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FINITE ELEMENT VISUALIZATION IN THE CAVE VIRTUAL REALITY ENVIRONMENT

by

Edward J. Plaskacz
Computational Scientist
Argonne National Laboratory

Mary A. Kuhn
Mechanical Engineering Intern
Northern Illinois University

ABSTRACT:

Through the use of the post-processing software, Virtual Reality visualization (VRviz), and the Cave Automatic Virtual Environment (CAVE), finite element representations can be viewed as they would be in real life. VRviz is a program written in ANSI C to translate the mathematical results generated by finite element analysis programs into a virtual representation. This virtual representation is projected into the CAVE environment and the results are animated. The animation is fully controllable. A user is able to translate the image, rotate about any axis and scale the image at any time. The user is also able to freeze the animation at any time step and control the image update rate. This allows the user to navigate around, or even inside, the image in order to effectively analyze possible failure points and redesign as necessary. Through the use of the CAVE and the real life image that is being produced by VRviz, engineers are able to save considerable time, money, and effort in the design process.

INTRODUCTION:

Traditionally, engineering design has involved running finite element codes to simulate the response of a structure under applied loads, writing the output data to a file, and "post-processing" the results at a later time. In general, the term "post-processing" refers to the reduction of finite element results to a manageable level of information. Prior to the availability of computer graphics, much of this data reduction was done manually. This process was tedious, error-prone and only feasible with the crude models being studied at the time. Initial computer graphics devices were specialized as well as centralized. Thus, the role of computer graphics was restricted to being passive; that is, the desired drawings were specified before the computing was done and executed some time after the information was produced. The analyst needed to draw on his intuition to apriori choose the necessary drawings. To remove this uncertainty, the next generation analysis codes stored all the information in data files and introduced interactive computer graphics to display the results. However, the graphics were still being executed some time after the information was produced.

As computational capabilities continued to increase and hardware costs drop, computer graphics were seen as a necessity for dealing with the shear volume of data generated in the course of a simulation; the execution times for many models

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dropped to a point where submitting them as batch jobs became unnecessary. Engineers then found it desirable to observe finite element simulations on a graphics terminal as the computation proceeded, select the desired drawings, and obtain hardcopies for future reference and documentation.

Today, through the use of virtual reality, data from finite element simulations may be examined as three-dimensional images. In this paper we will present an overview of the basic capabilities of the CAVE Virtual Reality Environment. We will describe our use of the CAVE as a "control room" for the interactive visualization of finite element results. Our application allows the user to navigate around, or even inside the image in order to effectively analyze possible problem areas and redesign as necessary. This is accomplished through sliders and buttons controlling image orientation and size as well as a group of buttons analogous in function to the controls on a VCR which allow the user to step through the simulation at various speeds and even stop and pause at frames of particular interest.

OVERVIEW OF THE CAVE:

The CAVE (Cave Automatic Virtual Environment) [1] is a virtual reality environment and is used in the visualization of images. These images are generated through the execution of the parallel distributed nonlinear explicit transient finite element code described in [2] and [3]. The CAVE is a step up from other virtual reality systems. It is a wholly immersive environment which allows peripheral vision, multi-person use, and has full sound and visualization capabilities. The post-processing computer code developed, VRviz (Virtual Reality visualization),

