spectrum (EIS) is a frequency based relationship for the peak energy input per unit mass to a series of single-degree of freedom (SDOF) oscillators from a base acceleration. The EIS represents total input energy contributions (kinetic, damped and absorbed energy). Temporal information includes overall shape of the transient shock pulse envelope E(t) (rise, plateau, decay) and five temporal moments. When EIS, E(t) and temporal moments compatibility are added to the synthesis procedure, an improved base acceleration results. To quantify the significance of these quantities, a regression analysis was performed based on linear and nonlinear 3DOF model responses. The regression analysis confirmed that compatibility with SRS, EIS and five temporal moments were significant factors to improve MDOF model response accuracy. To test this finding, a base acceleration was synthesized with the expanded procedure. Four other accelerations were synthesized with current state of the art methods which match the SRS only. The five synthesized accelerations were applied to a 3DOF model based on a US naval medium weight shock machine (MWSM). MWSM model results confirmed that the SRS, EIS, and temporal moment compatible acceleration resulted in improved MWSM model accuracy of peak mass accelerations and displacements in the majority of the cases, and consistently gave more accurate peak energy input to the MWSM model. Energy input to a structure is a significant factor for damage potential. The total kinetic, damped and absorbed energy input represents a system damage potential which the structure as a whole must dissipate.

ADVANCEMENT OF NAVY ENHANCED SIERRA MECHANICS (NESM)

NAVY ENHANCED SIERRA MECHANICS (NESM) VERSION 4.1

Dr. E. Thomas Moyer, NSWC Carderock Division
Dr. Najib Abboud, Thornton Tomasetti Weidlinger Applied Science
Dr. Garth Reese, Sandia National Laboratories
Mr. Jonathan Stergiou, NSWC Carderock Division

Navy Enhanced Sierra Mechanics (NESM) is the DoD HPCMP CREATE Ships Shock/Damage software product providing massively parallel computational tools for ship shock and structural vulnerability predictions due to threat weapon engagements. NESM is designed to take full advantage of High Performance Computing (HPC) systems allowing for solution of models needed for high physical fidelity. The newer capabilities in NESM v4.1 include the Navy Enhanced Modeling Oracle (NEMO) hydrocode for the accurate prediction of threat weapon loads, parallel coupling increasing scalability on HPC, several enhancements to the Sierra Solid Mechanics (SM) and Sierra Structural Dynamics (SD) solvers as well as significant progress toward the goal of Automated ReMeshing (ARM). Included are various recent examples which demonstrate and partially validate these capabilities.

NAVY ENERGETIC MODELING ORACLE (NEMO) UPDATES

Mr. John Gilbert, NSWC Carderock Division
Mr. Paul Hassig, Thornton Tomasetti Weidlinger Applied Science
Dr. Badri Hiriyur, Thornton Tomasetti Weidlinger Applied Science
Mr. Michael Miraglia, NSWC Carderock Division
Mr. Jonathan Stergiou, NSWC Carderock Division

The use of physics-based modeling & simulation for the prediction of the shock response and structural damage due to weapons loading is expanding greatly in the support of the design and assessment of current and future fleet assets. To meet this expanding need, NSWC Carderock Division developed the

Navy Energetic Modeling Oracle (NEMO) - a robust, scalable Eulerian hydrocode which couples to Sandia National Laboratories' Sierra Mechanics suite (Sierra/SM and Sierra/SD) for fluid-structure interaction (FSI) problems via a novel embedded boundary methodology developed by the Farhat research group at Stanford University which enhances the current state-of-the-art [1]. This paper presents an overview of the technical capabilites offered in the current release of NEMO, results of recent numerical validation studies, and discuss future horizons in the development and deployment of NEMO as a component of the Navy Enhanced Sierra Mechanics (NESM) toolbox.

[1] K. Wang, A. Rallu, J-F. Gerbeau, and C. Farhat, "Algorithms for Interface Treatment and Load Computation in Embedded Boundary Methods for Fluid and Fluid-Structure Interaction Problems", International Journal for Numerical Methods in Fluids. 2011; 67:1175-1206.

VERIFICATION & VALIDATION OF NESM

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Mr. Michael Miraglia, NSWC Carderock Division
Dr. E. Thomas Moyer, NSWC Carderock Division
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Dr. Nicholas Reynolds, NSWC Carderock Division CD
Mr. Jonathan Stergiou, NSWC Carderock Division CD
Dr. Jesse Thomas, Sandia National Laboratories

The Navy Enhanced Sierra Mechanics (NESM) development effort follows robust software engineering practices which include software verification and validation (V&V), an integral part of the development process for production software. This process encompasses testing and comparison at multiple software levels, from unit tests through full physics modeling. Software V&V is a challenging task for codes designed to solve complex multi-physics problems. For the NESM toolkit, these V&V efforts are achieved through a combination of comparisons with analytic solutions, physical test data, and code-to-code benchmarks. Developer tools are employed to check for code robustness and identify potential issues to prevent negative impact to the userbase.

