SAVIAC
Shock and Vibration Information Analysis Center

Abstracts

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ELECTRIC BOAT CORPORATION
A GENERAL DYNAMICS COMPANY

Excellence in Testing
ATC
Aberdeen Test Center

U.S. Army Research Laboratory

INTRODUCTION

The Shock and Vibration Symposium is the oldest continuing meeting (since 1947) dealing with the specialized engineering problems and effects of dynamic environments on vehicles, structures, equipments, components and humans. The Symposium was created as a mechanism for the exchange of information among Government agencies concerned with design, analysis and testing. It provides a valuable opportunity for the technical community in Government, private industry and academia to meet and discuss problems of mutual interest.

This year's Symposium is co-hosted by the US Army Aberdeen Test Center, General Dynamics Electric Boat Corporation, and the US Army Research Laboratory. These organizations are represented on the TAG by Mr. William (Skip) Connon III, Mr. Austin Alvarez, and Mr. Abraham (Ami) Frydman, respectively.

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ME1: Analytical Methods #1 (Classified)

Representation of Fluid-Structure Interaction Using Hydrodynamic Mass Coupling

Neal H. Guilmette, Stephen F. Gordon & Albert Page, *Electric Boat Corporation*

For rigid-body motions at low accelerations, fluid-structure interaction of multiple bodies may be represented via a hydrodynamic mass coupling matrix. A methodology has been developed for determining the mass coupling matrix of arbitrary bodies using USAERO, an unsteady potential flow code. Results of this methodology have been validated to closed-form analytic solutions and experimental data, and its implementation into transient shock analyses have been correlated to simple 2-D and 3-D finite element models. The advantage of this methodology is its computational efficiency since it does not require discretization of the fluid via finite elements.

ME2: Engineering for Cost Reduction (Classified)

Correlation Techniques and Issues in Comparing Experimental and Analytical Data for the Shock Response of the Wide Aperture Array (WAA)

Dr. Robert Haberman, Fred Burke & Daniel Hamel, *BBN Systems Technologies*

The process of shock qualifying ship systems by analysis has positive implications for costs and scheduling. Acceptable correlation between experimental data and analytical predictions is required to approve modeling methods and analysis techniques. This paper presents the correlation results of the UNDEX response of the SSN688 Wide Aperture Array design. Various correlation metrics including Geers' Error Factors, Zilliacus' Error Index, Whang's Inequality Index, and UERD's Error Measure are investigated. The results emphasize the complex nature of the WAA model and the sensitivity of elastic joints, baffle response fiberglass modeling.

TB1: Acoustics

Estimation of the Acoustic Energy Radiated Underwater Via the Propulsion Shaftlines in Ships

Dr. George D. Xistris, *Naval Engineering Test Establishment*

The twin screw diesel powered propulsion train of a 5,000 ton vessel has been discretized as a combined lumped parameter and continuous mass mechanical system comprising 73 distinct sections. The axial and torsional vibratory responses have been determined from the receptance characteristics of the complete rotor/bearing/propeller system, and the coupling of the torsional and axial modes introduced by the propeller action has been investigated via perturbation methods. The spatial distribution of pressure pulsations at the propeller plane was subsequently employed to estimate the radiated sound power field treating the propeller as a rigid piston constituting an assemblage of monopole sources.

The results obtained by the model show encouraging agreement with available underwater acoustic measurements at the frequencies of interest.

Modeling and Redesign of a High-Intensity Noise Generator Valve for Improved Performance

Damin J. Siler, Howard F. Wolfe & Arnel B. Pacia, *Air Force Research Laboratory*

An air modulator valve assembly was redesigned to improve acoustic performance and fatigue life. These valves generate the high-intensity noise required in acoustic progressive wave tube testing of aircraft structures. The valve's complex geometry prevented closed-form static and dynamic solutions, so numerical analysis methods were employed via a combination of solid modeling, finite element and mathematical software. A parametric design methodology was developed to study the effects of changing multiple valve features. This allowed rapid comparison of thousands of parameter combinations and led to selection of an optimal redesign. The new valve features increased spring stiffness and a greater number of airflow vanes and voice coil turns. These and other changes will enhance the acoustic output and reduce the actuation power and probability of failure.

Refinement/Enhancement of a Predictive Tool to Quantify the Acoustic Environment Inside Open Weapons Bays

Terry K. Brewer, *McDonnell Douglas Aerospace*

The ability to predict the acoustic environment inside a weapons bay remains unreliable. In 1996, an empirical model was developed based on wind tunnel data to provide approximations of the acoustics with good results. The model focused on the "classic" cavity acoustics problem. The weapons bay was assumed empty, unsuppressed and oriented to straight and level flight. Since that time, the model has been refined to provide more accurate results. Also, enhancements have been added to provide

predictions for a wider range of cavity aspect rations. A summary of the model and refinement/enhancement results are described in this paper.

A Discrete Approach to Modeling Acoustic Phenomena in an Imperfect Solid Including the Simulation of Dynamic Fracture

John Song, *Weidlinger Associates, Inc.*

The acoustic wave phenomena in a solid are numerically simulated using a discrete approach in which the acoustic signal recorded at a point in the material is visualized through linear interactions between that point and its neighboring points. The linear interactions are derived from Newton's Law and they are incorporated into the numerical model using spring of randomly varying stiffnesses and threshold lengths which, when exceeded, result in dynamic fracture. Because the interactions can be stimulated in this random manner, the acoustic phenomena in both inhomogeneous and homogeneous solids can be delineated from the numerical modeling.

Implementation of an Acoustic Infinite Element in the Time and Frequency Domains

Michael Butler, *Electric Boat Corp.*

An acoustic infinite element was implemented and exercised in a general purpose structural finite element method code. The element is formulated in prolate spheroidal coordinates, and it couples directly to fluid velocity potential finite elements which are used to model the fluid between the structure and the prolate spheroidal infinite element mesh. The element was exercised in both the time and frequency domains, and submerged structural response predictions were compared to Helmholtz boundary element method and doubly asymptotic approximation solutions. This element has several advantages, and the comparisons were very encouraging.

Symmetric Conjugated Infinite Elements for Acoustics and Shock

J.L. Cipolla, *Naval Undersea Warfare Center*

Infinite elements simulate exterior domain wave problems using a mesh of finite size. Properly constructed, infinite elements maintain the desirable properties of finite elements: spatial and temporal locality, and accurate interpolation of the solution inside the element.

The key new development is the creation of polynomial interpolants that symmetrize the conjugated semi-isoparamteric Burnett formulation. This ensues from a straightforward solution for polynomial coefficients that zero a single antisymmetric term. The element has the desirable properties of: convergence to the far-field solution, accuracy, symmetry, and mass-damping-stiffness form.

Derivation, element-level numerical tests, and discussion are presented.

The Application of Spectral Elements to the Solution of Midfrequency Vibration Problems

John E. Huff Jr., *Electric Boat Corporation*

The need for analysis techniques which are efficient in the mid to high frequency ranges has lead to a number of different numerical approaches. The Spectral Element Method (SEM), as developed by Doyle, is on such approach which is very compatible with the conventional Finite Element Method (FEM). In addition to being compatible with displacement based FEM, SEM is able to model a system with a greatly reduced set of degrees of freedom in the midfrequency range. Comparisons between FEM and SEM will be presented as well as an example analysis of a 3D frame structure.

TC1: Composites

Effect of Multi-Material Layering on the Response of a Generic Hull Structure

Aaron D. Gupta & Christopher Meyer, *U.S. Army Research Laboratory*

The dynamic response of a basic generic composite multilayered vehicle hull with a large circular opening for the turret assembly has been compared with that of an equivalent single layer basic metallic hull with identical geometry to assess the influence of multilayered composite armor panel structure on the model response. Both models without the engine block, mountings, transmission and the base support system consisting of tracks, wheels, sprockets, torsion bars etc. were generated using PATRAN 3 to facilitate computational model analysis and comparative evaluation of the influence of multimaterial layered construction of the free vibrational response.

Comparison of computed frequencies and modeshapes of the multilayered armored hull configuration with those from the aluminum hull shows noticeable difference between transient responses of the two structures. Predictions for the composite armored hull indicate consistent increase in both fundamental and higher order frequencies for the first 15 flexible modeshapes in the low frequency regime. Stiffness to mass ratio which from equation (1) is a function of the frequency of oscillation of the hull structure, is

consistently higher in case of the composite armored hull than the corresponding ration for the equivalent aluminum hull in the entire low frequency regime. However, the equivalent mass density of the multilayered armor with the exception of the thin Kevlar layer is somewhat higher than the density of 5083 aluminum armor indicating that the composite armor has increased stiffness resulting in a stiffer modal response and reduced modal deformation relative to the response of the aluminum hull.

The addition of layers of titanium, high hard steel, Kevlar and silicon carbide to aluminum results in significant improvement in stiffness, impact strength, high temperature and corrosion resistance over monolithic aluminum armor with corresponding improvement in modal response at both fundamental and higher frequency in the low frequency regime considered in this investigation. It will be worthwhile to extend this study to transient response due to forced vibration in the high frequency study regime in which multimaterial multilayered armored hull construction may prove to be more advantageous over conventional monolithic aluminum hull structure for armored personnel carriers.

High Cycle Fatigue Testing of BlackGlasTM Composite Coupons Using a Half Sine Clamp

Michael P. Camden, Donald B. Paul, Larry W. Simmons, Larry Byrd & Howard F. Wolfe, *Wright Laboratory*
Richard R. Batzer, *Lockheed Martin*

With the continuous introduction of new polymer derived composite materials such as Blackglas^{TM} ceramic composites, the development of life prediction techniques for these new materials are essential. These techniques must be accurate since over conservative methods will result in over weight structures and non-conservative methods will result in premature structural failures. One method currently used for life prediction is the development of dynamic high cycle fatigue S/N curves. This is typically done using cantilevered beams on an electro-mechanical shaker. When testing polymer derived ceramic composites using a typical specimen fixture, with a perpendicular clamping line at the root of the specimen, there is concern that stress concentrations and edge effect unrealistically decrease fatigue life. The intent of this paper is to demonstrate the use of a "half sine clamp" to control these stress concentrations and eliminate edge effects. Analytical and experimental comparisons will be made between Blackglas^{TM} data collected from a typical specimen fixture versus the half sine clamp.

Effects of UNDEX High Strain Peaks on a Glass Reinforced Plastic

Robert Hubbard, *Electric Boat Corporation*
Ellen Kumar & Peter Sjoblom, *University of Dayton Research Institute*

Glass reinforced epoxy (GRP) was tested at various strain rates to determine whether customary static material properties are adversely effected by the high strain rates caused by an underwater explosion (UNDEX). University of Dayton Research Institute, sponsored by Electric Boat, tested 163 specimens of quasi-isotropic Cycom 5920-1583. A fast hydraulic/gas powered Instron system was used to induce strain rates from approximately 150 to 300 in/sec on the high end to 0.05 in/min statically. Tension, compression, inplane shear, interlaminar shear, and mode II fracture toughness properties were measured. Strength and strain-to-failure were both observed to increase with strain rate. Modulus values, when compared over a suitably high strain range (typically 10,000 -15,000 microstrain) also showed an increase with strain rate. It was concluded that use of static GRP material properties for UNDEX analysis is probably conservative.

TD1: The Dr. Mel Baron Memorial Verification & Validation Session

Practical Aspects of Numerical Simulation of Dynamics Events

J. A. Zukas, *Computational Mechanics Consultants, Inc.*

The most efficient method, in terms of cost and accuracy, to address a difficult problem in structural dynamics or wave propagation is through a combination of numerical computations, experiments, and material characterization at high strain rates. Sometimes computational results just don't agree with experiments. This paper reviews the various reasons such disagreements occur. These include problems in building a mathematical model from a physical model, problems that are counter-intuitive in nature and discretization errors resulting from modeling a continuum with an infinite set of degrees of freedom as a mathematical system with a finite number of degrees of freedom.

Some of the above are quantifiable and predictable. The really big problems are caused by humans. These include poor element or grid selection, leaving out fundamental physics in the analysis, failing to understand and account for the effects of contact surfaces on numerical solution or failure to recognize instabilities as they occur. Extensive examples are presented to illustrate each of these points.

Model Validation and Verification of Reinforced Concrete Walls Subjected to Blast Loading

Mark C. Anderson, Timothy K. Hasselman & John E. Crawford, *ACTA Inc.*

Validation and verification of nonlinear structural dynamic models is usually performed ad hoc by trial and error. A method based on Principal Components Analysis has been developed which yields an equivalent nonlinear model and permits systematic

model-test correlation, statistical parameter estimation, and uncertainty prediction. The method is applied to the problem of a reinforced concrete wall subjected to blast loading. Three models are analyzed with respect to their prediction of the maximum deflection of the wall. These models include a simple engineering model, moderately complex ADINA model, and a high-fidelity DYNA3D model.

How "The Quantifiable Tends to Obscure the Significant" in Computational Mechanics

Hans U. Mair, *Institute for Defense Analyses*

The focus on physics-based simulation in the U.S. defense community is accelerating, but a significant part of this rapidly maturing technology has not been adequately quantified - quality assurance, or VV&A (verification, validation, and accreditation). A systems engineering approach to the verification and validation of physics-based simulation tools is endorsed - the interaction of all the levels of sub-models employed in the codes should be quantified, and those sub-models should be verified, validated, and accredited. Similarly, we need to quantify the phenomena present in our experiments, such that the utility of existing data for benchmarking/VV&A can be determined, and tests can be planned that fill in the gaps. Unfortunately one of the most obvious "models" in computational mechanics is the discretization as defined by the analyst; must we therefore accredit the analysts?

A Submerged Shock Response Problem Suitable for Use as a Benchmark

David Ranlet & Raymond P. Daddazio, *Weidlinger Associates, Inc.*

An underwater shock experiment performed in 1974 on the DNA/ONR 33.6 Model is analyzed using the latest version of the ELSHOK code. Specifically, this paper considers the transient response of a submerged ring-stiffened, circular, cylindrical shell of finite-length, containing internal structure, to side-on loading from a full-envelopment shock wave of a long time duration. Good correlation between theory and experiments is obtained. The original calculation performed for this problem served as the second proof-test of the Doubly Asymptotic Approximation and validated and verified the original version of ELSHOK. The experimental data, recently approved for public release, should serve as a useful benchmark for the validation and verification of computer codes for submerged shock response.

TE1: UNDEX (Classified)

USS Princeton Mine Incident Effects on Ordnance

Wayne Schneider, *Naval Surface Fire Support Program Office*
Tom Pugh, *Syscon Corporation*

USS Princeton (CG-59) is the thirteenth of the AEGIS class ships that comprise the world's most powerful warships. She is capable of conducting offensive and defensive warfare simultaneously against air, surface, land and subsurface targets. On 18 February 1991, while deployed in the North Arabian Gulf during Operation Desert Storm, Princeton detonated an underwater influence mine. Although severely damaged, damage control measures prevented loss of the ship and enabled her to make port. Repairs were made and she is currently serving with the Pacific's Seventh Fleet.

The blast impact was highly localized under the stern and decreased significantly with distance. After the detonation, it was determined that missile launching capability was retained with half of the aft Vertical Launching System (VLS) and all of the forward VLS. This included surface-to-air STANDARD Missiles and TOMAHAWK Land Attack Missiles. Five of eight harpoon Missiles were still functional as were all MK 45 Gun ordnance. Of the 35 MK 46 Torpedoes onboard, none had shock related damage that would impair proper performance.