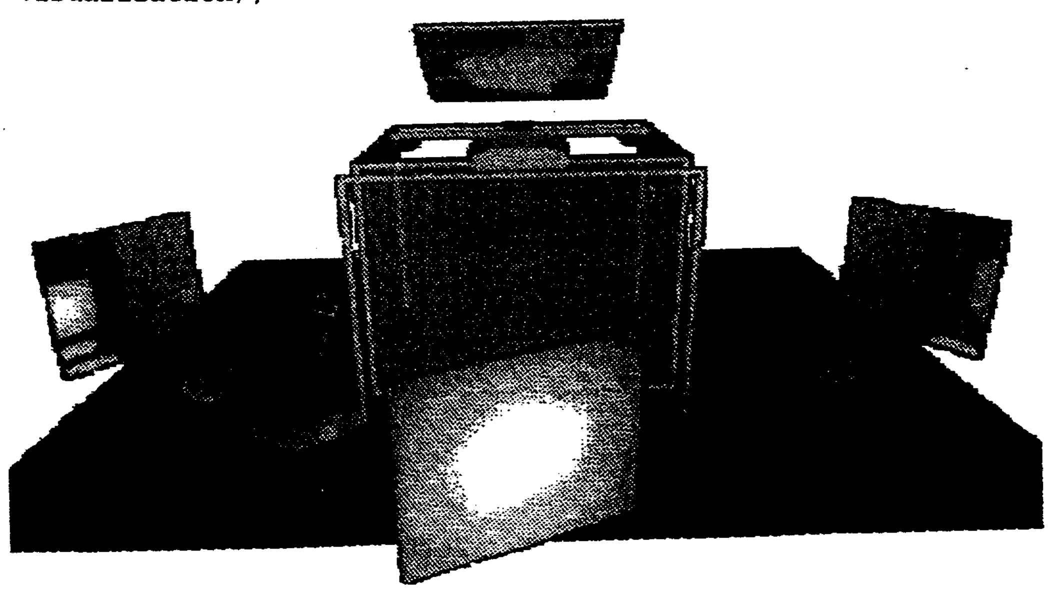

Figure 1. The CAVE Hardware Setup (http://www.ncsa.uiuc.edu/evl/html/CAVE.html)

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allows the results of finite element simulations to be visualized in the CAVE or on a CAVE simulator.

The CAVE Automatic Virtual Environment is a 10 × 10 × 10 ft, multi-person, high-resolution, 3-dimensional video and audio environment (see Figure 1). A CAVE environment consists of a projectable floor and three rear projection screen walls. A projector is set up overhead and the image is bounced off a mirror to reflect onto the floor. Three projectors and mirrors are also set up behind the three projection screen walls. Images are projected in stereo into the CAVE with a resolution of 1024 × 760 pixels. The purpose of the CAVE is to achieve a real life perspective of a 3-dimensional process that could otherwise only be viewed in two dimensions. This visualization technique aids in the understanding of dynamic processes by allowing the visualization of 3-dimensional objects in real time or slow motion. The same reference, right-handed, coordinate system is shared by all walls in the CAVE (see Figure 2).

Stereo glasses are used while in the CAVE in order to view the virtual environment in 3D. Two views are produced for every image, one for the left eye and one for the right eye. In order to see in stereo, a small button on the right side of the glasses is pressed. Stereo emitters around the edges of the CAVE synchronize the stereo glasses and the screen update. The glasses are synchronized to the screen at an update rate of 96 Hz. The two halves of the stereo image are seen 48 times per second by each eye separately. The brain then combines these two views into one 3-dimensional image.

Graphics in the CAVE are produced by a Silicon Graphics Onyx which houses three Reality Engine graphics CPUs. These Reality Engines have direct RGB outputs to Electrohome video projectors. In order to provide audio as well as visual effect, the CAVE utilizes a surround-sound audio system. This system is driven by a SGI Indy running audio server software.

One viewer in the CAVE wears a special pair of stereographic glasses with a six-degree-of-freedom head-tracking device attached. A hand held device called a wand (which is basically a 3-D mouse) is also tracked by a tracking system which is mounted on top of the CAVE. Three buttons on the wand, CAVEBUTTON 1, CAVEBUTTON 2, and CAVEBUTTON 3 can be programmed to perform different functions in the CAVE. The wand placement is utilized by the programmer as a means of control over the image. The programmer can enable the wand to manipulate the CAVE objects directly or through the use of visual buttons and controls on the CAVE walls. The tracking system records the current position of the wand and the headset, both of which act as visualization tools to the user. The head tracker controls the perspective of the image based on its location and elevation in the CAVE. As the viewer moves inside the CAVE, the correct stereoscopic perspective projections are automatically produced.

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OVERVIEW OF VRviz:

The focus of the post-processing software VRviz is the visualization of finite element data in the CAVE. VRviz is a program written in ANSI C [4] with the use of the Silicon Graphics Graphic Library (GL) [5] [6]. This program is written to complement finite element analysis programs such as the Argonne developed IMPACT code [2] [3] and act as a post-processor. VRviz is set up to run finite element results in the CAVE or CAVE simulator. This software allows the conversion of mathematical results to practical visual results through the CAVE. This decreases post-processing time and increases the quality of the results to the designer. The time steps computed can be incremented in slowed time in order to gain a more accurate view of the process as it occurs. In many post-processors, only individual still-frames can be produced. VRviz allows the combination of a sequence of still frames in order to achieve an actual representation of the entire process. A brief description of the functions of VRviz, the virtual reality finite element post-processing program follows below.

