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SIMULATION OF OCCUPANT KINEMATICS IN ROLLOVERS USING THE MVMA 2-D MODEL

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Prepared by:

D. H. Robbins
Transportation Research Institute
Institute of Science and Technology
University of Michigan
Ann Arbor, Michigan 48109

Prepared for:

Crash Injury Section
Biomedical Science Department
General Motors Research Laboratories
Warren, Michigan 48090

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16. Abstract

This report describes the results of the first phase of a study entitled "Simulation of Occupant Kinematics in Rollovers." What little information is available on the kinematics of vehicle occupants during rollovers has been obtained either after the fact by accident reconstruction or by expensive experimentally-staged accidents. The report describes the use of less expensive analytical techniques to graphically illustrate the applicability of occupant motion simulation computer models to this problem. It also provides guidelines and tutorial information for future users of the software in this application.

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1.0 INTRODUCTION AND SUMMARY

The report which follows describes the results of the first phase of a study at the University of Michigan Transportation Research Institute entitled "Simulation of Occupant Kinematics in Rollovers." What little information is available on the kinematics of vehicle occupants during rollovers has been obtained either after the fact by accident reconstruction or by expensive experimentally-staged accidents. The remainder of the report describes the use of less expensive analytical techniques to graphically illustrate the applicability of occupant motion simulation computer models to this problem. It also provides guidelines and tutorial information for future General Motors users of the software for this application. The first phase report deals with the development of two-dimensional rollover simulations using the MVMA two-dimensional occupant motion model.

The report is divided into two parts. The first is an introduction and summary. Included are review sections on the analytical tools used, the data required for operation of the models, the output generated by the example rollover simulation, and conclusions. The second part of the report contains sections detailing the preparation of data for use in simulating rollovers using the MVMA 2-D occupant model. Additional results are included which address the problem of occupant ejection. An appendix to the report contains a complete sample exercise.

1.1. Analytical Tool Used. The MVMA 2-D Occupant Motion Simulation.

The analytical tool chosen for the two-dimensional simulation of a pure rollover is the MVMA 2-D Occupant motion simulation computer program. Figure 1 is a schematic of the vehicle occupant configured for the most traditional simulation using the software. Among the features available for use of the software are:

- Occupant or pedestrian with a nine segment body linkage
- Generation of forces on the occupant due to interaction with vehicle structures and restraint systems
- Capability for inclusion of vertical, horizontal, and rotational vehicle crash pulses

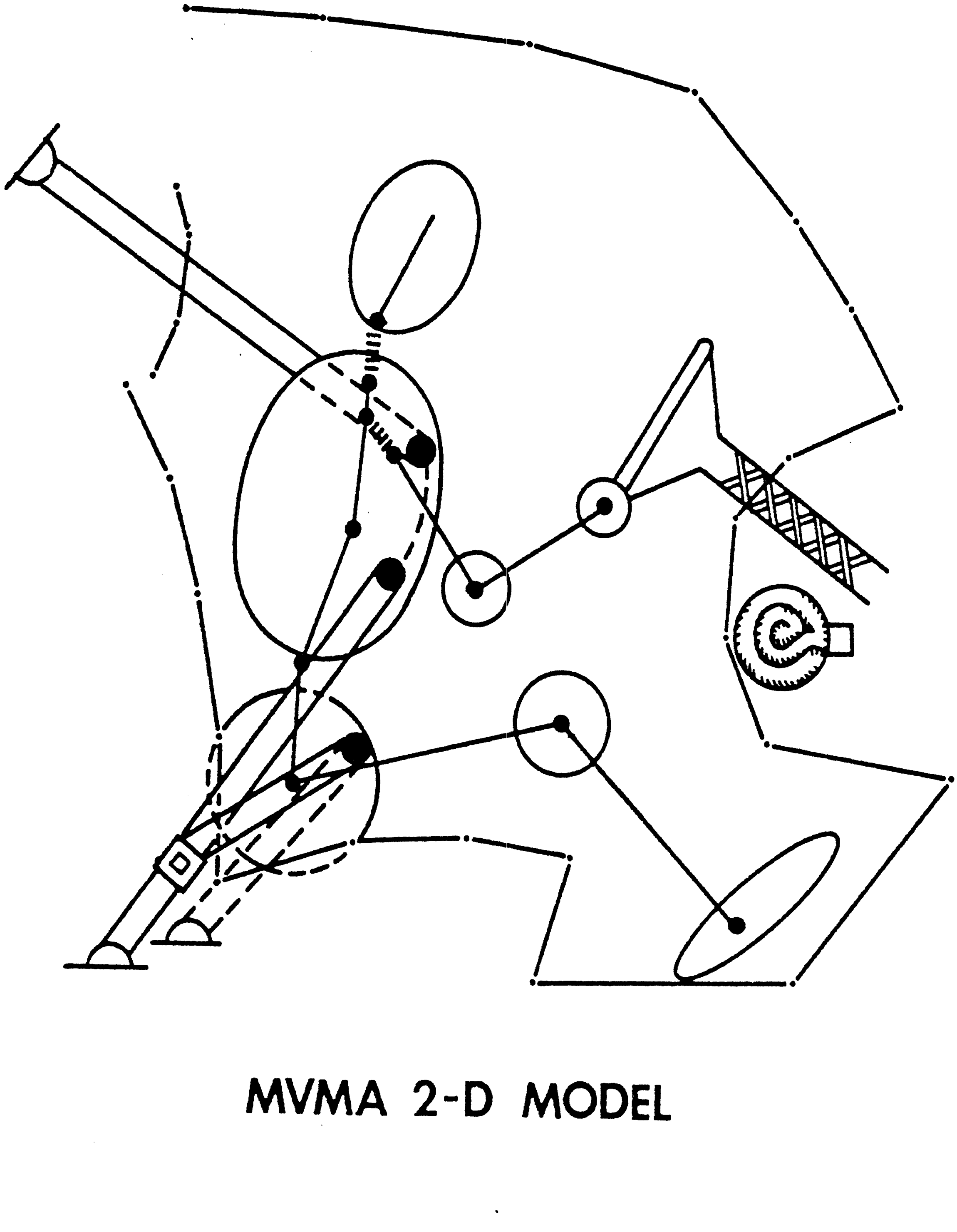
- Prediction of occupant motions and responses such as HIC, femur loads, and neck forces
- Capability to model intrusion of vehicle regions such as roof and side door structures
- Graphical display of results in the form of acceleration and force plots as a function of time
- Computer-generated animation of occupant motions during the time period of the impact event

1.2. Data Required for Operation of the Model

A schematic of the side view of a typical seated occupant is shown in Figure 2. From the rear, this occupant would appear as is shown in Figure 3. These geometric view concepts were developed during a project conducted for MVMA entitled "Baseline Data for Describing Occupant Side Impacts and Pedestrian Front Impacts in Two Dimensions" (Reference 1). The occupant/vehicle configuration shown in Figure 4 is based on the MVMA baseline and represents the configuration of an anthropomorphic test device in the driver position of a 1973 Buick prior to a dolly rollover test conducted at the General Motors Proving Grounds. Any vehicle geometry, occupant size, or occupant position could have been used in developing a configuration with the overall features of Figure 4.

Definition of the rollover event can be presented in terms of known vehicle motions. In cases where test data are available, these can be derived either from accelerometers mounted in the test vehicle or from high speed motion pictures of the event. In the case of a real crash event, a reconstruction of the vehicle trajectory would be required based on the estimates of initial velocity, vehicle contact points with the ground, final resting location, and extent of damage to the vehicle.

In the example case of the 1973 Buick test rollover, both vehicle accelerometer data and movies of the event were available. Use of the movies was selected as the simplest procedure to determine vehicle position and rotation angle as a function of time. Plots of vehicle position and angle as derived from the movies are shown in Figures 5, 6, and 7.



MVMA 2-D MODEL

FIG. 1. SCHEMATIC OF MVMA TWO-DIMENSIONAL OCCUPANT MOTION SIMULATOR

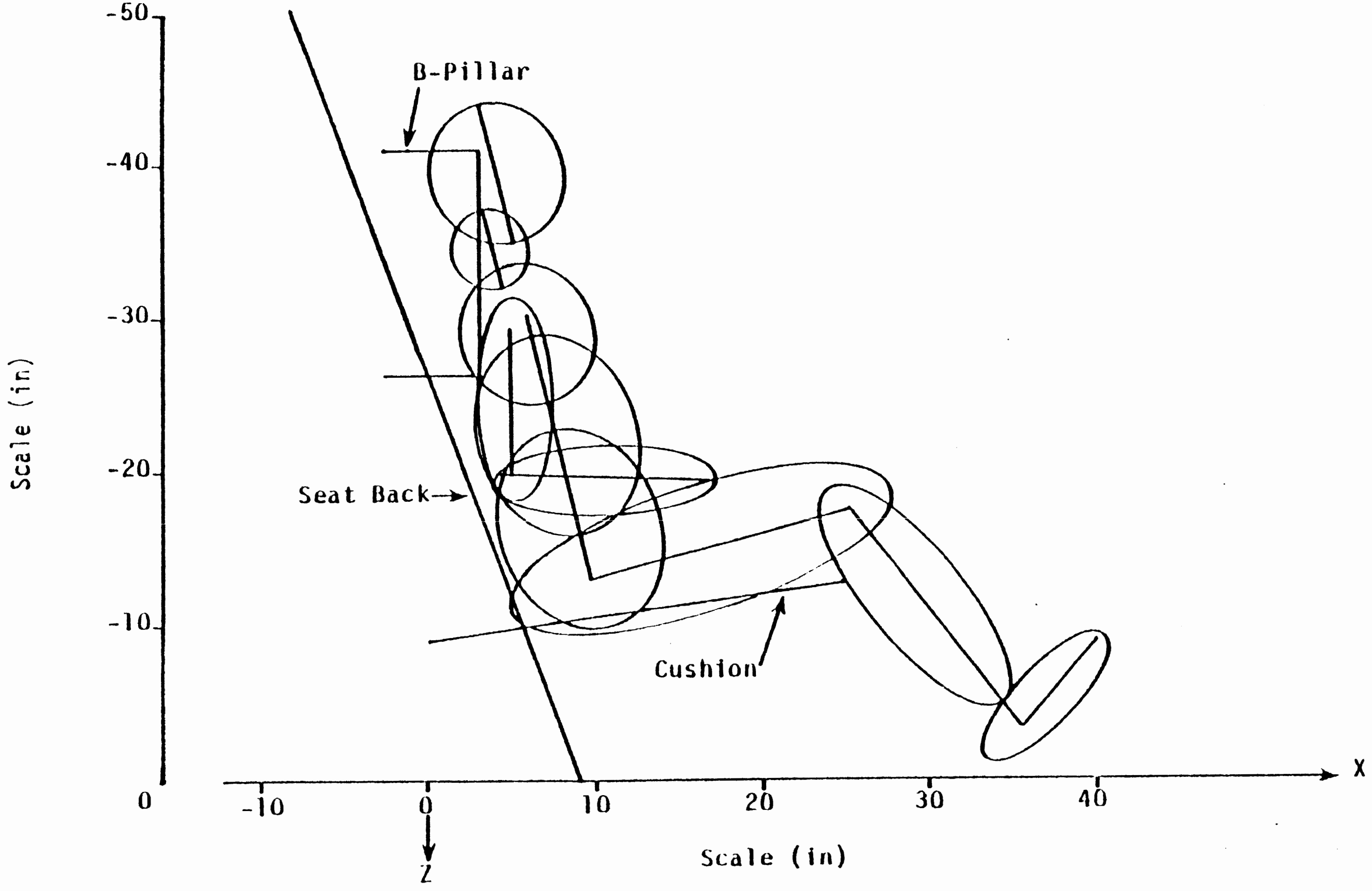


FIG. 2. OCCUPANT FOR SIDE IMPACT SIMULATION (SIDE VIEW).

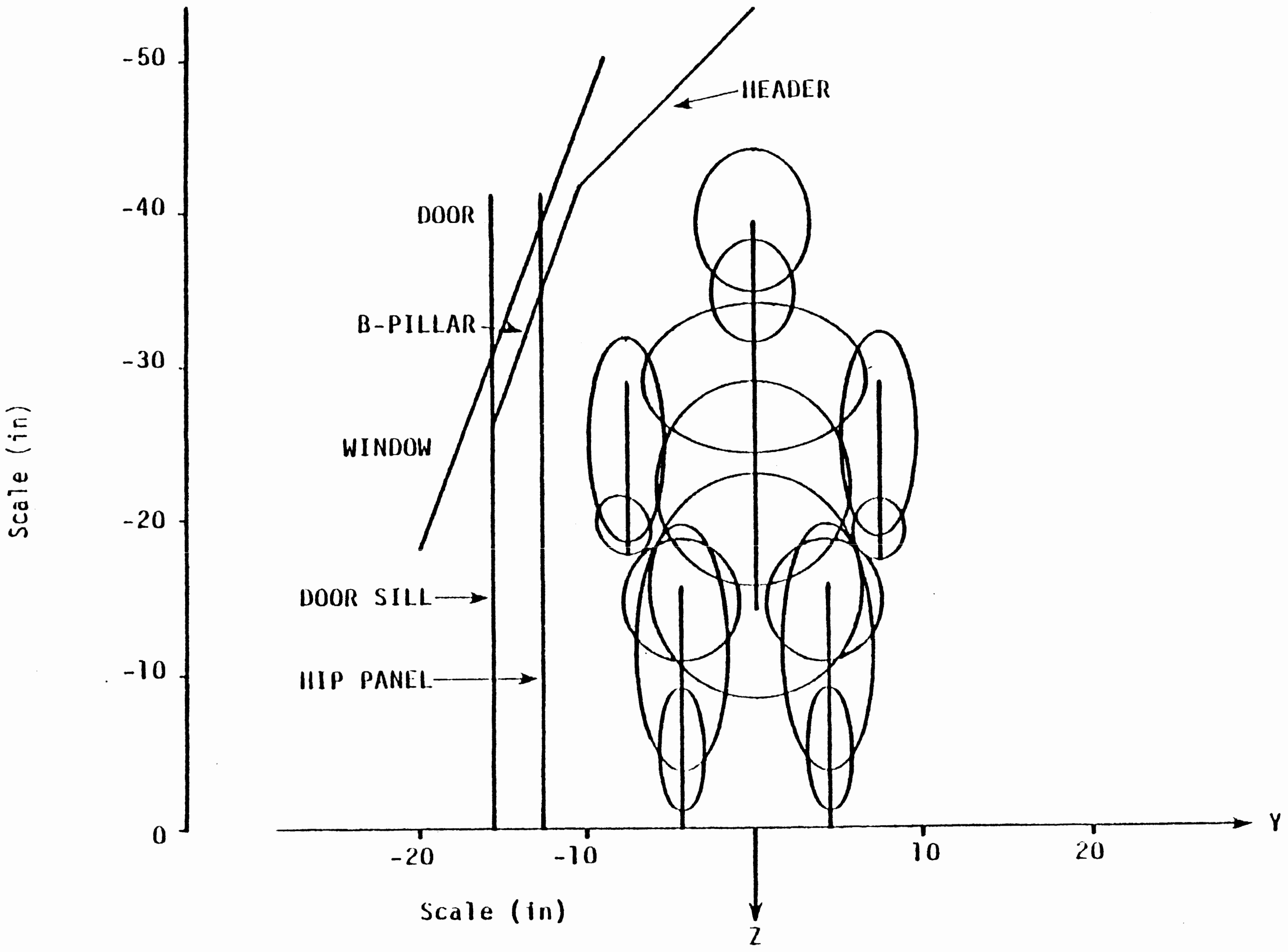


FIG. 3. OCCUPANT FOR SIDE IMPACT SIMULATION (REAR VIEW).

