

NEW APPROACHES TO MULTIDISCIPLINARY DESIGN AND OPTIMIZATION

Year 2 Progress Report NGT 51102L

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Year Two Objectives and Results

Research under the subject grant is being carried out in a jointly coordinated effort within three laboratories in the School of Aerospace Engineering and the George Woodruff School of Mechanical Engineering (see titles above). The objectives and results for Year 2 of the research program are summarized the table below. The "Objectives" and "Expected Significance" are taken directly from the Year 2 Proposal presented in October 1994, and "Results" summarize the what has been accomplished this year. A discussion of these results is provided in the following sections. A listing of papers, presentations and reports that acknowledge grant support, either in part or in whole, and that were prepared during this period is provided in an attachment.

Objectives	Expected Significance	Results
1. Develop and Document a Framework and Design Specification for the IDES using the HSCT wing optimization problem	1. Provides the structure and disciplines necessary to complete development of IDES addressing a relevant MDO problem	1. Disciplinary tools for the HSCT wing optimization problem are available, integrated in a multilevel analysis and optimization schedule.
2. Merge the MDO structure from Year One into the IDES Meta-design based on the Decision Support Problem Technique (DSPT).	2. Provides the initial IDES prototype for evaluation and identification of changes for incorporation into the final IDES design	2. The Intelligent Multidisciplinary Design Environment (IMAGE) is nearing completion. Agents for HSCT modeling are incorporated.
3. Define the High Performance Computing Requirements for the IDES Prototype and identify the requirements for the final IDES design..	3. Provides the requirements and documentation for the IDES heterogeneous computer environment and identifies required changes.	3. A dynamic, object-oriented data model was developed and implemented. Parallelization efforts progressed. Performance predictions for parallel solvers were developed.

Development of New Approaches:

Decision Support in MDO

A *robust concept exploration method* has been developed (Chen, 1995a). Robust concept exploration is facilitated by bringing rigorous analysis tools generally used in the later design stages into the early design stages for simulation and/or approximation. The integration and implementation of statistical methods and robust design techniques allows for efficient and effective exploration of different design concepts. Given overall design requirements, then, the Robust Concept Exploration Method is used to identify top-level (system level) design specifications with quality considerations. These specifications are then used for the preliminary design of major subsystems (subsystem embodiment). This approach to determining top-level specifications for airframe geometry and the propulsion system is demonstrated for the HSCT airframe configuration and propulsion system (Chen 1995a) and a general aviation aircraft (Simpson 1995a). Related publications include Chen 1995b,c.

We are laying the foundation for designing *open systems* using MDO (Simpson, 1995a). There are two aspects to designing an open engineering system. First, there is the product which is an open engineering system. Second, there is

the process which is being used to design the product. Under the umbrella of the proposed Georgia Tech IPPD methodology a decision-based design methodology which embodies phases, events, tasks, and decisions is being developed to enhance openness in the design of engineering systems (Hale et al., 1995).

Problems in complex systems design are difficult to analyze and solve, and require methods to handle such issues as multilevel decomposition, mixed discrete/continuous models, and multiobjective and highly constrained design spaces. Specifically, we are working on developing a common lexicon for MDO, based on mapping the work of Balling/Sobieski and our decision-based approach to complex systems design (Lewis and Mistree, 1995a), identifying a ranged sets of top-level specifications (Lewis et al., 1995b), the solution and coordination of mixed discrete/continuous complex systems models (Lewis, 1996), and investigating both hierarchical and nonhierarchical decomposition schemes specifically along a design time-line (Lucas 1995a,b, Vadde 1995, 1994). Other publications include one dealing with multiattribute selection Mistree et al. 1994 and another dealing with design for manufacturing Simpson et al. 1995b.