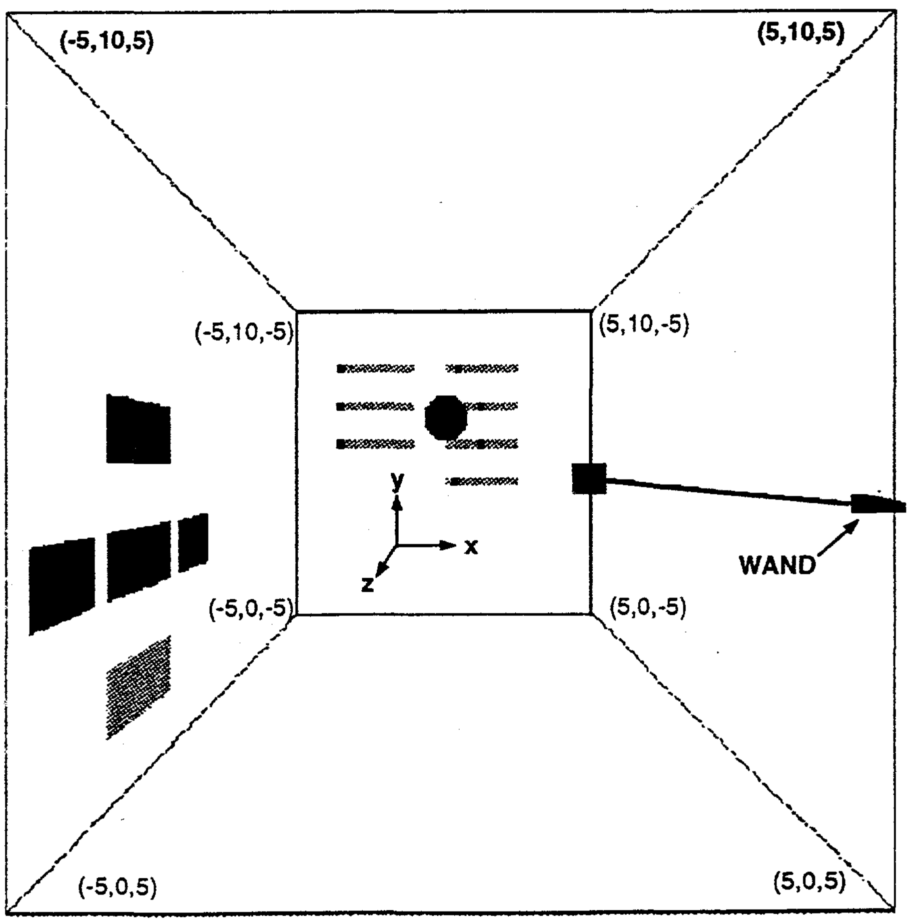


Figure 2. The CAVE Coordinates, Controls, and Wand

VRviz has several visualization options. The controls are all marked for easy utilization. In order to activate any button or control, CAVEBUTTON 1 on the wand must be pressed and the blue box at the end of the projected red line from the wand must be on the button or control (see Fig. 2). The red beam projected from the wand when CAVEBUTTON 1 is pressed stops at the point on the respective wall and a blue box is projected to give the user a better visualization of where the beam is hitting. The beam which comes from the wand can be projected on any CAVE side. The point of the beam on the wall is determined vectorially based on the direction of the wand and the position of the user [7]. The buttons on the left-hand wall control the time frames (see Fig. 3). The "GO" button prescribes replay at the fastest speed. "SLOW" replays the simulation results in slow motion. This control in VRviz allows the evolution of deformations and stresses in individual elements to be studied thus allowing designers to gather ideas for changes and alternate designs in their own environment. The ">" and "<" buttons allow the user to go forward or backward, respectively, by one time step. The image will then remain on that time step until another button is activated. The "STOP" button stops the image at the current time step.