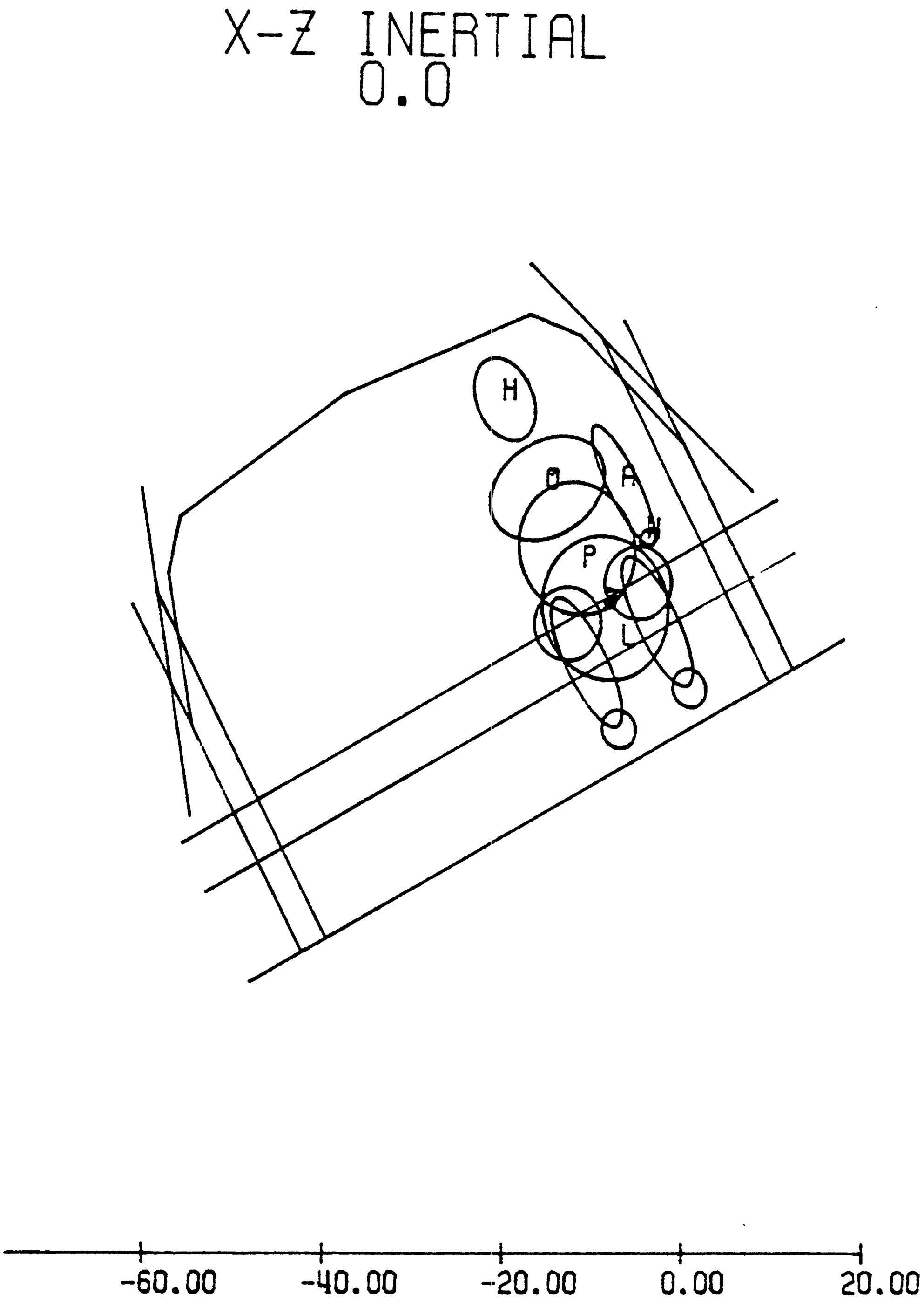


FIG. 4. INITIAL CONFIGURATION OF OCCUPANT IN VEHICLE FOR SIMULATION OF DOLLY DROP ROLLOVER.

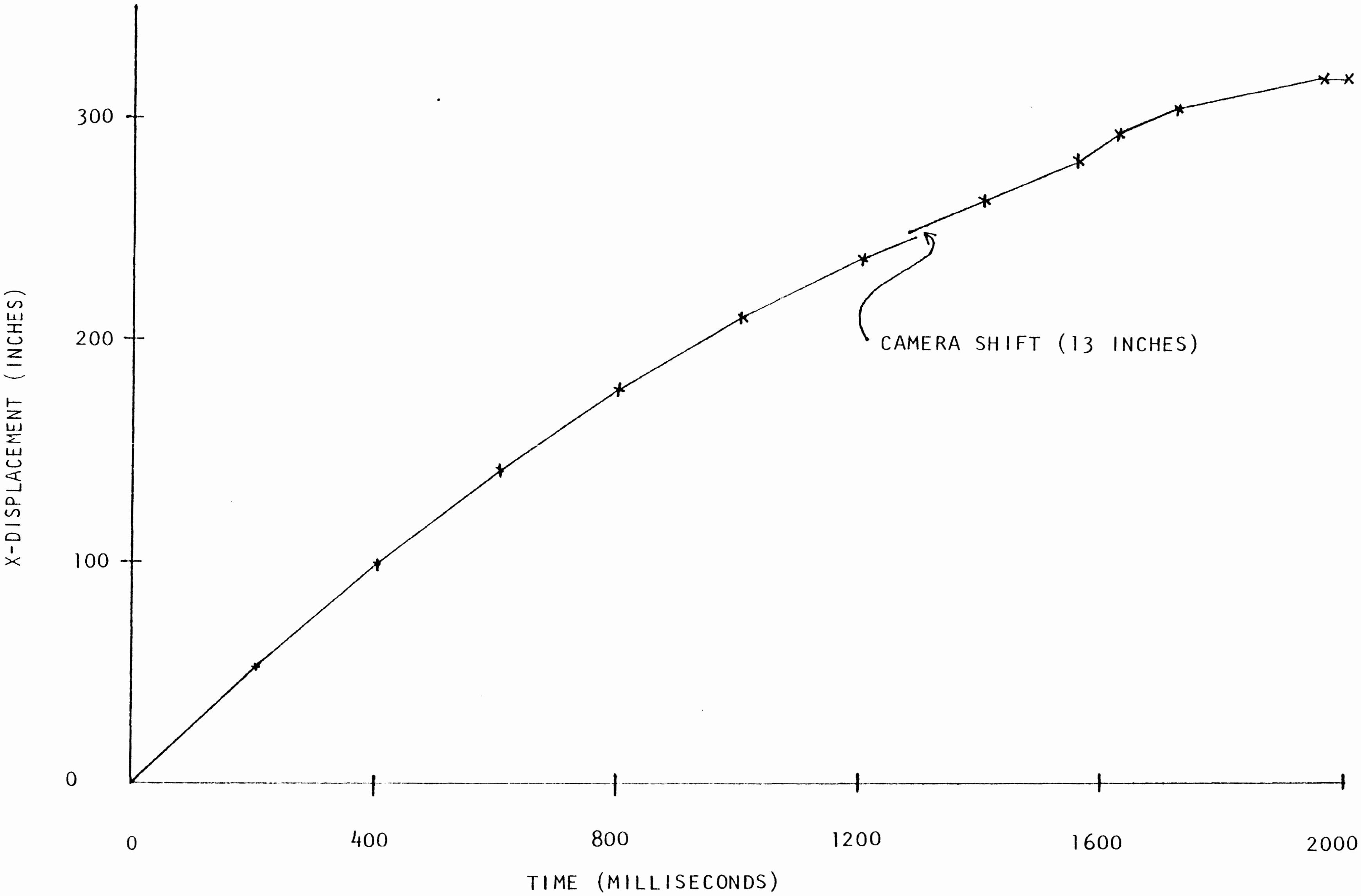


FIG. 5. VEHICLE POSITION ALONG GROUND AS A FUNCTION OF TIME.

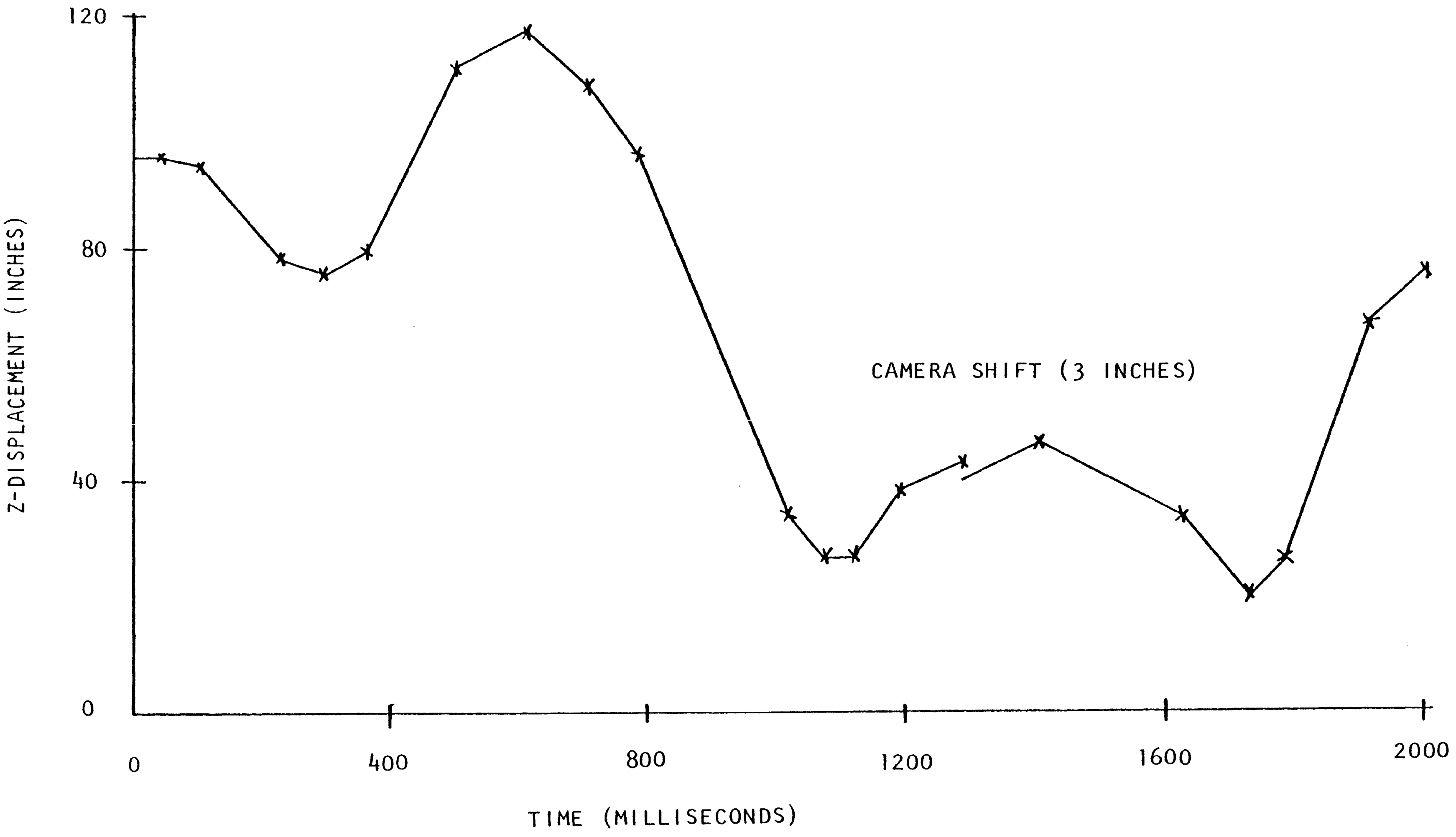


FIG. 6. VEHICLE VERTICAL POSITION AS A FUNCTION OF TIME.

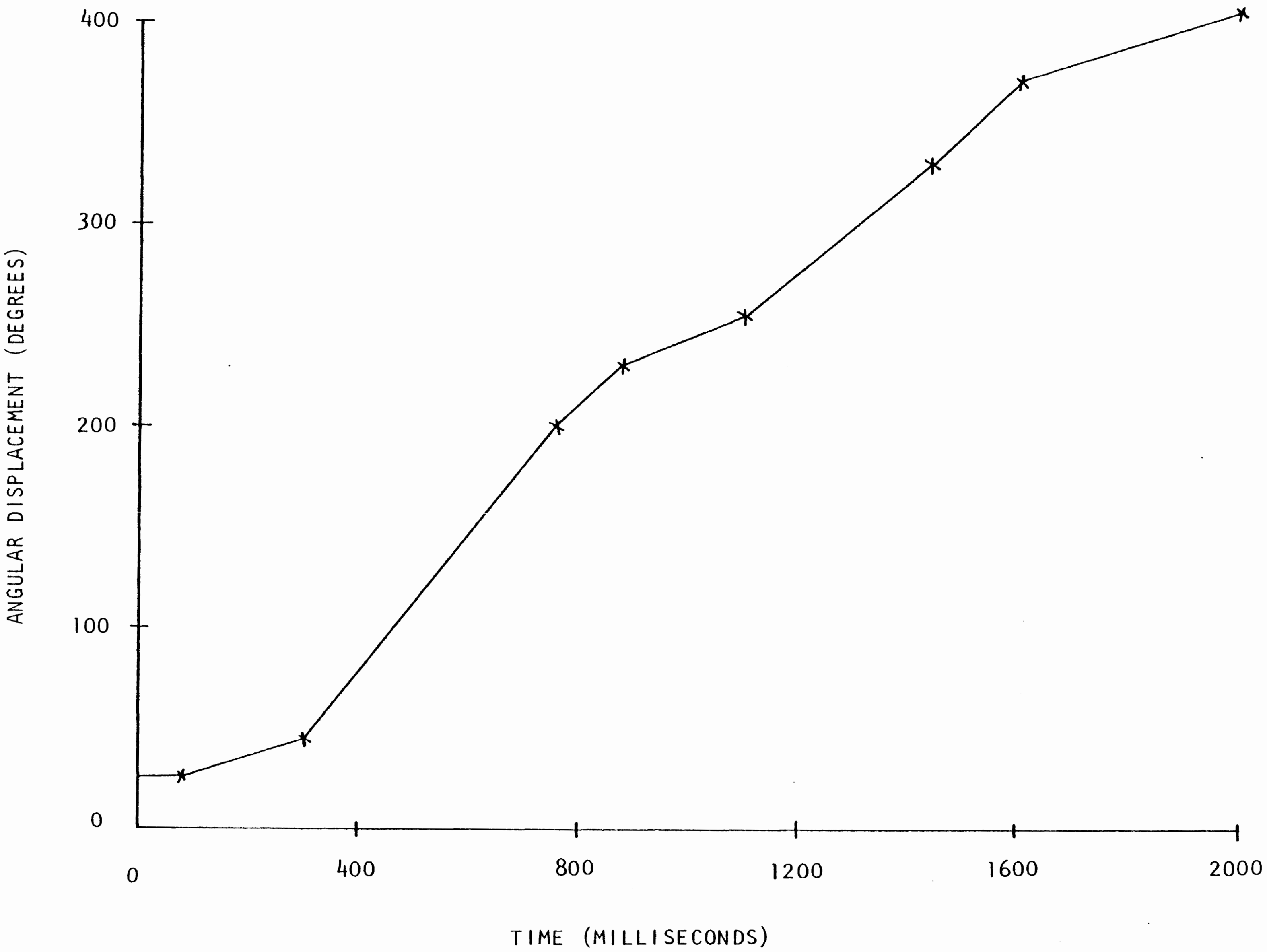


FIG. 7. VEHICLE ROTATION (ROLL) ANGLE AS A FUNCTION OF TIME.

