The Development of a Visualization Tool for Displaying Analysis and Test Results*

W.L. Uncapher, D.J. Ammerman, J.S. Ludwigsen
Sandia National Laboratories

R. Knight
Geo-Centers, Inc.

S.D. Wix
GRAM, Inc.

INTRODUCTION

The evaluation and certification of packages for transportation of radioactive materials is performed by analysis, testing, or a combination of both. Within the last few years, many transport packages that were certified have used a combination of analysis and testing. The ability to combine and display both kinds of data with interactive graphical tools allows a faster and more complete understanding of the response of the package to these environments. Sandia National Laboratories has developed an initial version of a visualization tool that allows the comparison and display of test and of analytical data as part of a Department of Energy-sponsored program to support advanced analytical techniques and test methodologies. The capability of the tool extends to both mechanical (structural) and thermal data.

TOOL COMPONENTS

An important element of evaluating structural or thermal responses is the collection of reliable instrumentation measurement data. The analysis of this data is of paramount importance in determining the response of the package. One component of the visualization tool is a software system developed by Sandia that performs digital signal processing of both transient structural and thermal data. This data is collected in the course of monitoring the responses of radioactive material packaging to controlled thermal and impact experiments. This particular package provides a suite of signal processing functions common to the evaluation of both types of data. Data can be presented and processed in both the time and frequency domains, and a choice of units is available. With appropriate peripheral equipment the system has the capability to create single- or multiplot displays in monochrome or color. This system provides a powerful mechanism to assist in the analysis and display of data collected from radioactive and hazardous material package testing. The system can also be used to process and display analytical data and therefore allows direct comparison between test and analysis. The system, known as KAPP, a

---

* This work was performed at Sandia National Laboratories, Albuquerque, New Mexico, for the U.S. Department of Energy under Contract No. DE-AC04-94AL85000.

loose acronym for "Comprehensive Analysis Plotting Package", has been in development at Sandia since 1993 and is the subject of another paper at this conference which discusses its features in greater detail (Ludwigsen et al. 1995).

A second component of the visualization tool is an interactive gateway into Sandia National Laboratories' BLOT display subsystem. BLOT is a graphics program for post-processing of finite-element analysis data that is stored in the EXODUS database format (Mills-Curran et al. 1988). It is command-driven with free-format input, and can drive any graphics device supported by the Sandia Virtual Device Interface (SVDI) (Erickson and Simons 1981) . For visualization tool implementation, only the ability to route graphics output to the analyst's CRT monitor is supported. BLOT produces displays with highly configurable representations of analysis variables in the form of mesh plots, line contours, banded contours, vector plots of two and three variables (e.g., velocity, stress, strain) and symbol plots (e.g. temperature). Pathlines of analysis variables can also be drawn on the meshes. BLOT can produce X vs. Y curve plots of individually selected analysis variables, including time vs. variable plots or variable vs. variable plots. It is also capable of generating distance vs. variable plots at selected time steps, where distance is computed as the time-accumulated distance between pairs of nodes or element centers (Gilkey and Glick 1993).

BLOT was developed in the late 1980's by Sandia National Laboratories' Fluid Mechanics and Heat Transfer Division in response to the need for real-time visualization of finite-element data models, and represents a synthesis of several earlier programs (Gilkey and Flanagan 1987; Gilkey 1986a; Gilkey 1986b).

A third analysis capability integrated into the visualization tool is an interface to the finite element visualization functionality of Advanced Visual System's Corporation's AVS® modeling software and incorporates many modules written or customized at Sandia. This interface, known as FEAVR (Schoof 1995), frees the analyst from the details of the AVS Geometry Viewer and Network Editor while providing access to most AVS features. It requires data in the EXODUS II V2.0 (or later) format (Schoof and Yarberry 1994). FEAVR allows management of the graphics output, database time plane and variable of interest, and selection of the desired visualization technique directly from user dialogs on the analyst's monitor. Almost any processing sequence of AVS-compliant co-routines and subroutines can be used to drive this system.

Another important component incorporated into the visualization tool is the ability to display high-speed photographic video results of a test in conjunction with experimental data. This gives the analyst the option to step through the results of the test by viewing the individual frames of the photographic recording. The ability to simultaneously view video and test data improves the correlation between global environments and local responses to those environments. For example, in structural testing, deformations of the package container during an impact experiment can be viewed in any of the previously described software systems *concurrently with simulated real-time images of the deformations as they were recorded during the actual test.* This is clearly an advantage in correlating the observed measurements with the physical events which generated them.

