8

BIODYNAMIC SIMULATION IN RECONSTRUCTION OF REAL WORLD AUTOMOTIVE COLLISIONS USING A MICROCOMPUTER

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1. General Description of Simulation Software

The software developed and used by us in occupant simulation is called DYNAMAN. It is a software package that allows an analyst to simulate the dynamics of a vehicle occupant or pedestrian/ cyclist involved in a crash event. This package consists of the following modules:

1. A preprocessor that enables the analyst to interactively set up an input data file or to modify an existing data file that is needed to carry out the simulation.

2. A simulation module which accepts the input file that was created using the preprocessor, and produces output files that contain various dynamic variables that describe the three-dimensional motion of the occupant, e.g. accelerations, displacements, contact forces, etc. The simulation module is based on the Articulated Total Body Program (ATB Version 4.0).

3. A postprocessor that can be used to view the output of the simulation module in pictorial, graphical, and tabular forms.

The software package will run on 80286- and 80386-based personal computers under DOS 3.xx. There are both 16-bit and 32-bit versions. A picture of the general menu of the DYNAMAN program is given in Figure 1.

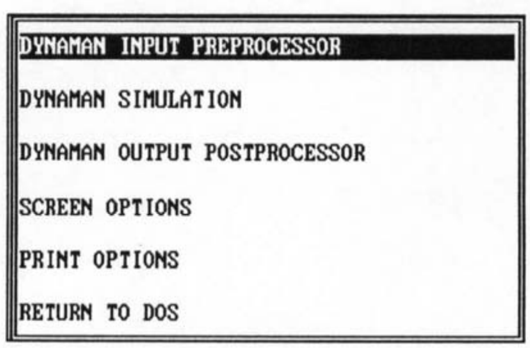


Figure 1: DYNAMAN General Menu

2. Elements of Simulation Input

In order to simulate the motion of a vehicle occupant or pedestrian, the following broad categories of information are required:

1. Geometric and inertial properties of the occupant
2. Environment around the occupant
3. Motion of the vehicle
4. Initial position of the occupant and belt restraints
5. Integration and output parameters to run the simulation module.

The DYNAMAN preprocessor is used to set up the various input data. Figure 2 displays a sample view of the screen showing the inertial properties of the occupant segments. Figure 3 displays the data for the vehicle motion. Figure 4 shows data for defining the various functions in the input data.

Seg Name	Seg Wt	Ixx	Iyy	Izz
LLL	7.237	.6708	.6745	.03970
LF	2.756	.00670	.05240	.04910
RUA	4.597	.1024	.09970	.01090
RLA	3.820	.1200	.1203	.00710
LUA	4.597	.1024	.09970	.01090
LLA	3.820	.1200	.1203	.00710
RHD	1.290	.01140	.00930	.00360
LHD	1.290	.01140	.00930	.00360

Figure 2: Sample Data Screen

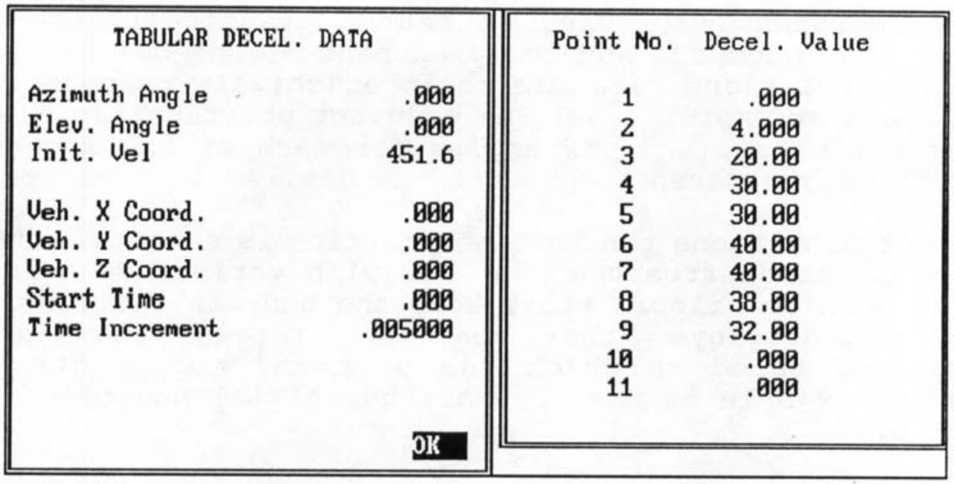


Figure 3: Screen for Defining Deceleration

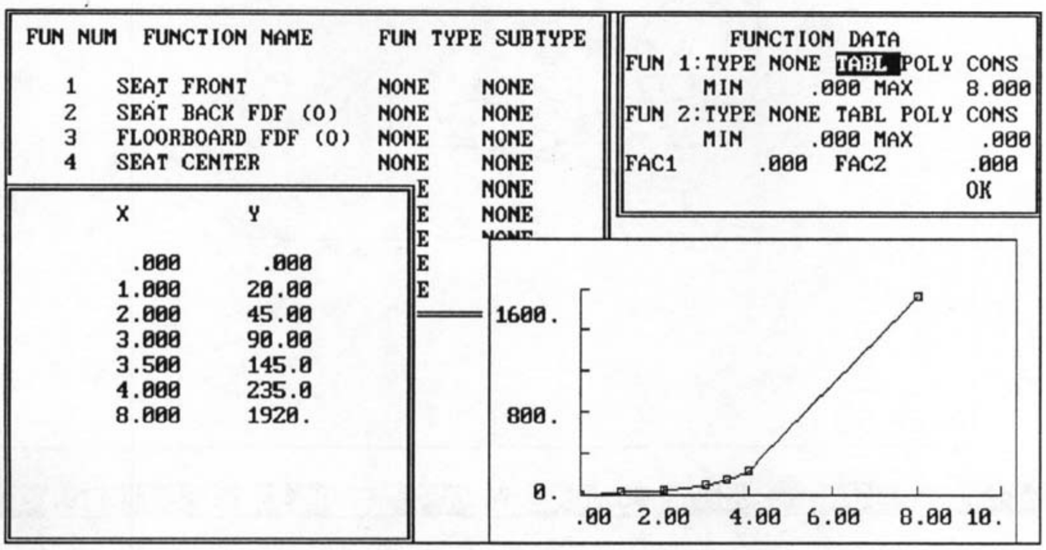


Figure 4: Additional Windows to Define Function Values

The preprocessor is used to set up graphically the initial position of the occupant and the placement of the belt restraints. The viewing angles and size can be interactively changed to allow the user the most useful view. The occupant position can be changed and the roll, pitch, and yaw angles for each of the segments can be interactively altered to produce the desired initial position.

