

## **Virtual Reality Visualization (VRV) of Realistic Weapons Effects Predicted Using LS-DYNA**

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*Abbreviations:*

APFSDS	Armor Piercing Fin Stabilized Discarding Sabot
DLL	Dynamic Link Library
DXF	Drawing Exchange Format
IGES	Initial Graphics Exchange Specification
UCF	University of Central Florida
VRV	Virtual Reality Visualization
PDL	Program Design Language

*Keywords:*

Ballistic Impact, Virtual Reality Visualization, Weapons Effects

## ABSTRACT

A prototype of low cost system is described for visualization of realistic weapons effects experienced by targets undergoing blast and impact, to be used in training of personnel for livefire environments. The system is based on integrating two tools:

- (a) The Finite Element (FE) impact code LS-DYNA
- (b) A Virtual Reality Visualization (VRV) system

The VRV system was recently developed by DUAL Incorporated of Lake Mary, FL in partnership with the University of Central Florida (UCF). It consists of a PC-level graphics workstation, a head mounted display, motion trackers, a multi-degree of freedom mouse, drivers and a software toolkit, all of which have been established at DUAL and UCF.

## INTRODUCTION

VRV represents a major technological advance over traditional graphics on 2D computer screens. It offers five degrees of freedom (three positional and two rotational), as well as control over textures, lighting, shading, opacity and even sound. Using devices such as a head mounted display, the trainee becomes *immersed* in the environment being visualized. Furthermore, he/she has total control over the viewing process, *flying by* and *flying through* the visual field. The experience of VRV is very stimulating and informative.

LS-DYNA (Hallquist, 1993) is used to model the target response to different terminal ballistics effects thought to be representative of a livefire environment. The output files generated from the analysis are converted to *Weapons Effects Files* (WEFS) capable of VRV. For example, the trainee is able to observe the penetration of the weapon and fragmentation of weapon/target as if he/she were actually inside the target. Virtual reality visualizations of the responses of a helicopter (direct hit/fragmentation and crash into a mountain) and of a light truck (direct hit) are described.

The system has great potential in any ballistics environment where training is needed for large numbers of personnel, such as helicopter pilots. It likewise has great potential in enhancing the performance of analysts requiring better visualization of crash and impact scenarios. With further development, the system can be available to the civilian aviation community and the automotive/highway safety communities.

## VIRTUAL REALITY VISUALIZATION SYSTEM

Figure 1 shows the basic configuration of the Virtual Reality Visualization System in terms of hardware. Nomenclature for the items listed in Figure 1 are explained just after the figure.

In terms of software, LS-DYNA and a VRML plug-in such as:

- Microsoft VRML 2.0 viewer (Hartman, 1996)
- Intervista WorldView 2.1
- SGI CosmoPlayer 2.1

should be installed under Microsoft Internet explorer 4.01 and above.



Figure 1 – Virtual Reality Visualization System

Nomenclature of Figure 1:      1 – Tri-Star Graphics Workstation  
   2 – Head Mounted Device  
   3 – Motion Trackers  
   4 – Audio Out

Figure 2 shows details of the head mounted device used in the VRV system.



Figure 2 – Head Mounted Device

Other platforms are currently under development to allow use in UNIX systems and other PC configurations, using alternative software such as dVISE.

### MODELS

The models used for VRV of realistic weapons effects correspond to LS-DYNA analysis of two targets structures:

- (a) Military/civilian helicopter
- (b) Light truck (also used by army forces)

#### *Helicopter*

The helicopters presented in this work were originally obtained as Drawing Exchange Format (DXF) files, as represented in Figure 3. Many different aircraft structures (e.g., B-17, Bell, Cobra, Comanche, MIG, DC-10, F-14, F-16, HIND24, MK9HAWK) were obtained from a public URL on the Internet. LS-DYNA is only able to read lines from DXF files, due to the old translator currently built into the software. The files downloaded from the Internet represent models in terms of areas and surfaces, which cannot be read by the LS-DYNA DXF translator. Fortunately, the Initial Graphics Exchange Specification (IGES) translator in LS-DYNA is capable of reading the model elements of interest. For this reason, the files have been translated into IGES files inside AutoCAD before being read into LS-DYNA.

