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ABSTRACT

This paper presents a method of determining a vehicle crush and equivalent barrier speed using digital photogrammetry. A state-of-the-art documentation technique called close-range photogrammetry allows engineers and accident reconstructionists to create three-dimensional computer models of damaged vehicles utilizing photographs. Utilizing photogrammetric software, engineers can digitize accident scene photographs to create accurate three-dimensional computer models of the vehicles, which can be used to quantify structural damage sustained by the vehicles. Crush deformation can be quantified utilizing this process and the resulting crush dimensions can be input into engineering software to determine a vehicle's equivalent barrier speed. Knott Laboratory, Inc. has utilized these techniques on cases worldwide including the Princess Diana accident in France [1][2].

INTRODUCTION

For a number of years, the ability to determine equivalent barrier speed based on vehicle crush has been available. In the past, engineers would inspect a vehicle and physically document the extent of crush using tape measures. In order to measure the crush, the vehicle had to be available for inspection; however, many times the vehicle had either been repaired or destroyed, and the only evidence of crush had been recorded on photographs. Utilizing close-range photogrammetry, the amount of crush now can be quantified as it could have been if the vehicle were physically available. It is no longer necessary to make an estimation of the vehicle's speed by just reviewing photographs of the vehicle and approximating the amount of crush. Close-range photogrammetry can be utilized to determine the amount of crush to within one-quarter inch under optimal circumstances and to within one inch under typical circumstances.

DISCUSSION

GATHERING AND ANALYZING PHOTOGRAPHIC DATA – The first step in the process is to determine whether or not there are enough photographs of good quality to perform the photogrammetric analysis. All the following requirements must be met in order for the photogrammetric process to be successful:

Number of Photographs – The first photograph depicts the two dimensional aspect of the vehicle; the second photograph provides information about the third dimension. Although it is possible to complete a project with only two photographs as shown in Figure 1, it is advisable to use more. In the example, six photographs were utilized to create a complete three-dimensional model of the vehicle. The purpose of creating a complete three-dimensional model, even though the crush to only the front end is desired, is so that the accuracy of the project can be determined by comparing uncrushed dimensions of the subject vehicle to an exemplar vehicle.

Photo Separation – It is important that the photographs show the area of interest from two different camera positions, preferably at right angles to each other. Photographs taken from the same position will not provide enough information about the third dimension and the accuracy of the project will be unacceptable.

Photo Coverage – To maximize the accuracy of the project, the area of interest should cover a large portion of the photograph. If points are centered in one small area of the photograph, the accuracy of the project will suffer.

Photo Quality – Typically, photographs from a 35mm camera are utilized and the quality of the images is usually good. However the quality of Polaroid photographs is poor, and the accuracy of the project may not be acceptable; therefore it is recommended that the use of Polaroids be limited.

PHOTOGRAMMETRIC ANALYSIS – There are several photogrammetric software programs available on the market today. These engineers utilized PhotoModeler [3] to perform the photogrammetric analysis.

Scan Photographs – The first step in the computer process is to scan the photographs of a crushed vehicle into the computer, which can be done utilizing a flatbed scanner. PhotoModeler will accept both color and black and white photographs. It is Knott Laboratory's experience that color photographs are easier to use when identifying damage, but the file size of the color photographs is approximately three times larger than black and white photographs.

Camera Characteristics – The next step is to input the camera characteristics of the camera that took the photographs. The focal length is an important input value. The vehicle can look quite different while looking through the camera and adjusting the focal length. Knott Laboratory's experience is that photographs are usually taken with one camera at one focal length. Investigators should input the focal length if it is known. If the focal length is not known, the software has a utility "Inverse Camera" that will assist in determining the camera's focal length. The camera characteristics can be determined if there are known dimensions in the photographs. This process has been reviewed and published previously by Knott Laboratory, Inc [4].

Identify Similar Points – This is the step in which a three-dimensional computer model is created. In order for the software to determine the three-dimensional position of key points in the photographs, the common points on the photographs must be identified (see Figure 2). The more photographs that are used to identify a selected point, the greater the accuracy; however, a minimum of two photographs must be used to identify a single point in order to create a three-dimensional model.

Process the Information – Once at least seven points have been identified on each photograph, the software is capable of determining the three-dimensional position of the identified points and camera. It is advisable to process the project when between 7 to 10 points have been identified on at least two photographs. If more than 10 points are added, the processing becomes cumbersome because the software is performing an iterative process in which it is repositioning the points and camera positions in space and determining the error after each iteration. With a greater number of points there are often too many solution sets generated by the iterative process for the processing to be successful.

Add Points to Increase Model Detail – In order to increase the detail of the model, additional points can be identified on each of the photographs ensuring that the points show up on at least two different photographs. It is Knott Laboratory's experience that the project should be processed after 7 to 10 additional points have been added.

