Attention: Please Read This Page

This paper was prepared in 1998. While we believe that the material is important and will be interesting to current users of Foresight Systems software, we have been through some changes since the paper was written.

Nu Thena Systems, Inc. was a predecessor company to Foresight Systems M&S. All references to Nu Thena are obsolete. Readers should assume that Foresight Systems M&S replaces all instances of Nu Thena Systems, Inc.

The company referred to as Savantage Inc. is now operating as SavanSys Solutions LLC.

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The diagrams and illustrations included here were prepared with versions of the software current at the time that the paper was prepared. Some of them may not be identical to equivalent images from the current version of the software. We apologize for any potential confusion.

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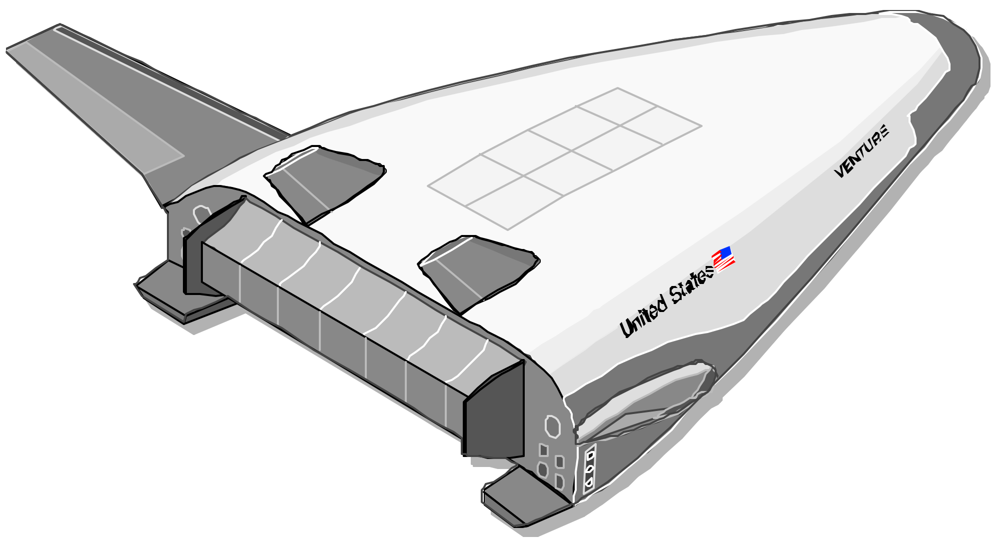
RLV Vehicle Health Management System Modeling and Simulation



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RLV Vehicle Health Management System Modeling and Simulation

Reducing Program Costs and Increasing Mission Success

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Abstract

Sanders, a Lockheed Martin Company, is leading the development and integration of the Vehicle Health Management (VHM) system for Lockheed Martin's VentureStar Reusable Launch Vehicle. The primary objective of this effort is to provide an automated health status and decision-making system for the vehicle.

A detailed simulation of the VHM system on RLV is currently being developed using the Foresight™ Design and Modeling Tool. The simulation will consist of models of key components of the RLV VHM system. An effective detailed system simulation will allow for system and design engineering, as well as program management teams, to accurately and efficiently evaluate system designs, analyze the behavior of current systems, and predict the feasibility of making smooth and cost-efficient transitions from older technologies to newer ones. This methodology will reduce program costs, decrease total program life-cycle time, and ultimately increase mission success.

1.0 Introduction

NASA has been endeavoring to find faster, cheaper, and better processes to reduce total life-cycle costs for access to space. In order to reduce total costs, future launch vehicles like the VentureStar Reusable Launch Vehicle (RLV) should include highly reliable and flexible systems, incorporating expedited decision-making and robust health management architectures.

Sanders is a key partner in the development and integration of the Vehicle Health Management (VHM) system for RLV and X-33 (an Advanced Technology Demonstrator for the verification of critical RLV technologies). The objective of the VHM effort is to provide an automated health decision and maintenance system. VHM on X-33 currently consists of two VME-based computers and fifty MCM-based Remote Health Nodes (RHNs). A pair of FDDI optical data buses connect half of the RHNs to VHM Computer A and half to VHM Computer B. The RHNs provide the direct connection to vehicle health sensors: each RHN processes data from its attached sensors, and under direction of its control computer, transmits the data to VHM-A or VHM-B via the optical bus. See Figure 1.