NAVY ENHANCED SIERRA MECHANICS (NESM) ROADMAP

Mr. Jonathan Stergiou, NSWC Carderock Division
Dr. E. Thomas Moyer, NSWC Carderock Division
Dr. Garth Reese Sandia National Laboratories
Dr. Jesse Thomas, Sandia National Laboratories

Since 2008, the Navy Enhanced Sierra Mechanics (NESM) product has made great strides in meeting the needs of the U.S. Navy's survivability and weapons effects community. At the request of the DoD HPCMP CREATE Program, the NESM team developed a detailed roadmap highlighting technologies planned for future implementation in the toolkit. The roadmapping effort includes feedback from stakeholders in the community and guidance from both NAVSEA technical authority as well as the CREATE Ships Board of Directors. This talk presents the process of roadmap development along with a detailed discussion of highlighted technologies and their impact on the community's problem set.

Verification and Validation of the User-Defined Mount Capability in NESM

Dr. Heather Reed, Thornton Tomasetti, Weidlinger
Mr. Ryan Anderson, Thornton Tomasetti, Weidlinger

Navy Enhanced Sierra Mechanics (NESM) is an innovative computational platform whose strategic objectives are to predict shock and damage effects of US Navy assets, while reducing the need for their physical testing. One of the capabilities that has been recently integrated into the platform is the user-defined mount. This feature, developed in Sierra SD, increases the number of complex nonlinear problems that NESM is capable of tackling, while addressing myriad of equipment and deck isolation design challenges.

Recently, NSWCCD has coordinated a verification and validation effort of this NESM capability. The basis for the verification and validation effort is the legacy Ultra Low Gravity (ULG) mount system, an advanced prototype mount system evaluated by NAVSEA in the early 2000 time frame. This paper summarizes the V&V effort that demonstrates the methodology and feasibility for developing user-defined mounts in NESM.

Fluid Structure Interactions in Massively Parallel Navy Applications

Mr. Garth Reese, Sandia National Laboratories

Fluid/structure coupling for navy interactions has been studied for many years, and a variety of solutions are available for numerous use cases. These applications range from structural acoustics problems with highly accurate far field solutions to near ship shock, involving highly nonlinear fluid and structural responses. The coupling mechanisms to achieve these goals are also varied, including fully coupled analyses in frequency and time, and staggered time solutions.

New hardware and software architectures influence these couplings. In particular, large distributed computers add complexity to the approach. We review the fluid/structure coupling algorithms that have been successfully exercised in the NESM arena.

Structural acoustics has been dominated by full matrix coupling. When this coupling is combined with node on face constraint equations at the wetted surface, the distributed software model is simplified by adding acoustic degrees of freedom to the wetted surface nodes. This ensures that the structural and acoustic degrees of freedom of the coupling matrix are all available on the same processor unit (or MPI rank), thus localizing the storage of that matrix.

NEMO/Sierra has developed the Navy Standard Coupler (NSC), using message passing as the communication strategy. The NSC is based on a multiple program, multiple data (MPMD) strategy and general coupling. The MPMD coupling permits uncoupled development of independent structural and fluid analysis and software. Coupling options include second order staggered approaches, such as that presented by Farhat et al, but the coupler is flexible enough to also handle subiteration within a timestep. Variations on this coupling are being employed for the CREATE/AV coupling as well.

INTERNAL BLAST RESEARCH AND PENETRATION TEST METHODS

OVERVIEW OF AFRL JOINT WEAPON EFFECTS RESEARCH
Mr. Ernest Staubs, AFRL/RWML

The harsh environments resulting from a detonation can injure inhabitants, infrastructure, and disrupt the operation of critical equipment in a target. Tools currently used to predict functional degradation and component damage often under predict the results. This can result in unnecessary sorties being conducted to insure a desired level of damage in a target, placing aircrews and the local population at additional risk. The Department of Defense conducts weapon effects experiments attempting to duplicate those harsh environments. The effect of these environments on personnel, infrastructure, and critical electronic equipment is not fully understood, so it isn't well modeled. Experiments were conducted investigating the response of urban structures to weapon detonations. In addition to the primary structural response objectives, the test team conducted research on the secondary debris generated by the detonation. The study is two-fold. The goal is to provide verification and validation data for fast running models that predict the generation of secondary debris and to determine the ability of this debris to cause additional damage or casualties.

AN INTRODUCTORY SCALABILITY INVESTIGATION OF EXPLOSIVE CHARGE DETONATIONS INSIDE A SUB-SCALE STRUCTURE
Mr. Roosevelt Davis, Air Force Research Laboratory
Dr. Alan Ohrt, Air Force Research Laboratory
Dr. John Rogers, Air Force Research Laboratory

Confined airblast testing in multiple room structures is limited by high cost and test site availability. These two factors are often factors driving scientist and engineers to find less expensive and more available ways of doing things. The Air Force Research Laboratory has locations available to conduct confined airblast testing. These locations are not controlled by AFRL and typically requires AFRL to be queued with low priority. Extensive confined airblast testing has been conducted in a multi-room full-scale building. Due to the amount of data available from the full-scale building, it was a logical choice for investigating sub-scale testing in a multiple room structure. A sub-scale test structure was constructed to facilitate this need. The potential to collect a larger volume of data for improving fast running models, building new models, and developing a better understanding of internal confined airblast are also motivators.