Repeat Steps with Exemplar Vehicle – In order to determine the amount of crush, a comparison between the crushed vehicle and an uncrushed vehicle should be performed and the net crush values should be determined (see Figure 3). The same photogrammetric process can be performed on an exemplar vehicle so that the two vehicles can be compared side by side in three-dimensional space.

CREATING AND ANALYZING THE THREE-DIMENSIONAL MODELS –

Prepare Models for Export – To compare the crushed vehicle to the exemplar vehicle, both models can be exported into a separate computer aided drawing (CAD) package such as AutoCAD or 3DStudio. PhotoModeler can create both a mesh model and a textured model for output (see Figures 4 and 5). For documenting crush to the front end of a vehicle, textured models are placed side by side to quantify and compare deformation (see Figure 6). When the crush occurs to the side of a vehicle, mesh models are laid on top of each other to quantify the amount of deformation.

Determining Accuracy of Data – A statistical analysis of the accuracy of the project can be performed comparing the computer models to the actual technical specifications of the vehicles (see Figure 7). This statistical analysis determines the accuracy of the crush measurements, which will affect the accuracy of the equivalent barrier speed. Below is an example of a table quantifying the accuracy.

Measurement	**Processed Dimension**	**Physical Dimension**	**Accuracy**
Length	177.2	175.0	1.2%
Wheel Base	104.5	103	1.5%
Width	67.7	67	1.0%
Front Track Width	52.8	53	0.4%
Rear Track Width	54.2	54	0.4%
Height	59.8	61	2.0%
Average			1.1%

The maximum amount of crush measured in this project was 12 inches. The accuracy of the measurement is within $1/8^{th}$ of an inch, which is excellent for this project, but not typical in most projects. An accuracy within one inch is achievable under typical circumstances, which is an acceptable level of accuracy for data input into EDCRASH.

UTILIZING THE THREE-DIMENSIONAL MODEL –

Determining EBS – There are several software programs available on the market to determine equivalent barrier speed (EBS) utilizing crush data. For this process, EDCRASH developed by Engineering Dynamics Corporation [5] was used to calculate EBS. These authors will not discuss the details of how data is input into EDCRASH. This information can be found in the EDCRASH technical manuals [5]. In general, crush data is gathered from the three-dimensional computer model generated from the photogrammetric process (see Figure 8). This data is input into the EDCRASH system along with other vehicle data such as the vehicle stiffness coefficients, weight, and dimensions. Utilizing this information EDCRASH can calculate the amount of energy required to crush the vehicle and subsequently the vehicle equivalent barrier speed (see Figure 9).

Determining Occupant Compartment Dimensions – During many rollover accidents, the vehicle's occupant compartment dimensions change, sometimes crushing the occupant inside. Utilizing this photogrammetric technique to quantify the dimensions of the occupant compartment before and after the accident can assist an engineer in quantifying the amount of change in the occupant compartment. For example, Knott Laboratory was able to quantify the changes in the occupant compartment in a rollover accident involving a Peterbilt tractor (see Figures 10 and 11). In the accident, the occupant was unbelted and was ejected from the tractor during the rollover sequence. By quantifying the changes in the occupant compartment, engineers were able to determine that the occupant compartment was not crushed to the extent that had the driver been seatbelted, he probably could have survived the accident.

Determining Roadway Markings – Not only can three-dimensional objects such as vehicles be measured utilizing this photogrammetric method, two-dimensional objects such as roadway tire marks can be modeled and quantified. This process has been discussed in detail in SAE Paper 970944 [4]. Being able to quantify roadway marks allows engineers to better determine a vehicle's path and speed during an accident sequence.

CONCLUSION

Utilizing close-range photogrammetric techniques, engineers can measure vehicle crush utilizing photographs instead of physically measuring the vehicle. This method is of great value when the vehicle is no longer available, and photographs are the only documentation of the vehicle damage, which is quite common when an engineer must reconstruct an accident years after the accident occurred. Utilizing close-range photogrammetry, a three-dimensional model of the damaged vehicle can be created, and the crush deformation can be reconstructed with an accuracy of one inch under typical circumstances. Knowing the crush dimensions allows engineers to calculate a vehicle's equivalent barrier speed and changes in occupant compartment dimensions.

