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Validation of Quasi-Static Reentry Engineering Analysis of a W76 Surrogate Article, Part I: Overview of Systematic Validation Process

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This series of four talks presents the results of a verification & validation (V&V) study applied to a surrogate test article for a W76 NEP sub-system assembly. The first talk is an overview of the problem of interest, including a description of the system-level phenomenon, the relevant sub-system, the mechanics of interest and the surrogate test article used to reproduce the relevant physical effects. The V&V study is formulated using a hierarchical approach that identifies and investigates the mechanics relevant to the problem of interest. In this case, a surrogate test article is used to investigate the system mechanics while avoiding the hazardous materials of the real assembly. A systematic V&V process is applied to determine the accuracy of the finite element model calculations and the parametric uncertainties associated with the underlying mathematical models.

Validation of Quasi-Static Reentry Engineering Analysis of a W76 Surrogate Article, Part II: Development and Numerical Accuracy of Finite Element Model

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In support of W76 LEP, engineering assessments of cushion performance are desired. The characterization of deformation in a cushion is realized through the utilization of an implicit finite element model. Prior to assessing the relative predictive accuracy of the FE model against experimental data, it is necessary to verify an acceptable level of numerical accuracy. This numerical accuracy assessment can be described as checking the implementation of important mechanics in the code (code verification), and estimation of numerical error associated with the discretization of the problem (calculation verification.) This presentation will cover the development of the finite element model, code verification for the relevant mechanics, and verification of the numerical accuracy of the calculation.

Validation of Quasi-Static Reentry Engineering Analysis of a W76 Surrogate Article, Part III: Parametric Sensitivity Analysis and Uncertainty Propagation

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An integral part of validating any engineering analysis is 1) determination of parameters important to the comparison metric of interest and 2) quantification and propagation of uncertainty from the input parameters of interest to the output feature, or comparison metric. This work uses parametric sensitivity analysis to first isolate important parameters (where the output feature is a predetermined comparison metric). Sensitivity analysis is presented with increasing complexity, first using linear sensitivity analysis, then a significant effects analysis and finally an analysis of variance (ANOVA) approach. Using the parameters deemed important, a surrogate model, or metamodel is generated for use in uncertainty propagation. Probability distributions on input parameters are estimated and uncertainty is propagated to the comparison metric using Monte Carlo analysis and the aforementioned metamodel. Use of the metamodel allows for the large number of samples necessary to make Monte Carlo analysis viable. Results are presented and conclusions made based on the uncertainty propagation.

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Validation of Quasi-Static Reentry Engineering Analysis of a W76 Surrogate Article, Part IV: Analysis of Experimental Uncertainty and Assessment of FE Model Predictive Capability

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Los Alamos National Laboratory

The final talk of this series describes the methods used to evaluate the uncertainties on the experimental data from the surrogate test article, as well as the methods used to assess the errors between the FE calculations and the experimental data in the presence of uncertainties on both. The experimental uncertainties are analyzed using measurements from replicate runs of the experimental apparatus, as well as an analysis of the measurement system uncertainties. The assessment of the FE calculation accuracy is performed using a statistical metric, and both the absolute and relative error values are considered. The final phase of this step in the V&V process is the judgment of the validation assessment to determine whether or not the model can be considered to be "validated."

A Model Validation Test Unit for Abnormal Thermal Environments (Export Controlled Information)

Nicholas D. Francis, Jr, Dean Dobranich, James T. Nakos
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A model validation test unit (MVTU-2) was designed, instrumented, assembled, tested, and simulated to develop and explore a model validation process for normal thermal environments. An incremental approach was followed to establish temperature time-histories at critical internal locations for a range of normal environments. An analogous incremental approach is followed to develop and explore a model validation process for abnormal thermal environments.

Before exposing the MVTU-2 to radiant heat, relatively simple disk calorimeters are tested first to fully characterize the radiant heat boundary condition. Once the high heat flux boundary condition is characterized using different heat source temperatures, the MVTU-2 is tested. Because investigation of abnormal heating environments involves temperature boundary conditions that will result in the destruction of the validation test unit (e.g., foam decomposition), several low-temperature experiments are initially conducted with MVTU-2. The lower temperature tests are specified such that the test unit and its internals are not damaged in the process while still providing important heating data. Finally, one high temperature test is conducted with MVTU-2. Pre-test simulations are used to select the appropriate heat flux levels for the non-destructive and destructive tests.