In most situations the initial position is selected, such that the reaction forces from the contacts with various vehicle panels (e.g. seat cushion, floor, etc.) keep the body in equilibrium. The preprocessor displays the reaction forces for a given configuration, based on which the user may modify the initial position. An example of the view of the initial position is given in Figure 5.

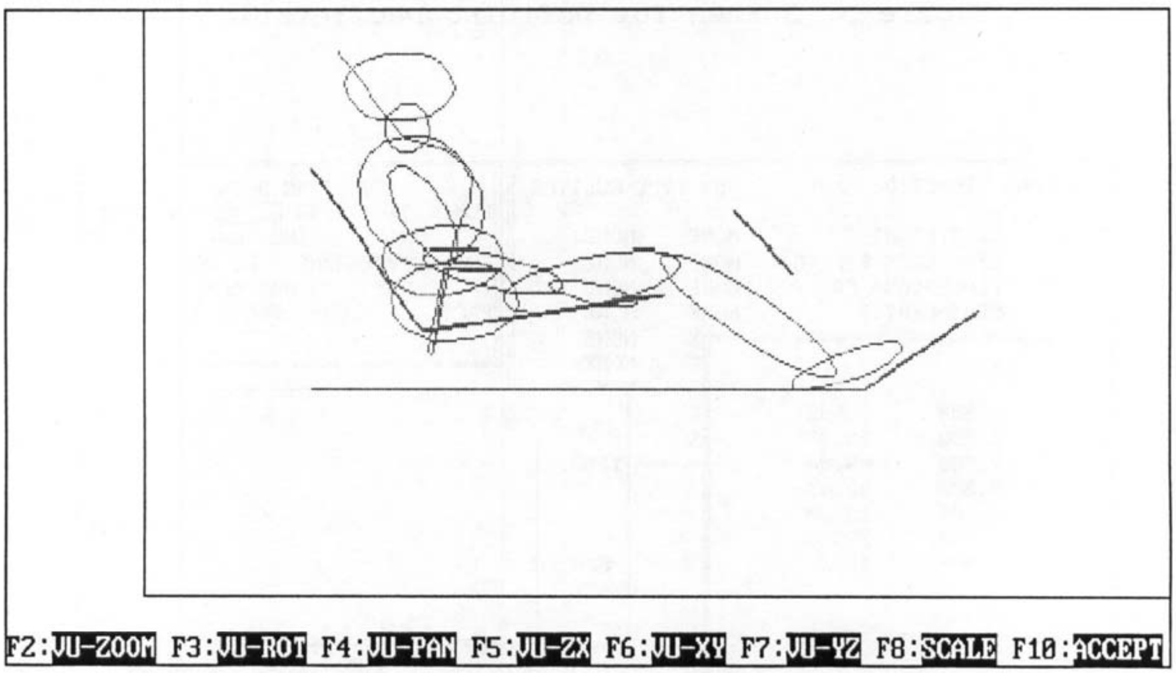


Figure 5: Initial Position Screen

The belts are also defined graphically, and belt points can be inserted, deleted, and moved interactively. A sample view of the screen showing the belt points is given in Figure 6.