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ABOUT THE AUTHORS

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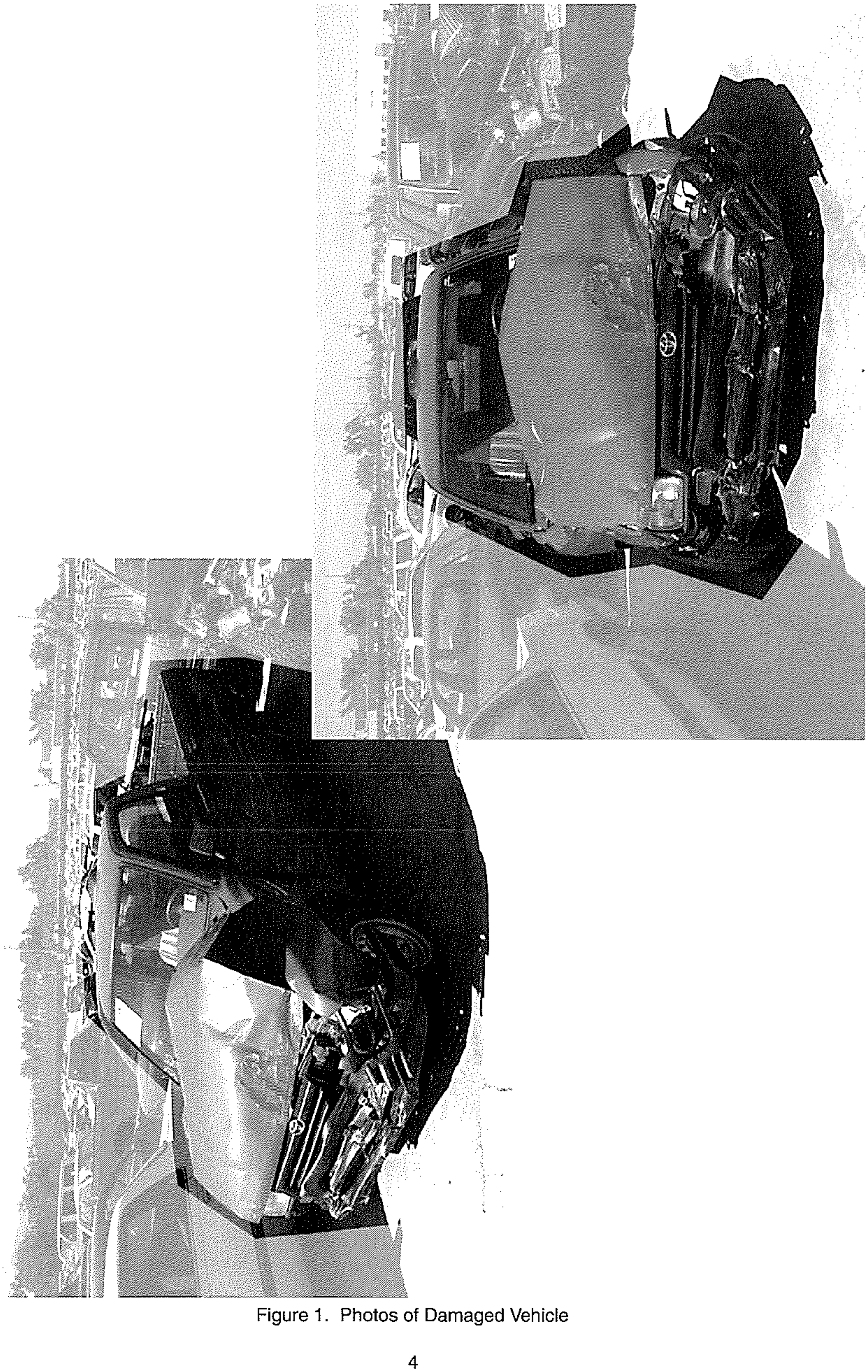