MDO Methodology

Implementation of the multilevel wing optimization strategy developed in the first year effort resulted in a tool for multidisciplinary wing design, documented in Dr. Röhl's Ph.D. Thesis, which was used for optimal wing jig shape and aeroelastic tailoring studies in consideration of buckling constraints. The environment in which this tool was created is modular and flexible, thus open to the addition of further disciplinary modules. With this in mind, a framework for integrating methods and tools developed in this work with other disciplines (including contributions from Rockwell International) was established. This framework conceptually links analysis modules of Dr. Röhl's multilevel method with tools for aerodynamic and loads analysis. Rockwell's maneuver load program, ISMD, provides for the computation of structural loads. This framework provides the starting point for Year 3's goal of an integrated aero-structures-controls application in IDES.

A Process-Based Cost (PBC) model for the production cost of an HSCT wing (fabrication and assembly) has been developed and integrated into the top-down Aircraft Life-Cycle Cost (LCC) Analysis code, ALCCA. The resulting multi-level LCC model permits the generation of LCC profiles that are sensitive to alternative concepts, materials, and manufacturing processes of the HSCT.

Infrastructure for MDO:

Specific MDO methodologies developed in the present grant are coordinated in an MDO *infrastructure and integration* project that is also supported by NASA GSRP funding. This work was identified in the original proposal (and all subsequent to it) as the Integrated Design Engineering Simulator (IDES), but it is currently identified by the project name, DREAMS, which stands for "Designing Robust Engineering Analysis Models and Specifications." The bulk of the computational architecture development is being pursued under GSRP funding with project name, IMAGE (Intelligent Multidisciplinary Aircraft Generation Environment). However, the guidance for much of this architectural development is based on the requirements established by DREAMS to accommodate the new MDO approaches being developed under the grant. Additional specifications are being derived from related projects such as FIDO and ASOP. Recent publications (Hale 1994a-b, 1995a-d) listed at the end of this report highlight year 2 accomplishments in defining the information structures and the decision support process to be incorporated in this environment.

The computational and information environment is being designed and constructed to provide a method for consistently applying a decision-based design methodology within an integrated computing environment across the design timeline for open engineering systems. It is based around an agent integration technology and results to date have demonstrated the feasibility in situations of practical complexity level. A distributed, object-oriented database definition with dynamic schema editing has also been demonstrated.

The infrastructure is being designed to support the DREAMS methodology by incorporating:

- a design partitioning process;
- a mechanism for solving the resulting design sub-problems; and
- a design information model;

and by supporting:

- information generation in context for informed decision-making;
- efficient and cost-effective application of design resources; and
- geographically distributed design activities.

Figure 1 below shows the basic approach in a schematic form, and it refers to the following specific functional capabilities incorporated in the system:

- *Design Activities* in which a designer partitions a problem into activities for solution; this also provides for comprehensive information management;

- *Available Assets* which include a variety of design resources (e.g., programs) that provide aid in the generation of design knowledge; resources may include performance simulation codes, object-oriented databases, CAD packages, etc.;
- *Agent Collaboration* as implemented with a generic toolkit that allows resources to be incorporated into the design infrastructure with minimal effort by the engineering developers; the incorporation of a “model” (which describes precisely what an agent is capable of doing or providing and how it is accomplished) within the toolkit allows for knowledge to be generated in context allowing a designer to interrogate knowledge for the who, what, where, when, and how the information was created.
- *Computing Architecture* which includes components that are required for objects to operate in a distributed, homogeneous computing environment are included in an underlying infrastructure.

