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Visualization Design Environment

Jerrold A. Friesen, Kathryn R. Hughes, Jeffrey N. Jortner, Alan R. Pomplun, Jill Schwegel, Gary J. Templet

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Abstract

Improvements in the performance and capabilities of computer software and hardware systems, combined with advances in Internet technologies, have spurred innovative developments in the areas of modeling, simulation and visualization. These developments combine to make it possible to create an environment where engineers can design, prototype, analyze, and visualize components in virtual space, saving the time and expenses incurred during numerous design and prototyping iterations. The Visualization Design Centers located at Sandia National Laboratories are facilities built specifically to promote the "design by team" concept. This report focuses on designing, developing and deploying this environment by detailing the design of the facility, software infrastructure and hardware systems that comprise this new visualization design environment and describes case studies that document successful application of this environment.

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1 Introduction

Sandia National Laboratories is responsible for ensuring the safety, reliability, and performance of the nuclear weapons stockpile, without support of underground nuclear testing. To meet this challenge, Sandia is shifting away from test-based methods of stockpile stewardship towards computational based approaches. Recent advances in the performance of computer software and hardware have fostered dramatic improvements in modeling and simulation capabilities. However, these capabilities have brought a new challenge: how to visualize, comprehend and collaborate with others when large complex data sets are involved?

This LDRD approached the challenge by designing and creating the Visualization Design Center (VDC) – a facility and suite of tools for improving data visualization and collaboration. The VDC allows engineers to design, prototype, and test components in virtual space, and provides a means for analysts to explore and examine results of large-scale simulations. The VDC provides a forum for multi-disciplinary teams to meet (in person or via videoconferencing) and actively evaluate and modify designs in real time. This capability provides a considerable timesaving by permitting clearer, faster comprehension of data and effective collaboration with others.

The VDC consists of: (1) a facility equipped with the latest visualization displays, interface technologies and videoconferencing systems; (2) a software infrastructure comprised of commercial and in-house tools for visualizing and exploring data sets; and (3) a hardware system built upon state-of-the-art graphics engines and high performance networking and storage systems. Technologies brought together to build this design facility include graphical supercomputers, advanced visual projection systems, leading edge audio/video switching technology, videoconferencing systems, and state-of-the-art interactive modeling and analysis software.

The VDC capabilities have been validated through a number of case studies. During this process, the following design and analysis functions were demonstrated:

- Interactive viewing and manipulation of finite element analysis computations in a 3-dimensional environment.
- Incorporation of Kinematics and Dynamic analysis into animations of Mechanical Systems.
- Integration of flight-test data with visualization packages to produce physically correct animations.
- Animation of mechanical assemblies for training, assembly/disassembly, and archive purposes.
- Conversion of solid modeling assemblies into web-friendly formats for presentation purposes.
- Delivery of simulation and animation results over the network to customers.
- Archival of graphical results in multimedia databases for future use.

Results of the case studies show that data comprehension can be improved by using appropriate product-visualization and scientific-visualization packages to explore data, developing animations to depict complex motion or assembly procedures, and integrating computational and /or test data into visualizations to produce physically correct simulations. It also demonstrated that overall design cycle time can be reduced by working in an environment where remote team members participate interactively and designs are evaluated and modified in real time. These results show that the VDC is meeting the challenge of providing effective methods to visualize, comprehend and collaborate with others, even when large quantities of complex data are involved.

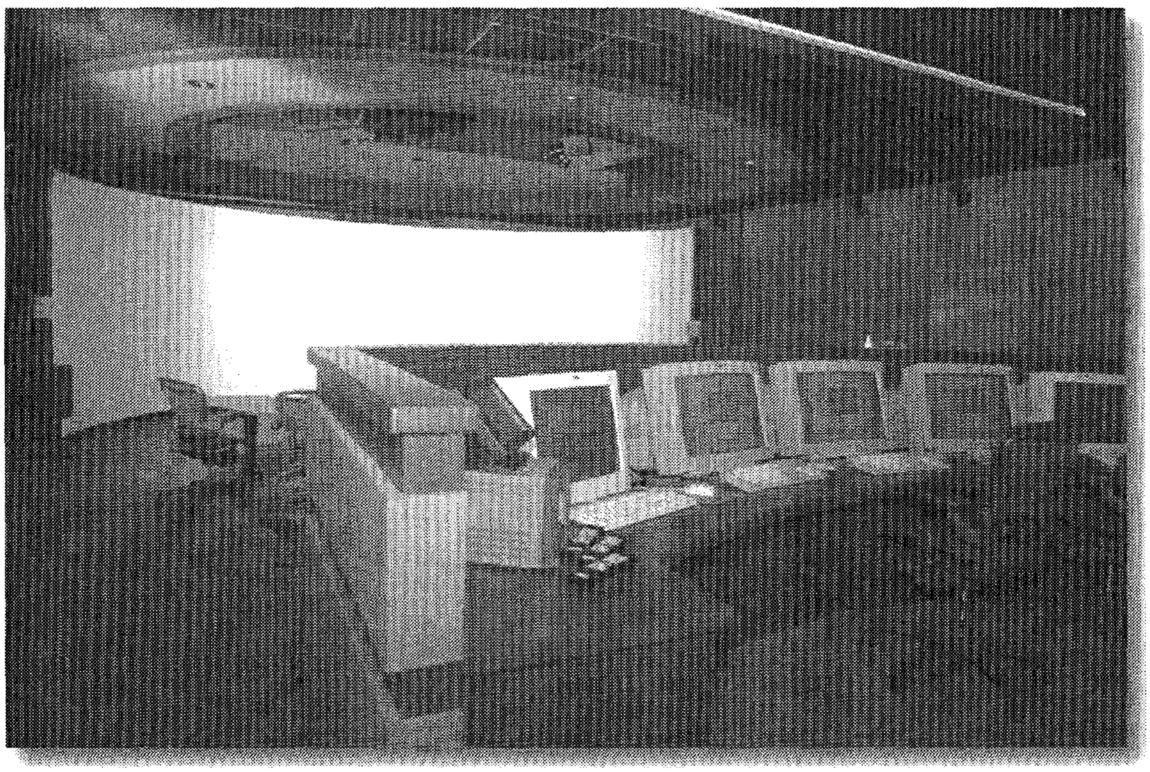

Figure 1-1 Visualization Design Center

2 Visualization Design Center

The Visualization Design Center is a state-of-the-art facility created specifically to meet the developing needs of the research and engineering communities by providing advanced methods for visualizing, comprehending, and communicating data.

2.1 Concept

The technical revolution over the past decade has dramatically changed today's work environment. Researchers and engineers are benefiting from rapid advances in the performance of high-end computing. High-speed computers and networks and large storage systems have made it possible for researchers to develop higher fidelity simulation models with improved three-dimensional physics and greater overall resolution. These improved models provide far more insight into the phenomenon being studied and are yielding results not possible a few years ago. Similarly, it is now standard practice for engineers to define products using 3-D modeling, and to use these models as a foundation throughout the entire Product Realization cycle. Once an object's geometry is defined in 3-D, this information is used to perform mechanical stress analysis, define machining algorithms, establish fit toward the next-level-assembly, etc.

Although these innovations in analysis and design have brought engineering and research capabilities to new heights, it has brought with it a host of new challenges. One of the biggest challenges is making effective use of information-rich 3-D models and the large quantities of data generated by complex simulations and analysis. The Visualization Design Center (VDC) has been developed to address this issue. Prior to the VDC, engineers' ability to navigate and render large complex assemblies was slow and cumbersome, and analysts were restricted in the amount of data they could view at any one time. The VDC significantly reduces this limitation by dedicating computers and display systems capable of processing and projecting information more quickly and in larger quantities than ever before. This new capability realizes a considerable timesaving as well as permits a clearer faster comprehension of the analysis data. A further benefit of the VDC is that it provides a forum for multi-disciplinary teams to meet and not only review designs, but also to actively evaluate and modify designs in real time. This capability was not possible before. By providing users direct access to their design data and analysis code and results, suggested changes can be implemented immediately, and in many cases, the results of the changes can be assessed immediately. The ability to perform these functions in real time will reduce the time and number of meetings required developing a design, thus reducing the cost of the project and the overall project cycle time

Essential design features of the VDC are described below.

Physical Layout

The VDC is a 30-foot by 40-foot room located in the basement of Building 912. This location was chosen because of its proximity to the majority of our primary customers -

weapon designers and analysts. The room is a vault-type-room (VTR), allowing use for both classified and unclassified work. The room is divided into a main visualization area and an equipment area, as shown in Figure 2-1. The dominant curved display screen is located at the front of the room with the control console at the rear. Furniture in the visualization area can be arranged to support either small working meeting of up to 10 people, or presentations to as many as 25 people.

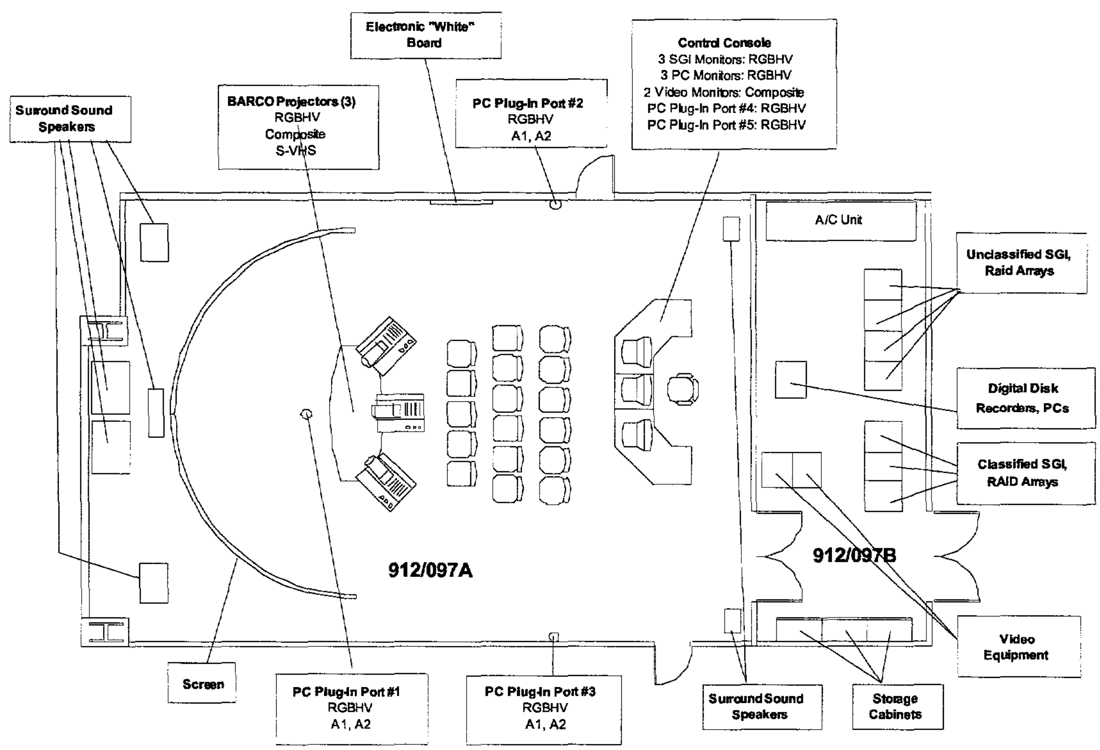

Figure 2-1 Visualization Design Center Layout

Computational Hardware

Primary computing power for the VDC consists of a pair of Silicon Graphics supercomputers; one which is used for classified work and the other for unclassified. Both computers are multiprocessor systems with InfiniteReality™ (IR) pipes and significant memory and disk storage. SGI computers were chosen because of their outstanding graphics capability and their dominant position amongst graphic-intensive software applications. Additional computers include a pair of Intergraph personal computers to support general-purpose applications and a pair of Compaq personal computers used for videoconferencing.

