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MODELING OF SHOCK WAVE AND DYNAMIC INTERACTIONS ON PC BASED COMPUTERS⁽¹⁾

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Cette communication décrit l'implantation et l'utilisation des codes aux éléments finis DYNA et NIKE développés au LLNL, sur des PC. Les versions de ces codes conviennent pour la modélisation de phénomènes sur PC couramment effectuées sur ordinateurs centraux ou stations de travail. Le transcodage complet du programme rend possible la simulation de tous les problèmes pouvant être résolus sur CRAY, systèmes VMS ou UNIX. Les avantages de cette approche sont principalement la réduction des coûts tant logiciel que matériel et la simplicité d'utilisation. De plus des augmentations de la rapidité de calcul peuvent être obtenues avec l'implantation de coprocesseurs numériques.

Abstract - The implementation and utility of 80386/80486 personal computer (PC) versions of the Lawrence Livermore National Laboratory developed DYNA and NIKE finite element codes are described and evaluated in this paper. These code conversions provide for the PC modeling of problems that are currently analyzed on mainframes, mini-computers, and workstations. A comprehensive conversion of the entire source code allows for simulation of all problems that can be run on the CRAY, VMS, and UNIX systems. Some advantages of this approach are lower hardware and software costs, a convenient upgrade path for existing PC users, and simplicity for novice or casual users that do not have the time or inclination to learn UNIX. In addition, low cost speed improvements are easily implemented with the addition of the 3167/4167 numeric co-processors from Weitek or with the more expensive board-based I-860 chip options.

1. - Introduction.

This paper describes the implementation and utility of the LLNL developed DYNA and NIKE finite element codes on PC's. The implementation that is described is comprehensive and allows for running any problem on the PC that can be run on any other platform. Example problems from a range of applications are described. The code implementations have primarily involved the conversion of the graphical interface, development of high resolution color and monochrome hard copy capabilities, and transformation of I/O and timing routines. Some advantages of this approach are summarized below:

1. There are many third party vendors and discounts available for the PC based systems resulting in lower hardware and software costs associated with PC related purchases.
2. It provides a convenient upgrade path for existing PC users that want to run hydrodynamic, impact, structural, thermal, and other finite element problems.
3. PC-DOS and DOS shells provide an alternative for novice or casual users that do not have the time or inclination to learn UNIX.
4. Low cost floating point unit (FPU) speed improvements are easily implemented with the addition of the Weitek 3167/4167 numeric co-processors chips or with the more expensive board-based I-860 chip options.
5. Computing can be done at home with a low cost 386 system or in the field with a high powered portable based 486 system.

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A typical high end PC based workstation would consist of a 33 MHz 80486 microprocessor, VGA graphics, 16 Mbytes RAM, and 200 Mbyte hard disk. This computing platform can be obtained for much less than a comparably priced UNIX workstations. This system can be used for wordprocessing, desktop publishing, program management, and CAD, as well as for solving a 48,000 element DYNA2D or DYNA3D problem at speeds that are substantially faster than the VAX 11-780. Mesh generation and post-processing of the analysis can be visualized with 800 x 600 color graphics monitors while high resolution (300 DPI) grey scale and color postscript files provide state-of-the-art hard copy output. The central processing unit (CPU) run time for a 33 MHz 80486 system is competitive with UNIX workstations with computational throughput (elapsed time) being about an order of magnitude less than for a typical timeshared CRAY.

2. - Code implementation and modifications.

There were few real problems associated with the porting of these mainframe codes to the PC environment. Typically, changing the wrong thing was the only reason that road blocks and dead ends were encountered. Ultimately, the codes changes that were required to convert the codes basically fell into the following categories.