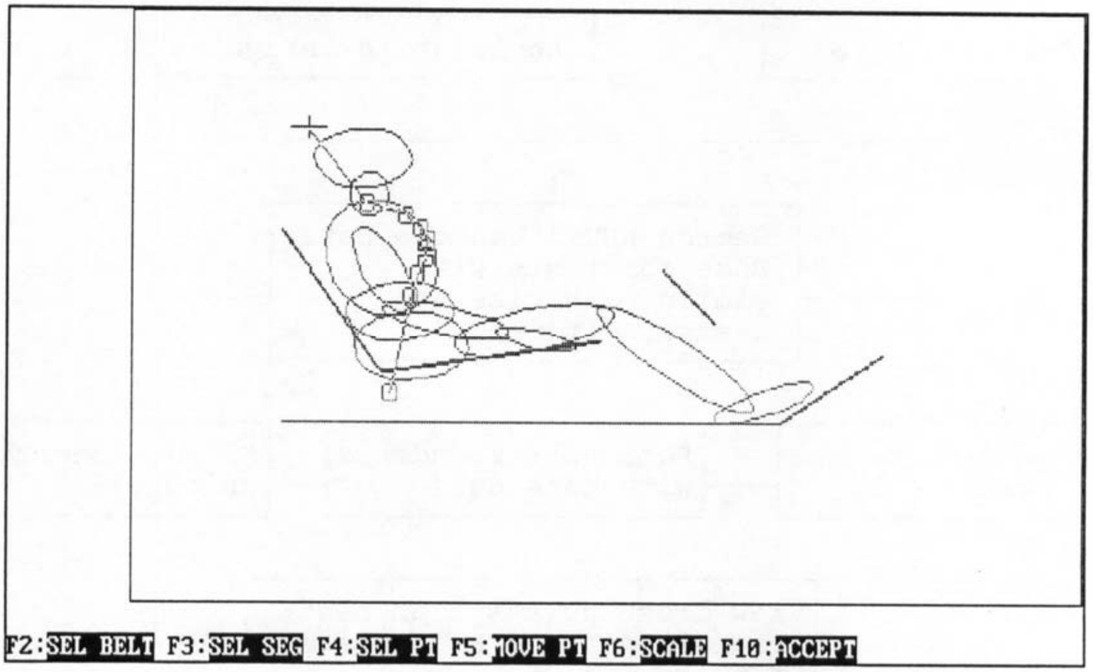


Figure 6: Harness Belt Screen

3. Methodology for Reconstruction of Occupant Motion

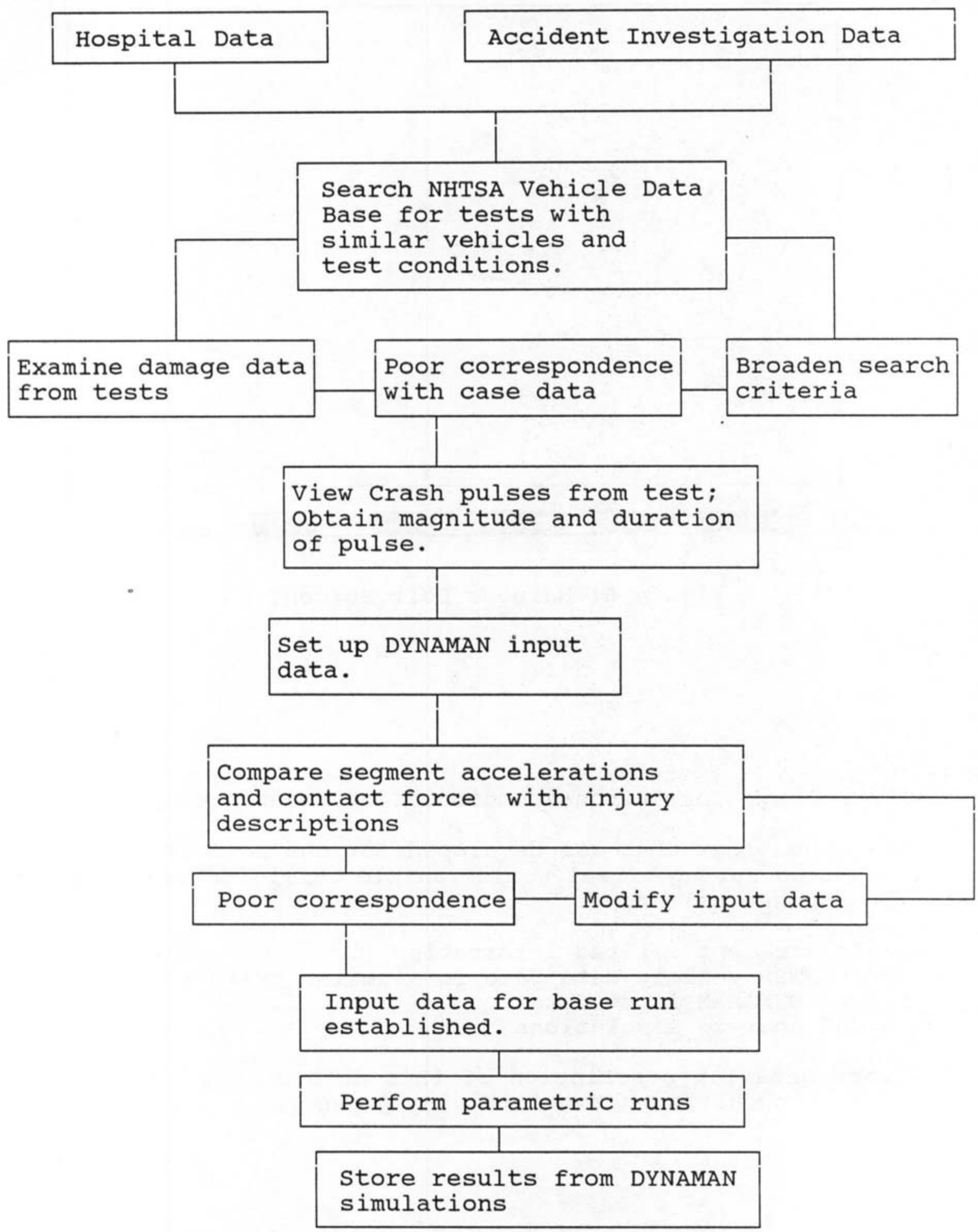
The methodology that was developed for the reconstruction of occupant motion during a real world vehicle collision consisted of the following general steps:

1. Obtain accident related information
2. Query NHTSA vehicle data base for similar crash event
3. Prepare DYNAMAN input data
4. Run and analyze simulations

A more detailed description of this methodology is given in a series of flowcharts on the following pages.

3.1 Summary of Methodology

The following diagram describes the steps involved in making a simulation starting with the accident related data.

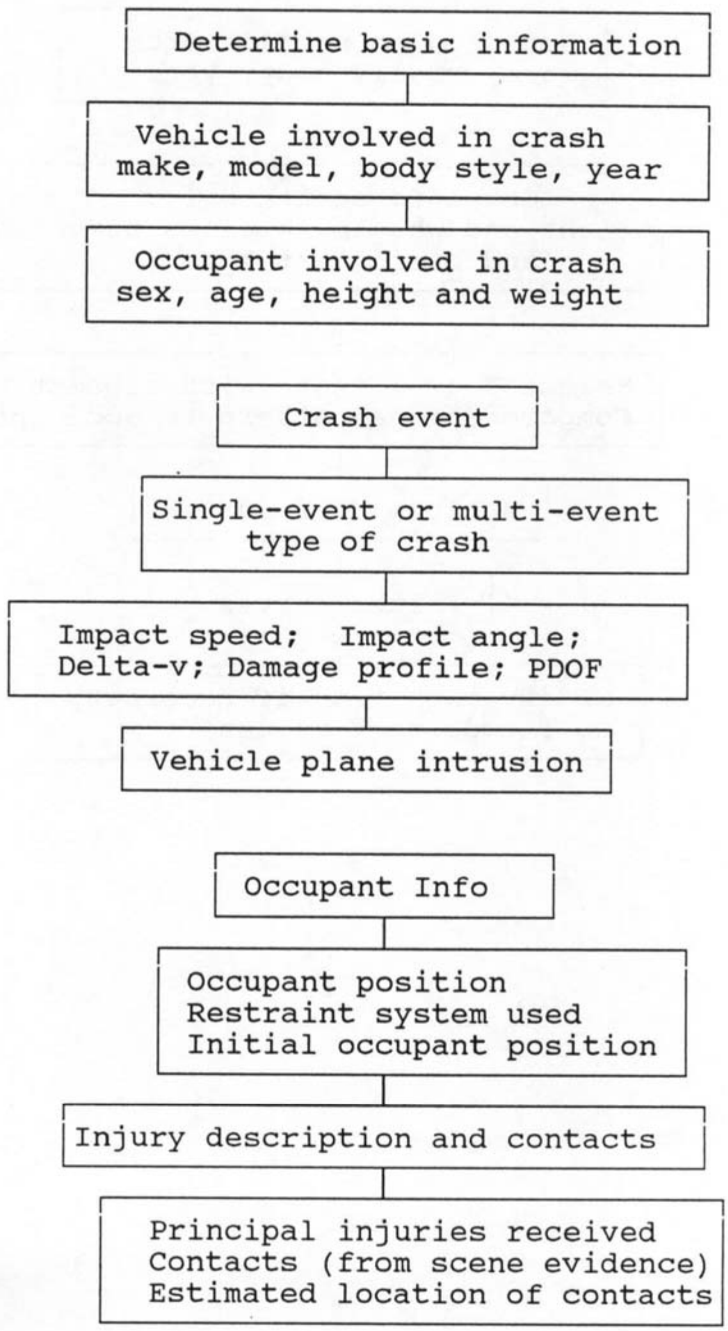


3.2 Accident Related Information

The accident related information consists of the following:

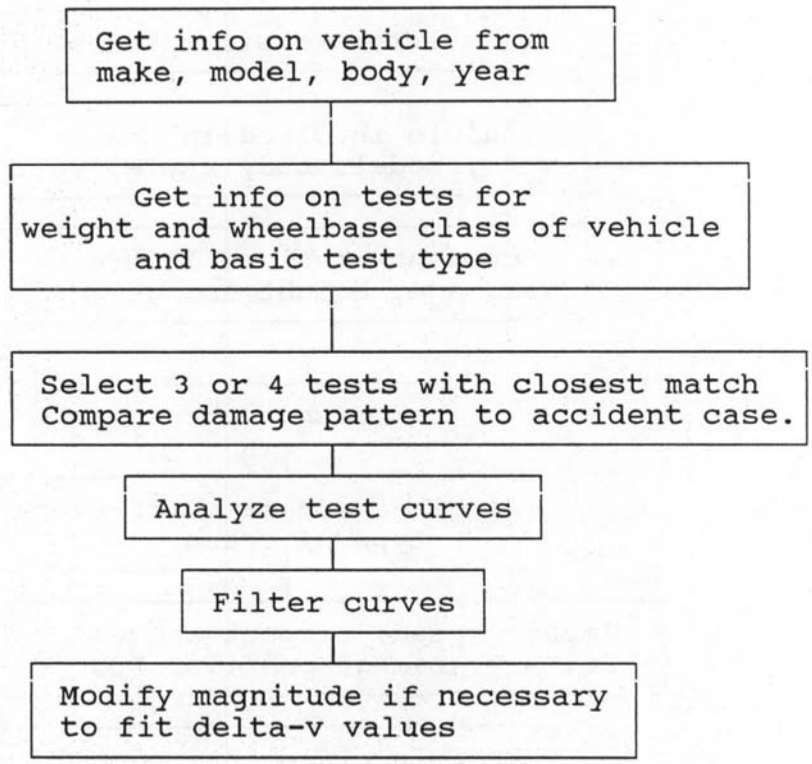
1. Basic vehicle and occupant information
2. Description of the crash event
3. Description of occupant position and injuries

These aspects are described in the flow chart below.



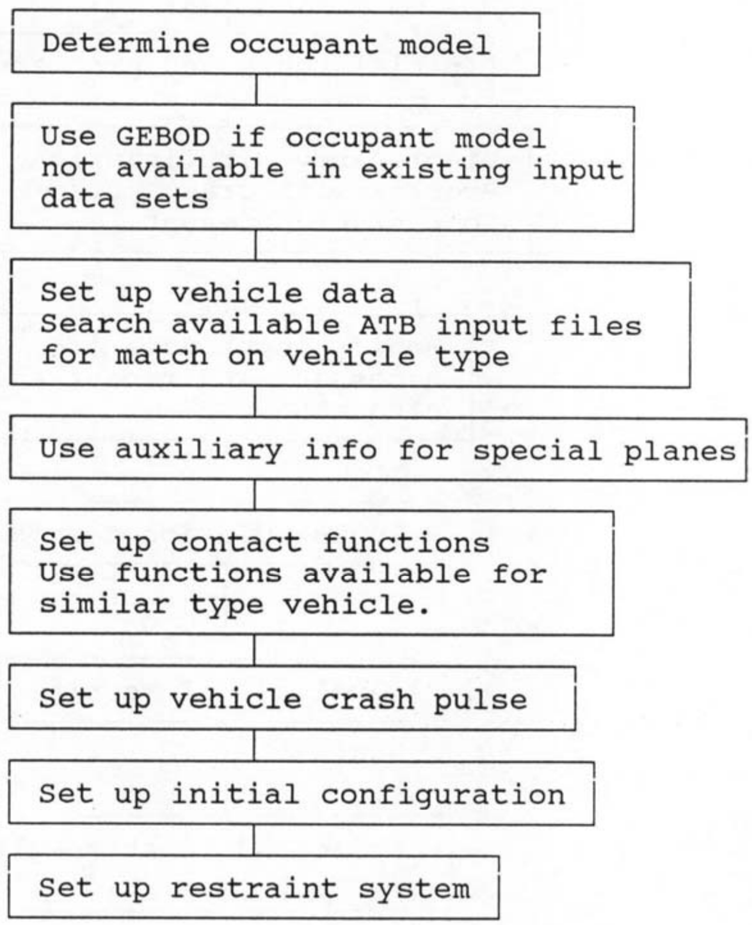
3.3 Query NHTSA Vehicle Data Base

After an accident is selected, the NHTSA vehicle data base is queried to determine if any vehicle crash test exists which display general similarities to the accident. The objective of this search is to obtain a crash pulse for a similar crash situation. An estimate of the magnitude and duration of the pulse is also made based on the damage profile, delta-v values, and the vehicle weight and size. The steps in this search is described below.



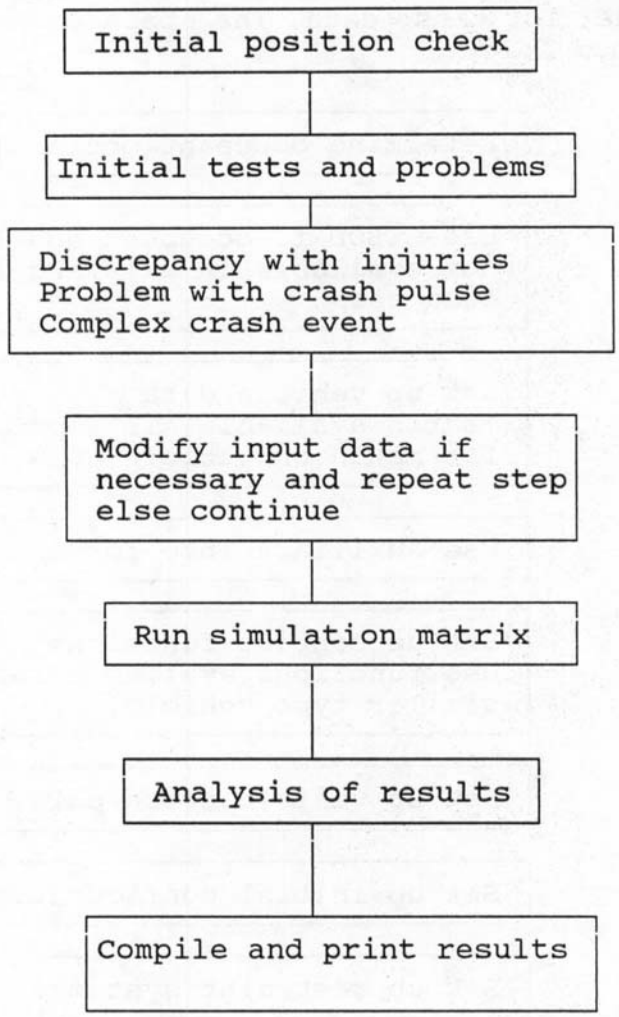
3.4 Preparation of DYNAMAN input

Once a crash pulse can be determined, the remaining portion of the input data required for running the simulation is created. For some situations, the occupant sex, height, and size will be reasonably close to one of the data sets for different dummies (e.g. 50% male, 5% female, 95% male, etc.). When there is departure from an available dummy size, the computer program GEBOD is used to generate occupant inertia and geometry information, based on a statistical model for these data. The steps in setting up the input data are outlined below.