Display Hardware

The display system consists of a large (33' wide x 9' high) curved screen with three high-resolution projectors. The screen curvature enhances the feeling of 3-D immersion through peripheral vision. Each of the three projectors displays onto one third the width of the screen. They can project three independent images or a single seamless composite image.

Video Conferencing Systems

Three videoconferencing systems will be available to meet various requirements of the VDC. The first supports unclassified video-conferencing between the VDC and the NM WEPRE facility. The second supports classified videoconferencing between the two facilities. The final system provides classified videoconferencing to future facilities that have access to SecureNet. The three systems are all commercial products selected because they provide the best video quality while still meeting DOE security requirements.

Software

The VDC has a core set of software packages capable of handling most customer needs. Software selection was based on the following criteria; (1) compatibility with Pro/Engineer™ software – Sandia's standard CAD package (2) ease of use (3) ability to handle large data sets and (4) well supported commercial-off-the-shelf product. The VDC core software capabilities include visualization of product data, analysis of scientific data, production of animations, simulation of mechanical motion, interaction with data in a 3-D environment, and collaboration with remote sites. In addition to the core software, a number of readers and translators are available to assist the user move from one application to the next.

Remote Display Systems

Two methods of providing remote visualization are available. For intra-site distribution, dedicated fiber extenders have been installed between the SGI graphics engine and remote displays. This method provides high performance data transmission with no loss of graphic resolution, however it does have two limitations. It is costly since it requires dedicated lines to each remote display and line distances are limited to 10,000 feet. For inter-site distribution, console displays may be converted to video signals and transmitted over an ATM network. This concept is still under evaluation. If it proves successful, the method may be used as a lower-cost lower-performance alternative to the dedicated fiber extenders for intra-site visualization.

2.2 Design and Implementation

2.2.1 Hardware Systems

The Visualization Design Center employs multiple computing platforms to generate data and perform supporting tasks. Three high-resolution video projectors and numerous monitors display the data within the facility. Video tape players, digital disk recorders (DDRs) and a digital video disk player (DVD) enable the playback of prerecorded information and the recording of data from the output devices. A video switching system routes signals from the various output devices to the display and recording devices.

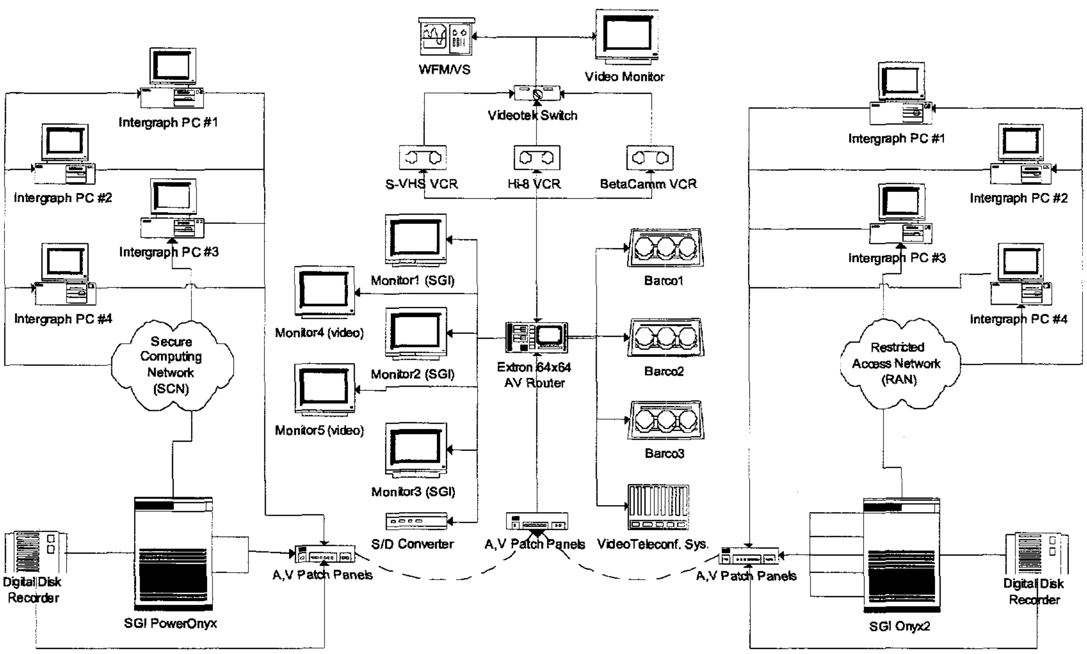

Figure 2-2 Video Component Network

The VDC is primarily driven by Silicon Graphics graphical supercomputers. As we work with both classified and unclassified data, we have built-up two separate but similar machines for visualization. The classified computer is a SGI PowerOnyx™ system. This system has 4 R10K processors, 2.5 GB of memory, 300GB of disk storage, a Serial-Audio card, Sirius™ video, and one InfiniteReality™ (IR) pipe containing a single 64MB raster manager.

The unclassified computer system is a SGI Onyx2™ with 6 R10K processors, 7.5GB of memory and 900GB of disk storage, a Digital Video option, and 3 InfiniteReality pipes. Two of the pipes have single 64MB raster managers and a DG5-2 interface which allows the output of two simultaneous 1280x1024 video streams from each pipe. The third pipe has a DG5-8 interface and two raster managers that allow the output of up to eight simultaneous hardware video signals from the pipe. This enables having a framebuffer size of 3840x1024 that can be displayed across three video outputs. The three InfiniteReality pipes can also be utilized together in a three-display configuration where all the pipes are used for generating the display. The system also includes both a Digital Video Option (DIVO) and Graphics Video Option (GVO). These two options are used for real-time digital video input/output.

These systems were chosen for their graphics and video capabilities. The strength of the SGI computer lies in the graphics capabilities, but with multiple CPUs and graphics cards, they can also accommodate multiple users as well as multiprocessing applications. At the start of this project, many of the graphics-intensive software applications of interest were only available for the SGI platform. Software support is provided through SGI's Varsity program, which provides most of the SGI software for a nominal fee. This is particularly beneficial in the area of graphics software.

The InfiniteReality hardware has numerous features not all available in other commercial hardware, but are important for real-time visualization. Some of these are: wide range of display resolutions and number of simultaneous displays, high-performance real-time anti-aliasing, real-time texture mapping, and 3-D texture mapping with broadcast-quality live video. Each InfiniteReality pipe has the capability of scan-converting any portion of the framebuffer into a NTSC or S-VHS video signal. The GVO board adds the capability of outputting serial digital video from the framebuffer. The DIVO board is capable of streaming lossless non-compressed real-time digital video and audio data into and out of system memory. These boards are used in content creation applications and real-time recording and playback.

Attached to each SGI computer is an Accom, Inc. WSD/2Xtreme™ Digital Disk Recorder (DDR). The unclassified DDR holds 20 minutes of computer video and audio; the classified DDR holds 10 minutes. These specialty storage devices are primarily used as intermediate cache storage for video imagery that will later be saved to video tape recorder (VTR) devices. Once a video clip, or "title", is saved on the DDR, it can then be played back at different frame rates, forward and reverse, and combined with other titles. The DDR is especially useful when used as the real-time playback device for titles that take a long time to render. It is also accessible through both a direct SCSI connection to the SGI and the computer network, and controllable by most software applications (SOFTIMAGE™, VisLab™, Alias/Wavefront™, 3D Studio Max™, etc.)

To create the VDC's immersive environment, we use three high-resolution BARCO DataGraphics™ 1209s projectors and a 33-foot wide by 9-foot high curved projection screen with a 160-degree arc. Each projector is configured to display on one third of the screen's total surface area. The projectors are precisely aligned and registered to display a seamless single composite image from three SGI IR pipe data streams. The projection screen is curved to a constant radius to provide a feeling of 3-D immersion through peripheral vision.

Three projectors used working together, dramatically increase the resolution of the projected image. The maximum resolution obtainable through a single SGI data stream is 1280 horizontal pixels by 1024 vertical pixels. If this image were projected to cover the entire VDC screen, the individual pixels would be apparent and the image quality would be perceived as poor. With three projectors, data can be generated with three separate SGI IR pipes and integrated as a single projected image with a horizontal resolution of 3840 pixels. The vertical size (and resolution) remains constant at 1024 pixels, producing a high quality, wide screen image that fills the viewer's visual field of view, creating the immersive sensation.

An Extron Matrix 6400 Series AV switcher is the heart of the VDC's hardware system configuration. All of the system components' audio and video input and output signals are wired directly into the switcher. Within the switcher, the incoming signals can be individually routed to any of the output devices. System operators use a simple touch panel control to select source devices and their destinations. For example, the output of the unclassified SGI's IR pipe #1 can be sent simultaneously to any or all of the projectors, the console monitors, and the video recorders simply by selecting those devices on the touch panel.

To physically separate classified and unclassified data, a series of audio and video patch panels are used. These panels are configured to normally pass signals from the unclassified SGIs, PCs and DDR directly into the Extron video switch. When the classified devices are used, manual wire "patches" connect the classified device outputs to the switch in place of the unclassified ones.

The VDC has three video devices to play prerecorded video material in three formats: Betacam SP, Super VHS, and digital video disk (DVD). The Betacam device is also configured to record audio and video from the various system source devices.

The VDC is equipped with five independent input ports to enable users to connect laptop computers, display boards, and other devices as needed. These ports are wired into the video switch and can be selected and displayed via the touch panel controls.

The VDC's immersive environment is enhanced by a seven-speaker surround sound system. A Yamaha digital-processing amplifier creates simulated audio listening environments from surround or non-surround audio signals.

Multiple videoconferencing systems are used to implement quality videoconferencing between the Sandia/California VDC and the Sandia/New Mexico WEPRE Facility. The three systems currently under design and construction are: (1) unclassified videoconferencing between the two design centers, (2) classified videoconferencing directly between the two design centers, and (3) classified videoconferencing to future Visualization Design Centers with access to SecureNet. The systems are being implemented in phases.

Phase One - Unclassified Videoconferencing

Unclassified Videoconferencing is performed using a PictureTel Live200™ product at each center that uses ISDN lines for a maximum of 128-Kbps video calls. In January 1999, this product will be upgraded to the PictureTel SwiftSite 2™, which also uses ISDN lines to place 384-Kbps video calls. In March 1999, the PictureTel SwiftSite 2 will be upgraded to enable videoconferencing over the unclassified network to Sandia/New

Mexico WEPRE Facility at 384-Kbps. Testing will begin on 768-Kbps desktop videoconferencing using a PC running Windows NT™ 4.0, as soon as a stable product is available on the market.

Phase Two - Classified Videoconferencing

In April 1999, the PictureTel SwiftSite 2 will be capable of placing a 384-Kbps videoconference call over the corporation's classified network to the Sandia/New Mexico WEPRE Facility. At this time, the SwiftSite will either become a standalone resource for classified-only videoconferences, or become a shared resource with unclassified once the necessary security plans have been approved.

Phase Three - Classified Videoconferencing across SecureNet

SecureNet is the Department of Energy (DoE) networking infrastructure for providing classified communications capabilities throughout the nuclear weapons complex. Currently, Sandia, Lawrence Livermore National Laboratory (LLNL), and Los Alamos National Laboratory (LANL) have connectivity to this infrastructure. All communications protocols that run on SecureNet must be authenticated using a DCE/Kerberos™ password. Unfortunately, there are no immediate solutions within today's technology that will provide the necessary security to meet SecureNet's requirements. This problem is still under research.