The full-scale building was scaled down to a manageable size. Scalability considerations were not only given to the structure but also to the charges to be tested in the sub-scale structure. The sub-scale charges mass and explosive type were all selected to be sub-scale representations of charges previously tested in the full-scale building. This will be discussed to greater detail in this paper.

AN EVALUATION OF CONFINED AIRBLAST ENVIRONMENTS FROM A SINGLE AND MULTIPLE DISTRIBUTED CHARGES
Mr. Roosevelt Davis, Air Force Research Laboratory
Dr. Alan Ohrt, Air Force Research Laboratory

Typically, multiple room structures are engaged with traditional warheads on the order of hundreds to thousands of pounds. A new train of thought brings about the question whether several small charges can have the same effect on multiple room structures as a single larger charge. This paper will discuss an initial investigation of a single large charge compared to multiple smaller charges detonated in a subscale structure.

Charge size is a significant contributor to weapon selection when engaging any target. Larger weapons with large explosive weights do, in fact, produce relatively large overpressures for inducing damage throughout a structure. However, one large charge can only be in one place at one time. This places burden on the large charge of producing enough overpressure to sustain desired damage levels throughout a multiple room structure. Several smaller charges could potential improve or match the ability of a single large charge to produce overpressures necessary for desired sustained damage throughout a structure.

An investigation comparing several small charges to one single large charge was conducted utilizing a sub-scale multiple room structure. A single charge of mass M was detonated inside the sub-scale structure. Several smaller charges of mass M/n, where n is the number of charges detonated simultaneously, were detonated inside the sub-scale structure. Pressure data during all detonations was collected from which relative impulse was derived. A subsequent initial comparison of this data will be presented.

RESEARCH INTO SECONDARY DEBRIS AND ITS POTENTIALLY DAMAGING EFFECTS ON PERSONNEL, INFRASTRUCTURE, AND EQUIPMENT

Mr. Ernest Staubs, AFRL/RWML

The harsh environments resulting from a detonation can injure inhabitants, infrastructure, and disrupt the operation of critical equipment in a target. Tools currently used to predict functional degradation and component damage often under predict the results. This can result in unnecessary sorties being conducted to insure a desired level of damage in a target, placing aircrews and the local population at additional risk. The Department of Defense conducts weapon effects experiments attempting to duplicate those harsh environments. The effect of these environments on personnel, infrastructure, and critical electronic equipment is not fully understood, so it isn't well modeled. Experiments were conducted investigating the response of urban structures to weapon detonations. In addition to the primary structural response objectives, the test team conducted research on the secondary debris generated by the detonation. The study is two-fold. The goal is to provide verification and validation data for fast running models that predict the generation of secondary debris and to determine the ability of this debris to cause additional damage or casualties.

EXPLOSIVE FILL RESPONSE MEASUREMENTS IN PENETRATING WEAPONS

Mr. Justin Bruno, Applied Research Associates
Mr. John Perry, Applied Research Associates
Mr. Drew Malechuk, Applied Research Associates
Mr. James Wertz, Applied Research Associates
Mr. Craig Doolittle, Applied Research Associates
Mr. David Truncellito, Applied Research Associates
Mr. Nicolas Jarrett, Applied Research Associates
Mr. Edwardo Freeman, AFLCMC/EBD
Mr. Tyler Underwood, AFLCMC/EBD

Next generation penetrating weapons are expected to relocate fuzes from the traditional tail of the weapon into the explosive fill to improve the survivability of the fuzing system and potentially control the energetic output as well. ARA has developed a measurement device to characterize the pressure and acceleration environment of explosive fills in full-scale penetration events that is being used to develop validate requirements for embedded fuzing solutions. The REAPR (Recorder for Embedded Acceleration and Pressure Response) is unique in its design, as the data recorder and measurement transducers are all containing within the embedded system. Only a small battery and communications cable are required outside the weapon. The design allows for the traditional fuzewell to be available for fuze testing or hard mounted tail data collection. The REAPR has been designed to survive pressure environments up to 45,000 psi and has successfully measured pressures near its limit. The data collected from the REAPR has been used to qualify embedded fuzing solutions requirements and is being used to validate and improve explosive fill constitutive models. To date, three full-scale sled tests have been conducted with the REAPR, each successfully measuring dynamic pressure and accelerations. The presentation will focus on the REAPR methodology along with collected test data and comparisons to simulation results.

RECENT IMPROVEMENTS TO THE BLASTX ENGINEERING LEVEL CODE

Mr. Gregory Bessette, US Army Engineer Research and Development Center
Mr. Gustavo Emmanuelli, US Army Engineer Research and Development Center
Mr. Van Le, Integrated Solutions for Systems
Dr. Alan Ohrt, Air Force Research Laboratory

