HPCC Methodologies for Structural Design and Analysis on Parallel and Distributed Computing Platforms

Grant NAG-1-1873

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Summary of Research

In this grant, we have proposed a three-year research effort focused on developing High Performance Computation and Communication (HPCC) methodologies for structural analysis on parallel processors and clusters of workstations, with emphasis on reducing the structural design cycle time. Besides consolidating and further improving the FETI solver technology to address plate and shell structures, we have proposed to tackle the following design related issues: (a) parallel coupling and assembly of independently designed and analyzed three-dimensional substructures with non-matching interfaces, (b) fast and smart parallel re-analysis of a given structure after it has undergone design modifications, (c) parallel evaluation of sensitivity operators (derivatives) for design optimization, and (d) fast parallel analysis of mildly nonlinear structures.

While our proposal was accepted, support was provided only for one year. During that year, we addressed only the following two topics.

An optimal FETI solver for realistic aerospace structures

Most if not all realistic aerospace structures consist essentially of plate and shell components, for which the original (one-level) FETI method is not numerically scalable. For this reason, we have first developed a two-level FETI method for solving iteratively on massively parallel processors large-scale systems of equations arising from the finite element discretization of static and dynamic plate bending problems. This method is essentially an extension of the FETI domain decomposition algorithm to fourth-order problems. The main idea is to enforce

exactly the continuity of the transverse displacement field at the substructure corners throughout the preconditioned conjugate projected gradient iterations. This results in a two-level FETI substructuring method where the condition number of the preconditioned interface problem does not grow with the number of substructures, and grows at most polylogarithmically with the number of elements per substructure. We have demonstrated these theoretically proven optimal convergence properties of the new FETI method for several finite element plate bending static and transient problems. Then, we have extended this approach to shell problems, revisited the preconditioning problem, addressed the efficient implementation of the corresponding iterative solvers on massively parallel processors, highlighted the computational price of mathematical optimality and discussed its consequences, and reported some impressive performance results on two Paragon XP/S and IBM SP2 massively parallel processors for several realistic plate and shell based aerospace structures.

Parallel coupling and assembly of three-dimensional heterogeneous substructures with non-matching interfaces

The need for assembling independent finite element substructure solutions arises in several aerospace engineering problems including the design and analysis of complex structural systems, component mode synthesis, global/local analysis, adaptive refinement, and parallel processing. We have addressed the solution of such problems by a two-field hybrid method where the substructures are joined with low-order polynomial or piece-wise polynomial Lagrange multipliers, and present a Rayleigh-Ritz based smoothing procedure for improving the accuracy of the computed coupled solution in the presence of various substructure heterogeneities. We have considered both conforming and non-conforming substructure meshes, and demonstrated the benefits of the proposed two-step solution method with several examples from aerospace structural engineering.

Publications that have resulted from the first year of support

Refereed journals

1. C. Farhat, P. S. Chen, J. Mandel and F. X. Roux, "The Two-Level FETI Method - Part II: Extension to Shell Problems, Parallel Implementation and Performance Results," *Computer Methods in Applied Mechanics and Engineering*, Vol. 155, pp. 153-180 (1998)

2. C. Farhat and J. Mandel, "The Two-Level FETI Method for Static and Dynamic Plate Problems - Part I: an Optimal Iterative Solver for Biharmonic Systems," *Computer Methods in Applied Mechanics and Engineering*, Vol. 155, pp. 129-152 (1998)

3. D. Rixen, C. Farhat and M. Géradin, "A Two-Step, Two-Field Hybrid Method for the Static and Dynamic Analysis of Substructure Problems with Conforming and Non-Conforming Interfaces," *Computer Methods in Applied Mechanics and Engineering*, Vol. 154, pp. 229-264 (1998)

4. C. Farhat, P. S. Chen, F. Risler and F. X. Roux, "A Unified Framework for Accelerating the Convergence of Iterative Substructuring Methods with Lagrange Multipliers," *International Journal for Numerical Methods in Engineering*, Vol. 42, pp. 257-288 (1998)

Refereed proceedings

1. C. Farhat and J. Mandel, "Scalable Substructuring by Lagrange Multipliers in Theory and in Practice," in: *Domain Decomposition Methods for Partial Differential Equations*, ed. by P. Bjorstad, M. Espedal and D. Keyes, Domain Decomposition Press, Bergen, pp. 20-30 (1998)

2. D. Rixen and C. Farhat, "Preconditioning the FETI and Balancing Domain Decomposition Methods for Problems with Intra- and Inter-subdomain Coefficient Jumps," in: *Domain Decomposition Methods for Partial Differential Equations*, ed. by P. Bjorstad, M. Espedal and D. Keyes, Domain Decomposition Press, Bergen, pp. 472-479 (1998)

3. F. X. Roux and C. Farhat, "Parallel Implementation of the Two-Level FETI Method," in: *Domain Decomposition Methods for Partial Differential Equations*, ed. by P. Bjorstad, M. Espedal and D. Keyes, Domain Decomposition Press, Bergen, pp. 480-487 (1998)