1.3. Output Generated by the Model

Output from the model is generated in the form of tables and graphical displays. Standard output is in the form of tables of a large number of physical variables such as:

- vehicle motions
- body segment motion, velocity, and accelerations
- forces generated by body contacts with the vehicle as a function of time
- forces, torques, and relative motions at all joint structures
- post-processed quantities such as HIC (for 1000 time steps), resultant accelerations at specified locations in the head and chest, and femur loads.

Graphical displays are available as plots of the physical variables versus either time or other variables. Occupant motions can be presented in an animated display or movie of the occupant moving within the vehicle during the impact event. Example plots of forces generated by the head and hip regions of the occupant as a function of time are shown in Figures 8 and 9. Figure 10 illustrates the vehicle and occupant kinematics from the moment the vehicle is released from the dolly at a velocity of 29.6 mph until the vehicle is nearing its final rest point after about 2000 milliseconds.

The most striking feature shown by these three figures is the large number of individual dynamic interactions which take place. The head interacts with doors and the roof on both sides of the vehicle. The torso and legs also interact with structures on both sides of the vehicle. Body segment accelerations are moderate throughout the event. The individual head contacts do not appear to be of a level which would lead to fatal injuries.

The first in a sequence of major contact events takes place at about 200 milliseconds. The vehicle begins to drop toward the ground after release from the dolly. During this period the vehicle/occupant combination is in freefall. The seat cushion exerts just enough force to cause the occupant to move toward the roof.

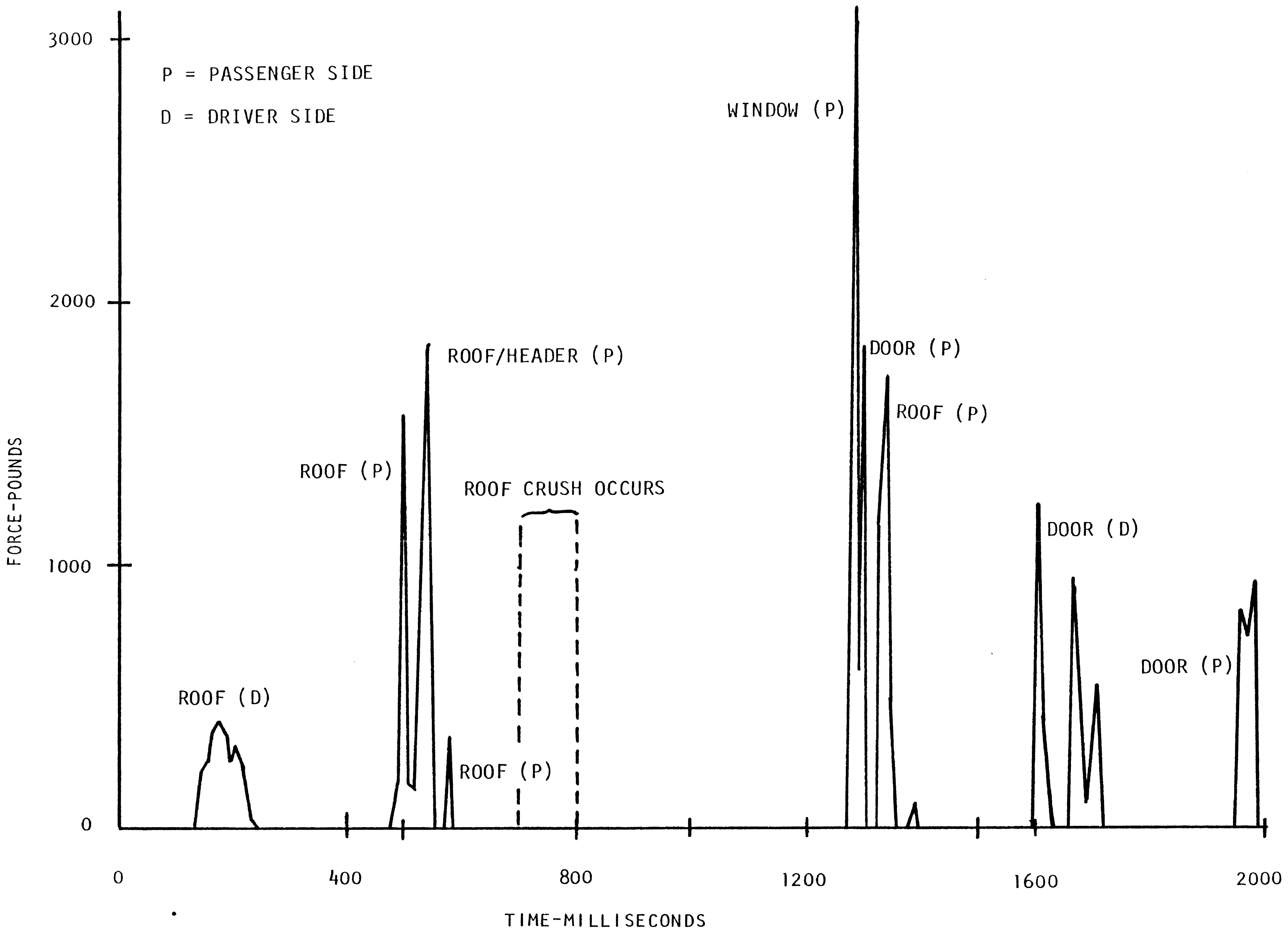


FIGURE 8. CONTACTS OF HEAD WITH VEHICLE INTERIOR (BASELINE ROLLOVER).

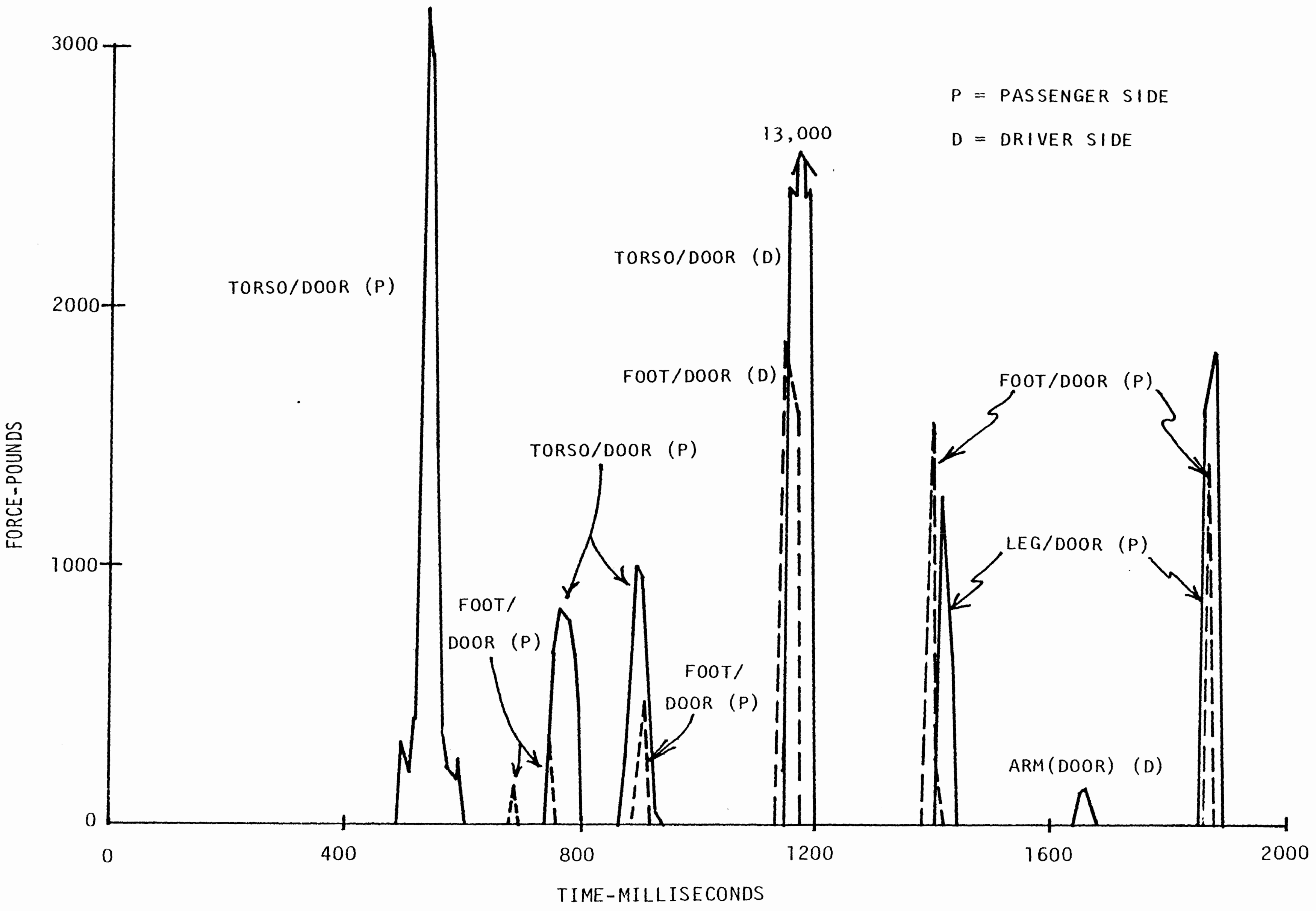


FIG. 9. CONTACTS OF TORSO AND LEGS WITH VEHICLE INTERIOR (BASELINE ROLLOVER).

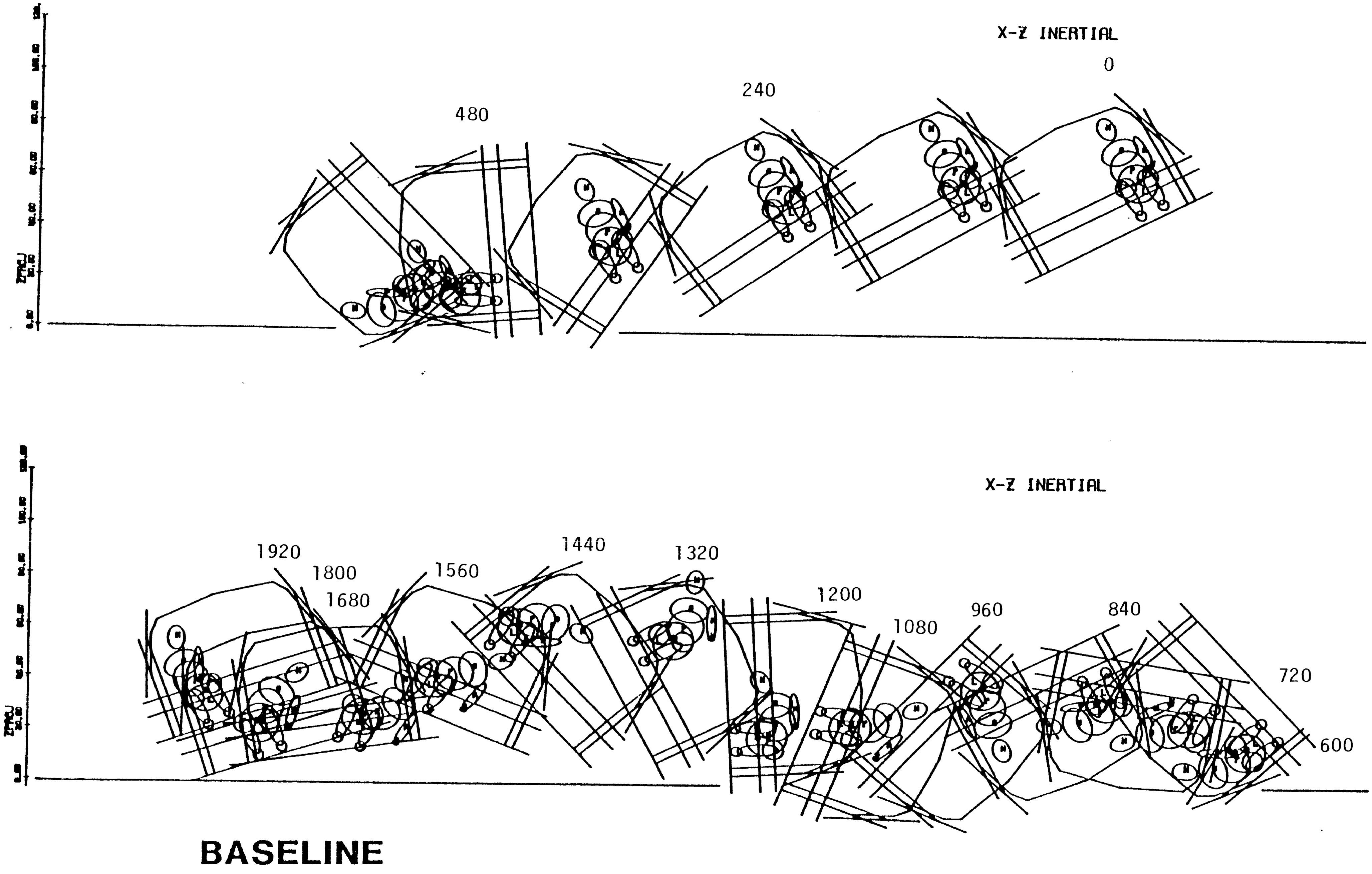


FIGURE 10. BASELINE OCCUPANT MOTIONS.

The contact of the vehicle tires with the ground at about 300 milliseconds initiates the rollover sequence. The vehicle has passed 90 degrees of roll by 480 milliseconds which is about the same time the occupant has dropped, largely through freefall, toward the passenger door. Between 400 and 600 milliseconds there are several contacts of the torso and head with the door and roof structures. In addition, there is restraining action of the knees and feet by the instrument panel as was observed in the impact test movies.

The test movies show production of roof crush during the period between about 700 and 800 milliseconds. Figure 10 shows the head of the occupant well away from the roof during this period. Movies taken with a vehicle-mounted camera also do not show evidence of dummy/vehicle contact during this period.