3.5 Running Simulations

Once an input data file for an accident case is set up, the simulation program is run and the accelerations and impact loads on various segments compared with the injury description of the occupant. If serious discrepancies exist, some of the input parameters are varied till a more favorable match is obtained. The procedure for running the simulations is outlined below.



4. Crash Reconstruction Examples

Case 1

Vehicle: The case vehicle was a subcompact (1986) and some basic dimensions were obtained from the NHTSA Vehicle Database. Additional planes included the passenger side door panel and window, and the front seat back. The location and size of these planes were estimated from photographs and the dimensions of the vehicle interior.

Occupant: The occupant was a young female sitting in the right rear passenger position. Because the occupant weight and height (114 lbs, 63 in) departed from average 50% female size, the program GEBOD was used to generate the segment data. The joint functions for a 50% female were used.

Crash: Front of a tanker truck struck right side of vehicle. Impact speed of 40-50 mph. Caused door intrusion of about 12 inches.

Injuries: Brain contusions (AIS5), fractured ribs (AIS3), fractured pelvis (AIS3), ruptured spleen (AIS4), fractured sacrum (AIS3).

Contact Functions: Functions defined in ATB input data file for contact with the interior planes another subcompact were used. Segment-segment contacts, such as between the leg segments, and between the arms and upper torso were defined using functions from an existing ATB input file.

Deceleration pulse: Since the crash event was with a large truck/tanker (> 50,000 lbs), the event was modeled as a side impact with a barrier. From the NHTSA crash test data base one test was found to have a similar maximum crush but a somewhat different damage distribution. For this test the acceleration curves located at the vehicle c.g. and rear deck (for all three directions) were found. The curves were filtered, and the peak and duration compared well with that expected from the damage (a peak of 29G and a duration of 100 msec was used). Only acceleration in the y-direction was used. Motion for the door frame was also included by allowing for an intrusion of about 12 inches over the pulse period.

Initial Position: The simulation was run with the body in the right rear passenger position and in normal resting position. In the lateral direction the body was placed just inside the door panel. For this case several simulations were attempted with a second occupant being modeled by three lumped masses representing the torso, upper leg and lower leg. This was to make an evaluation of the effect of inter-occupant contact. Several different initial data were created and the results compared.

File	Initial Configuration	HIC	HSI	CSI	Max Head Accel (G)
C1	Normal resting position	1430	1600	916	178 @ 64ms
C1A	Moved laterally left 2"	2000	2190	1310	170 @ 68ms
C1B	Moved laterally left 4"	2480	2730	1560	173 @ 81ms
C1C	Moved laterally left 6"	2770	3090	1720	184 @ 86ms
C1D	Rotate upper body forward 5 deg	1430	1650	920	178 @ 64ms
C1E	Rotate upper body forward 10 deg	1440	1620	910	180 @ 64ms
C1F	Decrease motion of door by 2 inch (13" to 11")	1510	1670	940	179 @ 64ms
C1P	Model contact with 2nd occupant	1590	2100	2200	210 @ 74ms

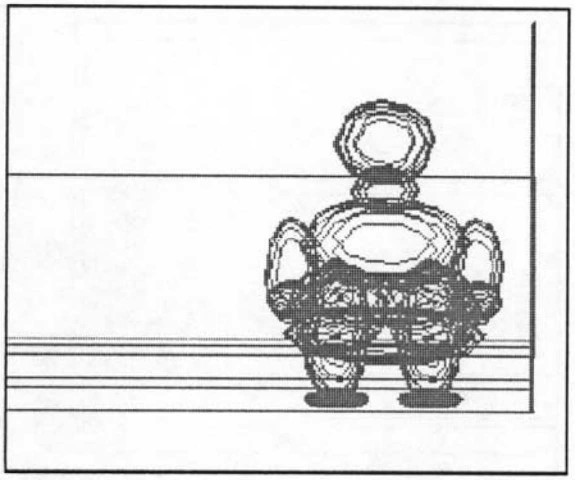
The HIC value is most sensitive to the positioning in the lateral direction, where a 2" displacement further away from the door results in an increase of HIC by over 30%. The maximum acceleration on the head is almost unchanged, but the duration is increased substantially resulting in the higher HIC value. Since this level of HIC would account well for the AIS5 head injury, the input data defined in the first two sets were used for evaluating the overall results. When contact with the second occupant was modeled, the HIC value did not change substantially, but the CSI value more than doubled, indicating very serious torso injuries.

Simulation Results: The simulations shows the following serious contacts.

Head: Head contact with rear window - 1300 lbs
Maximum head accel - 177 G at 64 msec (in -Y dir)
Maximum head angular accel - 1200 rev/sec**2 (in -X dir)
The HIC value corresponds well with the severe AIS 5 head injuries.

Chest: Upper torso contact with door panel - 2100 lbs
Lower torso contact with door panel - 440 lbs
Maximum torso accel - 91 G at 68 msec (in -Y dir)
When contact with 2nd occupant is modeled:
Upper torso contact with 2nd occup - > 5000 lbs
Lower torso contact with 2nd occup - 3500 lbs
This large loading is partially artificial, since the inter-occupant contact function is being guessed at. In any case, it appears to be a very severe impact. The head motion is not effected appreciably but the chest severity index is more than doubled.
Compatible with multiple chest injuries.
Legs: Right upper leg contact with door - 2500 lbs
Right lower leg contact with door - 150 lbs
The large lateral loading on the leg is compatible with the lower extremity injuries though the magnitude appears to be higher than the level of injury suffered.
Feet: Right foot with floor - 570 lbs
Left foot with floor - 730 lbs
Arms: Right upper arm contact with door - 1790 lbs
Right lower arm contact with door - 100 lbs