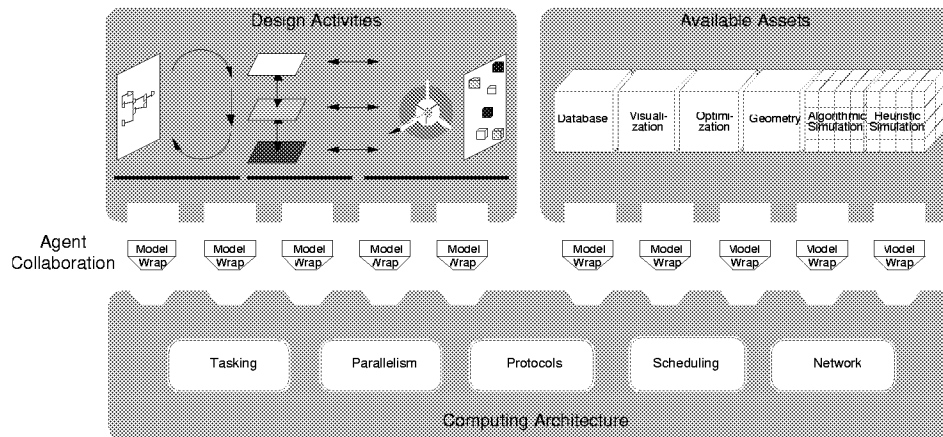


Figure 1. Infrastructure

To date approximately 60% of the basic capabilities have been developed and tested in prototype form. Year 3 plans will complete the core development and preliminary application to implementing the DREAMS methodology.

Computational Methods:

The analysis of large scale complex structures by finite element methods requires: (1) fast computational capability to satisfy the real time MDO requirement, and (2) reasonable simulation costs. To achieve the first goal, parallel matrix solution methods on a scalable massively parallel (thread-driven) machine were developed for matrix decomposition and forward/backward substitution. Two memory management schemes were considered for parallel matrix decomposition. Previous approaches used only shared memory schemes (scheme 1); a new scheme with the mixed use of local and shared memory was developed (scheme 2). Results to date show significant performance improvements in the case of a wing model using up to a 28 processor implementation. In addition, a parallel performance prediction model was designed and verified through several actual computations on a KSR computer (32 processor configuration). Estimations using this model for the wing case indicate that for scheme 1 a performance saturation will be encountered for a critical number of processors, while scheme 2 will exhibit continued performance improvement (90% performance gain over scheme 1).

In order to achieve the second goal, an optimal processor mapping algorithm for the efficient use of massively parallel processors in the concurrent heterogeneous substructure computation was developed. The algorithm uses a parallel matrix solver performance prediction model. The feasible domain is zoomed by dynamic programming, and an iterative search is performed in the zoomed zone for final solution. The results so far show good performance when applied to representative MDO tasks suitable for parallel processing.

In the area of data management, a relational database design was developed for the conceptual design phase of the HSCT in order to evaluate how data management can aid in improving the efficiency of the aircraft design process. The steps utilized in the database design synthesis included: (1) representation of the conceptual design process, (2) development of a data dictionary, and (3) determination of data relationships. IDEF0 modeling methodology was used to produce a function model of the conceptual design process. The IDEF0 model provided a structured representation of the functions of conceptual design process, and of the information and objects which interrelate those functions. The HSCT design process model developed included a database schema and a data dictionary. An IDEF1X model was used to provide a semantic data model which defined the meaning of data within the context of its interrelationships with other data. A relational database design was initially chosen due the level of maturity of relational database technology. The intent of this initial study was to identify the processes and data requirements at the conceptual design level and to uncover those areas where further research is warranted. The relational database design synthesis provided a fundamental understanding of the basic data problems and insights into possible solutions.