2.2.2 Software Environment

Sandia's mechanical design community has been performing solid model design for many years. Parametric Technology Corporation's (PTC) Pro/Engineer™ is a feature-based, solid-model CAD tool used by Sandia's mechanical design community. Further, it is the agreed standard CAD package for the entire nuclear weapons complex. Based on this, it was determined that any visualization packages developed or purchased for use during this project be compatible with Pro/Engineer.

Pro/Engineer is mainly a Computer Aided Design package designed to produce solid models with engineering accuracy and as such uses analytical representations of curves and surfaces. This allows designers to change the model and still have an exact mathematical representation, triangulated models are a simplified representation and should not be used for design changes. A detailed mathematical representation is computationally more expensive to display than similar, triangulated model. The Pro/Engineer model can then be converted to other visualization packages which convert the analytical model to an accurate triangulated model which requires less memory and can be displayed much more quickly. Changes in design should always be performed in the Pro/Engineer model as it is the most accurate.

While Pro/Engineer has proven to be an effective design package, its user interface is daunting and learning curve extensive. Engineers not using Pro/Engineer on a daily basis tend to have a difficult time remembering how to move around in order to examine assemblies. In addition, as the assembly size grows, navigation and rendering slow due to the use of solid models.

In consideration of the above, the following criteria were developed to evaluate the various visualization packages: (1) a seamless interface to Pro/Engineer, (2) ease of use, and (3) the ability to navigate large assemblies at near real-time. We also chose to limit our search to Commercial Off-the-Shelf (COTS) applications. Finally, while not a requirement, it was desired that the chosen application(s) compliment, rather than compete with existing tools currently in use by Sandia's design community.

In the search for appropriate design tools, a survey was conducted of Sandia's various simulation, animation, and analysis tools currently in use. In the area of simulation, we evaluated Deneb's Envision™ (formerly IGRIP), Sense8's World Up™ and WorldToolKit™ (now owned by EAI) along with MUSE™ (a.k.a. EIGEN/VR). Animation tools included Alias's Wavefront™ and Avid's SOFTIMAGE 3D™. The two mechanical analysis tools we looked at were CADSI's DADS™ and PTC's Mechanica™. Other tools examined included applications used to visualize data obtained from various analyses packages. This included CEI's EnSight™, Advanced Visualizations Systems' AVS™ and AVS/Express™, Math Work's MATLAB™ and IBM's Data Explorer™ (DX). Of these tools, SOFTIMAGE 3D, DADS, and EnSight best suited our needs and were incorporated into our core suite of visualization tools. However, there was still a need for a method to digitally prototype product design. While the above simulation tools can be used for this purpose, they did not fulfill the criterion set for seamless interface to Pro/Engineer, ease of use and near real-time navigation of assemblies. Finally, with regard to the remaining applications, it was decided the best practice was to work with the groups using them, but not commit to supporting them as part of our core suite. Thus, it became apparent that we would need a tool(s) to provide a common interface for the data derived from these various applications.

Our next step was to evaluate various commercial applications on the market. To begin our search, we used information gathered at SIGGRAPH 96. SIGGRAPH was an opportunity to evaluate software products that were available at the time and software products still in development. Two applications came to the forefront: EAI's Vis Suite (VisFly™, VisLab™) and Division's dVision™ tools. Both applications provide the necessary seamless interface with Pro/Engineer that allows for direct translation from Pro/Engineer to the relevant package. However, only EAI's suite of applications fulfilled the remainder of our criterion. Two measures that were identified later, the ability to interact with the models and add product simulation behaviors, were provided by Division's software. It was decided to purchase both applications and incorporate them into our core services.

The remaining piece of the puzzle was the ability to work with other engineering applications. For this, we needed a way to move data between the various applications -- in particular 3-D models. For this, we acquired two applications, InterChange™ from ViewPoint Data Labs and PolyTrans™ from Okino Graphics. Both applications support files exported from Pro/Engineer and can convert them into any format we've been asked to support. The strength of PolyTrans is its command line interface which can be used for building scripts to make batch conversions. InterChange has a graphical, easy to use, user interface and has the capability of importing files in Inventor format.

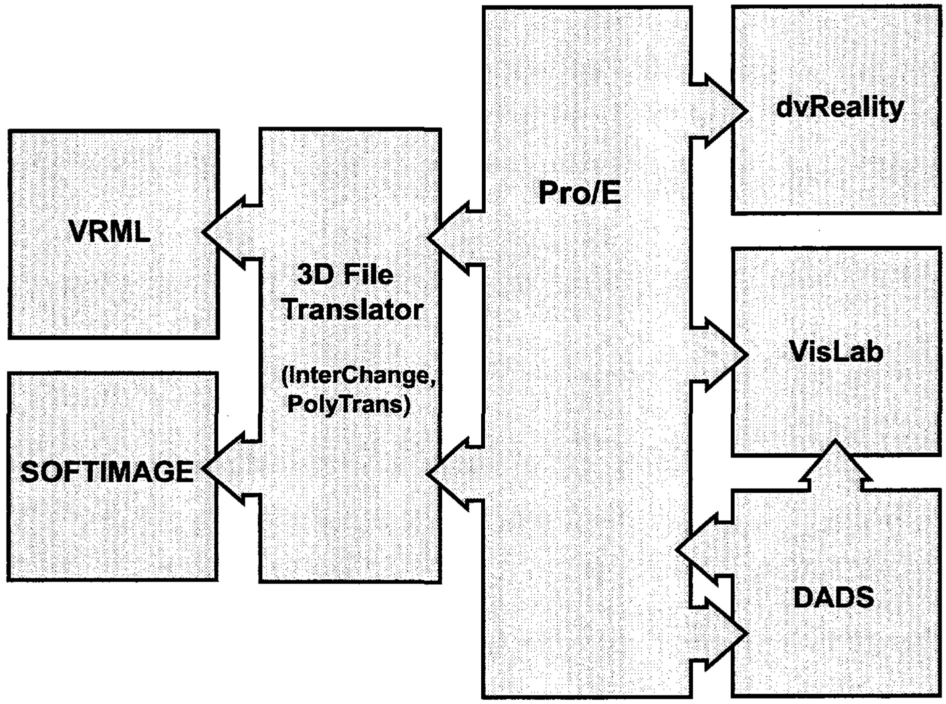

Figure 2-3 Software Interface Diagram

Figure 2-3 shows our suite of visualization tools and graphically illustrates their interconnectivity. Detailed descriptions of the tools and their applications follow this section.

2.2.2.1 Mechanical Simulation Tools

DADS™ (Dynamic Analysis and Design Systems) is a mechanical simulation tool from Computer Aided Design Software, Inc. (CADSI) that is being used by Sandia to perform mechanical analysis on critical stockpile components such as the stronglink safing mechanism. The DADS software package allows engineers to perform quickly and accurately the mechanical analysis of 3-D mechanical systems. DADS can perform rigid body, as well as flexible body, analysis. It can also simulate friction and impact between bodies. Simplified representations of the devices may be created in the DADS environment, or a detailed model may be taken directly from the original assembly, usually created in Pro/Engineer. DADS analysis can be useful in the concept design phase as it allows quick analysis of a simplified system. More detailed analysis can be performed as the system becomes more defined through design iterations. The main advantage of DADS is allowing designers to iterate their designs quickly, cheaply, and accurately in the DADS environment.

In the past, the mechanical design process involved several iterations of design, analysis, and testing. Errors in the early iterations were discovered in the testing phase and corrected in later designs. This process is time-consuming and expensive, and while the resulting product may perform, it may not be an optimal design solution. DADS allows designers to bring a majority of design iterations into the digital realm through numerical simulation. Using numerical simulations, design iterations are faster and cheaper and often more accurate, as many problems are quite difficult to solve without the benefit of numerical solution methods. The ultimate goal is to reduce the number of physical iterations to one, the final product.

In the early stage of design when the layout of the mechanism is still being defined, the DADS environment provides a quick way to create a rough sketch of the mechanism and perform accurate analysis of these early conceptual designs. This would be similar to working with a modular kit of parts or cardboard cutouts; of course, the DADS environment makes this process quicker and more accurate. As the design progresses and the parts approach their final state, a more detailed analysis can be performed based on the assembly defined by the Pro/Engineer model.

One major benefit of using the DADS analysis package is that it has a seamless interface with Pro/Engineer. In fact, a large portion of the setup for the mechanical analysis can be performed in the Pro/Engineer environment. DADS may be started from the Pro/Engineer menu and the basic elements of the DADS analysis can be setup using the full capability of the Pro/Engineer interface. The setup of the system involves defining motion constraints, joint, etc., contacting surface, external driving forces and torques, springs and dampers elements, bushings, or any element usually found in mechanical systems. These elements are defined using coordinate systems and are much easier to place through the Pro/Engineer environment than the DADS environment. Once the basic elements of the system have been set, the setup is usually completed in the DADS environment. The analysis is usually performed in the DADS environment. It is during the analysis phase that the power of numerical simulation becomes apparent. In this phase t he designer can vary the parameters of the model and compare the effects of changing one value or another. Both Pro/Engineer and DADS are able to run on an engineer's workstation (PC, SGI, etc.). The animation resulting from the DADS analysis can be quickly viewed in the DADS environment.

Although the DADS software allows for a quick 3-D visualization of the results, the mechanism appears cartoon-like since objects are visually represented by coarsely triangulated surfaces. The DVS team is working to incorporate the analysis results of the DADS software into software packages that specialize in visualization, such as VisLab, VisMockup, and DVMockup. These software packages can create high-resolution animations that have realistic appearance and motion. This will make the results available to more people as these animation packages can port animations to videotape, MPEG movies, web interfaces, etc.

The DVS team has used the results of DADS analysis to animate the operation of the BIOS wing design. Through uses of DADS and animation, a design flaw was found and corrected.