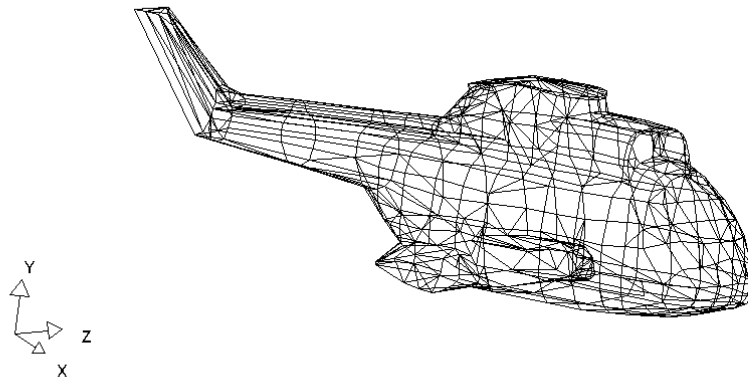


Figure 3 – Helicopter structure obtained as a DXF file

LS-DYNA prompts for missing information/data and reports errors, while importing files. No error messages were encountered during this procedure, meaning that the files were completely translated inside LS-DYNA. In particular, the IGES files were read by FEMB into FMB files.

Once the geometry was imported into LS-DYNA, it became obvious that only points, surfaces and volumes were defined. As one step to transform the IGES files into a finite element model, nodes and elements would have to be created. Unfortunately, the package is not able to automatically create a mesh from the available point, surface, and volume information. Therefore, nodes and elements

were manually created inside LS-DYNA. In order to ensure the connectivity between the elements, minor adjustments were performed in the given files. Figure 4 represents only the outside structure of a military helicopter being transformed into a finite element model for LS-DYNA analysis. The internal structure and the rotors were not included in this simulation, due to the execution time. At this point in the project, however, the omitted parts represent no significant difference in procedure terms; they only represent more elements in the simulation. Furthermore, the outside structure plays an important role in any military vehicle. It provides a critical shielding effect, but must be as light as possible. Accordingly, the initial simulations are all performed using the structure shown in Figure 4. Once the files were transformed into LS-DYNA executable files (DYN format), the impacts, crashes and explosion simulations were all implemented through the user interface.

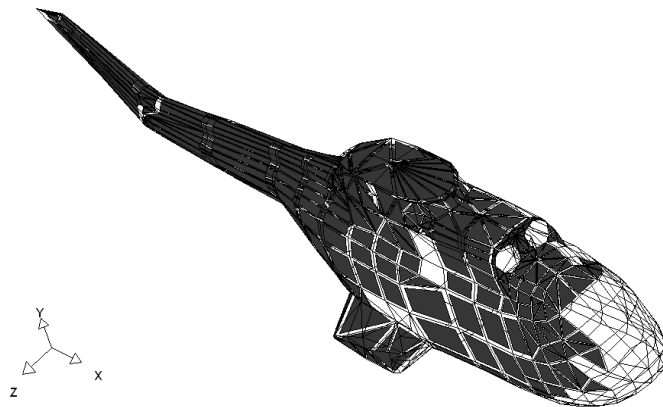


Figure 4 – Transforming a DXF into FMB and into a DYN file

#### *Light Truck*

The light truck model was also obtained from a public URL on the Internet. This model however, was directly downloaded as a LS-DYNA model. The model can be obtained from the ‘National Highway Traffic Safety Administration’ home page ([http://www.nhtsa.dot.gov/search97cgi/s97\\_cgi.exe](http://www.nhtsa.dot.gov/search97cgi/s97_cgi.exe)). Figure 5 shows the light truck used in the current analysis.