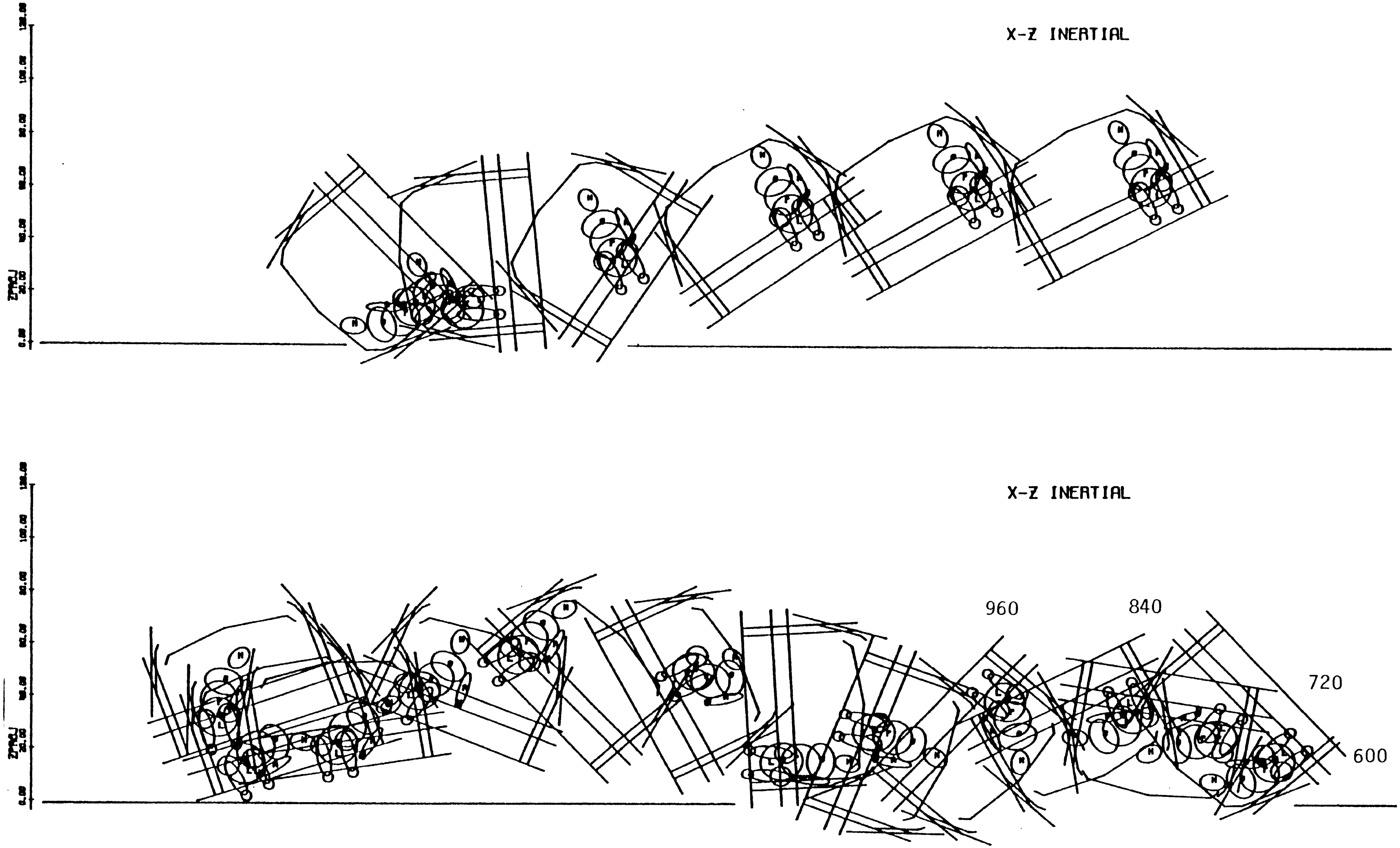
After the roof contacts the ground while the vehicle is 180 degrees inverted, the vehicle again becomes airborne with the occupant compartment rotating through 270 degrees at about 1200 milliseconds. The driver door restrains the occupant from ejection at this point and redirects his motion toward the opposite side of the vehicle.

Final contacts with the passenger door occur near the end of the simulation when the vehicle wheels again contact the ground essentially stopping the horizontal motion of the vehicle. The driver once again moves across the vehicle to contact the passenger side structure. Seat cushion forces are large during this last interaction.

Figure 11 shows vehicle and occupant kinematics for a second computer exercise where over 7 inches of roof crush are added between 700 and 800 milliseconds. Note that the location of the head of the occupant at 720 and 840 milliseconds is not near the roof. It is not until after 900 milliseconds that head contact with the vehicle is again observed. Even though there are more contacts of the head with the roof in the case of roof crush, their level of force is no larger than those contacts observed when the roof remained intact.

1.4. Conclusions

The basic conclusion reached during Phase I activity on this project is that simulation is a useful technique for the study of



ROOF CRUSH

FIGURE 11. OCCUPANT MOTIONS IN CASE WITH ROOF CRUSH.

rollovers. Although two-dimensional techniques are limited to "pure" rolls, it is anticipated that three-dimensional techniques will be applicable to the general problem.

In addition, it has been found that computer graphics is an exceptionally valuable tool for study of occupant and vehicle motions in the mind-boggling geometry of a rollover. Animation of the rollover event, similar to high speed impact test movies, is valuable. These can be supplemented with individual frames from the dynamic event to study contact interactions at specific time points in detail.

Finally, in order to utilize simulation effectively, particular attention must be paid to the following items in preparing input data:

- quality detailed accident definition or reconstruction
- correlation of observed occupant/vehicle contact points with injuries
- vehicle interior geometry and material property definition

Although these items are important and critical to the success of any simulation exercise, it should be noted that model use is inexpensive compared with full-scale tests. As a result, it is possible to estimate a range of values for parameters which are not well-defined. This can be followed by multiple exercises in order to see how changing parameter values affects occupant dynamics.

2.0 TECHNIQUES FOR USE OF MVMA 2-D OCCUPANT MOTION MODEL IN SIMULATION OF ROLLOVERS

2.1. Description of Impact Event

2.1.1. Data Required

In order to simulate a rollover or other crash event using the MVMA 2-D occupant motion model, it is necessary to define the initial location and velocity of the vehicle as well as a time history of its motions. The specification of location and velocity requires:

- definition of a planar two-dimensional coordinate system in which the vehicle roll motion takes place
- the x- and z-location of the vehicle origin within the coordinate system
- the initial pitch (or roll) of the vehicle (θ),
- the initial velocity of the vehicle in the two translational and one rotational directions

Several input data options are available for the specification of the motion time history. These are:

- Data from vehicle-mounted x- and z-accelerometers
- Acceleration data for the vehicle origin
- Position of the origin as a function of time
- A combination of one translational acceleration with the other translational position
- Data from an x-accelerometer reading and a measured point about which the vehicle rotates

These position data must be supplemented by angular position or acceleration as a function of time.

2.1.2. Example Case

As an example, an instrumented test of a vehicle dropped from a moving dolly was selected for simulation. This test involved a 1973 Buick which was released from the dolly at an initial velocity of 29.6 mph. High speed cameras were positioned along the course of the roll to record gross vehicle motions. A camera was also mounted within the vehicle to monitor the motions of the two unbelted anthropomorphic test devices in the front bench seat. Triaxial accelerometer packs were located on the left and right rocker pans.

The movies were reviewed to ascertain whether the event qualified as a roll in which the motion was predominantly in a plane. Although some vehicle pitching was noted (less than 10 degrees) during the roll, it was concluded that the event fairly well approximated the case of a pure rollover. It was also necessary to review the anthropomorphic test device motions. The driver dummy appeared to move with a predominantly planar motion when viewed from the rear. Basically, it slid across the seat from door to door. It also rose to contact the roof. The torso rotated sideways down toward the seat in addition to its back-and-forth translational motion. The feet appeared to move from side to side but were somewhat restrained in their motions by interactions with the floor and lower instrument panel.

Two of the alternative techniques mentioned previously were reviewed for use in specifying vehicle position. The first of these techniques used accelerometer data from the test. Triaxial accelerometer packs mounted in the right and left rocker pans were observed to record lateral and vertical accelerations which were significantly larger than the longitudinal values. This reflected the predominantly roll quality of the event. The accelerometer data traces wee hand-digitized for the simulation. Estimates of accelerometer locations were obtained relative to the vehicle coordinate system. In order to supplement the accelerometer data with the necessary vehicle angular (roll) data, the test films were analyzed. The cameras were positioned to view the front of the vehicle as the roll event progressed. Roll angle was estimated as the angle a line drawn between the vehicle head lamps made with a ground line.

These accelerometer and angle data were then used as input to the simulation. The resulting vehicle motion, based on integration of the accelerometer data, showed the vehicle rising several hundred inches in addition to its motion along the ground. In order to test the quality of the input data for isolation of the problem, angular motion and acceleration data values were varied. There was no significant change in the results. Finally, it was observed that a 1 G acceleration applied to a mass will cause it to fall approximately the same amount observed in the simulation results which covered a time duration of 2000 milliseconds. Review of the accelerometer traces revealed that a 1 G signal was in the noise range of the recorded signal and probably was zeroed out prior to test initiation. Thus the conclusions were reached that the test data were reasonable, the simulation worked properly, and another vehicle motion input data technique should be explored.

The second technique supplemented the angular roll data with vehicle position data measured directly from the test movies. The position along the direction of roll (both horizontal and vertical) of the center of a line constructed between the headlamps was chosen as the vehicle point. The location of this point in a coordinate system attached to the H-point was estimated to specify occupant compartment position as a function of time. The resulting data are shown in Figures 5, 6, and 7. These curves were represented by a subset of points for use in the input data set. Some inaccuracies are inherent in these data due to the lack of a correction for non-planar vehicle rocking (pitch) motions. It was not possible to measure this correction without additional three-dimensional camera coverage. It was found that the distance along the ground over which the roll took place was similar for both the integrated accelerometer data and the measurements from the movies. This lends some credibility to the conclusions both about the need for a gravity correction and the integrated and digitized vehicle resting position at 2000 milliseconds.

2.1.3. Conclusions and Recommendations for the User

Three key conclusions and recommendations have been extracted from the previous two sections.

1. In specifying the vehicle response, the user should develop position data using film coverage whenever possible.

2. If accelerometer data are to be used, the 1 G vertical acceleration should be removed from the resultant signal by removing the

appropriate fraction from the components based on vehicle angular orientation as a function of time.

3. Before a simulation using the MVMA 2-D occupant motion model is attempted, a decision must be made, based on review of accident investigation or test data, on whether the event can be represented by a two-dimensional simulation.

2.2. Description of Baseline Occupant

The starting point for developing a description of the occupant was the baseline developed for side impact simulations under an MVMA project entitled "Baseline Data for Describing Occupant Side Impacts and Pedestrian Front Impacts in Two Dimensions" (See Reference 1). This was based on an earlier three-dimensional occupant linkage developed for use with the Calspan 3-D CVS (Reference 2). Figure 2 shows a side view of the original three-dimensional occupant while Figure 3 shows a rear view with the linkage projected into the vertical-lateral vehicle plane. Figure 4 shows the occupant, configured for MVMA 2-D use, in the vehicle prior to initiation of the rollover event. The occupant outline and linkage are very similar to the three-dimensional case. The primary differences are lack of a right arm and lumping together of the left and right leg masses.

The numerical values for quantities such as segment mass, moment of inertia, position in space, ellipse axes, link angles, and joint properties are given in Table 1 which is a listing of the baseline rollover data set. The Part 572 data set, developed at Calspan and supplied with the Calspan CVS Version 20, was used as the initial basis for the occupant used in the rollover simulations.

The two types of changes to the occupant data, which were made in the process of developing simulations which yielded results qualitatively similar to those observed in full scale rollover tests, involved modifications to:

- the number of occupant/vehicle contacts allowed
- the joint stiffness properties

TABLE 1. BASELINE ROLLOVER DATA SET (PAGE 1 OF 4).

```
 1                ROLLS                                                            100
 2                3D-2D: REAR VIEW OF DRIVER                                       200
 3                                                                                 300
 4                                                                                 400
 5                                                                                 500
 6                                                                                 600
 7                                                                                 700
 8                                                                                 800
 9      1.        -40.      32.174    .0001     0.        2000.     .5        10.       100.     101
10      0.        0.        0.        0.        0.        0.        10.       .000001   10.      102
11      .2        .02       600.      500.      30.       .05       10.       1.        1.       103
12      HEAD                WINDOW                                                         106
13      HEAD                HEADER                                                         106
14      HEAD                DOOR                                                           106
15      HEAD                P.WINDOW                                                       106
16      HEAD                P.HEADER                                                       106
17      HEAD                P.DOOR                                                         106
18      HEAD                ROOF                                                           106
19      HEAD                P.ROOF                                                         106
20      UPPER TORSO         ROOF                                                           106
21      UPPER TORSO         P.DOOR                                                         106
22      UPPER TORSO         SEAT CUSHION                                                   106
23      UPPER TORSO         P.ROOF                                                         106
24      UPPER TORSO         DOOR                                                           106
25      LOWER TORSO         ROOF                                                           106
26      LOWER TORSO         P.ROOF                                                         106
27      LOWER TORSO         SEAT CUSHION                                                   106
28      LOWER TORSO         HIP PANEL                                                      106
29      LOWER TORSO         P.HIP PANEL                                                    106
30      RIGHT UPPER LEG     SEAT CUSHION                                                   106
31      RIGHT FOOT          FLOOR                                                          106
32      LEFT UPPER LEG      SEAT CUSHION                                                   106
33      LEFT UPPER LEG      DOOR                                                           106
34      RIGHT UPPER LEG     P.DOOR                                                         106
35      LEFT FOOT           FLOOR                                                          106
36      LEFT FOOT           DOOR                                                           106
37      RIGHT FOOT          P.DOOR                                                         106
38      RIGHT FOOT          ROOF                                                           106
39      RIGHT FOOT          P.ROOF                                                         106
40      LEFT FOOT           LOW DASH                                                       106
41      RIGHT FOOT          LOW DASH                                                       106
42      LEFT UPPER ARM      DOOR                                                           106
43      LEFT LOWER ARM      DOOR                                                           106
44      0.        0.        0.        0.        0.        0.        1.        0.        1.       107
45      0.        0.        0.        0.        0.        0.        1.        0.        1.       108
46      1.        1.        0.        0.        0.        0.        0.        0.        1.       109
47      1.        1.        0.        0.        0.        1.        1.        1.        1.       110
48      0.        0.        1.        0.        0.        0.        0.        0.        0.       111
49      HEAD                                    1.        1.                                   219
50      HEAD                0.        0.        4.4897    3.1                                  220
51      UPPER TORSO         THORAX MATERIAL     2.        1.                                   219
52      UPPER TORSO         0.        0.        4.83205   6.78                                 220
53      CENTER TORSO        THORAX MATERIAL     3.        1.                                   219
54      CENTER TORSO        -1.9563   0.        6.87638   6.35                                 220
55      LOWER TORSO                             4.        1.                                   219
56      LOWER TORSO         0.        0.        7.4339    6.94                                 220
57      LEFT UPPER LEG                          5.        1.                                   219
58      LEFT UPPER LEG      .781836   -4.45     3.72875   3.74                                 220
59      LEFT LOWER LEG                          6.        1.                                   219
60      LEFT LOWER LEG      -.36406   4.45      7.33778   2.23                                 220
61      LEFT FOOT                               6.        1.                                   219
62      LEFT FOOT           7.3       4.45      2.        1.8                                  220
63      RIGHT UPPER LEG                         5.        1.                                   219
64      RIGHT UPPER LEG     .781836   4.45      3.72875   3.74                                 220
65      RIGHT FOOT                              6.        1.                                   219
66      RIGHT FOOT          7.3       -4.45     2.        1.8                                  220
```

TABLE 1. BASELINE ROLLOVER DATA SET (PAGE 2 OF 4).