2.2.2.2 Interactive 3-D Tools

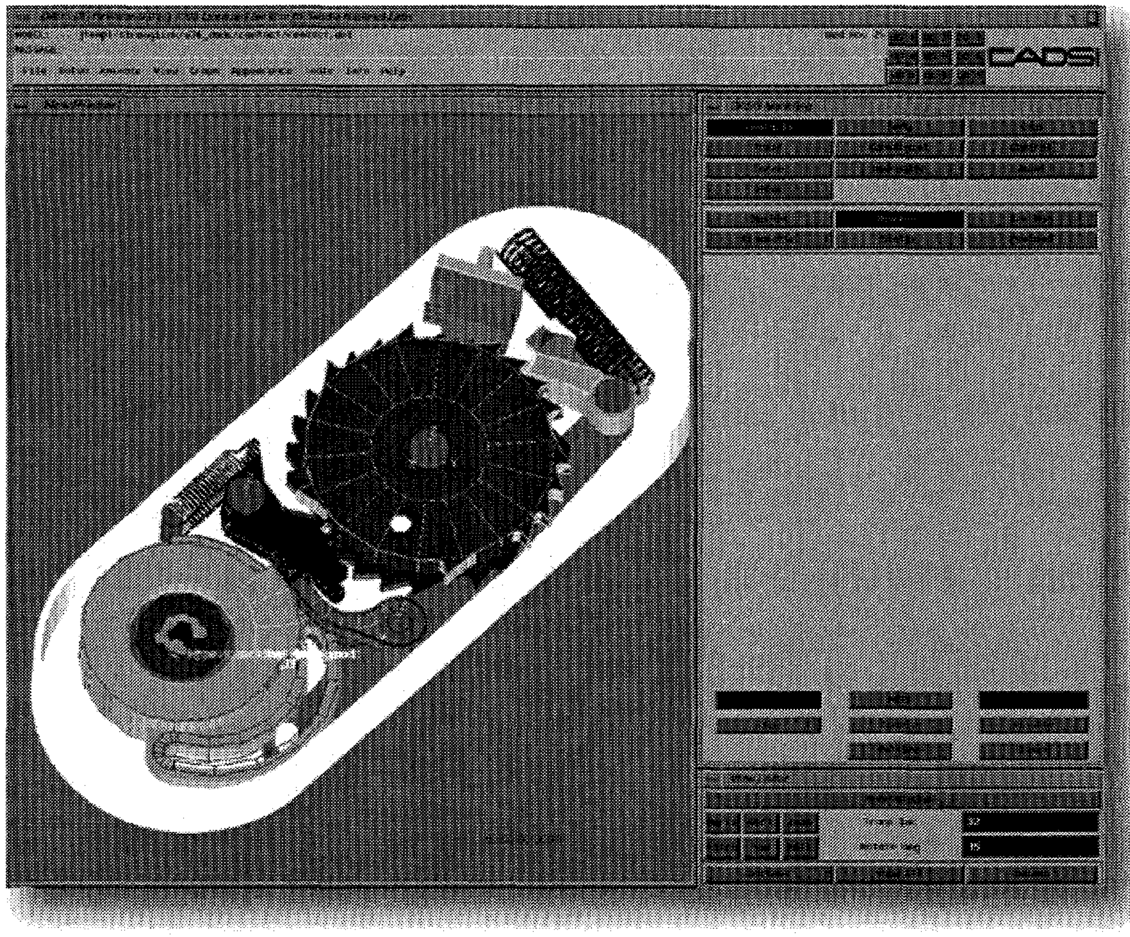

Figure 2-4 DADS Graphical User Interface

A collection of complementary software tools from Division--DVISE™ and DVMock-up™-- allows users to quickly visualize an existing Pro/Engineer model in an interactive 3-D environment. Division's software gives designers a method of interacting with a 3-D model that mimics their interaction with the physical device. Animating the results of an engineering analysis is a powerful method of illustrating the operation and functionality of a device. However, there are characteristics and properties of a product that are not elucidated through analysis alone. A problem arises when these characteristics must be defined, modified, and understood during the early design iterations when a physical mock-up is not available. Most important are how the users will interact with the product and how the product responds to events in its environment.

At the heart of Division's software is DVISE, a kernel that is used to create and maintain the virtual environment and all the objects it contains. DVMockup is a Graphical User Interface (GUI) which allows user to manipulate objects in the environment by changing their various properties. Most user interaction takes place through the GUI. Three Applications Program Interface (API) libraries allow access to the DVISE kernel and can be used to create custom DVISE applications or plugin applications that enhance the capabilities of the standard DVMockup GUI. Since DVISE was designed as a virtual reality application, it can easily be interfaced with immersive devices such as 3-D goggles, crystal eyes, glove-input devices, etc. However, the desktop interface is very powerful and the entire functionality of DVISE is accessible from an engineering workstation with only a monitor and a 2-Button mouse.

As with DADS, DVISE has a seamless interface to Pro/Engineer. This makes converting the assemblies created in Pro/Engineer a simple task. Each part in the Pro/Engineer assembly has a separate DVISE geometry file. Therefore, an update to the Pro/Engineer model can quickly be incorporated into the DVISE environment.

All objects in the DVISE environment have user-defined *properties* which define how an object will respond to an *event* in the DVISE world. Numerous events can occur in the DVISE environment. A few are listed here:

- An object may be *selected* by the user.
- One object may *collide* with another.
- The user may depress a keyboard key causing a *keypress* event to occur.

The *events* described above, and many others, may be linked to an *action* which is executed when the *event* occurs. *Actions* may then effect a change in the DVISE environment by modifying the properties of one, many, or all object. A few useful actions are listed below:

- *dvAssemblyFlash* causes an object to flash to a bright red at a specified frequency
- *dvAssemblyDrop* causes the user to drop the assembly
- *dvAssemblyVisual* changes the visual properties of the assembly
- *dvAssemblyResetPosition* restore an assembly to it's original position

The *properties* of an object determine how the object appears to the user, responds to actions, and interacts with other objects. The properties of a DVISE assembly are outlined below:

- *Animation properties* - a series of key-framed position, orientation, and scaling information that define an animation sequence. Each object may have multiple animation properties.
- *Audio properties* - determine what sounds are associated with an assembly
- *Base properties* - are the position and orientation of an object.

- *Behavior properties* - register an object's interest in a certain event. When the event occurs, a corresponding action function is executed.
- *Collision properties* - determine how the object may collide with other objects in the environment; choices range from a bounding box to polygonal representation.

- *Constraint properties* - may be used to constrain the motion of an object by limiting motion in any of the 6 Degrees of Freedom (DOF) by specifying a range of motion or eliminating motion in a particular degree of freedom.
- *Light properties* - determine how light will fall upon an object, reflectivity, emissivity, etc.
- *Visual properties* - determine how an assembly will appear in the DVISE environment by determining the 3-D geometry that represents the object and the material of which the object consists. The material can be changed to appear as common materials such as wood, metal, plastic, rubber, etc.

Once the DVISE environment has been defined, users can be given access in a number of different ways. First, the user may simply run the DVMockup GUI and have full access to the DVISE environment. Second, the user can view MPEG movies DVISE created. Third, the user can view the DVISE environment over the Internet using Netscape and Division plugins. For collaborative efforts, DVISE also allows multiple users to enter the DVISE environment from networked engineering workstations. The various interfaces to DVISE make it a versatile and efficient method of delivering interactive 3-D visualization environments to multiple users.

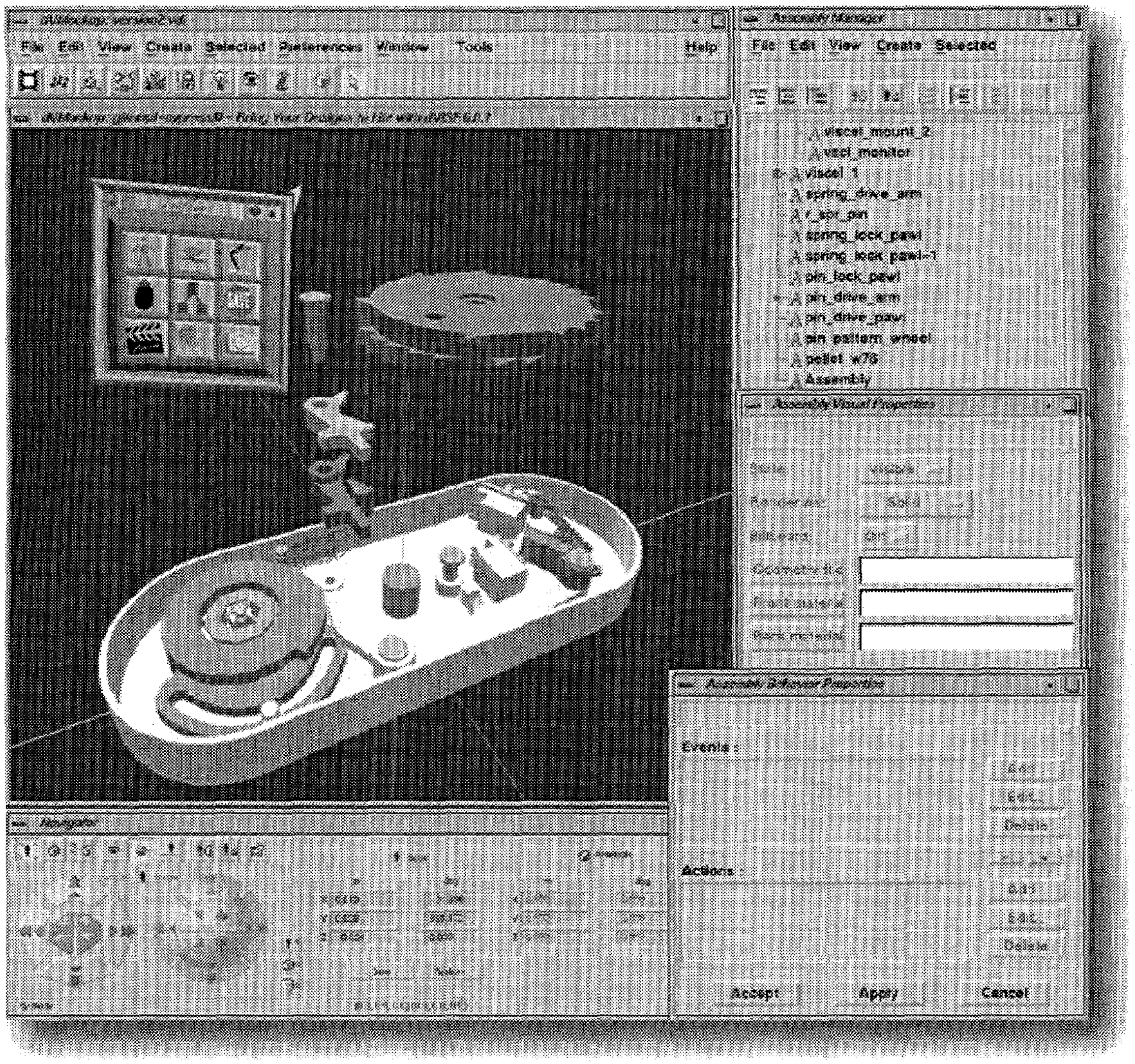

Figure 2-5 Division Graphical User Interface

2.2.2.3 Animation Tools

As stated earlier, the standard 3-D solid modeling software used at Sandia for design work is Pro/Engineer. Although Pro/Engineer is very good at modeling individual parts and small assemblies, large assemblies become very cumbersome to both manipulate and view. For collaborative purposes, it is necessary to dynamically manipulate large assemblies in real time. To look into the details of the assembly, the capability of changing the visual properties of parts (i.e. color, transparency, texture, and geometric representation) is critical. In addition, for assemblies with moving parts, it is very important to be able to visually simulate part motion. Finally, it is crucial to deliver analysis and simulation results to colleagues at distant locations.

Based on the above needs, we selected VisLab™ and VisMockup™ products from Engineering Animation, Inc. (EAI) as the product of choice for animation rendering. Engineering and manufacturing departments can use EAI's digital prototyping and digital assembly solutions to enable early discovery and communication of design and assembly issues with all team members. VisLab is a leading-edge 3-D-visualization software tool for engineering design. VisMockup is a high-performance engineering visualization tool that allows interactive real-time viewing of complex CAD designs. The EAI products were chosen based on the following properties:

- Direct interface with Pro/Engineer
- Maintains Pro/Engineer assembly structures
- Accepts data from a host of standard and industry-accepted analysis programs including SDRC I-DEAS, ANSYS, RASNA as well as Sandia's in-house programs
- Interactive, dynamic inspection of large assemblies
- Ability to animate deflection and stress data
- High-speed rendering optimized for accelerated hardware graphics
- Designed for use by both engineers and visual animators
- Process only the components that have been altered since the last database update, providing the most current design iteration
- Products are easy to learn and use and have high performance and capacity

VisLab is used to generate realistic and accurate animations that demonstrate and/or simulate motion, finite element analysis, and particle flow. Engineers can use VisLab to create simulations that demonstrate operations and procedures to technicians, support personnel, etc. They can also create training videos to show step-by-step assembly instructions to manufacturing personnel, by graphically exploding or imploding any subassembly into it's associated parts, at any speed and any angle, then re-assemble them.

Using the VisMockup software, engineers can check for part conflicts and interference, by conducting an interactive fly-through of the assembled model looking for errors. They can also use interactive functionality to manually zoom into and inspect any part of the design during a live review process. Animations created in VisLab can be imported into VisMockup, thus allowing engineers to fly-through a dynamic assembly with moving parts.