CASE 1: SUBCOMPACT W/ LARGE TRUCK - SIDE IMPACT
RIGHT REAR PASSENGER - NO BELTS



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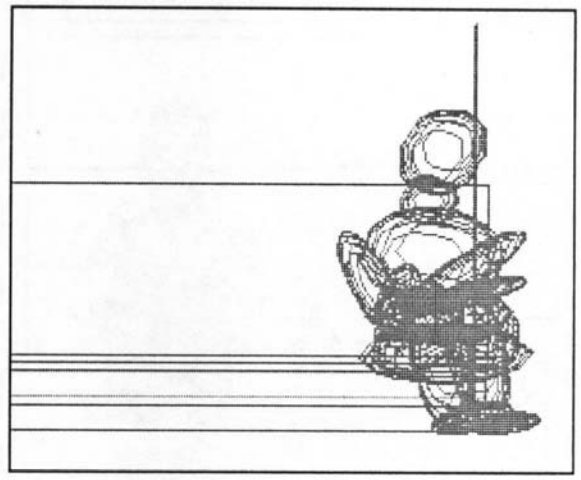

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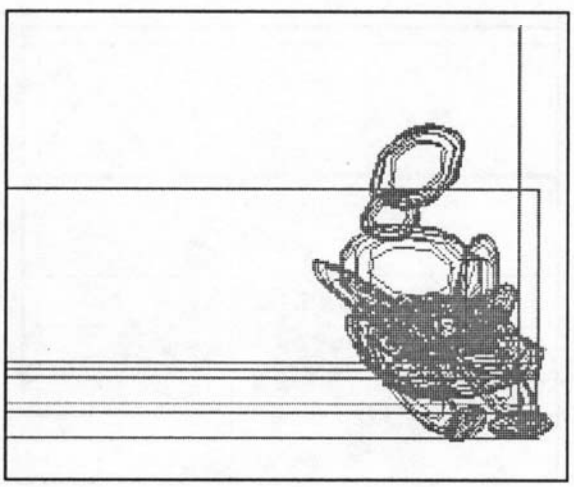

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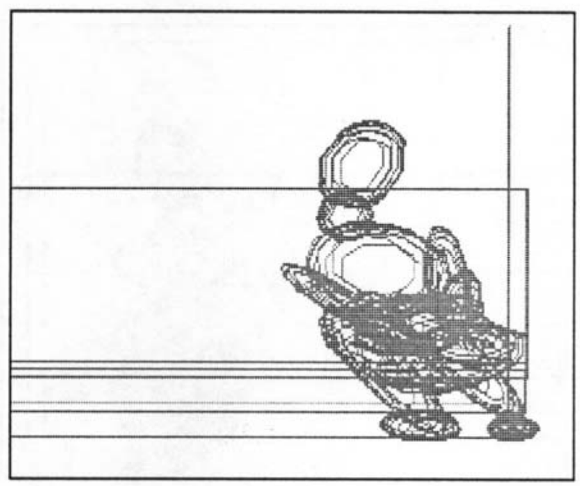

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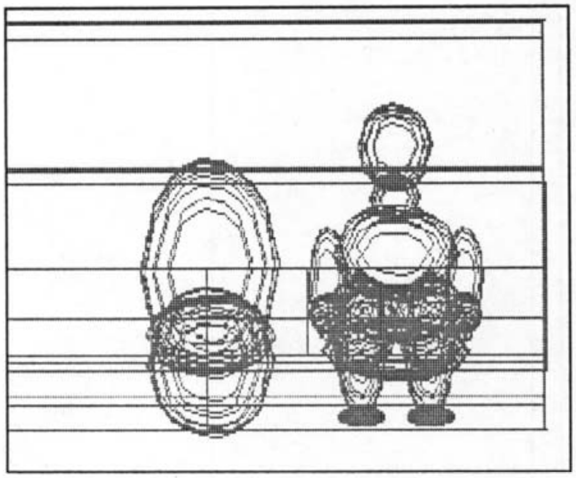
CASE 466: SUBCOMPACT W/ LARGE TRUCK - SIDE IMPACT
RIGHT REAR PASSENGER - NO BELTS
MODEL OF INTERACTION WITH LEFT PASSENGER



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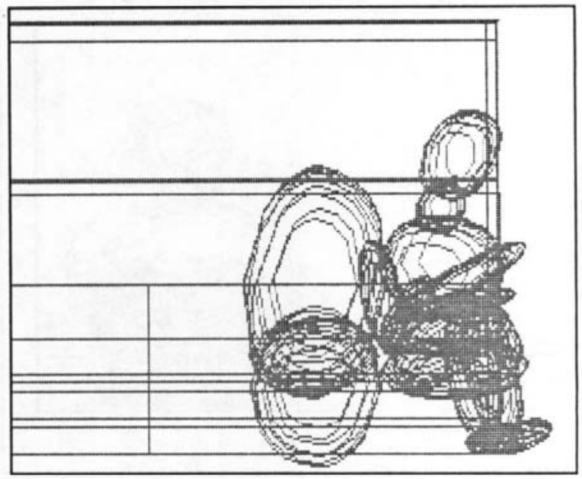

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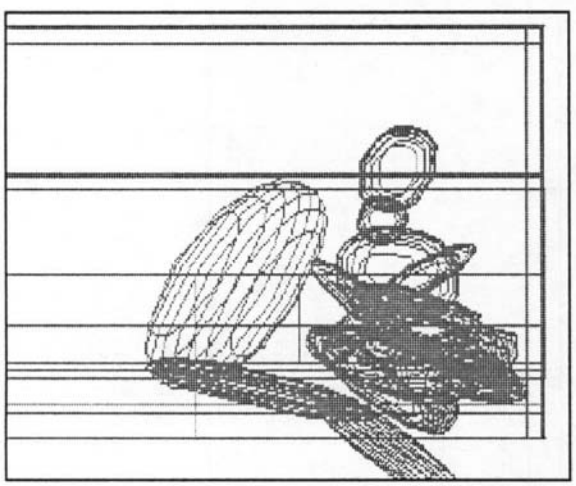

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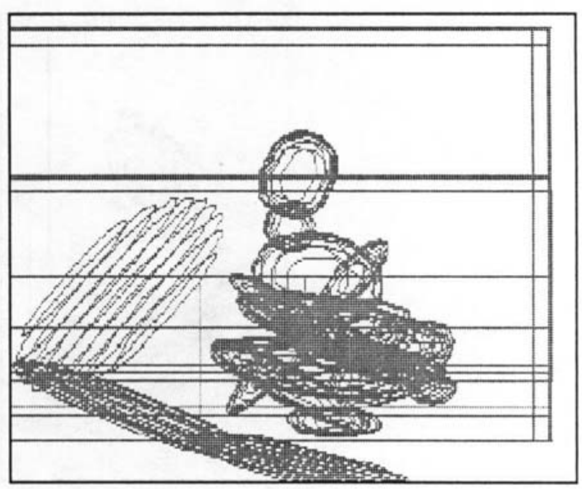


TIME = 200 MSEC

Case 2

Vehicle: The case vehicle was a small pickup and some basic dimensions were obtained from the NHTSA Vehicle Database. Dimensions for another compact were available from an existing input data set were also used. An additional plane representing a left instrument panel was also used.

