

**Final Report for AFOSR Grant
Theory and Algorithms for Global/Local Design Optimization
2-11-2001 to 31-12-2004**

**Raphael T. Haftka
Principal Investigator
Department of Mechanical and Aerospace Engineering
University of Florida**

Abstract: This is the final report on AFOSR grant F49620-02-1-0070. The research was motivated by aircraft structural design problems where the overall (global) design of the structure need to be coordinated with the design of components (local). The research focused on improved methods for decomposition, for coordinating the component and overall design as well as on exploration of global optimization algorithms. In the former category, heuristic decomposition was followed with proof that it solves the original problem. In the latter category, stochastic algorithms (genetic algorithms and particle swarm optimization) were explored as well as the DIRECT deterministic global algorithm. Part of the research was done in collaboration with researchers at Virginia Tech who were funded under AFOSR grant F49620-02-1-0090.

Introduction: Aircraft and spacecraft structural design operates at several scale levels. There is the overall design of the entire vehicle, the design of major components such as wings, the design of smaller components, such as stiffened panels, and detail design, such as reinforcements near small holes. It is not possible to carry on the structural design optimization at all levels simultaneously, because the number of design variables and the complexity of the analysis would make the problem computationally intractable. Therefore, aerospace structural designers tend to iterate between the levels. They design at one scale, obtain forces on components on a scale below and use them to design at the lower scale. This process does not need to converge, and if it does converge, it does not need to converge to the optimum design. The research described below was motivated by input from designers from Boeing and McDonnell Douglas who alerted us to the difficulties they were experiencing.

The research focused on improved methods for decomposition, for coordinating the component and overall design as well as on exploration of global optimization algorithms. In the former category, heuristic decomposition was followed with proof that it solves the original problem. In the latter category, stochastic algorithms (genetic algorithms and particle swarm optimization) were explored as well as the DIRECT deterministic global algorithm. Part of the research was done in collaboration with researchers at Virginia Tech who were funded under AFOSR grant F49620-02-1-0090.

Description of research results

Decomposition: Heuristic decomposition algorithms were developed for coordinating the structural design of aircraft wings (Refs. 6-8, 10, 22). These were verified against results

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

20050901 017

REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-05-

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestion, Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork

0334

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE	FINAL REPORT
4. TITLE AND SUBTITLE Theory and Algorithms for Global/Local Design Optimization			5. FUNDING NUMBERS F49620-02-1-0070
6. AUTHOR(S) Raphael T. Haftka			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Department of Mechanical and Aerospace Engineering University of Florida Gainesville, FL 32611-6250			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Office of Scientific Research 875 North Randolph Street Suite 325, Room 3112 Arlington, VA 22203 <i>JM</i>			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION AVAILABILITY STATEMENT <i>Approved for public release, distribution unlimited</i>			12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) This is the final report on AFOSR grant F49620-02-1-0070. The research was motivated by aircraft structural design problems where the overall (global) design of the structure need to be coordinated with the design of components (local). The research focused on improved methods for decomposition, for coordinating the component and overall design as well as on exploration of global optimization algorithms. In the former category, heuristic decomposition was followed with proof that it solves the original problem. In the latter category, stochastic algorithms (genetic algorithms and particle swarm optimization) were explored as well as the DIRECT deterministic global algorithm. Part of the research was done in collaboration with researchers at Virginia Tech who were funded under AFOSR grant F49620-02-1-0090.			
14. SUBJECT TERMS			15. NUMBER OF PAGES
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

at a single level (Ref. 6), and then they were generalized to a decomposition approach where at upper level budgets are assigned for the component designer, and at the lower level the component designer maximizes constraint satisfaction. References 4 and 5 developed the mathematical framework for the approach, showing that it is equivalent to the single level formulation. Furthermore, it was demonstrated by simple examples in Refs. 4 and 5 and by engineering examples in Refs. 23, 24 and 27, that the decomposition approach allows for more efficient global optimization than a single-level approach. Decomposition approaches were also examined for optimization used for system identification in bio-motion, specifically the identification of human joint parameters from records of motion (Ref.s. 11, 25, and 27).