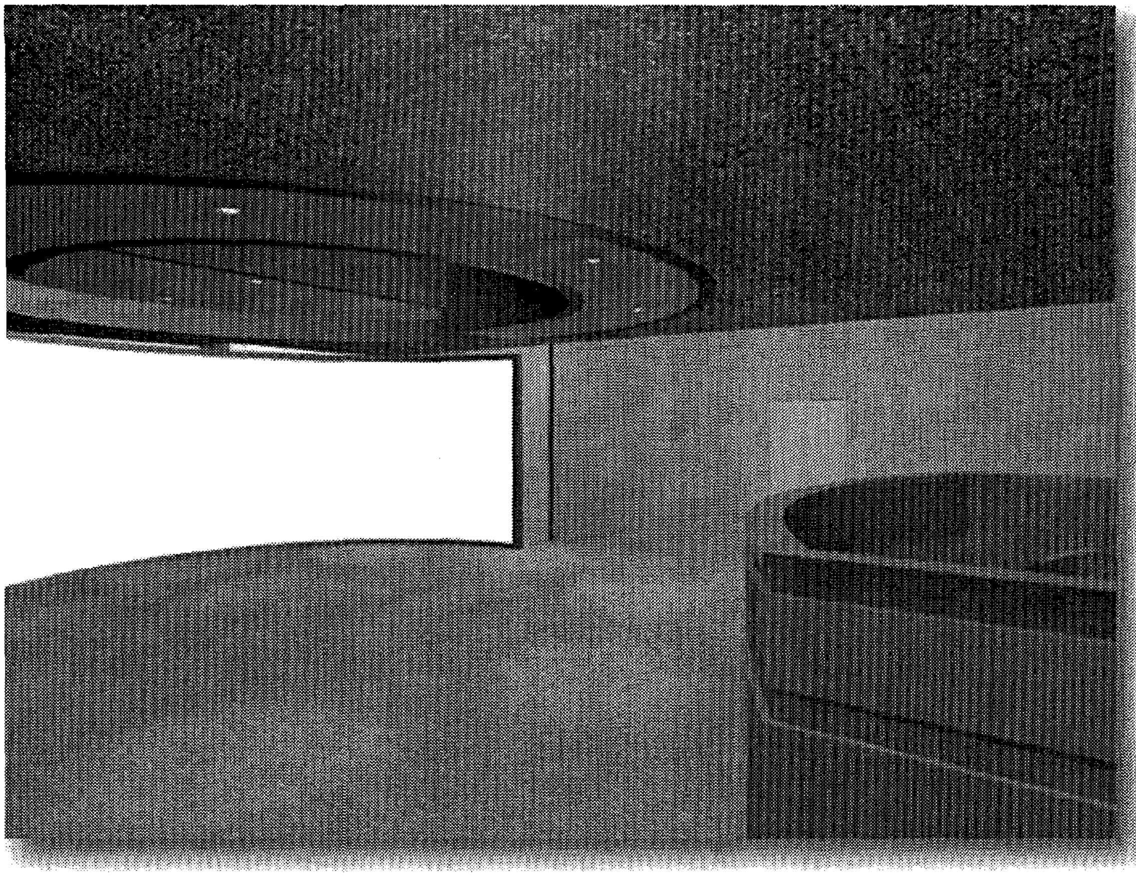

Figure 2-6 Visualization Design Center – Screen View

To create photo-realistic images, we use Avid SOFTIMAGE 3D™. SOFTIMAGE 3D is a fully integrated, high-end 3-D modeling, animation and rendering package that is widely used by the games, film, broadcast and advertising industries. SOFTIMAGE 3D is comparable to Alias Wavefront in that engineers, to visualize their product design, can also use it.

A prototype of the DVC, shown in Figures 2-6 and 2-7, was created using SOFTIMAGE 3D. The 3-D models used for the prototype were a mixture of objects created both in SOFTIMAGE and in Pro/Engineer. Pro/Engineer models needed to be run through a conversion process that included exporting them in .SLP format and using a 3-D-file converter (InterChange) to convert them into SOFTIMAGE objects. Once assembled, the object database was used to render photo quality images of the room. A sequence of images was used to create a QuickTime VR version of the room. Both formats allow for viewing at the desktop using a web browser.

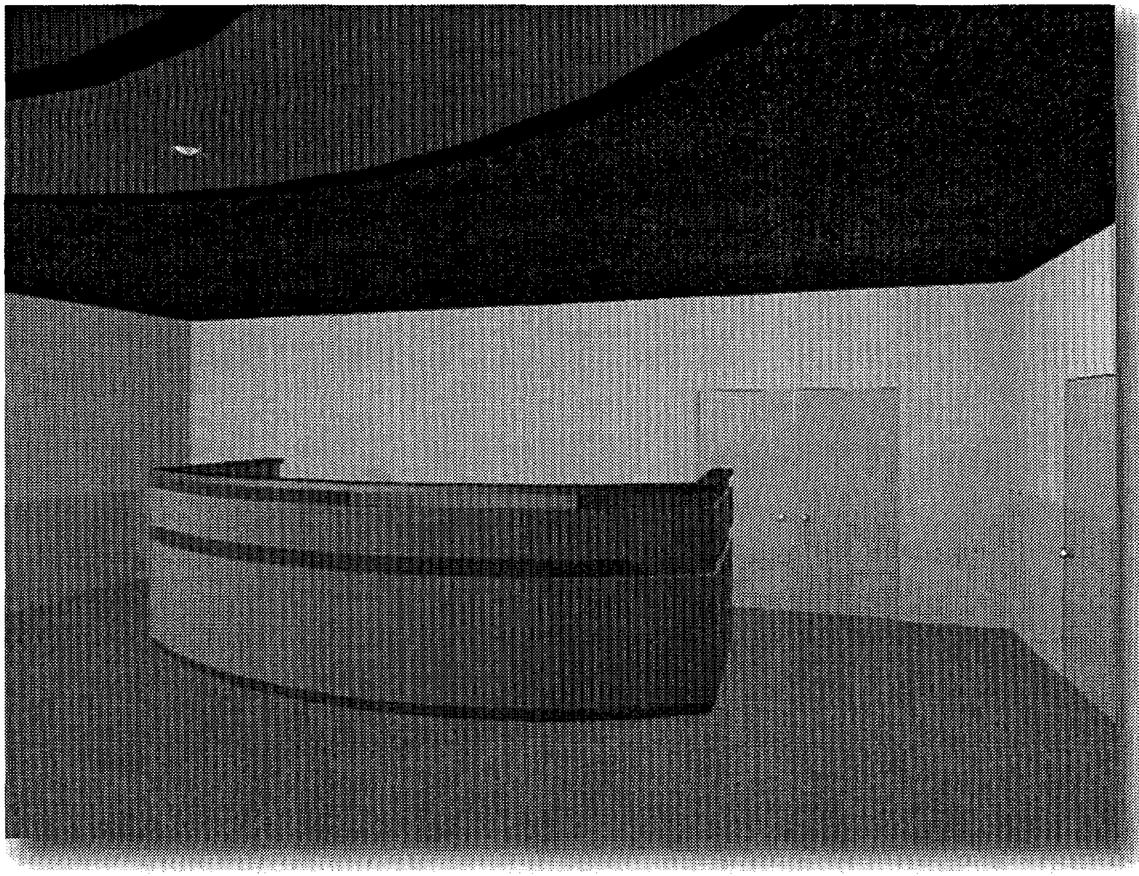

Figure 2-7 Visualization Design Center – Console View

2.2.2.4 Scientific Visualization Tools

EnSight™ is a commercial software package for the postprocessing, visualization, and animation of complex datasets. One of EnSight's unique features is it ability to run in a distributed mode, sharing the workload between a Server process (handling data I/O and compute intensive functions) and a Client process (managing user-interface interaction and rendering). The client and server processes can run on a single workstation or the client can run on a workstation with the server running on a remote workstation.

EnSight was selected by the ASCI Visualization team as the primary commercial off-the-shelf software for Finite Element visualization needs. EnSight was chosen because it includes the functionality required by a large number of users. It includes standard features such as colors, contours, isosurfaces, particle traces, clip planes, vector arrows, displacements, and queries. Additional features are multiprocessor computation support, stereo display, VRML output and multiple formats of file input. One other major feature is the support for simultaneous use and display of both structured and unstructured data. EnSight also has an intuitive, easy-to-use user interface.

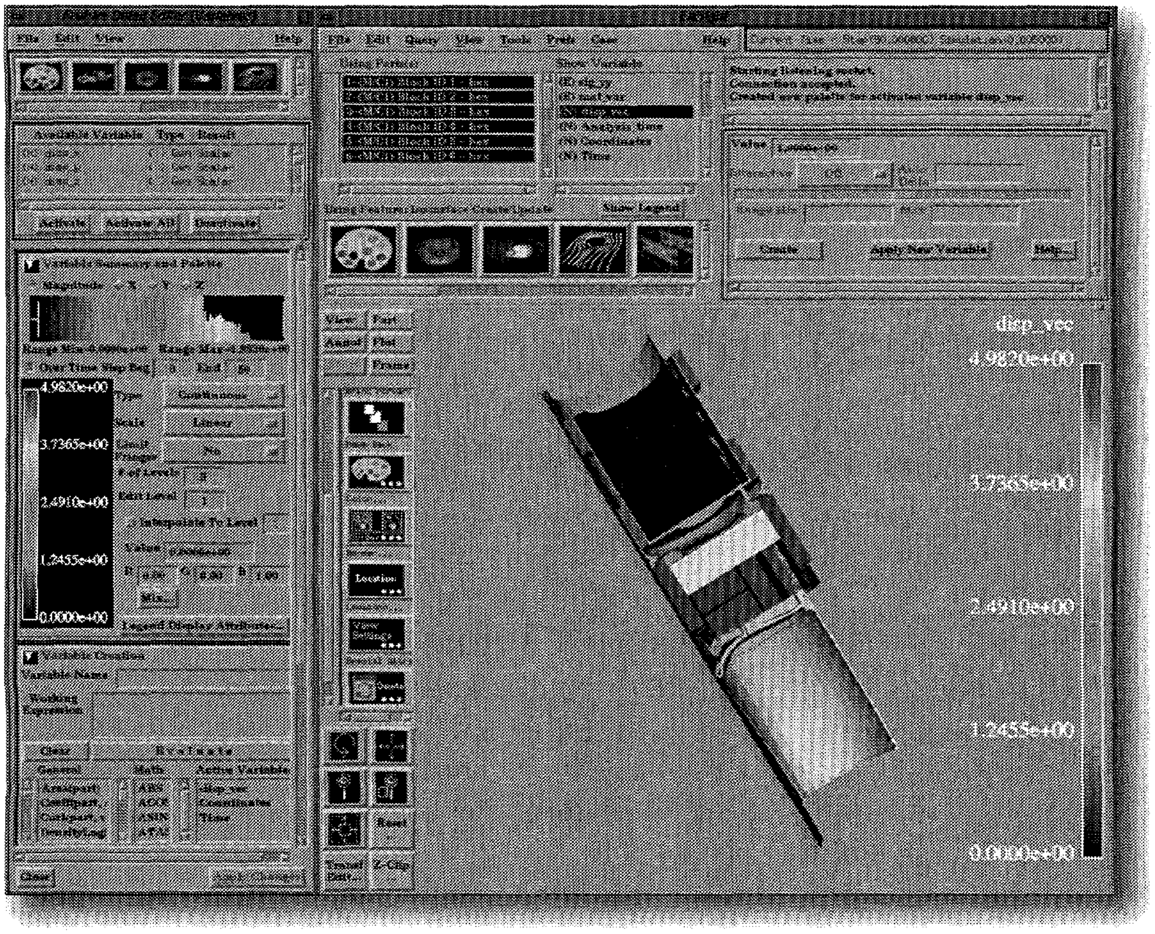

Figure 2-8 Displacement using EnSight

EnSight can read a large number of commercial data formats. However, Sandia utilizes the Exodus and PDS/PIO formats extensively and EnSight does not directly support them.