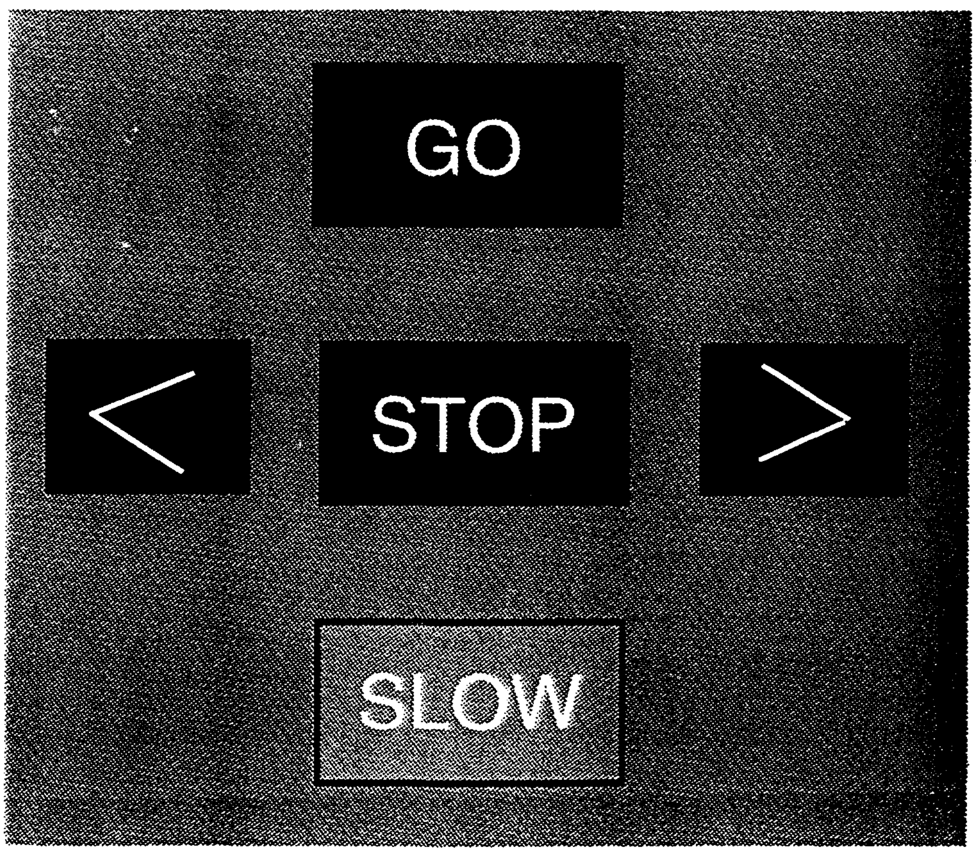


Figure 3. Time Control Panel

