Space Systems, Policy, and Architecture Research Consortium (SSPARC)
Draft 10/8/04

"SSPARC BOOK" MATERIAL for Lecture 8

Prepared by:

Hugh McManus
Metis Design

Draft for evaluation only. Do not distribute.

DEDICATION AND NOTE ON SOURCES

This document is an excerpt of a future book or hyper-book on the MATE-CON method. It is provided for class use as a draft. Suggestions for improvement are welcome, as are warnings of errors or omissions. The notes below apply to the entire work in progress; the work or excepts of it should not be reproduced in any form without these notes.

This document is dedicated to the memory of Joyce Warmkessel, a colleague, mentor, and friend to many in the SSPARC and LAI communities. Many of the core ideas behind this work were originally expressed and developed by her, and she was a key mentor and facilitator to the development of all of this work.

The content of this document was developed by the SSPARC consortium. The primary compilers and codifiers of the MATE-CON method were Lt. Nathan Dillar and Adam Ross, in Master's thesis entitled, respectively, "Utilizing Multiple Attribute Tradespace Exploration with Concurrent Design for Creating Aerospace Systems Requirement," [1] and "Multi-Attribute Tradespace Exploration with Concurrent Design as a Value-Centric Framework for Space System Architecture and Design."[2] Major contributors of the original concepts within the method, and/or complimentary methods and tools, include our SSPARC faculty and staff colleagues Elisabeth Paté-Cornell of Stanford University, Joel Sercel and Fred Cullick of Cal Tech, and Amar Gupta of MIT, post-doctoral researcher Bill Kaliardos, and graduate students Jimmy Benjamin, Jason Derleth, Bobak Ferdowsi, Dave Ferris, Russ Garber, Andre Girerd, Seth Guikema, Cyrus Jilla, Chris Roberts, Satwik Seshasai, Nirav Shah, Todd Shuman, Tim Spaulding, Dave Stagney, Dan Thunnissen, Myles Walton, Annalisa Wiegel, and Brandon Wood, along with their advisors and committees. Many other students, staff, and undergraduate researchers also contributed. Bill Borer, Kevin Ray, and John Ballenthin of the Air Force Research Laboratory, Steve Wall of NASA JPL, and Pete Hendrickson of the Department of Defense aided with the development of the method and the development of the case studies. SSPARC research work has been supported by an active group of industry practitioners, through both an Industrial Advisory Board (IAB) and on-site implementation activities.

The text of this manual is built on SSPARC research and member documents. Much of its contents are excerpts, modifications, or paraphrases of published or unpublished work done under SSPARC sponsorship. Every effort has been made to correctly attribute all contributions. Word-for-word excerpts are identified with quotes or indented, with citations. Many other excerpts have been edited to varying degrees and are integrated into the text for clarity. Their sources are cited in the text or in endnotes. Any omissions or errors of attribution should be brought to the authors' immediate attention for correction.

11.OPTIMIZATION

This brief section will answer the question "what is the relationship between MATE and more traditional Multidisciplinary Optimization (MDO)?" MATE takes a fundamentally different approach, *avoiding* selecting an optimal design early in the development process, when uncertainties are large and change is likely. Nevertheless, there are similarities and synergies between the two methods.

A direct analogy can be made between MATE and MDO as follows. If the utility function developed in Section **Error! Reference source not found.** is combined with cost to create an objective function, and the models developed in Section 8 are placed within an optimization driver, the "best" design can be quickly arrived at. In this case, the MATE method is used to rationally set up a classic MDO analysis. This approach, for reasons that should be clear from the discussion of tradespace exploration in Section 9, should not be done blindly. Much of the richness of the tradespace analysis will be lost, and a "classic" mistake of early selection of a sub-optimal architecture is quite possible.

Jilla[3] used several different kinds of MDO on a MATE-type tradespace. Four classes of multidisciplinary design optimization (MDO) techniques were investigated – Taguchi, heuristic, gradient, and univariate methods. The heuristic simulated annealing (SA) algorithm found the best architectures with the greatest consistency due to its ability to escape local optima within a nonconvex trade space. Accordingly, this SA algorithm forms the core single objective MDO algorithm in Jilla's methodology. The problem scope was then broadened by expanding from single objective to multiobjective optimization problems, and two variant multiobjective SA algorithms were developed. Knowing the global Pareto boundary of a trade space is clearly useful, and several methods were explored for approximating the true global Pareto boundary with only a limited knowledge of the full trade space. Finally, methods for improving the performance of the SA algorithm were tested, and it was found that the 2DOF variant of the SA algorithm is most effective at both single objective and multiobjective searches of a trade space.

The outcome of Jilla's work was to show that

1) MDO techniques, particularly simulated annealing, could be used to find an optimum point in a MATE tradespace
2) These tradespaces are typically nonconvex, with many, often deep, local minima
3) MDO techniques could be expanded to find not just an optimum point, but to approximate the Pareto front with much less computational effort than enumerating the entire tradespace

Jilla also created a framework, which he dubbed the multiobjective, multidisciplinary design optimization systems architecting methodology (MMDOSA) method. It laid out in considerable detail how to best use optimization methods to explore a tradespace. It is particularly suited to tradespaces with excessively large numbers of possible designs. MMDOSA was demonstrated through its application to the conceptual design of three separate distributed satellite systems – the civil NASA Origins Terrestrial Planet Finder mission, the military TechSat 21 GMTI space-based radar mission, and the commercial broadband satellite communications mission. In each case, the methodology identified more cost-effective system architectures than those previously considered for the single objective optimization problem, and a Pareto optimal set of architectures for the multiobjective optimization problem.

Jilla's work is summarized in a paper.[4] A further review of optimization methods, with emphasis on genetic algorithms, was collected by Hassan.[5]

REFERENCES

[1] Diller, N. P., "Utilizing Multiple Attribute Tradespace Exploration with Concurrent Design for Creating Aerospace Systems Requirements," Master of Science Thesis in Aeronautics and Astronautics, Massachusetts Institute of Technology, June 2002.

[2] Ross, A. M., "Multi-Attribute Tradespace Exploration with Concurrent Design as a Value-Centric Framework for Space System Architecture and Design," Master of Science Thesis in Aeronautics and Astronautics, Massachusetts Institute of Technology, June 2003.

[3] Jilla, C. D., "A Multiobjective, Multidisciplinary Design Optimization Methodology for the Conceptual Design of Distributed Satellite Systems," Doctoral Thesis in Aeronautics and Astronautics, Massachusetts Institute of Technology, May 2002. Some of the text in this section is modified from this document

[4] Jilla, C. D., and Miller, D. W., "A Multi-objective, Multidisciplinary Design Optimization Methodology for Distributed Satellite Systems", J*ournal of Spacecraft and Rockets*, Vol. 41, No. 1., Jan.-Feb. 2004, pp. 39-50.

[5] Hassan, Rania, "Efficient Searches of Tradespaces," unpublished.