Animation features include the capabilities to (1) view pre-recorded VHS video directly from an input device, if one is connected, and to display the results in a window on the analyst's monitor; (2) capture video stills from the VHS input and save them to disk in TIFF, JFIF, or JPEG format from which they can be imported into any of several commercial image editors such as ADOBE Photoshop®; (3) record VHS input directly from an active VHS device and store it on disk in JPEG format; (4) playback a video sequence of JPEG images stored on disk on a frame-by-frame basis with cursor-controlled fast forward, rewind, and stop action functions. For these functions, extensive use is made of Parallax Graphics Corporation's VideoStream® software, which provides the application interface between the visualization tool and the X-Windows server for rendering the images on the analyst's computer monitor.

AUXILIARY FUNCTIONS

The visualization tool also supports a limited data management capability. Upon entry to the program, the analyst may specify the location within the file system in which the data files that he wishes to process reside. These would typically include a combination of ASCII files, EXODUS data files, and any available video files. The software then recognizes these files as defaults during execution of the individual programs. Of course each application has its own interface through which the default can be modified on a case-by-case basis.

The tool also has the capability to capture the contents of any window, including the contents of an arbitrary rectangular bounding region of the monitor display, and to record it on disk, or route it directly to a printer or plotter. One or more output devices are configurable by means of an ASCII file in which the device characteristics are encoded. This feature is based on AutoGraph International's EasyCopy/X® software, Version 4.1.0.

An additional function is provided which instantiates a simple window shell (via Xterm) for issuing shell level commands.

USER INTERFACE

All subsystems are invoked via push-button from a main application menu. The program detects whether an individual application is already active to prevent multiple copies of the same subsystem from running simultaneously. All windows are movable and iconifiable. A restriction is that the Photo Stills and Video Playback functions should not be run at the same time; this restriction is imposed by the VideoStream software.

Subsystems are instantiated by a series of *fork* and *exec* calls to the UNIX® system kernel. Because of the nature of the *exec* process, this may not be done directly since several of the subsystems have core images larger than the parent program itself. In these cases, the "child process" is a separate shell which in turn invokes the application.

The user interface was written in X11R5 and X11R5 Instrinsics and utilizes OSF's Motif 1.2 for asthetics, widget design, and window management.

HARDWARE

The development platform consists of a Hewlett-Packard 9000/755 CPU operating under HP-UX Release 9.05, equipped with 2 GB of disk storage and 196Mb of physical memory. The main cabinet has been outfitted with a Parallax PowerVideo700 Plus® video board to support the VideoStream functions.

CASE HISTORY

Case results are presented using data from a selected Structural Evaluation Test Unit (SETU) cask impact test. This test is one in a suite of tests which were conducted to determine the deformation response of containment packages subjected to controlled drops. All drops utilized impact velocities exceeding the severity level of the fundamental design basis accident defined by the U.S. Nuclear Regulatory Commission (U.S. NRC 1983).

For the selected test, the cask weight was 6,650 lbs, dropped with an impact velocity of 20.1 m/s (45 mph). A description of the physical characteristics of the cask, the details of this and the remaining tests, as well as a complete analysis of the responses can be found in the report by Ludwigsen (Ludwigsen and Ammerman 1995).

Figures 1a and 1b show data from a trio of accelerometers (channels 1, 2, and 3) as a function of elapsed time during impact, and the frequency response of the lowpass IIR filter used to smooth them. The filter is a 6-pole lowpass Butterworth filter with a 500Hz cutoff. The results are from the KAPP subsystem.

Figures 2a and 2b show a mesh element display of the cask at 10 ms after impact, and a composite display of the σ_{xx} values for incremental node elements from #50 through #250. At 10 ms the deformation of the impact limiter at the base of the cask becomes significant, as do the initial deformations of the inner and outer cask walls. These data are taken from the BLOT subsystem.