Global optimization algorithms: Our initial focus was on genetic algorithms. A permutation genetic algorithm, needed for two-level wing design was developed (Ref. 21). Later the focus shifted to two other stochastic global optimization algorithms. The first type was statistical optimization using estimated probability distribution of good design points (Refs. 2, 3, 14-20). This included the development of an improved statistical algorithm that combined statistical information from two different models of the design problem (Refs. 3, 17, 20). The second global optimization algorithm was particle swarm optimization in the context of application to bio-motion system identification (Refs. 11-13, 25-28). Here we also explored the opportunities to parallelize the algorithm (Ref. 12). Finally, the deterministic DIRECT algorithm was also examined as an alternative for global optimization (Ref. 1).

Students: The grant supported three PhD students. Boyang Liu, who finished his PhD in 2001 and stayed on as a research associate for several months after that. He is working for The ABAQUS software company in Providence, RI. employed. Laurent Grosset, finished his PhD in 2004 with a joint PhD degree from UF and the University of St. Etienne in France and is now working for Renault, Paris France. Jaco Schutte is scheduled to finish his PhD at the end of 2005.

References:

A. Journal papers

1. Cox, S.E., Haftka, R.T., Baker, C.A., Grossman, B., Mason, W.H., and Watson, L.T., "A Comparison of Global Optimization Methods for the Design of a High-speed Civil Transport," *J. of Global Optimization*, **21**, pp. 415-433, 2001.
2. Grosset, L., Le Riche, R. and Haftka, R.T., "A study of the effects of dimensionality on stochastic hill climbers and estimation of distribution algorithms," *Lecture Notes in Computer Science*, Vol. 2936, selected and revised papers from the 6th International Conference on Artificial Evolution (EA03), Springer Verlag, May 2004, pp. 27-38.
3. Grosset, L., Le Riche, R. and Haftka, R.T., "A Double-Distribution Statistical Algorithm for Composite Laminate Optimization," Accepted for publication in *Structural and Multidisciplinary Optimization*.

4. Haftka, R.T., and Watson, L.T., "Multidisciplinary Design Optimization with Quasiseparable Subsystems," *Optimization and Engineering*, 6, 9-20, March 2005.
5. Haftka, R.T., and Watson, L.T., "Multidisciplinary Design Optimization with Mixed Integer Quasiseparable Subsystems," Submitted to *Optimization and Engineering*.
6. Liu, B., and R.T. Haftka, "Minimization of Composite Wing Weight Using Flexural Lamination Parameters," *Structural and Multidisciplinary Optimization*, Vol. 26, pp. 111-120, Springer Verlag, 2004.
7. Liu, B., Haftka, R.T., and Akgün M.A., "Two-Level Composite Wing Structural Optimization Using Response Surfaces," *Structural Optimization*, 20(2), pp. 87-96, 2000.
8. Liu, B., R.T. Haftka, and P. Trompette, "Maximization of Buckling Loads of Composite Panels Using Flexural Lamination Parameters," *Structural and Multidisciplinary Optimization*, Vol. 26, pp. 28-36, Springer Verlag, 2004.
9. Liu, B., Haftka, R.T., and Watson L.T., "Global-Local Structural Optimization Using Response Surfaces of Local Optimization Margins," *Structural and Multidisciplinary Optimization*, 27(5), 352-359, 2004.
10. Ragon, S. A., Gürdal, Z., Haftka, R. T., Tzong, T. J. "Bilevel Design of a Wing Structure using Response Surfaces," *Journal of Aircraft*, Vol. 40, No.5, September/October 2003, pp. 985-992.
11. Reinbolt, J. A., Schutte, J. F., Fregly, B. J., Koh, B. I., Haftka, R. T., George, A. D., and Mitchell, K. H. (2005) Determination of patient-specific multi-joint kinematic models through two-level optimization. *Journal of Biomechanics* 38, 621-626.
12. Schutte, J.F., Reinbolt, J.A., Fregly, B.J., Haftka, R.T., and George, A.D., "Parallel global optimization with the particle swarm algorithm," *Int J Numerical Methods in Engineering*, 61(13), 2296-2315, December 2004.
13. Schutte, J. F., Koh, B.-I., Reinbolt, J. A., Fregly, B. J., Haftka, R. T., and George, A. D., "Evaluation of a particle swarm algorithm for biomechanical optimization," *Journal of Biomechanical Engineering* (in press).