1. There were source code modifications required for compilation and correct execution. These changes involved issues related to common block alignment, size of the blank common "A" array, and variables declared double precision. A majority of these code conversions are now made automatically by a source code converter which reads a single source code file, makes all of the appropriate changes, and then creates separate files for each subroutine.
2. A graphics library was created that provides a transparent interface between the mainframe versions of the codes and the varying PC graphics options available (EGA, VGA, Super VGA) in the DOS environment was required. The primary effort for this task involved the development of a PC device driver for the DIGLIB graphical interface.
3. Conversion of I/O and timing routines were necessary to provide the user with a consistent interface regardless of the computing platform. Examples of modifications in this area include the input line prompts, CPU and I/O timing routines using the embedded DOS time calls, and interactive I/O response remaining on the same line as the interactive prompt.
4. Sense switch controls (i.e. "SW1.") mapping to the PC function keys (i.e. "F1") was used to simplify and eliminate the CTRL-C interrupt procedure used in the VMS and UNIX operating systems.

Additionally, modifications and augmentations to the codes are continually being made to make the codes more user friendly, improve usefulness, and take advantage of system features available on the PC. These include multiple plots on the same screen, the provision for high resolution postscript hardcopy output, implementation of a reference materials database in the mesh generator, online help for input line format and sense switch key descriptions, and software security protection. Multiple plots on the same screen allows for viewing 4 sequential plots at the same time with each plot scaled 50%. The high resolution hardcopy output is in the form of Encapsulated Postscript Files that can be imported, manipulated, and printed by the many standard software and hardware products available. The material database is based on published data for materials and can be expanded to include material properties that have been refined from experimental data or are specific to a particular analysis methodology.

3. - Performance benchmarks.

Performance comparisons for several computer systems are summarized using "standard" benchmark test results as well as CPU execution times for running a sample DYNA2D problem. The "standard" benchmark test results are based on the single/double precision LINPAC. This test result can be somewhat misleading in that the benchmark actually evaluates the computer/compiler efficiency which can be optimized to look good for the benchmark. However, published results of the Livermore Loops benchmark are typically consistent with the LINPACK results. The benchmark numbers for the PC and UNIX systems were extracted from Personal Workstation magazine. The LINPACK benchmark numbers, which have also been normalized to the VAX 11-780 computer, are summarized in Table 1.

The sample DYNA2D problem provides a representative evaluation for the analysis of a real problem. The problem used for comparison of actual run times is the Taylor impact problem. This experimental procedure was used by G. I. Taylor to study the propagation of longitudinal waves when a short steel rod impacts

a rigid boundary [12]. Computational studies by Wilkens identified this method as a simple approach for determining constitutive properties of the projectile material [13]. This simulation described below is for a cylindrical OFHC copper projectile impacting a rigid flat surface. The constitutive properties of the projectile are modeled using the Johnson-Cook material model with the published properties [14]. The impact velocity is 0.0190 cm/ μ sec. The impact surface is simulated with a rigid wall boundary condition that does not constrain the projectile to remain attached to the wall. The mesh of the projectile at the end of the deformation process (70 μ sec) is shown in the left frame of Figure 1. The initial projectile diameter and length are 0.76 cm and 2.54 cm respectively. It is modeled with 10 elements in the radial direction and 50 elements axially. Shaded fringe plots of effective plastic strain at the end of the deformation process are shown in the right frame of Figure 1.

COMPUTER	SP/DP LINPACK	11-780 VAX MIPS
VAX 11-780	0.25/0.14	1.0
386/387-20MHz	0.25/0.20	1.4
VAX 11-785	0.50/0.21	1.5
386/1167-20MHz	0.67/0.38	2.7
SUN 3/160 w/FPA	0.62/0.41	2.9
386/387-33MHz	0.54/0.43	3.1
SUN 4/110	1.20/0.86	6.1
486-25 MHz	1.15/1.08	7.7
SG Iris 25D	2.62/1.35	9.6
486-33 MHz	1.58/1.46	10.4
SPARCstation 1	2.75/1.47	10.5
MIPS RS2030	2.90/1.69	12.7
486/4167-25 MHz	3.80/1.90	13.5
DECstation 5000	6.46/3.21	23.0
486/I860-40 MHz	5.00	35.7
CRAY 1S CFT	12.00	85.7

Table 1. Single/double precision LINPACK benchmark comparisons for several computer systems (single value displayed is DP). The double precision LINPACK results are also normalized and referenced to the VAX 11-780 computer.

