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LLNL-TR-747674

High Performance Parallel Processing Final Report CRADA No. TC-0824-94-C

J. Goudreau, F. Fernandez

March 12, 2018

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

DISCLAIMER

High Performance Parallel Processing

Final Report

CRADA No. TC-0824-94-C

Date: September 8, 1997 Revision:

A. Parties

The project is a relationship between the Lawrence Livermore National Laboratory (LLNL) and Arete Engineering Technology Corporation (AETC).

University of California
Lawrence Livermore National Laboratory
7000 East Avenue, L-795
Livermore, CA 94550

Arete Engineering Technology Corporation
8910 University Center Lane #900
San Diego, CA 92122-1029

B. Project Scope

The primary objective for this work was to demonstrate the use of the T3D in the simulation of a grand challenge problem, namely the structural acoustics problem. To do this, LLNL was to produce a parallel structural acoustics application that could be used by AETC and the LLNL structural acoustics group for the analysis of complex geometry acoustic fluid-structure interaction problems.

LLNL worked on developing the acoustic fluid-structure simulation code, PING, and mapping the application to the CRAY T3D in several phases. LLNL ran the PING test problems identified in the milestones below, and assisted AETC in the running of further models they developed and wished to run.

The primary deliverable was the parallel version of PING for the T3D. LLNL and AETC prepared quarterly reports and a final report at the conclusion of the project. In addition, informal working notes, technical reports, and a journal article were prepared to describe the research and simulation results. At the conclusion of the CRADA, AETC was given access to PING and was to acquire a license for its further use.

C. Technical

1	Evaluation of Communications	11/94	12/94
2	Port of driven boundary/rigid scattering module to T3D	03/95	04/95
3	Optimize Wave Solver Communication	06/95	06/95
4	Deliver deformable structure data set (nonparallel) to AETC	10/95	11/95
5	Provide AETC T3D user account and mesh generator manual	12/95	12/95
6	Prototype with AETC scalable mesh for simulation of acoustic response on nonaxisymmetric structures	12/95	12/95
7	Host AETC technical visit; provide workstation version of INGRID mesh generator, and scalable mesh	02/96	03/96
8	Perform first nonaxisymmetric analysis and provide results to AETC	03/96	04/96
9	Develop a methodology for three-segment partitioning of the fluid plus structure mesh to allow for load balanced parallel computation	05/96	05/96
10	Implement basic parallel, iterative linear solver, plus pre-conditioning (as needed), to provide prototype parallel solution of the coupled problem	08/96	08/96
11	Test prototype parallel code, and benchmark results against scalar/vector code	08/96	09/96
12	Finalize with AETC scalable mesh for simulation of acoustic response on non-axisymmetric structures	09/96	
13	Perform two simulations with new mesh and on parallel machines; provide results to AETC	09/96	
14	Optimize computations and communications within the parallel structural module of PING	12/96	
15	Final optimization of parallel version of PING	04/97	
16	Integrate parallel graphics into T3D function	06/97	
17	Evaluate software with an ISMS Model (tbd)	08/97	

D. Partner Contribution

AETC defined the interface between PING and the imaging software for the rapid exchange of time history data. AETC also defined the PING-imaging interface, developed appropriate code modules for the efficient I/O of large-scale time history datasets, and performed preliminary imaging computations using PING time history data to validate the I/O modules and the parallel PING results.

AETC prepared the input deck model and also provided data for the loading of a scale model geometry consistent with the ISMS facility and performed simulations with PING and their imaging software to demonstrate the use of large-scale scientific simulation for acoustic detection, identification, and design. AETC defined the ISMS simulation parameters to be studied (frequencies, incident direction, etc.), and they continued with the PING-imager validation studies. Final streamlining of the data interface between PING and the imaging software was made at this point. AETC aided in the validation and demonstration of the parallel version of PING for simulations that are beyond the current capabilities of conventional acoustic fluid-structure software.

E. Documents/Reference List

1) Reports:

Quarterly Reports:

December, 1994
March, 1995
June, 1995
September, 1996

A Mixed Time Integration Method for Large Scale Acoustic Fluid-Structure Interaction, M. A. Christon, S. J. Wineman, G. L. Goudreau, J. D. Foch, Lawrence Livermore National Laboratory, ASME, Chicago, 1994.

Large-Scale Fluid/Structure Interaction, G. L. Goudreau and Richard Procassini, Lawrence Livermore National Laboratory, Joseph Sabatini, Terry Bazow, and Frank Fernandez, Arete Engineering Technologies Corporation, "High Performance Parallel Processing Project Progress Reports for Fiscal Year 1995," February 9, 1996.