Figure 1. Photos of Damaged Vehicle

Figure 2. Common Points on Two Photographs

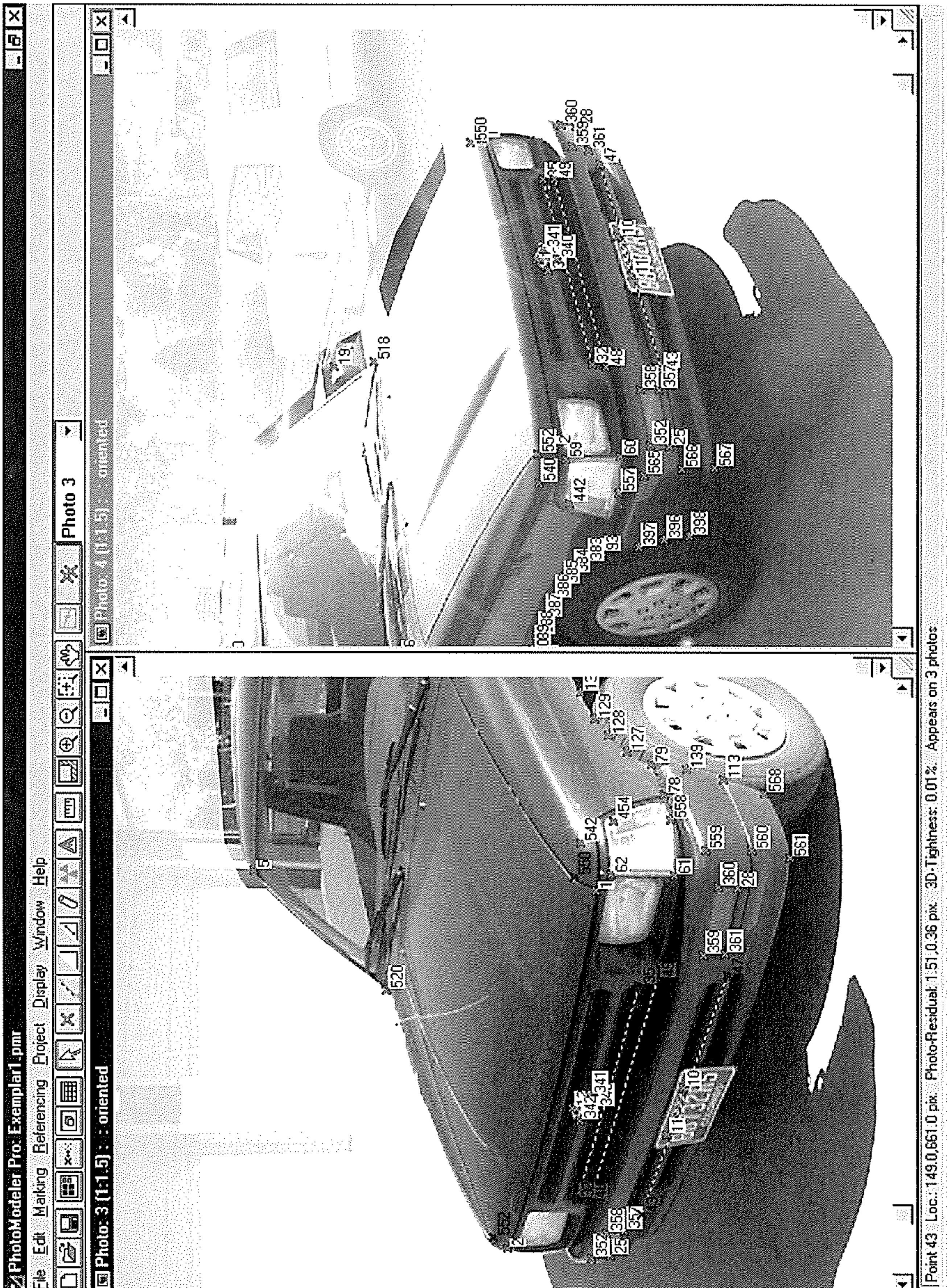

Figure 3. Common Points on the Exemplar Vehicle

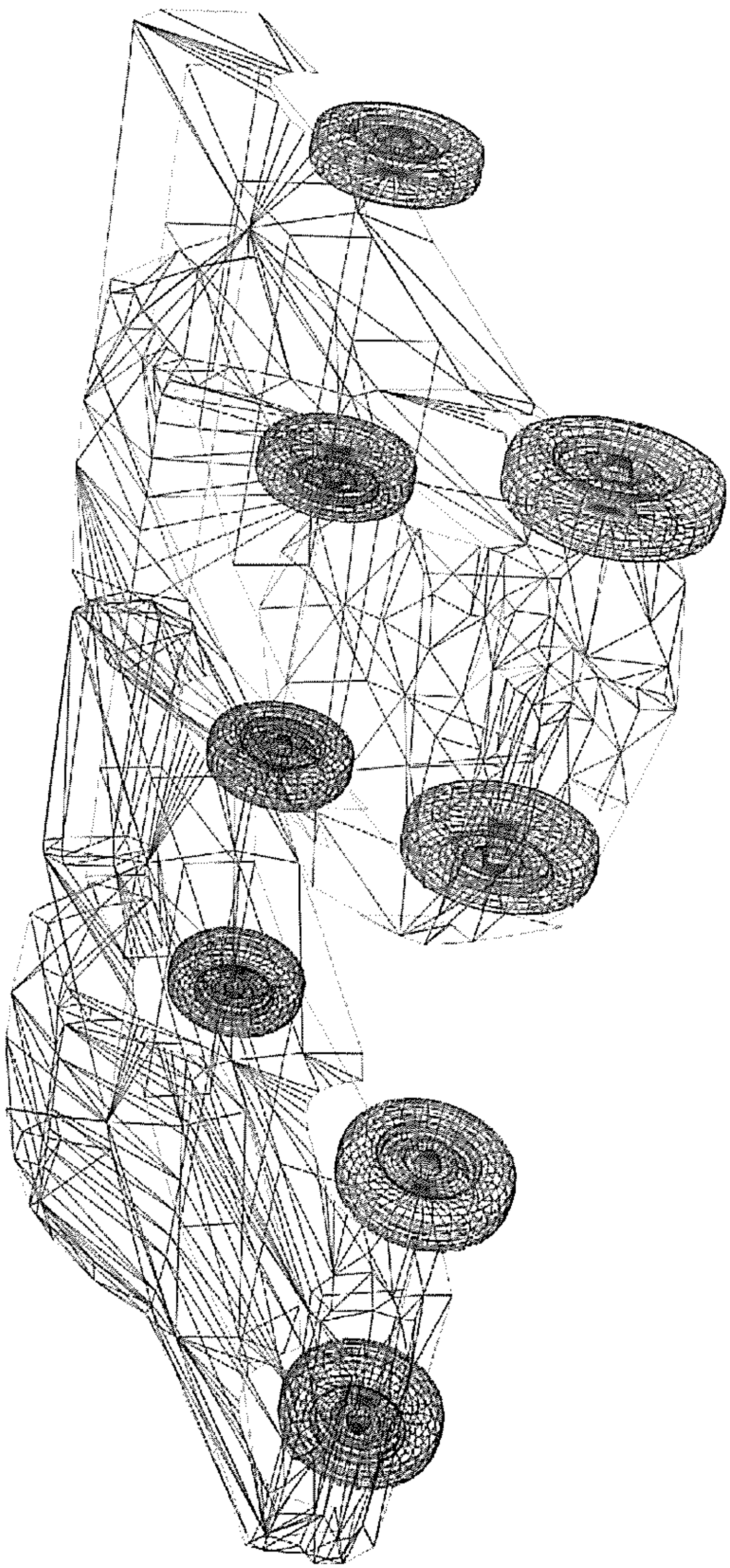