Exodus is a model developed to store and retrieve data for finite element analyses. An Exodus data file is a random access, machine independent, binary file written and read via C, C++, or FORTRAN library routines that comprise the Exodus API.

PDS/PIO is a simple, parallel library designed to support efficient transfers of massive, grid-based, simulation data among memory, disk, and tape subsystems. The higher-level PDS (parallel data set) library manages data within a finite-element context, while the lower-level PIO (parallel input/output) library reads/writes data arrays with permutation, as needed. The entire library is implemented in C with Fortran-callable PDS wrappers. Users should access the library only at the PDS level. PXI (parallel Exodus interface) provides even higher-level data abstraction. PXI is built upon PDS to support parallel, Exodus II-like functionality.

2.2.2.4.1 Readers/Converters

An Exodus to EnSight converter was written to incorporate Sandia's data with EnSight. This converter is used to convert geometry, scalar and vector multivariate data from Exodus files into either ASCII or binary EnSight formatted files. This generates a large number of files as the EnSight data format uses individual files for each variable and geometry at each time step. Similarly, a PDS to EnSight converter was written utilizing the PXI interface. Both converters utilize the same command syntax that requires knowledge of the variables and number of time steps in the initial dataset. A dataset query program was created for the Exodus and PDS formats to retrieve this information.

After these programs were written, a user-defined reader capability became available for EnSight. By following a reader template, it became possible to write a module for reading non-native data formats directly into EnSight. This capability was then developed for both the Exodus and PDS formats. The new readers have more functionality than the converters and are easier to use. However, there is one drawback to using the user-defined reader. When reading a very large dataset the user-defined reader ties up an EnSight license while importing the data. For some of Sandia's datasets this can take up to a half-hour in some cases. The EnSight data format generated using the converters can be read in more quickly and can be done in a batch fashion. Thus, both the readers and converters have a place that is really dependent on dataset size.

2.2.2.5 Desktop Delivery Tools

The Virtual Reality Modeling Language (VRML) is a file format for describing interactive 3-D objects and worlds. VRML is designed to be used on the Internet, Intranets, and local client systems. VRML is also intended to be a universal interchange format for integrated 3-D graphics and multimedia. VRML may be used in a variety of application areas such as engineering and scientific visualization, multimedia presentations, entertainment and educational titles, web pages, and shared virtual worlds.

VRML 1.0 is based on the Inventor File format (ASCII) with some additional web enhancements such as linking out to the web (equivalent to HREF anchors in HTML). While a VRML browser provides a means for a user to "fly" through or around objects, models created using the VRML 1.0 specification are mainly static with the only as much user interaction as an HTML link can provide.

VRML 2.0 extends the VRML specification by adding animation, interaction and behaviors. Another feature of the 2.0 specification was a simplified scene graph that helped to decrease the file size. Scalability was added by the creation of the PROTO statement that allows for the definition of a new node type by combining existing node types. Also created was an EXTERNPROTO statement that, like the PROTO statement, not only allows one to created new nodes but also makes it possible to use definitions that exist anywhere on the Internet. Using the EXTERNPROTO statement, libraries of scenes can be built, stored on more than one machine and can be reused by anyone with access to them. VRML 2.0 became an International Standard in 1997 (ISO/IEC 14772) and is now known as VRML97.

VRML was used to enable the viewing of engineering data at the users' desktop. The viewing of these files required nothing more than an Internet connection and a VRML browser or Netscape browser with a VRML plug-in. Three scenes were created each depicting a different way of distributing engineering information.

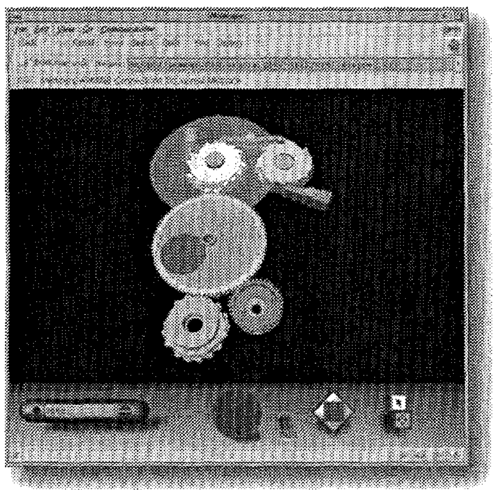

Figure 2-10 VRML Stronglink

The first scene consists of an animated stronglink assembly (Figure 2-11). The model consists of parts created in Pro/Engineer that were exported to inventor format. Using SGI's Cosmo Worlds software, animation was added to the assembly based on data exported from EAI's VisLab. This scene provides a means for an engineer to interactively view the mechanism close-up while it was stepping through its various states. While several predefined "camera" positions were set, the user could further explore the model using the fly-through capabilities of the VRML browser.

The second scene depicts a time stepped thermal analysis of a part (Figure 2-12). Using data from EnSight, models were exported, in VRML format, at various time steps. The files were merged and, with additional modification, made to interact to a mouse click by stepping through the various thermal states.

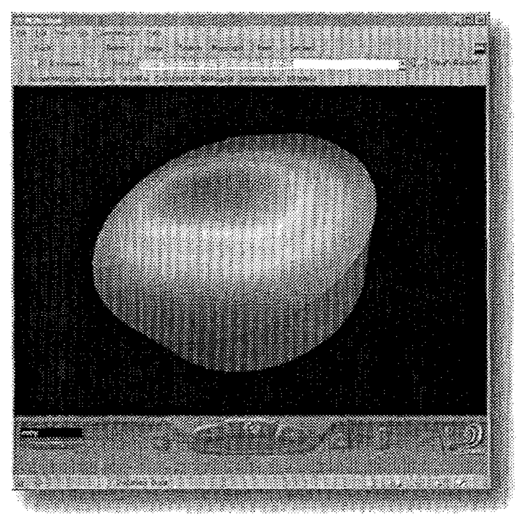

Figure 2-9 VRML Thermal Analysis

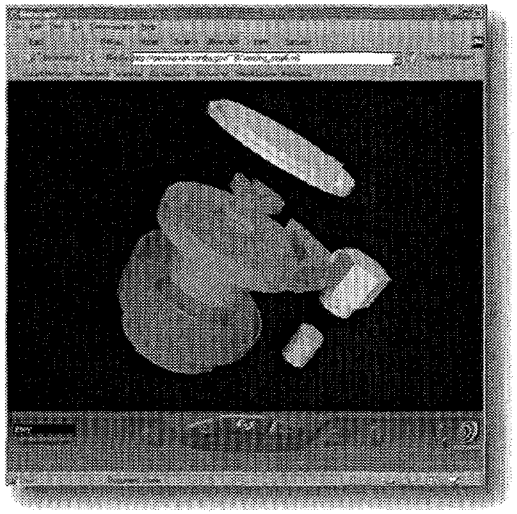

Figure 2-11 VRML Assembly Procedure

The third scene was a prototype for an assembly procedure (Figure 2-13). Again, models were exported from Pro/Engineer and reassembled into Cosmo Worlds. Touch sensors were added to the various parts. Now when viewed in a browser, a user could click on a part and remove it from the assembly. Although not done in this example, scripting could be added to the various nodes that would reflect the true disassembly of the model.

2.2.3 Remote Consoles

High performance graphical supercomputers with adequate memory and disk storage for Sandia's problems are in short supply and high demand. They are also very expensive, so every possible method which increases the availability of these computers should be considered. One of the technical problems we are investigating is the machine accessibility. Logging on remotely and executing batch functions have been improved by the growth of robust, high-speed computer networks. Execution speed has been exponentially increased by the development of today's high-performance CPU's. However, the true power of these machines lies in their ability to visualize and render the extremely large data sets and assemblies generated by analysts and designers. This functionality is only truly available when using the high-speed graphics boards that drive the computer's local graphics console. Therefore, to provide this functionality to remote locations--either intra-site or inter-site--some technical obstacles need to be addressed.

2.2.3.1 Intra-site Distribution of Visualization Displays

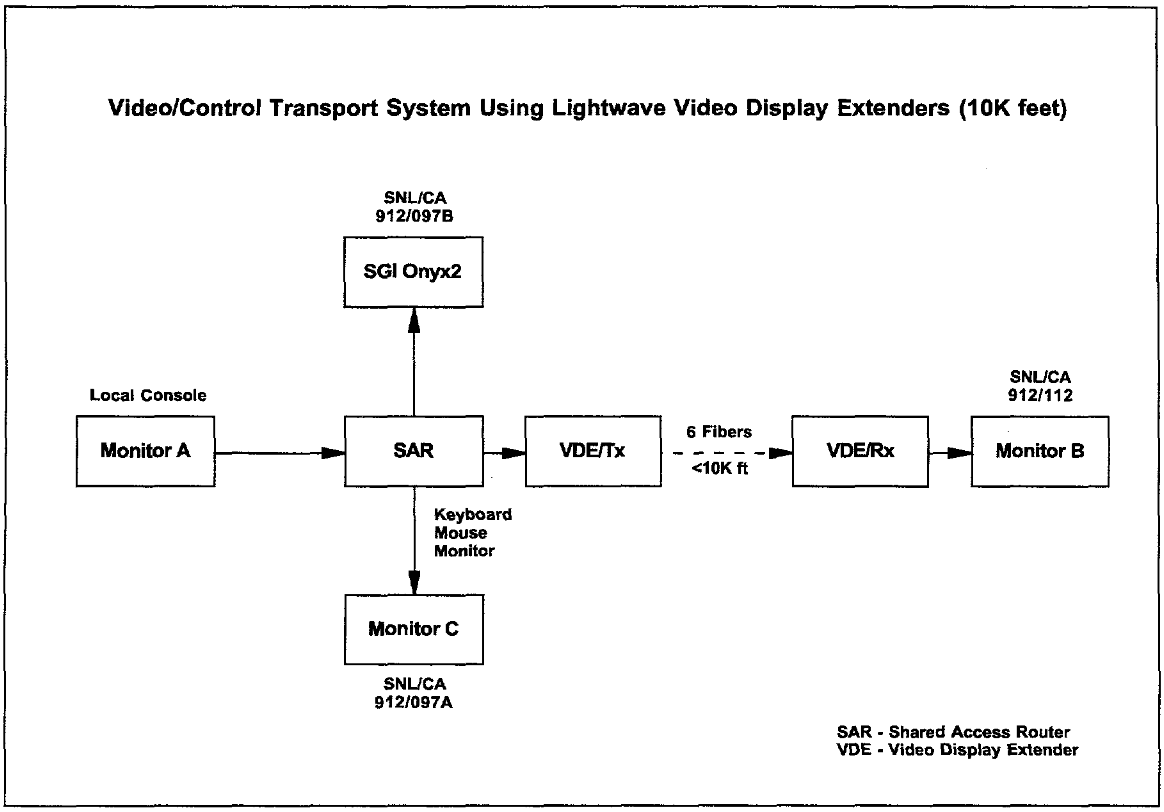

Figure 2-12 Intra-site Console Distribution using Lightwave Hardware

The first scenario to be addressed is the distribution of computer displays intra-site. For example, at Sandia/CA there was a need to distribute the single console of our classified PowerOnyx between three locations: the local console, the VDF, and an analyst's vault. The solution employed (Figure 2-12) uses routing and display extension hardware purchased from Lightwave Communications, Inc.