Presentations:

1. R.J. Procassini, A.J. DeGroot, and J. Maltby, "An Analysis of Graph Partitioning Methods as Applied to the Decomposition of Three Dimensional Unstructured Finite Element Meshes," Supercomputing '94, 14-18 November 1994, Washington, D.C.

2. R.J. Procassini, "Parallel Implementation of a Structural Acoustics Code for Use on Massively Parallel Processors," Supercomputing '95, 4-8 December, 1995, San Diego, CA.

3. R. J. Procassini, "Parallel Implementation of a Structural Acoustics Code on the Cray T3D Massively Parallel Processor," Cray PAPT Users Workshop, 28-29 August 1995, Pasadena, CA.

4. Mark Christon and G.L. Goudreau, "PING, the LLNL Structural Acoustics Code," ONR Annual Research Review, January 15, 1995, Bocha Ratan, FL

5. G.L. Goudreau and James Foch, "Benchmark Studies with the LLNL Structural Acoustics Code PING," and "Status of H4P CRADA T3D parallel port, and Large Problem Scaling Laws," ONR Annual Research Review, Feb. 12-16, 1996, Orlanda, FL.

6. Terry Donich, multiple presentations to Navy and DOD Program officers, furthering the LLNL Maritime Systems Program, seeking funding for further development of PING.

2) Intellectual Property

i) Subject Inventions

Art. I: "Subject Invention" means any invention of The Regents or Participant conceived or first actually reduced to practice in the performance of work under this CRADA.

Art. XIV: The Parties agree to disclose to each other each and every Subject Invention, which may be patentable or otherwise protectable under the Patent Act.

<u>LLNL Sole Subject Inventions:</u> None

<u>AETC Sole Subject Inventions:</u> None disclosed

<u>Joint Subject Inventions:</u> None

ii) Computer Software:

CRADA Article XIII requires that for all copyrighted computer software produced in the performance of this CRADA, the Party owning the copyright will provide the source code, an expanded abstract, and the object code and the minimum support documentation needed by a competent user to understand and use the software to DOE's Energy Science and Technology Software Center.

Computer software developed by LLNL:
Parallel version of PING for the T3D. This included porting several components of PING, such as the NIKE3D and acoustics components.

Computer software developed by AETC:
None

Copyrighted computer software:

LLNL did not assert copyright in any software developed under this CRADA.

iii) Licensing activity:

Appendix C, Intellectual Property Agreement, provides that to the extent that The Regents obtains title or authority to license Intellectual Property first arising or produced under this CRADA, The Regents shall negotiate in good faith with AETC for a license to rights in such Intellectual Property, on reasonable commercial terms, for the term of this CRADA plus a period of not more than six months after the completion or termination of this CRADA.

AETC has not indicated an interest in licensing any LLNL Intellectual Property developed under this CRADA.

F. Acknowledgment

Participant's signature of the final report indicates the following:

1) The Participant has reviewed the final report and concurs with the statements made therein.
2) The Participant agrees that any modifications or changes from the initial proposal were discussed and agreed to during the term of the project.
3) The Participant certifies that:
   a) all reports either completed or in process are listed;
   b) all subject inventions attributable to the project have been disclosed or are included on a list attached to this report; and
   c) appropriate measures have been taken to protect intellectual property attributable to this project.
4) The Participant certifies that if tangible personal property was exchanged during the agreement, all has either been returned to the initial custodian or transferred permanently.
5) The Participant certifies that proprietary information has been returned or destroyed by LLNL.

Jerry L. Goudreau 5/23/00

Donald Miklovac Date	Jerry L. Goudreau Date
Arete Engineering Technology Corp.	Lawrence Livermore National Laboratory

Attachment I – Final Abstract
Attachment II – Project Accomplishments Summary
Attachment III – Final Quarterly Report

High Performance Parallel Processing

Final Abstract
Attachment I
CRADA No. TC-0824-94-C

Date: September 8, 1997 Revision:

The term "fluid-structure interaction" encompasses a broad class of physical problems in which the interaction between a structural system and the surrounding fluid produces a coupling effect that influences the net elastic behavior of the structure. In the design of underwater vehicles and structures and in underwater exploration and recovery, the identification and reduction of the acoustic signature of submerged vehicles and structures is of great importance. A clear understanding of the interrelationship between hull geometry and acoustic signature is crucial to the design of "quiet" hulls and to the related goal of detecting and accurately identifying underwater vehicles and structures.

