Modeling and Simulation for Mission Systems

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A. Introduction

For the last two years, NASA's Jet Propulsion Laboratory has been engaged in the process of re-engineering the way in which it does business. A significant portion of this effort is devoted toward improving engineering processes such as the building of advanced spacecraft and the design of scientific missions to investigate the solar system and beyond.

The primary objective of this re-engineering is to reduce costs by redoing the time which it takes to develop a mission. The goal is a reduction in development time by a factor of two, compared with the already austere schedule which was used for the Mars Pathfinder project.

The approaches to re-engineering are several and complex, but two principles which predominate are the use of concurrency and the employment of modeling and simulation techniques.

Concurrency deals both with putting people together -- collocation -- and executing tasks as much as possible in parallel rather than *seriatim*. The power of the **simple act of collocation was shown in the creation** of JPL's Advanced Projects Development Team, "Team X'. Putting people together in one room, equipped with supporting software, has enabled a fundamental change in the Laboratory's approach to proposals and advanced studies. Instead of a weekly cycle, where a meeting is held and reports are given and action items assigned (to be worked during the subsequent week), problems are worked during one day (and contiguous days).

During the past year, Team X was able to handle 74 proposals and saw an estimated cost reduction of at least 40%. Some of the increase in efficiency arises from intrateam learning: emulation of best practices.

Concentration of resources to address selected tasks is not restricted to Team X (and the facility within which it operates, the Project Design Center). JPL has created a Flight System Testbed to facilitate spacecraft design; it allows mixing of hardware-defined and software-defined subsystems. The Design Hub focuses on later phases of the life cycle of a project than does Team X. The Proposal Center provides a facility where a Principal Investigator and team can work various issues related to the development of their proposal (in addition to services that the proposal team may obtain from Team X).

Modeling and simulation, as mentioned, is a second emphasis in the new environment and is addressed below.

B. Modeling and Simulation

Modeling and simulation (M & S) is extremely widespread, and its use is growing because "Moore's law" (the historically-validated doubling of computer capabilities every 18 months) has presented analysts and designers with powers that could only be dimly foreseen, even just a few years ago. That power is to be able to "do it on silicon" before doing it in the wider world of aluminum, epoxy, and spacetime. See, for example, [1] and [2].

M & S in the context of the JPL re-engineering process takes the form of a set of computer models of engineering systems, models which are being built through the auspices of the "Develop New Products (DNP)" project, which has been charged with re-engineering within the engineering domain.

The reasons for using a model-driven design process, rather than a paper-based one, are several and include:

1) reduction of cycle time through connecting the model to design and manufacturing processes,

2) optimization of mission and system design,

3) early validation of the system design (which provides risk-management advantages)

4) establishment of a re-usable process (with cost, optimization, and reliability implications).

One of the most promising avenues, related to objective 1, above, is capturing requirements with a model. The traditional approach to dealing with the necessity of specifying requirements for any system (e.g., as described in [3]) involves writing sets of requirements, at various levels of detail and for the component subsysems, and than linking them vertically and horizontally to insure effectiveness and consistency. But even when assisted by computer-based templates, the task is daunting and onerous.

An alternative is to build a model of the system and use this as the guide to what is to be built rather than through linguistic specification of requirements. The approach has the advantages of being in the direct line of development of the system -- from concept to realization -- rather than a linguistic loop and of being, in several ways, more manageable. One must, however, insure that the user inspects the model with sufficient care to extract all of the requirements and that no artifacts have been incorporated.

Top-level characteristics of the models include:

1) Language: C, C++, VHDL, spreadsheet
2) Analytical basis: deterministic, probabilistic
3) Temporal: discrete event, real time, different from real time, static
4) Output: code, parameters, graphs, images.

A set of models produced by DNP is described in Table 1.

The principle of concurrency was illustrated, in one of its senses, through collocation of people and immediacy of work. Another sense of "concurrency" is the parallel development of products which traditionally have been handled in largely serial fashion. For example, one might build a functional model of a system and then pass rapidly to a spatiotemporal representation (CAD) and insertion of the entire system in a mission "plot", with simulation of scientific-data collection. As one encounters opportunities for optimization or for correction of problems, in these more realistic stages of simulation, a loop through the earlier stages is conducted to update functionality, etc.

The common-sense idea which underlies this engineering concept of concurrency is achieving an optimal balance between the efforts expended on doing design and looking ahead to some consequences of that design.

DNP Models

		Characteristics						
Model Objective	**Type**	**Language**	**Basis**	**Fidelity**	**Time**	**Executable**	**Output**	**Purpose**
Mission & System Requirements	Behavioral	Graph/C	Deterministic, probabilistic	linear, non-linear	>R.T.	yes	code, graph	system optimization & validation
Mission Design	Performance	mixed	mixed	mixed	<R.T.		graph	mission design & optimization
Subsystems						e s		
Performance	Performance	mixed	mixed	mixed	<'i T.	yes	graph	optimization
Functional	Behavioral	Graph/G	Deterministic	linear	R.T.,>R.T.	yes	code, graph	optimization, validation
Electrical Design	Behavioral	Graph/C	Deterministic	lin/non-lin	R.T.,>R.T.	yes	code, plot	design, validation
Mechanical Design	Behavioral	parametric	Deterministic	mixed	<R.T. (analyses)	NA	plot	design, validation
Unit/Assembly								
Functional	Behavioral	Graph/C	Deterministic	linear	R.T.,>R.T.	yes	code, graph	optimization, validation
Electrical Design	Behavioral	Graph/C	Deterministic	lin/non-lin	R.T.,>R.T.	yes	code, plot	design, validation
Mechanical Design	Physical	parametric	Deterministic	mixed	<R.T (analyses)	NA	plot	design, validation
Subassembly/Component								
Electrical Design	Behavioral	Graph/C	Deterministic	lin/non-lin	R.T.,>R.T.	yes	code, plot	design, validation
Mechanical Design	Behavioral	parametric	Deterministic	mixed	<R.T. (analyses)	NA	plot	design, validation
Environmental	Performance	mixed	mixed	mixed	variable	yes	graph	supports performance
Management	Performance	graphical/ spreadsheet	Deterministic	linear	<R.T.	no	graph	supports performance

Table 1. Some DNP Models

C. Acknowledgments

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D. References

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