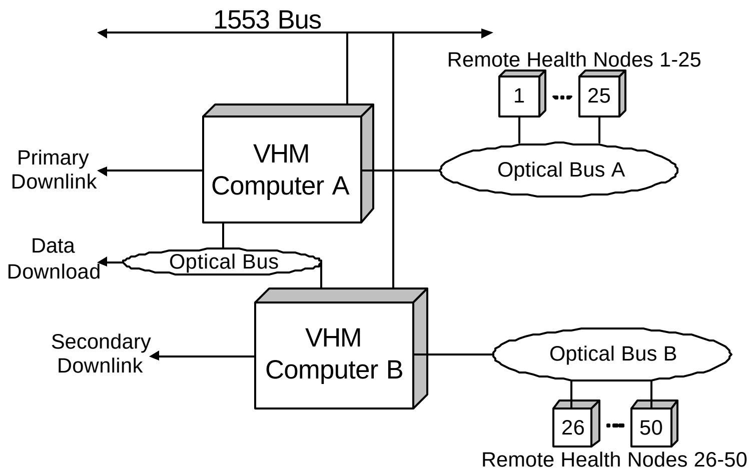

Figure 1. Schematic diagram of Vehicle Health Management system

A detailed architecture and functional design simulation of the RLV Vehicle Health Management System is currently being developed. This simulation will be used during VHM system development to evaluate the VHM system design, pinpoint system design risks, and analyze architectural tradeoffs.

A comprehensive system simulation is an essential part of any Virtual Design Environment (VDE) in which team members at different locations collaborate efficiently in real-time. Through collaborative system design and trade analyses, systems engineers will be able to manage risk and ultimately reduce overall program costs. An effective simulation will allow teammates to significantly reduce the number of physical design iterations and increase their chances for current and future mission success.

2.0 Foresight Design and Modeling Tool

The RLV Vehicle Health Management system architectural and functional simulation is being developed using Foresight Design and Modeling Software for Complex Systems. Foresight™, a product of NuThena Systems Inc., is a systems modeling tool suite which has been chosen by Lockheed Martin's Engineering Process Improvement (EPI) center for use in real-time modeling and systems analysis.

Foresight software is used by systems engineers to create and analyze functional and physical executable system models. It incorporates both graphical and textual modeling to simulate a system's dynamic behavior, functionality, architecture, information flow, and interface requirements.

The tool is based on structured analysis techniques. Models are built in hierarchical structures from executable modeling constructs. The highest level of modeling construct is the data flow diagram. This construct is built using Foresight supplied library elements, state transition diagrams, and mini-specifications. The hierarchical models are saved and used as reusable user-defined library elements, which can be reused in future models. Figure 2 shows one possible model hierarchy.

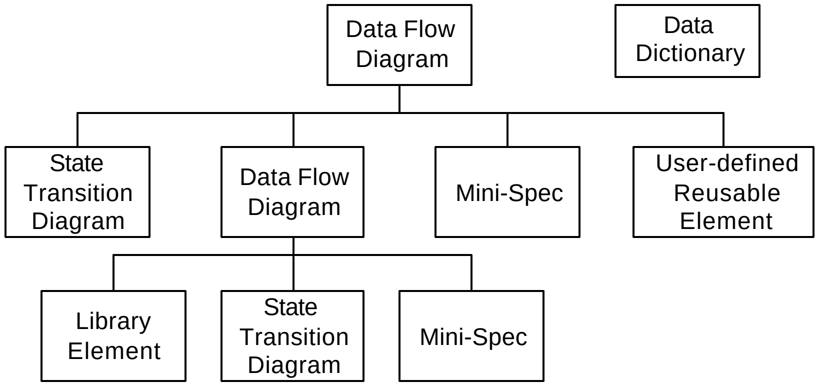

Figure 2. Example of Foresight model decomposition into executable descriptions

Using simulation tools, systems engineers can model the dynamic behavior of a system, as well as the performance of system components. Engineers can use the model to trade architectures and components. The resulting model can be used to identify whether or not a system design meets the set requirements and design constraints.