BlastX is a fast-running engineering-level code designed to predict the airblast environment associated with open-air and internal detonations. For the latter, the code can model the shock transmission through complex, multi-room structures. Further, it can track the later time gas flow throughout the structure. There have been a number of recent developments that sought to improve both functionality and accuracy of the code. These include the development of a modern graphical user interface (GUI), implementing support for non-orthogonal wall panels, and the development of a new dynamic gas pressure model. The new GUI was developed under the Qt framework and is supported on Windows platforms. It has been modernized to allow users to develop and view multi-room, multi-story structures. An additional improvement to functionality focused on supporting non-orthogonal wall panels. Prior versions of the code required that wall panels in a room be rectangular. This presented a limitation for some users when trying to model blast in structures with vaulted ceilings and off-axis rooms/hallways. BlastX now supports panels comprised of irregular quadrilateral and triangular shapes, allowing for a broader range of blast environments to be modeled. The last improvement discussed in this paper is the development of a dynamic gas pressure model. BlastX has traditionally treated the shock and quasi-static gas phase environments independently due to their disparate time scales. The code still takes this approach; however, a third component has been added to the blast solution – the dynamic gas flow. It is well known that the dynamic flow of gases associated with internal detonations can lead to increased damage potential to equipment in rooms well away from the detonation location. The new model incorporates a time-dependent room-fill model that tracks the leading edge of the gas front. This is more representative of the underlying physics of the gas flow problem and overcomes limitations with the older model that relied on a homogeneous room fill within multi-room structures. An initial implementation of the model is in BlastX with validation on-going with subscale tests being conducted by the Air Force Research Laboratory.

MECHANICAL SHOCK TEST DESIGN & ANALYSIS

SHOCK RESPONSE SPECTRUM SHAPING USING STRUCTURAL MODIFICATIONS

Dr. Jason Blough, Michigan Technological University
Dr. James DeClerck, Michigan Technological University
Mr. Charles VanKarsen, Michigan Technological Univeristy
Mr. David Soine, Honeywell FM&T

This paper presents a case study on how structural dynamics of a test system shape a Shock Response Spectrum (SRS). A detailed experimental modal analysis was performed and used to correlate a finite element model of a shock response plate with attached fixture. Various structural modifications were then performed to the model or experimentally and SRS's predicted to understand the effects of various modifications on the SRS. Modifications included boundary condition changes, adding masses, adding damping, adding tuned mass dampers, and moving the test fixture to different locations on the shock response plate.

FIXTURE EVALUATION FOR SHOCK TESTING

Mr. David Soine, Honeywell FM&T
Mr. Richard Jones, Honeywell FM&T

Improved testing and modeling capability has provided more accurate environments definition for environmental testing. When those efforts expand the shock testing performance envelope at a production test lab, legacy testing processes may need to be updated to ensure efficient testing and accurate environment reproduction. If new specifications contain reduced shock pulse durations or resonant fixture-type tests, legacy fixtures and legacy fixture designs may no longer be adequate. Failure to properly evaluate legacy fixture designs may lead to increased setup times and dramatically increased testing costs if those designs are carried over into shorter-duration shock tests. This work will examine approaches for fixture evaluation.

CONSIDERATION OF SRS DECAYED SINE TONE FREQUENCIES

Ms. Julie Harvie, Sandia National Laboratories
Dr. Michael Starr, Sandia National Laboratories

In order to perform a shock test on a shaker, a time history must be synthesized that roughly matches the desired Shock Response Spectrum (SRS). The sum of decaying sinusoids method is commonly used for time domain synthesis, as it allows the engineer to accurately match SRS profiles of just about any shape. The method uses a summation of several sinusoid waves at discrete frequencies to produce a composite wave whose SRS closely matches the desired SRS. The frequencies of the sinusoid tones are typically chosen to have a prescribed octal spacing. In this paper we investigate the sensitivity of response of a test article to the frequencies of the sinusoid tones, especially with respect to the test article's natural frequencies.

DESIGN OF A RESONANT PLATE SHOCK FIXTURE TO ATTENUATE EXCESSIVE HIGH-FREQUENCY ENERGY INPUTS

Dr. Carl Sisemore, Sandia National Laboratories
Mr. Matt Spletzer, Sandia National Laboratories

Resonant plate testing is a common test method for simulating high energy mechanical shock events in the laboratory. A plate sized for a desired fundamental resonant frequency is impacted with a projectile fired from a gas gun while the article under test is attached to the plate opposite the impact point. Since the plate is a fixed size, tuning of the resonant plate response is performed by adding weights and damping material to the plate and shaping the impact pulse using different materials between the projectile and plate. A recent concern was discovered during testing where excessive high-frequency energy beyond the 10kHz upper bound of the test spectrum was being transmitted to the test article. Numerous experiments were conducted to determine the source of the excessive high-frequency energy and a method was developed to help attenuate that energy significantly. Subsequent to that investigation, a new resonant plate was designed incorporating the high-frequency isolation concepts derived previously resulting in a resonant plate with very little energy excitation beyond the 10kHz range.

UNDERSTANDING THE EFFECT OF EMBEDDED SHAPES IN A POLYMERIC COMPOSITE UNDER SHOCK

Capt Hayley Chow, AFRL/RWMF
Dr. Jacob C. Dodson, AFRL/RWMF
Dr. Janet C. Wolfson, AFRL/RWMF
Mr. Christopher Green, KRC
Mr. Geoff Gwaltney, KRC

It is critical to be aware of the mechanical interaction between items electronic assemblies embedded in a polymeric fill and the interactions between the loading on the item and the composite. In a high shock event the dynamic motion of embedded electrical components may plastically deform the fill, while the composites internal pressure has the potential to crush the external housing of the electronic assembly. Primary design considerations include the optimal density tolerance, volume, and shape, of the embedded components.