This problem was analyzed on several computers and a comparison of run time and simulation results are given in Table 2. Note that number of cycles for 32 bit computers were all the same but different than for the CRAY's. DYNA2D is vectorized on the CRAY's which may explain why the CRAY CPU times are less than LINPACK extrapolations would suggest. The TPZC values are the average time per zone cycle (cpu time/zones/cycles). Simulation results for all systems were exactly the same with L, D, and W equal to 1.64 cm, 1.348 cm, and 0.997 cm. Experimental results for L, D, and W are 1.62 cm, 1.350 cm, and 1.010 cm. The calculated maximum effective plastic strain is 1.93 for all simulations.

4. - Example problems.

These example problems represent a small assortment of problems that can be modeled using the DYNA & NIKE series of finite element codes. As mentioned previously, the code porting to the extended DOS environment is comprehensive. Simulations of virtually any problem that can be run on another platform are possible on the PC.

The first example problem that is described shows the utility of the eroding slideline option that was recently implemented in DYNA2D. This simulation consists of a 2 cm long, 0.43 cm diameter steel projectile with velocity 0.30 cm/ μ sec impacting and penetrating a 1.0 cm thick steel plate. The initial geometry is shown in the upper left frame of Figure 2, with the deformed geometry at 5 μ sec intervals shown in the other three frames. The plastic failure strain used in the analysis was 300%.

Plots from other example problems are shown in Figure 3. The upper left frame shows fringe plots of pressure in the high explosive from an analysis of the liner collapse of the BRL precision 81 mm shaped charge. The coupled finite element/PER theory 2DJET code [11] is used to calculate the jet characteristics from the liner collapse conditions. The upper right frame shows HE detonation wave pressure just after liner impact from an analysis of a typical EFP. The lower left frame shows plastic strain fringes in a shear

hopkinson bar test specimen. The lower right frame shows an analysis of the ignition and growth of reaction in a cylindrical sample of TATB high explosive impacted by a steel flyer plate with a velocity of 0.25 cm/ μ sec.