In addition to real-time performance and architecture modeling, the Foresight software provides a virtual development and design environment. The tool can be used collectively by engineers on a company-wide network to develop, run, and test their designs. Engineers working on the project do not have to be in the same location to work together effectively. Foresight can also be integrated with other systems engineering tools to assist in the entire system development process. Foresight interfaces seamlessly with two key external tools: DOORS (Dynamic Object Oriented Requirements System), a product of QSS Inc., and SavantSys™, a product of Savantage Inc. DOORS provides efficient requirements management, information management, and information traceability. SavantSys is a design-to-cost and design-to-manufacturing modeling tool which identifies and assists in the analysis of essential cost, component, physical design, and manufacturing data.

3.0 Benefits of Simulation and Modeling, and Applications to RLVs

The behavior of complex instrumentation systems, such as those that will be used on Reusable Launch Vehicles, is difficult to predict without detailed operational and performance models. The many systems on an RLV also have additional complexity: changes in one subsystem often affect other subsystems, in both physical and functional design.

Cost concerns also add complexity to RLV system development, requiring engineers to make final decisions on first generation designs. Faced with cost pressures and the challenges of designing complex conglomerations of systems, engineers can find assistance in a tool which helps with decision-making by providing functional and architectural system behavior data. In designing a system, engineers must trade cost reduction while ensuring that the product meets performance standards. This entails effectively simulating the system, and also determining which pathways within the system may be critical.

Not only is simulation the key to success during functional and architectural development; it is also beneficial in technology tradeoff studies and upgrade decision-making. In these cases, choices often must be made when all the hardware is not yet in-house, or in some cases not even developed. Design changes and the effects of these changes on all subsystems can be seen and evaluated by all engineering teams working on the project through use of the simulation.

3.1 Model Design

The first step in incorporating a simulation into the system design process is to decide on the design of the model itself. The key to model design is to acknowledge and understand the important trade-off between the fidelity of a model and the benefit of that model's design analysis results. Ideally, model design begins with a low-fidelity global architecture. This can then be carefully expanded to represent and explore critical pathways of a system.

The design of the VentureStar Vehicle Health Management system simulation began with a high-level design of the VHM computer processor board and its direct interfaces. One piece of this high-level design can be seen in Figure 3.

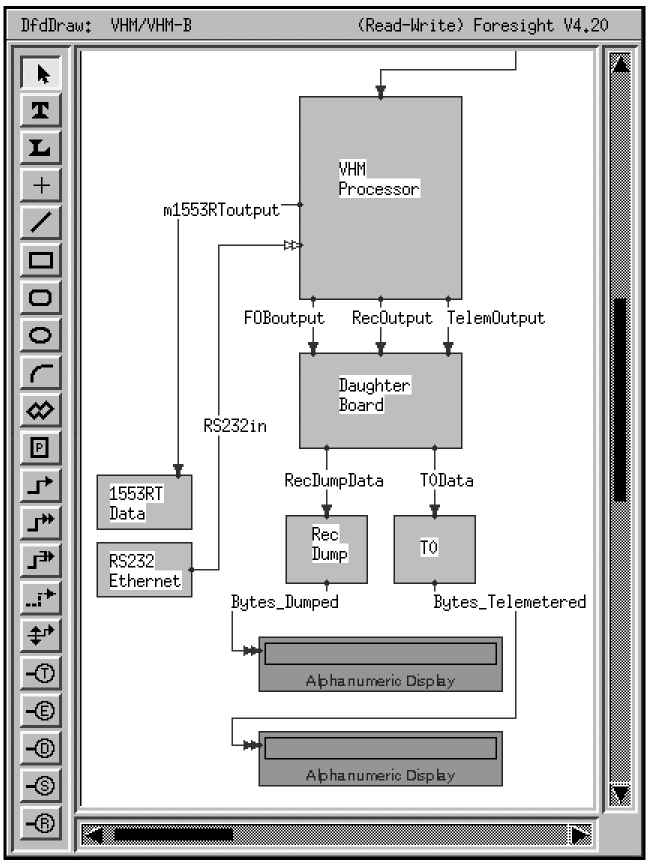

Figure 3. High level Foresight model of VHM processor and interfaces

This high level model addresses the data flow between the VHM processor, its daughterboard, and the output devices that interface to it. Gross measurements that can be gathered directly from this model are the amount of data transmitted to the ground via recorder dump and the amount of data sent via telemetry.