In order to define the optimal shape for embedded components, AFRL/RW is developing a methodology to assess the mechanical survivability of the polymeric simulants using embedded masses of differing form factors. RWMF researchers utilize air gun testing to subject a fixture, filled with a polymeric composite and embedded components with differing shapes to high impact events in order to subject the embedded masses to large dynamic environments. Pre and post x-rays are compared to determine any movement of the embedded mass during the test or damage to the polymeric fill. Then, the embedded masses are extracted from the simulant and examined for damage. Both 2D and 3D quasistatic and dynamic mass punch experiments were also performed to evaluate changes in geometry, fill properties, and surface finish of objects in the embedded environment. The final goal is to determine the optimal density tolerance, volume, and shape of the embedded electronic components that does not damage the surrounding media. This paper will discuss the current status and future work on developing an optimal embedded mass for operational functionality.

STRUCTURAL RESPONSE & NUMERICAL METHODS

METHOD OF DESIGNING ELECTRONIC ASSEMBLIES WITHOUT POTTING FOR GUN LAUNCHED APPLICATIONS THROUGH THE USE OF ADDITIVE MANUFACTURING

Mr. Steven Manole, ARDEC
Mr. Christopher Stout, ARDEC
Mr. Nickolas Baldwin, ARDEC
Mr. Richard Granitzki, ARDEC
Mr. James Caplinger, ARDEC
Mr. Douglas Weinhold, ARDEC
Mr. Alfred Rotundo, ARDEC

As precision and smart munitions continue to evolve with electronic technical advances, gun hardening techniques must also keep pace. Traditionally, potting and encapsulating of electronics is a common method for improving their survivability when experiencing a large amount of acceleration. Fully potting or encapsulating the electronics allows them to be fully supported from all sides as well as performing an environmental dampening function by reducing the stresses on the circuit board and its electronic components. Structural integrity issues arise when the entire Printed Circuit Board (PCB) is allowed to deflect past the critical strains which solder joints can typically withstand. As a rule of thumb this has been shown to be on the order of 0.004'' to 0.005'' of deflection. An entire PCB effectively deflects like a drum head, causing such failures to occur. Potting solves this deflection issue by uniformly providing a stiffener to the entire PCB, yet introducing thermal cycling issues. Moving one step further towards an alternative to potting, is the use of a plastic spacer to provide support between PCBs. The purpose of the spacer is to prevent the boards from deflecting, thus preventing the components on the boards from failing. The spacers, unlike potting are not permanently attached to the boards, but instead removable and provide support to the PCB in critical locations. This allows the electronics to be removed or reconfigured, if necessary, while still providing rigidity in the critical points of the design in order to control overall board deflections. In addition, the spacer does not constrict the components, and only makes contact with areas of the circuit board that can handle being compressed thus allowing components to expand and contract unconstrained during thermal cycling. In our development cycle, tests with different spacer designs had to be conducted, which was only feasible in a short time frame using Finite Element Analysis (FEA). The output of each analysis contained displacement data at each node of the model. By comparing two data points on the surface of the board, our team was able to determine axial deflection of the modeled PCB across the imaginary line connecting the two data points. With this data, prototype spacers were fabricated to support electronics systems during live fire 155mm MACS 4 testing events. Results of the tests are discussed.

3D FE AND 2DOF SIMULATIONS OF GROUND SHOCK EXPERIMENTS – REFLECTION PRESSURE TIME HISTORY DEPENDENCY DUE TO THE STRUCTURE'S STIFFNESS AND MASS

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This paper simulates, by using 3D Finite Element (FE) Autodyn and simple two degree of freedom (2DOF) model, experiments from 1980s conducted by S. Hultgren, FORTF, where Hultgren studied the structural response of a well-defined structure; a suspended piston-spring system buried in sand subjected for ground shock from an explosive charge. The experiments showed that if the suspended mass of the

piston is increased the initial reflected pressure also increases. Similarly, the experiments showed that if the stiffness of the suspended piston is increased the reflected pressure time history increases for the latter part of the reflected pressure curve. The first aim of the simulations was to better understand the physics of the observed experimental results. Based on this, the second aim was to find a methodology that can use simplified relationships for ground shock prediction, from e.g. Conwep, in combination with simplified models such as 2DOF, to predict the structural response for example a buried concrete wall.
The FE simulation models were generated in Autodyn-3D, where the sand was modelled with Euler cells and the piston, spring, and cylinder were modelled with Lagrange element. The sand was modelled with an Equation of State (EOS) designed for porous soils which was implemented in Autodyn as a user subroutine by the authors. The FE simulation results confirm the trend found in the experimental results. They also imply that the mass from the interacting ground material is greatly affecting the response of an underground structure subjected to impulse loading. The simple 2DOF model confirms some of the main behaviour found in the FE results and experiments.

