

## The Use of High Fidelity CAD Models as the Basis for Training on Complex Systems

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### Abstract

During the design phases of large and complex systems such as NASA's Space Station Freedom (SSF), there are few, if any physical prototypes built. This is often due to their expense and the realization that the design is likely to change. This poses a problem for training, maintainability, and operations groups who are tasked to lay the foundation of plans for using these systems.

The Virtual Reality and Visualization Laboratory at the Boeing Advanced Computing Group's Huntsville facility is supporting the use of high fidelity, detailed design models that are generated during the initial design phases, for use in training, maintainability and operations exercises. This capability was used in its non-immersive form to great effect at the SSF Critical Design Review (CDR) during February, 1993.

Allowing the user to move about within a CAD design supports many efforts, including training and scenario study. We will demonstrate via a video of the Maintainability SSF CDR how this type of approach can be used and why it is so effective in conveying large amounts of information quickly and concisely. We will also demonstrate why high fidelity models are so important for this type of training system and how it's immersive aspects may be exploited as well.

### Introduction

High fidelity Computer Aided Design (CAD) models provide an excellent basis for conventional design and analysis of complex systems. Boeing's Huntsville Visualization Laboratory has demonstrated that they also provide a good substrate for training and operations planning activities. In conjunction with SSF design engineers, we have shown how CAD models can be used to graphically demonstrate functional sequencing, identify the location of critical maintenance access points, and, with the addition of accurate human models, demonstrate the accessibility of these maintenance points. This demonstration was very favorably received at the SSF CDR in February of 1993.

The current visualization capability is based on the use of a proprietary visualization tool that allows interactive viewing of a shaded, three dimensional image of a CAD model in real time. Both immersive and non-immersive versions of the tool exist. The view perspective is interactively controlled with a mouse or other input device. Alternatively, a predetermined viewing path through the model provides a convenient and repeatable method of conducting a "tour" of the model. This path is specified by a B-spline.

While fully immersive, stereo views of the models are possible with the tool, the resolution of our Head Mounted Display (HMD) equipment is inadequate for viewing the complex models. This proves less restrictive than expected. The emphasis on engineering analysis favors high resolution displays over the wide field of view at lower resolution provided by HMDs.

This paper will discuss four aspects of this work at the Huntsville Visualization Lab. We will describe our efforts to perform maintainability analyses, expansion of the application domain to operations planning and training, planned enhancements to our tool suite and future directions of this research.

## **Maintainability Analyses**

Maintainability analysis studies the design attributes of a piece of equipment that are salient to the maintenance of the equipment. Critical to this analysis are a high fidelity model of the equipment, a set of models of typical human forms, and a relatively high fidelity simulation of the kinematics of the equipment and the human form. Of only slightly less interest is a simulation of the physics of the environment in which the maintenance will be performed.

An example maintainability analysis was conducted using a human model and an actual equipment rack. This analysis was presented at the SSF CDR in February, 1993. It showed the step by step procedure used to remove a pump assembly from a rack. We imported a model of the 95th percentile American male in the zero-g posture to provide a human form for this analysis. Other standard human models are available but were not used in the example study. These models would be used to conduct an exhaustive maintainability study.

The equipment models that were used in our example analysis were imported directly from the SSF Engineering Database. The visualization software allowed each model to be operated on independently, i.e. displayed, hidden, translated, rotated, etc. The amount of detail imported from each CAD model was bounded by the consideration of the overall complexity of the set of models to be viewed and was specified when the models were translated.

In order to demonstrate the rotation of the rack into a maintenance position and the translation of the pump out of the rack, multiple models of the rack, the pump and the human form, each in different orientations and positions, were loaded simultaneously and the operator turned the display of the nominal models off and the display of the corresponding translated (or rotated) models on manually.

Access to utility disconnect points was demonstrated by moving the viewing perspective through the access path that would be used by the astronaut performing maintenance. This provided a rough idea of how interactive analysis would look. The maintainability team liked the approach and announced their intention to model additional maintenance procedures in this fashion.