A lower level VHM model allows the system designer to concentrate and carefully analyze areas of the design which may be at risk of not performing optimally. In the case of the VHM subsystem, the high level of software processing that is performed by the VHM CPU has been determined to be a risk factor. Therefore, a low-level model of VHM software processing has been developed to carefully track this performance measurement. In this way, systems designers can verify that changes to sensors within the system, or additions to diagnostic functionality, will not exceed the VHM processor margin. A piece of the software processing model is shown in Figure 4.

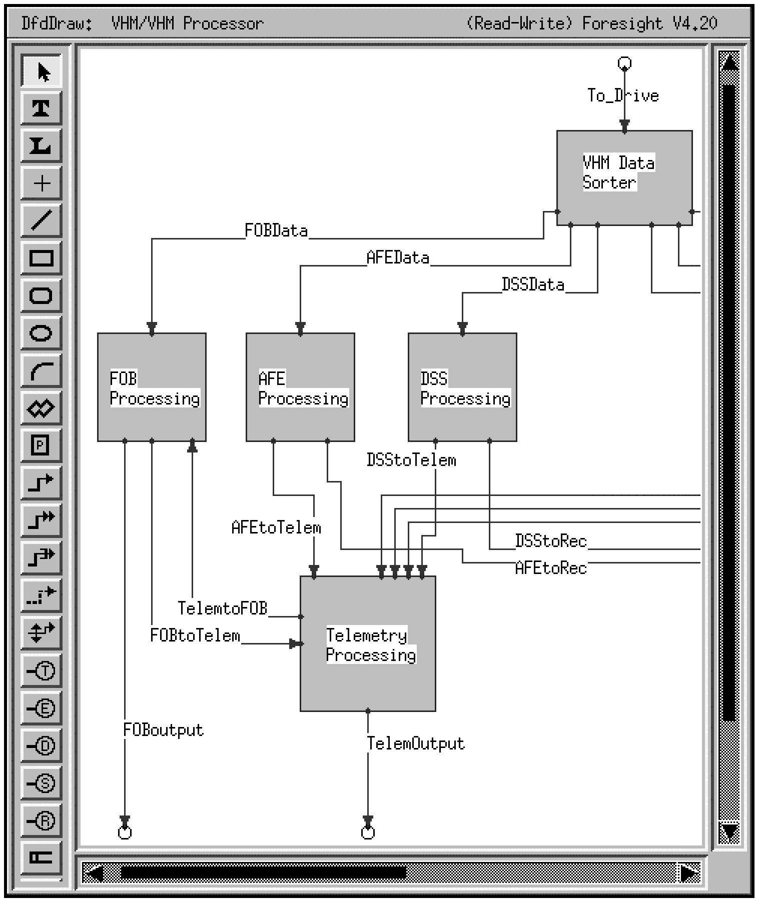

Figure 4. Low level Foresight model of VHM software processing

The second step in model design is to ensure that the model is flexible and reusable, so that it can be used throughout the system development process, from initial design through testing through upgrade studies. One way to ensure reusability is to build common module building blocks. The VHM hierarchy reuses VME bus blocks and FDDI node blocks, which were both developed for Sanders by NuThena Systems. In addition to these reusable models, an RHN block has been developed which is being reused many times within the VHM system simulation. A snapshot of the reusable RHN model interfaced to the FDDI optical bus is shown in Figure 5.

