VARIABLE-COMPLEXITY MULTIDISCIPLINARY OPTIMIZATION ON PARALLEL COMPUTERS

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Overview

This report covers work conducted under grant NAG-1-1562 for the NASA High Performance Computing and Communications Program (HPCCP) from December 7, 1993, to December 31, 1997. The objective of the research was to develop new multidisciplinary design optimization (MDO) techniques which exploit parallel computing to reduce the computational burden of aircraft MDO. The design of the High-Speed Civil Transport (HSCT) aircraft was selected as a test case to demonstrate the utility of our MDO methods. The three major tasks of this research grant included:

- development of parallel multipoint approximation methods for the aerodynamic design of the HSCT,
- use of parallel multipoint approximation methods for structural optimization of the HSCT,
- mathematical and algorithmic development including support in the integration of parallel computation for items (1) and (2).

These tasks have been accomplished with the development of a response surface methodology that incorporates multi-fidelity models. For the aerodynamic design we were able to optimize with up to 20 design variables using hundreds of expensive Euler analyses together with thousands of inexpensive linear theory simulations. We have thereby demonstrated the application of CFD to a large aerodynamic design problem. For the predicting structural weight we were able to combine hundreds of structural optimizations of refined finite element models with thousands of optimizations based on coarse models. Computations have been carried out on the Intel Paragon with up to 128 nodes. The parallel computation allowed us to perform combined aerodynamic-structural optimization using state of the art models of a complex aircraft configurations.

Highlights of Research 1994–1997

December 1993 – October 1994

- Selected response surface modeling as the method to implement multipoint approximation in HSCT optimizations.
- Selected the D-optimal experimental design method as the technique for selecting sample sites in the design space. Response surface models are created from the data acquired at the sample sites.
- Examined numerical noise sources in the HSCT analysis/optimization software.
- Evaluated GENESIS and MAESTRO software for use in structural optimization of HSCT aircraft and for suitability in a coarse-grained parallel computing environment.
- Performed the initial coarse-grained parallelization of HSCT aerodynamic analysis software using a 28-node Intel Paragon computer.

October 1994 – October 1995

- Developed a variable-complexity response surface modeling method based on the use of inexpensive analyses and geometrical constraints to define a reduced design space.
- Developed a four variable sample problem to evaluate the use of the variable-complexity response surface modeling method in HSCT optimization. Response surface models were created for three components of supersonic drag.
- Performed initial work on a 25 variable HSCT optimization problem that used a response surface model for wing bending material weight.
- Used algebraic models to identify intervening design variables for the estimation of bending material weight. This reduced the number of variables and increased the accuracy of the structural weight response surface model.
- Employed coarse-grained parallel computing on the Intel Paragon to routinely perform on the order of 10^3 structural optimizations and on the order of 10^4 aerodynamic analyses.
- Developed scientific visualization tools using Mathematica to project multi-dimensional data into three-dimensional plots.
- Evaluated the Euler/Navier-Stokes solver GASP for use in supplying high fidelity aerodynamic analysis data for HSCT optimization problems.

October 1995 – January 1997

- Developed five and 10 variable HSCT optimization problems to further evaluate the use of variable-complexity modeling and response surface modeling. The ten variable problem used four response surface models; three for supersonic drag components and one for the subsonic lift curve slope.
- Revised the 25 variable HSCT optimization problem to remove sources of numerical noise. A response surface model was created for wing bending material weight and the HSCT optimization problem was performed.
- Continued using coarse-grained parallel computing to perform HSCT structural optimizations needed in the 25 variable problem. Significant savings realized in computational time, e.g., 40 CPU hours in parallel execution versus 583 CPU hours (3.5 CPU weeks) in serial execution.

- Compared minimum variance and minimum bias design of experiment strategies for large numbers of design variables.
- Created theoretical models of peak parallel efficiency possible in the coarse-grained parallel execution of the aerodynamic analyses. Theoretical peak efficiencies and actual efficiencies were nearly identical over a range of three to 37 processors.
- Integrated Euler drag estimates at supersonic cruise into the five variable HSCT optimization problem.
- Explored the use of interpolating models from DACE (design and analysis of computer experiments) statistical literature for use in HSCT optimization instead of response surface models.

January 1997 – December 1997

- Created response surfaces for drag estimates based on Euler equations for 5,10,15 and 20 design variables.
- Showed the benefits of using information from low fidelity analyses to more efficiently generate response surface based on Euler drag estimates.
- Developed design space visualization plotting procedure based on contour plot on hyperplane in design space formed from 2 local optima and 1 additional feasible point.
- Evaluated linear correction response surface models for the HSCT wing bending weight based on fine and coarse finite-element structural models.
- Progress in performing HSCT optimization using response surfaces for both aerodynamic drag and structural weight for the 29 design variable HSCT problem

List of Publications 1994-1998

1994

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- Giunta, A. A., Dudley, J. M., Narducci, R., Grossman, B., Haftka, R. T., Mason, W. H., and Watson, L. T., "Noisy Aerodynamic Response and Smooth Approximations in HSCT Design," Proceedings of the 5th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Panama City Beach, FL, 1994, pp. 1117-1128. (AIAA Paper 94-4376)

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Graduated Students

- XiMing Huang, Ph.D., 1994, contractor for GM, Detroit, MI.
- Susan Burgee, M.S., 1995, University of Maryland, Baltimore County.
- Robert Narducci, Ph.D., 1995, Boeing Company, Long Beach, CA.
- Matt Kaufman, M.S., 1996, Lockheed-Martin, Sunnyvale, CA.
- Paul Crissafulli, M.S., 1996, Lockheed-Martin, Palmdale, CA.
- Pete MacMillan, M.S., 1996, Lockheed-Martin, Palmdale, CA.
- Oleg Golividov, M.S., 1997, Engenious, Inc., Cary, NC.
- Tony Giunta, Ph.D., 1997, NRC Fellow at NASA Langley, Hampton, VA.
- Vladimir Balabanov, Ph.D., 1997, Vanderplaats Research and Development, Inc., Colorado Springs, CO.
- Duane Knill, Ph.D., 1997, University of Washington and Boeing Commercial Aircraft, Seattle, WA

Continuing Students

- Denitza Kraznova: M.S. candidate Computer Science
- Chuck Baker: Ph.D. candidate Aerospace Engnieering