Lt. Jarema M. Didoszak, USN, Dr. Young S. Shin, and Capt. David H. Lewis, USN

Shock Trial Simulation for Naval Ships

ABSTRACT

Current Navy implementation of statutory requirements for naval surface combatants dictates the performance of a ship shock trial in order to determine the vulnerability of a ship to an underwater explosion (UNDEX) non-contact shock threat environment. The shock trial features a series of shots, typically three to four, at increasing levels of severity culminating in a two-thirds ship design level shock. The intensity is limited to two-thirds design primarily for crew safety considerations. Velocity and acceleration response data collected during the shock trial is then extrapolated to full design level and compared to equipment shock qualification levels in order to predict equipment performance.

Over the past 20 years, five whole-ship shock trials have been conducted on AEGIS ships: CG 48, CG 53, CG 62 (limited), DDG 53 and most recently on DDG 81. Although the lessons learned from these shock trials have been invaluable, we have now reached a level of diminishing returns (Shin and Schneider 2003). Furthermore, today's battlefield threat scenario has changed dramatically from that which formed the basis for the existing LFT&E shock trial requirement. In view of this, and given the significant costs and the environmental considerations associated with conducting shock trials, the time is ripe for a new approach. The computer modeling and simulation process presented herein has been shown to be a multifaceted and cost-effective predictive tool with the potential of changing the existing paradigm in ship shock trial program.

INTRODUCTION

As the most representative ship of the new line of Flight II-A Arleigh Burke class destroyer, the USS Winston S. Churchill (DDG 81) was chosen to undergo ship shock trials. Conducted in May and June of 2001 off the coast of Naval Station Mayport, Florida, these trials were necessary in order to evaluate the vulnerability and survivability of the hull and the mission essential equipment in a combat shock environment. This LFT&E event was also used to validate shock hardening criteria and performance of systems and equipment modified in this later version of the baseline DDG 51. Four previous Aegis ship shock trials had been conducted, one on a DDG 51 class ship (DDG 53), and three on Aegis Cruisers (CG 48, CG 53, and CG 62). These provided valuable engineering data and a significant body of lessons learned, but their results were inadequately captured, to the extent that a fifth Aegis ship shock trial was required for DDG 81 to validate the latest set of ship changes for the DDG 51 class of ships.

However, escalating costs, extensive coordination and planning across many agencies, crew safety and environmental impact considerations all must be accounted for when conducting ship shock trials at sea. These factors coupled with a data set limited to installed sensor locations, unpredictable weather conditions and operational downtime on the part of the ship, collectively lead to questions concerning the feasibility of conducting full scale ship shock trials in accordance with OPNAV Instruction 9072.2 (OPNAV 1987). Moreover these tests are performed after the first ship or ships are already built. This means that in order to incorporate changes based on the trials, costly ship alterations must be completed, as opposed to less expensive design changes occurring during the detailed design and construction phase.

With recent advances in computing power, modeling and simulation are showing themselves to be a plausible addition/alternative in investigating the dynamic response of a ship under the shock trials conditions. In addition to the full ship shock trial that was performed on DDG 81, extensive computer simulation of the ship shock trial has been conducted using a large-scale finite element model, which is comprised of the ship and surrounding fluid. LS-DYNA code (LSTC 2001) coupled with the Underwater Shock Analysis (USA) code

(DeRuntz 1996) was used to perform the analysis. The ship shock responses were calculated at selected sensor locations and the simulation results compared with those obtained from the measured ship shock trial data.

SHIP SHOCK TRIAL SIMULATION

In all, three shots were performed during the DDG 81 ship shock trial. Shot 1, the least severe of the three shots, was detonated forward of the port bow. In Shot 2 the charge was placed off the starboard beam, nearer the ship. For Shot 3, the most severe shot, the charge was detonated directly abeam the port side. This final shot had the closest charge geometry. Figure 1 gives a general concept of the shot orientation. The exact charge sizes and corresponding standoff distances are classified.

Modeling and Simulation

With over 40,500 nodes and nearly a quarter-million degrees of freedom in the ship system, the DDG 81 finite element model was the most complex ship model ever created. For each one of the three shots Gibbs & Cox, Inc, a member of the DDG 51 Class ship design team, provided a separate finite element model to the Naval Postgraduate School (NPS) shock simulation team. Details such as the liquid tank levels, exact weapons load-out, temporarily installed equipment and even the number of personnel onboard at the time of each shot, were accounted for in order to obtain the most accurate model possible for simulation of the ship shock trials. The DDG 81 finite element model included many additional improvements over previous models, such as more realistic mass distribution through the use of a significantly superior weight tape and simplified spring-mass models for key pieces of equipment such as the gas turbines and 5”/62 gun. The nominal mesh size of the ship model was 27 in x 48 in (Harrington 2002). Figure 2 shows the detail of the model in a cut-away view of the port side, aft of Frame 300.