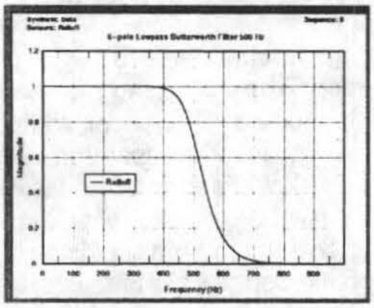

Figure 1a
KAPP IIR Filter Response

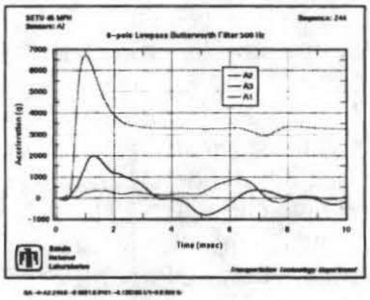

Figure 1b
KAPP Accelerometer Responses

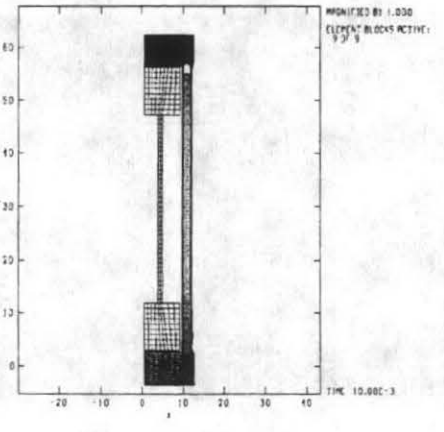

Figure 2a
BLOT Mesh Display

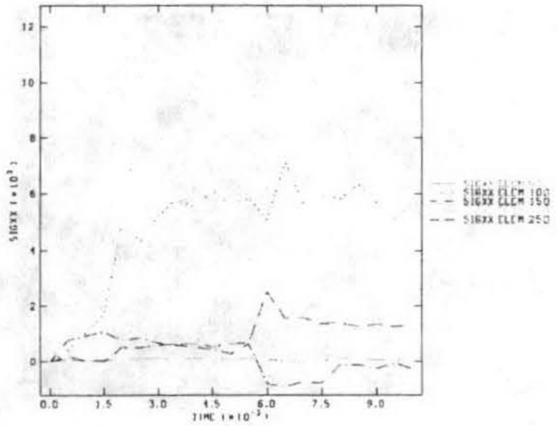

Figure 2b
BLOT σ_{xx} Values by Element

Figure 3a shows a mesh element display provided by the FEAVR system, again at 10 ms. The figure is a deformation threshold plot which indicates that a substantial number of the node elements have exceeded preset threshold g-values . Because the drop was vertical (zero inclination) there is minimal clustering evident in these "hot" elements. Figure 3b is a FEAVR display with σ_{xx} values superimposed on a similar mesh plot, also at 10 ms.

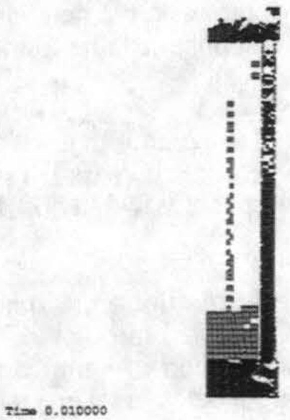

Figure 3a
FEAVR Deformation Mesh

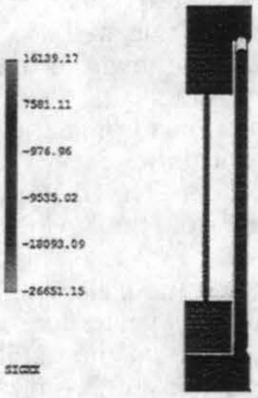

Figure 3b
FEAVR σ_{xx} Values Display

These data are now combined with the high-speed video, of which a pair of images are shown in Figures 4a and 4b. The first represents the moment of impact, and the second corresponds to the 10-ms time plane used in Figures 2a, 3a, and 3b. The accelerometer data for the first three sensors are shown in Figure 1. The significant compaction of the impact limiter and initial deformation of the lower rim and cask walls now becomes evident in both the test data and video. The video indicates that the package begins its primary rebound at about 1.5 ms after impact, and this time can be correlated with the data in Figure 1. Further examination of the video shows that second contact along the forward rim (at approximate clockwise azimuth 210° as measured from an axis into and normal to the plane of the photo) occurs at 54 ms, and approximately 3 ms later the secondary rebound begins. In a similar fashion, the analyst can proceed on a frame-by-frame basis to compare the film and experimental data for specific time planes of interest.

