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3-D Animations For Litigation of Highway Accidents

by Donn N. Peterson, P.E. (NAFE 239F)

Abstract

After a highway accident has occurred, answers are sought to the fundamental question "What Happened?" and to various related questions. Eye witness testimonies may be incomplete, inaccurate, and conflicting. Forensic engineers are often engaged to provide answers that are consistent with professional analyses of the evidence. If the case is not settled, litigation will proceed and the forensic engineer can expect to testify as an "expert" witness giving his/her opinions and explanations.

During testimony, the "expert" witness may use various items of demonstrative evidence to help explain the opinions. Computer hardware and software technologies have made it feasible in some cases to produce animations to illustrate those opinions. Courts have admitted 3-D scientific animations as demonstrative evidence when the proper foundations have been laid. If the animations fairly and accurately depict the "expert" opinions without prejudice and if they have been disclosed in a timely manner, then admissibility objections will probably be overruled.

Introduction

In the 1960's, sophisticated mathematical models and computer simulations were used in the aerospace industry. Most were developed originally for military and defense applications and required large expensive main frame computers. They were advantageous because various scenarios could be investigated without risking human life. They were even cost effective because the development testing of expensive prototype hardware could be significantly reduced.

In the 1970's, a popular television series was aired entitled "Quincy ME" starring Jack Klugman as a medical examiner with a social conscience. Quincy was a forensic pathologist who applied a variety of scientific principles in performing and interpreting human autopsies. He solved all the cases he investigated, and the side that called him to testify as an "expert" witness always prevailed. Quincy did call the public's attention to the benefits of "scientific" evidence and the use of "expert" witnesses in the court room, particularly in criminal homicide cases.

Donn N. Peterson, P.E., 7601 Kentucky Avenue North, Brooklyn Park, MN 55428

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In the 1980's, forensic engineering became formally recognized as a professional practice and personal computers (PC's) were introduced. Early models had limited memory and slow processing times for any but the simplest of operations. Computer aided drawing (CAD) was introduced initially for Architectural and engineering drawings. Computer animations were used in the motion picture and television industries. Abbreviated forms of CAD and animation software became available for PC's.

In the early 1990's, computer technology has rapidly advanced and has become more affordable in the process. High performance PC's can easily be obtained by small businesses and even by individuals. Complex mathematical models can be developed and computer simulations can be performed at the engineer's desk. CAD and animation software continually evolve with quality improvements and cost reductions.

In the late 1990's, 3-D CAD and computer animations will become a common source of demonstrative evidence for explaining "expert" witness testimonies. They will also be used to illustrate some substantive evidence. These technologies can be powerful tools for the forensic engineer. They also add another consideration for professional ethics.

Terms and Concepts

Mathematical model is a set of equations and logic statements which are developed to specifically describe the forces and interactions between the components in a given system. The mathematical model is usually programmed in computer language so the computer can perform the many calculations needed to describe the forces and motions of all the components in the system. The model is usually expressed mathematically by the state space representation, and the integrations are performed by numerical methods. Case specific numerical values can be input by the user and processed by the computer according to the mathematical model instructions.

Computer simulation is the action of a computer performing the instructions in the mathematical model for a given set of initial values, control inputs, and boundary conditions. The results are presented in a suitable output format such as tabulations, graphs, and pictures. A computer simulation predicts responses of the system and components to the hypothetical events and conditions as described by the given input. A flight simulator for training pilots and astronauts is an example of mathematical models and computer simulations applied in the "real world".

CAD is an acronym for computer assisted drawing which is the process of constructing computer files which can be used to produce physical drawings,

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video images, or digital output. A single CAD drawing often takes as much or more time to produce as a comparable drawing produced at a drafting board. However, CAD files can be easily and quickly changed leaving no distracting erasures. Changing scales and viewpoints typically involve only output commands and are quickly and easily accomplished.

Animation is a series of still images, each image being slightly different from the preceding one, which when viewed in rapid succession creates an illusion of motion. When the images are photographic in origin, the result may be a movie or a video. When the images are drawings, the result may be a cartoon where perceived motions can even defy physical laws. When the images are 2-dimensional (flat plane) drawings, the result is a 2-D animation. When the images are 3-dimensional (perspective) drawings, the result is a 3-D animation. When the images are computer generated, the result is a computer animation.