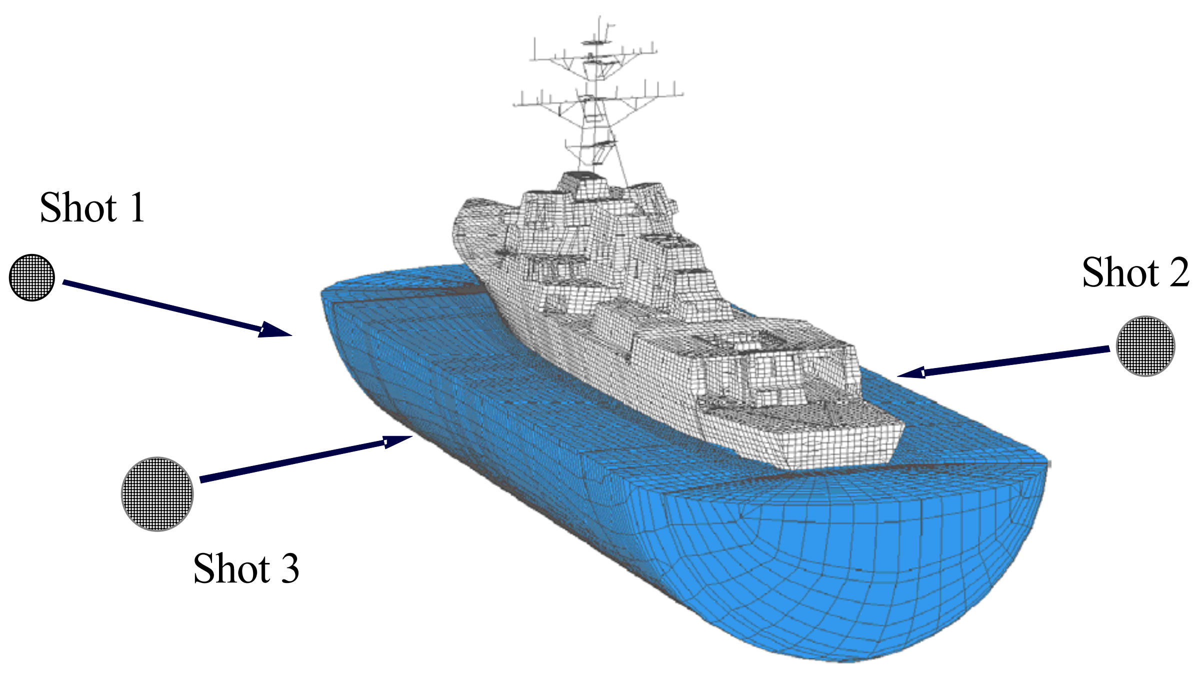

Figure 1. DDG 81 Ship Shock Trial Shot Geometry

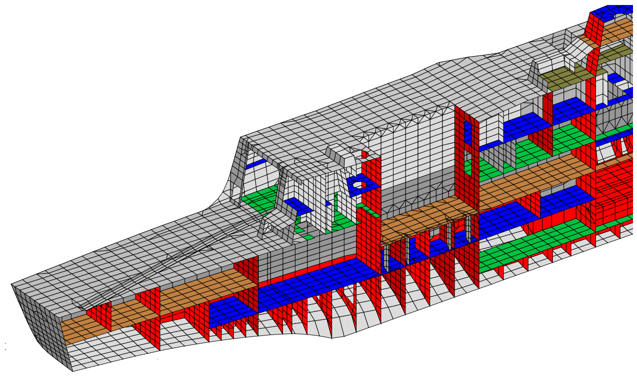

Figure 2. Cut-away view of the DDG 81 Finite Element Model (from Harrington 2002)

The fluid mesh was constructed using four subdivisions that were modeled separately and merged together: the inner liner, the inner mesh, the transitional mesh, and the outer mesh (Schneider 2003). Figure 3 is an exploded view of the ship and its surrounding fluid mesh. The effect of surrounding fluid on the simulation predictions were studied in order to determine the optimal amount of fluid to be included in the simulation. It was determined that a fluid model depth equal to at least the cavitation depth was required for an accurate simulation (Hart 2003). Furthermore, it was discovered that the fluid mesh density was not a critical factor in finding an acceptable solution. Refining the fluid mesh improved the accuracy to a limited degree (Schneider 2003).

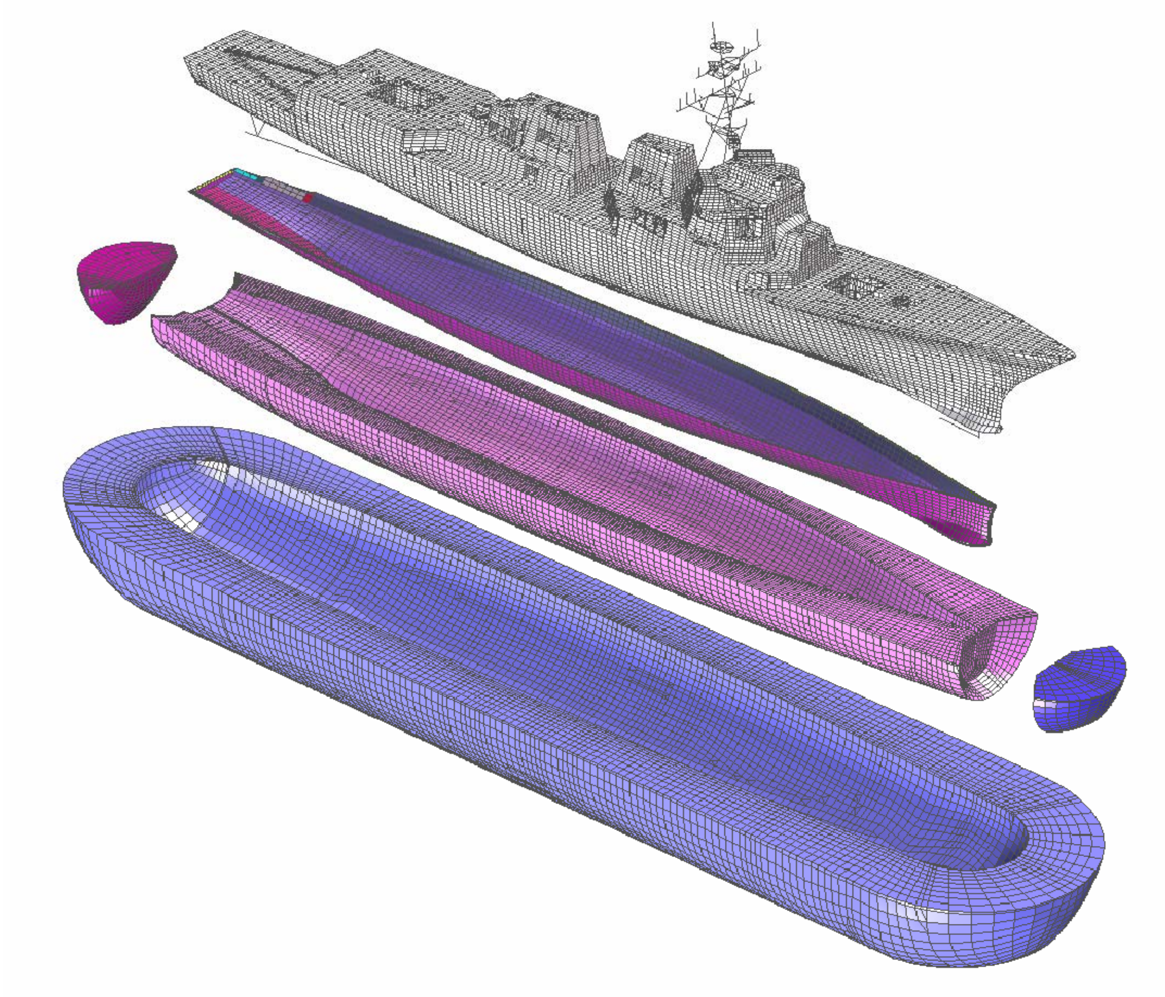

Figure 3. Exploded view of Ship and Fluid Mesh Model (from Schneider 2003)

An overview of the process used to conduct the ship shock trial simulations is shown in Figure 4.