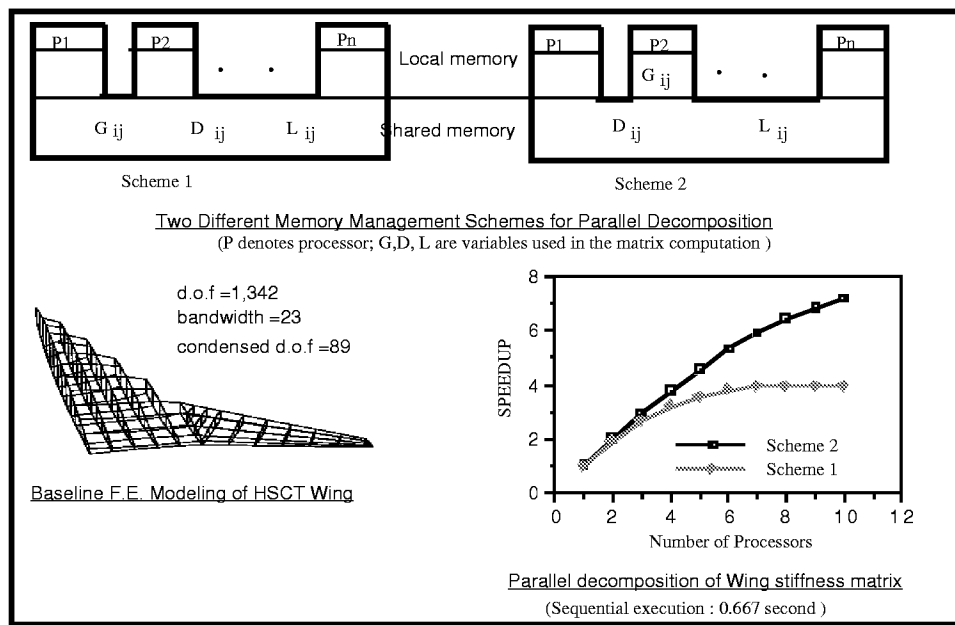


Figure 2. Problem Decomposition for Parallel Processing

Specific Applications:

A three-level hierarchical HSCT wing design problem has been completed and is described in a Ph.D. dissertation (Röhl 1995b). Specific analysis codes [FLOPS, ASTROS, PASCO] were integrated into a three-level framework for the structural design of the wing. The framework centers on a finite-element based structural optimization of the wing box under aerodynamic loads and subject to stress, flutter, and buckling constraints. The wing is represented by a varying complexity spar and rib model and utilizes multiple shape functions for distribution of design parameters. A wing box finite element model generator that uses system level geometric, mission and weight information to create a complete finite element design model of the wing structure and an aerodynamic panel model has been completed. An external buckling optimization procedure for buckling-critical skin panels enhances the capabilities of the structural optimization. The results of this process is depicted below in Figure 3.

Research Personnel

The key research areas identified in this Progress Report have been investigated during the past year by a number of graduate students in the ASDL, PPRL and SRL (laboratories) under the coordinated direction of the four co-principal investigators. The following table highlights the topics being investigated by the students and the footnotes indicate their current status and principal funding:

Topic	Researcher
RCEM - Robust Concept Exploration Method	Dr. Wei Chen*
IMAGE - Intelligent Multidisciplinary Aircraft Generation Environment	Mark Hale [†]
Information Management Strategies to Support Multidisciplinary Optimization Computations	Neil Hall
Application of Parallel Processing to Finite Element Systems	Jason Har Dr. Sang Y. Synn
The Solution of Mixed Discrete/Continuous Systems in Non-Hierarchical, Multidisciplinary Design	Kemper Lewis [†]
A Multilevel Decomposition Procedure for the Preliminary Wing Design of a High Speed Civil Transport Aircraft	Dr. Peter Röhl* Mr. Jae Moon Lee
Integrating Design and Manufacturing for the High Speed Civil Transport	William Marx [†]
Guiding Decision Based Design Processes Through Management of Design Information Content	Srinivas Vadde*

* Completed graduate studies and degree.

[†] NASA Graduate Student Research Program; research is closely coordinated with present program.

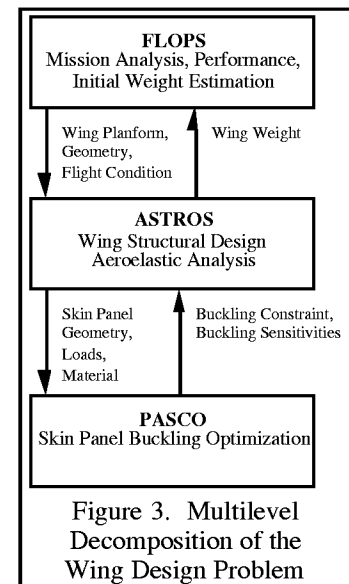


Figure 3. Multilevel Decomposition of the Wing Design Problem

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Year 2 Presentations, Publications and Workshops