67	LEFT UPPER ARM				7.	1.				219
68	LEFT UPPER ARM		0.	0.	6.88	1.64				220
69	LEFT LOWER ARM				8.	1.				219
70	LEFT LOWER ARM		0.	0.	.817523	1.11				220
71	RIGHT LOWER LEG				6.	1.				219
72	RIGHT LOWER LEG		-.36406	-4.45	7.33778	2.23				220
73	0.	8.80333	4.69511	4.89074	4.24		10.7	1.56504	-7.6	201
74	3.22789	2.15193	2.24974	2.44537	2.1982	6.05145	5.25	.573486	.76	202
75	.025	.095	.031	.098	.09	.05	.012	.012	.0047	203
76	.297	2.17	.31	1.78	.77	1.	.137	.27		204
77	31.2	5.	0.	0.	2000.	3000.	0.	-30.	1.	205
78	31.2	5.	0.	0.	2000.	3000.	0.	-30.	1.	206
79	50.	5.	0.	0.	2000.	3000.	15.	-15.	1.	207
80	50.	5.	0.	0.	2000.	3000.	15.	-15.	1.	208
81	16.	5.	0.	0.	2000.	3000.	-165.	-195.	1.	209
82	16.	5.	0.	0.	2000.	3000.	195.	165.	1.	210
83	16.	5.	0.	0.	2000.	3000.	90.	-10.	1.	211
84	16.	5.	0.	0.	2000.	3000.	30.	-30.	1.	212
85	751.	0.	757.	1.98						213
86	1000.	0.	800.	2.5			0.		1.	214
87	31.2	5.	0.	0.	2000.	3000.	30.	0.	1.	215
88	31.2	5.	0.	0.	2000.	3000.	30.	0.	1.	216
89	751.	0.	757.	1.98						242
90	0.	0.	0.	0.	-180.	180.	0.	0.		217
91	3.188	2.125	0.							218
92	THORAX MATERIAL		0.	0.	50.	100.	101.	0.	0.	221
93	THORAX MATERIAL		1.				THORAX	ZERO	GRRATIO	222
94	THORAX	-1.	4080.							225
95	90.	90.	90.	90.	90.	-90.	-90.	-90.	90.	301
96	0.	0.	-29.	0.	4.89074	0.				303
97	ROOF		FLOOR MATERIAL		0.	1.	1.	1.		401
98	HEADER		PANEL MATERIAL		0.	1.	1.	1.		401
99	DOOR SILL		PANEL MATERIAL		0.	1.	1.	1.		401
100	B-PILLAR		PILLAR MATERIAL		0.	1.	1.	1.		401
101	HIP PANEL		PANEL MATERIAL		0.	1.	1.	1.		401
102	WINDOW		GLASS MATERIAL		0.	1.	1.	1.		401
103	DOOR		DOOR MATERIAL		0.	1.	1.	1.		401
104	P.ROOF		FLOOR MATERIAL		0.	1.	1.	1.		401
105	P.HEADER		PANEL MATERIAL		0.	1.	1.	1.		401
106	P.DOOR SILL		PANEL MATERIAL		0.	1.	1.	1.		401
107	LOW DASH		PANEL MATERIAL		0.	1.	1.	1.		401
108	P.B-PILLAR		PILLAR MATERIAL		0.	1.	1.	1.		401
109	P.HIP PANEL		PANEL MATERIAL		0.	1.	1.	1.		401
110	P.WINDOW		GLASS MATERIAL		0.	1.	1.	1.		401
111	P.DOOR		DOOR MATERIAL		0.	1.	1.	1.		401
112	FLOOR		FLOOR MATERIAL		0.	1.	1.	1.		401
113	SEAT CUSHION		SEAT MATERIAL		0.	1.	1.	1.		401
114	ROOF		2.	1.	1.	0.	1.			402
115	HEADER		1.	1.	1.	0.	1.			402
116	DOOR SILL		1.	1.	1.	0.	1.			402
117	B-PILLAR		1.	1.	1.	0.	1.			402
118	HIP PANEL		1.	1.	1.	0.	1.			402
119	WINDOW		1.	1.	1.	0.	1.			402
120	DOOR		1.	1.	1.	0.	1.			402
121	P.ROOF		2.	1.	1.	0.	1.			402
122	P.HEADER		1.	1.	1.	0.	1.			402
123	P.DOOR SILL		1.	1.	1.	0.	1.			402
124	LOW DASH		1.	1.	1.	0.	1.			402
125	P.B-PILLAR		1.	1.	1.	0.	1.			402
126	P.HIP PANEL		1.	1.	1.	0.	1.			402
127	P.WINDOW		1.	1.	1.	0.	1.			402
128	P.DOOR		1.	1.	1.	0.	1.			402
129	FLOOR		1.	1.	1.	0.	1.			402
130	SEAT CUSHION		1.	1.	1.	0.	1.			402
131	PANEL MATERIAL		0.	0.	50.	100.	101.	0.	0.	403
132	PILLAR MATERIAL		0.	0.	50.	100.	101.	0.	0.	403

TABLE 1. BASELINE ROLLOVER DATA SET (PAGE 3 OF 4).

```
133    DOOR MATERIAL   0.      0.      50.     100.    101.    0.      0.          403
134    FLOOR MATERIAL  0.      0.      50.     100.    101.    0.      0.          403
135    SEAT MATERIAL   0.      0.      50.     100.    101.    1500.   2500.       403
136    GLASS MATERIAL  0.      0.      .001    .5      .6      0.      0.          403
137    PANEL MATERIAL  1.                              PANEL   ZERO    GRRATIO     404
138    PILLAR MATERIAL 1.                              PILLAR  ZERO    GRRATIO     404
139    DOOR MATERIAL   1.                              DOOR    ZERO    GRRATIO     404
140    FLOOR MATERIAL  1.                              FLOOR   ZERO    GRRATIO     404
141    SEAT MATERIAL   1.                              SEAT    ZERO    GRRATIO     404
142    GLASS MATERIAL  1.                              GLASS   ZERO    GRRATIO     404
143    GRRATIO -1.     0.                                                          405
144    GRRATIO -1.     1.                                                          406
145    PANEL   0.      0.                                                          407
146    PANEL   3.      3000.                                                       407
147    PANEL   4.      13000.                                                      407
148    PILLAR  -1.     4000.                                                       407
149    DOOR    -1.     1000.   -562.5  1031.25 -562.5  93.75                       407
150    FLOOR   -1.     860.                                                        407
151    SEAT    0.      0.                                                          407
152    SEAT    2.58    103.                                                        407
153    SEAT    4.      400.                                                        407
154    SEAT    5.      1000.                                                       407
155    SEAT    5.5     2000.                                                       407
156    GLASS   -1.     10000.                                                      407
157    ZERO    -1.     0.                                                          408
158    ROOF EDGE LINE  ROOF            5.      .5      1.      1.                  409
159    ROOF LINE       ROOF            5.      .203    1.      2.                  409
160    HEADERLINE      HEADER          4.5     .5      1.      1.                  409
161    DOOR SILL LINE  DOOR SILL       7.      0.      1.      1.                  409
162    B-PILLAR LINE   B-PILLAR        7.      .284    1.      1.                  409
163    HIP PANEL LINE  HIP PANEL       7.5     0.      1.      1.                  409
164    WINDOW LINE     WINDOW          4.5     0.      1.      1.                  409
165    DOORLINE        DOOR            6.8     0.      1.      1.                  409
166    P.ROOF EDGE LINEP.ROOF          5.      .5      1.      1.                  409
167    P.ROOF LINE     P.ROOF          5.      .203    1.      2.                  409
168    P.HEADERLINE    P.HEADER        4.5     .5      1.      1.                  409
169    P.DOOR SILL LINEP.DOOR SILL     7.      0.      1.      1.                  409
170    LOW DASH        LOW DASH        5.      .5      1.      1.                  409
171    P.B-PILLAR LINE P.B-PILLAR      7.      .284    1.      1.                  409
172    P.HIP PANEL LINEP.HIP PANEL     7.5     0.      1.      1.                  409
173    P.WINDOW LINE   P.WINDOW        4.5     0.      1.      1.                  409
174    P.DOORLINE      P.DOOR          6.8     0.      1.      1.                  409
175    FLOORLINE       FLOOR           4.      0.      1.      1.                  409
176    SEAT CUSHION LN.SEAT CUSHION    7.5     0.      -1.     1.                  409
177    ROOF EDGE LINE  4.                                                          410
178    ROOF LINE       4.                                                          410
179    HEADERLINE      4.                                                          410
180    DOOR SILL LINE  1.                                                          410
181    B-PILLAR LINE   4.                                                          410
182.   HIP PANEL LINE  1.                                                          410
183    WINDOW LINE     1.                                                          410
184    DOORLINE        1.                                                          410
185    P.ROOF EDGE LINE4.                                                          410
186    P.ROOF LINE     4.                                                          410
187    P.HEADERLINE    4.                                                          410
188    P.DOOR SILL LINE1.                                                          410
189    LOW DASH        1.                                                          410
190    P.B-PILLAR LINE 4.                                                          410
191    P.HIP PANEL LINE1.                                                          410
192    P.WINDOW LINE   1.                                                          410
193    P.DOORLINE      1.                                                          410
194    FLOORLINE       1.                                                          410
195    SEAT CUSHION LN.1.                                                          410
196    ROOF EDGE LINE  0.      -8.854  -42.881 -6.549  -45.515                     411
197    ROOF EDGE LINE  1271.   -8.854  -42.881 -6.549  -45.515                     411
198    ROOF EDGE LINE  1600.   -8.854  -42.881 -6.549  -45.515                     411
```

TABLE 1. BASELINE ROLLOVER DATA SET (PAGE 4 OF 4).

```
 199     ROOF EDGE LINE  1800.   -8.854  -42.881 -6.549  -45.515                      411
 200     ROOF LINE       0.      -6.549  -45.515 15.451  -48.015                      411
 201     ROOF LINE       1271.   -6.549  -45.515 15.451  -48.015                      411
 202     ROOF LINE       1600.   -6.549  -45.515 15.451  -48.015                      411
 203     ROOF LINE       1800.   -6.549  -45.515 15.451  -48.015                      411
 204     HEADERLINE      0.      -10.5   -41.    -8.854  -42.881                      411
 205     HEADERLINE      1271.   -10.5   -41.    -8.854  -42.881                      411
 206     HEADERLINE      1600.   -10.5   -41.    -8.854  -42.881                      411
 207     HEADERLINE      1800.   -10.5   -41.    -8.854  -42.881                      411
 208     DOOR SILL LINE  -1.     -15.5   0.      -15.5   -26.                         411
 209     B-PILLAR LINE   0.      -15.5   -26.    -10.5   -41.                         411
 210     B-PILLAR LINE   1271.   -15.5   -26.    -10.5   -41.                         411
 211     B-PILLAR LINE   1600.   -15.5   -26.    -10.5   -41.                         411
 212     B-PILLAR LINE   1800.   -15.5   -26.    -10.5   -41.                         411
 213     HIP PANEL LINE  -1.     -12.5   0.      -12.5   -40.                         411
 214     WINDOW LINE     -1.     -20.    -18.    -9.     -50.                         411
 215     DOORLINE        -1.     -15.5   0.      -15.5   -40.                         411
 216     P.ROOF EDGE LINE0.      39.756  -42.881 37.451  -45.515                      411
 217     P.ROOF EDGE LINE1271.   39.756  -42.881 37.451  -45.515                      411
 218     P.ROOF EDGE LINE1600.   39.756  -42.881 37.451  -45.515                      411
 219     P.ROOF EDGE LINE1800.   39.756  -42.881 37.451  -45.515                      411
 220     P.ROOF LINE     0.      37.451  -45.515 15.451  -48.015                      411
 221     P.ROOF LINE     1271.   37.451  -45.515 15.451  -48.015                      411
 222     P.ROOF LINE     1600.   37.451  -45.515 15.451  -48.015                      411
 223     P.ROOF LINE     1800.   37.451  -45.515 15.451  -48.015                      411
 224     P.HEADERLINE    0.      41.402  -41.    39.756  -42.881                      411
 225     P.HEADERLINE    1271.   41.402  -41.    39.756  -42.881                      411
 226     P.HEADERLINE    1600.   41.402  -41.    39.756  -42.881                      411
 227     P.HEADERLINE    1800.   41.402  -41.    39.756  -42.881                      411
 228     P.DOOR SILL LINE-1.     46.402  0.      46.402  -26.                         411
 229     LOW DASH        -1.     -22.    -16.    52.9    -16.                         411
 230     P.B-PILLAR LINE 0.      46.402  -26.    41.402  -41.                         411
 231     P.B-PILLAR LINE 1271.   46.402  -26.    41.402  -41.                         411
 232     P.B-PILLAR LINE 1600.   46.402  -26.    41.402  -41.                         411
 233     P.B-PILLAR LINE 1800.   46.402  -26.    41.402  -41.                         411
 234     P.HIP PANEL LINE-1.     43.402  0.      43.402  -40.                         411
 235     P.WINDOW LINE   -1.     50.902  -18.    39.902  -50.                         411
 236     P.DOORLINE      -1.     46.402  0.      46.402  -40.                         411
 237     FLOORLINE       -1.     -22.    .00001  52.902  .00001                       411
 238     SEAT CUSHION LN.-1.     -22.    -10.35  52.902  -10.35                       411
 239     1.      1.      .05                                                          412
 240     0.      43.4    -45.58  0.      -28.5   0.      42.6    0.      2.           601
 241     13.     0.                                                                   602
 242     0.      0.      200.    101.82  400.    190.06  600.    273.46
 243     800.    344.24  1000.   407.27  1200.   448.    1400.   503.27
 244     1550.   536.24  1620.   561.46  1720.   581.82  1960.   607.03
 245     2000.   607.03
 246     20.     0.                                                                   603
 247     0.      -45.58  40.     -45.58  100.    -44.8   225.    -37.24
 248     295.    -35.88  360.    -37.62  500.    -52.75  610.    -55.66
 249     700.    -51.39  780.    -45.77  1010.   -16.1   1070.   -12.61
 250     1120.   -12.61  1185.   -18.23  1400.   -23.37  1625.   -17.36
 251     1725.   -10.76  1785.   -13.87  1935.   -33.45  2000.   -37.33
 252     14.     2.      .1875   5600.                                                604
 253     0.      -28.5   40.     -28.5   100.    -31.    140.    -31.
 254     275.    -38.    355.    -56.    860.    -214.   1010.   -235.
 255     1360.   -305.   1430.   -310.   1560.   -337.   1710.   -377.
 256     1870.   -379.   2000.   -381.
1000                                                                                 1000
1001     0,1,46-48,10-14,21,22,37,5,38,49,50,15,23-26,2-4,18-20,33-36,30-32,16,      1001
1002     27-29,39,17,40,45                                                           1002
1003     1.      1.      -31.    62.     3.      -52.    5.      1.                  1500
1004     21.     0.      0.      1.      1.      0.      1.      0.      0.          1501
1005                                                                                 1600
```

The primary additions to vehicle components were roof structures, contact surfaces on the passenger side of the vehicle, and a lower instrument panel. In order to contain the occupant within the vehicle, it was necessary to allow most body segments to contact most vehicle components. The contacts which were added to the baseline side impact data set include:

- head (passenger window, passenger header, passenger door, roof, passenger roof)
- upper torso (roof, passenger door, seat cushion, passenger roof)
- lower torso (roof, passenger roof, passenger hip panel)
- left upper leg (door replaces hip panel)
- right upper leg (passenger door)
- left foot (door replaces sill, lower instrument panel)
- right foot (passenger door, roof, passenger roof, lower instrument panel)

It should also be noted that B-pillar and door sill contacts have been deleted.

One of the new contacts is specified to be between the feet and the lower instrument panel. The reason for this contact is based on comparisons between the results of early attempts at rollover simulation and the dolly rollover test discussed earlier. In the tests the legs and feet were observed to remain under the instrument panel, perhaps being trapped. In the early simulations the occupant literally did cartwheels within the vehicle while bouncing from contact to contact. The foot/lower instrument panel contact was inserted to limit motion of the lower extremities to the lower portion of the vehicle. This resulted in dramatic improvements in simulated occupant motion when compared with the rollover test movies.

Based on results generated in early rollover exercises, it became clear that work was required on the joint properties. Early results showed considerable oscillation between adjacent body segments demonstrating that energy absorption was lacking. Also, due to the large motions which took place between segments, well-defined joint stops were required. Changes to the data cards numbered 205-216 included:

- addition of non-zero linear spring characteristics to knee, shoulder, and elbow joints
- addition of quadratic joint stop characteristics to all body joints
- addition of frictional resistance to all joints

These additions and changes ensured model operation. In order to tailor the occupant kinematics to mimic impact tests or accident results, it is expected that considerable additional work will be required in each individual rollover case to assure reasonable and realistic results.