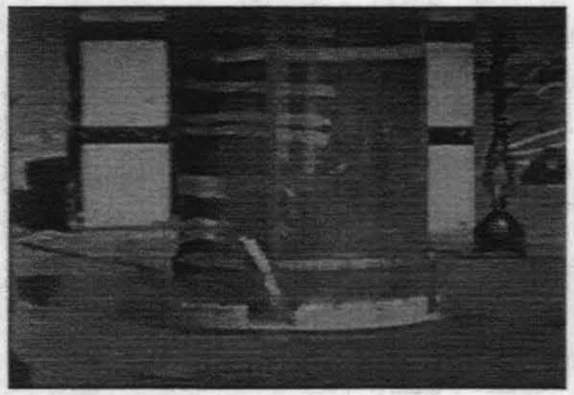

Figure 4a

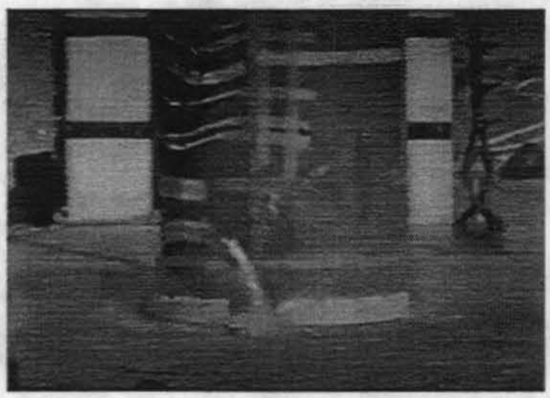

Figure 4b

SYNCHRONIZING TEST DATA AND VIDEO

Clearly the correlation of film images with presentation of the experimental data demands some attention to synchronization in time. Typically field data will contain lengthy tapers prior to zero time, i.e., the moment of impact. Preprocessing is routinely used to remove these tapers; thus time zero becomes the moment at which the data of interest commence.

Likewise, video recordings will begin at some point prior to the actual onset of the experiment. In addition, multiple videos may be shot from different distances, angles, and elevations. High speed VHS recording rates may range from several hundred to several thousand frames per second (fps). The most direct way of synchronizing separate media is to use an event (such as the moment of impact in a structural test) as a zero-time reference for all media and to use playback rates for the video which are multiples (or submultiples) of the time step of the experimental data. In the SETU cask drop test just described, the video recording was made at 2,000 fps. The standard operating speed for commerical video equipment is 30 fps, corresponding to an actual time retardation factor of 67. Choosing a recording sample rate of 15 fps when the video is transcribed to JPEG format means that the apparent video events during playback are still retarded in time by the same factor, but now individual frames correspond to 1 ms of real time, so that the video *counter* increments in time steps of 15 ms. In general, one is constrained to selecting subsampling rates which are common factors of both recording frequencies in order to avoid interpolation, a situation which may be circumvented if a variable speed video input source is available for the transcription to JPEG. With a proper choice of transcription recording rates for video from a standard NTSC VHS source, the graphical interface to the Videostream software allows time sequence editing during playback, and this permits the analyst to achieve an acceptable relative synchronization.

This transcription of offline video media to online storage is an indispensible step in the preprocessing stage of any analysis which includes video imaging. The mechanical delays and issues of time synchronization obviously preclude reading directly from tape itself. Past experience has shown that one can expect to generate file sizes proportional to 23 to 25 Kb per frame for compressed JPEG images corresponding to a window size of 640x480 pixels (NTSC). For a 20 fps 60 second movie, this translates into approximately 28-30 Mb (audio track excluded). It is evident that judicious use of online storage is to be recommended if system resources are limited.

SUMMARY

A new tool is under development for the time-synchronized visualization of analytical and test results in support of radioactive materials transportation package development and characterization. The tool provides a common interface to several existing systems for finite element analysis and plotting, as well as a system for display and post-processing of thermal and structural data acquired through field test experiments. It also provides the capability of recording and rendering video data, and displaying it simultaneously with output from the other supported subsystems. A suite of control functions allows the video to be time-synchronized and scanned on a frame-by-frame basis. These capabilities allows an analyst to correlate model, test, and visual data, which can be an important step in refining analytical models for forecasting purposes. Additional tools include the ability to capture individual windows or subregions of the display, and to record the images on disk or route them to a printer.

Amalgamation of the subsystems into a single tool permits them to be initiated from a common user interface, and to be managed by a single application program (Figure 5). It also automates setup procedures (such as setting up separate runtime environments) and frees the analyst from performing these steps. It also creates a platform from which potential remote clients may access subsystems they use, displaying the results on their own computer monitors. It can also consolidate license administration for third party commercial elements of the software which require license management.