Figure 4. Mesh Models of Undamaged and Damaged Vehicles

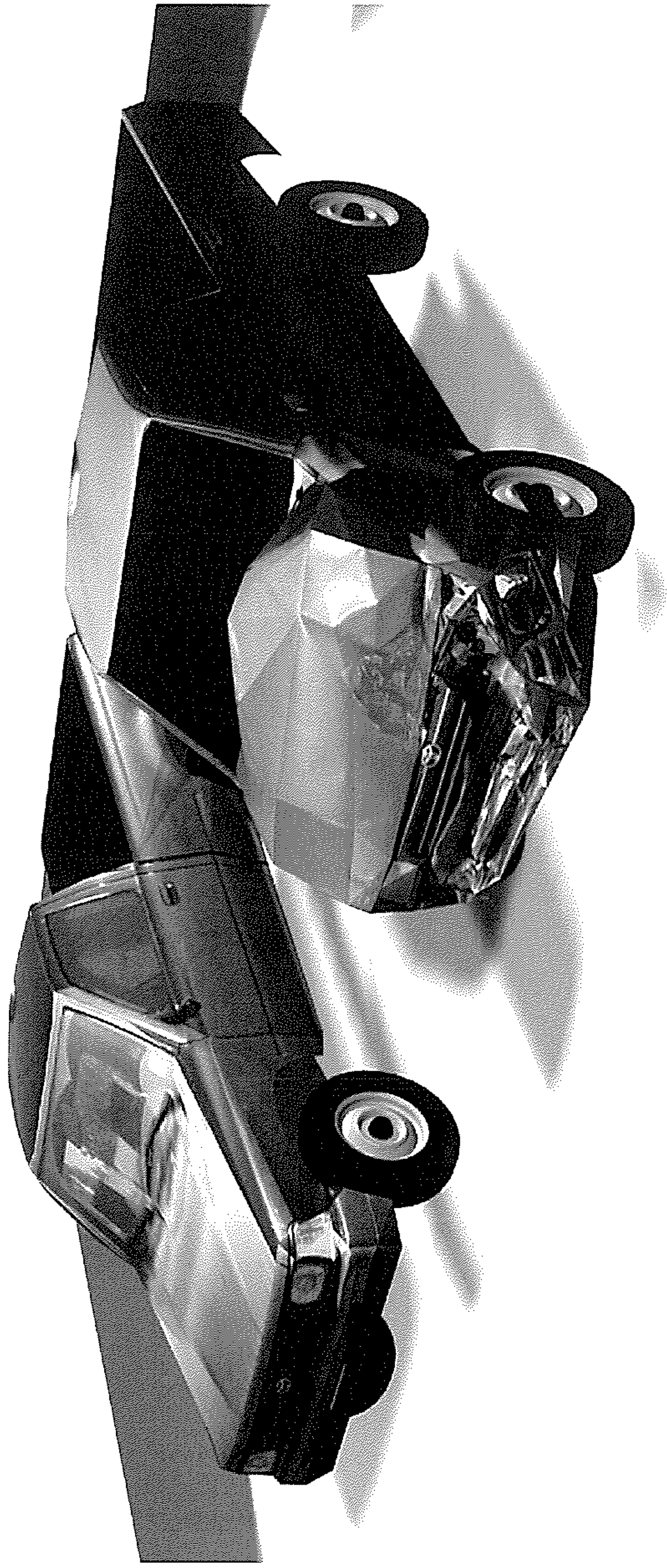

Figure 5. Textured Models of Undamaged and Damaged Vehicles (Perspective View)