B. Conference papers:

14. Grosset L., Le Riche, R., and Haftka, R.T., "Statistical Optimization of Composite Laminates: Introduction of Coupling via a Change of Variables," AIAA Paper 2002-5462, Proceedings 9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Atlanta, Ga, Sept. 4-6, 2002.
15. Grosset, L., Le Riche, R., and Haftka, R.T., "A comparison of an estimation of distribution algorithm and a stochastic hill-climber for composite optimization problems." Proceedings of the American Society for Composites 18th Technical Conference, Gainesville, FL, October 19-13, 2003, paper No. 168.
16. Grosset, L., Le Riche, R., and Haftka, R.T., "A Study of the Effects of Dimensionality on Stochastic Hill Climbers and Estimation of Distribution Algorithms," Proceedings of the 6th International Conference on Artificial Evolution, October 27-30, 2003, Marseille, France.

17. Grosset, L., Le Riche, R., and Haftka, R.T., "A Double-Distribution Statistical Algorithm for Composite Laminate Optimization," 45th AIAA/ASME/-ASCE/AHS/ASC Structures, Structural Dynamics & Materials Conference, Palm Springs, CA, April 2004 - paper AIAA-2004-1910.
18. Grosset, L., Venkataraman, S., and Haftka, R.T., "Genetic optimization of two-material composite laminates," Proceedings, 16th ASC Technical Meeting, Blacksburg, VA, September 2001.
19. Grosset, L., Venkataraman, S., and Haftka, R.T., "Probability-based genetic algorithm for composite laminate optimization" AIAA Paper 2002-1673, Proceedings 43rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Material Conference, Denver, CO, April, 2002.
20. Grosset, L., Le Riche, R., and Haftka, R.T. "A Two-Tier Estimation of Distribution Algorithm for Composite Laminate Optimization" Proc. 10th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, 30 August - 1 September 2004, Albany, NY, paper AIAA-2004-4529.
21. Liu, B., and Haftka, R.T., "Maximization of Continuity of Complex Composite Structures by Permutation Genetic Algorithms," Proceedings 4rd World Congress of Structural and Multidisciplinary Optimization, Dalian China, June 4-8, 2001.
22. Liu, B. and Haftka, R.T., "Composite Wing Structural Design Optimization with Continuity Constraints," AIAA Paper 2001-1205, Proceedings 42nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Material Conference, Seattle, WA, April, 2001.
23. Liu, B., Haftka, R.T., and Watson, L.T., "Global-Local Structural Optimization Using Response Surfaces of Local Optimization Margins," 3rd ISSMO/AIAA Internet Conference on Approximations in Optimization, www-tm.wbmt.tudelft.nl/~wbtmavk/3rd_approx_web_conf, Oct. 14-25, 2002.
24. Liu, B., Haftka, R.T., and Watson, L.T., "Global Local Structural Optimization Using Response Surfaces of Local Optimization Margins," 5th World Congress of Structural and Multidisciplinary Optimization, Lido di Jesolo, Italy, May 19-23, 2003.
25. A, Reinbolt, J.F. Schutte, R.T. Haftka, A.D. George, K.H. Mitchell, B.J. Fregly. Determination of Patient-Specific Functional Axes Through Two-Level Optimization. 2003 Summer Bioengineering Conference, June 25-29, 2003, Key Biscayne, Florida.
26. Schutte, J., Fregly, B.J., and Haftka, R.T., "A Parallel Particle Swarm Optimizer," 5th World Congress of Structural and Multidisciplinary Optimization, Lido di Jesolo, Italy, May 19-23, 2003.
27. Schutte, J.F., Haftka, R.T., and Watson, L.T., Decomposition and Two-level Optimization of Structures with Discrete Sizing Variables, 45th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Palm Springs, CA, April 2004 - paper AIAA-2004-1541.
28. J.F. Schutte, B.I. Koh, J.A. Reinbolt, R.T. Haftka, A.D. George, B.J. Fregly. Scale-Independent Biomechanical Optimization. 2003 Summer Bioengineering Conference, June 25-29, 2003, Key Biscayne, Florida