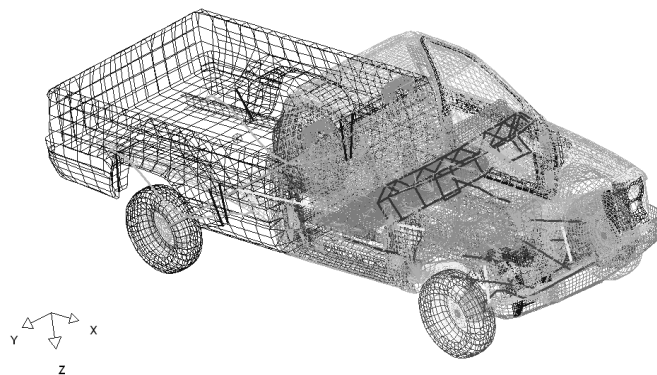


Figure 5 – Light truck model

The finite element model shown in Figure 5 has over 65000 elements (beams, shells and solids). All the engineering properties found in this model are assumed realistic and are not questioned.

### NUMERICAL SIMULATIONS

For the sake of simplicity, all materials assigned to the helicopter structures shown in this work are the default material from LS-DYNA (Elastic-piecewise plastic material). The actual engineering values for the helicopter structures are not available to this study.

#### *Helicopter Crash into Mountain*

The first simulation performed in the software is the crash of the helicopter into a mountain at 75 mph. This is a realistic scenario and it has happened due to accidents or due to combat maneuvers. The mountain is simulated here as a rigid wall. The helicopter impacts the mountain at an angle of 30 degrees.

Figure 6 depicts the structure at the onset of analysis with all the boundary conditions and the initial conditions already defined by the user. The sliding surfaces are also defined as well. The crash angle and position chosen are one of the worst scenarios for the pilot.

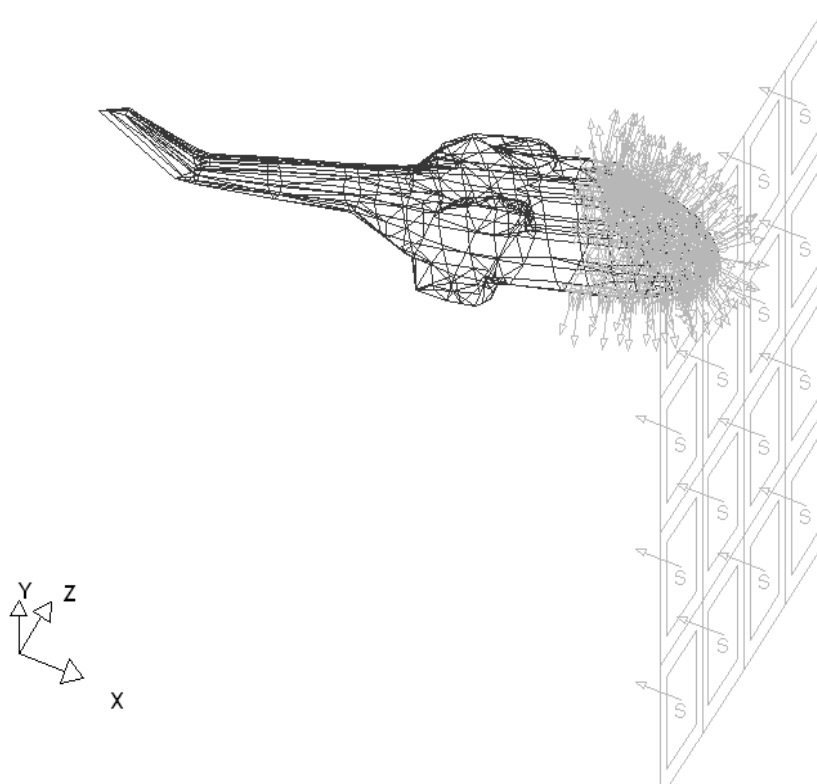


Figure 6 – Helicopter structure against a rigid wall, ready for analysis

The numerical solution of the crash simulation is shown in Figure 7. As was obviously expected, the mountain (rigid wall) does not move or deform. The helicopter, however, crashes and its front structure buckles to the inside, in the direction of the pilot. This simulation is extremely important, as it enables the test

of many different materials that can be used as an aircraft shield, and as it helps prepare pilots for situations that cannot be reproduced in actual flight training.