Primary objects are "things" which are the central focus in a drawing, mock-up, or animation. Examples of primary objects include vehicles and objects involved in an accident, accident scene features contributing to accident causation, items forming a foundation for the accident reconstruction analyses, etc. Primary objects should be reproduced to scale, at least approximately, and positioned with reasonable accuracy.

Secondary objects are "things" which are used to enhance the quality of presentation but have no effect on the purpose of the drawing, mock-up, or animation. Examples of secondary objects include vehicles not involved in the accident, buildings and vegetation which do not restrict sight lines, highway signs not in dispute, utility poles not involved in collision or lighting issues, etc. Secondary objects are not necessarily accurate in all details of size, shape, and position.

Scientific animation is an animation in which all the primary objects are reproduced to scale (at least approximately) and to the same scale, positioned with reasonable accuracy, and perceived to move according to the physical laws of motion and constraints. Secondary objects do not materially misrepresent any relevant elements or issues and are included only to enhance the presentation. Entertainment cartoons are animations, but they would not qualify as scientific animations.

2-D animation depicts motion in a plane. Object positions are described by 2 Cartesian coordinates, time, and 1 rotation angle as variables. Examples are: x, y, t, and yaw; y, z, t and roll; z, x, t, and pitch. The advantages of 2-D animations include simplicity, less data, less computer memory, less labor, less time to produce, and lower cost. Disadvantages include inability to include effects of lighting, shadows, and changes in camera view.

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3-D animation depicts motion in 3-dimensional space. Object positions are described by 3 Cartesian coordinates, time, and 3 rotation angles as variables. The variables x, y, z, t, yaw, roll, and pitch are depicted for each object simultaneously. Advantages include realistic images, lighting and shadow effects can be included, the animation can be viewed from any specified camera position (e.g stationary or moving in a prescribed path), surface textures can be applied, and intricate details can be included. A current disadvantage is that each of these desirable features still takes time and skill to incorporate into any given animation. Currently, PC animation software is only partially integrated with CAD software and they do not take input directly from computer simulation software and mathematical models.

Substantive evidence are items which are relevant and make the existence of any fact of consequence to be either more probable or less probable than it would be without the evidence. Examples include testimonies under oath, relevant documents, physical objects, etc. Substantive evidence is shown to the trier of fact during the proceedings and is usually available to the trier of fact during deliberations.

Demonstrative evidence are items which fairly and accurately depict the "expert" opinion(s) without prejudice and which will aid the "expert" in explaining the opinion(s) to the trier of fact. Examples include charts, graphs, models, drawings, learned treatises, animations, etc. Demonstrative evidence is shown to the trier of fact during the testimony, but is not made available to the trier of fact during deliberations.

Litigation of Highway Accidents

When litigation of an highway accident is contemplated, forensic engineers are often retained to develop professional opinion(s) to a reasonable degree of engineering and scientific certainty to answer questions such as:

What Happened?

Could the accident have reasonably been prevented?
    If so, how and by whom?

Could the damages have reasonably been reduced?
    If so, how and by whom?

What negligent acts contributed to the cause?

What negligent acts contributed to enhancement of damages?

The forensic engineer must collect, review, test, and analyze the substantive evidence, and occasionally procure demonstrative evidence to aid in the

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analyses. After the forensic engineer has answered the questions to his/ her own satisfaction, the answers must be provided to the client. This task may be accomplished by oral, informal letter, or formal written reports. If the case can not be settled, then the litigation process will proceed and the forensic engineer can anticipate being called to testify as an "expert" witness.

When the proper foundations are laid, scientific animations can be used as demonstrative evidence during the forensic engineer's "expert" testimony. In order to be admissible, the animations must be fair and accurate portrayals of the opinions being given. Therefore, the witness should review the animations in detail prior to them being offered for illustrative purposes. It is desirable for the animations to have been produced by or under the direct supervision of the witness.