It was concluded that the damage to the ship was controlled and loss of warfighting capability was quickly restored due primarily to a successful training program combined with a combat system designed to survive. The authors intend to discuss how designing for shock help minimize the effects of mine related damage to onboard ordnance.

Underwater Explosion Failure Experiment/Analysis of the Mk6 Mine Case Using Surrogate Source Blast Waveforms

Daniel Hamel & William Marshall, *BBN Systems and Technologies*

Surrogate source blast waveform tests were performed in April of 1997 to demonstrate that Mk6 mine cases would fail. The surrogate source is a primer cord helix whose pitch, diameter and length is configured for maximum end fire peak pressure and impulse.

The paper will focus on: 1) the surrogate source experiment, and 2) pre-test LS DYNA/USA non-linear failure analysis results will be compared to experimental Mk6 mine case damage.

Finite Element Comparisons to Medium Weight Shock Machine Tests of an Advanced Capability Torpedo in a Dry Torpedo Tube Environment

Nicholas M. Nardacci, *Naval Undersea Warfare Center*

The Advanced Capability Torpedo (ADCAP) is currently undergoing several system level modifications in an effort to improve reliability, reduce manufacturing costs, and enhance performance specifications. As part of this effort, underwater shock design issues are being addressed by an extensive test and analysis program. Of particular interest, is the dry torpedo tube environment and its impact on the forward guidance and control (GNC) components when subjected to a shock. Medium Weight Shock Machine (MWSM) tests have been performed on this ADCAP subset in a simulated torpedo tube environment. Experimental measurements have been collected at various points of interest from the test fixture. The focus of this study is to investigate the interaction of these components using finite element methods; particularly using the LS-DYNA FEA code. Results from the explicit dynamic calculations will present comparisons to experimental data and model predictions regarding the contact conditions between weapon and torpedo tube and applied forces to internal GNC components.

TB2: Earthquake

Optimal Shock Isolation using Passive Systems

Dr. Walter D. Pilkey, *University of Virginia*

The paper begins with a review of the limiting capabilities of protection of isolation systems against shock disturbances. Then, mathematical proofs are given, showing how closely passive SDOF systems can be designed to approximate their limiting characteristics. It is shown that a passive isolator consisting of a power law isolator with a spring and damper can closely approximate the limiting isolation. In fact, certain passive systems can perform as well as the theoretical limiting optimal system. This is the case for an impulsively loaded isolator with (a) a linear spring and quadratic law damper and (b) a bang-bang spring and a dry friction damper. Other isolators are analyzed and it is shown, for example, that the optimal linear isolator exceeds the limiting performance by only 4%.

An Approximate Method for Assessment of Seismic Damage on Buildings

Dr. Mario Paz, *University of Louisville*

An approximate method to evaluate the damage of the buildings under progressive seismic intensity is presented. The building is modeled as a three-dimensional structure with lateral force resisting elements consisting of structural walls and columns. The resisting capacity of these elements are assumed to be reached at the development of a plastic hinge. The damage on the building is assessed as the intensity of the earthquake (peak ground acceleration) is increased until its final collapse.

Computer-Aided Implementation of Multinational Seismic Codes

Dr. Mario Paz, *University of Louisville*

This paper presents a general description of the provisions in the seismic codes for countries in active seismic regions. It also presents the basic techniques for modeling buildings for the implementation of code provisions and a simple method to obtain the response in terms of forces, moments, and deformations of the structural elements of the building. These three features, building modeling, code implementation, and structural response have been incorporated in a general computer program that may be used in the implementation of the seismic code of virtually any country.

The paper includes the application of earthquake resistant design using the computer program developed to two buildings: (1) a four story reinforce concrete building located in Canada, designed according to Canadian seismic code NBCC (National Building Code of Canada, 1990) and (2) a 20-story steel building in USA, designed in accordance to the seismic code UBC (Uniform Building Code, 1994)

A Statistically Based Validation Method

A. Misovec, *Logicon-RDA*
W. Gilbert, *Naval Surface Warfare Center*

The method develops a measure of difference between a (sample) set of target response gages and correlating calculated values. A "difference" statistic is formed as a measure of difference between a calculated response function of time and a measured time history of that function. The mean value and the standard deviation for this statistic are both calculated and a cumulative distribution function is developed for the sample set. The user decides upon a statistic and selects and upper tail confidence limit in order to develop a confidence interval with associated risk probability. The "validation" of the calculation is associated with the calculated confidence interval. Thus several calculational schemes can be compared and rated via the validation confidence interval.

The method has been incorporated in a Pascal based PC program called CONFDNT. A sample problem is developed in order to demonstrate both the validation method and CONFDNT for a variety of known difference statistics. These difference statistics include both "absolute value" and "sum of squares" formulations.

Structural Vibration Reduction with RSPM Control Technology

Dr. George Lee, *National Center for Earthquake Engineering Research SUNY Buffalo*
Dr. Brian Houston, *Naval Research Laboratory*
Dr. Kenneth Tomita, *Enidine Inc.*
Mr. William D. Gottwald III, *Naval Surface Warfare Center, Carderock Division*

A number of vibration reduction technologies have been developed for selected types of simple structures. At the same time, there are a large number of low frequency vibration problems requiring solutions. One such area is the M-DOF structure under random excitations. For complicated structures, vibration reduction cannot be effectively dealt with by standard passive damping or isolation technologies.

This paper presents a semi-active control system to address these needs, as they pertain to the seismic protection of structures, and the shock protection for deck structures on submarines. The vibration reduction effect of the system is derived from a set of control schemes to dynamically modify the structural parameters of control object, which is referred to as Real -Time Structural Parameter Modification (RSPM).

TC2: Material Modeling

A Study of Shock Mitigating Materials in a Split Hopkinson Bar Configuration - Part II

Dr. Vesta I. Bateman, Fred A. Brown & Ned R. Hansen, *Sandia National Laboratories*

Sandia National Laboratories (SNL) designs mechanical systems with electronics that must survive high shock environments. These mechanical systems include penetrators that must survive soil, rock, and ice penetration, nuclear transportation casks that must survive transportation environments, and laydown weapons that must survive delivery impact of 125 fps. These mechanical systems contain electronics that may operate during and after the high shock environment and that must be protected from the high shock environments. A study has been started to improve the packaging techniques for the advanced electronics utilized in these mechanical systems because current packaging techniques are inadequate for these more sensitive electronics. In many cases, it has been found that the packaging techniques currently used not only do not mitigate the shock environment but actually amplify the shock environment. An ambitious goal for this packaging study is to avoid amplification and possibly attenuate the shock environment before it reaches the electronics contained in the various mechanical systems.

As part of the investigation of packaging techniques, a two part study of shock mitigating materials is being conducted. Last year, seventeen, unconfined materials were compared for their shock mitigating characteristics with a split Hopkinson bar configuration. It is hypothesized that a shock mitigating material has four purposes: to lengthen the shock pulse, to attenuate the shock pulse, to mitigate high frequency content in the shock pulse, and to absorb energy. Both time domain and frequency domain analyses of the split Hopkinson bar data were performed to evaluate the materials' achievement of these purposes. No attempt was made to compute stress-strain or to develop constitutive relationships for these materials because of the variation of these materials' properties with stress.

In this paper, the second portion of the shock mitigating material study continues with five materials from the first part of the study. These materials were chosen because they demonstrated the desired characteristics of a shock mitigating material and for their ease of use in real structures. These materials are: Teflon, Sylgard 184, GE RTV 630, HS II Silicone, and Polysulfide Rubber. These materials have been evaluated at ambient, -65°F, and +165°F. Two thickness of 0.125 and 0.250 in. have been used. Both confined and unconfined samples were evaluated at the two load conditions of 25 fps and 50 fps with a 100 μs pulse duration for both amplitudes. Both time domain and frequency domain analyses of the split Hopkinson bar data have been performed to evaluate the materials. The energy analysis of the split Hopkinson bar data is presented for both parts of the study.

*Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under DE-AC04-94AL85000.

TE2: Ground and Air Combat Vehicle LFT&E (Classified)

An Experiment, Analysis, and Model of the Propagation of High Frequency Shock

J. Terrence Klopcic, *U.S. Army Research Laboratory*

This study deals with the propagation of the leading, high frequency edge of the shock wave emanating from an impact point on an armored vehicle, specifically, in an experiment on an M113 Armored Personnel Carrier subjected to explosive charges.

The amplitude of the transverse wave can be well fit by a semi-empirical equation which accounts for both longitudinal and transverse waves, exponential decrease with distance, mixing of waves at edges, and amplification at points near edges. Comparison of wave speeds with published data confirm the roles of longitudinal and transverse disturbances.

The resulting equation constitutes an algorithm suitable for incorporation into production-level vulnerability analysis codes.

Effects of Helicopter Main Rotor Damage on Fixed System Rotor Disk Vibration

Ki C. Kim and Joe Fries, *U.S. Army Research Laboratory*

When a helicopter main rotor blade is sufficiently damaged (e.g., in combat, by ballistic high explosive projectile), rotor system dynamic imbalance (inertial and/or aerodynamic) occurs. This results in undesirable asymmetrical forces and motions that can affect rotor as well as helicopter system performance. Consequences of rotor blade damage include impeded crew function, increased structural fatigue, and degraded flight capability. The determination of a helicopter's vulnerability to rotor blade damage involves an analytical assessment of these factors.

This paper presents a study of the effects of loss of an outboard section of one rotor blade (in a four-bladed system) on the fixed system (non-rotating) motion of the rotor disk. (The term disk refers to the coupled multi-blade rotor system.) Changes in the dynamic response of the damaged blade and how these changes influence the disk's fixed system motion are explored, beginning with the damaged blade's varied forcing contribution. The study considers individual harmonic frequencies (integer multiples of rotor rotational speed) in order to obtain a first principle understanding of the rotor imbalance phenomenon.

The analysis uses Newtonian approach to derive two degrees of freedom equations of motion for the blades. Each blade is represented as a flapping/twisting element with a root effective (flap) hinge and a root angular (twist) spring. In addition, the rotor system hub mass is represented to include fuselage motion effects. Each blade is forced with a harmonic vertical shear at the tip. Numerical results are presented for a helicopter with a four-bladed articulated main rotor system. This study is part of the helicopter ballistic vulnerability analysis methodology development effort at the U.S. Army Research Laboratory.

Simulation of Ballistic Shock in Composite Armored Vehicles

Eric C. Dalton & Robert B. Loper, *Military Technologies Inc.*
Abraham Frydman, Morris Berman & Dean Li, *Army Research Laboratory, Adelphi Laboratory Center*

The U.S. Army is experimenting with composite material hulls to reduce the weight of future generations of armored vehicles. To design survivable components for this new vehicle class, it will be necessary to characterize the transmissiveness of ballistic shock through the composite structure and particularly through the interconnecting joints. Because of the high frequency range of ballistic shock, practical analysis methods have only recently emerged for vehicles composed of *isotropic* materials. The greatly added complexity of composite structures is therefore a significant challenge to the theoreticians and computer code developers. In this paper, the authors propose a solution using virtual mode synthesis and simulation (VMSS), which has been previously applied successfully to isotropic structures. The VMSS process develops dynamic response equations by curve-fitting couple modal frequency response functions to the envelope of a frequency response function that originates from energy balance models (i.e., statistical energy analysis) or non-destructive tests. The resulting dynamic response equations can then be solved by convolution with an estimate of the ballistic contact load history. In the interim, composite materials are represented in VMSS using frequency-band-average properties that are *frequency-macroscopic replicas* of their isotropic counterparts. This paper will summarize the VMSS theoretical background with emphasis on how the latter properties are used. Case study results for the quarter section of the Composite Armored Vehicle (CAV) will be discussed, including non-destructive testing performed to characterize the modeling parameters as well as response simulation comparisons to ballistic test measurements.

WA1: Data Analysis

Equivalence of General Spectral Esimates - Part 2

Ronald G. Merritt, *Naval Air Warfare Center- Weapons Division*

This paper is the second of a two-part paper addressing the "equivalency" of general spectra estimates. Part I of this paper series addressed two tests for spectral equivalency for sufficiently smooth and unbiased spectral estimates. It was noted in this paper that if two spectral estimates are deemed equivalent then the information in the spectral estimates may be summarized by computing a weighted average of the individual spectral estimates. This paper broadens the scope of the first paper. In particular, the question is addressed, "Given several spectral estimates what useful summary information, if any, can be obtained from the spectral estimates." Several summary statistical tests are provided along with an assessment of their general applicability, usefulness and error characteristics. The results of this paper are restricted to unbiased spectral estimates but are not limited to autospectral density estimates on stationary random data.

Error Measures for Comparing Transient Data: Part I: Development of a Comprehensive Error Measure

David M. Russell, *Electric Boat Corporation*

This paper presents the development of new set of magnitude, phase, and comprehensive error measures. These error measures can be used to evaluate the differences between two general functions, or test and analytical data, by providing a robust means for quantifying the difference in magnitude, the phasing, and overall error between the functions. The error factors are on the same relative scale and will be shown to have specific physical interpretations. The phase and magnitude error factors can also facilitate the identification of common discrepancies. (This work was performed under DSWA Contract No. DNA001-94-C-004, UCB Subcontract - Purchase Order No. BS0045773.)

Error Measures for Comparing Transient Data: Part II: Error Measures Case Study

David M. Russell, *Electric Boat Corporation*

Part I of this paper presented the development of magnitude, phase, and comprehensive error measures. These error measures can be used to evaluate the differences between two general functions, or test and analytical data, by providing a robust means for quantifying the difference in magnitude, the phasing, and overall error between the functions. The error factors are on the same relative scale and will be shown to have specific interpretations. In this paper a comprehensive evaluation is made between these new error measures and existing error measures implemented at Electric Boat Corporation. (This work was performed under DSWA Contract No. DNA001-94-C-004, UCB Subcontract - Purchase Order No. BS0045773.)

Correcting Numerical Integration Errors Caused by Small Aliasing Errors

David O. Smallwood, *Sandia National Laboratories*

Small sampling errors can have a large effect on the numerically integrated waveforms. An example is the integration of acceleration to compute the velocity and displacement waveforms. These large integration errors complicate checking the suitability of the acceleration waveform for reproduction on shakers. The errors become significant when the frequency content of the waveform spans a large frequency range. It is shown that these errors are essentially independent of the numerical integration method used, and are caused by small aliasing errors from the frequency components near the Nyquist frequency. A method to repair the integrated waveforms is presented. The method involves using a model of the acceleration error, and fitting this model to the acceleration, velocity, and displacement waveforms to force the waveforms to fit the assumed initial and final values. It is assumed that the error can be represented by a step, impulse, and/or jerk in the acceleration waveform. A location of the error is then found which will minimize the error in the integrated displacement. The correction is then subtracted from the acceleration before integration. The method is effective where the errors are isolated to a small section of the time history. It is shown that the common method to repair these errors using a high pass filter is ineffective for this class problem.

Salvaging Transient Data with Overloads and Zero Offsets

David O. Smallwood & Jerome S. Cap, *Sandia National Laboratories*

We are sometimes presented with data with serious flaws, like overloads, zero shifts, and impulsive noise, including much of the available pyrotechnic data. Obviously, this data should not be used if at all possible. However, we are sometimes forced to use this data as the only data available. Methods to salvage this data are discussed. Using the methods requires judgment, and the results must be accepted with the understanding that the answers are credible, not necessarily correct. None of the methods will recover information lost due to overloads or non-linearities of the data system. The best that can be accomplished is the recovery of data after the data system has recovered from the overload.