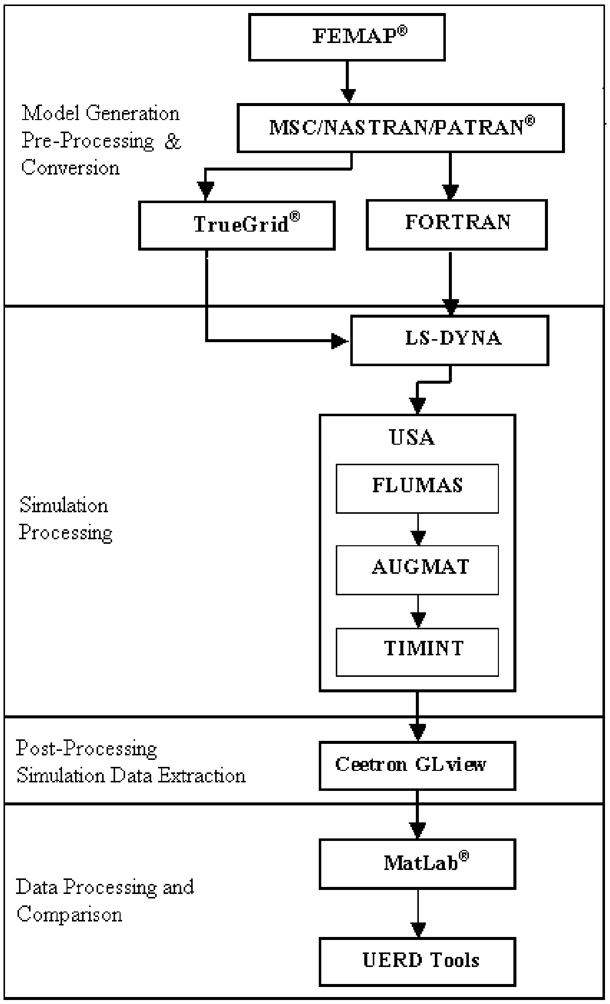

Figure 4. Modeling and Simulation Process Flow Chart (from Schneider 2003)

First, the finite element model was converted from the MSC/NASTRAN input deck into a nonlinear dynamic analysis code (LS-DYNA) keyword file. Next the surrounding fluid mesh was created using TrueGrid (XYZ Scientific Applications 2001). The fluid mesh and ship model were then joined together in LS-DYNA, which was coupled with the USA code. The LS-DYNA code is an explicit and implicit finite element program capable of analyzing the nonlinear dynamic response of three-dimensional inelastic structures.

USA uses the Doubly Asymptotic Approximation (DAA) to solve the fluid structure interaction equations. This method allows the problem to be solved taking into account the cavitation effect. This step is where the simulation of the shock event actually occurred. The nodal response data generated by LS-DYNA was then transferred to GLview for post-processing. Finally, UERD Tools was used to compare the measured ship shock trial data with the shock simulation results.

Ship System Damping

As part of the DDG 81 simulation effort, a study comparing the effect of ship system damping was completed (Shin and Ham 2003). Two sets of Rayleigh damping parameters were applied to the LS-DYNA input deck and simulations were conducted for Shot 2 of the DDG 81 ship shock trials. The response data from these simulations were compared against the measured ship shock trial data in the manner previously described.

Rayleigh damping is used to set the system damping in the simulation process (Shin 1996). The damping matrix, [C], is defined as

$$C = \alpha[M] + \beta[K] \tag{1}$$

in the general expression for the structural equation of motion, Equation (2).

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{F\} \tag{2}$$

The damping coefficients α and β are constants. Equation (2) can be normalized using mass normalization such that

$$[\phi]^T[C][\phi] = [2\zeta_r\omega_r]_{diag} = \alpha[I] + \beta[\omega_r^2]_{diag} \tag{3}$$

In a complex system such as a ship, the subscript *r*, which signifies the number of modes, exceeds the two modes necessary to determine the solution of the equation. In this case the system is over determined and the coefficients can be found using measured data and a least squares curve fitting method.

For each mode of the ship response the modal damping ratio is calculated using Equation (4).

$$\zeta_i = \frac{1}{2}\left(\frac{\alpha}{\omega_i} + \beta\omega_i\right) \qquad (4)$$

A set of damping coefficient values was determined by extensive analysis of measured data taken from the DDG 53 ships shock trials. The ship was divided into 67 area groups for the damping analysis, which included data from 773 sensors. For the frequency spectrum of interest, 0 to 250Hz, both the athwartship and vertical response were measured and recorded. A least squares curve fit, as shown in Figure 5, was applied to each area group. The area groups were given weighted averages based on the number of modes used in the curve fitting process in order to find α and β. Data points which contained modes with a modal amplitude less than one thousandth of the maximum value in each grouping were removed from consideration in the final curve fit as were modes that contained damping ratios greater than 0.5. The overall results are shown in Table 1 (Shin and Ham 2003).

Table 1. Weighted Mean Values of α and β

Damping Coefficient	Athwartship Direction	Vertical Direction
α	18.4	19.2
β	2.82E-06	2.09E-06

Table 2. Damping Values Used in DDG 53 Simulation Effort

Damping Value	α	β
4%	2.64	4.99E-05
8%	4.93	9.89E-05

Table 2 provides the damping coefficients that were used for the simulations conducted during the DDG 53 simulation effort (Shin and Park 1999). These values were found by fixing the damping ratio, ζ, at two particular frequencies, namely 5Hz and 250Hz in this case. Then curves were generated across the frequency spectrum using those fixed points and Equation (4). Figure 6 illustrates the difference in damping curves as plotted on a linear scale. The highlighted points at 5Hz and 250Hz indicate where the 4% and 8% damping curves were fixed to the values of ζ. The NPS damping values, α = 19.2 and β = 2.09E-6, in the vertical direction, and α = 18.4 and β = 2.82E-6, in the athwartship direction were used to find the system response in all cases. Notice the great disparity in the two damping coefficients. This indicates that the damping in the system is mass driven.

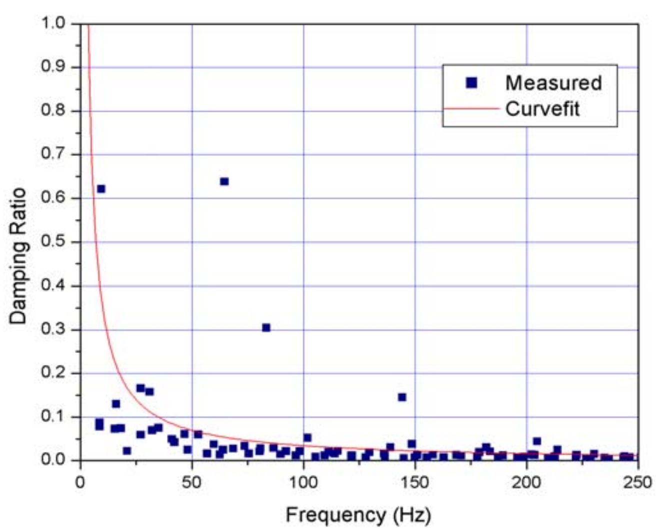

Figure 5. Example of Modal Damping Ratio for One Area Group (from Shin and Ham 2003)