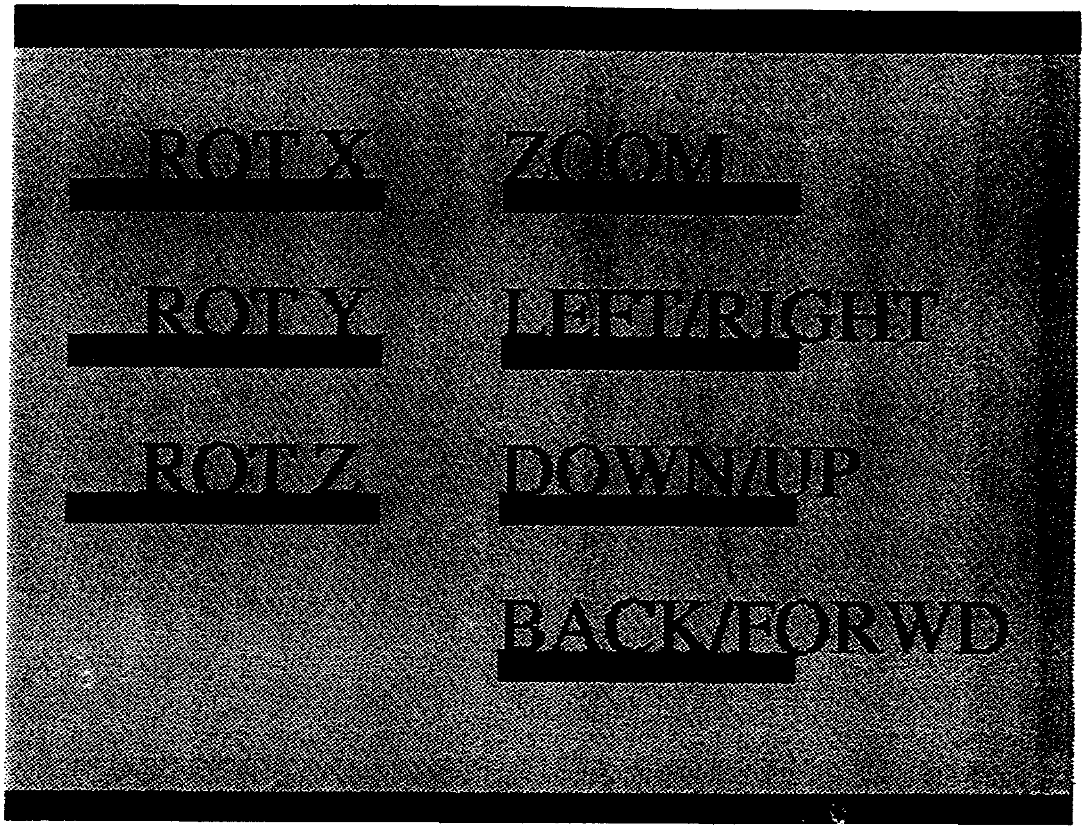
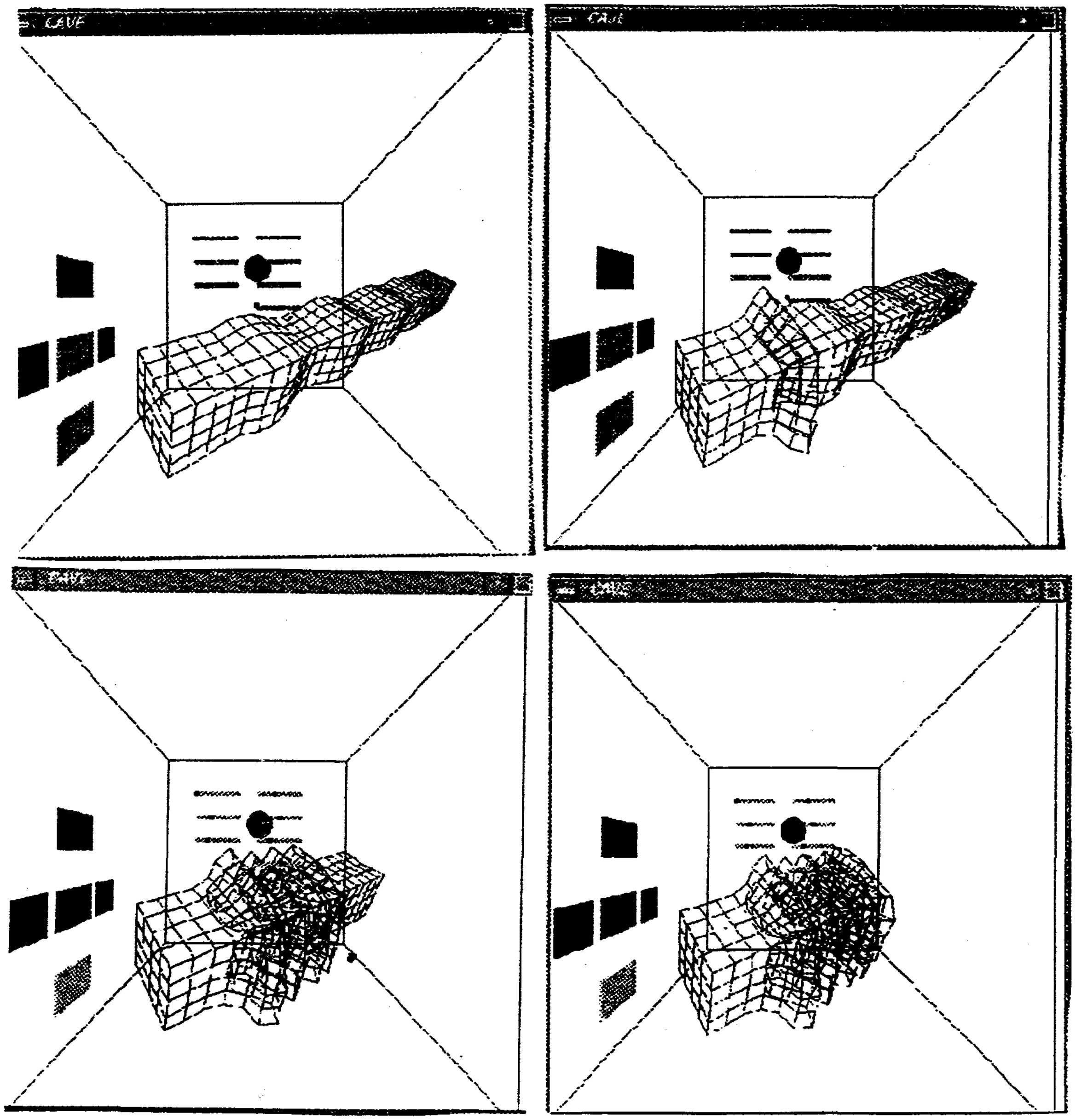