The methods require assumptions on the characteristics of a credible data set. A model of the acceleration error is chosen, and the error model is fitted to the acceleration, velocity, or displacement waveforms to force the waveform to fit the characteristics of a credible data set. A common assumption is that the initial and final acceleration, velocity, and/or displacement are all zero or are known. Another assumption often used is the acceleration and velocity waveforms should both be oscillatory. A set of models for the errors in the data are provided and the model which best suites the data is selected. Three models of the errors discussed are: 1) A combination of a jerk, and/or impulse, followed by a zero offset; 2) An overload with an exponential recovery, followed by a zero offset; and 3) The errors are essentially low frequency and a high pass filter will correct the data set.

A companion paper illustrates the first method for the correction of some aliasing errors, and in some cases the same procedures can be used to salvage data with other flaws. The second method uses an exponential window (to model the zero shift) to model the error. A set of parameters (amplitude and decay rate of the exponential window, the amplitude of the rectangular window, and the location in time of the start of the error) are optimized to minimize the mean square error between the correction and the original data set. The correction is then subtracted from the original data set to give the corrected data set. A risk of all the methods is that the corrected data will under-predict the environment as data is lost from the overload. The risk of the first two methods is that if the error model does not fit the data unrealistic corrections will result. The third method involves several forms of high pass filtering to remove the flaws. Guidelines for choosing the high pass filter parameters are discussed. The risks of the third method include-- If the cutoff frequency is set too high useful data is lost, but if the cutoff frequency is too low unrealistic velocity and displacement

waveforms persist; If the rate of the filter roll-off rate is too high phase shifts and overshoot effect the results, but if the roll-off is too low unrealistic velocity and displacement waveforms persist.

Examples showing the results of the methods will be given using flawed pyrotechnic data.

Test Site Integration

Gary A. Cooper, *Aberdeen Test Center*

Over the past two decades, Aberdeen Test Center (ATC) has made a significant investment in the digitization of the ballistics and fire control ranges used in weapons system tests. The list of systems acquired in this digitization process includes: Weibel Doppler radars, Hadland cameras, video scoring of targets, systems to measure blast and chamber pressures, systems to measure the performance of weapons control and flash x-ray imaging systems. This conversion to digital data acquisition systems has provided ATC the capability to provide test data for review and analysis in near real-time. ATC has also made a significant investment in an activity wide local area network (LAN). This network has facilitated the collection and transmission of test data, both within the test range and throughout the activity. Test Site Integration (TSI) is the final building block in this digitization process. TSI is a generic system designed to integrate the digital test instrumentation and store test data at the various ballistics and fire control ranges located at ATC. With this system, the test director and test sponsor have near real-time access to all of the digital data collected at a particular test range through a user friendly graphical user interface (GUI) running on a UNIX workstation. The GUI allows the user to view and compare data from many rounds/runs, displaying text, images, plots, and digitized video. In addition to local data storage, TSI systems also provide utilities for automatically forwarding test data to a corporate data repository for on-line archival. Analysis programs have been integrated into the interface, allowing raw data to be processed and reviewed in near real-time. A countdown automated procedure (CAP) system is also integrated into TSI. The CAP provides an automated system for arming certain test instrumentation and firing test weapons. The CAP also provides a countdown abort capability to the operators of the various test instruments, helping to minimize data loss and maximize range safety. Another feature of TSI is an interactive display of the current status of every digital test instrument being used for a particular test. TSI provides test directors with a user friendly system that automates test control and provides for near real-time analysis and display of test data.

WB1: Products and Services

Use of Advanced IST Digital Data Recorders to Collect BRU-55 Flight Vibration Data

Scott Fling & Kelly Binkley, *Sverdrup Technology Inc., TEAS Group*
David Wrenne, *Sentel Corporation, TEAS Group*

Two F-16/BRU-55 vibration fly-around mission were successfully completed at Eglin AFB, FL using advanced digital data recorders developed by IST. These digital recorders have not been used before to collect flight vibration data. They consist of a small ruggedized recording box and three external accelerometers which are installed within the store. The digital data recorders were chosen because they provide several advantages over tape recorders and conventional telemetry systems while providing significant cost savings. This paper discusses the pros and cons of using these digital recorders; in addition, the flight tests execution and results will be presented.

Applying SYMOS Numerical Simulation to the Selection of Wire Rope Isolators for the Medium Weight Shock Machine Test

Claude Prost, *SOCITEC*
Herb LeKuch, *Shock-Tech, Inc.*

COTS electronic equipment for Navy shipboard installation often requires shock isolation protection in order to survive the Navy Medium Weight shock machine test as defined in the MIL-STD-901. Wire rope mounts are a common type of isolator used in such an application. However, their non linearity together with the complexity of the shock machine make a proper selection of mounts for low g's response difficult and confusing. Attempts to use the acceleration history measure on the machine table as an input have often proved unreliable, so that Socitec and Shock-Tech have developed a global numerical model with a multibody non-linear computer program. The combination of machine, isolators and cots equipment is modeled as four rigid bodies connected with non linear stiffness and damping coefficients. The simulation program is known as Symos. Its use provides a straight forward shock analysis that takes the machine parameters into account and allows for the direct evaluation of candidates isolators by changing only a few key variables, just as if the real test was actually implemented. Test results versus analytical model are reviewed and a type of cable isolator is described.

This paper is an extension of an earlier technical paper entitled Navy Shock Machine Calibration by using Numerical simulation published at the 1995 Shock an Vibration Symposium in San Diego.

Chatter of Dynamic Brake: Numerical Model vs. Experimental Prototype

Khanh Ly, *GEC-Marconi-Aerospace, Inc.*

A dynamic brake is designed to stop a rotation of about 400 Nm at 2000 rpm within 5 degrees. The most significant features that classify this new type of brake as a "smart brake" in comparison to conventional brakes are: mechanical feedback loop, therefore no delay time between input command and brake response; input speed command; low input torque command only 2% output; no hydraulic control, therefor no maintenance is needed in unit life.

The main function of this smart brake is to retard the output speed to the input command speed. The vibration during dynamic braking and related anti-vibration solutions are discussed. In addition, vibration obtained from numerical simulations is compared to chatter resulted in a physically real test unit.

A New Capacitive Accelerometer

Ernst Schonthal, *PCB Piezotronics, Inc.*

The capacitive accelerometer Model 370A02 from PCB Piezotronics can be sued in a wide range measurements and control applications such as: 1) Assessment of automobile ride quality; 2) Control of disturbance in vibration sensitive processes; 3) Vibration analysis of bridges, buildings, and aircraft, and satellites.

Since these applications require DC coupling for low frequency measurements a capacitive sensor is ideal. The results of practical measurements will be discussed.

Underwater Explosion (UNDEX) Test Facility

Robert R. McHugh, *U.S. Army Aberdeen Test Center*

The Underwater Explosion (UNDEX) Test Facility at the U.S. Army Aberdeen Test Center (ATC) at Aberdeen Proving Ground, Maryland was built to allow the U.S. Navy Naval Sea Systems Command (NAVSEA) to conduct its live fire and shock test and evaluation programs in a more (environmentally friendly) controlled environment than the open-ocean-waters.

The UNDEX Test Facility is a man made elliptical shaped pond measuring 1070 ft. long by 920 ft. wide with a maximum depth of 150 ft. The side walls of the pond were excavated on a 2.5:1 slope from elevation +15 ft. to elevation -70 ft, and a 2.0:1 slope to elevation -150 ft. This results in a bottom footprint 300 ft. by 150 ft.

In the first 18 months of operation, The UNDEX Test Facility has supported a variety of Navy Live Fire and shock test programs.

Test items are brought to the UNDEX test facility in a variety of ways. They are barged via the Chesapeake Bay and Bush River or brought on land by tractor trailer (railroads).

When a test item is delivered up the Bush River the barge is positioned at the barge slip to allow transfer of the test item from the barge to the loading/off loading area. Once supported on the hydraulically powered wheel boogie system, the test item is then moved along sets of rails built into the facility and onto the marine railway launch car. The Marine railway system is then used to launch and retrieve test items.

When the test item is delivered by land on truck and trailer, the permanent facility equipment is used to off load it. It is then craned into the pond or the Marine railway system is used.

The test item is positioned in the pond and live fire and/or shock tested with charges up to 4100 lb. of TNT equivalent. All aspects of testing are carefully controlled by instrumenting the test item, the pond and the surrounding area.

Autonomous Control of Test Vehicles (ACTV)

Jeffrey S. Murter, *Aberdeen Test Center*

The Autonomous Control of Test Vehicles (ACTV) project is a research and development effort for robust exterior autonomous navigation of vehicles under test at Aberdeen Test Center (ATC). The ACTV system is conceived to be a non-intrusive instrumentation package of functional modules that each solves a portion of the overall navigation task. The decomposition of the navigation task includes segmentation of the task planner, path following, and motion control aspects of the feed-forward control loop. In parallel with this, a continual feedback loop is maintained for collision sensing, position sensing, and environmental sensing modules that are inputs to the sensor fusion and perception module, and finally to the environmental map. The sensing and control hardware have recently been developed and fielded in limited test bed environments. ACTV's POSE (position and orientation) instrumentation is based upon the use of redundant and complementary position estimation sensors, fused and integrated together to provide robust operation. The POSE instrumentation consists of: a Differential GPS (code/carrier based), an Inertial Navigation System - INS (including 3 inertial grade accelerometers and 3 angular rate gyros), and a Land Navigation System - LNS (including a fluxgate compass, wheel odometers, a barometric altimeter, and 2 axis inclinometers). This approach considers constraints due to a combination of theoretical and practical limitations of the above sensor performance characteristics, and the limitations of sensor fusion and integration algorithms.

The nature of ATC's three main test courses (Perryman, Churchville, and Manson Test Areas) is that they are a controlled, outdoor vehicle endurance and performance test environment, thus lending themselves as the perfect test bed to apply this

autonomous control technology to more efficiently, safely, and consistently perform ATC's land vehicle testing mission. In addition, replacing the driver with autonomous control instrumentation will provide a safe means to extend the envelope of vehicle testing. This paper will document the results of initial ACTV systems tests conducted at ATC from July 1997 through September 1997.

Faster Than a Speeding Bullet

Mark Stern, David Jennings & Todd G. Rumbaugh, *Aberdeen Test Center*

Electronic digital imaging is rapidly replacing traditional film-based recording as a research and evaluation tool. The U.S. Army Aberdeen Test Center, ATC, is at the forefront of this developing technology with an array of specialized high speed and ultra high-speed imaging systems.

Faster recording times and immediate playback means faster turn around times for continued testing. Recording of images equivalent to 20 million frames per second are possible with digital image converters. Used to document shock and vibration test these cameras and imaging systems document data unavailable with other systems.

WD1: Simulation of Underwater Explosion Effects #1

Free-Field Simulation of the BEAST Experiment with the FUSE Code

Ivan Sandler & Robert Atkatsh, *Weidlinger Associates, Inc.*

The BEAST test series, conducted by the Defense Special Weapons Agency (the Defense Nuclear Agency at the time), involved the response of a test structure to underwater explosions in shallow water, some of which were partially or fully buried below the water bottom. These tests were intended to assess the consequences of burial on mine effectiveness. An artificial bottom material was used to control the mechanical properties of the bottom material.

The Far Field Underwater Shock Effects code (FUSE) was used to simulate the free field environment resulting from the detonations, using CAP models of the bottom materials (both artificial and natural). This paper describes the code procedures and material models used in these simulations. It shows some of the results of both pre-test, and post-test calculations, and compares them with corresponding free-field measurements. In addition to confirming the expected loss, due to burial, of mine effectiveness against floating structures, the simulation effort highlighted the difficulty of physically controlling the actual in situ dynamic properties of the prepared bottom material.

BEAST - A Study of Mines Buried in the Bottom Underwater

A. Misovec, *Logicon-RDA*

A series of six explosive tests were conducted in a pond at the WES Big Black facility in the late summer of 1995. These tests were conducted each with eight pounds of Pentolite detonated as follows: 1) in the bottom (three tests), 2) on the bottom (two tests) and 3) in the water (one test). The water was eight feet deep and he bottom material consisted of a six foot deep layer of specially mixed grout. A ship "section" model of three foot draft was instrumented and set in harm's way. Free field instrumentation was deployed both in the water and buried in the bottom. A preliminary "calibration" test was done in May, 1995 in which eight pounds of Pentolite, buried three feet deep in the grout, were detonated without the section model.

Several mathematical models were developed and were run for the calibration shot. Two of these "hydracode" mathematical models agreed rather well with the calibration shot free field gages. These calculations, along with the gage records infer strongly that the presence of a light amount of entrapped gas in the bottom has the effect of disproportionately reducing the damage potential of a charge that is buried in the bottom underneath a relatively shallow body of water.

The six-shot test series was hampered by the fact that the manufactured bottom material failed to contain the required 0.7% gas content that was desired. It is show in this report that the gages indicated that the buried explosions "loaded" the section model much less than did either the in-water explosion or the explosions that occurred on the bottom. The damage potential of the buried explosion with about 0.3% bottom gas content was estimated to be less than half the damage potential of an (equivalently distanced) unburied explosion.

An Implementation of a Fluid Finite Element Based on a Velocity Potential Formulation

Chris Abate, Steve Gordon & John Waters, *Electric Boat Corporation*

A fluid finite element based on a velocity potential was implemented in the Vibration Engineering and Structural Analysis (VIBES) family of finite elements software. The velocity potential formulation (VPF) has several desirable attributes for the modeling of enclosed fluid volumes, namely: one DOF per node, symmetric matrices, automatic enforcement of irrotationality, and a simple fluid-structure coupling interface. This capability was implemented in a user-friendly manner and requires little additional effort by the user. The VPF is available for time domain (shock analysis) and frequency-domain (forced vibration) applications. This paper will briefly discuss the theory, implementation, and validation and applications.

A Closed Water-Filled Cylinder Test for Testing Non-Ideal Explosives

R. McKeown, J. Kelley & R. Guirguis, *Naval Surface Warfare Center Indian Head*
S. Zilliacus, *Naval Surface Warfare Center Carderock*

Numerical simulations of a small-scale test in which the detonation products of a small non-ideal explosive charge are confined at high pressure in a closed cylinder completely filled with water is presented. This is done in order to allow the slow reacting components in non-ideal explosives enough time to react. Traditionally, when testing non-ideal explosives, large explosive charges are used. For example, unlike ideal explosives for which a 1" cylinder test is usually adequate, 4" and 8" cylinder tests are often required to characterize the equation of state of non-ideal explosives. In underwater tests, the inertial resistance of the water also helps slow the expansion of the products. But because the gases expand in all directions, the spherical divergence quickly reduces the pressure and temperature inside the bubble. Restricting the expansion of the detonation products of a small explosive charge to one-direction, thus reducing the divergence and slowing the rate of pressure decrease, was exploited in the Moby-Dick experiment. In this paper, an alternative is presented. Numerical simulations that show feasibility of completely confining the detonation products of a small PETN charge in a closed cylinder full of water were already presented. Here, we show how the rate of the slow reactions can be derived from the short-term history of deformation of the cylinder walls and the long-term evolution of pressure within the cylinder.