Occupant: Occupant was a middle aged male driver. Because of lack of information of the height and weight of the driver, the data for a 50% male dummy was used (Euler Part 572). The occupant was wearing lap and shoulder belts.

Injuries: Brain contusion (AIS3), facial fractures and lacerations (AIS1), abdominal injuries (tears in colon, small bowel, spleen - AIS2 and AIS3), fracture left lower arm (AIS2), fracture left lower leg (AIS2), fracture left foot (AIS2).

Crash: Front of case vehicle impacted the right side of a sports car. Estimated impact speed was about 40 mph. Travel speed of other car was about 55 mph. Delta-v was about 40 mph. The left A-pillar of the case vehicle intruded longitudinally about 12 inches.

Deceleration pulse: Searched NHTSA crash test data base for frontal vehicle-to-vehicle impacts for vehicles in the weight range and closing speed seen in the accident. Tests for which the damage data compared well with that from the case were selected. For these tests the acceleration curves located at the vehicle c.g., engine, and dash panel were found. The curves were filtered and the peak and duration compared well with that expected from the damage (a peak of 14G and a duration of 200 msec was used). Acceleration was defined both in the longitudinal and lateral directions. A separate motion of the left instrument panel, toepan, and steering wheel was defined, such that it would result in an intrusion of about 12 inches as observed in the accident.

Initial Position: The simulation was run with the body aligned with the seat back and seat cushion and the feet resting on the floorboard. The shoulder belt was placed diagonally across the chest and the lap belt around the lower torso. The following input configurations were tested. It is seen that when body is in resting position (inclined with seat back), the presence of belt slack produces a very large CSI, so it is probable, in the absence of severe chest injuries, the belt was configured correctly.

File	Initial Configuration	HIC	HSI	CSI	Max Head Accel (G)
C2	Normal resting position; raised left hand; no slack	230	360	150	65 @ 130 ms
C2A	belt slack= 2"	750	1800	>5000	
C2D	body erect and belt slack=2"	360	480	300	56 @ 115 ms

C2F	body erect and belt stiffness > 15%	290	380	200	61 @ 130 ms

Simulation Results: The simulations shows the following serious contacts.

Head: Head contact with steering wheel - 660 lbs
Maximum head accel - 56 G (in -X dir)
Max head angular accel - 4000 rad/sec**2 (yaw)
HIC = 230; HSI = 360

Contact partially compatible with AIS 3 and 2 injuries.

Chest: Upper torso contact with steering wheel - 670 lbs

Abdomen Upper torso contact with door - 230 lbs
Lower torso contact with door - 1470 lbs
Shoulder belt loading - 800 lbs
Maximum upper torso accel - 25 G (in -X dir)
Maximum lower torso accel - 39 G (in +Y dir)

The upper torso contacts are compatible with the chest injuries. The large lower torso lateral loading appears to be compatible with the spleen injuries.

Arms: Left upper arm with door - 800 lbs
Left upper arm with window sill - 500 lbs
Left lower arm with A-pillar - 780 lbs

The arm contacts are compatible with the fractures on the lower arm. Contact with the outside mirror was not made, since it is very sensitive to the precise initial conditions of the arm.

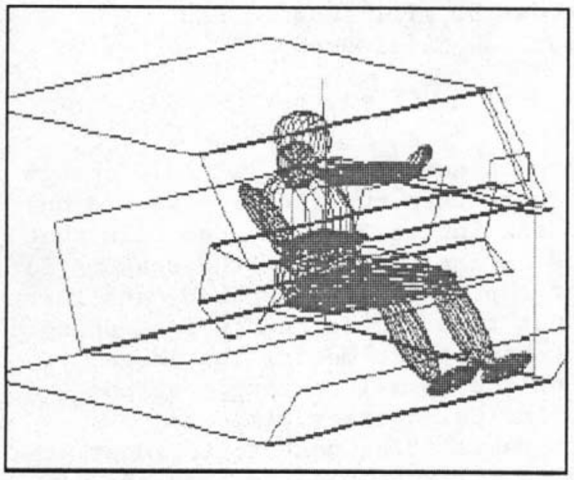
Legs: Left upper leg with L. inst. panel - 1170 lbs
Left lower leg with L. inst. panel - 730 lbs
Left upper leg with door - 970 lbs

The leg loads are appear to be compatible with the lower leg fracture and knee lacerations.

Feet: Left foot with toeboard - 1850 lbs
Right foot with toeboard - 1850 lbs

These loads are compatible with the feet fractures observed. The lower left leg fractures may also be partially explained with the large axial loads combined with the lateral load from the inst. panel.

CASE 2: PICKUP W/SPORTS CAR FRONTAL IMPACT
ADULT MALE DRIVER WITH BELTS



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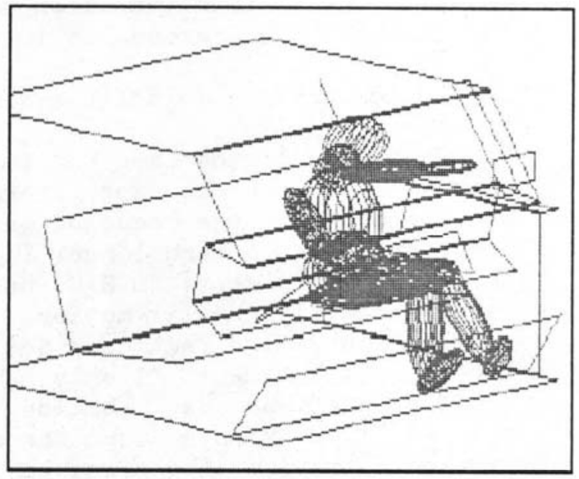

