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HISTORY & REFLECTIONS OF ENGINEERING

at Lawrence Livermore National Laboratory

"The Flywheel of the Laboratory"

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Lawrence Livermore National Laboratory

Making History
Making a Difference

1952–2002

On the Cover:

Walt Arnold, Art Werner, and an unidentified guard delivering a small device at Nevada Test Site.

The Methods Development Group

by Art Shapiro

Virtually all the major programs at LLNL rely heavily on Mechanical Engineering. In turn, mechanical engineering is becoming increasingly dependent upon computer simulations. Modeling and computers are now indispensable to the entire engineering process, from the initial refinement of an idea with computer-aided engineering tools (CAE), to its implementation with computer-aided design/drafting (CADD) and manufacturing (CAM) tools.

Computer models assist the design engineer to unravel the basic physical phenomena in a real process, whether it be the interaction between a high-energy laser beam and the optics it passes through, the shock deformation of a warhead penetrating the earth, or the thermal response of a nuclear fuel shipping container in a fire accident.

The special research and development work at LLNL imposes modeling requirements that are more complex and of a larger scale than those faced in the broader engineering community. We are asked to model high-energy laser events occurring in picoseconds and, on the other hand, model low-energy nuclear waste storage issues at Yucca Mountain on time scales of centuries. The unique Lab modeling need for engineering at extremes was the driver for the creation of the Methods Development Group (MDG).

The Early Years (1975-1995)

MDG was formed in 1975. Jerry Goudreau managed the group from its inception until 1995, providing a sandbox for the code developers to play in. He told me once that he placed a filter on the information coming down from above so we wouldn't be burdened by it.

The years from 1975 to 1987 were the John Halquist era. John's awesome programming productivity resulted in a suite of codes (*e.g.*, DYNA, NIKE, MAZE, ORION, TAURUS) that are still being maintained at LLNL. John was your classic LLNL "hero code developer," with incredible drive and focus.

The DYNA code was first released in 1976. DYNA is used to model the rapid nonlinear response of solids to an applied force. While LLNL applied DYNA to study the high-velocity impact of nose cones, Detroit used DYNA to model car crashes, and Coors to model the manufacturing of beer cans.

NIKE is an implicit computational mechanics code that is used for long (greater than 1 s) duration deformation modeling, to model weapon deformation response.

Courtesy of Federal Highway Administration/ National Highway Traffic Safety Administration (FHWA/NHTSA) National Crash Analysis Center.

Left: Graphic comparison of calculated and experimental deformation of a steel nose cone.

The source code to DYNA was freely circulated. John's opinion was that by the time others figured out what was coded, he would be so far ahead that they couldn't catch up. You could step through thousands of lines of code and never encounter a comment statement. There was just too much exciting numerical physics to code, and therefore why waste time with comments? John's codes were soon found in universities and government and industrial laboratories throughout the world.

"You could step through thousands of lines of code and never encounter a comment statement."

In 1987, John left LLNL and founded Livermore Software Technology Corporation. This very successful company has continued DYNA development for the worldwide industrial marketplace.

Many others contributed to the success of the MDG code suite, as noted below.

Steve Sackett (1977–1979) developed MDGLIB, with many subroutines written in assembly code for the linear equation solver and IO subroutines. Although re-coded several times over the years (the assembly code was dropped), the fundamental architecture of familied IO files is still used. Steve also developed the structural mechanics code SAP4, which was subsequently transformed into GEMINI by Bob Murray.

Bill Mason developed the TACO heat transfer code. In 1979 Bill joined Sandia and began naming his codes after Italian food (PASTA). Pat Burns (1979–1980) continued development, and then I, Art Shapiro, took over the code in 1981. I re-wrote the code using Halquist's vectorized style of coding in NIKE for the CRAY computer architecture. I continued the development of TOPAZ to the present time, and TOPAZ is used extensively throughout the Lab for heat transfer analysis. A particularly important application is distortion calculations for NIF final optic assembly. Since Mason was naming his codes after food, Hallquist after constellations (ORION, TAURUS), I chose gem stones (TOPAZ, FACET).

Dave Benson (1984–1987) developed ALE (Arbitrary Lagrangian Eulerian) methods and implemented them in DYNA2D. This allowed a new class of problems to be solved in which a deformable material could flow through an Eulerian mesh, preventing mesh entanglement due to large deformation. Dave also implemented single surface contact in DYNA3D. This allowed us to model the deforming surface folding in on itself (*e.g.*, the nose cone on page 124).

Bob Ferencz (1984–1990) worked on element-by-element preconditioned conjugate gradient iterative solution strategies as part of his PhD work at Stanford, and implemented them in NIKE3D. Bob left the Lab in 1990 and was one of the founders of Centric, Inc.