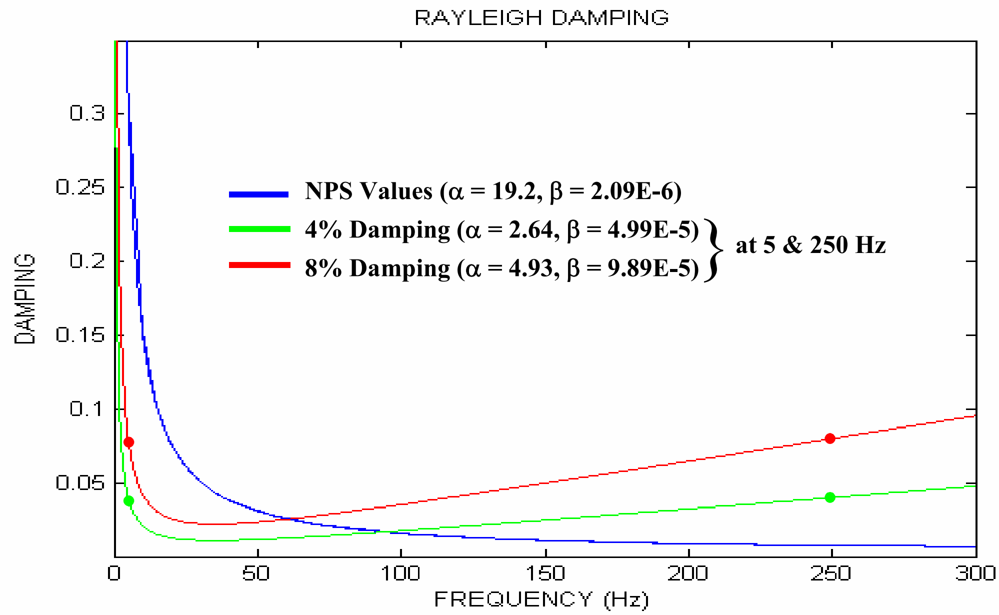

Figure 6. Proportional System Damping

Error Comparison

In order to calculate the Russell's error (Russell 1997, 1998), first two variables are defined as,

$$A = \sum_{i=1}^{N} f_1(i)^2 \tag{5}$$

and

$$B = \sum_{i=1}^{N} f_2(i)^2 \tag{6}$$

where $f_1(i)$ and $f_2(i)$ are the measured and predicted response magnitudes at each time step, which is denoted as *i*. Using the variables *A* and *B* from Equations (5) and (6), the relative magnitude error of the correlation is,

$$m = \frac{(A-B)}{\sqrt{AB}} \tag{7}$$

From Equation (7) the magnitude error is calculated as,

$$RM = \sin(m)\log_{10}(1+|m|) \tag{8}$$

The phase error is found as follows,

$$p = \hat{\phi}_1 \bullet \hat{\phi}_2 \tag{9}$$

where $\hat{\phi}$ is the normalized unit vector of the transient response. The phase correlation between the two data sets can be computed as,

$$p = \frac{C}{\sqrt{AB}} \tag{10}$$

where *C* is defined by,

$$C = \sum_{i=1}^{N} f_1(i) f_2(i) \tag{11}$$

The phase error is calculated as,

$$RP = \frac{\cos^{-1}(p)}{\pi} \tag{12}$$

Equations (8) and (12) are used in conjunction with Equation (13) to determine the comprehensive error.

$$RC = \sqrt{\frac{\pi}{4}(RM^2 + RP^2)} \qquad (13)$$

Though there is no definitive number that characterizes a "satisfactory" correlation between the data in all cases, the values listed in Table 3 have been agreed upon as a general guide and used as the acceptance criteria in both the earlier DDG 53 and current DDG 81 ship shock trial simulation projects (Russell 1998). These criteria were used in all comparisons that were made in support of this investigation.

Table 3. Russell's Comprehensive Error Factor Acceptance Criteria

RC < 0.15	EXCELLENT
0.15 ≤ RC ≤ 0.28	ACCEPTABLE
RC > 0.28	POOR

SIMULATION RESULTS

The measured ship shock trial data and LS-DYNA/USA simulation data were prepared in the following manner. Both sets of data were low pass filtered at 250Hz, removing all undesired high frequency noise. This is considered a valid technique since the majority of the energy in the response is in the lower frequency. Thus, filtering out the high frequency noise allows for a more accurate assessment of the transient response. Additionally the raw data from the ship shock trial was drift compensated using the built-in UERD Tools function in order to remove any drift error inherent in the sensor itself.

Damping Coefficient Effects

The following series of velocity response plots taken from the DDG 81 Shot 2 simulations compares the response resulting from use of the NPS damping values as defined in Table 1 against the velocity response found when using the damping coefficients from Table 2, which were employed in the DDG 53 simulation effort. Russell's error factor was chosen as a means of comparing the simulated velocity response data against the measured actual ship shock trial data. The approximate location of each sensor is indicated by a red dot on the ship sketch accompanying each of the time history plots.

The Russell's comprehensive error correlation factor was computed for each sensor. As illustrated in the velocity response plot comparisons shown in Figures 7 and 8, there is a closer correlation between the simulations using the NPS damping values and the ship shock trial data, than with the fixed 4% damping. The mean RC for the 4% damping cases was 0.25 while in comparison when the NPS damping values were used, the mean RC value fell to only 0.18. Recalling Russell's correlation criteria, a value below 0.15 is considered an excellent correlation. The simulations using the NPS damping values consistently showed better overall correlation and an average reduction in error of approximately 28% versus those using the fixed 4% damping.

Of the sensors considered during this portion of the study that were simulated using the NPS damping values, the Russell's Comprehensive error factor were all in the excellent and highly acceptable range, with the exception of two sensors, as shown in Figure 9. These two sensors correspond to sensors located at the extremities of the ship, namely the bow and stern.

It is noted that these areas are furthest from the shockwave impact point and are predisposed to finite element modeling limitations due to the complexity of the ship structure and fluid mesh geometry adjacent to the sonar dome and stern. Additionally, the bow and stern areas were outfitted with only a minimal number of sensors. Further analysis of the sensor data used in generating the velocity response correlations as are summarized in Figure 9, show that the time history response plots contain noticeable velocity drift, even after the standard correction has been applied. Since Russell's Error correlation is only a measure of curve similarity, this may in fact account for the level desirable correlation witnessed in these two particular data points.