Experimental data collected at the radiant heat facility are compared directly to finite element models developed using the Calore thermal analysis code. A variety of issues are encountered during model development including characterization of the radiant heat transfer boundary condition, consideration of complex geometries with many different materials and complex radiation enclosures, internal foam decomposition, and thermal property uncertainties. Uncertainty quantification is performed to assess the simulation uncertainty associated with input parameter uncertainty. These issues are readily explored with the finite element models thus allowing designers, experimentalists, and thermal analysts to consider a broad range of "what if" scenarios important to the weapons community.

Preliminary Abnormal Thermal Environment Simulations for the W76-1 MC4702 Firing Subsystem (Export Controlled Information)

Dean Dobranich
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A high-fidelity model of the W76-1 MC4702 firing subsystem was created and simulations were performed to address abnormal environment thermal response. Emphasis in model creation was placed on the part detail within the two stronglinks and the weak link. The container of the arming, fuzing, and firing (AF&F) assembly was included in the model to enable implementation of directed heating boundary conditions. Eight heating configurations were investigated. In addition, parametric simulations were performed to address the uncertainties associated with various design features and model parameters, such as container emissivity, weak-link conduction paths, and inclusion of optional foam blocks. Hydrocarbon fuel fire conditions were the focus of these preliminary simulations. All simulations indicated a positive thermal margin (i.e., the weak link failed before the stronglinks), which is the desired outcome. The thermal race response was dominated by the high heat capacity of the stronglinks relative to that of the weak link. Directing the fire heat load at the stronglinks did not stress the safety design because the slow thermal response of the stronglinks provided sufficient time for heat to diffuse to the weak link, which has a lower failure temperature. Scoping simulations indicate that propellant fire conditions more severely stress the thermal safety performance of the design and require additional investigation.

TT-1—A Thermal Qualification Activity for the W76-1 (Export Controlled Information)

Dean Dobranich
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TT-1, an acronym for Thermal Test 1, is a qualification activity that supports design and qualification tasks for the W76-1 life extension project (LEP). The purpose of this activity is to characterize the normal thermal environment thermal response of subsystems and components within the replacement arming, fuzing, and firing (AF&F) system (a. k. a. the MC4700).
Historically, the TT-1 activity was addressed using an approach in which AF&F hardware was built, instrumented, and tested. However, because of budget constraints, such hardware was not available in the necessary timeframe to support the W76-1 LEP. Therefore, an alternative simulation-based approach was devised to replace the test-based approach. The success of the model validation test unit project provided confidence that such a simulation-based approach was plausible, demonstrating that the temperatures within an AF&F system could be adequately predicted for normal environment flight scenarios. Although the approach pursued for the TT-1 activity was primarily simulation based, it also involved an experimental aspect that was included to address concerns regarding the uncertainties associated with predictive modeling of thermally activated batteries. Thus, test results from five thermal battery assemblies were used to provide model calibration data. In addition, experimental uncertainty from both thermocouple measurements and unit-to-unit variability were quantified.
The calibrated battery assembly model was incorporated into a full AF&F high-fidelity model that was then used to perform normal environment flight simulations, including an estimate of simulation uncertainty based on uncertainties associated with model input parameters. In addition, a variety of parametric simulations was performed to address potential design modifications. For example, material selection for the battery mount and the AF&F supports, the attachment method of arming and fuzing components, and the optimal placement of a resistive load were addressed computationally.

Simulating Static Initial Conditions in an Explicit Dynamic Analysis

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It is often necessary to simulate static initial conditions in a dynamic analysis. A common example is the initial static state of stress of members of a bolted connection that is subsequently loaded by a transient dynamic load. When an explicit FEM code is used for the analysis, getting the initial equilibrium state can be difficult to accomplish in a short amount of analysis time.

A few techniques will be discussed that can be used to quickly arrive at a state of static equilibrium using an explicit dynamic FEM analysis code. Artificial damping in the form of mass-proportional damping or stiffness-proportional damping ("Rayleigh damping"), have both been found to be useful. Other techniques such as dynamic relaxation also have some value. Examples of these techniques applied to a full-assembly model of the W76-1 will be presented and discussed, with particular attention to getting the quasi-static initial conditions into certain subassemblies containing pre-compressed cushions and preloaded bolted joints.

W80 LEP Neutron Generator Standoff

Daniel Kletzli
Marlin Kipp, Sandia National Laboratories

The W-80 life extension program (LEP) incorporates component and system level improvements in safety and performance. To assess neutron generator standoff margin of the new system, Eulerian hydrodynamic calculations have been performed using legacy and ASCI codes with high-fidelity three-dimensional models. These models incorporate the AF&F components and the warhead with a level of detail appropriate for shock wave analyses. Comparisons of the original Mod 0/1 and LEP Mod 3 designs are made. Time-of-arrival data from three hydro-test experiments are compared to simulations with both codes. All calculations were performed on the ASCI Red platform.