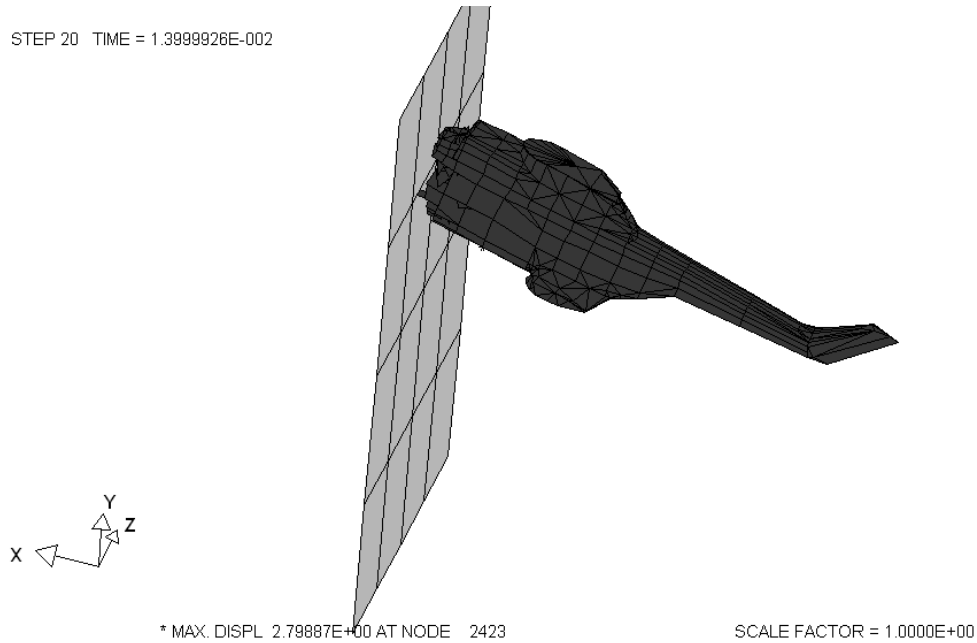


Figure 7 – Numerical results of the helicopter crash

*Projectile Impact at a Helicopter Structure*

The next simulation performed in LS-DYNA was a projectile impact. An Armor Piercing Fin Stabilized Discharging Sabot (APFSDS) projectile has been chosen. Figure 8 represents the result of this numerical simulation.