Scientific 3-D Animation Applications

Case Study 1. "From 0 to 90 in 7 Seconds"

On the first day of the school year, a junior high school student was riding her bicycle eastbound on a busy 2-lane street. The right front corner of the following eastbound passenger car struck her from behind the left side of the bicycle. She came to rest near the middle of the eastbound lane, the bicycle came to rest on the south road shoulder, and the car finally stopped about 2 blocks further east. The driver of the car immediately following the subject car testified about vehicle speed and gave details about bicycle motions prior to impact. This witness stated that immediately prior to the impact the bicycle had turned sharply to the left and was rotated nearly 90 degrees to the lane when the impact occurred. The drivers of additional following cars also testified about speeds and what they saw of the impact. The driver of the subject car gave vague and non-conclusive testimonies about the accident. Due to closed head injuries, the bicyclist has no memories about the accident.

At the request of the bicyclist plaintiff's attorney, the author performed accident reconstruction analyses. Results showed the bicycle speed and yaw angle to be much less and the impact point to be much closer to the south fogline than had been stated by the nearest witness. The author submitted a formal written report to plaintiff's attorney giving the foundation and results of the accident reconstruction analyses.

3-D drawings were prepared using AUTOCAD Release 12 software to illustrate the author's opinion of impact positions. The main accident scene features were based on measurements taken during the site inspection. The bicycle was inspected and measured while its computer image was being created. The bicyclist was created with a human form extracted from MANNEQUIN soft-

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ware and scaled to the height and build of the rider. The cars were created with purchased drawings of cars scaled to dimensions of the actual cars.

Figure 1A is a top view showing bicycle and rider final rest and impact positions.

Figures 1B, 1C, and 1D are closer top, front, and left side views respectively at impact.

Figure 1E is a perspective drawing at impact.