Optimization Methods for UNDEX

Russell D. Miller, *Engineering Technology Center*

Several advanced optimization methods have been introduced in recent years that are potentially advantageous for optimizing difficult multimodal problems with nonlinear or stochastic behavior. Among these methods are genetic optimization and simulated annealing. The purpose of this paper is to evaluate the effectiveness of these advanced optimization methods for solving shock problems.

The genetic optimization approach uses biological concepts to develop and optimum solution to a problem. Parents are generated at random and their chromosomes are encoded into binary form. Each set of chromosomes represents one potential solution for analysis. The number of individuals generated for analysis is a variable and, therefore, the solution takes a simultaneous multipath approach. Children are generated from the parent chromosomes through crossing the DNA at specific locations. The chromosomes associated with a given trait (or parameter) are placed together in the DNA to allow the optimized traits to remain unchanged through future generations. Additional genetic algorithm (GA) options include jump mutation, creep mutation, niching, and micro GA.

The simulated annealing approach performs optimization using the temperature annealing terminology generally associated with material science. An initial temperature is selected as a starting point that indicates the starting value of the optimization function. A step is selected that allows the temperature to follow a positive or negative gradient depending on probability functions. The use of the Metropolis criteria allows the solution to escape from a local minima. Thus the multimodal problem is addressed through the annealing process. As the routine approaches a true minimum (or maximum) the quenching process occurs as the final parametric steps (in vector space) are small and the probability of jumping out of the minima is reduced.

The above approaches are used for analyzing UNDEX problems of selected types using the DYNA/FSI program to compute the UNDEX solution. The DYNA/FSI program uses LS-DYNA and the doubly asymptotic approximation (DAA) for solving fluid-structure interaction (FSI) problems involving underwater explosions (UNDEX). The first type of UNDEX problem addressed is that of a submerged structure subjected to an underwater shock due to a given charge weight and stand-off. The optimization problem is to determine the optimal location of the charge in three-dimensional space to achieve maximum structural response. The second problem type is that of optimal structural parameters to survive a given charge geometry.

The genetic optimization and simulated annealing approaches are compared for selected UNDEX example problems. Solution times are related to the number of function calls to DYNA/FSI. The use of these advanced optimization methods versus the more classical calculus based approaches is discussed. The potential of the methods and associated advantages and limitations are described as associated with the small, medium and large UNDEX problems.

Improvement of the Reflected-Wave Virtual-Source (RAVS) Model

G.V.Waldo, Jr., *Naval Surface Warfare Center, Carderock Division*

The Reflected-Wave Virtual-Source (RAVS) Model (previously reported) provides a simple approximation for calculating acoustic fluid-structure interactions for rather complicated situations. Calculations using this model were shown to be in good agreement to the exact calculations that have been published. In this talk, a simple improvement of the RAVS model is presented. Calculations both with and without this improvement will be compared to various situations for which exact calculations have been performed. Included in these calculations will be the dynamics of elastic and rigid cylinders interacting with planar waves.

An Independent Evaluation of the Reflected Afterflow Virtual Source Method For Fluid-Structure Interaction Problems

John A. DeRuntz Jr., *Unique Software Applications*

The Reflected Afterflow Virtual Source (RAVS) Method for fluid-structure interaction problems in underwater shock was proposed in a series of reports published by the Carderock Division of the Naval Surface Warfare Center beginning in 1995. Its purpose was to introduce the effects of the fluid particle velocity phenomenon for a spherical acoustic wave known as afterflow, into the reflected and scattered waves emanating from a submerged structure due to its presence and subsequent motion under the shock wave excitation. The formulation was also designed to account for wet-surface curvatures of the structure as well.

RAVS was installed in the Underwater Shock Analysis (USA) code as an additional option to the existing list of fluid-structure interaction algorithms and evaluation studies were then carried out to determine its usefulness in underwater shock calculation of submerged structures.

Computations have been carried out for two standard benchmark problems in underwater shock that have a known exact analytical solution, an infinite circular cylindrical shell and a spherical shell. It has been found that RAVS does adequately treat early time response for underwater shock calculations but is only capable of extending the range of validity beyond the Plane Wave Approximation by at most a radial transit time and is incapable of replicating the late time features in such problems. This is due to the absence of a correct low frequency asymptote in its formulation as does the family of Doubly Asymptotic Approximations (DAA) upon which the USA code itself is based. A correct low frequency asymptote involves a fully coupled fluid mass matrix of the wet-surface discrete element model whereas RAVS only reduces to a diagonal added mass at late time.

The conclusion to be drawn from the results of this study is that RAVS should not be used for the computer simulation of underwater shock problems. RAVS is no better at early time as existing second order DAA formulations and RAVS can be substantially wrong at late time. Late time calculations are particularly important for the analysis of internal equipment mounted at low frequency for shock mitigation as well as for overall structural response during gas bubble pulsation and migration that is strictly a low frequency phenomenon. Second order DAA formulations can accurately treat the entire frequency range of response encountered in underwater shock problems whereas the RAVS approximation can only predict very limited early time information on structural behavior and cannot replicate the physics of low frequency response correctly.

WA2: Blast

Thermal Modeling of Detonation Within Luggage

David Chan & Rimas Viktora, *Northrop Grumman Corp., Military Aircraft Systems Div.*

One solution to protecting commercial aircraft from terrorist threats is to harden the cargo containers against the detonation of a concealed device. In designing hardened passenger aircraft cargo containers, it is important to understand the mitigating effects of luggage so that a light-weight, affordable design may be developed. High explosives generate appreciable quasi-static phase (QSP) pressures when detonated within confined volumes. This is due to the thermal energy released by the detonation of the explosive, the combustion of the products of the detonation, and the combustion of the luggage. The amount of luggage within the container as well as the location of the device with respect to that luggage determine whether the energy released during the blast is mitigated or intensified relative to an equivalent event in an empty container. Heat transfer is the principal mechanism by which luggage mitigates the effects of a blast. The thermodynamic properties of typical passenger luggage were determined by performing thermal flash and soak tests on actual lost luggage provided by the FAA. The resulting data were used to perform heat transfer analysis of the effects of luggage on the detonation of an explosive device within a hardened cargo container. The results of that analysis were compared with empirical data. This paper also presents a semi-empirical method to predict the quasi-static overpressures that result when a terrorist device is detonated within a full or partially full luggage container.

Enhancing the Blast Resistance of Existing Structures Through Retrofitting With Shotcrete

Willie E. McDonald, *U.S. Army Engineer Waterways Experiment Station*

This paper describes the retrofit application of shotcrete for enhancing the blast resistance of existing structures. The shotcrete application represented one of several retrofit applications evaluated in field explosive experiments. A comparative evaluation of shotcrete's performance was conducted with respect to performances by the other retrofit applications simultaneously subjected to the same explosive loading. Subsequent observations of corresponding performance results for each respective retrofit application showed that the shotcrete application provided the most effective enhancement.

Effects of Component Material Properties on the Flexural Response of High Strength, Reinforced Concrete

Andrew A. Prinaris, Paul F. Mlakar, Edward F. O'Neil III, & Billy D. Neeley, *U.S. Army Engineer Waterways Experiment Station*

As the production of high performance concrete with strength many times that of conventional concrete becomes practical, the opportunity for the design of flexural members with this material occurs. The moment-curvature characteristics of such sections

are analyzed herein from a linear strain distribution and the stress-strain behavior of the material. The results indicate an improvement in yield moment capacity and in ultimate strain energy which is attractive in blast resistant design. To reach the full potential of the high performance concrete, reinforcement with greater strength and ductility than conventional reinforcing steel is required.

Pressurized 747 Test, Bruntingthorpe, England

Stuart J. Sachs, *U.S. Army Aberdeen Test Center*

The Ballistics Instrumentation Branch provided instrumentation support to the Federal Aviation Administration, Aviation security Research and Development Service. This test was in support of the Aircraft Hardening Program.

The aircraft was a decommissioned Boeing 747-100 previously owned by Air France. Four simultaneous explosions occurred during the test. Three of the charges were located in hardened luggage containers or liners and the fourth was in a standard LD-3 luggage container.

Peak pressure, Quasi-static pressure, skin acceleration, component acceleration displacement, strain and temperature measurement were acquired using Pacific Instruments model 5700 transient data recorders.

WE2: Isolation (Classified)

Characterization of the TRIDENT SWS Shock Environment to Develop Improved Isolation of COTS Equipment

Chris Suciu, Dawn Barrasso & Austin Alvarez, *Electric Boat Corporation*

Due to diminishing vendor supplies, more and more commercial off the shelf (COTS) equipment is needed to support the service life of the Trident Class submarines. With the steady and rapid increase in electronics equipment technology, the "modern" submarine needs to be modified to accommodate (COTS) equipment. This integration can be accommodated by either individually isolating components or global compartment isolation. Working within the confines of the existing submarine structures, shock isolation techniques are being developed to accommodate COTS equipment. Existing test data on the stanchion hung decks and equipment on the Submarine Shock Test Vehicle (SSTV) is used to establish a validated methodology, which is subsequently applied to predict the shock response of today's Trident Class submarines. Shock isolation cannot degrade the operational, acoustic, or functional requirements of the overall submarine, and must satisfy backfit capabilities, while providing shock attenuation to ensure survivability of COTS equipment in today's submarine shock environment. Transient underwater shock predictions with and without isolation for nuclear, direct and bubble pulse loading will be presented. This work was sponsored by SSP under contract N00030-97-C-0028.

Use of Statistically-Based Validation Method to Determine Isolation Mount Forces and Confidence Intervals in the SITE-III Program

W.E. Gilbert, *Naval Surface Warfare Center, Carderock*
A. Misovec, *Logicon-RDA*

Several methods were used to estimate the mount force-time functions from instrumentation data measured as a part of the Shock/Acoustic Isolation Technology Evaluation Program, Phase III. In this program, a 250,000-lb raft loaded with COTS equipment was installed in the SSTV and isolated from the hull motions on 50,000-lb mounts. Dynamometers were installed between the mounts and the raft and instrumented to measure the mount forces, however, those dynamometers were constrained by available space and were mounted differently than they were in the calibration testing. As a result, the accuracy and sensitivity of the dynamometers to the loading was not optimum. Two of the methods to estimate the loads from the data used the dynamometer strain data, but one of them used finite element analysis results as calibration while the other used a modified form of the actual calibration test results. The third method was based on a single-value decomposition of the measured raft acceleration responses to infer the loadings at each of the mount locations.

This paper will discuss how a 'difference' statistic between the responses predicted at various transducer locations, using each of the loading functions, and the measured responses at those locations is used to evaluate the accuracy of the estimated loading functions and to calculate confidence intervals on the loading functions.

The statistical method has been incorporated into a Pascal based PC program call CONFIDNT. The paper presents how this program was used to evaluate the SITE loading functions, and the role it played in selecting the mount force functions. The differences in the estimated mount forces will be shown, the sensitivity of the raft response to those differences, and the confidence intervals for those forces will be presented.

An Alternative Procedure for Calculating Mount Forces from Acceleration Test Data Using SVD and MDR Techniques

David M. Russell, *Electric Boat Corporation*

The following discussion is a brief description of a comprehensive data analysis method which can be used to determine mount forces from deck accelerations. This method was applied in the context of the SITE III shock test, and is akin to computing **F=Ma**, where, **F** is the vector of desired force responses, **a** is a vector of pattern amplitudes, and **M** is a transfer matrix which relates **a** to **F**. In this method Singular Value Decomposition (SVD) and Multivariate Data Reduction MDR techniques are used to define the principal patterns of a structure from analytical data and reduce the measured responses to a set of pattern amplitude time histories, **a**. SVD is also used to compute **M** as a best fit for **F=Ma**, from analytical data. It is possible to relate **F** directly to the measured responses, but, by reducing the measured responses to pattern amplitudes it is believed that the method is robust. The method was also developed so that it is flexible and can accommodate and recover from unexpected events, or results, during a test in a timely manner.

Site III Test Series - Post Test Correlation and NSSN Lessons Learned

Stephen Foltz & David Russel, *Electric Boat Corporation*

The SITE III test series was performed in support of the NSSN program. Its purpose was to evaluate responses of a shock isolated deck structure under UNDEX events, specifically the evaluation of the load carrying and shock mitigating properties of the Electric Boat High Capacity Mount (EB HCM); assessment of Commercial-Off-The-Shelf (COTS) equipment; and the validation of the transient shock analysis tools used in the NSSN design process. Electric Boat Corporation will present post-test correlation studies and lessons learned from the SITE III program as applied to the NSSN design program.

WA3: Smart Transducer Interface Standards - IEEE P1451

Implementation of a Smart Transducer Using IEEE P1451 Interfaces

Robert N. Johnson, *Electronics Development Corporation*

The considerable advantages promised by the IEEE P1451 family of standards will be realized only when there are several types of networks and numerous transducers available commercially. For transducer manufacturers, this means that they need a convenient and rapid vehicle for converting existing transducers to IEEE P1451.2 Smart Transducer Interface Modules (STIMs). Several Members of the IEEE P1451.2 working group have offered assistance to transducer manufacturers in this conversion.

This paper describes the implementation of such a STIM using an off-the-shelf accelerometer and a commercially-available interface module. The overall design of the STIM, the packaging and physical interface with the network, and problems encountered in implementing the IEEE P1451.2 Transducer Independent Interface (TII) are discussed.

Smart Sensor Network System

Fernando GenKuong & Alex Karolys, *Endevco*

This paper describes a Smart Sensor Network System for applications requiring sensors connected in a multidrop configuration in order to minimize interconnecting cables. The communication protocol was optimized for high speed data collection. The Smart Sensor Network System was developed with the following goals in mind: cost reduction, reliability and performance increase.

The Smart Sensor Network System consists of a controller called the Bus Converter/Controller Module (BCM), and a maximum of 208 Transducer to Bus In-line Modules (TBIM) connected to traditional analog type sensors (Piezoelectric, strain-gages, variable capacitance, etc.). The BCM and TBIMs are interconnected through a four wire network bus.

The Smart Sensor Network System achieved cost, reliability, and performance goals. Total system costs were reduced as a result of a reduction in interconnecting cables, salvaging of existing analog type transducers, and ease of use and maintenance. Reliability was improved because of the self-test capability provided by the TBIM, and the reduced susceptibility to noise of digital signals (EMI, crosstalk, ground loops, etc.). Performance was improved because of the increased accuracy provided by the TBIM.

WB3: Precision-Scale High Explosive Experiments

Precision-Scale High-Explosive Cratering Experiments in the Army Centrifuge

Dr. Charles Robert Welch, Christo Lunderman, Tommy G. Ray & Levi Rodgers Coffing, *U.S. Army Engineer Waterways Experiment Station*
Dr. Scott Steedman, *Andrew N. Schofield & Associates, Ltd.*

A series of precision-scale experiments were performed to investigate explosion-induced craters in a dry sand. The experiments employed the recently completed Army Centrifuge at the U.S. Army Engineer Waterways Experiment Station. The experiments employed precision 5-g center-detonated spherical charges buried at 57.1 mm. Three of the experiments were conducted at simulated gravitational field of 44.9 g's; two experiments were conducted at 88.9 g's; and one experiment was conducted at 1 g's. Three of the experiments were instrumented with Tourmaline crystal pressure gages to record ground shock arrival times. An initial experiment addressed the performance of the precision charges using a 100-million frames/s digital camera to record charge detonation.