ALE3D Modeling of 1/4-scale Hypervelocity Reentry Vehicle Impacts

Gary L. Johnson
Lawrence Livermore National Laboratory

As part of the Ground-based Mid-course Defense lethality program a series of Light Gas Gun experiments were performed at Arnold Engineering Development Center. The purpose for these tests were to evaluate the lethality of a target when impacted at high velocities and to provide data to be used to validate the 3-D hydrocodes that will be used in the GMD program. The targets for these experiments were high-fidelity, 1/4-scale, inert threat replicas. The projectiles, of Lexan and aluminum, were launched from a two-stage gas gun at velocities up to 7 km/s.

This presentation details some of LLNL's comparisons between the LGG test results and hydrocode simulations of those tests using ALE3D. In most tests the diagnostic data available for direct hydrocode comparisons included time-resolved pressure measurements inside the warhead, shock time-of-arrival at various locations inside the warhead, x-rays of the impact event at two different times, and post-test target debris. Agreement between the simulations generated by ALE3D and the test data was good. Also, we were able to determine energy deposition criteria that accounted for dismemberment during later-time structural interactions.

Pre and Post Buckling Behavior of a Complex Thin Walled Structure using Parallel Processing and Subsequent Test Validation

Peter Zischka
Lawrence Livermore National Laboratory

An integral part of the analyzed system is subjected to loads capable of causing the part's complex thin walled structure to buckle. A thorough understanding of the pre and post buckling behavior of the part is required as it affects the total system behavior. Because of the time dependent nature of the loading, an explicit FEA code such as ParaDyn is well suited to the solution of this problem.

To accurately capture the buckling behavior, and particularly the post buckled plastic deformations of a thin structure, a minimum of five brick elements through the thickness is required. However, the small edge length of these elements drives the time step down to such an extent that the computational requirements are too great for parallel processing. To increase the computational efficiency of the model, shell, instead of brick, elements can be used where the structure is thin.

Due to the lack of thickness in shells, and hence lack of end rotational constraint, the structure buckles at a load approximately predicted by the Euler buckling load for a simply supported structure while the same structure comprised of brick elements buckles at a higher load. To correct this problem, a subscale model was constructed and modified to obtain a load verses deflection behavior that matched that of the same brick structure. Once an acceptable subscale model was created, a full-scale part was constructed and analyzed using ParaDyn on ASCI White.

Testing of this part in a system like mockup was performed, and conclusions as to the accuracy of the modeling techniques employed are presented.

Coupon Hydriding and Mesh Regression Calculations in TOPAZ3D

Mark A. Havstad
Ian Dennis Parsons

A simulation of hydriding chemistry, heat release, void growth, fill gas evolution and sample temperature rise has been prototyped in TOPAZ3D. Initial gas charge, input by the user, determines a time varying reaction rate and a rate of decay of fill. For early stages of hydriding of simple rectangular coupons, where less that half of the thickness of the part has been consumed by reaction from an initially small active area, we find low temperature rise and slow growth. For later stages of hydriding, where growth proceeds from a cylindrical hole twice the thickness of the part, we find larger temperature rise and faster growth. Mesh adaptation driven by surface regression has been performed using a new approach where the stiffness of each finite element in the rezoning step depends on element volume. This method has allowed larger recession before mesh entanglement than the more common approach where constant elastic properties are assigned.

W88 Stockpile Models

Chris Scully
Los Alamos National Laboratory

Over the past two and a half years LANL has been engaged in an effort to create Pro/Engineer solid models and associated drawings of the W88 that not only represent the production drawings but also represent as close as possible the as assembled state of the warhead. After a great deal of modeling, and verification with peer reviews, the final result is a set of configuration managed models that are used in many ways throughout the entire range of physics, engineering, manufacturing and inspection disciplines at LANL and other NWC production sites. This presentation will cover what was involved in creating these models and drawings, discoveries that were made in the process, and some of the uses for the models in the different disciplines.

EMPHASIS Support of W76-1 Electromagnetic System Qualification and Component Testing

R. S. Coats, W.A. Johnson, R. E. Jorgenson, J. D. Kotulski,and L. Warne
Sandia National Laboratories

This talk will discuss calculations performed by the electromagnetic codes EIGER and EIGER_S in the EMPHASIS suite in support of the W76-1 system. EIGER and EIGER_S are written in Fortran 90, use object-oriented features of the language, and have been ported to parallel platforms.