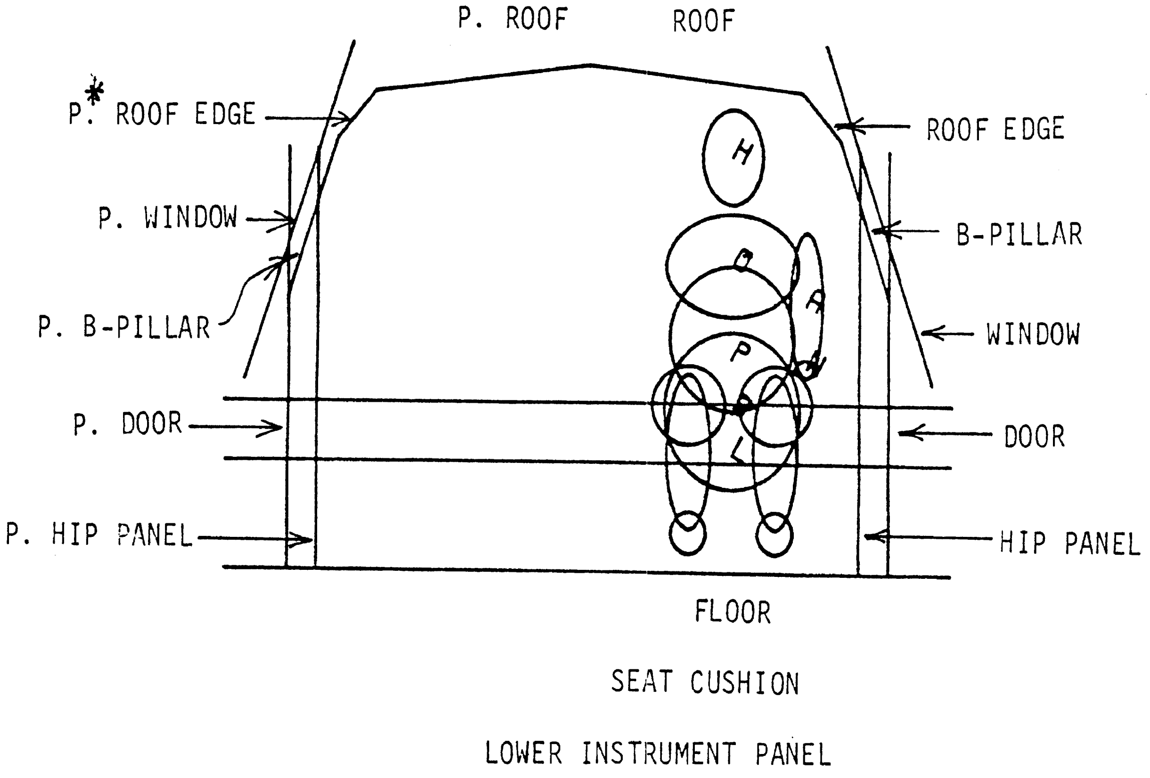
2.3. Description of Baseline Vehicle

In the original baseline data set which was developed for use in side impact simulations, the following contact surfaces were anticipated to be involved:

- seat cushion
- front door sill region (foot/lower leg contact)
- door panel lower region (hip and upper leg contact)
- door panel upper region (head contact)
- window panel (head contact)
- door header (head contact)
- floor (foot contact)
- B-pillar (head contact)

As discussed in Section 2.2 the number of contact surfaces was expanded to the complete set used for rollover simulation shown in Figure 12. Measurements of vehicle interior height and width were used to develop locations for the roof and passenger side contact surfaces.

The force-deflection characteristic curves governing interactions between the occupant and the vehicle have been derived from a variety of sources as discussed in Reference 1. Some are based on idealized vehicle component tests. Others are hypothetical estimates chosen to



*THE LETTER "P" REFERS TO PASSENGER SIDE OF VEHICLE.

FIGURE 12. VEHICLE INTERIOR CONTACT SURFACES (VIEW FROM FRONT).

fill voids in the available data. All are intended to be treated as baseline data which should be replaced when measured data are available for use in actual rollover studies. The only curve which was modified for this study was the force-deflection property of the seat cushion (Card 407 in the input). The original baseline for side impact was not defined suitably for the larger deflections generated by the occupant during the rollover. The new curve provides for considerable seat cushion stiffening when the seat deflection exceeds 4 inches.

The 411 cards included in the Table 1 baseline data set are set up to show the format for including roof crush. In many cases (roof edge line, for example), four time points are included (0., 1271., 1600., 1800. ms) for specification of the location of the contact surface endpoints. As the location of these endpoints does not change from one time to the next, no intrusion is included for this baseline example. More time points can be inserted if a complex motion is desired, or, in this case of no intrusion, one time point card would have been sufficient as in the case with contact surfaces such as door sill, hip panel, window, door, etc.

The only other change to the baseline developed for side impact was the addition of contact friction between body segments and interior components. It was observed that friction can have a major effect on occupant kinematics and energy absorption during the rollover events. The effect involves the time phasing of contacts. In other words a contact where an ellipse slides into a surface with friction will slide off more slowly than would be the case in a contact with a frictionless surface.

2.4. Model Operation and Results

Up to this point in the report, the discussion has been concentrated primarily on the physical problem and the generation of an input data set describing the rollover crash event, the vehicle, and the occupant. It remains to discuss model operation and the variety of results which are and can be generated.

2.4.1. Integration Time Steps

In the initial phases of this project, a time step of 5 milliseconds was chosen because of the relatively long duration of the event (2000 milliseconds or more) and the relatively low G's experienced by the vehicle in a rollover. In actual fact however, as noted in Section 1.3, the occupant experiences a series of dynamic interactions with the vehicle, each of which may be as severe as the single interaction of an occupant with the interior structures in a frontal barrier crash. Because of this, it was necessary to reduce step size to 0.5 milliseconds, which is a typical value used for most simulations.

As the result of the small integration time step, some problems with MVMA 2-D Version 3 information storage capabilities were observed. Affected are storage of head and chest resultant acceleration data which is limited to 2000 time points. Computations of HIC and severity index are not possible without increasing dimension sizes in the OUT processor to allow for these computations. This change is simple to make but will increase MVMA 2-D run cost.

2.4.2. Tabular Output

The tabular output which is available from the MVMA 2-D model includes most useful physical variables describing both the occupant and vehicle as functions of time. Computed results are stored by the GO processor at user option by means of variable categories defined on input data cards 107-113. These categories may be printed by their inclusion in a list contained on Cards 1001 and 1002 which are used by the OUT processor. Printer plots of stick figure graphics as a function of time are included in this specification.

Table 2 is a list of the variable categories which were actually included in the output tabulations for the baseline rollover simulations. This list is an index to the page in the output printer where each variable is located. The quantities include:

- body joint coordinates and velocities
- link angles, velocities, and accelerations
- forces and moments on body segments

TABLE 2. VARIABLE CATEGORIES PRINTED OUT DURING EXAMPLE EXERCISE (PAGE 1 OF 2)

CATEGORY AND CONTACT INTERACTION INDEX

DESCRIPTION		BEGINNING PAGE NUMBER
LISTING OF INPUTTED VALUES		1
BODY JOINT COORD		51
BODY JOINT VELS		52
BODY LINK ANGLES		48
BODY LINK ANG ACC		50
BODY LINK ANG VEL		49
CENTER OF MASS RESLTNT MOM		124
CENTER OF MASS X FORCE COMP		122
CENTER OF MASS Z FORCE COMP		123
CHEST C.G. MOTION		46
CONTACT ELLIPSE VS LINE		
ELL-LIN:HEAD	VS P.HEADERLINE	109
ELL-LIN:HEAD	VS P.ROOF EDGE LINE	107
ELL-LIN:HEAD	VS P.ROOF LINE	104
ELL-LIN:HEAD	VS ROOF EDGE LINE	112
ELL-LIN:HEAD	VS ROOF LINE	100
ELL-LIN:LEFT FOOT	VS DOORLINE	115
ELL-LIN:LEFT FOOT	VS FLOORLINE	118
ELL-LIN:LEFT FOOT	VS LOW DASH	103
ELL-LIN:LEFT LOWER ARM	VS DOORLINE	117
ELL-LIN:LEFT UPPER ARM	VS DOORLINE	116
ELL-LIN:LEFT UPPER LEG	VS DOORLINE	114
ELL-LIN:LEFT UPPER LEG	VS SEAT CUSHION LN.	101
ELL-LIN:LOWER TORSO	VS HIP PANEL LINE	113
ELL-LIN:LOWER TORSO	VS P.HIP PANEL LINE	105
ELL-LIN:LOWER TORSO	VS SEAT CUSHION LN.	99
ELL-LIN:RIGHT FOOT	VS FLOORLINE	120
ELL-LIN:RIGHT FOOT	VS LOW DASH	102
ELL-LIN:RIGHT FOOT	VS P.DOORLINE	110
ELL-LIN:RIGHT UPPER LEG	VS P.DOORLINE	119
ELL-LIN:RIGHT UPPER LEG	VS SEAT CUSHION LN.	111
ELL-LIN:UPPER TORSO	VS P.DOORLINE	108
ELL-LIN:UPPER TORSO	VS P.ROOF EDGE LINE	106
ELL-LIN:UPPER TORSO	VS SEAT CUSHION LN.	121
FEMUR AND TIBIA LOADS		127
FRICTION COMP JOINT TORQ		63
HEAD C.G. MOTION		45
HIP MOTION		47
JOINT RELATIVE ANGLES		58
JOINT REL ANGLE VELS		59
JOINT TORQUES		60
KINETIC ENERGY		126
LINE MVT OF B-PILLAR		85
LINE MVT OF DOOR		88
LINE MVT OF DOOR SILL		84
LINE MVT OF FLOOR		97
LINE MVT OF HEADER		83

TABLE 2. VARIABLE CATEGORIES PRINTED OUT DURING EXAMPLE EXERCISE (PAGE 2 OF 2)

CATEGORY AND CONTACT INTERACTION INDEX

DESCRIPTION	BEGINNING PAGE NUMBER
LINE MVT OF HIP PANEL	86
LINE MVT OF LOW DASH	92
LINE MVT OF P.B-PILLAR	93
LINE MVT OF P.DOOR	96
LINE MVT OF P.DOOR SILL	91
LINE MVT OF P.HEADER	90
LINE MVT OF P.HIP PANEL	94
LINE MVT OF P.ROOF	89
LINE MVT OF P.WINDOW	95
LINE MVT OF ROOF	82
LINE MVT OF SEAT CUSHION	98
LINE MVT OF WINDOW	87
LINEAR COMP JOINT TORQ	61
MUSCLE TEN FORCES AND TORQ	57
NECK AND SHOULDER FORCES	55
NECK JOINT COORDS	53
NECK REACTION FORCES	56
NONLINEAR COMP JOINT TORQ	62
PRINTER PLOTS OF STICK FIG	128
QNT FOR REG:B-PILLAR	68
QNT FOR REG:DOOR	71
QNT FOR REG:DOOR SILL	67
QNT FOR REG:FLOOR	80
QNT FOR REG:HEADER	66
QNT FOR REG:HIP PANEL	69
QNT FOR REG:LOW DASH	75
QNT FOR REG:P.B-PILLAR	76
QNT FOR REG:P.DOOR	79
QNT FOR REG:P.DOOR SILL	74
QNT FOR REG:P.HEADER	73
QNT FOR REG:P.HIP PANEL	77
QNT FOR REG:P.ROOF	72
QNT FOR REG:P.WINDOW	78
QNT FOR REG:ROOF	65
QNT FOR REG:SEAT CUSHION	81
QNT FOR REG:WINDOW	70
SHOULDER JOINT COORDS	54
UNFILTERED ACCELS	125
VEHICLE RESPONSE	44
VISCOSITY COMP JOINT TORQ	64

- head and chest center of gravity motion
- contact forces between occupant and vehicle
- joint relative angles and torques
- energies
- forces at neck and shoulder
- vehicle response
- accelerations
- stick figures

A printout for an entire rollover run is included as the Appendix to this report.

2.4.3. Sample Results Derived from Baseline Rollover Output

A sample of results from the baseline rollover exercise is presented in this section. These include quantities of interest such as contact interactions of various body segments with the vehicle interior, head accelerations, and forces on the neck at the head. Many other quantities are available for similar presentation and analysis.

Figures 8, 9, 13, and 14 show the forces predicted for many of the occupant interactions with the vehicle interior. These plots were assembled from several of the contact force tables contained in the printout. Overlay capabilities would be required in a computer graphics system to construct the same plots. The first interaction takes place at about 200 milliseconds with the vehicle and occupant in freefall. The occupant is forced toward the roof by the release of the compression force caused by the driver sitting on the seat cushion. During the period of 400-600 milliseconds, the vehicle is into its first roll. There are a variety of interactions of the driver with the passenger door and roof structures. Restraining action of the lower instrument panel is also evident. The vehicle is airborne at about 1200 milliseconds with the driver's door toward the ground (one 360° roll almost complete). The vehicle center of gravity has risen to its maximum point as the result of the ground interaction leaving the driver in contact with the door structures on the driver's side of the vehicle.

Due to the force of this interaction, most of the remaining interactions are with the passenger's side as the vehicle enters the end of the one- and one-quarter roll event. Figure 15 shows the resultant acceleration at the head center of gravity. As expected, the peaks correspond with the peaks in contact force. The one exception is the peak shortly before 1200 milliseconds which is transmitted to the head as the result of the interaction of the torso with the driver door.

Figure 16, 17, and 18 show the shear and compressive forces on the neck at the head as well as the moment exerted in the region of this junction. It should be noted that there is more of a correlation between shear force and moment than between either of these quantities and compressive force. This implies (as can be validated by reviewing occupant kinematics displays such as Figure 10) that the forces shown in Figure 8 are applied more toward the side of the head. In these cases the occupant is positioned more or less upright as he interacts with door and roof structures near the side of the vehicle. The effect of a vertex contact is shown in Figure 17 for the roof contact at about 200 milliseconds which results as the occupant rises nearly straight up from the seat cushion. There is virtually no shear force or moment on the neck during this contact. Although the quality of the actual predicted numerical values for the neck variables depends very strongly on the quality of data which describes the occupant, the availability of these predictions can be very useful in assessing direction of impact and the nature of the combined stresses which are applied to the neck. This applies whether the forces are transmitted to the neck as the result either of a blow to the head or to the torso.

The location of the occupant within the vehicle is most graphically illustrated by ellipse man computer-generated displays such as those illustrated by Figures 10 and 11. Figure 10 shows the sequence or flow of motions as an overlay but can be difficult to use for analysis of occupant position at a particular point in time. More useful for details is the single frame plot such as Figure 12 which can be obtained either in vehicle coordinates or in inertial coordinates with the vehicle oriented properly with respect to the ground.