Structural acoustics remains one of the computation "grand challenges" facing the U.S., as defined under the Federal High Performance Computing Program (1989). The requirement for high resolution meshes, relatively large computational domains, and complex structural geometry with internal detail (i.e., internal ribs and stiffeners), and the presence of many length scales, demands efficient algorithms.

The structural acoustics code, PING, is a high performance, robust code capable of treating large scale structural acoustic problems. The purpose of this project was to develop a highly efficient parallel version of PING for the CRAY T3D massively parallel processing (MPP) computer to be used by the industrial partner, Arete Engineering Technology Corporation (AETC), in reconstructing the characteristics of underwater objects and by the Department of Defense (DOD) for analysis and design of complex underwater bodies.

High Performance Parallel Processing

Project Accomplishments Summary (Attachment II)
CRADA No. TC-0824-94-C

Date: September 8, 1997 Revision:

A. Parties

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B. Background

The term "fluid-structure interaction" encompasses a broad class of physical problems in which the interaction between a structural system and the surrounding fluid produces a coupling effect that influences the net elastic behavior of the structure. In the design of underwater vehicles and structures and in underwater exploration and recovery, the identification and reduction of the acoustic signature of submerged vehicles and structures is of great importance. A clear understanding of the interrelationship between hull geometry and acoustic signature is crucial to the design of "quiet" hulls and to the related goal of detecting and accurately identifying underwater vehicles and structures.

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C. Description

The objective of this project was to develop a parallel version of the PING structural acoustics program and port the serial PING code to the Cray T3D MPP. The project goals included the following:

- Demonstrating problems requiring larger memory than the mainline YMP , C90, or J90 machines (2-10).
- Achieving and demonstrating performance, especially in the message passing method of interprocessor communication.
- Achieving and demonstrating performance in the linear equation solving portion of the implicit structural response and showing both parallel direct and parallel iterative solution techniques.
- Demonstrating the practical value of this predictive capability with an industrial partner, Arete, who would use the output to perfect their inverse code, which uses measured data to reconstruct the characteristics of unknown underwater objects.
- Providing DOD a high performance time domain structural acoustic capability for analysis and design of very complex underwater bodies.

There were three primary phases of the project: (1) the porting of PING to the CRAY T3D;
(2) optimization of the NIKE3D portion of PING on the CRAY T3D and optimization of the acoustics imaging modules on the T3D; and (3) migration of the imaging software to the T3D or appropriate platform as required and the evaluation of the simulation capabilities for the Intermediate Scale Measurement System (ISMS) experimental design.

LLNL and AETC collaborated on the development of simulation capabilities for structural acoustics, which can be applied to a broad range of problems. LLNL focused upon the implementation of PING on the CRAY T3D. After establishing a clear understanding of the communication issues on the T3D, LLNL ported the acoustics component of PING to T3D and evaluated a message passing implementation. This effort was followed by further optimization of the fluid-structure interface treatment and the assignment of fluid sub-domains to processors.

In the second phase, LLNL focused upon optimization of the fluid-structure interface treatment and the optimization of the NIKE3D portion of PING on the T3D. During this phase, alternative equation solvers for the structural system were investigated and further optimization of the acoustics component and load balancing among processors were performed.

This final phase was to focus on the evaluation of simulation capabilities with ISMS experimental design. LLNL was to continue to focus upon optimization of PING and to assist AETC to perform large-scale ISMS simulation with PING. AETC was to port the imaging software to the T3D as required. This effort by AETC would help to tune and validate PING for further large-scale simulations by AETC and LLNL's own Maritime Systems Group. However, this phase was not completed.

D. Expected Economic Impact

Developing a parallel PING Structural Acoustics code has provided scalable modeling software for the linear structural acoustic problems for both the Navy and other potential civilian applications. It has also provided a benchmark for other more sophisticated algorithms to beat.

This project is synergistic with other LLNL highly scalable software projects, such as DSI3D, which models linear electromagnetics in the time domain in a similar way. We share a common 3D parallel mesh generation project PMESH, which is a multiyear effort targeted toward the largest meshes (10)**7 to (10)**9.

The message passing strategy of the PING parallel code allows porting to other new parallel machines such as the Meiko CS-2 and the symmetric multiprocessors such as Cray J90, SGI Power Challenge and others.

This code, along with DYNA, NIKE, ALE, and DSI3D provide a powerful nucleus of unstructured grid codes that will drive computer vendors to address this class of indirect addressing requirements. This will affect the entire FEM commercial market, which has a wait and see attitude toward parallel platforms (e.g., NASTRAN).