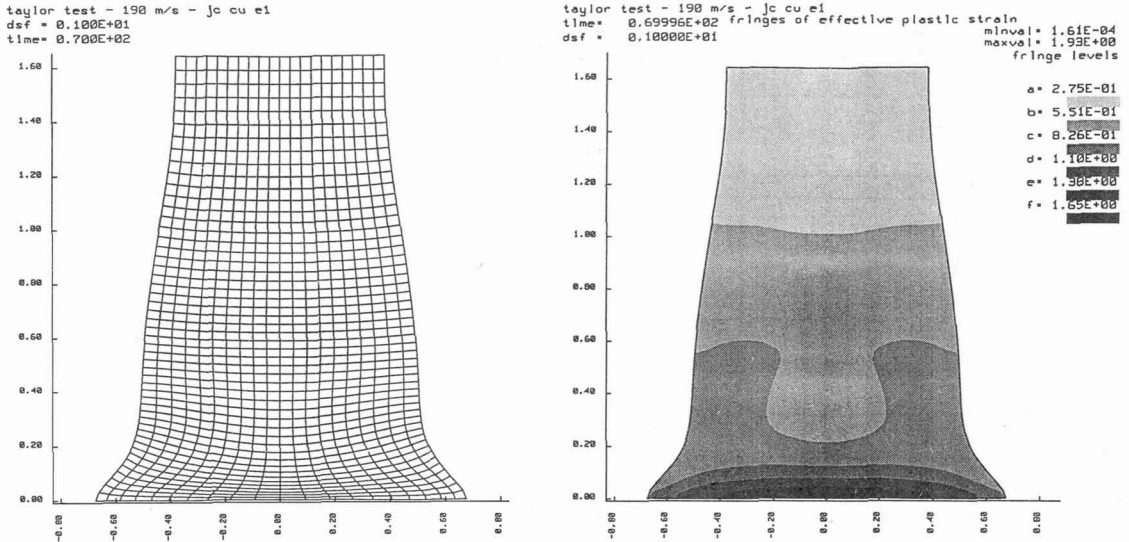


Figure 1. Analysis results for the Taylor impact analysis. The mesh of the OFHC copper projectile at the end of the deformation process (70 μ sec) is shown in the left frame. Shaded fringe plots of effective plastic strain are shown in the right frame. The impact velocity is 0.0190 cm/ μ sec and the impact surface is simulated with a rigid wall boundary condition that does not constrain the projectile to remain attached to the wall. The initial projectile diameter and length are 0.76 cm and 2.54 cm respectively. It is modeled with 10 elements in the radial direction and 50 elements axially.

COMPUTER	No. of Cycles	CPU (sec)	TPZC (μ sec)
386/387-20MHz	3519	5076	2885
VAX 11-785 w/FP785	3519	3063	1740
386/387-33MHz	3519	2643	1502
VAX 6310	3519	1561	887
486-25 MHz	3519	1232	700
DECstation 3100	3519	1057	601
486-33 MHz	3519	896	509
MIPS RS/2030	3519	782	444
SG Iris 25GT/4D	3520	748	425
SG Iris 210GT/4D	3520	594	338
SUN SPARKstation 2	3519	529	301
MIPS M/2000	3519	493	280
DECstation 5000/200	3519	489	278
SG Iris 310GT/4D	3520	386	219
486/4167-25 MHz *	3519	373	212
CRAY 1	3481	48.1	24
CRAY XMP	3481	23.7	14
CRAY YMP	3481	15.2	9

* values are extrapolated from LINPACK results

Table 2. Comparison of CPU and analysis results for the sample taylor impact problem. TPZC is the average time per zone cycle (cpu time/zones/cycles). Simulation results for all systems were exactly the same with L, D, and W equal to 1.64 cm, 1.348 cm, and 0.997 cm. Experimental results are 1.62 cm, 1.351 cm, and 1.010 cm.