Figure 4. View Control Panel

The seven sliders on the back wall are depicted in Fig. 4. These sliders control rotation about the x, y, and z axis, translation in the x, y, and z directions, and scaling. The purpose of these controls is to allow the user to change the view of the image. The control bars labeled LEFT/RIGHT, DOWN/UP, and BACK/FORWARD control the image location in the CAVE. The LEFT/RIGHT control will bring the center of the image from x = -20 in the far left corner to x = 20 in the right corner. The DOWN/UP bar will translate the center of the image from y = -20 to y = 20. The BACK/FORWARD button will bring the center of the object from z = -20 to z = 10. The ROTX, ROTY, and ROTZ sliders all rotate the entire image about the respective axis from 0 to 360 degrees. The ZOOM bar will zoom in or out. The scaling of the ZOOM control ranges from .1 to 5.8 times the original size. Virtually any view of the object can be attained. Through the use of the scaling control, the user is even able to enlarge the object enough to get inside of the image as the simulation is occurring. In finite element simulations, the analyst is able to view the response of different mesh regions from any imaginable position.

Many other options are able to be chosen in the configuration file. The image is able to be centered, scaled, and rotated initially. Changing the initial view in these ways merely saves time in manipulating the object in the CAVE or the CAVE simulator. VRviz also has the option of stress contouring. This stress contouring will shade the wire-frame and/or will fill the polygons. If the element size is relatively large, an accurate visual representation of stresses is more easily achieved by a stress-contoured wire frame mesh. In this case the element stress boundaries are blended and a realistic depiction of stress is the result. If the element stress is not currently being studied and only deformations need to be visualized, a white wire-frame model showing only the element outlines without shading may be chosen.



Figures 5a-5d. Quarter Box Beam Undergoing Impact

The speed of a particular computer will determine the animation frame rate. For a very fast computer, the frame rate will need to be decreased significantly. As a result, VRviz allows for increment slow down through the configuration file.

The user has the option of choosing the maximum stress on the stress scale or allowing it to be set automatically by the program. If the user allows the program to set the stress, the highest stress output will be taken as the maximum stress. The user also has the option of designating specific colors for groups of elements. This allows a clearer visualization of finite element meshes since key components may be isolated by color.

The simulation shown in Fig. 5 is that of a box beam impacting a rigid wall. An attached mass of 1400 kg at the free end is prescribed an initial velocity of 15.64 m/s. The beam measures 0.15 m in length, 0.03 m in depth and width and has a thickness of 0.0015 m. Due to symmetry, only one-quarter of the boxbeam is modeled by a mesh of 336 shell elements and 385 nodes. Frames 5a-d in Fig. 5 are snapshots of the simulation which reveal shell elements coming into contact with one another as the box beam buckles. A single-surface slideline is defined over the entire mesh. Contact between any two elements of the mesh is possible.

While viewing these, along with intermediate views, engineers are able to study transient behavior such as objects undergoing collision in motion. In order to achieve a more detailed and realistic visualization, more time steps would be output by the finite element code for display in VRviz.

CONCLUSION:

Incorporating greater degrees of interactivity through virtual reality will continue until visualization becomes a seamless extension of reality. It is conceivable that future engineering applications can be developed which will in effect allow the user to create a visual model that can be studied in a manner analogous to today's experimental models. Engineers will be able to observe simulations as the computation proceeds and even dynamically alter the parameters midstream in response to their observations. The resulting possibilities--checking the progress of a simulation, terminating unfruitful design directions midstream, altering and tuning parameters, and guiding algorithms will prove to be of extreme importance to the engineering community.

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