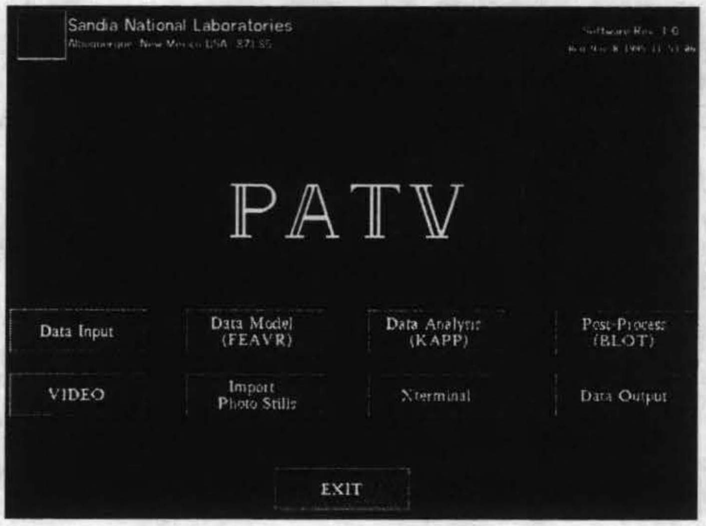

Figure 5
Main Application Menu

The tool is expandable and will be enhanced in the future to provide a gateway to additional new and emerging technologies for analysis, modeling, data processing, and visualization.

AVS® is a trademark of Advanced Visual Systems, Incorporated; Waltham, Massachusetts.

PhotoShop® is a trademark of Adobe Systems Incorporated; Mountain View, California.

PowerVideo® and **VideoStream**® are trademarks of Parallax Graphics, Inc.; Santa Clara, California.

UNIX® is a registered trademark of AT&T Laboratories, USA.

EasyCopy/X software copyright 1995 by AutoGraph International, Inc.; San Jose, California.

REFERENCES

Erickson, K. M., and Simons, R.W. *Functional Specification of the Sandia Virtual Device Interface (SVDI).* Sandia Report No. SAND81-1900, Sandia National Laboratories, Albuquerque, New Mexico (1981).

Gilkey, A. P. *SPLOT - A Distance-vs-Variable Plot Program for the Output of a Finite Element Analysis.* Sandia Report No. SAND86-0882, Sandia National Laboratories, Albuquerque, New Mexico (1986a)

Gilkey, A. P. *TPLOT - A Time History or X-Y Plot Program for the Output of a Finite Element Analysis.* Sandia Report No. SAND86-0883, Sandia National Laboratories, Albuquerque, New Mexico (1986b)

Gilkey, A. P. and Flanagan, D. P. *DETOUR - A Deformed Mesh / Contour Plot Program.* Sandia Report No. SAND86-0914, Sandia National Laboratories, Albuquerque, New Mexico (1987)

Gilkey, A. P. and Glick, J. H. *BLOT - A Mesh and Curve Plot Program for the Output of a Finite Element Analysis.* Sandia Report No. SAND88-1432, Sandia National Laboratories, Albuquerque, New Mexico (1993)

Ludwigsen, J. S., and Ammerman, D. J. *Analytical Determination of Package Response to Severe Impacts.* Proceedings of the 1995 Conference on Packing and Transportation of Radioactive Nuclear Materials (PATRAM); Las Vegas, Nev. (1995)

Ludwigsen, J. S., Uncapher, W. L., and Arviso, M. *Development of a Digital Signal Processing and Plotting Package to Support Testing of Hazardous and Radioactive Material Packages.* Proceedings of the 1995 Conference on Packing and Transportation of Radioactive Nuclear Materials (PATRAM); Las Vegas, Nev. (1995)

Mills-Curran, W. C., Gilkey, A. P., and Flanagan, D. P. *EXODUS: A Finite Element File Format for Pre- and Post-Processing.* Sandia Report No. 87-2997, Sandia National Laboratories, Albuquerque, New Mexico (1988).

Schoof, L. A. *FEAVR - A Finite Element Analysis Viewer.* Internal Correspondence. Sandia National Laboratories, Albuquerque, New Mexico (1995).

Schoof, L. A., and Yarberry, V. R. *EXODUS II: A Finite Element Data Model.* Sandia Report No. SAND92-2137, Sandia National Laboratories, Albuquerque, New Mexico (1994).

United States Nuclear Regulatory Commission. *Code of Federal Regulations, Title 10, Part 71.* USNRC, Washington, D.C. (1983).