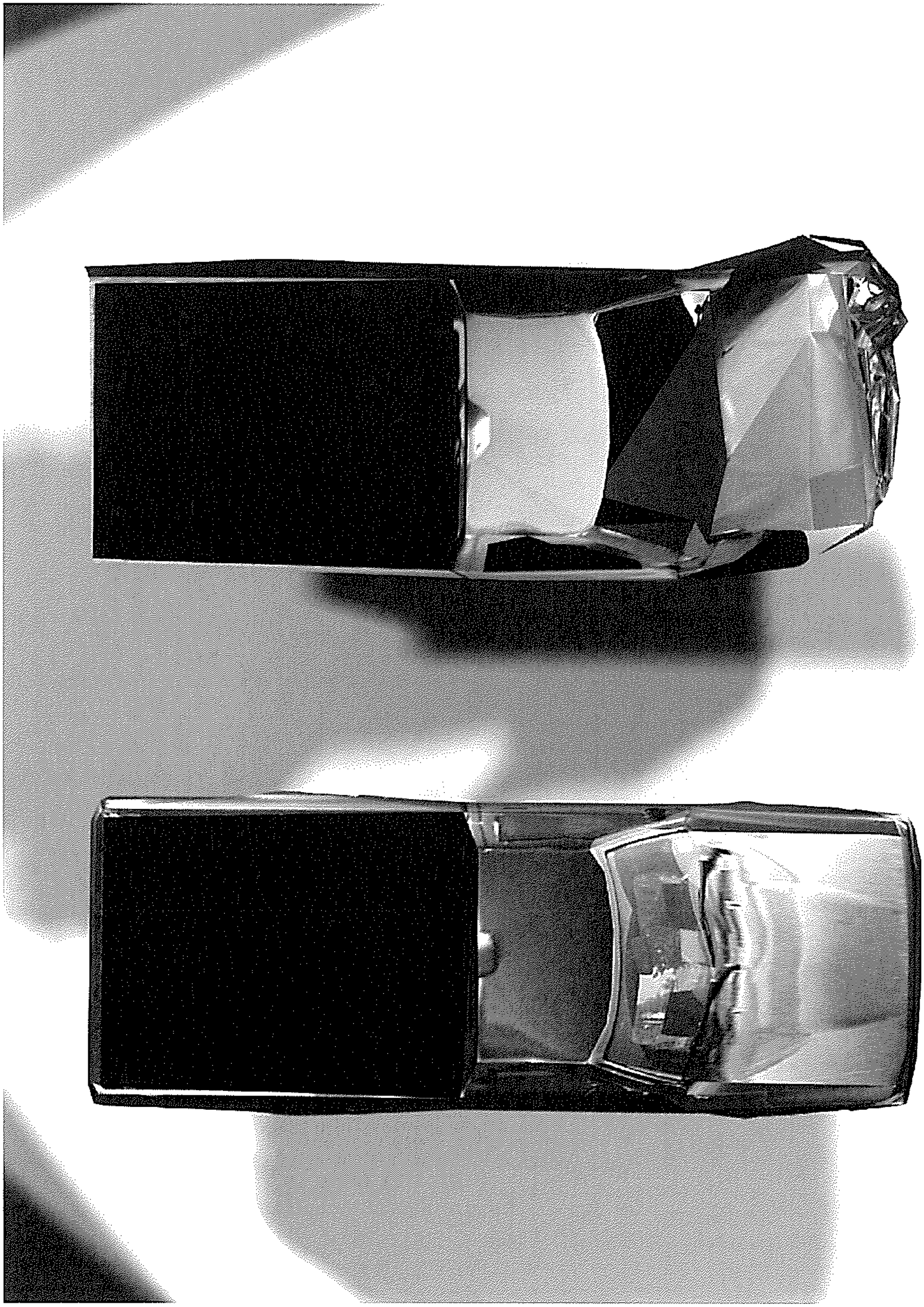

Figure 6. Textured Models of Undamaged and Damaged Vehicles (Top View)

1994 TOYOTA STANDARD BED 2DR PICKUP

[HORIZONTAL DIMENSIONS]

LENGTH	175 in.
WHEELBASE	103 in.
FRONT BUMPER TO FRONT AXLE	28 in.
FRONT BUMPER TO FRONT OF HOOD	3 in.
FRONT BUMPER TO BASE OF WINDSHIELD	45 in.
FRONT BUMPER TO TOP OF WINDSHIELD	63 in.
FRONT BUMPER TO FRONT WELL	10 in.
REAR BUMPER TO REAR OF TRUNK	___ in.
REAR BUMPER TO BASE OF REAR WINDOW	___ in.
REAR BUMPER TO REAR WELL	32 in.
REAR BUMPER TO REAR AXLE	44 in.

[DEPTH DIMENSIONS]

WIDTH	67 in.
FRONT TRACK	53 in.
REAR TRACK	54 in.

[VERTICAL DIMENSIONS]

HEIGHT	61 in.
GROUND TO:	
FRONT BUMPER (Top)	26 in.
HEADLIGHT - Center	30 in.
HOOD - Top Front	37 in.
BASE OF WINDSHIELD	49 in.
REAR BUMPER (Top)	25 in.
TRUNK - Top Rear	___ in.
BASE OF REAR WINDOW	___ in.