Figure 1A

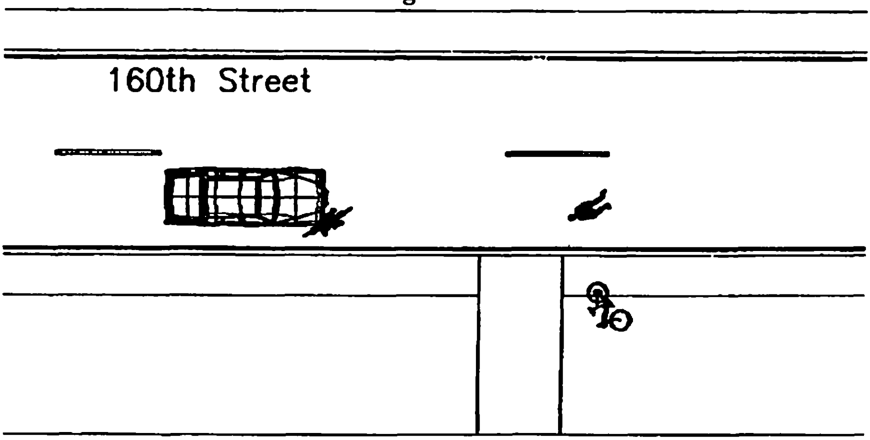

Figure 1B

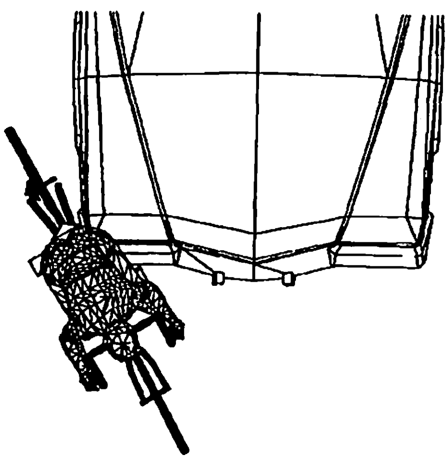

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Figure 1C

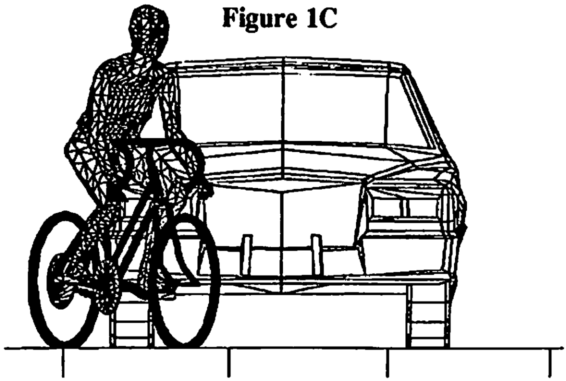


Figure 1D

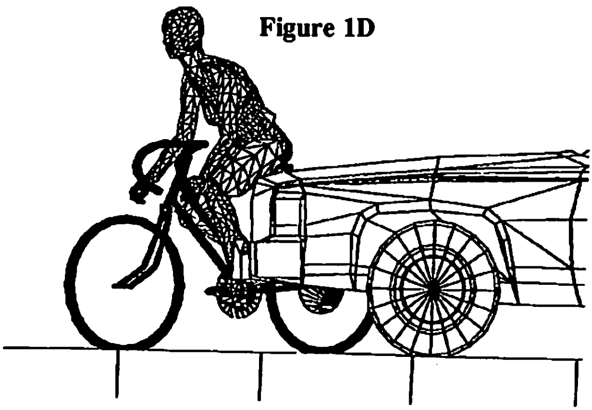
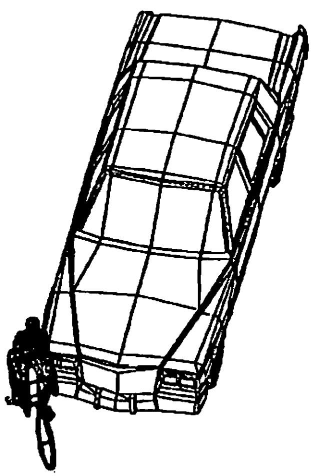


Figure 1E



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The car driver defendant's attorney retained a police officer reconstructionist whose brief letter report stated opinions which corroborated all testimonies of the nearest witness. The amount of contributory negligence to be assessed against the bicyclist would depend on whether the trier of fact accepted testimonies of the nearest eye witness and of the corroborating police officer reconstructionist or the testimony of the author as a forensic engineer. At all times through this stage of the litigation process, the defendant's settlement offer was 0.

Scientific 3-D animations were produced using 3-D STUDIO Release 3 software to demonstrate the author's accident reconstruction results. Speed-time-distance equations were used to calculate positions of the bicycle, rider, and cars at specific times (key frames). The computer and software calculated positions at intermediate times (frames) and created visual images for all frames for several camera viewpoints. All animations represent the identical sequence of events from different camera viewpoints over an elapsed time of 7 seconds.

One camera viewpoint is a plan (top) view. When selected frames in this animation are viewed with time "frozen", the views are similar to a standard accident scene drawing with overlays. This could be a basis for arguing admissibility as demonstrative evidence to a skeptical judge.

Other camera viewpoints were chosen to approximate views of key witnesses. The animations showed no significant discrepancies between the author's accident reconstruction and all eye witness testimonies except for portions of the nearest witness testimony regarding the actual impact. The animation for the camera viewpoint approximating the view of the nearest witness clearly showed that the subject accident car obscured visibility for this witness preventing her from seeing most details of the impact.

Copies of the animations were provided to plaintiff's attorney. Defendant's attorney was invited to a showing of the animations approximately 2 weeks prior to the scheduled trial. Within 24 hours after the showing, the defendant tendered a settlement offer of $90,000.

The defendant offered $0 before viewing the animations, and promptly offered $90,000 after viewing the 7 second animations. The plaintiff accepted the offer, and the case was settled without trial.