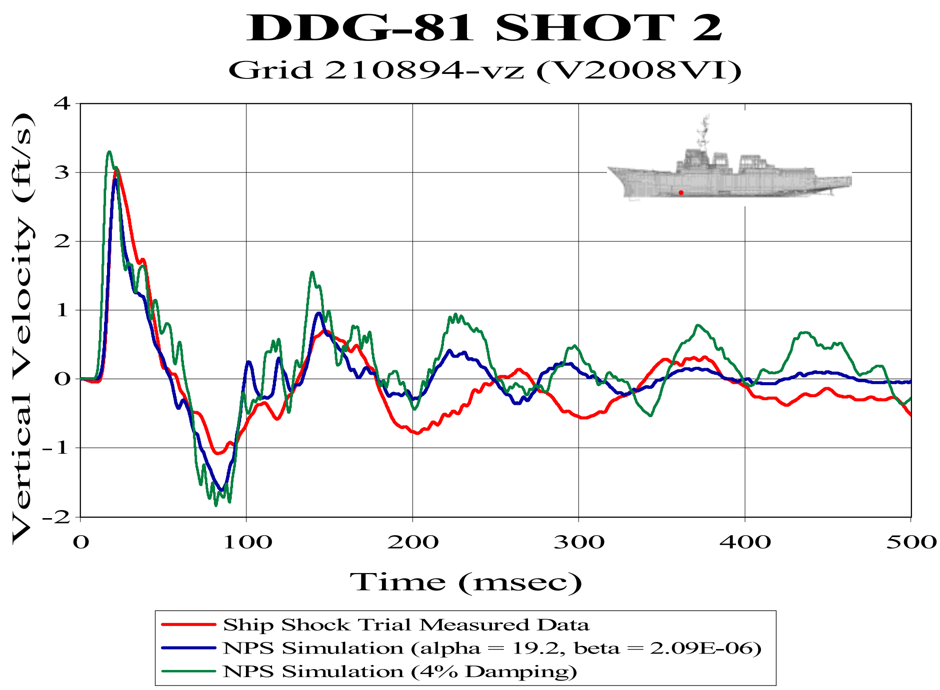

Figure 7. Vertical Velocity Response: Deck Sensor V2008VI

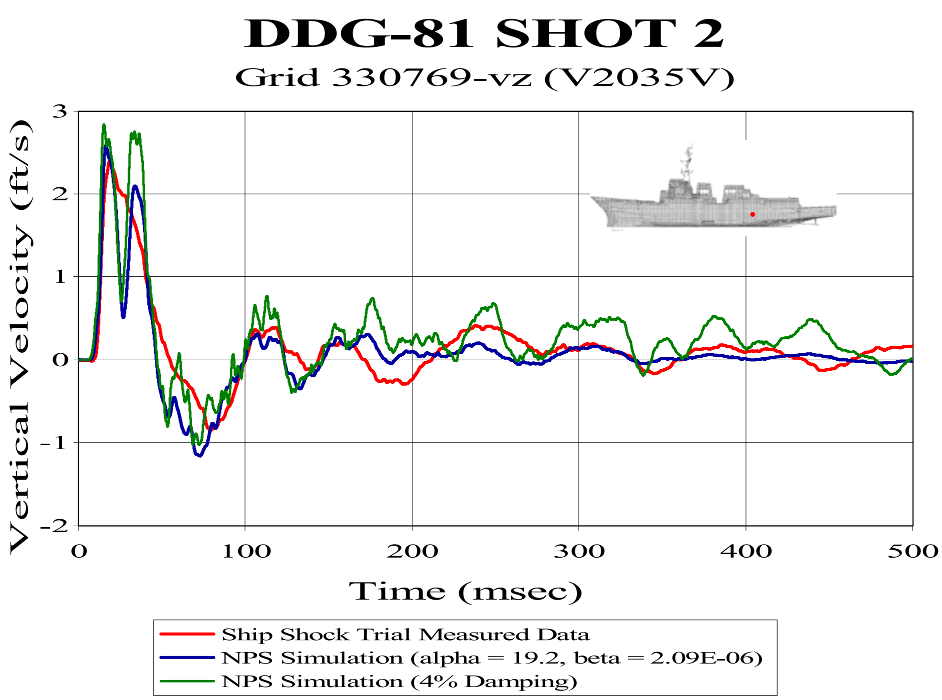

Figure 8. Vertical Velocity Response: Keel Sensor V2035V

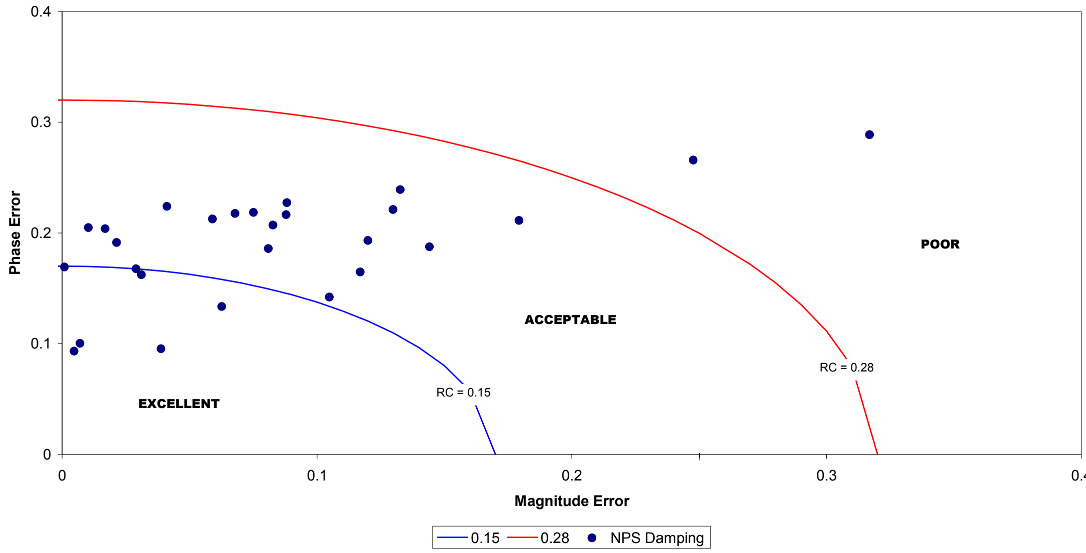

Figure 9. Russell's Comprehensive Error Factor for DDG 81 Shot 2

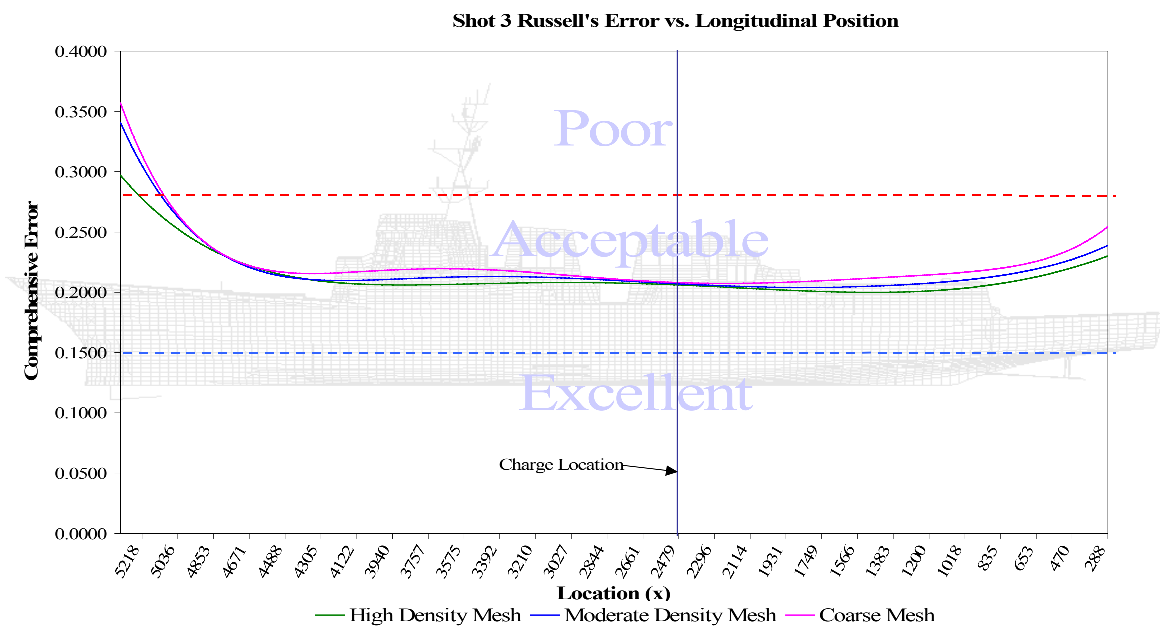

Figure 10. Russell's Comprehensive Error Factor as a Function of Longitudinal Position (from Schneider 2003)