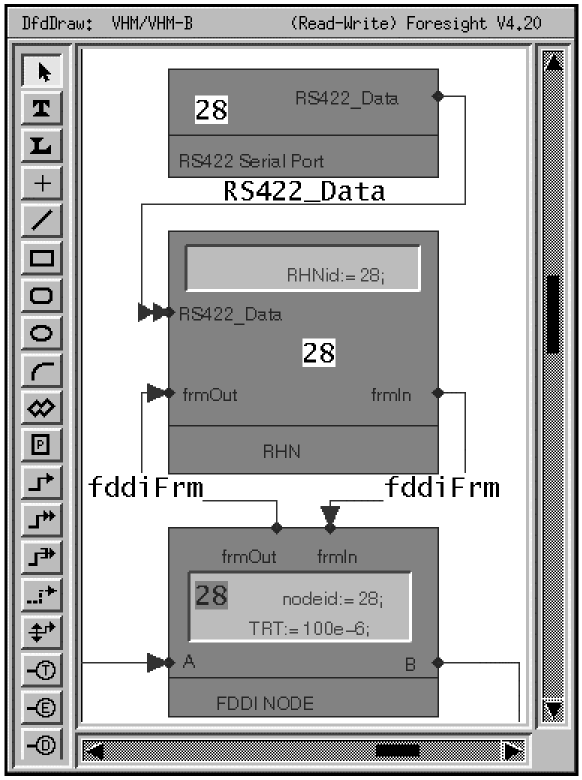

Figure 5. The RHN reusable element on the FDDI optical bus

Creating models that are effective and extendible is beneficial to system design. Systems engineers can use the flexibility and modularity of these models to concentrate on solving the most important problems currently at hand. This saves time not only in the initial stages of design, but throughout the development life-cycle of the product.

3.2 System Architecture and Functional Design

Initially, the most notable aspect of a simulation is the concrete data it provides at the design analysis stage. The simulation can be used to provide information about whether a certain system design will actually work: will the hardware architecture be able to support the software processing? Will the communication bus be able to support the flow of data? Does the proposed design meet the functional, physical, and financial requirements of the customer?

Simulation and modeling in Foresight is being used on the VHM system simulation to pinpoint system design flaws, monitor system changes, verify requirements compliance, and investigate future design possibilities. Specifically it is being used to provide systems engineers with data about crucial pathways in the system. For the VHM system, the most important considerations are data throughput over the optical bus connecting the RHNs to the VHM computers, processor utilization within the RHNs, and VHM CPU utilization.

The principal Foresight construct being used to model throughput and utilization in the VHM system is the “Process Resource”. The VHM CPU, for example, is modeled as a process resource with a certain computational speed. The resource is tasked as information is processed by the computer.

The amount of tasking can be monitored and displayed to the system designer. As changes are made to the VHM software or to the amount of data flowing through the system, the VHM processor utilization can be tracked. Figure 6 shows the Foresight model of the VHM processor resource.

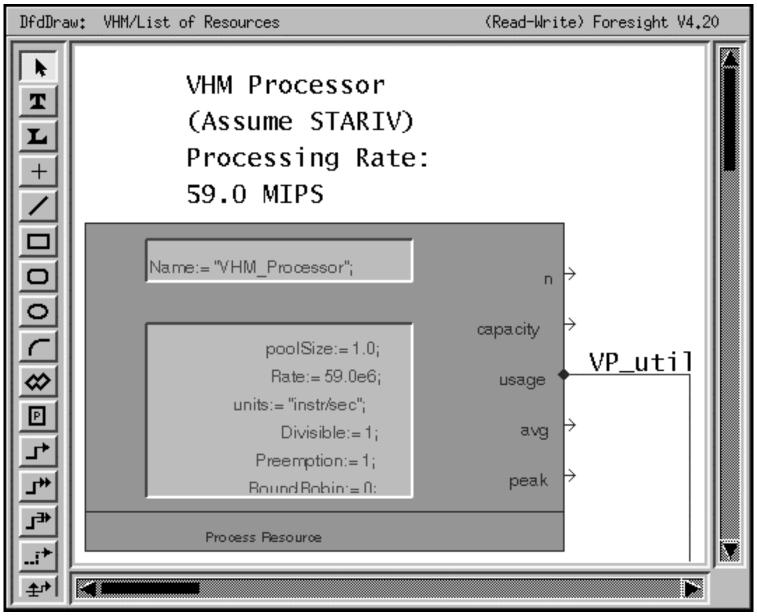

Figure 6. Resource modeling of the VHM processor

Using results from Foresight models, systems engineers will be able to give continuous feedback on resource utilization to hardware and software designers throughout the development process. This will reduce the risk of a situation in which the VHM processor (or any other hardware or software) proves inadequate during the final system integration and test stages.

Through each phase of the development process, in response to changes in customer requirements and engineering assumptions, the simulation can be "tweaked" to model the effects of changes on the rest of the system. The changes can be implemented at low cost over the course of the program rather than at high cost at the end of the program. The Foresight model will also interface with DOORS, the requirements management tool, to track compliance with all the requirements stated in customer specifications. In addition, size and cost tracking can be accomplished by using the SavantSys tool to provide design-for-manufacturability and design-to-cost estimates.

In addition to its use as a design validation tool, the simulation can be utilized during the final development phases for dynamic detailed design verification purposes and requirements compliance tracking. It can also be used to model the final implemented design for performance prediction and upgrade studies. The model can therefore be effectively used to provide constant feedback and means for improvement over the entire system development life-cycle.