Brad Maker (1990–1995) picked up NIKE3D development and added rigid bodies which significantly increased code execution for this class of problems.

Robert Whirley and Bruce Engelman (1988–1993) developed a coupled thermal-mechanical code called PALM by coupling NIKE and TOPAZ. They also developed an automatic solution driver, called ISLAND, that helped NIKE reach a solution in computationally difficult regions due to nonlinearities.

Along with the development of modeling codes came the need for mesh generation. The first finite-element mesh generator with TMDS graphics (remember that TMDS was really before its time) was ZONE (1975) by Mike Burger. ZONE had the infamous "switch" command that sometimes worked. This command would rotate the 2-D axisymetric mesh into a hexahedral 3-D mesh. However, computer power and memory limited the model to less than 2500 elements. Mike also developed our first attempt at interactive mesh generation. He implemented software to read engineering drawing line coordinates through a digitizer tablet and display the results on the TMDS.

Fully 3-D mesh code development can be traced to the INGEN code at LANL as the starting point. Two development paths evolved. In one, Mike Gerhard transformed INGEN into OASIS (something providing relief from a dull or dreary routine), and finally to SLIC (structural language with interactive commands). In the other path, Doug Stillman transformed INGEN into INGRID. Doug developed the idea of "index space" which greatly reduced (by about a factor of 100) the number of lines of input required to describe a 3-D mesh.

Bob Rainsberger took the next step by making INGRID interactive using a Graphical User Interface. Bob added features that made INGRID usable by engineers. Bob founded XYZ Scientific Corporation in 1991, and markets a significantly improved version of INGRID called TrueGrid, which is used throughout LLNL.

"...the idea of 'index space'...greatly reduced (by about a factor of 100) the number of lines of input required to describe a 3-D mesh.

Transition Years (1995-2000)

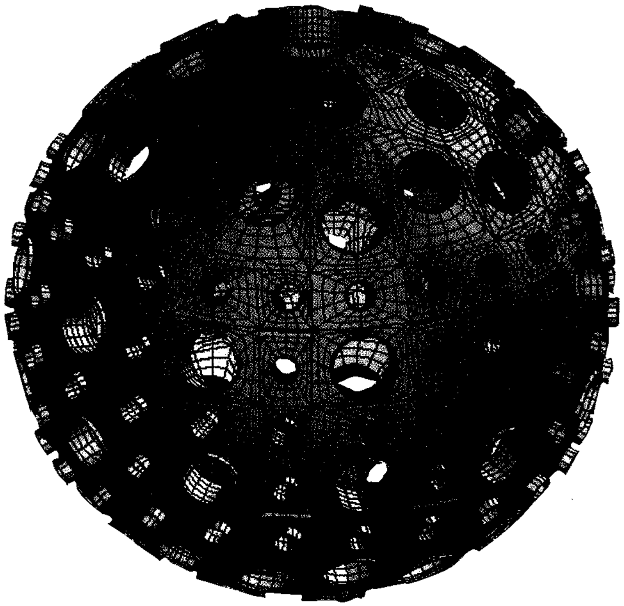
Peter Raboin became the MDG Group Leader in 1995. During these years the developers made many incremental, but significant, improvements to the suite of codes. Peter joined the group after several years as an engineering analyst. He brought a knowledge base of desired code features that would make the analysts' job easier, and proceeded to implement them in code. Also, during this time, Ed Zywicz developed automatic 3-D contact in DYNA3D and constitutive models for composite materials. Jerry Lin implemented rigid body switching in DYNA3D, by which the part could automatically switch between being modeled as a deformable object or as a rigid body.

Mike Puso focused on element technology and mathematical consistency of the various algorithms in NIKE3D. Mike's work greatly improved the convergence of NIKE3D in obtaining a solution to highly nonlinear problems.

The Age of ASCI

Carol Hoover is the current Group Leader of MDG. The code development focus has shifted from discipline-oriented codes to multi-discipline codes and to parallel computer architecture. The LLNL massively-parallel ASCI computers and high-speed workstation clusters have provided the opportunity to extend this suite of codes, DYNA, NIKE, and TOPAZ, with a new generation of computer programs.

The new software incorporates multidisciplinary coupling of solid and fluid mechanics, thermodynamics with chemical kinetics, and transport algorithms. Carol Hoover and Tony DeGroot are developing PARADYN, a parallel version of DYNA. Bob Ferencz and Mark Havstad are developing a new implicit multi-discipline code called DIABLO.



The finite element model of the National Ignition Facility target chamber shows laser beam entry locations and diagnostic instrumentation ports.