MECHANICAL RESPONSE OF STIFF SPHERICAL COMPONENTS IN A COMPLIANT MEDIUM OF A CLOSED SYSTEM UNDER EXTERNALLY APPLIED IMPACT LOADING

Dr. Catherine Florio, US Army ARDEC

In this work, a system consisting of a stiff rectangular enclosure housing, a compliant medium, and a set of stiff spherical masses embedded in the medium is subjected to an externally applied impact shock load. While the stress waves that are generated in a medium of this closed system are also imposed on components embedded within the medium, the embedded components disrupt the stress waves that are propagated through and reflected in the medium. They, therefore, alter the local magnitudes and timing of the dynamic system response and have the potential to significantly affect the behavior of the medium within the closed system undergoing shock or impact-like loads. The stresses imparted by the medium on the components and the alterations to the structural response of the closed system due to these included masses are functions not only of the mechanical properties, sizes, and shapes of the embedded components, but also of the number of components included and their locations and relative arrangement within the medium of the closed system. Because design requirements may place fewer restrictions on the number of embedded components and their placement within the medium than on their material or geometry, these parameters are the focus of this computational parametric study. The system studied is subjected to an acceleration load of approximately 10,000G. The surface averaged contact pressure at each wall and over each embedded component, the relative movements of the medium and the components, and the total energy changes are compared for systems consisting of a uniform compliant medium alone or one, two, or four embedded stiff spherical components in various arrangements. All spherical components have the same density as the more compliant medium as does the bounding housing structure. However, the elastic modulus of the compliant medium is three to four orders of magnitude lower than that of the other system components. Through the study, a better understanding of the effects of the inclusion of stiff components embedded in a closed system undergoing shock or impact-like loading is found. The study results can be used to guide design decisions to better control the pressures imparted on the embedded components or to control the behavior of the compliant medium in this kind of system.

RESEARCH ON CONSERVATISM OF SHOCK STRESS REDUCTION FACTOR IN STRESS EVALUATION OF STAINLESS STEEL PIPING BY ELASTO-PLASTIC DESIGN

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Shock dynamic load as compared with sustained mechanical loads is of less damage effect on materials with good ductility and plasticity, which is implemented in shock stress evaluation codes in a form of stress reduction factor when combing shock stress with stresses due to other mechanical loads, like a factor of 2/3 in ASME code ,0.5 for elastic design and 0.25 for elasto-plastic design in other shock evaluation codes. Laboratory shock tests show that stainless steel piping yielding an obvious plastic deformation after subjected to high shock can still remain pressure boundary integrity while failing to pass stress evaluation according to shock stress evaluation code, which shows a large conservative margin in shock stress evaluation code for stainless steel piping. Aiming at reducing over conservative margin of shock stress reduction factor in stainless steel piping designed by elasto-plastic rules, a method is used by carrying out elastic and elasto-plastic calculations for stainless steel piping with scaled three kinds of independent loads of gravity, pressure and shock loads, respectively, to obtain nominal stress and actual total strain for manifesting shock load's less damage effect on stainless steel piping. Comparative analysis results show that shock stress reduction factor 0.25 stipulated in shock codes is of conservative margin, and a new value of 0.2 is proposed for elasto-plastic design. Conclusion is that a new shock stress reduction factor of 0.2 by elasto-plastic design can not only meet code requirements of conservatism but also reduce over conservative margin in shock stress evaluation.

UNDEX II

INVESTIGATION ON CRITICAL PRESSURE OF DEFORMED RING STIFFENED CYLINDERS CAUSED BY UNDEX

Mr. Jun Wang, China Ship Science Research Center

The ring stiffened cylinders are the major forms of submarine pressure-resistant structure. Investigation on structural damage under underwater explosions and static pressure combained loadings is important in submarine shock-resistant. On this situation, the transient interaction of fluid and structure and the failure modes are very complicated. In this paper, the method on the critical pressure of deformed ring stiffened cylinders causrd by UNDEX loads was proposed based on the theory of shell structure, and the effect of static was also taking into account an experimental reult of the ring stiffened cylindrical shells subjected to underwater explosions and static pressure was compared with the computational results, which showed a good agreement. The method proposed in the paper will be substantial foundation for further study on submarine shock-resistant.

INVESTIGATION ON FLUID-STRUCTURE INTERACTION OF SHIP STRUCTURES WITH ANECHOIC COATING

Mr. Zeli Lou, China Ship Science Research Center
Prof. Jianhu Liu, China Ship Science Research Center

In order to get the dynamic response of ship structures with acoustic tiles subjected to underwater explosion, the analytical method of fluid-structure interaction was developed. Acoustic wave equation was adopted in the early time/ high frequency. By taking the propagation processes of shock wave in the water, anechoic coating and steel layer as the research object, equivalency of impulse was used to

modify the reflection coefficient of the shock wave in the Taylor's plate model. Then, combined with the Doubly Asymptotic Approximation (DAA2) method, the analytical method of fluid-structure interaction for the dynamic response was presented to analyze the dynamic response. Besides, the results of underwater explosion experiments on ringing stiffened cylinders covered with anechoic coating were used to validate the analytical method and a good consistent was achieved. Finally the validated analytical models were used to investigate the effects of mass, thickness, impedance and loss factor of tiles to the response of plate.