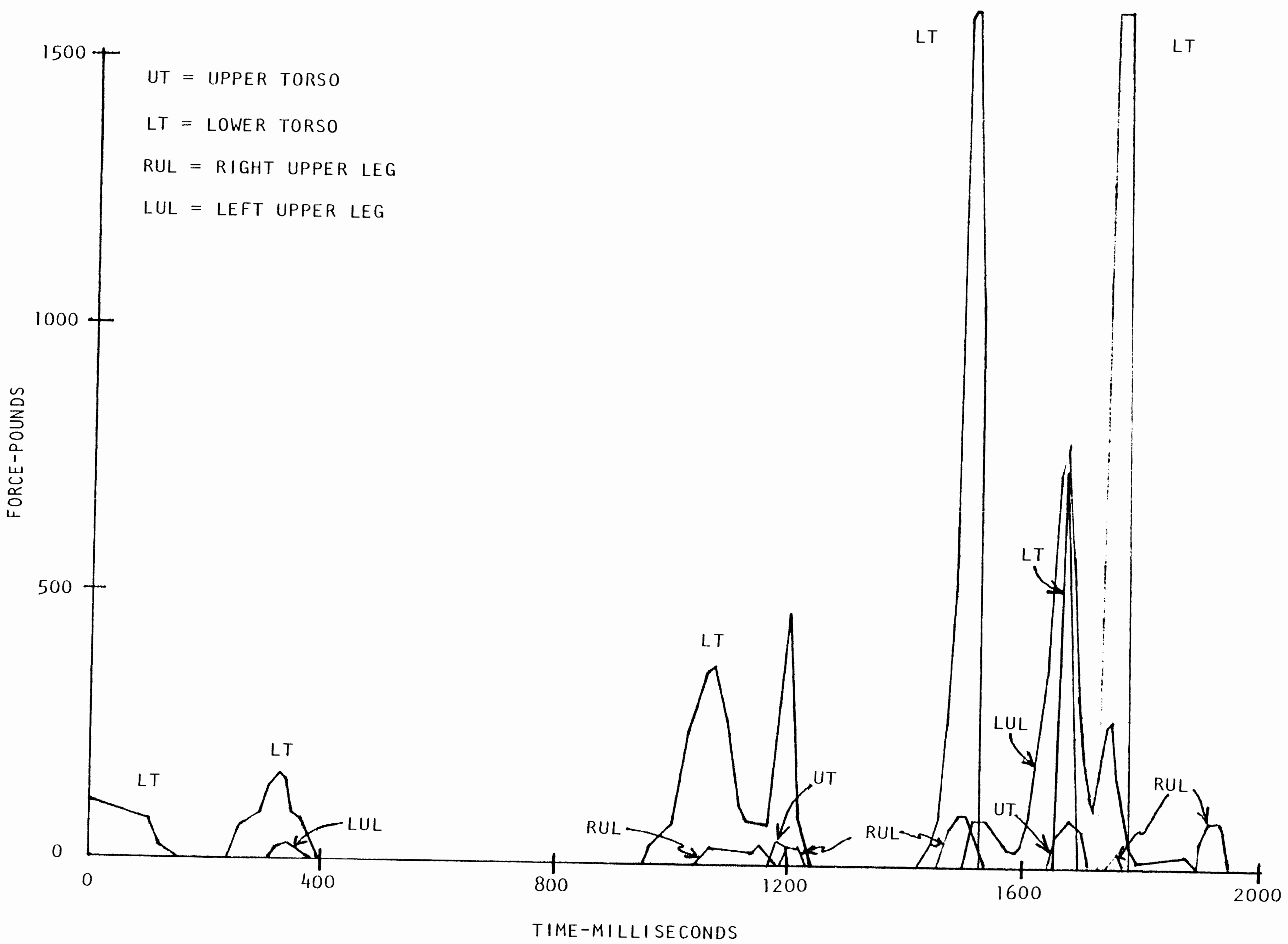


FIG. 13. CONTACTS WITH SEAT (BASELINE ROLLOVER).

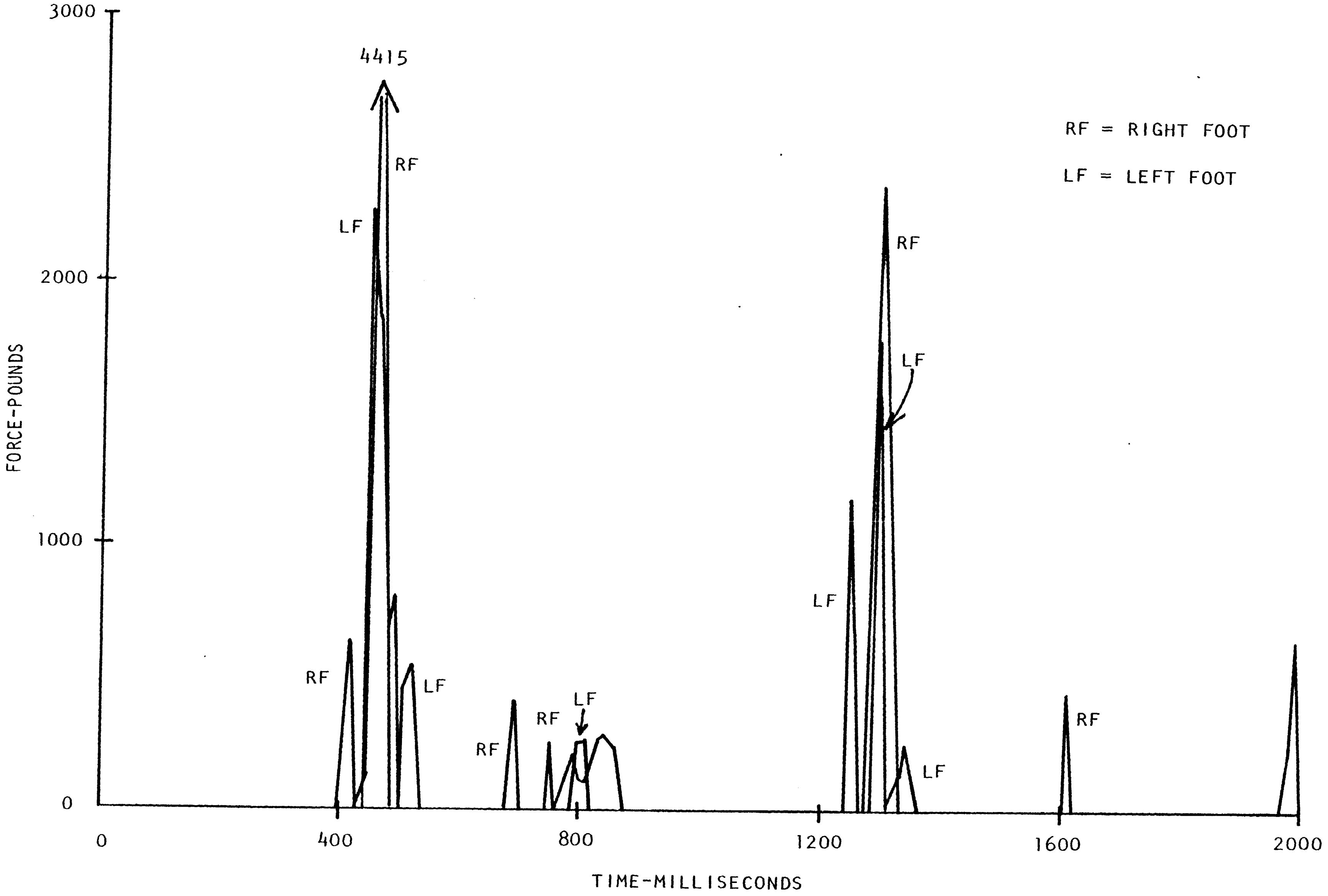


FIG. 14. FOOT CONTACTS WITH LOWER INSTRUMENT PANEL (BASELINE ROLLOVER).

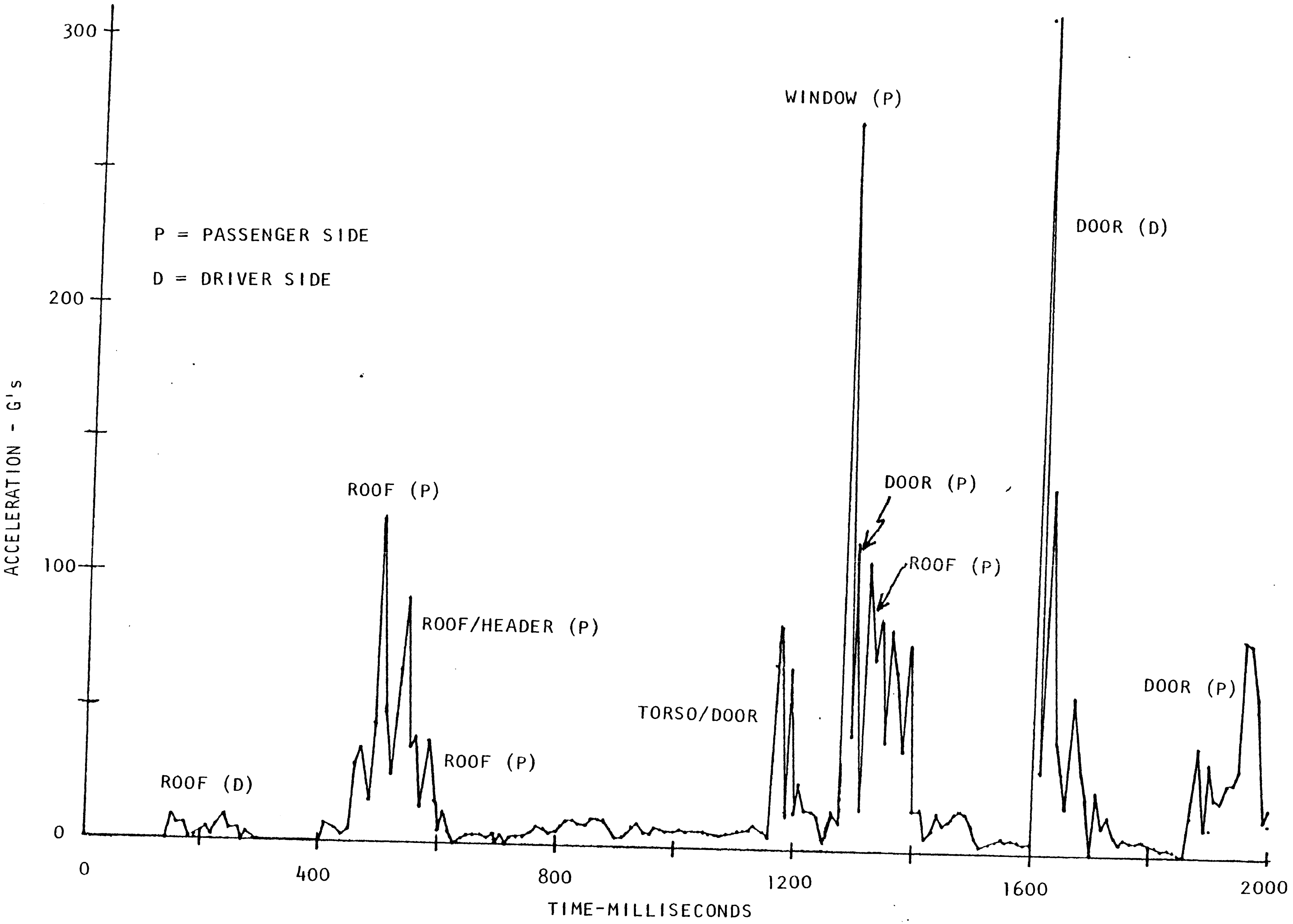


FIG. 15. RESULTANT ACCELERATION AT HEAD CENTER OF GRAVITY (BASELINE ROLLOVER).

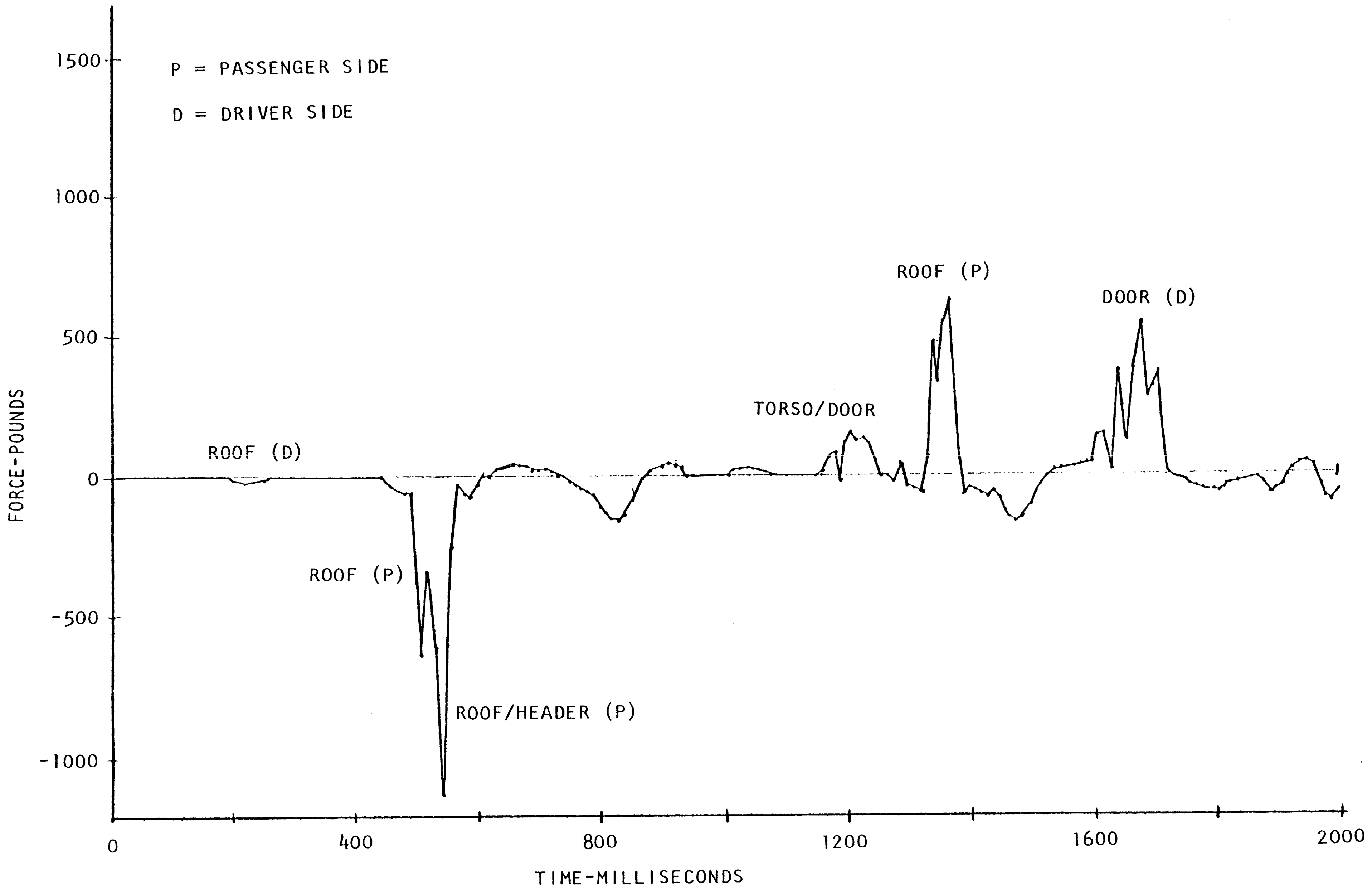


FIG. 16. SHEAR FORCE ON NECK AT HEAD (BASELINE ROLLOVER).