Grant NGT 51102L

October 16, 1995

The following workshops and publications (referencing support from the Grant 51102L) were accomplished under the second year's research effort:

- Chen, W., Allen, J.K., Mavris, D.N., Mistree, F., Tsui, K-L, 1995b, "Integration of Response Surface Method with the Compromise Decision Support Problem in Developing a General Robust Design Procedure," *Advances in Design Automation* (Azarm, S., et al. Eds.), New York: ASME, 1995, pp. 485-492. ASME DE-Vol. 82-2.
- Chen, W., Allen, J.K., Mavris, D.N., Mistree, F., 1995c, "Robust Concept Exploration for Developing the Top-Level Specifications of Complex Systems," *Engineering Optimization*, (in press).
- Chen, W., 1995a, A Robust Concept Exploration Method for Configuring Complex Systems, Ph.D. Dissertation, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA.
- Hale, M. A., 1994a, "Preliminary Agent Technologies with CATIA," presented at the CATIA Operators Exchange Meeting, Dallas, October 9-13.
- Hale, M. A., 1994b, "IMAGE: A Design Integration Framework Applied to the High Speed Civil Transport," HM301: First University/Industry Symposium on High Speed Civil Transport Vehicles, North Carolina A&T State University, December 4-6.
- Hale, M.A., 1995a, "A Computing Infrastructure that Facilitates Integrated Product and Process Development from a Decision-Based Perspective," Ph.D. Thesis Proposal, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA, January.
- Hale, M. A. and Craig, J. I., 1995b, "Use of Agents to Implement and Integrated Computing Environment," *Computing in Aerospace 10*, AIAA, San Antonio, TX, March 28-30, Preprint: AIAA-95-1001.
- Hale, M. A., Craig, J. I., Mistree, F., Schrage, D. P. , 1995c, "Implementing an IPPD Environment from a Decision-Based Design Perspective," ICASE/LaRC Workshop on Multidisciplinary Design Optimization, Hampton, VA, March 13-16.
- Hale, M. A., Craig, J. I., Mistree, F. and Schrage, D.P., 1995d, "On the Development of a Computing Infrastructure that Facilitates IPPD from a Decision-Based Design Perspective," 1st AIAA Aircraft Engineering, Technology, and Operations Congress, Anaheim, CA. Preprint AIAA-95-3880.
- Hall, N., and Fulton, R.E., "A Relational Database Application to Multidisciplinary Conceptual Design for HSCT," (Submitted for the publication).
- Lewis, K., Lucas, T. and Mistree, F., 1994, "A Decision-Based Approach for Developing A Ranged Top-Level Aircraft Specification: A Conceptual Exposition," AIAA/NASA/USAF/ ISSMO Symposium on Multidisciplinary Analysis and Optimization, Panama City, Florida, 465-481. Paper No. AIAA-94-4304-CP.
- Lewis, K. and Mistree, F., 1995a, "On Developing a Taxonomy for Multidisciplinary Design Optimization: A Decision-Based Perspective," First World Congress of Structural and Multidisciplinary Optimization, Goslar, Germany. Paper number 118.
- Lewis, K. and Mistree, F., 1995b, "Designing Top-Level Specifications: A Decision-Based Approach to a Multiobjective, Highly Constrained Problem," 36th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, New Orleans, LA. pp. 2393-2405.
- Lucas, T., 1995a, Formulation and Solution of Hierarchical Decision Support Problems, M.S. Thesis, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA.
- Lucas, T., Vadde, S., Chen, W., Allen, J.K. and Mistree, F., "Utilization of Fuzzy Compromise DSPs for Hierarchical Design Problems", 1994, AIAA/ASME/ASCE/AHS/ACS 35th Structures, Structural Dynamics and Materials Conference, Hilton Head, South Carolina, pp. 1753-1763. Paper No. AIAA-94-1543-CP.
- Mistree, F., Lewis, K. and Stonis, L., 1994, "Selection in the Conceptual design of Aircraft," AIAA/NASA/USAF/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Panama City, Florida, 1153-1166. Paper No. AIAA-94-4382-CP.
- Röhl, P.J., Mavris, D.N., and Schrage, D.P., 1994, "A Multilevel Decomposition Procedure for the Preliminary Wing Design of High-Speed Civil Transport Aircraft," First Industry/Academy Symposium on Research for Future Supersonic and Hypersonic Vehicles, Greensboro, NC, December.
- Röhl, P.J., Schrage, D.P. and Mavris, D.N., 1995a, "Combined Aerodynamic and Structural Optimization of a High-Speed Civil Transport Wing," 36th AIAA Structures, Dynamics, and Materials Conference, New Orleans, LA, April, Preprint AIAA 95-1222.