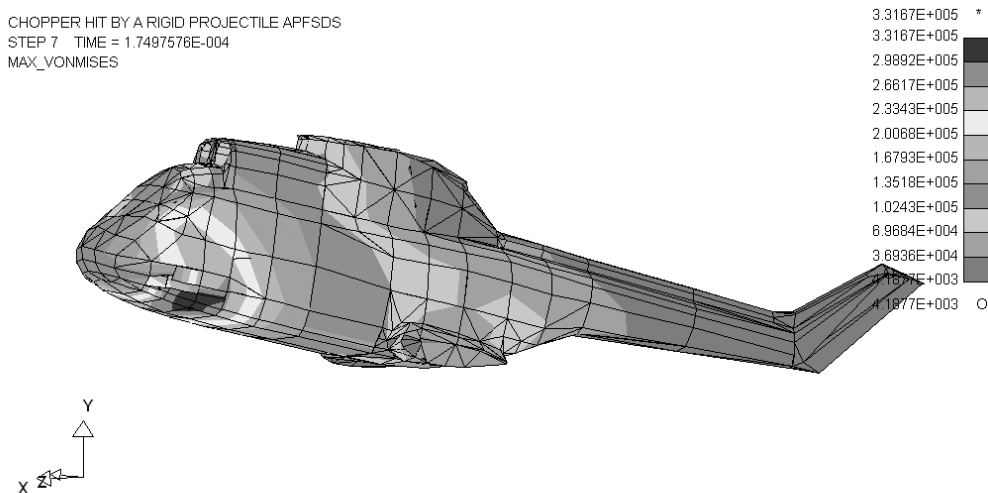


Figure 8 – Impact result of APFSDS hit onto a helicopter structure

Although this type of ammunition is not typically used against helicopters, it is well known to have maximum penetration properties. That is the reason why it is used against main battle tanks. For the sake of illustration, this simulation has been performed in LS-DYNA. The APFSDS projectile, considered in the simulation process as a cylindrical rigid body, impacts the structure at 4500 feet per second. As expected, full penetration is observed as a result of this simulation. Figure 9 represents an old version of this type of ammunition (3BM42M APFSDS).

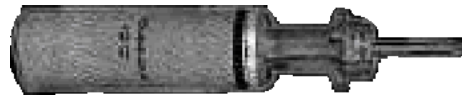


Figure 9 – APFSDS Ammunition

*Projectile Impact of .50 Ammunition against the Light Truck*

The numerical simulation performed on the light truck is based on .50” projectile impact. The hit occurs at approximately 980m/s and the projectile is simulated in terms of its core nucleus (cylindrical rigid body). Figure 10 depicts this idea.

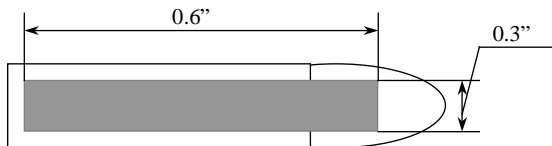


Figure 10 - .50” Ammunition and its core

Figure 11 next shows the numerical result of this analysis when a single hit impacts the driver side close to the back tire.

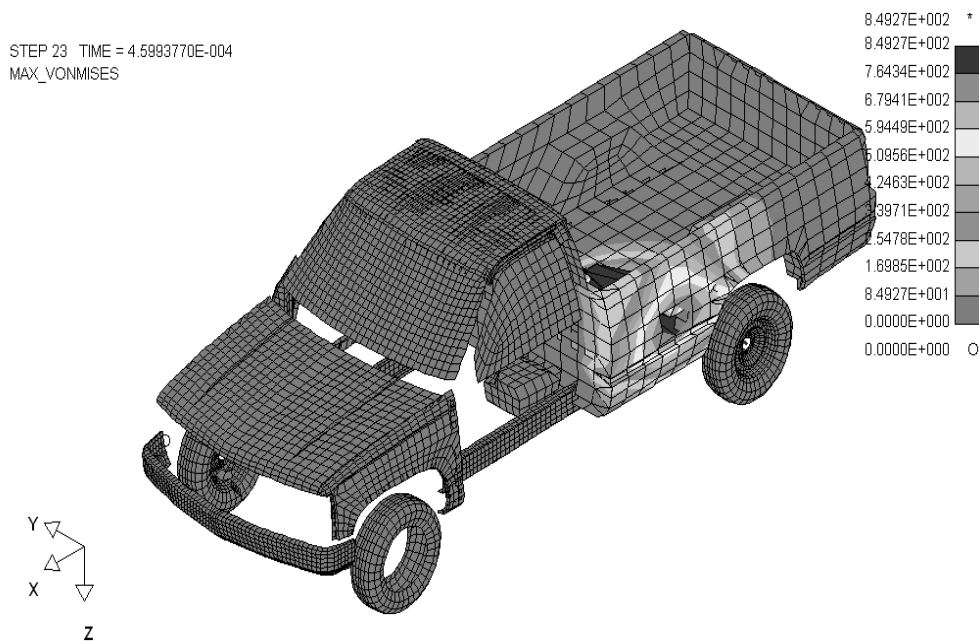




Figure 11 – Result of .50 ammunition impact (whole model is not shown)

### **TRANSLATOR – Dyn2VRML**

Dyn2VRML is the prototype of a fully integrated, user-friendly, Windows-based application that translates the standard ASCII output from the dynamic analysis code LS-DYNA into the standard VRML 1.0 format and it will later be translated to VRML 2.0.