In this paper, we discuss the precision-scale experimental methods used in the research and the results from the experiments.

In-Tunnel Airblast From External Detonations: Effect of Height-of-Burst

Charles E. Joachim, Dr. Charles R. Welch, and Christo V. Lunderman, *U.S. Army Engineer Waterways Experiment Station*
Dr. Mike Frankel, *Defense Special Weapons Agency*

This paper presents the results from precision-scale, high explosive experiments that were conducted to investigate the effects of changes in burst height on the overpressures generated inside a straight tunnel of constant cross-section. The experiments employed a model tunnel complex that has a diameter of 0.243 m and is a 1:23.2-scale model of a 5-m by 5-m tunnel. The experiment series consisted of nine 125-gram C-4 spherical explosive charges. All detonations occurred within six tunnel diameters of the portal. Four of the experiments investigated the influence of burst height; the remaining experiments evaluated the precision of the experiments. Airblast gages measured the induced overpressures at eleven locations inside the model tunnel.

In the paper, the experimental results are compared to an engineering model that predicts in-tunnel airblast for detonations made near the ground surface. Data are presented to demonstrate the fidelity of the precision-scale experimental methods at replicating full-scale behavior.

Precision Impact Testing and Numerical Simulation of Metal and Advanced Material Components

James O'Daniel, Kevin L. Koudela & Dr. Ted Krauthammer, *The Pennsylvania State University*

In this study, numerical analyses of precision impact events are performed for metal and advanced material structural components. Numerical simulations are conducted using implicit and explicit finite element algorithms. Results of the numerical simulations are compared to those for the instrumented precision impact tests to assess the validity of the numerical predictions and of the test approaches. Details of the structural component and impact test design are presented along with the results of the numerical simulations. Correlation between experiment and analysis is discussed. Conclusions from this study and recommendations for future applications of this procedures are presented.

Precision-Scale Explosion Experiments Using Laser-Driven Shocks

Jacob Grun, *Naval Research Laboratory*

The Naval Research Laboratory uses shocks initiated by a powerful laser pulse to study hydrodynamics phenomenology relevant to nuclear and conventional explosives, and to supernovae. A pulse from NRL's 1.5-kJ Pharos III laser is focused onto the surface of a period-sized piece of material placed in an ambient gas or in water. The laser heats the material to a few hundred eV creating a very powerful, miniature explosion with multi-kilobar pressures and material flow with Mach numbers up to a few hundred. This method has been used to produce the first measurements of blast-wave decursors, detailed measurements of blast-wave precursors, the first observations of blast-wave instability, measurements of shock coupling to solids, and measurements of shocks in water.

Precision Tests on Continua

Paul R. Gefken, James K. Gran & Alex L. Florence, *SRI International*

Precision tests on continua have been used by the Naval Surface Warfare Center (NAVSWC) and other Department of Defense organizations for validation of continua response computer models and for studying parameter effects. Tests were recently performed for the NAVSWC to characterize the dynamic response of saturated sand with different air content levels. The Defense Special Weapons Agency (DSWA) has performed numerous precision test in a variety of geologic media including limestone, granite and Nevada Tuff. In particular, these tests have been used to study the effects of saturation, pore water temperature (frozen), and the

inclusion of joints. In addition, precision tests have been used by the DSWA to study cratering from shallow high energy buried explosions under scaled gravity.

The precision test arrangement typically consists of generating a spherical wave from a small scale explosive source that is placed at the center of the continua. The spherical wave exercises the material under divergent loading and unloading conditions that are relevant to actual weapon loading conditions. The particle velocity gauge and the flatpack stress gauge are used for the material response characterization.

In this paper we describe the precision testing arrangement and measure continua response for saturated sand tests, jointed limestone tests, and cratering tests.

WE3: Next Generation Design (Classified)

Advantages to Submarine Shock Survivability Offered by a Double Hull Concept

A. White, D. Barrasso, A. Alvarez & S. Shaw, *Electric Boat Corporation*

Future U.S. Navy submarines will be required to meet more stringent acoustic goals and other aggressive mission requirements. Double hull submarine concepts offer the opportunity to use an "outside-in" approach to submarine design, affording significant ship-wide improvements in acoustic signatures, hydrodynamics performance, and survivability. Survivability of the double hull is enhanced by increased reserved buoyancy, for using the outer hull and standoff for coating and other shock attenuating features. This paper will investigate the improvements in shock survivability afforded by double hull submarine configurations, addressing variations in 1) hull standoff distance, 2) hull scantlings, 3) alternate pressure hull to non-pressure hull attachments 4) longitudinal vs. transverse framing and 5) coating of the external hull surfaces. Technology gaps and the need for improved tools and methods will be identified and discussed. Results from these shock parametric studies will be integrated with parallel acoustic and hydrodynamic studies to support the development of future innovative submarine concepts.

WB4: Transient Analysis

An Approximate Method for the High-Frequency Shock Response of a Continuous Structure

Robert R. Reynolds, *University of Arkansas*

The linear, impulse response of a continuous structure is determined using transient, asymptotic modal analysis (AMA). For this analysis a thin, elastic panel is examined and the high-frequency, response of the panel is determined. Results are compared to predictions made with classical modal methods, finite element solutions and experimental measurements. It is found that the spatially averaged response of the panel can be predicted well using the AMA approach and that this method provides significant effort and time savings over other alternatives.

Several authors have applied statistical means to the prediction of impulse responses. When random excitation is applied, similar steady-state asymptotic modal analysis (AMA) has been shown to provide an excellent estimate of the structural response. However, the application of asymptotic methods to *transient* responses has only recently been attempted. Transient AMA makes stepwise, asymptotic simplifications to classical modal theory (CMA) to achieve a simple and efficient approximation for the spatially averaged (RMS) response. The method requires only a frequency range with a sufficient modal density. The results are accurate for short to moderate periods after the excitation impulse.

Efficient Transient Analysis for Large Locally Nonlinear Structures

Dr. Joshua H. Gordis, LCDR Jeffrey Radwick, *Naval Postgraduate School*

A general and exact theory for transient structural synthesis is extended to address structural systems with an arbitrary number of localized sources of structural dynamic nonlinearity. The formulation is independent of model size, in that only those model degrees-of-freedom of interest need to be retained in the synthesis. The theory provides for the efficient calculation of nonlinear transient response due to externally applied loads and prescribed base motions. The theory functions as a substructure coupling and structural modification procedure allowing structural nonlinearities to be isolated from the remaining linear substructures, which are solved once. The nonlinear synthesis in effect installs the nonlinear elements and calculates the nonlinear transient response.

Solid Mechanics FEA Utilizing an Excess of 10 Million Degrees of Freedom

Photios P. Papados & Robert L. Hall, *U.S. Army Engineer Waterways Experiment Station*

The objective of this task was to predict the response of a reinforced concrete slab subjected to a detonation of high explosives embedded in the slab. State-of-the-art, nonlinear constitutive models were used. The reinforcement was modeled using

several solid elements through the thickness in order to capture the wave propagation. A 3.5-million element grid was generated in order to meet the requirements for the detailed modeling of the reinforcement. The analysis requirements include memory in excess of 220 Mb and 55 hours of CPU time. This computation was performed using the C-90 available at the DoD High Performance Computing Center located at the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

WE4: Analytical Methods #2 (Classified)

Investigation of Underwater Explosion Structure Interaction Using Eulerian/Lagrangian Hydrocode

Bong Rhee & L. Robert Hill, *Naval Surface Warfare Center Carderock*

A numerical study has been conducted to model underwater explosion (UNDEX) structure interaction for application of the Eulerian/Lagrangian hydrocode MSC/DYTRAN. First, the detonations of an explosive charge in deep water and shallow water are simulated and the resulting pressures at selected locations are compared with test data. Second, a ship bottom model subject to UNDEX is simulated using Arbitrary Lagrangian/Eulerian and Coupled Eulerian/Lagrangian techniques. Numerical results are compared with test data. Finally, a parametric study of numerical modeling is conducted to simulate holing of double hull models resulting from a close UNDEX attack.

SEAWOLF Ship Shock Test - Whole Ship UNDEX FEM Studies

Jonathan Webster, Steven D. Ollhoff & Roland Trailor Jr, *Electric Boat Corporation*

Traditionally, beam and compartment (zone) finite element models have been used to predict submarine responses due to UNDEX shock. In preparation for the 1998 SEAWOLF Ship Shock Test, beam models and compartment models have been used to provide pre-test predictions of component responses and whole ship motions. Also, a detailed model of the SEAWOLF submarine has been constructed with several goals. First, whole ship predictions from this model will be compared to beam and compartment model predictions. In areas previously modeled with only beam elements, the detailed whole ship model will provide the most accurate predictions for shock response. Second, the whole ship model will be used to study the effects of transitioning from a detailed compartment finite element model to a beam model. Animations will be shown which compare beam model, compartment model and full ship model response predictions.

A Transient Shock Method Using Structural Acoustic Reciprocity for Simultaneous Shock and Acoustic Assessments

Jessie Modzelewski, Frank Giurleo, Steve Gordon & John Wilder, *Electric Boat Corporation*

An analytical method employed to predict the dynamic response of a submerged structure due to an underwater explosion is shown capable of also predicting the far field radiation characteristics. Acoustic and shock considerations can be evaluated simultaneously, using a common model, during initial design development stages. This allows timely and lower cost evaluation of various design concepts, results in robust designs and reduces reliance on costly scale model fabrication and acoustic performance tests. Application of full structural acoustic reciprocity was used to assess the radiation efficiencies of various design modifications and to judge their relative acoustic merits. Recommendations for further development and validation of these analytical capabilities for structural / acoustic design are provided.

Finite Element Analysis of a Type 8 Mod 3 Periscope Subjected to Underwater Shock

Vincent Isgro, Michael Tucchio & Vincent Godino, *A&T Engineering Technology Center*
Robert LaFreniere, *Naval Undersea Warfare Center, Division Newport*

An underwater shock analysis of the Type 8 Mod 3 periscope head window in the stowed position at periscope depth and operational depth was performed using USA/DYNA. A three-dimensional finite-element model of the head was used to capture the window response. The effects of the window gaskets, the periscope tube, and the periscope mast were included in the model. Detailed discussion of the model is addressed along with appropriate failure criteria.

HA1: Machinery Diagnostics

Increasing Machinery Reliability Using Frequency Response Functions and Modal Analysis

Eric R. Saller, *IMI, A Division of PCB Piezotronics Inc.*
Art Crawford, *ARC Associates*
Mike Lally, *The Modal Shop*

Predictive maintenance programs provide an excellent assessment of machinery condition. Analysis of the information yields and indication of the type of the machinery fault present. Root-cause analysis transforms the predictive maintenance practice to a proactive maintenance effort. Proactive maintenance looks beyond the fault and determines the root cause of the failure.

One root cause analysis method is resonance testing. By impacting structures and measuring their responses, system resonances can be measured. This paper/presentation is a case study of a boiler feed pump at a power plant whose fault condition is corrected using this type of root-cause failure analysis.

Modification of the Exciter Bearing on Large Nuclear Turbine Generators

Zlatan Racic & Dr. Baodong Sun, *Siemens Power Corporation - Fossil Division*

This paper deals with the experimental and theoretical investigation of unstable vibrations which were observed at the #11 bearing at the exciter. Vibrations of the #11 bearing change with the load change of the unit and are much larger in the horizontal than in the vertical direction. An experimental investigation has indicated that the #11 bearing is very lightly loaded. A detailed theoretical analysis shows that the increase of gravity load and/or reducing the clearances of the existing bearing would lead to another problem, i.e., it would bring the exciter rotor "first critical speed" even closer to operating speeds of 1800 RPM. The solution found is to change to another type of bearing. The selected bearing is a cylindrical offset halves bearing. With this bearing the rotor system critical will be moved above the unit operating speed, thus becoming less "sensitive" to variations of excitations due to changes of the operating parameters.

Time and Frequency Domain Synthesis in the Optimal Design of Shock and Vibration Isolation for Large Structural Systems

LT. Dennis E. Florence & Dr. Joshua H. Gordis, *Naval Postgraduate School*

Methods for the efficient optimal design of shock and vibration isolation for large structural systems are developed. Specifically, rapid static, transient and steady-state dynamic re-analysis, which is independent of model size, is achieved through the use of time-and frequency-domain structural synthesis. These synthesis methods provide exact solutions for new static, transient and steady-state response resulting from structural modifications of arbitrary size and distribution, including frequency-dependent, non-proportional dampers. In the context of optimal isolation design, the synthesis methods are used to install and modify isolator elements, and to calculate the new static and dynamic response, without re-solving the full model (the full model is solved once, prior to optimization).

Radial Pump Casing Vibration

Dr. Andrej Predin, *University of Maribor*

Present paper discussed about the radial pump casing vibrations as a consequence of the exit flow from the radial impeller acting. These vibrations are transmitted due to intake and exit pump pipe system. However, the vibrations cause also the sound/noise propagation due to the pipe system and they are therefore undesirable. By rubber compensator setting at the intake and at exit pump pipe connectors can be damped these pump casing vibrations or its vibration propagation due to the pipe system, but from the pump operating aspect it still exists. Therefore for the active vibration damping the vibration main sources it must be known. By experimental measurements the basic vibration frequency amplitudes and its frequency spectra are determined. In this way the main vibration sources can be found in dependency of the pump geometry and its temporary operating parameters. With the vibration sources knowledge the pump casing vibrations can be reduced by the suitable pump dimension change or by the pump operating parameters change. Given are the experimental measuring results of the casing vibration amplitudes, frequency spectra in dependency of the pump operating parameters (capacity and impeller speed), and the mathematical model for the vibration amplitude and its frequency calculation.

Analysis and Solution of Abnormal Vibration Problem of Exciter

Dr. Baodong Sun & Zlatan Racic, *Siemens Power Corp.*

This paper concerns the experimental and theoretical investigation of abnormal vibration of Grand Gulf exciter, which had been balanced in the BOS (Balance and Over Speed Facility) and had to be balanced in the field during the first run with the exciter. Finite element analysis of exciter shows that the exciter in field (on three bearings) had different vibrational characteristic comparing with that of BOS (on two bearings). This led to the change of the unbalance condition of the exciter which had been balanced well in BOS. The recommended methods for making a good balance of the exciter both in field and in BOS are presented.

HB1: Environmental Specifications

Current Fatigue Design Methods for Fabricated Steel and Aluminum Structures

James G. Faller, *U.S. Army Aberdeen Test Center*

A typical "mechanical engineering" type fatigue analysis of metal structures is based on the mean fatigue strength of small smooth specimens. This approach based on the Goodman diagram was the state-of-the-art in fatigue design at one time. In the late seventies and early eighties research conducted in the U.S. and Europe on full size structural elements revealed that the Goodman diagram approach was overly optimistic with regard to the determination of an allowable fatigue stress range for fabricated structures. A more conservative method evolved from these findings. This method utilizes S-N curves based on the nominal stress range. This "modern" approach has been incorporated in structural design specifications worldwide, including those for highway bridges, buildings, ships offshore structures and cranes. Although the methodology is nowadays used by some heavy-duty vehicle manufacturers, many mechanical engineers are not aware of these developments and still conduct analyses based on the outdated approach of the Goodman diagram. The paper will contrast and compare the old and new methods of fatigue evaluation for steel and aluminum structures containing welded details.

