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From Idea to Innovation: The Role of LDRD Investments in Sandia's Recent Successful B61 Experiments *by Marie D. Arrowsmith (Sandia National Laboratories)*

The Laboratory Directed Research and Development (LDRD) program, authorized by U.S. Congress in 1991, enables Department of Energy (DOE) laboratories to devote a small portion of their research funding to high-risk and potentially high-payoff research. Because it is high-risk, LDRD-supported research may not lead to immediate mission impacts; however, many successes at DOE labs can be traced back to investments in LDRD. LDRD investments have a history of enabling significant payoffs for long-running DOE and NNSA missions and for providing anticipatory new technologies that ultimately become critical to future missions. Many of Sandia National Laboratories' successes can be traced back to investments in LDRD. Capabilities from three LDRDs were critical to recent tests of the B61-12 gravity bomb—tests that would previously have only been performed experimentally.

Ensuring the safety, reliability, and performance of the US nuclear weapons stockpile, given a moratorium on underground testing and increased constraints on non-nuclear testing, was one objective of the DOE Accelerated Strategic Computing Initiative (ASCI), announced in 1996. Computationally based solutions were needed to quickly simulate the response of complex structures in extreme environments. With the installation of ASCI Red at Sandia National Laboratories in 1997, researchers had access to massively parallel (MP) supercomputing power that enabled the processing of programs over thousands of processors utilizing distributed memory. However, no commercial application existed that could perform simulations of weapons under stress utilizing this new architecture.

In anticipation of this need, researcher Garth Reese (computational sciences) led an LDRD project (1996-1999) to develop an algorithm to solve highly complex structural dynamics equations, taking advantage of MP platforms. This algorithm, an MP eigensolver, was integrated with existing general-purpose Sandia parallel computing software. The result, Salinas, was capable of performing structural dynamics finite element analysis on MP systems, and represented a fundamental advance in Sandia's capabilities to model responses of weapons and others systems under stress at high fidelity.

The development of Salinas during this period provided a critical engineering modeling tool. As model complexity grew, so did the computational burden due to increasing numbers of equations to be solved in order to generate results. The ability to obtain solutions to modeling (and other) problems quickly, even on ASCI Red, was of interest to researcher Clark Dohrmann (computational sciences). Leading an LDRD project (2001-2003), Dohrmann developed two linear solvers that were subsequently integrated into Salinas. This work greatly improved the speed at which structural dynamics equations could be solved, enabling the solution of problems that were not solvable with commercial software. The capability developed through this LDRD project was used in 2002 to simulate structural dynamic responses to mechanical excitation in the W76-1 Arming, Fuzing, and Firing system—a significant milestone in the qualification of the W76-1.

To broaden the scenarios that Salinas could model, early career researcher Tim Walsh, experienced in acoustical engineering, led a one-year LDRD in 2003 to develop a fully coupled structural acoustics capability that could be integrated into Salinas. This would allow users to quantify how acoustic effects impacted components (e.g., vibration of internal components due to the acoustic properties of the respective environment). The research focused on designing an algorithm (domain decomposition) to solve the coupled structural acoustic problem in a parallel environment. Users could now simulate the effects of mechanical excitation on complex structures, including MEMS (microelectromechanical systems), SAWS (surface acoustical-wave systems), re-entry vehicles, buried bunkers and caves, acoustical weapons, and submarines. Additionally, it has led to spin-off technologies used by industry and other government agencies.

Following these LDRD projects that greatly improved Salinas, mission programs began utilizing the code for weapons simulations, integrating it into Sierra, Sandia's engineering mechanics code suite, as a structural dynamics and acoustic module (Sierra/SD). The researchers who had worked on developing the LDRD-funded enhancements to structural modeling continued to test and improve the software, with a focus on scaling to account for improvements in computational capabilities. One such improvement came in 2011, with the introduction of a forward/inverse acoustics computational simulation capability into Sierra/SD. Prior to this enhancement; the models created in Salinas would be used to predict component responses. Now, experimental measurements could be used in Salinas to predict source inputs and material properties.

In 2013, the forward/inverse capability was expanded to include coupled structural acoustics; by performing inverse simulations, the desired experimental conditions could be computed to create complex spatially varying environments. For example, Sierra/SD could now simulate under wing captive carry vibration conditions for the B61 and vibrational environments for reentry vehicles. Sierra/SD enabled the numerical simulation of ground-based acoustic tests of weapons systems at Sandia for the first time in 2014. Measurements were taken from subscale experiments on the B61 to replicate acoustics and vibration inputs for various environments. These were then used by Sierra/SD to model the input forces on the whole weapon. In the past, this result could have only been achieved experimentally. The successful tests completed on the B61 are a realization of the goals of the ASCI program and critical to continued verification and validation of the US stockpile. They also illustrate the important role that LDRD played in contributing to this vital nuclear weapons mission capability.

Research & Development

From *idea*... ...to *innovation*

Salinas, a powerful structural dynamics modeling code, began out of the DOE's Accelerated Strategic Computing Initiative. The code was developed to ultimately simulate stresses on aircraft carriers, buildings, re-entry vehicles, and certain aspects of the nuclear stockpile.

Laboratory Directed Research and Development (LDRD) was critical to successful evolution and application of Salinas (now called Sierra/SD). The tools and expertise resulting from three unique LDRD projects significantly advanced capabilities in modeling and simulating the behavior of complicated engineering systems under real-world conditions. Interest from government and industry has led to new uses of Sierra/SD and contributed to improvements in the code's function and performance.

The advancements resulting out of the early LDRD work, along with improvements made over time, enabled, for the first time, the simulation of ground-based structural dynamics and acoustic tests at Sandia. This represents a significant achievement in assuring the reliability of our stockpile.

1998

Advanced by LDRD

A massively parallel eigensolver (LDRD) is integrated into Sandia's Salinas, representing a fundamental advance in structural dynamics modeling capabilities.

2001

Power added by LDRD

The development and implementation of two linear solvers (LDRD) into Salinas greatly improves the speed at which structural dynamics equations are solved, and enables the solution of problems that were not solvable with commercial software.

2003

Enhanced by LDRD

Adding acoustical simulation capability (LDRD) into Salinas allows, for the first time, insight into the coupling of acoustic phenomena with complicated engineering structures.

Early Payoff

W76-1

Arming, Fuzing, and Firing simulations using these LDRD-developed tools aid in stockpile stewardship activities.

2005

Mission Ready

Sandia's *Weapons Systems Engineering Assessment Technology* campaign adopts Sierra/SD (formerly Salinas) to support mission activities. Continued improvements are made to enhance capability.

2008

2011

Unique Capability

A new forward/inverse structural-acoustics computational simulation capability is integrated into SIERRA/SD, which simulates under wing captive carry vibration conditions for the B61 and the vibrational environments for re-entry vehicles.

2014

New Tools for Life Extensions

Sierra/SD enables the simulation of ground-based structural dynamics and acoustic tests at Sandia. Previously, these tests could only be performed experimentally.

W78

W87

B61-12

Applications