The core translation subroutines are written in FORTRAN90 using double precision dynamically allocatable arrays for memory optimization. These core subroutines are compiled into Dynamic Link Libraries (DLLs) to be used by the Windows-driven graphical interface, currently in development. Currently, Dyn2VRML works as a console application. The additions of graphical interface features are currently being implemented, along with the embedding of the VRML browser, to make a fully integrated tool. Also under development is the program DYN2dVISE, where the dVISE package is used instead of the VRML Viewer.

#### *Main Program*

The main program of Dyn2VRML structures the translation process into several steps. These steps are described in the following Program Design Language (PDL):

```
BEGIN PDL "MAIN PROGRAM"
  DECLARE dynamic arrays for the translation process. (To
  optimize use of memory, arrays are allocated into memory before
  the subroutine that uses them.)
  OPEN the geometry information output file of LS-DYNA, which
  has the extension OTF.
  INPUT the essential information of the model such as the number
  of materials, number of nodes, and number of elements from the
  OTF file.
  CALL the subroutine that reads the geometric configuration.
  CREATE a file to store the initial VRML translation.
  CALL the subroutine that transforms the nodal identification into
  an ascending number sequence.
  CALL the subroutine that filters the nodes of 8-noded brick
  elements that lie inside the body and stores the external (visible)
  nodes.
  CALL the subroutine that generates the connectivity of surface
  elements from brick element filtering.
  CALL the subroutine that translates the information into an
  initial VRML file that contains the model geometry and the
  material composition.
  OPEN the deformation file for the model output by LS-DYNA.
  CALL the subroutine that reads the nodal displacement
  (deformation).
  OPEN the stress distribution file for the model output by LS-
  DYNA.
  CREATE a file to store the final VRML translation.
  CALL the subroutine that translates the information into a final
  VRML file that contains the model geometry, deformation, and
  stress distribution.
END PDL "MAIN PROGRAM"
```

All subroutines called by the main program are already operational.

### **VIRTUAL REALITY VISUALIZATION**

#### *Octant Concept*

The main intent for this system is training of a large number of personnel. Since LS-DYNA simulation cannot be performed in real-time for purposes of visualization (due to the necessary elapsed time for the numerical solution), the notion of creating a library of possible zones of ballistic impact was adopted. For the sake of 'proof of principle', the ballistic zones are described as octants in a three dimensional space. Figure 12 represents the octant concept used to build the library of hits.

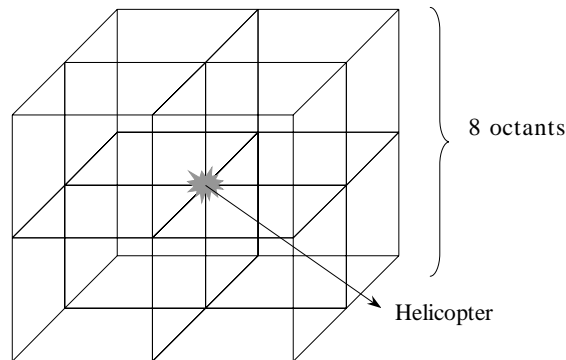


Figure 12 – Concept of octants used to build the library of hits

Once the user defines a zone, the closest damage result is shown according to hit probability functions. The models used for predicting hit distribution are not discussed here. The octant concept considerably accelerates the time response of the VRV system. As a starting point, a small library already exists with one retrievable simulation for each octant.

Figure 13 shows the result of the fragments hit of 30mm ammunition (from a BOFORS Cannon) that exploded in the 3rd octant of the helicopter model. The Probability distribution is supposed to predict that two fragments hit the helicopter structure with enough power to produce damage. The type of fuse used in this case was a proximity fuse, which detonates when it attains a critical distance from the metallic structure.