Using a Simple Vehicle to Establish Modeling and Testing Parameters in the Dynamic Analysis and Design (DADS) Software Package

Joseph E. Bucci & James G. Faller, *U.S. Army Aberdeen Test Center*

With modeling and simulation now a mandate for the military developer and tester, a standard method for assembling models must be established. In this paper, the authors propose a generic, modular assembly technique based on their work with a simple vehicle model. The technique involves establishing standardized modules which can be tailored using menu driven commands in DADS. The modules are then assembled at user defined reference points to produce a model with defined utility.

Statistical Analysis of a Large Sample Size Pyroshock Test Data Set

William O. Hughes & Anne M. McNelis, *NASA Lewis Research Center*

The EOS spacecraft will launch on an Atlas IIAS launch vehicle on its mission to planet Earth in June 1998. the new design of the spacecraft's pyroshock separation system was characterized by a series of 13 separation tests. The analysis methods used to evaluate this unusually large amount of shock data will be discussed in the paper, with particular emphasis on population distributions and finding statistical significant families of data, leading to an overall shock separation interface level.

A Methodology for Defining Shock Tests Based on Shock Response Spectra and Temporal Moments

Jerome S. Cap & D.O. Smallwood, *Sandia National Laboratories*

Defining acceptable tolerances for a shock test has always been a problem due in large part to the use of Shock Response Spectra (SRS) as the sole description of the shock. While SRS do retain a wealth of information if one knows what to look for, it is commonly accepted that different agencies will generate vastly different time domain test inputs whose SRS all satisfy the test requirements within a stated tolerance band. At an even more basic level, the laboratory test specification often starts to lose any resemblance to the actual field environment even though the SRS are within some stated tolerance. It would seem that a concise means of bounding the time domain inputs would be of great benefit in reducing the variation in the resulting shock tests. The purpose of this paper is to present a proposed methodology for applying band limited temporal moments to this problem. In short, temporal moments consist of a set of scalar values (3-5 at most) that are unique to a given time history. By including these scalar quantities as a part of the test requirement (along with the SRS), it should be possible to more tightly constrain the variation in the test specifications that are considered to be an acceptable match for the underlying test requirement.

An On-Road Shock & Vibration Response Test Series Utilizing Worst Case and Statistical Analysis Techniques

Jerome S. Cap, *Sandia National Laboratories*

Defining the maximum expected shock and vibration responses for an on-road truck transportation environment is strongly dependent on the amount of response data that can be obtained. One common test scheme consists of measuring response data over a relatively short prescribed road course and then reviewing that data to obtain the maximum response levels. The more mathematically rigorous alternative is to collect an unbiased ensemble of response data during a "long" road trip. The problem with the latter approach is the increased demand on the data acquisition system. Sandia recently obtained response data for certifying a new tractor trailer design using a two part test series that attempted to utilize the best of both test schemes. The goal was to obtain a statistically significant worst case response data with a minimal amount of effort.

Development of Missile/Submunition Interface Dispense Shock Requirements from Prototype Warhead Testing

S.P. Poynor, *Lockheed Martin Vought Systems*

As part of a recent development program, two series of static dispense tests were conducted using prototype hardware. An instrumented warhead structure, for instrumented submunition simulants, nine uninstrumented simulants, dispense system hardware, skins and skin severance were used to characterize the performance of and to measure the shocks imparted to the submunitions as a result of operation of the skin severance and dispense systems during submunition dispense events. These events consisted of a skin severance event, an outer ring ejection of ten (10) submunitions, and an inner ring ejection of three (3) submunitions. The results of the skin severance events have been documented in a previous paper. The dispense (ejection) shocks measured during these test represented the first measurements for this category of environment for the submunitions. Measurements made during these tests were used to develop preliminary missile/submunition interface pyrotechnic shock environmental requirements.

Vibration Exposure to Telephone Equipment During Operation

Dag Sjogenbo, *Ericsson Radio Systems*

Environmental requirements in Europe for telephone equipment are given by ETSI (European Telephone Standards Institute).

Use within ERICSSON and elsewhere of the ETSI standard (and consequently data from IEC 721) have revealed requirement conditions being questionable or unrealistic. It may be easy to spot an unrealistic requirement but unfortunately it is more difficult to produce data that are realistic.

ERICSSON decided about an investigation of vibration exposure for some typical (or worst cases of) telephone equipment conditions. Beside vibration levels, task also included investigation of character of vibrations as being harmonic, random or transient to guide when selecting appropriate vibration testing methods.

Investigation was carried out during first part of 1997 with a final report at hand in the end of June.

Results will be taken under consideration by the ETSI working group for dynamic (mechanical) requirements. Time plan is to have a first draft with revised requirements to be presented for ETSI committee at latest in March 1998.

Results will also be available when IEC TC 104 decides to revise publication 721.

Vibration Environment for Telephone Equipment: Measurement and Analysis

Kjell Ahlin, *Ingemansson Technology AB*

The vibration environment for modern telecommunication equipment, base stations for cellular phones, has been characterized. More than 30 different sites have been explored. The vibration sources have been road traffic, trains, industrial activity, fans, blasting and piling. The analysis has been extensive and the resulting data base is believed to be of good use as a tool to describe the vibration environment. The paper describes the methods used for measurements and analysis.

Vibration Environment of the EXDRONE Unmanned Aerial Vehicle

Charles L. Brodell, *NASA Goddard Space Flight Center*

The flight vibration environment of the EXDRONE unmanned aerial vehicle (UAV) was measured and analyzed to define its characteristics, provide information allowing frequency sensitive payload design, and assist development of payload test specifications. The EXDRONE is a remotely piloted flying wing with an eight-ft. wing span. A miniature telemetry system and on-board data recorder were flown to collect acceleration, vibration, attitude, thermal and GPS data. Vibration testing was performed with this payload to record its frequency characteristics and factor them out of the reduced data. The spectral data contains sharp primary peaks in the 94 to 115 Hz range corresponding to engine speed. The maximum peak of 3.3 g's was recorded in the Z (up) axis. The data magnitude was dependent on axis orientation with respect to engine orientation. Launcher travel consisted of a 20 "g" shock load and a 10 "g" steady state acceleration. These results provided important information relating to payload design and qualification testing.

Probabilistic Distribution of Shock Intensity Experienced in Rail Transport

Janet Gipson, *Military Traffic Management Command Transportation Engineering Agency*

The Military Traffic Management Command Transportation Engineering Agency (MTMCTEA) is currently initiating an effort to define the probabilistic distribution of shock intensity experienced in rail transport. To support this effort, environmental data recorders will be used to measure shock intensity (amplitude and duration) experienced by the railcars and equipment during transport. The data will be compiled and utilized to provide design guidance to the Army acquisition community as well as provide insight to typical shock levels experienced during rail transport. MTMCTEA is in the early stages of gather data and is seeking venues for possible partnerships and sharing of data.

HC1: Dynamic Measurements

UNDEX Interface Pressure Measurements on a Composite Steel-Foam Plate

Paul R. Gefken, James K. Gran & Mohsen Sanai, *SRI International*
William Gottwald & Erik Rasmussen, *Naval Surface Warfare Center, Carderock Division*

The Naval Surface Warfare Center (NAVSWC) is interested in enhancing their computational capability for calculating the underwater shock response of structures that are covered with a protective foam layer. Essential to NAVSWC's program is a validation of the pressure time histories calculated on the foam surface and at the foam-structure interface. To provide this needed data SRI is performing an experimental program to develop the capability for making interface pressure measurements. Because the interface pressure gage must have the capability of deforming with the structure, a unique and innovative pressure gage is required. The SRI ytterbium flatpack gage design is being used as a point of departure for the interface pressure measurement technique. To validate the measurement technique experiments are being performed in which pressure is measured on the surface of a rigid 2-in.-thick flat steel plate and at the interface between a steel plate and a 2-in.-thick foam layer. The UNDEX applied loads are generated in SRI's water shock pool facility and range from peak pressures of 2000 to 7000 psi. This paper describes the experimental technique and presents the interface pressure results.

Evaluation of a Hopkinson Bar Flyaway Technique for High Amplitude, Shock Accelerometer Calibration

Thomas C. Togami, Dr. Vesta I. Bateman & Fred A. Brown, *Sandia National Laboratories*

A split Hopkinson bar technique to evaluate the performance of accelerometers that measure high amplitude shock has been proposed. An evaluation of this teehnique has been conducted in the Mechanical Shock Laboratory at Sandia National Laboratories (SNL) for use in practical calibrations of accelerometers. The evaluation consists of three tasks. First, the quartz crystal was evaluated in a split Hopkinson bar configuration to determine its performance at force levels of 4,000, 8,000, and 12,000 lbs for ambient, -55°F, and +165°F temperatures. Since the quartz crystal is used as the reference measurement in the Hopkinson bar flyaway technique, it is important to establish the linearity and frequency response of the quartz crystal for these conditions. Secondly, the flyaway technique was evaluated at shock amplitudes of 50,000 g, 100,000 g, 150,00 g and 200,000 g for ambient, -55°F, and +165°F temperatures. The reference measurements for these tests are strain gages on the Hopkinson bar and a certified Laser Doppler Vibrometer. An ENDEVCO 7270A accelerometer is used on the flyaway for the acceleration measurement. Lastly, the frequency domain performance of the Hopkinson bar flyaway technique with a NIST certified Kistler 805 accelerometer at shock levels up to 50,000 g was conducted. These three tasks have resulted in a certification of this technique by the SNL Primary Standards Laboratory.

This work was supported by the U.S. Department of Energy under Contract DE-AC04-94-AI85000.

Self-Generating Accelerometer Cable Response in a Shock Environment

Fred A. Brown, *Sandia National Laboratories*

Tests have been performed to characterize the response of an accelerometer cable with a titanium Hopkinson bar. The accelerometer cable is used for a piezoresistive accelerometer and consists of silverplated 36 gage copper conductors with SPC shield and fluorocarbon jacket. The shielded accelerometer cable has four conductors that are color-coded green, white, red, and black. For the accelerometer, output is measured on green and white; excitation is provided on red and black. This same convention was followed during the tests discussed in this short topic. The shock applied to the cable was about 12,000 g at 45 μs, a nominal velocity with 10 fps magnitude and 90 μs duration. The accelerometer cable was held in contact with the titanium Hopkinson bar with black electrical tape so that the shock was applied along the longitudinal axis of the wire. The input impedance for the amplifier is 10 MΩ shunted by 500 pF on all gain settings. A gain setting of 50 was used for all tests.

Eleven tests were performed for a variety of terminations of the cable. Plots will be shown of the input as measured by strain gages in the middle of the titanium Hopkinson bar (0.75 in. diameter and 72 in. long) and by a certified laser doppler vibrometer pointed at the end of the bar and the response as measured at the output of the amplifier with a Nicolet oscilloscope. The above measurements were confirmed with simultaneous measurements by the usual Mechanical Shock Laboratory Data Acquisition System and a Tektronix Oscilloscope with and input impedance of 1 MΩ shunted by 10 pF. Additionally, similar outputs to those reported above were obtained with two separate cables taped to the bar in response to a hammer impact. One cable response was recorded by the usual Mechanical Shock Laboratory Data Acquisition System, and the other output was recorded by a Tectronix Oscilloscope with an input impedance of 1 MΩ shunted by 10 pF.

The accelerometer cable has an output in response to stress waves that will be shown to be substantial in some cases. The accelerometer cable is subjected to stress waves in most applications because the cable is often taped to the item on which the accelerometer is mounted to provide stress relief for the cable. The output is about 10% when the cable is terminated with the low impedance bridge in the accelerometer; it can be ten's of volts when the cable is terminated with a high impedance load. The cable is not suitable for applications where the load has a high impedance. The error caused by the cable output should be corrected in precision applications.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under DE-AC04-94AL85000.

Dynamic Calibration Experiment of a Multiple Sensor Fish Surrogate

Vincent P. Chiarito & James Evans, *U.S. Army Engineer Waterways Experiment Station*

A dynamic calibration experiment was designed and conducted to calibrate a Multiple Sensor Fish Surrogate (MSFS) for hydrodynamic acoustic frequency response. The MSFS is a fish-shaped structure with piezoelectric sensors for measuring hydrodynamic pressures acting on a fish's body.

A cylindrical tank was constructed and mounted on an electrohydraulic exciter system with servo-control and force feedback. A calibrated hydrodynamic pressure transducer was mounted in the tank with the MSFS. A series of sine-sweeps, sine dwells, and random excitation experiments were conducted to obtain frequency responses from 16 pressure-sensing elements mounted on the surface of the MSFS. Hydrodynamic pressures were measured in the tank by both transducers and compared.

HD1: Undex-Related Ship LFT&E

Simulated Ship Shock Tests/Trials?

Hans U. Mair & Ronald Reese, Institute for Defense Analyses

Submarine Shock Tests and surface ship Shock Trials are vital components of ship test and evaluation (T&E) in general, and of Live Fire Test and Evaluation (LFT&E) requirements in particular. Shock Tests/Trials, surrogate and component tests, the Total Ship Survivability Trial (TSST), and associated analyses, simulations, and pre-test predictions are key components of an alternative to full-up, system-level testing using munitions likely to be encountered in combat. Ship Shock Tests/Trials, although conducted under conditions more benign than realistic threat conditions, provide insight into platform vulnerabilities with respect to underwater proximity bursts and produce significant decision-making data for taking corrective actions.

The high cost of conducting a Shock Test/Trial and the tremendous advancements made in simulation capabilities are driving the question: "Can simulations be substituted for ship Shock Tests/Trials?" Unfortunately, current simulation capabilities still seem insufficient to provide decision-making data of equal utility to ship Shock Tests/Trials. Simulations hold the potential, however, to provide complementary decision-making data of greater value than ship Shock Tests/Trials. Simulation capabilities must therefore continue to be advanced.

The relative overall utility of Shock Tests/Trials and simulations are contrasted in this paper. A list of advantages for both tests and simulations is presented, with strong arguments in favor of a combination of both approaches.

Biodynamic Response of a Human Male to an Underwater Explosion Event

LT D.B. Oglesby and Y.S. Shin, *Naval Postgraduate School*

Sophisticated computer simulations of human response, such as those made possible by the Articulated Total Body (ATB) Model, may be used to estimate crew survivability during underwater explosion events. With this goal in mind, collected data and video taken of a seated Hybrid III Anthropomorphic Test Device (ATD) during underwater explosion testing was used to develop and validate an ATB model of the chair and deck excitation. Subsequently, this model was used to estimate the biodynamic response and injury potential for a seated human male in a vessel subjected to an underwater explosion event.

HE1: Blast and Shock (Classified)

Design of Small-Scale Structure-Medium-Interaction Experiments

Jon E. Windham, Bruce R. Phillips, Denis D. Rickman & Stephen A. Akers, U.S. Army Engineer Waterways Experiment Station

Four small-scale structure-medium-interaction experiments were conducted to provide a database for evaluation/validation of first principle structure-medium-interaction codes. Three of the four experiments consisted of spherical explosive charges detonated in sand backfill above the roof of a box structure; the masses of the C4 explosive charges were 0.91, 1.81, and 2.72 kg. The experiments were designed to optimize code validation while maintaining physical reality with the prototype. Design considerations involved in defining the experiment geometry, structural details, and measurement types and locations are summarized.