Lightwave's Shared Access Router™ (SAR) allows sharing access to our SGI computers. The SAR routes the console of our SGI PowerOnyx (display, keyboard and mouse) between multiple dedicated graphics consoles. The SAR is configurable for either Instant Access (hot key activation provides immediate access) or Central Control (a push button control on the front panel of the SAR allows central override). For classified use, we insist upon using the Central Control technique. The SAR is also configured so that only the active console can view the display. The system is upgradable to up to 20 locations, but we currently only distribute the console to two different locations (Building 912, Room 097A and Building 912, Room 112).

Lightwave's VDE/200 Video Display Extension™ System is used to distribute the consoles to the remote locations. The VDE/200 allows remote access from a keyboard, monitor, and mouse up to 10,000 feet, fiber optically, with no loss of graphic resolution.

This is a good solution for fixed displays located at the same site, but will not work for inter-site distribution.

2.2.3.2 Inter-site Distribution of Visualization Displays

One method to distribute remote visualization displays inter-site is to convert the console display to a video signal and ship this over an ATM network (Figure 2-13). FORE Systems, Inc. provides hardware to distribute video over an ATM network. The StreamRunner™ AVA/ATV product is a state-of-the-art digital video network product family providing full-motion JPEG video imaging and transmission over ATM networks. The StreamRunner AVA/ATV consists of the StreamRunner AVA-300 for video encoding and transmission, and the StreamRunner ATV-300 for video decoding and reception. For our production system, one to four pairs of AVA/ATV's can be used to ship the remote console display to the local display, depending on the fidelity required. A single AVA/ATV pair can ship the full display (down-converted to 640x480 resolution), or multiple pairs can ship almost the full 1280x1024 resolution using a quadrant technique. The signals can then be recombined at the local end using a video recombination system. The system we are most interested in is the SuperView1000™, marketed by RGB Spectrum. This product is capable of displaying up to 10 live video images on a single screen, with an overall resolution of 1600x1200 pixels. It also permits zooming within each video signal.

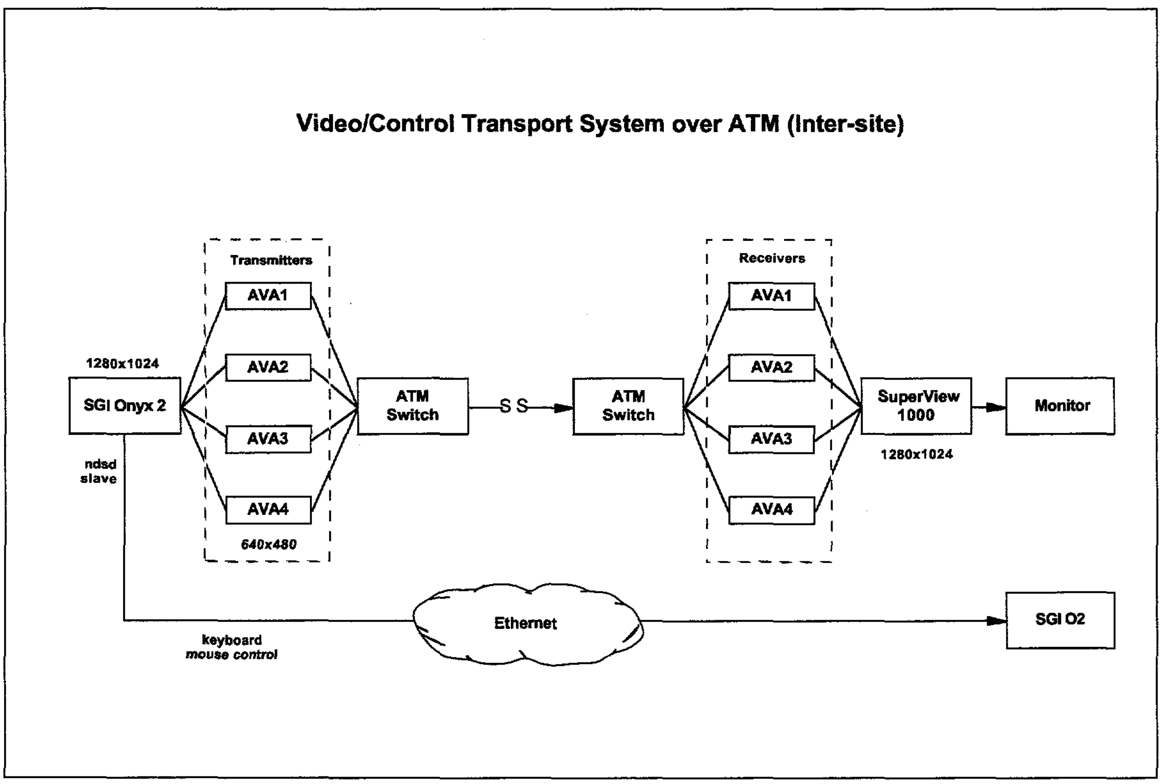

Figure 2-13 Inter-site Transport System

2.2.3.3 Remote Control of Visualization Consoles

It is not enough to be able to view a remote computer's console locally. In order to perform the engineering design and analysis functions required the local user must be able to control the contents of the remote visualization computer's display. X-Windows provides the ability to display a window from the remote computer on the local display, but does not permit the control of the console itself. The technique we employ uses software provided on SGI workstations. The Networked Dual-head Software Daemon, ndsd, enables a machine with ndsd software, the "slave" machine, to accept keyboard and mouse input from another machine on the network. The slave machine appears as a virtual desktop to the left (or right) of the master machine's desktop. In the test configuration we employed, when the user moved the mouse past the right edge of the master display, the mouse and keyboard then controlled the slave computer. Using this software, in combination with the FORE AVA/ATV hardware, we are able to control the remote visualization console using the local keyboard and mouse, and display this on a local monitor or projector.

3 Case Studies

This chapter describes related work performed for other Sandia departments over the past two years. The work has been predominately the animation of Pro/Engineer assemblies, through which we have been able to convert a large number of people to the visualization design center paradigm. Some projects have been one-time affairs, others are on-going and we are still heavily involved. All projects have been greatly enhanced by the use of the visualization design center equipment, software, and techniques.

3.1 Stronglinks

The first Sandia part chosen for proof-of-concept was the MC4438 Single Stronglink Assembly (SSA). This mechanism is one of two independent stronglinks used in the Pit Reuse for Enhanced Safety and Security, Cruise Missile applications (PRESS/CM). The stronglink is a rugged, mechanical device used to ensure the safety of nuclear weapons in both normal and abnormal environments. In the prototype environment that was built for

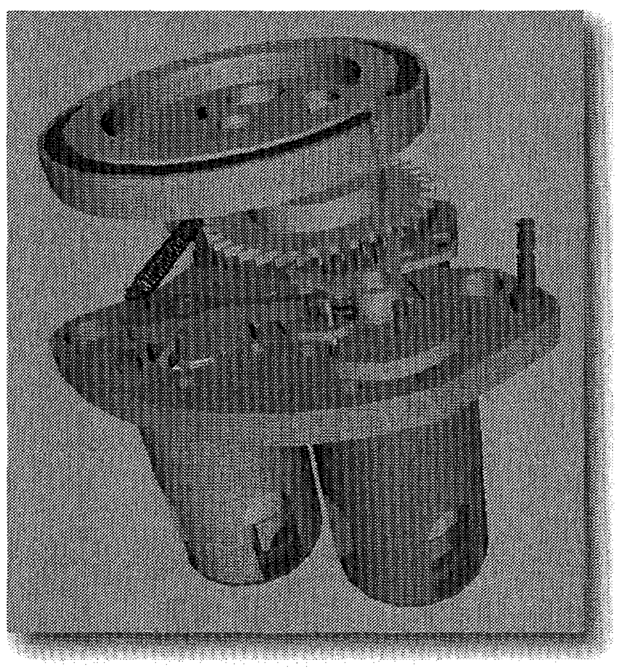

Figure 3-1 Stronglink Iterations

this project, the simulated design team was able to view and manipulate the stronglink assembly by using both the solid modeling application (Pro/Engineer) and the interactive engineering visualization/animation tools (VisMockup/VisLab). Additionally, a static VRML model of the assembly and a kinematic animation were generated for viewing with a World Wide Web (WWW) browser. For this application, just the first four steps of the stronglink device were animated.

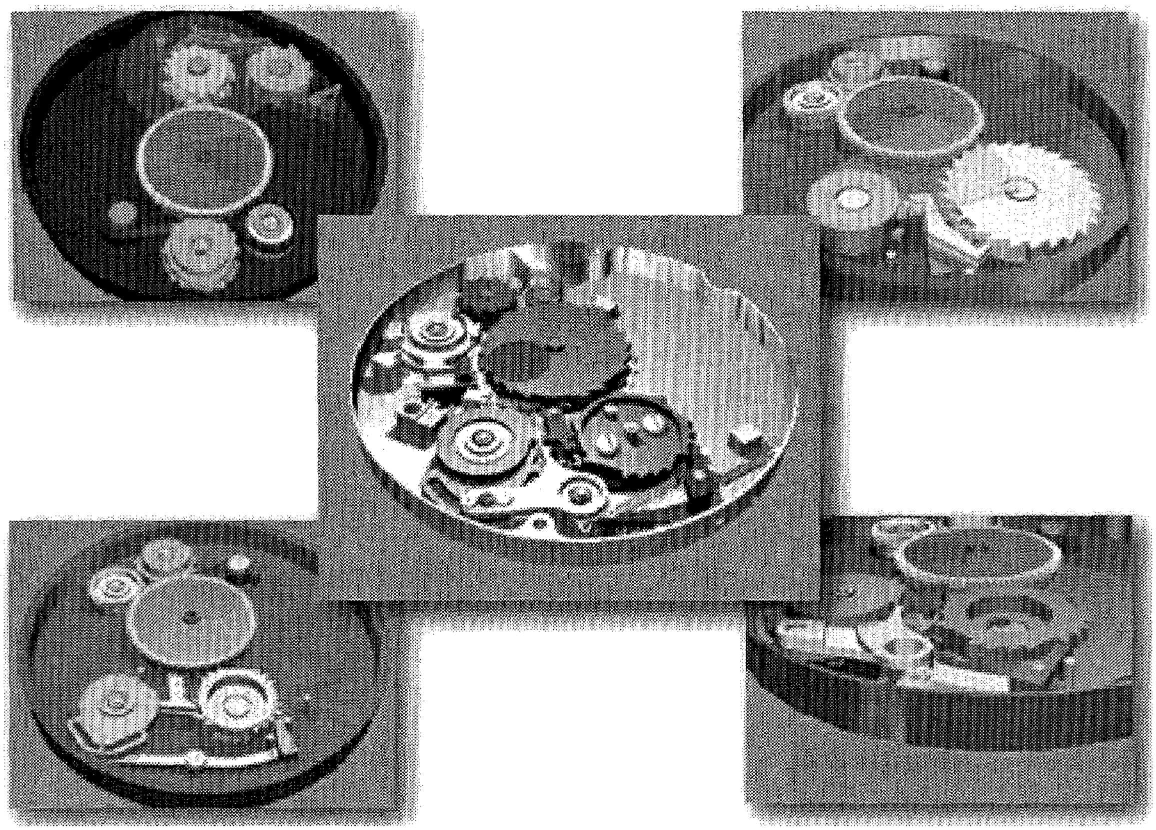

Figure 3-2 Five Versions of the CDSL

When shown the capabilities of the environment, the engineers and designers of the current generation stronglinks requested a simulation of the motion of their current Colocated Detonator Stronglinks (CDSL) safety system for SWPP/PR. Figure 3-2 shows pictures of five generations of stronglinks taken from video clips generated for their project. Figure 3-3 is a picture of a prototype stronglink being proposed for the W87. The last video clip produced was an animation showing, from different perspectives and with varying visible parts, how a lockup occurs when an incorrect sequence is entered.