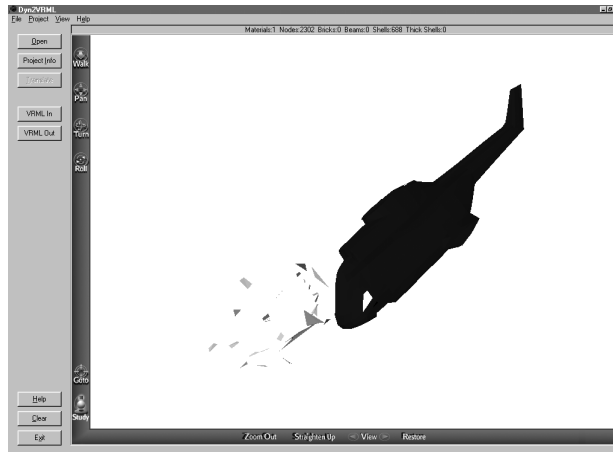


Figure 13 – Helicopter hit at the 3<sup>rd</sup> Octant by 30mm ammunition – Dyn2VRML  
 Figure 14 shows the result of a helicopter structure crashing into a mountain at 75 mph. Many conversions were performed in order to verify the operability of the software Dyn2VRML.

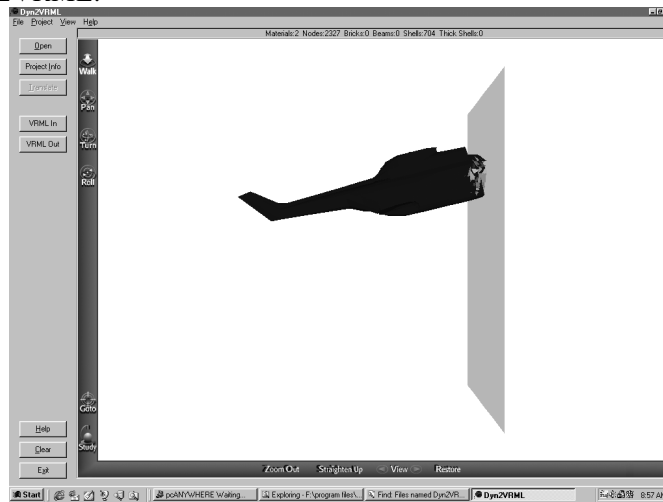


Figure 14 – Helicopter impact into a mountain at 75mph – Dyn2VRML

Table 1 next describes some of the LS-DYNA numerical analysis already transformed into VRV files

Table 1 – LS-DYNA numerical analysis already transformed into VRV files

File Name	Analysis	Description
Beam01.otf	Cylindrical beam under compression	Displays a quarter portion of a symmetrical beam under compression, The VRV file provides a clear distribution of the von Mises stress concentration
FiestaBlast01.otf	Ford Fiesta under mine blast	This detailed model contains brick, beam, and shell elements and was used to test the translator with a multi-element configuration. The car

		drives over a mine under the front left tire and receives the blast from below.
ChopperImpact01.otf	Helicopter model under mountain impact.	This model depicts a coarse discretization for a military helicopter crashing into a solid wall at a constant speed.
ChopperBlast01.otf	Helicopter model under projectile blast.	This is the same geometric model as the previous example, but in this case a projectile impacts and goes through the side of the helicopter.
C2500Blast01.otf	C2500 light truck under missile blast.	This is a detailed model of a light truck, which contains all different types of elements. The analysis is performed with a projectile impact to one of the sides.

Representative examples of the VRML models generated by the translator from LS-DYNA output can be viewed at <http://home.mpinet.net/edivo/dual>. See <http://cws.internet.com> for shareware VRML browsers available for download. We recommend the Cosmo player from SGI for viewing VEWEV files.

### FINAL REMARKS AND CONCLUSION

A low-cost prototype system for visualization of realistic weapons effects experienced by targets undergoing blast and impact was just described. All analysis made use of finite element techniques and VRV.

All FEA is performed using LS-DYNA. Dyn2VRML is the software used to integrate the two tools. This fully integrated, user-friendly, Windows-based application is under continuing development. However, the initial results obtained up to this point, show that the program has great potential.

The LS-DYNA analysis are converted into WEFS and then stored in libraries, which are later retrieved for visualization and used for the training of a large number of personnel.

### ACKNOWLEDGEMENT

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