Results form Small-Scale Structure-Medium-Interaction Experiments

Bruce R. Phillips, Denis D. Rickman, Stephen A. Akers & Jon E. Windham, *U.S. Army Engineer Waterways Experiment Station*

The U.S. Army Engineer Waterways Experiment Station is conducting research to develop numerical techniques for predicting explosive-induced loads transmitted to buried hardened structures from subsurface conventional weapon detonations. Four

small-scale structure-medium-interaction experiments were conducted to measure ground shock and structure loads, motions, and damage for use in validating the numerical techniques. Three of the four experiments consisted of spherical, explosive charges detonated in sand backfill above the roof of a box structure; the masses of the C4 explosive charges were 0.91, 1.81, and 2.72 kg. Comparative analyses of the ground shock, structure interface loads and motion, and structural damage are presented.

A Numerical Simulation of the Small-Scale Structure-Medium-Interaction Two Experiment

Stephen A. Akers, Bruce R. Phillips, Denis D. Rickman & Jon E. Windham, *U.S. Army Engineer Waterways Experiment Station*
Major Darren L. Rice, *Defense Special Weapons Agency*

Three-dimensional finite element simulations of the structure-medium-interaction environment in the Small-scale Structure-Medium-Interaction (SSMI) 2 experiments are presented. The principal objectives of the simulation were to predict the ground shock, structure-medium-interaction, and structure response of the primary loaded roof element due to the detonation of a 1.81-kg sphere of C4 explosive in a sand backfill. The roof experienced moderate damage, i.e., six to seven degrees of rotation. Data obtained measured in the SSMI 2 experiment are compared to the calculated results.

High-Performance Computing Simulation of Land Mine Explosion for the Mine Clearing Vehicle

Raju Namburu & Tommy Bevins, *USAE Waterways Experiment Station*
William DePorter, *United Defense LP*
Mitul Modi, *US Army Tank-Automotive RDE Center*

This paper discusses a joint project between TACOM, United Defense, and CEWES on modeling and simulation of the response of a mine clearing vehicle plow blade to a mine explosion. The simulation of mine explosion and its interactions with the vehicle clearing blade during plowing involves analyzing shock physics and large deformation structural response phenomena. Hence, this problem can be analyzed as a coupled problem or two decoupled problems. This paper addresses the first decoupled problem, namely, land mine explosion in the presence of spoil in front of the plow clearing blade. Simulations were performed starting from the initiation of an explosion in the soil to its impact on the clearing blade using shock physics software. Two soil material models, namely clay and dry sand, were characterized in the shock physics software on parallel computers to perform the above simulations. Characterization of soil for simulating a clay or dry sand response in the shock physics software will be discussed in the paper. Further, the paper discusses the following simulations showing comparison for clay and dry sand materials: (1) role of spoil, (2) the role of ground shock on the blade, and (3) the cratering efficiency.

HA2: Shock Testing

Improved Deck Environment Fixture for the Medium Weight Shock Machine

J. Rick Griffen & Brian V. Mokry, Newport News Shipbuilding

The MWSM (Medium Weight Shock Machine) is used for shock qualification of shipboard equipment by test under Mil-S-901. These tests intend to subject equipment to shock inputs characteristic of its intended shipboard hull, bulkhead or deck mounting location.

Duplication of the location characteristic is achieved by interposing different mounting fixtures between the MWSM and tested equipment. No standard fixture is available for decks.

Interest in a deck fixture continues as deck inputs are significantly different from the hull condition. Substitution of the available standard hull fixture produces a significant overtest for many items

This effort: 1) Established a target deck shock environment (See companion abstract); 2) Developed an improved MWSM deck fixture and test procedure; 3) Developed and ABAQUS model of the MWSM, fixture and equipment; 4) Built a fixture prototype and conducted instrumented MWSM tests; 5) Verified model's ability to closely predict response time history; 6) Demonstrated the new fixture's improved simulation of the deck environment.

This paper will summarize and present results from steps 2 through 6.

NATO Standardization Agreement on Testing of Surface Ships Equipment on Shock Testing Machines

Robert Regoord, *TNO Centre for Mechanical Engineering*

In NATO countries shock specifications regarding acceptance testing of naval shipboard equipment differ widely. In that situation the existing STANAG 4141 is shown to be not a practical document for international procurement. The paper concentrates on a new STANAG as produced under auspices of a NATO Working Group on Ship Vulnerability (AC/141 (NG/6) SG/7). This STANAG fully specifies an agreed way of acceptance testing. This as an approach parallel to the existing and remaining national Shock Specifications like MIL-S-901D. Thereby concentrating on meeting defined shock spectrum levels and not excluding any testing machines on forehand. These levels are to be specified and to be made available from national authorities.

Shock Test System Performance Prediction and Feed-Forward Control Using High-Fidelity Nonlinear Dynamic Hydraulic System Modeling

Thomas M. Hessburg, Donald G. Krantz & Allen J. Clark, *MTS Systems Corporation*

This paper describes a powerful new technique for using high fidelity dynamic models to predict system performance of a high-energy hydraulically-actuated shock test system. The same models are then used to formulate an advanced feedforward controller for the system. Not only does the technique support system development, performance prediction, and feedforward control, but it enables some aspects of virtual testing by precisely predicting forces to be applied to a test specimen. The data presented show that the system simulation was able to predict system performance very well, and that the feedforward control system demonstrated its ability to meet its performance objectives.

Method for Low Cost, Single Axis Shock Mount Characterization

Kevin S. O'Neal, *Newport News Shipbuilding*

Drop tests for the purpose of shock mount characterization offer a low-cost alternative to live fire shock tests. These characterizations must be adequate to support analytical predictions of the response of the isolated systems to shock. The 3 Kip Shock and Acoustic Mount (SAM), developed for the United States Navy's Advanced Ship Shock Isolation System Technology (ASSIST) Program, underwent drop tests and floating shock platform (FSP) shock tests to determine its force-deflection characteristic. This paper presents and correlates the results of the SAM's drop tests and the results of the SAM's FSP shock tests. This correlation shows that drop test are cost effective for single mount characterization.

'The JERK' - The Third Derivative, An Empirical Solution

Mendel N. Silbert and Paul J. Clements, *Salisbury State University*

This paper presents an empirical method to measure the shock acceleration or Jerk loading of a free falling body. This free falling body is connected to a fixed ceiling beam by an 8 foot Kevlar test bridle that is assumed to be inelastic. This technique may be best described as "bungee jumping" with zero stretch.

HC2: Analysis Methods #1

The Benefits of Complex vs. Simplified Analytical Models in Predicting Occupant Lethality for a Reinforced Concrete Blockhouse

David D. Bogosian, *Karagozian & Case*
Jon D. Chrostowski, *ACTA, Inc.*

A reinforced concrete blockhouse structure at Vandenberg Air Force Base was subjected to detailed finite element analyses to determine its resistance to blast loads from nearby impact of explosive rocket fragments. The same structure had been analyzed for the same purpose several years prior using simplified single degree of freedom (SDOF) models. Comparison of results from the two sets of analyses, both in terms of structural response as well as expected casualties, provides valuable insight on the areas of applicability for SDOF models and the degree of conservation involved in using similar engineering models.

Extraction of Modal Parameters from Closed-Loop Vibration Control Test Data

L. Hermans, H. Van der Auweraer & J. Debille, *LMS International*
M. Abdelghani, *IRISA-INRIA*

In environmental qualification testing, real life vibrations of test objects are simulated in well-controlled laboratory conditions in order to assess whether they will withstand their operating environment. Difficulties are encountered when one wants to reduce the transmissibilities, power spectral densities or spectra of accelerations measure during random or sine sweep testing to modal parameters as typically, the force inputs could not be measured. This is also true for acquired transient time data in case shock loads were imposed on the test object. Therefore, the need arises to develop modal identification techniques from output-only data.

In this paper, two techniques are investigated for their application to power spectral densities and to short transient time data. They include polyreference LSCE using correlation functions and the stochastic subspace identification technique. The theory of both methods is outlined and illustrated by modal analyses of environmental qualification test data acquired on a realistic test object.

Dynamical System Modeling Via Signal Reduction and Neural Network Simulation

Dr. Thomas L. Paez, Sandia National Laboratories
Dr. Norman F. Hunter, Los Alamos National Laboratory

Many dynamical systems tested in the field and the laboratory display significant nonlinear behavior. Accurate characterization of such systems requires modeling in a nonlinear framework. One construct forming a basis for nonlinear modeling is that of the artificial neural network (ANN). However, when system behavior is complex, the amount of data required to perform training can become unreasonable. We reduce the complexity of information present in the system response measurement using decomposition via canonical variate analysis. We describe a method for decomposing system responses, then modeling the components with ANNs. A numerical example is presented, along with conclusions and recommendations.

High Fidelity Virtual Simulation of Articulated Multiflexible Body Systems

Dwayne McDaniel & Dr. Norman Fitz-Coy, University of Florida

In this paper we present a procedure for developing cost effective, high fidelity models of articulated multiflexible body systems for the purpose of virtual simulation. The analysis shows that reduced-order components of a system can be obtained while maintaining the salient features of the full-order system. These component models have actuators and sensors placed at locations which will provide the responses required for virtual simulation. Time domain simulations of both the reduced-order and the full-order models were conducted in DADS. The results indicate that there is significant time savings (hence cost) in using the reduced-order model without any significant sacrifice in the accuracy of the results.

HE2: Terrorist Threat Protection #1 (Classified)

Validation of the Spherical Source and Shockwave Reflection Models of the BLASTX Code

J.R. Britt, *Science Applications International Corporation*
A.P. Ohrt, *U.S. Army Engineer Waterways Experiment Station*

Two primary foundations of fast-running analytical/empirical codes (such as BLASTX) for calculation of air blast propagation in structures are (1) the explosive source model and (2) the shock wave reflection model. An earlier paper (Britt, Klump, and Ohrt, 1996) introduced spherical blast source models used in BLASTX that calculate pressure, particle velocity, and density wave forms by interpolation of tables computed by the RAGE hydrocode. Code results were compared with the Kingery-Bulmash TNT empirical standard. In the paper, BLASTX spherical source results are validated with free-air test data for the additional explosives PBX-9404, RDX, and Pentolite. Equivalent charge weights relative to TNT are determined for both peak pressure and impulse for a number of explosives based on the RAGE calculations. The shock reflection model in BLASTX is validated against height of burst (HOB) test data for several explosives including Ammonium Nitrate / Fuel Oil (ANFO), PBX-9404, NP, HMX, and TNT. Detailed comparisons are presented between BLASTX results and measurements for low HOB. These data include (1) TNT surface tangent spheres and similar very low HOB explosions of ANFO and Comp C-4 from large scale tests (Swisdak, 1983 and more recent data) and vehicle bomb tests (Hossley, 1995), (2) Direct course (ANFO at 1.56 ft/lb$^{1/3}$ hob), and (3) Mineral Find 2 and Mighty Mach (HMX at 1.0 ft/lb$^{1/3}$ HOB).

Comparisons of BLASTX Cylindrical Explosive Source Model Output with Experimental Results

J.R. Britt, *Science Applications International Corporation*
A.P.Ohrt, *U.S. Army Engineer Waterways Experiment Station*

An explosive source model to predict airblast environments produced by cylindrically-shaped explosive charges has been developed and incorporated into the BLASTX computer code. This explosive source model, based on RAGE hydrocode calculations, is described in a companion paper. Several interesting phenomena associated with the cylindrical shape of explosive charges are predicted and quantified by this model. In order to evaluate the validity of the cylindrical source model, experimental configurations were modeled with BLASTX and the BLASTX output compared to the experimental results. Model output was compared to data from experiments involving the detonation of cylindrical charges at or near the ground surface and also experiments involving detonations within a structure. Much of the phenomenology predicted by the cylindrical explosive source model is observable in the experimental data. Complex interaction of the airblast from the cylindrical explosive source with the ground plane sometimes resulted in incorrect time phasing of airblast pulses, prompting modifications to the cylindrical explosive source model. This paper presents the results of the cylindrical explosive source model evaluation, including discussion of the model's limitations and range of validity.

A Cylindrical Explosive Source Model for the BLASTX Computer Code

A.P.Ohrt, *U.S. Army Engineer Waterways Experiment Station*
J.R. Britt, *Science Application International Corporation*

Most analytical/empirical methods for airblast prediction employ explosive source models which assume spherical explosive geometry. Such explosive models exploit obvious advantages in symmetry to achieve computational efficiency, ease of use, and traceability to practical experiments. However, most real explosive sources (i.e., munitions, demolition charges, etc.) are of more complex shape, with cylindrical explosive geometries being particularly abundant. In order to better predict airblast from cylindrically-shaped explosive charges, a cylindrical explosive source model has been developed for the BLASTX computer code. This model is based upon a suite of RAGE hydrocode calculations and adapts to the ray-tracing and non-linear shock addition algorithms utilized in BLASTX. This paper describes the cylindrical explosive source model and shows the predicted influence of L/D ratio and angular position from the cylindrical charge on airblast. A companion paper compares model output to published experimental data.

Numerical Simulation of Alternate Scenario For Khobar Towers

Dr. James T. Baylot, PhD, *U.S. Army Engineer Waterways Experiment Station*

A building at the Khobar Towers Complex was severely damaged by the effects of a truck bomb. The pre-cast structure failed primarily at connections between structural panels. A numerical model, which explicitly considers connection failure and impact of panels on other panels, was developed and used to predict the response of the structure to an alternate scenario. The analysis results indicate that damage to the structure for the alternate scenario would have been greater than for the actual event. These numerical models may be used to quickly evaluate the effectiveness of security/safety measures used to minimize the effects of these events.

HA3: Isolation #1

The Characterization of Nonlinear Mount Responses for Implementation in Large Scale Transient Analyses

David M. Russell, Stephen F. Gordon & Chris Abate, *Electric Boat Corporation*

With an increased desire for accuracy in the analytical simulation of shock events on large complex structures, it has become necessary to accurately represent the nonlinear behavior of resilient mounts and snubbers. In order to keep the cost of these large-scale transient shock analyses (TSA) down it is necessary to develop these characterizations as relatively simple expressions, algorithms. This paper describes a general process for defining the gross, *macro*, level response of a mount from either test data or more commonly from detailed analyses of the mount.

Deck Structural Stiffness Study for Surface Ship Isolation

Kevin E. Arden, *Newport News Shipbuilding*

The purpose of this study is to identify the effects of below mount deck stiffness and above mount raft stiffness on shock isolation systems. A simple parametric study was done using several dynamic models of rafts and ship structure.

The study shows that below mount stiffness is significant. Shock isolation mounts isolate equipment from sudden or violent impulses seen in the keel or bulkheads. However, deck structure flexibility already mitigates the "shock" loading to a lower frequency input. Typically a shock isolator will only amplify or slightly modify a flexible deck environment.

Advanced Ship Shock Isolation System Technology, ASSIST, Program Shock Design of the 3 Kip HYTREL Shock and Acoustic Mount

Tom Feldhaus, *Newport News Shipbuilding*

A 3 kip capacity shock and acoustic mount, using a HYTREL element sliding on metal conical surfaces, similar to the previously developed SAM mount, was developed for Naval surface ship application. The mount is designed to limit equipment shock excitation within a specific mount deflection when exposed to various GFI velocity shock inputs. This mount also provides acoustic isolation for the supported equipment. The mount uses two optimum stiffnesses, one above and one below a transition load, over the shock deflection excursion. The HYTREL element was designed using Master Series and ABAQUS to exhibit stiffness characteristics that were determined to be optimum by a FORTRAN programmed mount algorithm.