Figure 10 illustrates a correlation between longitudinal position along the ship and Russell's Comprehensive error factor. There is some hesitation in accepting these data points that fall well outside of the pattern of the others within their grouping. These data points should be considered suspect, but were included in this portion of the study for completeness. Furthermore, when comparison of the accelerometer data and velocity meter data was conducted it was discovered that there was significantly greater error induced in the physical response data collected by the velocity meters, which carried over to the error factor correlations (Schneider 2003). When considering only accelerometer data the correlation was vastly improved as shown in Figure 11.

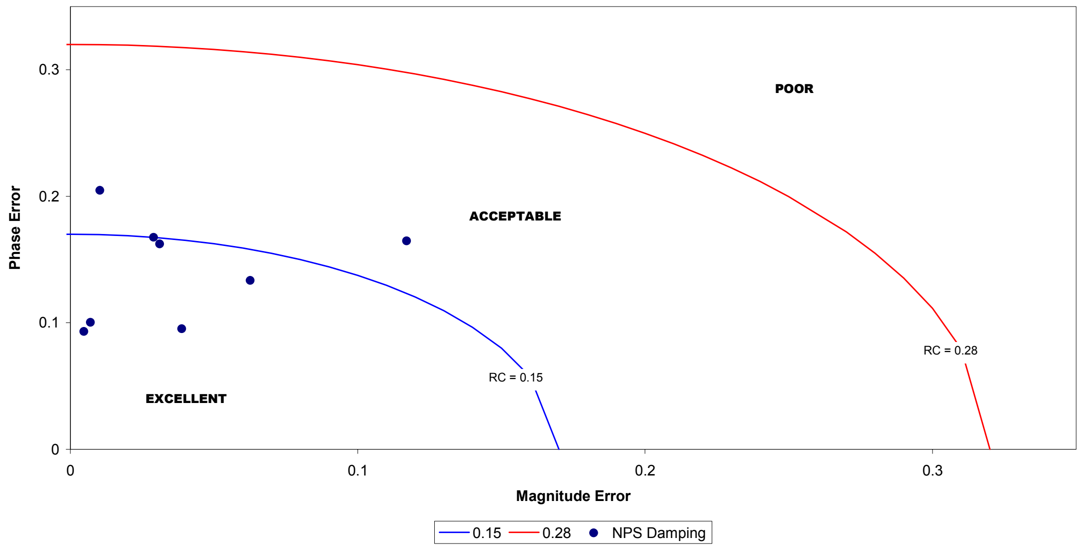

Figure 11. Russell's Comprehensive Error Factor for DDG 81 Shot 2 (Accelerometer Data)

CIC Vertical Velocity Analysis

Localized vertical velocity comparisons were made in the critical Combat Information Center (CIC) area. With all of its electronic equipment, communications devices and weapons systems consoles, determining the response values for CIC was a NAVSEA priority during in DDG 81 ship shock trial program. Results obtained from the vertical response comparisons of this specific area within the ship correspond well with the overall vertical velocity results. The data correlation between the simulated and measured data was found to be generally acceptable, with only a few data points falling outside of the RC = 0.28 curve, as shown in Figure 12.

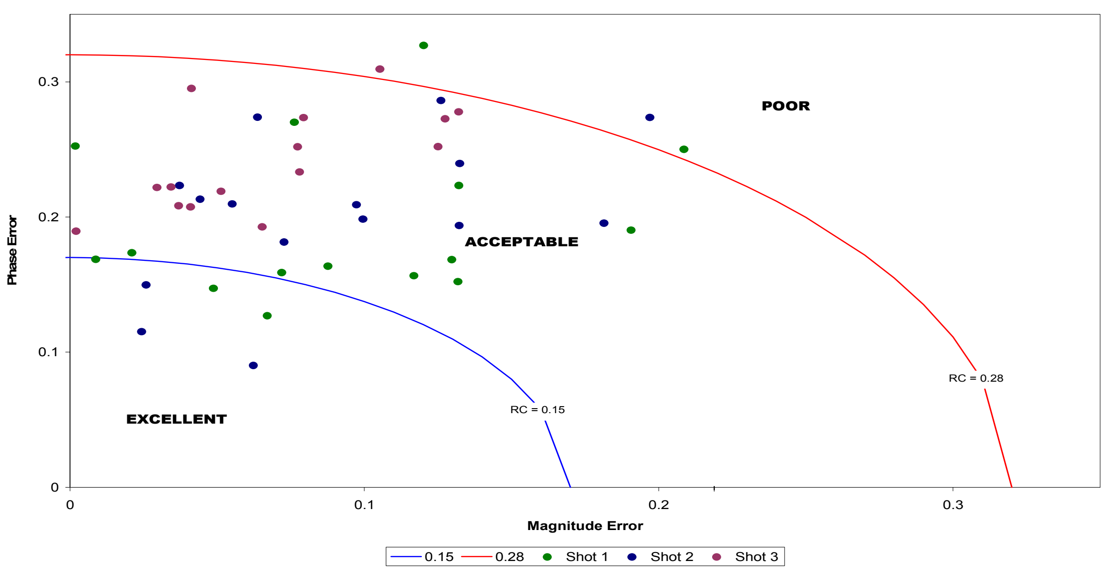

Figure 12. Russell's Comprehensive Error Factor for DDG 81 (CIC Area)

Figures 13 and 14 are examples of the correlation obtained in the CIC localized response comparisons. The overall RC for all shots is approximately 0.2075. In comparison, the average RC value determined during the shipwide vertical velocity comparison was 0.2042 (Schneider 2003).