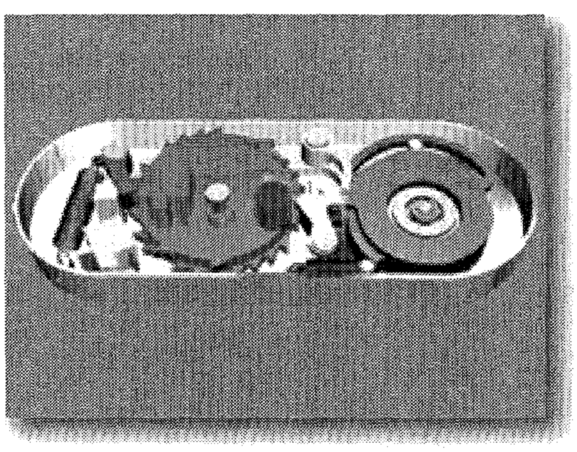

Figure 3-3 Prototype W76 Stronglink

These video clips have been used to show the interior workings of mechanisms before the part was actually built, detailing even the motions of coil and leaf springs in a manner that can be easily understood by both designers and engineers. They have been perceived as a great success for the visualization efforts at Sandia.

3.2 SWPP

The SLBM Warhead Protection Program (SWPP) is a joint DOD/DOE program to examine replacement options for the W88/Mk5 and W76/Mk4 systems. During the progress of the Pit Reuse Option, a prototype system is being assembled for a flight test in 2000. Multimedia assembly procedures are being developed to replace the traditional paper bound instruction procedures used in the past. The goal of these multimedia assembly procedures is to create a more thorough assembly procedure and record of assembly by incorporating various forms of media (pictures, video, and computer simulations) into a single database.

The following statements summarize some of the benefits of each type of media:

- Photos are much more descriptive than sketches and are the quickest information to incorporate into the multimedia procedures.
- Videos provide a realistic view of the time and complexity of a process by showing footage of actual assembly steps being completed.
- Computer simulations have some unique characteristics relative to the photos and filmed videos.

EAI's VisLab software was used to create the computer simulations used in the multimedia assembly procedures. The simulations were developed based on Pro/Engineer models of the system. These models were then modified to make certain components transparent providing a unique perspective of the assembly process that was previously not available. There are often assembly steps that are blind operations where the user can not see the internal interactions of parts. By showing transparent models of the system, the user can better understand the blind interactions of these internal components. Providing this additional information to the user creates a better understanding of the assembly, and ultimately helps to reduce errors during the assembly process. In a time critical project, errors in the assembly would be extremely detrimental to the on time and successful completion of flight-test unit assemblies. The use of very descriptive multimedia assembly procedures that utilize a combination of photos, video, and simulations will be integral to the successful completion of the SWPP Pit Reuse flight test assemblies.

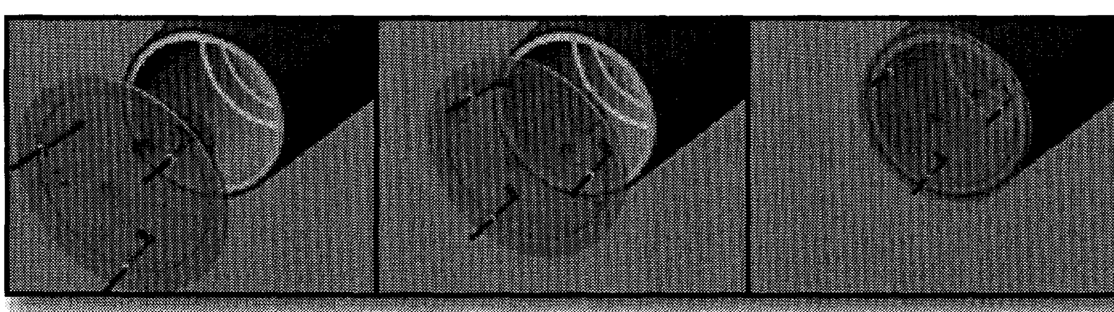

Figure 3-4 SWPP Animation Frames

3.3 Re-entry Body

Empirical testing provides data that is used to verify the behavior of new and modified designs as well as the results of numerical analysis. 3-D visualization can be a powerful qualitative method of interpreting these various types of time-series telemetry data collected during empirical testing. The visualization goal for telemetry data is to "replay" the flight or operation in real-time using 3-D computer representations of the device of interest. In this way, the virtual objects will have the same behavior as the physical objects. Data such as position, orientation, and even audio can be combined such that someone viewing the visualization feels as though they are flying along with the vehicle of interest and witnessing the flight first-hand through multiple senses. The visualization process can give a better understanding of behavior and can highlight errors present in the design, testing procedures, or in the data acquisition system.

In the past, the only method of interpreting telemetry data was through simple X-Y plots of the output of a particular data channel. It is quite a difficult task to discern complicated gross motions and behaviors, such as orbital maneuvers, from 2D (2 Dimensional) data plots. With 3-D visualization tools, data from multiple channels can be combined to recreate the motion recorded in the data. More insight into behavior can be gained with the introduction of audio data. The integration of audio and animations allows users to see and hear events that occurred during testing.

The purpose of the 3-D visualization process is to qualitatively combine as many different data sources as possible to impart to the viewer a more accurate idea of the behaviors that generated the data. It is therefore very important that the visualization accurately reflects the collected data. If errors are present in the data, they will also be present in the visualization.

Ensuring the data is accurate is a separate issue and ideally should be completed before the visualization process begins; the visualization result is only as good as the data used in its creation. If the visualization process is correct, then behavior in a visualization that appears erratic or in error may result from errors in design, testing procedures, data collection, or may result from unpredicted behavior in the system. In either case the visualization has provided invaluable insight to the designer by illustrating an unexpected result.

A prime example of the power of 3-D visualization of empirical data is flight-testing. A recently completed DVS team project involved creating an animation by incorporating data collected during a test flight of a W87 re-entry body and a Pro/Engineer assembly of the re-entry body. The data used for visualization consisted of yaw rate, pitch rate, and roll rate (all in degrees/sec), and sounds recorded during the flight. In this case the data was integrated to obtain the yaw angle, pitch angle, and roll angle at discrete points in time. This orientation information was then used to create a key-framed animation of the flight. The view is that of an observer travelling along with the body but not rotating with it, i.e. an observer in an airplane flying along with the body.

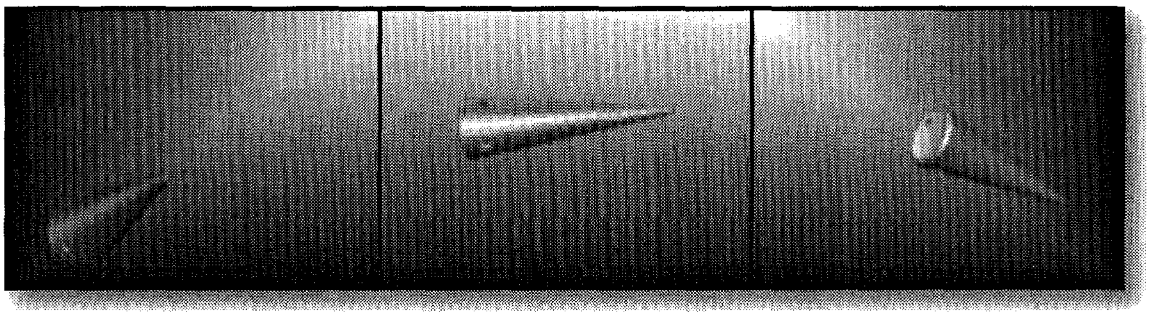

Figure 3-5 W87 Re-entry Body in Flight

Our customers were delighted with the resulting animations, which they say has given them new insight into the behavior of the re-entry body, insight which could not be gained from 2D X-Y plots. This type of animation is the closest anyone can realistically come to witnessing a flight of this nature first-hand.

The tools used for this project included Pro/Engineer for solid modeling, C programming for data conversion, DVISE for proof-of-concept simulation, and VisLab for rendering. Video frames were stored on the Digital Disk Recorder, and combined with the audio data to produce a 5-minute video clip. The result was then transferred to VHS videotape that the customers have used extensively at design reviews and presentations.

A current project that incorporates experimental data with visualizations is a visualization of a complete flight of a missile, from sub-based launch, through separation and orbit, to impact. This project is still in the developmental stages and is a goal for FY 99.

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4 Conclusion

The Visualization Design Center was built to meet increasing demands for visualizing large data sets, improving comprehension of complex data, and interacting with remote team members and their associated information. The VDC addresses these needs by:

- Providing a facility where multi-disciplinary teams can meet and remote participants can interact via videoconferencing and collaborative tools.

- Supplying dedicated computers and display systems capable of rapidly processing and projecting large amounts of information.

- Integrating several software packages into a cohesive suite of tools dedicated to viewing, exploring and comprehending data.

- Developing new techniques for integrating computational and/or test data into visualizations.

These capabilities were successfully demonstrated through a number of case studies. It was concluded that the VDC does provide a true collaborative work environment and promotes improved data comprehension, thus enabling an overall reduction in design cycle time. These results show that the VDC is meeting the challenge of providing effective collaborative methods for visualizing and comprehending large quantities of complex data.

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Appendix A Acronyms

ASCI	Advanced Scientific Computing Initiative
API	Applications Program Interface
ATM	Asynchronous Transfer Mode
BIOS	Bomb Impact Optimization System
CAD	Computer Aided Drawing
CADSI	Computer Aided Design Software, Inc
CDSL	Co-located Detonator Stronglinks
CORBA	Common Object Relocation Broker Access
COTS	Commercial off the shelf
DADS	Dynamic Analysis and Design System
DCE	Distributed Computing Environment
DDR	Digital Disk Recorder
DoE	Department of Energy
DVD	Digital Video Disk
EAI	Engineering Animation, Inc
EUVL	Extreme Ultra-Violet Lithography
GUI	Graphical User Interface
ISO/IEC	International Standards Organization/IEC
LANL	Los Alamos Nation Laboratory
LLNL	Lawrence Livermore National
Ndsd	Networked Dual-head Software Daemon
PRE	Product Realization Environment
PTC	Parametric Technology Corporation
SAR	Shared Access Router
SGI	Silicon Graphics, Inc
SLBM	Submarine Launch Ballistic Missile
SWPP	SLBM Warhead Protection Program
VDC	Visualization Design Center
VDE	Video Display Extension
VRML	Virtual Reality Modeling Language
VTR	Video Tape Recorder

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Appendix B References

Companies

Accom, Inc. – http://www.accom.com
BARCO, Inc. – http://www.barco.com
CADSI – http://www.cadsi.com
Crestron, Inc. – http://www.crestron.com
Division – http://www.division.com
Engineering Animation, Inc. – http://www.eai.com
Extron Electronics – http://www.extron.com
FORE Systems, Inc. – http://www.fore.com
Lightwave Communications, Inc. – http://www.lightwavecom.com
Silicon Graphics, Inc. – http://www.sgi.com
VRML Consortium – http://www.vrml.org
VRML Repository – http://www.sdsc.edu/vrml/
SOFTIMAGE 3D – http://www.softimage.com/
Stewart Filmscreen Corporation – http://www.stewartfilm.com/commercial/
InterChange – http://www.viewpoint.com/
QuickTime VR – http://www.apple.com/quicktime/
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1	MS 0899	Technical Library, 4916
1	MS 9021	Technical Communications Dept., 8815/Technical Library, MS 0899, 4916
1	MS 9021	Technical Communications Dept., 8815 for DOE/OSTI
1	MS 0188	D. Chavez, LDRD Office, 4001