[WEIGHT DIMENSIONS]

CURB WEIGHT	2690 lbs.
Curb Weight Distribution:	FRONT = 56% REAR = 44%
GROSS VEHICLE WEIGHT	4400 lbs.

EXPERT AUTOSTATS(c) Reg.To:KNOTT LABORATORY S/N:98R-921016AA03201

1994 TOYOTA STANDARD BED 2DR PICKUP

[ACCELERATION/BRAKING]

ACCELERATION 0-30 mph	___._	ft/sec/sec
ACCELERATION 0-60 mph	___._	ft/sec/sec
ACCELERATION 45-65 mph	___._	ft/sec/sec
BRAKING 60-0 mph	___	ft

DRIVE WHEELS	4X2 / 4X4
TURNING CIRCLE (DIAMETER)	35 ft.
NUMBER OF WHEELS	4
WHEEL RADIUS	14 in.
TIRE SIZE	195-75R15

BUMPER STRENGTH	___ mph
STEERING RATIO	22.90:1

[INTERIOR DIMENSIONS]

FRONT SHOULDER ROOM	55 in.
FRONT HEAD ROOM	38 in.
FRONT LEG ROOM	42 in.
REAR SHOULDER ROOM	___ in.
REAR HEAD ROOM	___ in.
REAR LEG ROOM	___ in.

FRONT DISC - REAR DRUM - ABS UNKNOWN
3pt LAP & SHOULDER - front, Rear - None or Unknown, NO AIRBAGS
5spd MANUAL