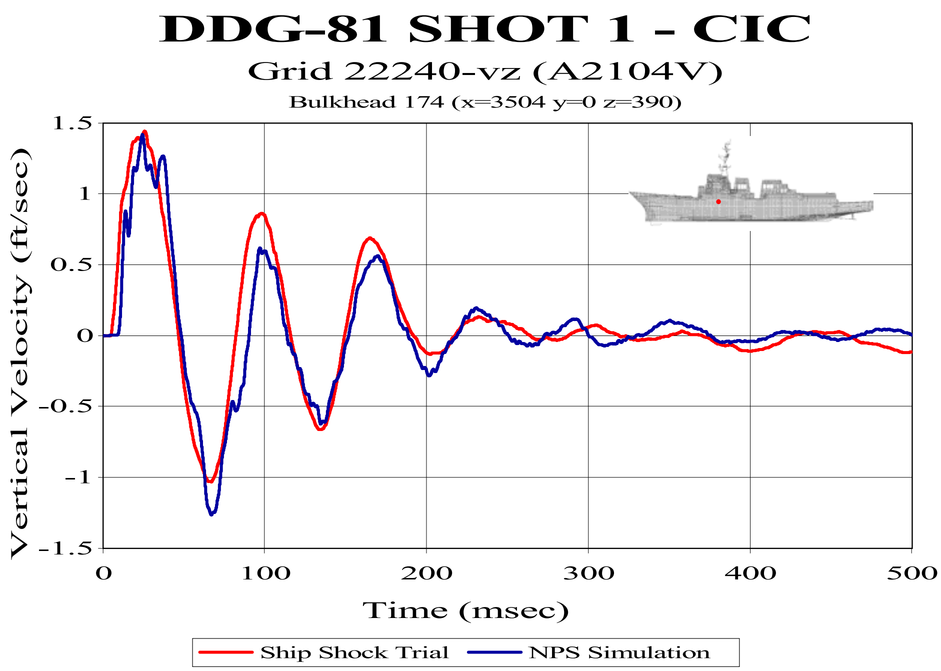

Figure 13. Vertical Velocity response: CIC Area

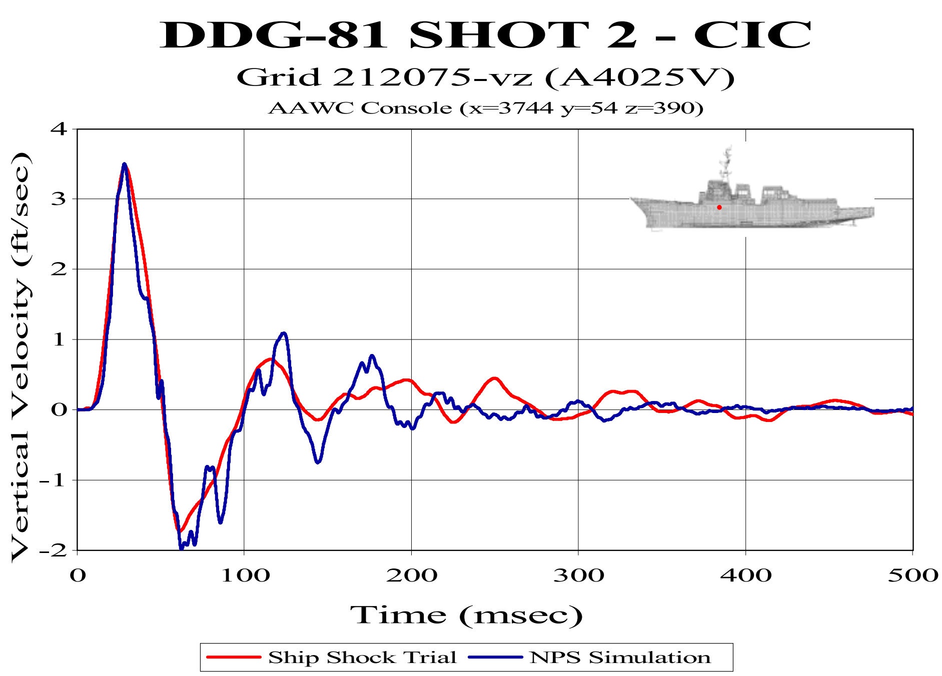

Figure 14. Vertical Velocity response: CIC Area

Athwartship Analysis

Figure 15 shows a time history response plot for the athwartship velocity of sensor A2015A from DDG 81 Shot 2. The correlation for this accelerometer located amidships near the keel has a value of RC = 0.2847. This correlation is just outside the acceptable range. In general the Russell's Comprehensive error factor correlation was outside the acceptable range for the athwartship direction. In this investigation it was found that the magnitude of the correlation was generally acceptable whereas the phasing appeared to be at fault. It should be noted that the athwartship response velocities are significantly smaller than those experienced in the vertical direction, which is the primary response direction. Another factor that could have negatively impacted the correlation in the athwartship direction is the physical installation of the sensors. In some cases the sensors were mounted to beam webbing or equipment foundations and not directly on the true deck. In this instance the energy path becomes more complex than in the vertical direction. Further study of the athwartship response is currently underway.

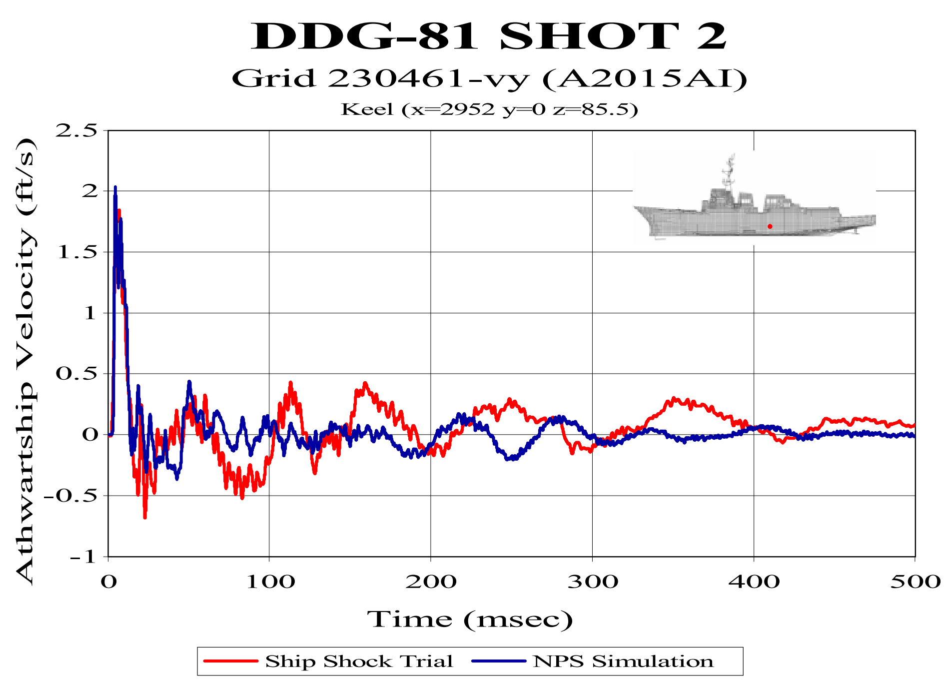

Figure 15. Athwartship Velocity Response: Keel Sensor A2015AI

CONCLUSIONS

Ship shock trial simulation through the use of a virtual underwater explosion (UNDEX) environment has been successfully demonstrated for multiple cases as presented in this paper. Using Russell's error factor as an acceptance criteria the correlation of the simulation response data to the measured ship shock trial data was determined to be highly acceptable. Furthermore, implementation of the Rayleigh damping coefficients found through detailed study of the DDG 53 measured data, significantly improved the correlation of the simulation response as compared to the simulations performed using the previously accepted fixed 4% damping coefficients. The athwartship velocity response data did not correlate as well as the comparisons made in the primary direction and warrants further study.