E. Benefits to DOE

The DYNA and NIKE solid/structural mechanics codes are a core competency of Engineering in supporting the Weapons and broader Laboratory programs. These codes will have direct benefit to the ADAPT (currently ASCI) program in simulation of metal forming of nuclear materials in near net shape to classified geometries and specifications. The ParaDyn project has invested heavily in the parallel evolution of the explicit DYNA codes. Parallelization of time implicit NIKE is just beginning. PING represents the simplest test vehicle for parallel equation solvers for NIKE-like codes.

Of indirect benefit to DOE in its spin-off mission to assist DOD missions is the direct benefit to DOD (i.e., the Navy) in addressing one of their grand challenges, structural acoustics.

Also of indirect benefit to DOE's ASCI mission is the role engineering codes play in assisting the main weapons design codes in shaking down new high performance computing systems. PING is the simplest linear, but large capacity, code in the DYNA/NIKE suite, much like its EM counterpart DSI3D, whose very large scale requirement, and early time deliverables, will shake out the new generation of massively parallel computers on the special class of unstructured grid physics. With the heavy emphasis of hardware vendors on system and application software for structured grid physics, much more emphasis on unstructured grid applications is required. Joint effort with ASCI code development on parallel I/O, mesh generation, graphics, and data structures is highly synergistic.

F. Industry Area

Maritime industry, underwater detection companies, U. S. Navy, parallel processing computer industry.

G. LLNL Point of Contact for Project Information

Jerry Goudreau
P.O. Box 808, L-125
Livermore, CA 94551
PH:(510) 422-8671
FX: (510) 423-4097

H. Company Size and Point(s) of Contact

Company Size: 35 employees
Point of Contact: Frank Fernandez: (619) 450-6729

I. Project Examples

Drawing of "Partitioned Submarine Cavity and Fluid Island Mesh."

J. Intellectual Property

i) Subject Inventions

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RELEASE OF INFORMATION

I certify that all information contained in this report is accurate and releasable to the best of my knowledge.

Karena McKinley, Director
Industrial Partnerships
and Commercialization

6/1/00
Date

RELEASE OF INFORMATION

I have reviewed the attached Project Accomplishment Summary prepared by Lawrence Livermore National Laboratory and agree that the information about our CRADA may be released for external distribution.

Donald Miklovac
Arete Engineering Technology Corp.