## **Operations Planning**

Operations planning historically is not feasible until the first hardware prototypes are built. It is difficult to foresee operational constraints from studying two dimensional CAD drawings. This forces the consideration of operational issues to be deferred until late in the design process. Most design decisions have been committed to by this time and design interdependencies have proliferated. Design changes at this stage are typically prohibitively expensive.

Imagine the enthusiasm that an opportunity to effect the operational aspects of a design early in the design process generates in the operations planning staff. Analysis of this sort is being pursued with the SSF operations planning organizations. These organizations can evaluate design proposals for operational characteristics before the first prototype is built. The results of these analyses can be fed back to the design engineers for incorporation in design revisions.

Another benefit of early involvement by the operations planning staff is an early start on developing the operator training for a piece of equipment. Operator training requires understanding of operational procedures. The early development of these procedures allows training developers to start their activity much earlier in the equipment development cycle. As a result of their early involvement, training developers can participate in the analysis of equipment and operations designs adding a training perspective to and exerting a timely influence on these designs.

Other beneficial side effects of earlier training development include higher quality training resulting from more time to develop training materials and earlier availability of training materials. Earlier availability of training materials increases flexibility in the scheduling of training programs. All of these benefits can be equated with higher quality operations procedures and training programs at lower cost.

## **Planned Enhancements**

Several capabilities are required to effectively realize the planned maintainability analyses, operations planning, and training development activities. While turning multiple copies of a model in different locations and orientations on and off is adequate to demonstrate the potential benefit of this approach, interactive rotation and translation of models must migrate into the basic functionality of the tool suite.

Furthermore, kinematic modelling of object movement, i.e., constraining the movement of a model to the set of motions that are physically possible, is also required to fully realize the potential benefits of this approach. Kinematic modelling is only half of the picture, however. Behavioral modelling must be provided to generate completely interactive simulations of the environments of interest.

Much of this functionality could be provided through the addition of a scripting language. Ideally this language would provide functional abstraction, conditional execution and hooks for executing external programs. These capabilities are currently undergoing detailed analysis and design.

## **Future Directions**

Simulation packages of adequate fidelity for modelling various behavior of interest already exist but mechanisms to provide connectivity between the visualization environment and these external simulation packages must be established. This allows us to use existing simulation work directly and also simplifies the scope of any built in scripting language.

A method of integrating descriptions of detailed behavioral models with visual models must be developed. A general world model building tool would allow information at various levels of abstraction to be added to the world description without the danger of inconsistencies creeping in that is inherent in separately constructed models.

A grand vision is emerging of a complete virtual implementation of a program from start to finish, before any hardware is built. This would include a virtual prototype of not only the equipment, but the facility that would produce the equipment, the operations procedures associated with the equipment, and any special training requirements of the equipment. Such extensive simulation would allow the trade-offs between proposed projects to be examined in depth before any resources were allocated to the implementation of any one project.

One could even imagine a suite of tools for building immersive simulations that were available as an immersive simulation, giving new meaning to the phrase "Programmers' workbench." The work that is already in progress at our lab is taking the first steps toward realizing this vision.

## **Conclusions**

This work has met with much enthusiasm from the engineers working directly on various design activities. They appreciate the ease with which mistakes can be found in the three dimensional representation of the CAD drawings. The operations planning group appreciates the early opportunity to evaluate the operational feasibility of the design and provide design feedback at a stage where minor redesign is still more economically feasible. And the training developers appreciate the extra time before development in their schedule to develop the training materials

While the non-immersive tool is extremely valuable to present activities, fully immersive applications are not yet useful. This is primarily due to the lack of resolution of current HMD technology. We anticipate this issue to be

addressed by enhanced HMDs in the next two or three years. The addition of a scripting language will allow exploration to occur at a much faster pace.

The connectivity with other behavioral modelling software is inherently more difficult. World building software that integrates visual and behavioral modelling is much further from availability.

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