Case Study 2. "A Rear End Collision Really Can Cause Injuries"

A truck driver was preparing to turn off a state highway onto an intersecting roadway. He was moving slowly waiting for oncoming traffic to clear. His head was turned toward the right, and he was looking at the right outside rear view mirror. Another truck going the same direction was approaching from the

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rear. The second driver did not react in time, and the front end of the second truck collided with the rear end of the first truck. Both vehicles were damaged and the driver in the first truck suffered "whip lash" type soft tissue injuries. Expert medical opinions differed significantly about the severity of the injuries. Investigating officers took many photographs showing both trucks at the accident scene. No scene measurements were available, and both trucks had been repaired prior to the author's involvement. Photogrammetry techniques were applied to determine skid mark lengths, vehicle separation distance at rest, and crush depths. Accident reconstruction analyses were applied to determine the approximate speeds of each truck at impact. A mathematical model was developed to represent forces and interactions between parts of a dummy body and the vehicle seat restraints during collision and was programmed in the computer language BASIC. Computer simulations were performed to predict the motions of the dummy body segments and the forces acting on them during a collision substantially similar. Calculated results showed large tension forces and bending moments in the dummy neck for short time durations. Simulation results were presented in tables, graphs, and elementary screen drawings.

Figures 2A, 2B, and 2C are table, graphical and drawing outputs respectively from the computer simulation.

Figure 2D is a 3-D CAD drawing prepared in AUTOCAD with human forms extracted from MANNEQUIN software placed according to the computer simulation output.

The 3-D drawings were exported from AUTOCAD into 3-D STUDIO where surface colors and textures were added. Body positions were input at specific times (key frames) as described in the output from the computer simulations. 3-D STUDIO then calculated positions at all intermediate time frames and created screen images for all