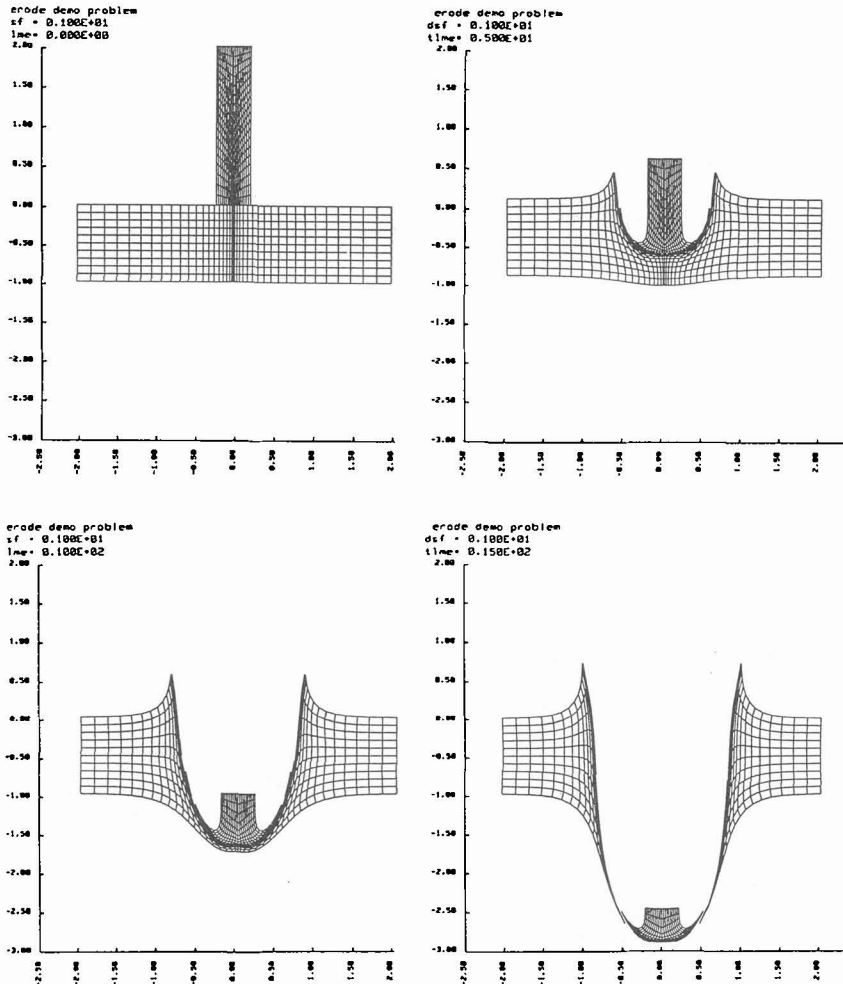


Figure 2. This figure shows an example analysis describing the utility of the eroding slideline option in DYNA2D. The simulation consists of a 2 cm long, 0.43 cm diameter steel projectile with velocity 0.30 cm/ μ sec impacting and penetrating a 1.0 cm thick steel plate. The initial geometry is shown in the upper left frame with the deformed geometry at 5 μ sec intervals shown in the other three frames. The plastic failure strain used in the analysis was 300%.

5. - User perspective of PC versus UNIX workstation.

One objective of this paper is to show that using PC based computers for finite-element number crunching is a viable alternative to other platforms. It is apparent that codes can be ported to the PC and thus, the availability of codes on the PC is not an issue. Size of the problem is not an issue either, as PC systems with up to 64 Mbyte can be obtained. In current and future markets, the increasing overlap between PC's and UNIX workstations will make it more difficult for a user to decide which platform to use. If your problems are primarily CPU intensive, the workstation may be the best option. The only caveat is that you need to know, or are willing to learn, UNIX. If you are not willing to learn UNIX or can accept a small reduction in speed, a PC based system may be a better choice. If you have a limited budget and are price driven, then the PC may be the best platform for computing because PC maintenance and software costs are typically less than for a workstation and discounts for PC related hardware purchases are frequently greater.