N.S.D.C. = 1994 - 1995
___ = Value not in Database

EXPERT AUTOSTATS(c) Reg.To:KNOTT LABORATORY S/N:98R-921016AA03201

Figure 7. Technical Specs

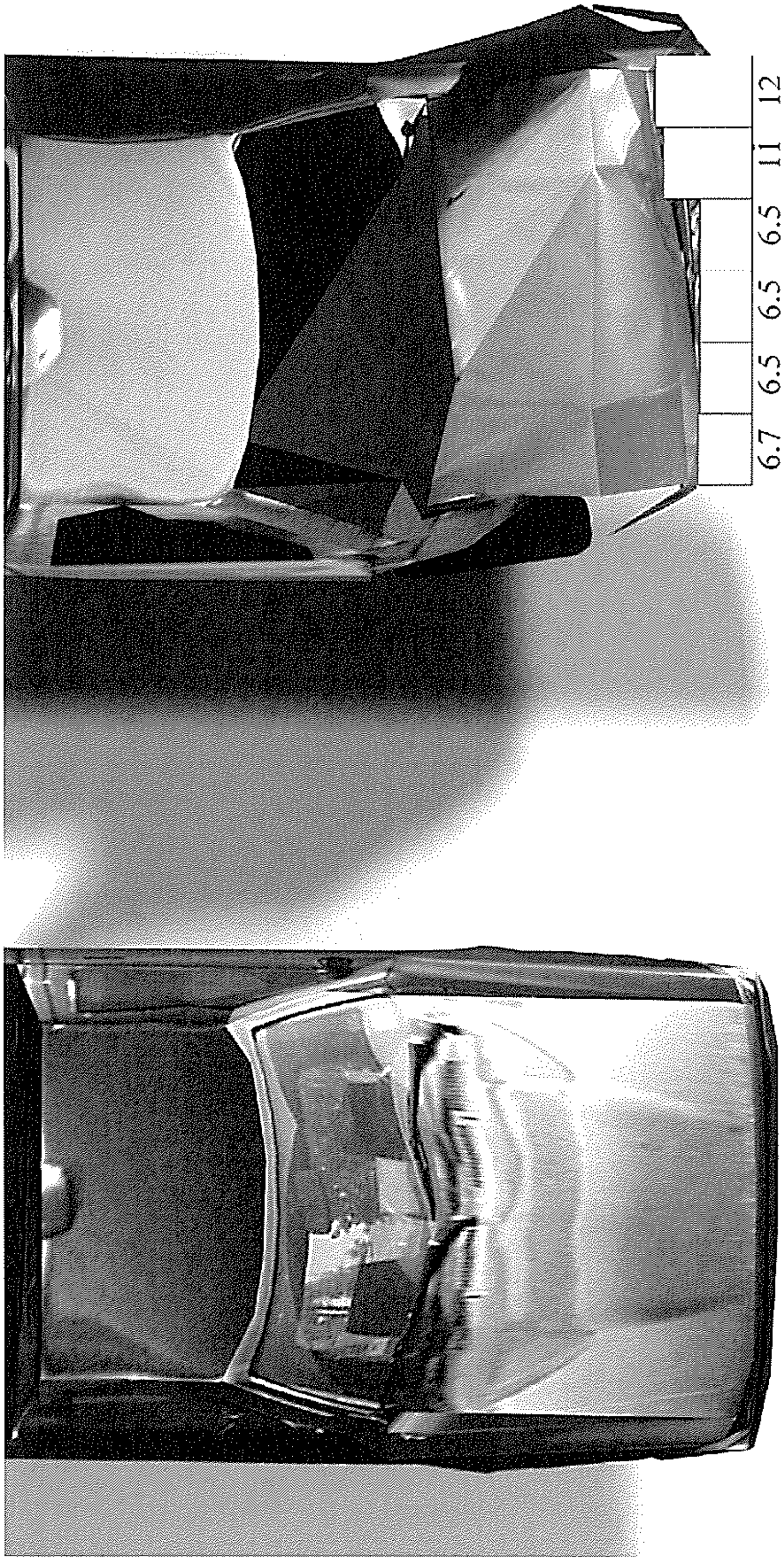

Figure 8. Vehicle Comparison and Net Crush Values

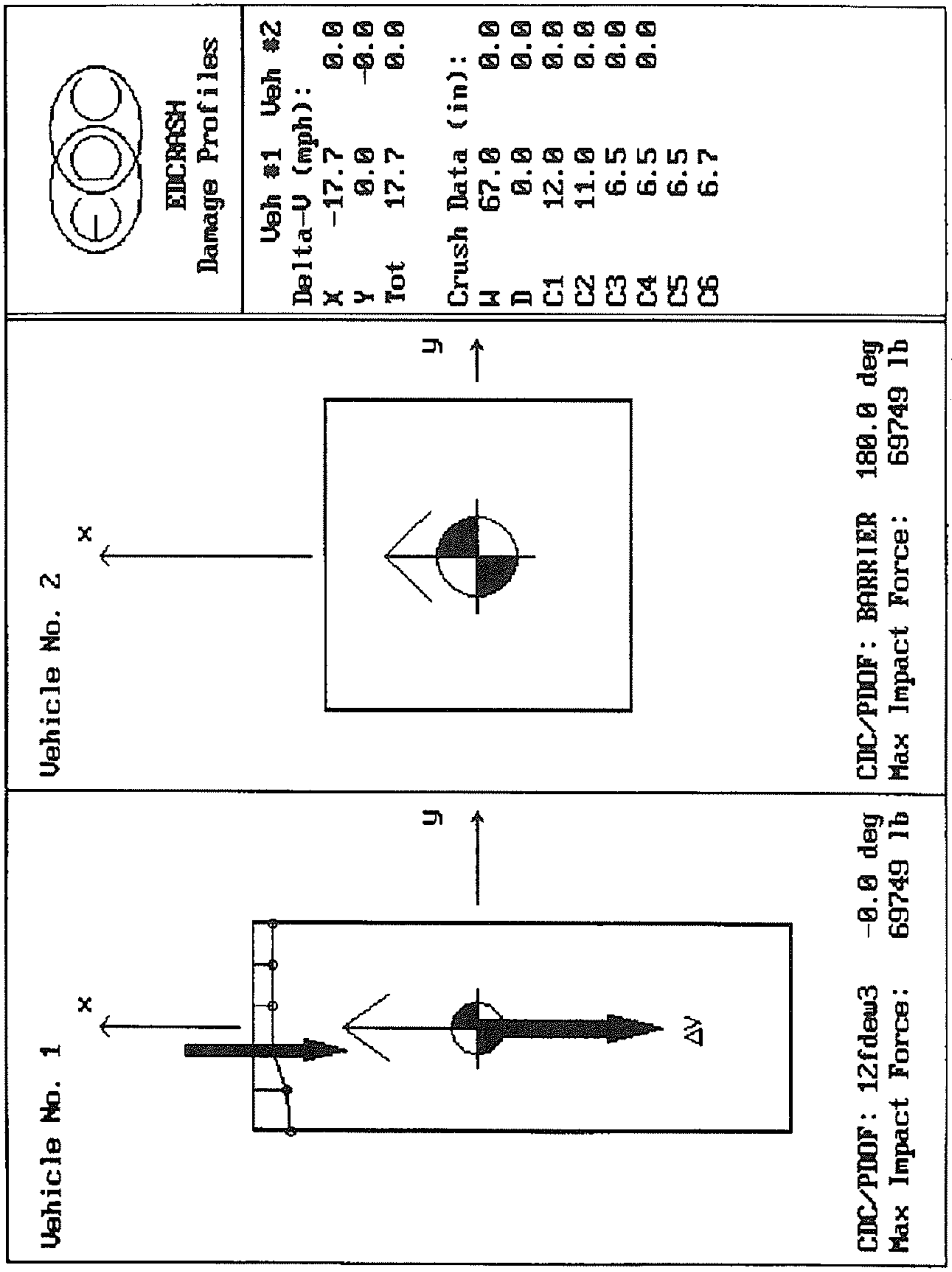

Figure 9. EDCRASH EBS Determination

Figure 10. Analysis of Crush Sequence (Solid Model)

Figure 11. Analysis of Crush Sequence (Transparent Model)