INVESTIGATION ON DISTORTION EFFECT IN UNDERWATER EXPLOSION PRESSURE MEASUREMENT CAUSED BY ACCELERATION

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Mr. Haibin Mao, China Ship Science Research Center
Ms. Jing Yang, China Ship Science Research Center

In some cases of underwater explosion pressure measurement, the sensitive elements would be of great acceleration, which may change the original distribution of pressure field, and accordingly make the waveform distortion that would reduce the measurement reliability. In this paper, An intensive investigation on this problem was executed. Firstly, the mechanism of distortion caused by acceleration were analyzed. The theory model was established basing on the dynamic response governing equation of sensitive elements, and then the influence laws of sensors to acceleration were put forward for the free field pressure measurement and the wet-surface pressure measurement Secondly, the relevant two type of pressure sensors were tested using the drop hammer machine, and the relations of the acceleration input and the distortion pressure waveform output with no pressure load input were obtained. Finally, a series of underwater explosion tests for different sensors were carried out. Combining with the drop hammer machine results, and the established theory model were validated with the test results. it is showed that, the influence factor of the distortion effect were mainly affected by the measuring medium, the overpressure value and frequencies, the supporting mass of sensitive elements A recovery method was proposed for dealing with the distorted measuring waveform of an underwater explosion shock pressure. The findings may be helpful for the reliable measurement of underwater explosion pressure and the structural design of the sensors.

THE EQUIVALENCE OF SHOCK ENVIRONMENTS OF THE REAL SHIP AND THE SFSP TO A HEAVY RESILIENT MOUNT EQUIPMENT

Prof. Jianqiang Pan, China Ship Scientific Research Center
Mr. Bin He, China Ship Scientific Research Center
Mr. Xuebing Chen, China Ship Scientific Research Center

The low frequency shock environment down to 5 hertz of a naval ship to UNDEX is controlled by the shock wave load and that of the standard floating shock platform (SFSP) is controlled by the bubble pulsation load. The above difference may cause some discrepancy in the real shock loading to the heavy resilient mount equipment for shock validation test even if with the same shock spectrum at the rigid basis frequency. In order to investigate the equivalence of shock environments of the real ship and the SFSP to the heavy resilient mount equipment, the test and numerical method were employed in this paper. The difference of the loading mechanism between real ship and the SFSP to the heavy resilient equipment was compared. A series of UNDEX test were executed to the SFSP and the shock environment and the responses of a resilient mount equipment were measured. The responses of the same equipment on a ship to UNDEX were investigated by FEM numerical method. It is shown that the

damping effects are the main factor that cause the different responses of the equipment with the same shock spectrum.

INVESTIGATION OF UNDERWATER EXPLOSIVE EFFECTS IN CLOSE PROXIMITY OR CONTACT TO AN AIR-BACKED PLATE

Mr. Zhangtao Zhou, China Ship Scientific Research Cetner

Measurement of wall-pressure and velocity together with high-speed imaging have been used to study the interaction of an underwater explosion in close proximity or contact to an air-backed plate, where the stand-off distance was less than or equal 6 times of radius of explosive charge. Variation of the distance between the plate and explosive charge generated different cases of interaction in which the wall-pressure, the plate velocity to shock wave and cavitation were studied. The plate panel under the same experimental conditions was numerically analyzed using AUTODYN code. Fluid-structure interaction mechanisms in close proximity or contact cases were examined. The result showed that the shock reflection between the bubble and the plate caused cavitation and its subsequent collapse reload.

BLAST – NUMERICAL COMPARISONS

COMPUTATIONAL AND EXPERIMENTAL COMPARISON OF COMPLEX COMPONENTS UNDER MECHANICAL SHOCK

Dr. Janet Wolfson, Air Force Research Laboratory

No abstract available.

NEW APPROACH TO MODELING BLAST WAVE PHENOMENON

Mr. Justin John, US Army ARDEC Picatinny Arsenal
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Mr. David Geissler, US Army ARDC Picatinny Arsenal

Designing a test fixture that can survive the harsh conditions of energetic blast relies on predicting non-linear structural response while capturing both fixture strength and inertia. Hydrocodes, such as Abaqus Explicit,can be extremely useful in predicting the structural flexure and damage due to shock waves traveling through air. The blast wave pressure amplitude and impulse values can be approximated using TNT mass scaling based on empirical data. These values are often difficult to apply to complex structures due to numerical difficulties. A novel approach of applying the blast pressure tand impulse onto a structure, employing CONWEP and the Coupled Eulerian Lagrangian technique, was developed and is described in this investigation. The paper explores this new methodology and reveals rebound wave phenomenon off basic and complex shapes associated with the blast test stand. The analysis was used to down select possible test fixture designs before hardware fabrication. The models used in this research are paired with proper validation from field experiments to provide high confidence in results. This paper will provide a direct comparison of structural response of a test fixture between experimental and analytical blast overpressure data.

EXPERIMENTAL AND NUMERICAL PERFORMANCE EVALUATION OF A TOWER COMPONENT SUBJECTED TO BLAST LOADING

Mr. Robert Browning, US Army Engineer Research and Development Center
Mr. Vincent Chiarito, U.S. Army Engineer Research and Development Center
Dr. James Baylot, U.S. Army Engineer Research and Development Center
Mr. Donald Nelson, U.S. Army Engineer Research and Development Center
Mr. John Geringer, U.S. Army Engineer Research and Development Center

The blast environment around structural components can be difficult to quantify, especially when the geometry of the structure is complex. Conservative approximations can be made, but usually at the expense of more economical designs. Therefore, it is often necessary to make use of high-fidelity numerical simulations to guide the design process. Similarly, an experimental assessment may also be warranted to provide confidence in the simulation results.