Figure 2A

10 V1 = 40:V2 = 5:DV = 35:TF = .3:N = 8:M = 1

DPCRASH run on 11-10-1993 15:15:50

Time	Acc1	Acc1B	Crus1	Acc2	Acc2B	Crus2	StrA2	AccN2	MomN2	AccT2	MomT2
0.0	-0.8	0.0	0.0	-0.4	0.0	0.0	0.0	0.0	-0.0	0.0	0.0
5.0	-1.0	-6.3	1.6	-0.2	6.5	0.9	0.0	0.0	0.0	0.0	-2.3
10.0	-1.4	-6.6	3.6	0.1	6.6	1.9	0.0	0.0	0.1	0.0	-2.6
15.0	-1.8	-6.7	5.7	0.5	4.5	2.9	0.0	0.0	0.2	0.0	-0.8
20.0	-2.3	-6.7	7.7	0.9	4.4	3.9	-0.0	0.0	0.1	0.0	3.3
25.0	-2.8	-6.6	9.7	1.4	4.2	4.9	-0.0	0.0	-0.0	0.0	6.4
30.0	-3.4	-6.4	11.7	1.8	4.0	5.9	-0.0	0.1	-0.3	0.0	8.1
35.0	-3.9	-6.2	13.7	2.3	3.8	6.8	-0.0	0.1	-0.5	0.0	8.8
40.0	-4.5	-6.0	15.6	2.7	3.6	7.8	-0.1	0.2	-0.8	0.0	9.2
45.0	-5.0	-5.8	17.5	3.1	3.4	8.7	-0.1	0.2	-0.9	0.0	10.1
50.0	-5.5	-5.6	19.4	3.4	3.3	9.5	-0.2	0.3	-1.0	0.0	11.9
55.0	-5.9	-5.5	21.2	3.8	3.1	10.4	-0.3	0.3	-1.2	0.0	14.6
60.0	-6.3	-5.4	22.9	4.1	3.0	11.2	-0.5	0.4	-1.4	0.0	18.0
65.0	-6.7	-5.3	24.6	4.4	3.0	11.9	-0.6	0.4	-1.7	0.1	22.0
70.0	-7.0	-5.3	26.2	4.6	3.0	12.7	-0.8	0.5	-2.1	0.1	26.2
75.0	-7.3	-5.3	27.7	4.8	3.0	13.4	-1.0	0.6	-2.5	0.1	30.7
80.0	-7.5	-5.3	29.2	4.9	3.0	14.0	-1.2	0.8	-3.0	0.1	35.3
85.0	-7.7	-5.4	30.6	5.1	3.1	14.6	-1.4	0.9	-3.6	0.1	40.1
90.0	-7.9	-5.5	31.9	5.2	3.2	15.2	-1.7	1.1	-4.1	0.1	45.0
95.0	-8.0	-5.7	33.1	5.3	3.4	15.7	-2.0	1.3	-5.0	0.2	50.0
100.0	-8.1	-5.8	34.3	5.3	3.5	16.2	-2.3	1.6	-6.1	0.2	55.1
105.0	-8.2	-6.3	35.3	5.3	3.7	16.6	-2.6	2.0	-7.5	0.3	60.4
110.0	-8.2	-6.1	36.3	5.4	3.8	17.0	-2.9	2.4	-9.0	0.3	65.7
115.0	-8.3	-6.3	37.1	5.4	3.9	17.4	-3.2	2.8	-10.5	0.4	71.2
120.0	-8.3	-6.8	37.9	5.3	4.1	17.7	-3.5	3.3	-12.0	5.8	76.7
125.0	-8.3	-6.6	38.6	5.3	4.2	17.9	-3.8	2.8	-10.3	6.2	91.9
130.0	-8.2	-6.7	39.2	5.3	4.3	18.1	-4.1	2.0	-7.6	6.5	30.6
135.0	-8.2	-6.4	39.8	5.2	4.4	18.3	-4.4	1.0	-4.7	6.8	20.1
140.0	-8.1	-6.9	40.2	6.2	4.4	18.4	-4.7	1.0	-3.2	7.1	190.9
145.0	-8.1	-7.0	40.5	5.2	4.5	18.8	-4.9	1.4	-3.3	7.4	198.6
150.0	-8.0	-7.0	40.8	5.1	4.5	18.6	-5.2	1.6	-3.3	7.7	178.1
155.0	-7.9	-7.0	41.0	5.0	4.8	18.6	-5.5	1.4	-2.3	8.0	144.2
160.0	-7.8	-7.0	41.1	5.0	4.8	18.6	-5.7	0.9	0.1	8.2	109.0
165.0	-7.7	-6.3	41.0	4.9	4.4	18.5	-6.0	0.8	3.5	8.3	80.0
170.0	-7.6	-6.4	41.0	4.9	4.3	18.4	-6.2	8.2	33.6	7.6	334.7
175.0	-7.5	-6.7	40.8	4.8	4.3	18.3	-6.5	7.9	35.5	7.8	616.0
180.0	-7.0	10.4	40.6	4.4	-8.0	18.2	-6.8	7.4	32.5	8.0	648.9
185.0	-8.7	8.3	40.4	3.5	-6.5	18.1	-7.2	8.9	24.9	8.2	639.1
190.0	-6.5	6.2	40.1	2.6	-5.1	17.8	-7.6	12.6	14.6	8.1	599.5
195.0	-3.2	4.2	39.6	1.7	-3.6	17.5	-8.1	17.0	4.8	7.8	544.4
200.0	-2.1	2.3	39.1	0.9	-2.2	17.1	-8.5	20.8	-1.6	7.2	485.6
205.0	-1.1	0.6	38.5	0.1	-1.0	16.7	-8.9	23.4	-0.0	6.5	433.2
210.0	-0.2	-1.0	37.9	-0.5	0.1	16.3	-9.2	24.8	10.0	5.7	393.3
215.0	0.6	-2.2	37.3	-1.1	1.0	15.9	-9.5	25.2	26.9	4.9	365.6
220.0	1.2	-3.3	36.8	-1.5	1.7	15.5	-9.7	24.8	39.3	4.8	348.8
225.0	1.6	-4.1	36.3	-1.8	2.3	15.1	-9.8	23.5	49.7	4.3	341.6
230.0	1.9	-4.6	35.8	-2.0	2.7	14.8	-9.8	21.5	55.3	4.2	339.2
235.0	2.1	-4.9	35.4	-2.2	2.9	14.6	-9.7	18.9	57.3	4.4	337.3
240.0	2.2	-5.1	35.0	-2.3	3.0	14.2	-9.6	16.2	57.3	4.5	335.9
245.0	2.2	-6.0	34.8	-2.2	2.9	14.0	-9.4	14.0	56.9	4.5	332.4
250.0	2.0	-4.8	34.8	-2.1	2.8	13.9	-9.1	12.6	56.3	4.5	326.6
255.0	1.8	-4.5	34.4	-1.9	2.5	13.8	-8.8	12.1	55.3	4.3	310.6
260.0	1.6	-4.1	34.3	-1.8	3.2	13.7	-8.5	12.2	53.6	4.1	290.0
265.0	1.3	-3.6	34.3	-1.6	1.9	13.7	-8.1	12.3	50.8	3.7	263.4
270.0	1.0	-3.1	34.3	-1.3	1.5	13.8	-7.7	12.1	46.9	3.2	232.6
275.0	0.7	-2.5	34.4	-1.1	1.1	13.8	-7.2	11.4	42.3	2.6	200.3
280.0	0.3	-2.0	34.5	-0.9	0.8	13.9	-6.7	10.1	37.3	1.9	169.2
285.0	0.1	-1.5	34.6	-0.6	0.4	14.0	-6.2	8.3	32.5	1.3	142.0