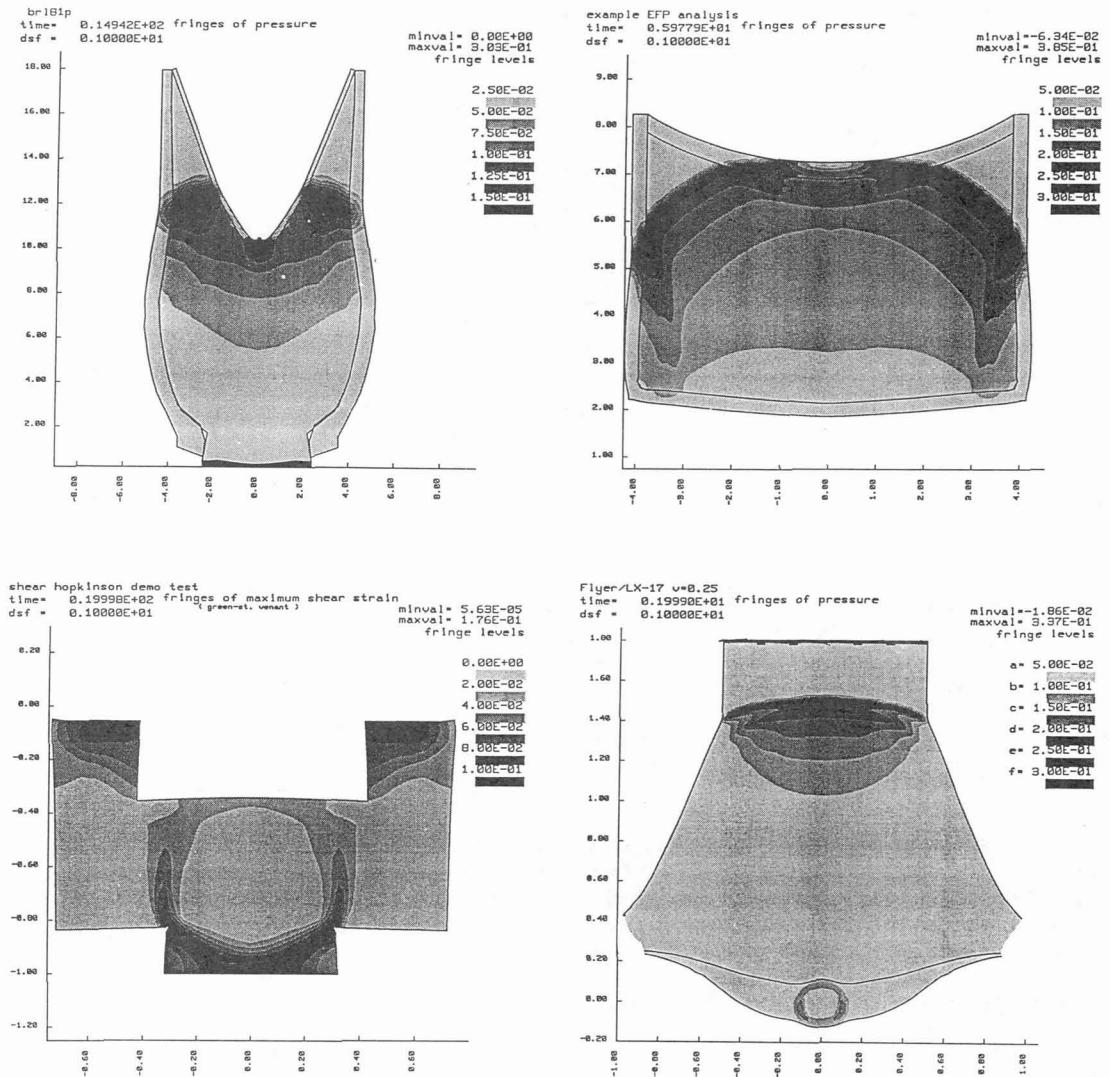


Figure 3. This figure describes other example problems that can be analysed using the PC DYNA2D code. The upper left frame shows fringe plots of pressure in the high explosive from an analysis of the liner collapse of the BRL precision 81 mm shaped charge. The coupled finite element/PER theory 2DJET code [11] is used to calculate the jet characteristics from the liner collapse conditions. The upper right frame shows HE detonation wave pressure just after liner impact from an analysis of a typical EFP. The lower left frame shows plastic strain fringes in a shear hopkinson bar test specimen. The lower right frame shows an analysis of the ignition and growth of reaction in TATB high explosive impacted at 0.25 cm/ μ sec.

Independent of a corporate edict, the final decision between PC and UNIX workstation basically comes down to personal preferences and past inertia. If a PC has been used in the past, upgrading to a more powerful PC system is a logical choice. In a majority of the problems encountered, PC speed improvements will provide sufficient computing capability such that the power of the workstation is not required. Conversely, if a mainframe or UNIX based workstation has been used in the past, upgrading to the next generation workstation can be anticipated. Finally, the simplicity of the PC will attract novices and new users.

6. - Acknowledgement.

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