This presentation will discuss the process of performing a scaled experiment for a concrete tower component subjected to blast loads that resulted in a complex loading environment. An Eulerian model was run using DYSMAS to simulate the blast event, and the resulting loads were then applied to a Lagrangian model of the structure that was run in LS-DYNA. A comparison between the experimental and numerical results will be made, and the lessons learned from the numerical modeling process will be discussed.

INVESTIGATION INTO UNRESOLVED DISCREPANCIES BETWEEN AIRBLAST CODES AND A HISTORICAL SET OF SHOCK TUBE EXPERIMENTS

Mr. Andrew Barnes, US Army Engineer Research and Development Center
Dr. James O'Daniel, U.S. Army Engineer Research and Development Center
Dr. Greg Bessette, U.S. Army Engineer Research and Development Center
Dr. Carol Johnson, U.S. Army Engineer Research and Development Center

First-principle codes are routinely used to make predictions of blast-related events. These codes should be benchmarked against experimental data to produce confidence in their predictive capabilities and to identify any discrepancies between the simulated and experimental results.

As part of an ongoing effort, the Defense Threat Reduction Agency (DTRA) tasked the U.S. Army Engineer Research and Development Center (ERDC) to reexamine a set of experiments studying the interaction of a non-decaying shock wave with a stationary block at three different Mach speeds that was conducted at the Zephire Shock Tube Facility at the Centre d'Etudes de Gramat (CEG) in France during the late 1980s to early 1990s time period. In multiple studies dating from 1995 to 2012, several high-fidelity codes routinely used to simulate airblast had difficulty reproducing the results from these experiments. ERDC reexamined this set of experiments and the ability of the current generation of codes to recreate the experiments and investigated the cause of the differences observed between the experimental and computational results.

To further investigate the differences, a similar class of experiments was conducted in ERDC Blast Load Simulator (BLS) to produce supplementary experimental data for which the test-to-test variability and uncertainty could be quantified. These test results were very repeatable and produced experimental data with features similar to the CEG data. As with the CEG experiments, several codes had difficulty reproducing certain aspects of the BLS experiments.

The codes in the current study were CTH, DYSMAS, Loci/BLAST, and SHAMRC. Discrepancies between the calculations and the experimental results, the origin of these differences, and recommendations to overcome them will be discussed.

GROUND BASED FLIGHT SIMULATION

THE IMPORTANCE OF COMBINED ENVIRONMENT TESTING

Mr. Edward Romero, Sandia National Laboratories
Mr. Rich Jepsen, Sandia National Laboratories

The high cost and infrequent opportunities for flight testing and the criticality for mission success make ground-based testing essential. In the past, the approach has been to analytically assess components with limited ground test capabilities and then rely on flight tests as part of the qualification evidence. Although this is a reasonable approach based on existing ground test capabilities, a superior method is to analyze and test the components with more realistic, coupled environments to build confidence before, or in place of, flight testing. Recent progress in combining vibration and acceleration (Vibrafuge) has demonstrated a significant impact on understanding flight systems and is becoming integral to development, qualification and surveillance testing. The Vibrafuge has dramatically demonstrated the differences in component and system performance. For example, nearly 20 systems have been tested using the Vibrafuge with 90% demonstrating measurable differences in performance or operational margin to the extent of pass/fail criteria.

SUPERFUGE: ADDING SPIN TO THE VIBRAFUGE

Mr. David Siler, Sandia National Laboratories
Ed Romero, Rich Jepsen, Sandia National Laboratories

It has been demonstrated that combining test environments to achieve the most realistic ground based tests possible is a vital aspect of system and subsystem testing that should not be ignored. This has been shown by the development and use of 6DOF vibration systems and the Vibrafuge. Over the past three years Sandia National Laboratories has been developing a new test capability that will provide testers with the ability to perform spin-tests on full scale weapon systems and subsystems while also experiencing the inertial loads. The long term goal is a turn-key “Superfuge” capable of testing re-entry vehicles to the same acceleration, vibration and spin environments encountered during actual launch, flight and atmospheric re-entry. Progress with system development and testing will be discussed.

ADDING FLIGHT SHOCK ENVIRONMENTS TO SUPERFUGE CAPABILITY

Mr. Richard Jepsen, Sandia National Laboratories
Mr. Troy Skousen, Sandia National Laboratories
Mr. Edward Romero, Sandia National Laboratories

Compelling evidence supporting the importance of combined environments in testing suggests that other known environments in flight should also be developed such that they can be combined with the inertial loads from centrifuge testing. The addition of vibration with inertial loads has been developed and studied extensively. The addition of spin with vibration and inertial loads is being developed. An important aspect of flight environments yet to be combined includes staging and separation shocks that occur during flight. Inclusion of these environments will further Sandia’s commitment to testing systems to the most realistic environments possible while strengthening the confidence and reliability of our systems. There are many potential technologies that may be used to implement flight shock on a centrifuge and Sandia is investigating and will be proof-testing the strongest candidate(s). Another aspect of this work that will be discussed includes the study and integration of the appropriate time history of when and how shock is integrated with acceleration, vibration and spin.