- Röhl, P.J., 1995b "A Multilevel Decomposition Procedure for the Preliminary Wing Design of a High Speed Civil Transport Aircraft," Ph.D. Thesis, School of Aerospace Engineering, Georgia Institute of Technology, June 1995.
- Röhl, P.J., Mavris, D.N., and Schrage, D.P., 1995b, "Preliminary HSCT Wing Design Through Multilevel Decomposition," 1st AIAA Aircraft Engineering, Technology, and Operations Congress, Los Angeles, CA, September 19-21, AIAA 95-3944.
- Simpson, T.W., 1995a, Development of a Design Process for Realizing Open engineering Systems, M.S. Thesis, School of Mechanical Engineering, Georgia Institute of Technology, August 1995.
- Simpson, T.W., Bauer, M.D., Allen, J.K. and Mistree, F., 1995b, "Implementation of DFA in Conceptual and Embodiment Design using Decision Support Problems," *ASME Advances in Design Automation* (Azarm, S., et al. Eds.), New York: ASME, pp. 485-492. ASME DE-Vol. 82-2.
- Synn, S.Y. and Fulton, R.E., 1994a, "The Concurrent Element Level Processing for Nonlinear Dynamic Analysis on a Massively Parallel Computer", Third National Symposium on Large-Scale Structural Analysis for High-Performance Computers and Workstations, Norfolk, VA, November 8-11, (also in *Journal of Computer Systems in Engineering*).
- Synn, S.Y. and Fulton, R.E., 1994b, "The Prediction of Parallel Skyline Solver and its Implementation for Large Scale Structural Analysis," Third National Symposium on Large-Scale Structural Analysis for High-Performance Computers and Workstations, Norfolk, VA, November 8-11, (Also, in *Journal of Computer Systems in Engineering*).
- Synn, S.Y., 1995a, "Practical Domain Decomposition Approaches for Parallel Finite Element Analysis," Ph.D. Thesis, School of Mechanical Engineering, Georgia Institute of Technology, January 1995.
- Synn, S.Y. and Fulton, R.E., 1995b, "Practical Strategy for Soncurrent Substructure Analysis," *Journal of Computers & Structures*, Vol.54, No.5.
- Synn, S.Y., Schwan, K., and Fulton, R.E., 1995c, "Analysis of Large Scale Heterogeneous Structures on Massively Parallel Computers," *Journal of Concurrency: Practice and Exercise* (Submitted for the publication in the *Journal of Concurrency, Practice/Experience*).
- Vadde, S., 1995, *Modeling Multiple Objectives and Multilevel Decisions in Concurrent Design of Engineering Systems*, M.S. Thesis, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA.
- Vadde, S., Allen, J.K., Lucas, T. and Mistree, F., 1994, "On Modeling Design Evolution along a Design Time-Line," AIAA/NASA/USAF/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Panama City, Florida, 1474-1482. Paper No. AIAA-94-4313-CP.

Workshops Supported by NASA Grant NGT 51102L:

HSCT External Advisory Board Meeting and Workshop, Georgia Institute of Technology, Atlanta, GA, May 1995.