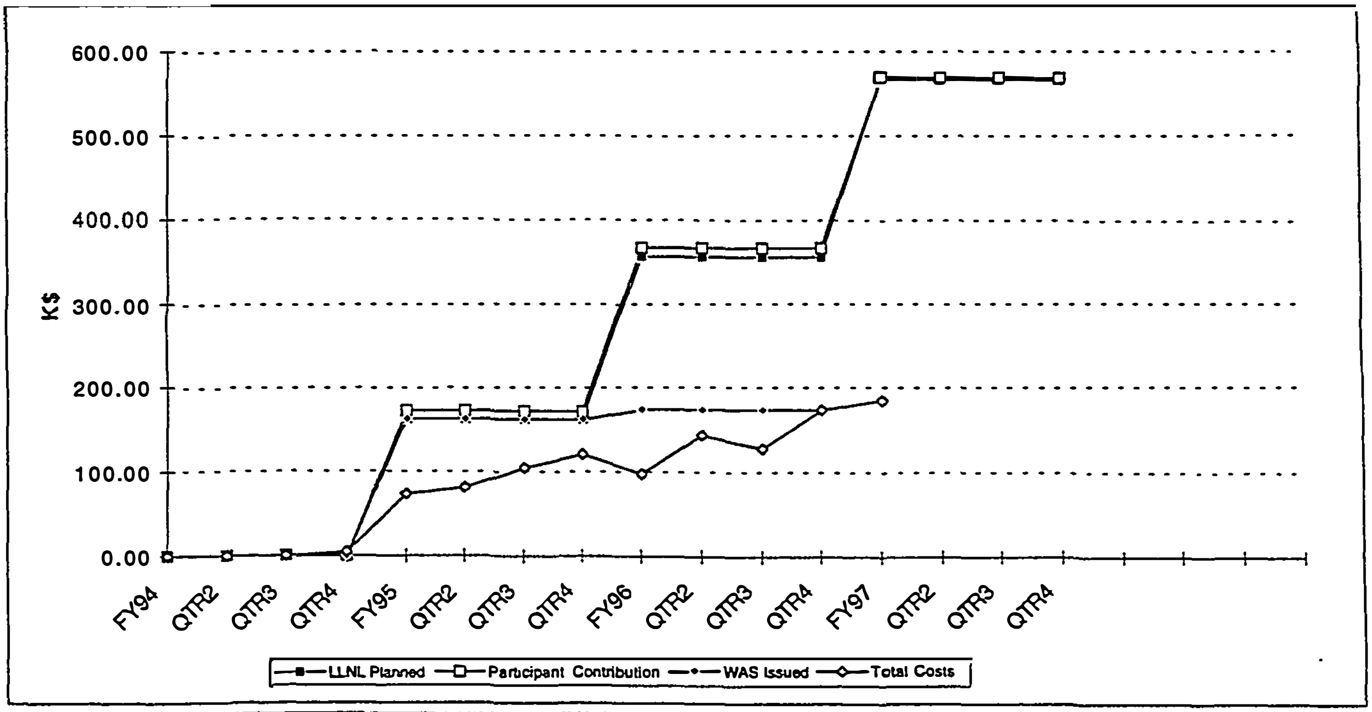
Date

Lawrence Livermore National Laboratory
Final Quarterly Report (Attachment III)

Title:	HPPP Large Scale Fluid/Structure Interactions	Reporting Period:	07/01/95 - 09/30/96
Participant:	Arete Engineering Technology Corp.	Date CRADA Executed:	9/26/94
DOE TTI No.:	94-MULT-003-XX-1	DOE Approval Date:	9/22/94
CRADA No.:	TC-0824-94-(C)	Scheduled Ending Date:	9/25/97
Account Number	4745-79, 89	Project Completion Date:	11/30/96
Accounts Closed:	12/21/96	B & R Code(S):	DP0301, YN01000

Approved Funding Profile ($K)

	FY94	FY95	FY96	FY97	FYOUT	Total
LLNL Planned	4	158	195	209	0	566
Participant In-Kind	0	172	195	202	0	569
Paticipant Funds-In	0	0	0	0	0	0
WAS DP0301	0	55	13	11	0	79
LDRD Funds	0	107	0	0	0	107
Total Costs	4	116	54	11	0	186



DP0301	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	FYTD	186
FY94	0	0	0	0	0	0	0	0	0	0	0	4	4	
FY95	24	23	22	34	11	-37	10	8	5	4	5	7	116	
FY96	-64	23	18	13	13	20	5	-29	7	13	19	15	54	
FY97	7	5	0	0	0	0	0	0	0	0	0	0	11	
FYOUT	0	0	0	0	0	0	0	0	0	0	0	0	0	

YN01000	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	FYTD	0
FY94	0	0	0	0	0	0	0	0	0	0	0	0	0	
FY95	0	0	0	0	0	0	0	0	0	0	0	0	0	
FY96	0	0	0	0	0	0	0	0	0	0	0	0	0	
FY97	0	0	0	0	0	0	0	0	0	0	0	0	0	
FYOUT	0	0	0	0	0	0	0	0	0	0	0	0	0	

STAFF w/phone:

Lab PI: Jerry Goudreau (510) 422-8671
Resource Manager: Steve Stinson (510) 423-2888
DOE OAK: Jerry Scheinberg (510) 637-1653

Participant: F. Fernandez (619) 450-6729
DOE HQ: A. Larzelere (202) 586-1101

Reporting Period 07/01/95 - 09/30/96
DOE TTI No.: 94-MULT-003-XX-1
CRADA No.: TC-0824-94-(C)

Milestones and Deliverables:

List the complete set of milestones for all phases of the CRADA. Continue on a separate page if necessary.
Report any changes from the original CRADA or previous quarterly report on the CRADA Change Form.

Completion Date:
Scheduled Actual

See attached report

Verification of participants' in-kind contribution was made in accordance with LLNL policy. Explain basis of verification: Please initial: YES X NO ____

List any subject inventions by either party (include IL# for LLNL inventions), additional background intellectual property, patents applied for, software copyrights, publications, awards, licenses granted or reportable economic impacts.

Verification that all equipment and proprietary information has been returned to the initial owner or permanently transferred. Please initial: YES X NO ____

Accomplishments

Describe Technical/Non-Technical lessons learned and other observations.
Summarize causes/justification of deviations from original scope of work.

See attached report

Reviewed by CRADA project Program Manager: ____________ Date: ____

Reviewed by Karena McKinley, Director, LLNL/IP&C: Karena McKinley Date: 6/1/00
Direct questions regarding this Report to IP&C Resource Manager, Carol Asher, at (510) 422-7618