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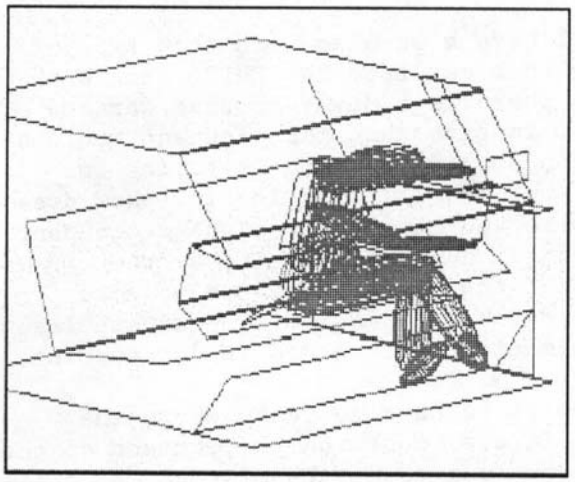

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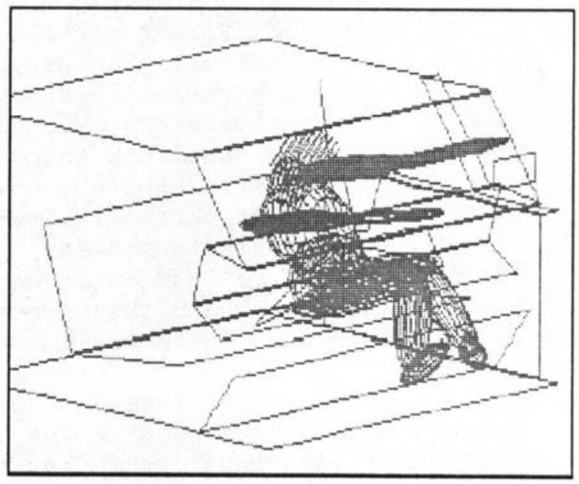

TIME = 200 MSEC

PAPER: Biodynamic Simulation of Real World Automotive Collisions Using a Microcomputer

SPEAKER: Tariq Shams, GESAC

Q. Joseph Kanianthra: I assume that those peak g's that you are recording are all occurring at approximately the same time. Did you notice a separation time when the plane leaves the head?

A. Yes, the maximum intrusion was at about 80 milliseconds and for the head, it started leaving at about 100 milliseconds.

Q. Is it the same in all the cases?

A. What we call the base run that we use is not the same. It did change when we moved the occupant laterally by more then two inches. We had one simulation where the occupant was up to six inches from the door. In that case, there was a much longer lag period. That is one of the reasons for the dramatic increase in HIC, because of the motion of the head, and that was principally angular motion. From that time on the head was snapping back in the roll direction. So I do not have the time for the large lateral displacement. I only have it for the normal resting position. What happened was, as I remember, the principal contact time was changed. For Example, when the occupant was sitting next to the door, the time of intrusion into plane was around 65 milliseconds and when the occupant was 4 inches from the door it went up to 80 milliseconds. That would be reflected in the time at which it departed from the plane also. It would be offset by about 20 milliseconds.

Q. Priya Prasad, Ford Motor Company: I have a problem with this type of reconstruction scheme. You are picking up a car from the NHTSA data bank for which a crash test already exists. There is a dummy in that car and you have all the data that you can keep. Imagine that the occupant would be your model. Now the first thing that you should be doing is trying to simulate that test. Find out how good your model simulation is. How does it agree with that particular test, before you can put in another occupant of a different size in the car. From what I can see, looking at the kinematics when you had only one occupant, the kinematics were no good. You should go back and check your NHTSA database. Look at the kinematics of the occupant. Those are not the kinematics that we see in our testing.

A. As I said, since in real life accidents, we have to go by where the contact points were seen in the vehicle itself, based on the contact of the particular individual; such as, the contact points on the armrest, at the mid-door panel and at the rear window. Now, in this particular case, the vehicle, a truck actually, there was strong reason to believe that the occupant made contact with the front of the truck as well. We made the door panel a very stiff surface to represent that. So, with the contact function in such an acute case, where there was AIS 5 injury, it probably would not have mattered if we had included the door padding.

Prasad: Well, it doesn't look like what we've seen. The first thing you should be doing is establishing the validity of the model against well known tests.

A. We have been doing that.

Prasad: I have not seen much of that.

A. Side impact has always been a problem. That is why it is plunging the model into areas where validation has not been complete, since all the cases concerned have been typically AIS 3 injuries and above. If we were looking at lower level injuries, where much finer distinctions had to be made, then I think you are absolutely right. Here, we are basically having between 1,500 lbs and 2,000 lbs loading on the pelvis. Two thousand and 3,000 lbs on the pelvis is probally beyond the tolerance level already. Most of the accidents we were studying, for this particular study, were of that variety. So, we felt that the lack of validation here was not of prime concern, that much of this was rigid body motion, sort of, and in full. Finer elements of the complex simulation model which would arise where you had to distinguish between very fine acceleration pulse and then obviously differences in the actual contact functions which would contribute to the interaction would then come into play. We did a number of cases where we had slightly lower level injuries. This was one of the severe ones. However, this was typical of the cases we studied. So I don't know how much it would have proved. As I said, because we moved the body around quite a bit it was simply not because it was such a drastic injury, it would not have changed the severity indices that we obtained. So if the body was sitting sort of humped towards the front seat it still would not have changed the overall level that we obtained.

Prasad: The problem is, some of these things are ending up in the courts and they are deciding it's the manufacturer's fault.

Q. John Tomassoni, Jetech

I have a question relative to what you showed in one of your slides. You investigated the effect of intrusion by reducing it by two inches or so. Can you explain how you went about that?

A. This was sort of a curve fitting for the plane. Once we had the overall crash pulse for the vehicle we tryed to estimate what would be the effective acceleration of the door panel in order to end up with an intrusion. Sometimes, it would run over the duration of the pulse but as long as it would start at relative rest with respect to the vehicle and and would end up at relative rest with respect to the vehicle, those were the constraints. Then we had to determine what the acceleration of the door would be so that it would fit these two constraints? The uncertainty was what was the exact time of the maximum acceleration of the door itself. There were sort of three parameters. We had three constraints actually. The velocity of the beginning and velocity at the end must match the velocity of the vehicle. We had the amount of intrusion estimated from the accident. We ended up with modeling it as an additional acceleration pulse. We took the simplest triangular shape relative to the acceleration of the vehicle itself. So, we had a triangular pulse shape superposed on the acceleration of the vehicle. We then ended up with tha amount of intrusion and with the fact that the velocities at the beginning and end of the pulse had to match that of the vehicle. That forced us to get what the peak would be. Obviously, that was the shape that we thought was the simplest to start out with because we had no records of how to actually do that. For these levels of contact where you are having 1,000 lbs of loading on the head, it wouldn't really matter too much if the door panel had intruded completely at the time of maximum or had intruded halfway. This level of severity washes out a lot of the finer points of what is required in properly validating a simulation model.