One set of simulations address qualifying the W76-1 to the electromagnetic radiation environment. These simulations concentrate on supporting the tests that measure the shielding effectiveness of the aero shell. The results of the simulations will be used to help identify appropriate frequencies and placement of probes to capture the worst-case field coupling. For these simulations EIGER, a frequency domain method of moments code, will be used. In addition, EIGER incorporates sub-cell algorithms that allow the calculation of field coupling through the slots without having the grid resolve the slots.

A second set of simulations address voltage breakdown and current leakage predictions for various stronglink designs that will be eventually be used in the W76-1 system. These simulations use the code EIGER_S, a static domain method of moments code. For the voltage breakdown problem the field is calculated and using the knowledge of how the primary ionization coefficient behave s with respect to filed strength allows one to predict breakdown. For the leakage problem the field distribution is calculated from which surface and volumetric resistance can be derived.

This presentation will briefly describe the capabilities of EIGER and EIGER_S and show some representative calculations for the different problems described. Comparisons will also to be made to analytic and experimental results.

A Computed Tomography Reconstruction Code and its Applications to Different Reconstruction Algorithms

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We have developed an x-ray Computed Tomography (CT) reconstruction code, RECON, to provide us with the following capabilities: (1) to solve large volume reconstruction problems (2000^3 or more pixels) such as will be generated with the Pantex flat panel system; (2) to explore different reconstruction algorithms including parallel beam (direct FFT and filtered back projection) and cone beam (Feldkamp); (3) to provide for customization, including filtering options, centering options, background removal for flaw detection, limited-view reconstructions, and different file formats. Additional ground rules for the code are (4) fast execution – coded in C/C++ as opposed to higher level languages like IDL or MATLAB; (5) use of parallel computer clusters and MPI to multiply computing speeds; (6) multi-platform – Windows and Unix versions are compiled using same source code; (7) use of a graphical user interface (GUI) that is weekly coupled through files to the C/C++ executable, which runs independently of the GUI.

We will describe the current status of the RECON code, including features listed above, and show some recent results from using the code. The current MPI implementation is for ASCI, running on Blue Mountain. We are transferring the code to the LANL's Alpha processor based system Q. We are looking at running the code on a PC cluster running MPI. The two parallel beam algorithms were developed first. The Feldkamp cone beam algorithm, now under development, is the main justification for the ASCI implementation. With this code and computing platform, we can perform large CT volume reconstructions efficiently.

Integrating CAD Evaluation into MCNPX

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Tim Tautges
Sandia National Laboratories/University of Wisconsin

MengKau Wang
University of Wisconsin

Work has been ongoing at UW-Madison to integrate CAD evaluation into MCNPX, such that CAD models can be imported and evaluated directly in a geometric modeler rather than through translation into MCNPX geometry construction commands. This tool will be applied at Los Alamos to radiographic non-destructive testing (computed tomography and radiography). Coupling more realistic weapons CAD models with NDE simulations will allow the optimizing of inspection protocols and procedures on the computer itself, without the expenses of equipment and operator use, and will significantly improve confidence in radiographic and CT inspections. The CAD evaluations are provided by the Common Geometry Module (CGM), which is linked directly into MCNPX. MCNPX to eliminate the need for specifying problem geometry using surfaces and cells, replacing it with a command to find geometry in a specific file. This file is read into CGM, and functions in the CGM API are called to provide geometry data required by MCNPX. This talk will conclude with a discussion of current performance data, and future plans to improve that performance.

Finite Element Modeling of the SP-6 Over-Pressure Test

Francisco Guerra
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A Type 126 pit was instrumented with strain gages for an over-pressure test on May 20, 2003. A finite element model of the unit was developed which included

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several of manufacturing steps. The experimental results are compared with the finite element models. Good correlations seen between the measured strains and adjusted strains for different models. The finite element results also show that significant residual strains are introduced by the manufacturing steps and that further research is needed to measure or quantify the actual residual state of strain.

Testing and Analysis of Coring Process

Mark Miller
Los Alamos National Laboratory

Coring is a machining process used in the fabrication of metallography specimens for routine surveillance purposes. The coring tool transfers linear and torque loads to localized regions in the work piece that result in significant heat generation adversely affecting the cored material. Poor coring results prompted an investigation into this process that includes a series of machining tests and a coupled thermal / mechanical model of the process to predict the temperature distribution and stresses in the cored material. The results show good agreement with measured core temperatures and are being used to evaluate, modify and qualify a new coring process using advanced tooling.