3.3 Technology Trade and Upgrade Studies

The Virtual Design Environment can capture complex system-level designs at many levels of abstraction. These models can be used to ensure that all performance, cost, size, weight, and reliability requirements set by the customer are satisfied. A key to producing an optimal system that meets these requirements is Pre-Planned Product Improvement, or P^3I. This involves evaluating architecture tradeoffs before final decisions have to be made about the physical architecture of the system.

The VHM simulation's open architecture can be used at the beginning of the design process to select between currently available technologies. The open model architecture allows system designers to make educated critical decisions, because they can easily test different architectures within the flexible, modular simulation. Engineers can inexpensively and quickly experiment with the various options available (such as FDDI versus ATM networks) to see how they impact the entire system design, and to ensure that they are feasible from a cost and production standpoint. The use of COTS technology can also be promoted, since its effects on a system can be gauged to some extent without significant investment in the product itself. A VDE allows systems engineers to experiment with and validate a system model before actually committing to a design, which can result in a system which is very well suited to performing the task it is being designed to do. P^3I will not only lead to a faster and cheaper program, but to a product which is considerably better.

Because state of the art technology is always more expensive now than in the near future, analysis of design trades can be performed based on cost benefit. Foresight, in conjunction with SavantSys, can be used to answer questions such as: what might be the benefits of adding new technology right now? Would it be better to wait for a reduction in cost? At many stages during the design process, questions such as these must be posed and answered, because the amount of performance improvement is not always obvious. Figure 7 shows that, at times, a large investment in new technology may increase relevant system performance by a small amount, while at other times a small investment in certain important components may make the system performance soar.

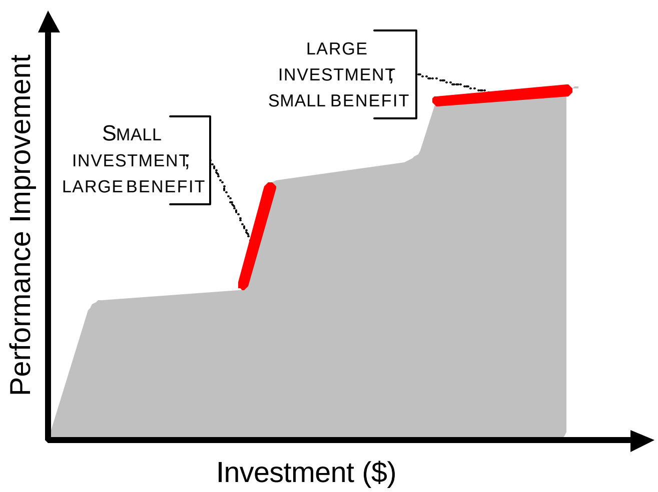

Figure 7. Investment cost vs. benefit to project

VDE simulation can help the system designer decide when the integration of a new technology into the system is worth the time and investment.

4.0 Conclusion: Faster, Cheaper, Better

Without the use of simulation and modeling in a VDE, system-wide problems are too often found only after the hardware is tested in some form in the laboratory. This almost always leads to costly redesign and scheduling delays. Studies have shown that 83% of all system development errors occur during the analysis stage of a product's life cycle, and that it can be up to one hundred times cheaper to correct these errors during analysis rather than during production. *(See [3])*

Using simulation and modeling, systems engineers will be able to concentrate on solving the relevant problems and issues they face in designing and upgrading a system. A detailed system simulation will permit engineering teams, as well as program management teams, to solve potential conflicts well in advance, thereby improving overall program performance.

Sanders is committed to the use of simulation and modeling for the VHM on the VentureStar Reusable Launch Vehicle. We believe it will lead to a cheaper, better, and faster development process, and a launch vehicle that is affordable to produce and to maintain. System development costs will be managed and reduced through risk assessment, design analysis, and architecture trade studies. Future projects will also benefit as current models are revised to reflect state-of-the-art technology, and as these models are used to help with upgrade and new design decisions. Finally, this process will support progress toward establishment of a "virtual company" that can take advantage of talent across corporate divisions, making the entire development process more efficient.

Incorporating simulation and modeling into an entire life-cycle development process will be beneficial to the project currently underway as well as to future endeavors in the development of complex systems.

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