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Figure 2B

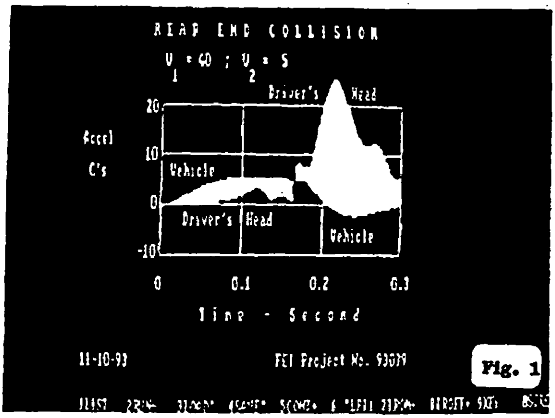
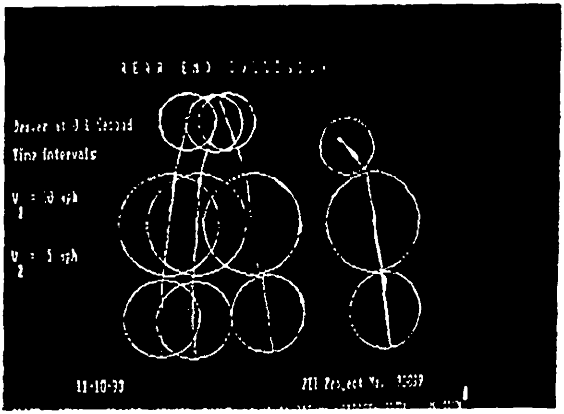


Figure 2C



time frames for various camera angles. The results are 3-D animations of the dummy body motions for those computer simulations.

Computer simulation numerical results were accepted by the court and presented to the jury. Still drawings were accepted as demonstrative evidence. The author testified that calculated values for head accelerations greater than 20 g's or moments greater than 40 lbs-ft meet SAE published criteria for probable cervical injuries. 3-D animations were completed a few days before the trial and were not accepted into evidence because disclosure was not timely.

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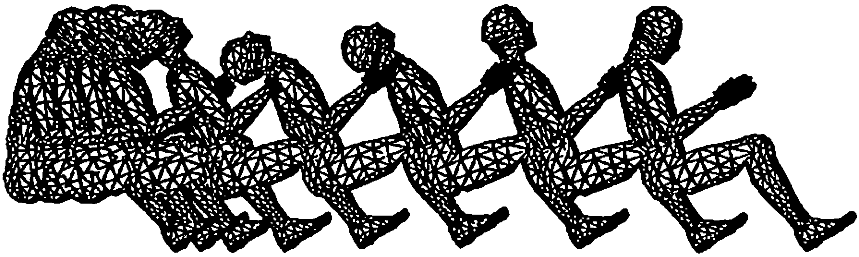
Figure 2D



Summary

3-D scientific animations are a powerful tool for illustrating "expert" opinions regarding objects in motion. They have been successfully and affordably applied to highway accident cases. They have been accepted as demonstrative evidence by courts when proper foundations have been laid. However, they are still viewed with skepticism by some courts which currently may require some extra persuasion in order to be able to show them to a jury. The author predicts that in the near future they will be commonly used for demonstrative evidence and they will be occasionally used for substantive evidence. Scientific animations should be able to pass ethical scrutinies that non-scientific animations would probably fail.