There are several benefits in conducting computer modeling and simulation of ship shock trials. It allows for an extensive battery of simulations to be executed prior to performance of a LFT&E shock trial. These predictions can then be used in order to focus the at-sea testing to specific scenarios that were found to be of interest in the virtual UNDEX environment. Simulation of the LFT&E shock trial also permits realistic testing of the ship's vulnerability and survivability to be accomplished through the scaling of charge geometry to simulate design level (or higher) shock events. As the cost and environmental impacts of traditional full ship shock trials continue to rise, this method of analysis becomes an appealing, alternative approach. If the method discussed here were to be used to establish baseline shock performance of a future final ship design, with some high level of confidence in it's technical veracity, then actual ship shock events could be conducted to explore unknown areas of ship shock performance, or areas that are determined to be of interest, again, from use of this analysis method.

A core tenant of the Department of Defense Live Fire Test and Evaluation process is to test to "realistic threats". Thus, a whole ship shock trial is an engineering event, not a true LFT&E event. However, it is used to satisfy the OPNAV requirements since there was no technically acceptable alternative available. If the analysis methods discussed herein could be used to achieve the engineering objectives of a ship shock event, then the actual ship shock events could be more closely focused on representing realistic threats. These potential realistic threat events are ones that ships will most likely see in combat, and thus, these test events would be the most interesting and useful to conduct, for the purpose of developing future ship designs or modifying current ship designs to improve their combat performance. If extended to other ship classes, this research can open an entirely new dimension for ship shock trials, making shock trial results more relevant to the war fighting needs of the Navy and more useful to the ship designer and ship maintenance communities.

REFERENCES

DeRuntz Jr., J.A., The Underwater Shock Analysis (USA) Manual, Unique Software Applications, Colorado Springs, CO, 1996.

Harrington, M.J., Gibbs & Cox, Inc., "DDG-51 Flight IIA Shock Simulation", Presentation at the Naval Postgraduate School, August, 2002.

Livermore Software Technology Corporation, LS-DYNA Keyword User's Manual, Version 960, LSTC, Livermore, CA, March 2001.

OPNAV Instruction 9072.2, "Shock Hardening of Surface Ships," January 1987.

Russell, D.D., "Error Measures for Comparing Transient Data: Part I: Development of a Comprehensive Error Measure," 68th Shock and Vibration Symposium Proceedings, Vol. I, November 1997.

Russell, D.D., "Error Measures for Comparing Transient Data: Part II: Error Measure Case Study," 68th Shock and Vibration Symposium Proceedings, Vol. I, November 1997.

Russell, D.D., "DDG 53 Shock Trial Simulation Acceptance Criteria," 69th Shock and Vibration Symposium, October 1998.

Schneider, N.A., "Prediction of Surface Ship Response to Severe Underwater Explosions Using a Virtual Underwater Shock Environment," Master's Thesis, Naval Postgraduate School, Monterey, CA, 2003.

Shin, Y.S. and Ham, I., "Damping Modeling Strategy for Naval Ship System," Technical Report NPS-ME-03-003, Naval Postgraduate School, September 2003.

Shin, Y.S., "Naval Ship Shock and Design Analysis," Course Notes for Underwater Shock Analysis, Naval Postgraduate School, Monterey, CA, 1996.

Shin, Y.S. and Park, S.Y., "Ship Shock Trial Simulation of USS John Paul Jones (DDG 53) Using LS-DYNA/USA: Three Dimensional Analysis", 70th Shock and Vibration Symposium Proceedings, Vol. I, November 1999.

Shin, Y.S. and Schneider, N.A., "Ship Shock Trial Simulation of USS Winston S. Churchill (DDG 81): Modeling and Simulation Strategy and Surrounding Fluid Volume Effects", 74th Shock and Vibration Symposium, October 2003.

XYZ Scientific Applications, Inc., TrueGrid User's Manual, Version 2.1.0, Livermore, CA, September 2001.

Lt. Jarema M. Didoszak *is an engineering duty officer currently assigned to the Naval Postgraduate School, Monterey, California. He received his Bachelor of Science degree in Naval Architecture & Marine Engineering from the University of Michigan in 1994. After serving as Strike Warfare Officer in USS KINKAID (DD-965) and as Navigator in USS RENTZ (FFG-46), he went on to train recruits as a Barracks Officer at Recruit Training Command, Great Lakes, Illinois. In 2003 he earned his Master of Science degree in Mechanical Engineering from the Naval Postgraduate School, where he also completed the Total Ship Systems Engineering program. LT Didoszak is a member of ASNE, SNAME and UESA.*

Dr. Young S. Shin *is currently a Professor of Mechanical Engineering at Naval Postgraduate School (NPS), Monterey, California. Before joining NPS in 1981, Dr. Shin was with General Electric Company, Argonne National Laboratory and FMC Central Engineering Laboratories over a period of ten years. Prof. Shin received his Ph.D. degree in Solid Mechanics from Case Western Reserve University at Cleveland, Ohio; Master's degree from University of Minnesota, and B.S. from Seoul National University, Seoul, Korea. He is the author of over 50 papers on flow -induced vibrations, fluid-structure interaction, vibration damping, condition-based machinery monitoring and diagnostics and underwater shock testing, analysis and design. Dr. Shin is a Fellow of American Society of Mechanical Engineers and Registered Professional Engineer in States of California and Ohio. He is a member of Editorial Board of Journal of Shock and Vibration. He is currently a member of ASME PVP Fluid-Structure Interaction Committee and was a past Chairman.*

Capt. David H. Lewis *is currently assigned as the Aegis Shipbuilding Program Manager in the Program Executive Office for Ships. His at sea assignments include Communication Officer aboard USS SPRUANCE (DD 963), Fire Control Officer and Missile Battery Officer aboard USS BIDDLE (CG 34), and Combat Systems Officer in USS TICONDEROGA (GC 47). Captain Lewis has served as the CG NTDS course coordinator at Fleet Combat Training Center, Atlantic in Dam Neck, Virginia, and as the Amphibious Ship Maintenance Officer and Amphibious Ship Type Desk Officer while assigned to the Naval Surface Force Pacific Readiness Support Group, in San Diego, California. Subsequent tours included duty at PMS 400 as the Branch Head for Combat Systems Test and Trials in the DDG 51 Shipbuilding Program Directorate and as Director for Surface Combatants in the Office of the Assistant Secretary of the Navy for Research, Development and Acquisition. Captain Lewis' last assignment prior to taking Command was as the Aegis Program Manager's Representative and the Production, Operations, Test and Trials Process Director at the Supervisor of Shipbuilding, Conversion and Repair, Bath, Maine.*

Captain Lewis is a qualified Surface Warfare Officer, Tactical Action Officer, is a proven Combat System Specialist (66P) and is also a graduate of the Naval War College Command and Staff School. He is a member of the Acquisition Professional Community (Level III Certifications in Program Management and Production Quality Management) and has completed his civilian Program Management Professional certification. He holds a Bachelor of Science in Computer Science from the University of Nebraska, Lincoln and a Master of Science in Computer Science from the Naval Postgraduate School.