HB3: Numerical Methods

Nonlinear Power Flow Finite Element Analysis of Frame Structures

Albert L. Stiehl, *The Pennsylvania State University*

The power flow finite element method, a statistical energy analysis method, was introduced to analyze the high frequency response of beams with a single wave type. The method was further developed for the linear analysis of frame structures consisting of beam members with multiple wave types. The method is further developed herein for the nonlinear analysis of frame structures. The nonlinearity of the problem occurs in mechanical conductance properties of finite elements which model power flow at structural joints. The conductive property is shown to be dependent upon energy density values of nodes defining joint element and nodes adjacent to the defining nodes.

Dynamic Modeling for Design: Space-Time Finite Element Formulation of an Euler Beam

Eric L. Kathe, *U.S. Army, Benet Labs*

The purpose of this paper is to demonstrate the application of finite element methods to the partial differential equations that govern Euler beam dynamics; in both space and time. The approach enables the posing of design problems for the structural response of beams subject to shock and vibration loading from a static perspective. Numerical validation of the results using a forward Euler ordinary differential equation solver is shown.

Analysis of the Collision of a Submarine

Christian Montfort & Marc Chauvet, *DCN - Naval Systems Technical Agency, French Department of Defense*

On March 2, 1994, a submarine hit a reef off Cap Ferrat. This accident did not jeopardize the safety of the submarine. Information on the structural condition was collected after the accident.

The analysis was made by numerical simulation. The results were then compared with the submarine damage data. The numerical code used for the analysis is based on the finite element method.

It demonstrates the deformation mechanisms, gives an estimate of the energy absorbed by the main structures and various mechanical quantities.

The following paper discusses the simulation results. They are consistent with the damage observed, demonstrating that such a numerical code is capable of calculating the deformations of various structures. Finally, lessons on the equipment response to the shock and submarine safety were drawn from this analysis.

Comparison of Dynamic Shock Responses of a Coupled Structure

Dr R.J. Scavuzzo, *University of Akron*

A structure, designed to develop strongly coupled vertical and rotational (or horizontal) motion from vertical shock inputs, was analyzed using both a spectrum response analysis (DDAM) and a time-history analysis. Structures of this type have been encountered in the shock analysis of combat ship systems. Significant differences in calculated peak shock responses are observed at various locations in the structure.

The prescribed vertical time-history shock pulse has a vertical acceleration of 20g to a peak velocity of 2 ft/sec and a deceleration of 2g until a zero displacement is obtained. This base motion is used as input to the time-history analysis. Then, a spectrum analysis of this input shock pulse was calculated. Values at the modal frequencies were determined exactly for input to the structure. Calculated peak accelerations from a DDAM analysis were compared to time-history values.

Results indicated significant differences in the calculated response between the two analytical approaches for this type of structure. At some locations, modes associated with the time-history analysis are out-of-phase resulting in a low dynamic response even though there are high accelerations in each mode. Using the NRL Sum in DDAM, these modes add to each other leading to a prediction of a false high shock response.

HC3: UNDEX

Dynamic Response Analysis of Scaled Steel/Aluminum Hulls Under Direct Shock Wave and Bubble Loadings

Jim Lua, Vincent Godino, Russel Miller & Thomas Littlewood, *A&T Engineering Technology Center*
Kyle Martini, *Cambridge Acoustical Associates, Inc.*

Underwater explosions on model surface hulls play a very important role in providing information obtainable from costly full-scale tests. To be able to simulate the response sequence of the full surface ship under an underwater explosion and capture key response characteristics associated with both direct shock and bubble pulsation, it is imperative to explore the optimal model surface

hull via numerical simulations. Under this research effort, both a 1-D mass/spring model and a 3-D finite element model were developed for various scaled hulls with different materials, number of stiffeners, and geometric and charge configurations.

The 1-D model based on a mass/spring system with a plane waver approximation was developed to explore the effect of cavitation on hull response parameters and to examine the response difference of various scales. To determine both the stress distribution and whipping frequency of the entire hull structure, a 3-D finite element analysis using FSI/DYNA3D was performed on a scaled hull for cases with and without cavitation. The 3-D finite element results on the bottom panel are comparable with the results simulated from the 1-D model. These numerical results provide an insight into the optimal hull design, fabrication, and experimental instrumentation.

A Small Scale High Strain Rate Test for Determining the Relative Damage Effects of Underwater Explosions on Panels

Warren D. Reid, *Aeronautical and Maritime Research Laboratory*

A high strain rate test has been developed for determining the behavior of panels to explosive charges detonated underwater in the near-field regime. The test has specifically been designed to observe the relative damage effects of shock-wave bubble pulse and bubble collapse loadings at stand-offs equivalent to three bubble radii or less.

Experimental results at this stage have looked at the behavior of both aluminum and GRP panels against explosive charges up to 100 grams. The response of the panels to each of the loading mechanisms has been characterized by using high speed video and displacement transducers.

Small-Scale Tank Facility for Studying Underwater Explosion Phenomena

Gerry Rude & John E. Slater, *Defence Research Establishment Suffield (DRES)*

A small-scale tank facility has been established at DRES for investigating the blast physics of underwater explosion (UNDEX) phenomena and obtaining data which can be used for code validation. The open-top water-filled tank, 2-m diameter by 2-m high, is particularly suitable for conducting test using 1-g size detonator to study the complex nature of the fluid-structure interaction phenomena of close-proximity explosions at shallow depth. High-speed photography and precision instrumentation can be used to examine the highly transient loading and structural response of a target due initially to the shockwave contact, then the fluid cavitation formation and closure, and finally the detonation-bubble expansion and collapse leading possibly to water-jet impact. The tank can also be used to test underwater instrumentation such as pressure gauges which are used for measuring the UNDEX free-field conditions as well as target surface loading.

This paper will give a description of the tank facility, photographic equipment and some of the test apparatus used to investigate the UNDEX phenomena. Selected test results in the form of high-speed photographs showing the complex nature of the fluid-structure interaction; and time-history plots of the measured free-field pressure condition, and target surface loading and motion response are presented to illustrate the capability of the tank facility. Information gained from the small-scale experimental investigations has been vital in providing an insight into the complex nature of the underwater explosion phenomena, particularly with close-proximity fluid-structure interaction, which can cause severe target loading and structural damage. The test data have also been essential for the development and validation of suitable numerical models and solution methods for simulating the UNDEX phenomena and target response.

HE3: Terrorist Threat Protection #2 (Classified)

Application of Engineering Level Tools to Counter-Terrorism

Dr. Thomas R. Slawson, PE, *U.S. Army Engineer Waterways Experiment Station*

The U.S. Army Engineer Waterways Experiment Station has developed several useful tools for the analysis of blast loaded structures. These include the In-Structure Shock (ISS) models and the Wall Analysis Code (WAC). ISSv5 is a two-dimensional frame element model, and ISS3d is a three-dimensional shell/space frame model. both versions of ISS include "manual type" drivers to predict the blast load environment from conventional weapons detonations. WAC is a single-degree-of-freedom model for the analysis of reinforced concrete and masonry walls subjected to blast loads. This paper summarizes several applications of these engineering level tools to blast loaded conventional structures, typically encountered in Counter-Terrorism studies.

Response Predictions of Reinforced Concrete Structures Subjected to Combined Airblast and Fragment Loadings

Darren Tennant and Howard Levine, *Weidlinger Associates, Inc.*

The ability to predict the response of the reinforced concrete structures subjected to combined airblast and fragment loadings from internal detonations is of interest in assessing the survivability and vulnerability of structures. In this paper a method for handling the combined effects of airblast and fragments using an explicit, large deformation, finite element code, FLEX, is presented. A procedure for including discrete fragment impacts and their interaction with the structure developed under DSWA sponsorship in

conjunction with other organizations, is detailed. This method, coupled with an advanced constitutive model to handle rate dependence, material degradation, softening and localization, is used to calculate the response of a series of half scale tests for different weapons, wall thicknesses and reinforcement arrangements. Calculations are compared with the test data to evaluate the methodology. Explanations for differences between the predictions and experimental data are suggested.

Water Tamping Effects from Near Surface Cylindrical Charges

R.R. Namburu, Dr. J.P. Balsara, B. Armstrong & T.L. Bevins, *US Army Engineer Waterways Experiment Station*

Experience with recent terrorist attacks indicates that the current analytical prediction methods are inadequate for characterizing and understanding complex charge geometries and tamping effects. The problem involves modeling of high-explosive initiation, detonation, rupture, fragmentation and blast wave propagation. To model these phenomena, a three-dimensional simulation may require solving millions of nonlinear equations. Computational Structural Mechanics (CSM) CHSSI scalable software PCTH along with material fits is used on a Cray T3E to perform simulations. PCTH is a two step explicit solution scheme to march in time and uses message passing interfaces to communicate between processors. The numerical simulations have provided a wealth of information necessary to understand asymmetry of the blast pressures and effects of water tamping from near surface cylindrical charges. The computational domain is discretized using 32 million finite volume cells to adequately model the problem. Simulations are performed on a Cray T3E using 128 processors and 150 Mbytes of memory on each processor. Linear scalability of the PCTH software is observed on the Cray T3E. Due to the complex nature of the phenomena, parametric studies using numerical modeling is the only way to understand tamping effects for near surface cylindrical explosions. Numerical simulations and comparison with experiments will be discussed.

Simulation of Damage to Multistory Building From a Terrorist Bomb

Raju Namburu, T. Bevins & Dr. J. Baylot, *US Army Engineer Waterways Experiments Station*

The threat to our operational forces and facilities is posed by increasing sophistication of terrorist weapons. The Services need to develop new technologies for designing or retrofitting military facilities to ensure their security and survivability against terrorist attacks from a wide spectrum of weapons they employ. This study addresses a part of the DOD HPC challenge problem, namely effects of asymmetric blast propagation and its effect on a multistory building. A multistory building is modeled to the level of interior walls, doorways, windows and stair wall landings, providing for a detailed airblast propagation and complex reflections with building materials throughout the interior of the building. The analysis was performed using Computational Structural Mechanics (CSM) CHSSI scalable Eulerian explicit software PCTH on a Cray T3E using 256 processors. Recent advances in hardware have made it possible to simulate the blast propagation and building response in sufficient detail to accurately characterize large deformation response. To simulate a terrorist bomb detonation and blast wave propagation into the building, the problem domain is discretized using 85 million three-dimensional cells. The memory required for the problem is about 145 Mbytes for each processor. The results provided an insight into the blast and its interaction with building components.

HA4: Isolation #2

Application of Hermetically Sealed Fluid Dampers For Low-Level, Wide Bandwidth Vibration Isolation

Alan R. Klembczyk & Michael W. Mosher, *Taylor Devices Inc.*

This paper examines the feasibility of using hermetically sealed fluid dampers for the isolation of extremely low level, wide bandwidth vibration. Typical problems encountered by the designer of an effective isolation system include the existence of hysterisis within the damping system, a wide operating temperature range, reduced pressure environments and a requirement for low weight.

Analytical and empirical test results are presented which demonstrate the effectiveness of a relatively simple, yet robust passive isolation system, using hermetically sealed fluid damper and mechanical spring combination to successfully isolate a given component to various vibration environments.

Limiting Performance Estimates for the Active Vibration Isolation in Free-Free Multi-Degree-of-Freedom Mechanical Systems

V.M. Ryaboy, Newport Corporation

An approach is presented to estimate the maximum possible effectiveness of active vibration isolation in a linear multi-degree-of-freedom conservative oscillatory system. Contrary to the preceding work on this topic (V.M. Ryaboy, *Journal of Sound and Vibration*, vol. 186(1), 1995, p. 1-21) dealing with rigidly supported systems, here the free (non-supported) systems are considered. Such systems can serve as models simulating *large space structures*. Exact bound are obtained for the work of the internal active control forces on the system displacements necessary for the external disturbance compensation.

Intelligent Shock Mitigation and Isolation System Through Applied Semi-Active Vibration Control Technology

Frances F. Rasmussen & William D. Gottwald III, *Naval Surface Warfare Center, Carderock Division*
Edward J. Krasnicki, *Enidine Inc.*
George Lee, *National Center for Earthquake Research at State Univ. of New York at Buffalo*

This paper describes an ongoing project investigating the use of semi-active isolation for dual use in isolating equipment on submarines from the effects of underwater explosions and improving the resistance of building to earthquake loadings. Preliminary experiments and analyses have been conducted which look promising. A full-scale seismic demonstration and a quarter-scale underwater explosion demonstration are planned. Objectives of the program, isolation system description, results of preliminary testing, and plans for large-scale demonstrations will be given. This project is funded by DARPA as part of its Technology Reinvestment Program. The Navy participant in this project is the Naval Surface Warfare Center, Carderock Division and the private consortium is made up of Enidine Incorporated, Hydro-Line Incorporated, and The Research Foundation of the State University of New York.

HB4: Analysis Methods #2

The Role of Simulation Based Design in the Shock and Vibration Finite Element Analysis Environment

Dan Reed, Newport News Shipbuilding

"*Simulation Based Design (SBD) is a set of tools and standards which form an infrastructure to link data...*"[1]. This paper will define the concepts of SBD and explain how SBD fits into the analyses of tomorrow. In the SBD environment, the engineer can use geographically distributed data to analyze components for shock and vibration and develop a cost efficient design. The focus of this paper is the implementation of SBD philosophy in shock and acoustic analyses of typical submarine deck.

[1] - Excerpt from the SBD web site, "http://sbdhost.parl.com/support/whatIsSBD.html"

Operational Vibration Specification Development for Nonstationary Events Using Wavelet Analysis

Michael T. Hale, *Redstone Technical Test Center, US Army TECOM*
Reza Adhami, *University of Alabama in Huntsville*

Laboratory based vibration testing has been successfully employed as a screening technique for both structural and operational reliability for many years. There are numerous users, ranging from the automotive industry to the Department of Defense (DoD), who rely heavily on vibration testing to help ensure the survivability and performance of their specific products. The problems addressed in this research originated in DoD based scenarios, however, the analysis techniques considered are applicable to vibration testing in general.

The majority of structural integrity based vibration specification development performed by DoD agencies are done in accordance with the guidelines provided by MIL-STD-810D or International Test Operations Procedure (ITOP) 1-1-050. The guidelines provided in the two documents approach the specification development process from different perspectives, however, both methods are based on equivalent damage theory and the assumption that the test data is stationary. Operational based vibration specification development is intended to characterize the functional environment, and typically does not consider fatigue issues. However, the core signal analysis tools still assume stationarity of the test data.

The stationarity limitation of the procedures discussed above prohibits addressing the vibration specification development of a relatively large number of nonstationary vibration environments encountered by many DoD systems. It is the intent of this research to investigate signal analysis techniques, feasible vibration specifications methodologies, and signal reconstruction procedures for such nonstationary vibration events.

Wavelet based signal analysis techniques are proposed as key tools in establishing a methodology for developing and documenting vibration specifications for nonstationary events and as a signal synthesis technique to provide a corresponding time-domain reference waveform. The reference waveform can be used either as the forcing function for simulation based studies, or as the reference waveform of a closed loop laboratory based vibration tests using classical electro-dynamic or electro-hydraulic exciters.

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