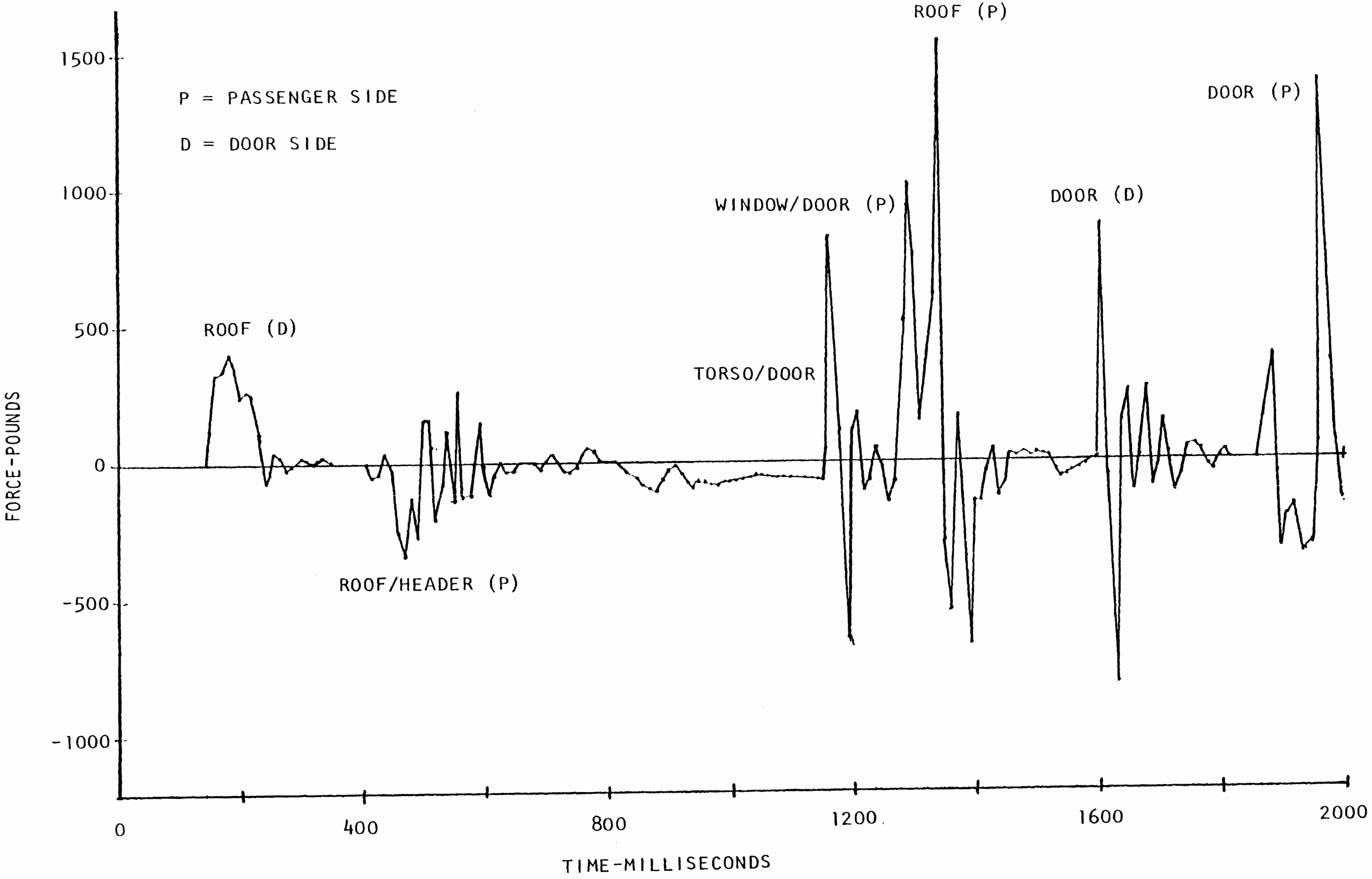


FIG. 17. COMPRESSIVE FORCE ON NECK AT HEAD (BASELINE ROLLOVER).

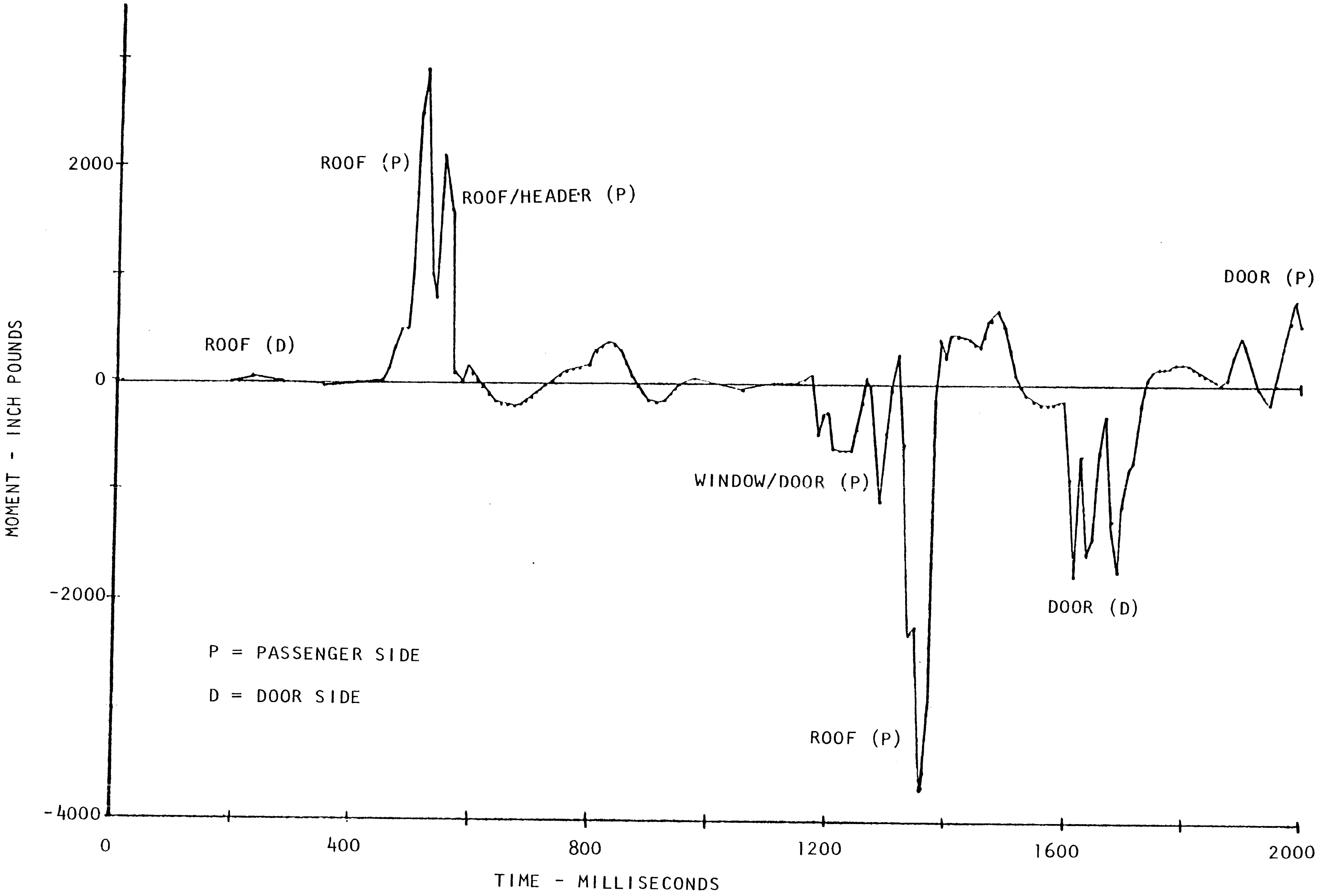


FIG. 18. MOMENT ON NECK AT HEAD (BASELINE ROLLOVER).

This sample of results has been selected to demonstrate the flexibility available for viewing and analysis of results. Occupant motions, while available as tabular data or plots of variables as a function of time, are more readily viewed using the ellipse man displays. Forces of interaction and all the other dynamic quantities are most usefully viewed as computer-generated plots, in many cases using overlays.

2.4.4. Parameter Variations

Four additional exercises were conducted to examine aspects of roof crush and ejection. All used the baseline data set given in Table 1 as a starting point. The first variation involved inclusion of roof crush. Table 3 contains this data set. Timing and duration of the roof crush were based on that period of time during the baseline run when the vehicle was inverted and in contact with the ground as estimated from the test movies. An arbitrary deflection of roof structures downward into the vehicle was initiated at 700 milliseconds. By 800 milliseconds the roof structures intruded into the occupant compartment by more than 7 inches. After 800 milliseconds, the roof structures held the deformed position. The following contact surfaces were involved in the intrusion:

- roof edge line
- roof line
- passenger roof edge line
- passenger roof line

Others could have been included or the surfaces could have been skewed to represent crush on one side only. The technique for implementing these data is illustrated on the 411 Cards in Table 3.

Figure 11 shows the ellipse man occupant motion display for this case while Figures 19 and 20 show forces generated during occupant/ vehicle interactions. It has been noted previously that the location of the head of the occupant (from a review of ellipse man plots) is not near the roof during the period roof crush is occurring. It is not until after 900 milliseconds that head contact with the vehicle is again

TABLE 3. ROLLOVER DATA SET INCLUDING ROOF CRUSH (PAGE 1 OF 4).

```
                 ROLL5                                                                100
                 3D-2D: REAR VIEW OF DRIVER                                           200
                                                                                      300
                                                                                      400
                                                                                      500
                                                                                      600
                                                                                      700
                                                                                      800
1.         -40.       32.174   .0001     0.        2000.    .5        10.       100.  101
0.         0.         0.       0.        0.        0.       10.       .000001   10.   102
.2         .02        600.     500.      30.       .05      10.       1.        1.    103
HEAD                  WINDOW                                                          106
HEAD                  HEADER                                                          106
HEAD                  DOOR                                                            106
HEAD                  P.WINDOW                                                        106
HEAD                  P.HEADER                                                        106
HEAD                  P.DOOR                                                          106
HEAD                  ROOF                                                            106
HEAD                  P.ROOF                                                          106
UPPER TORSO           ROOF                                                            106
UPPER TORSO           P.DOOR                                                          106
UPPER TORSO           SEAT CUSHION                                                    106
UPPER TORSO           P.ROOF                                                          106
UPPER TORSO           DOOR                                                            106
LOWER TORSO           ROOF                                                            106
LOWER TORSO           P.ROOF                                                          106
LOWER TORSO           SEAT CUSHION                                                    106
LOWER TORSO           HIP PANEL                                                       106
LOWER TORSO           P.HIP PANEL                                                     106
RIGHT UPPER LEG SEAT CUSHION                                                          106
RIGHT FOOT            FLOOR                                                           106
LEFT UPPER LEG        SEAT CUSHION                                                    106
LEFT UPPER LEG        DOOR                                                            106
RIGHT UPPER LEG P.DOOR                                                                106
LEFT FOOT             FLOOR                                                           106
LEFT FOOT             DOOR                                                            106
RIGHT FOOT            P.DOOR                                                          106
RIGHT FOOT            ROOF                                                            106
RIGHT FOOT            P.ROOF                                                          106
LEFT FOOT             LOW DASH                                                        106
RIGHT FOOT            LOW DASH                                                        106
LEFT UPPER ARM        DOOR                                                            106
LEFT LOWER ARM        DOOR                                                            106
0.         0.         0.       0.        0.        0.       1.        0.        1.    107
0.         0.         0.       0.        0.        0.       1.        0.        1.    108
1.         1.         0.       0.        0.        0.       0.        0.        1.    109
1.         1.         0.       0.        0.        1.       1.        1.        1.    110
0.         0.         1.       0.        0.        0.       0.        0.        0.    111
HEAD                                     1.        1.                                 219
HEAD                  0.       0.        4.4897    3.1                                220
UPPER TORSO           THORAX MATERIAL    2.        1.                                 219
UPPER TORSO           0.       0.        4.83205   6.78                               220
CENTER TORSO          THORAX MATERIAL    3.        1.                                 219
CENTER TORSO          -1.9563  0.        6.87638   6.35                               220
LOWER TORSO                              4.        1.                                 219
LOWER TORSO           0.       0.        7.4339    6.94                               220
LEFT UPPER LEG                           5.        1.                                 219
LEFT UPPER LEG        .781836  -4.45     3.72875   3.74                               220
LEFT LOWER LEG                           6.        1.                                 219
LEFT LOWER LEG        -.36406  4.45      7.33778   2.23                               220
LEFT FOOT                                6.        1.                                 219
LEFT FOOT             7.3      4.45      2.        1.8                                220
RIGHT UPPER LEG                          5.        1.                                 219
RIGHT UPPER LEG .781836 4.45             3.72875   3.74                               220
RIGHT FOOT                               6.        1.                                 219
RIGHT FOOT            7.3      -4.45     2.        1.8                                220
```

TABLE 3. ROLLOVER DATA SET INCLUDING ROOF CRUSH (PAGE 2 OF 4).

67	LEFT UPPER ARM				7.	1.				219
68	LEFT UPPER ARM		0.	0.	6.88	1.64				220
69	LEFT LOWER ARM				8.	1.				219
70	LEFT LOWER ARM		0.	0.	.817523	1.11				220
71	RIGHT LOWER LEG				6.	1.				219
72	RIGHT LOWER LEG		-.36406	-4.45	7.33778	2.23				220
73	0.	8.80333	4.69511	4.89074	4.24		10.7	1.56504	-7.6	201
74	3.22789	2.15193	2.24974	2.44537	2.1982	6.05145	5.25	.573486	.76	202
75	.025	.095	.031	.098	.09	.05	.012	.012	.0047	203
76	.297	2.17	.31	1.78	.77	1.	.137	.27		204
77	31.2	5.	0.	0.	2000.	3000.	0.	-30.	1.	205
78	31.2	5.	0.	0.	2000.	3000.	0.	-30.	1.	206
79	50.	5.	0.	0.	2000.	3000.	15.	-15.	1.	207
80	50.	5.	0.	0.	2000.	3000.	15.	-15.	1.	208
81	16.	5.	0.	0.	2000.	3000.	-165.	-195.	1.	209
82	16.	5.	0.	0.	2000.	3000.	195.	165.	1.	210
83	16.	5.	0.	0.	2000.	3000.	90.	-10.	1.	211
84	16.	5.	0.	0.	2000.	3000.	30.	-30.	1.	212
85	751.	0.	757.	1.98						213
86	1000.	0.	800.	2.5			0.		1.	214
87	31.2	5.	0.	0.	2000.	3000.	30.	0.	1.	215
88	31.2	5.	0.	0.	2000.	3000.	30.	0.	1.	216
89	751.	0.	757.	1.98						242
90	0.	0.	0.	0.	-180.	180.	0.	0.		217
91	3.188	2.125	0.							218
92	THORAX MATERIAL		0.	0.	50.	100.	101.	0.	0.	221
93	THORAX MATERIAL		1.				THORAX	ZERO	GRRATIO	222
94	THORAX	-1.	4080.							225
95	90.	90.	90.	90.	90.	-90.	-90.	-90.	90.	301
96	0.	0.	-29.	0.	4.89074	0.				303
97	ROOF		FLOOR MATERIAL		0.	1.	1.	1.		401
98	HEADER		PANEL MATERIAL		0.	1.	1.	1.		401
99	DOOR SILL		PANEL MATERIAL		0.	1.	1.	1.		401
100	B-PILLAR		PILLAR MATERIAL		0.	1.	1.	1.		401
101	HIP PANEL		PANEL MATERIAL		0.	1.	1.	1.		401
102	WINDOW		GLASS MATERIAL		0.	1.	1.	1.		401
103	DOOR		DOOR MATERIAL		0.	1.	1.	1.		401
104	P.ROOF		FLOOR MATERIAL		0.	1.	1.	1.		401
105	P.HEADER		PANEL MATERIAL		0.	1.	1.	1.		401
106	P.DOOR SILL		PANEL MATERIAL		0.	1.	1.	1.		401
107	LOW DASH		PANEL MATERIAL		0.	1.	1.	1.		401
108	P.B-PILLAR		PILLAR MATERIAL		0.	1.	1.	1.		401
109	P.HIP PANEL		PANEL MATERIAL		0.	1.	1.	1.		401
110	P.WINDOW		GLASS MATERIAL		0.	1.	1.	1.		401
111	P.DOOR		DOOR MATERIAL		0.	1.	1.	1.		401
112	FLOOR		FLOOR MATERIAL		0.	1.	1.	1.		401
113	SEAT CUSHION		SEAT MATERIAL		0.	1.	1.	1.		401
114	ROOF		2.	1.	1.	0.	1.			402
115	HEADER		1.	1.	1.	0.	1.			402
116	DOOR SILL		1.	1.	1.	0.	1.			402
117	B-PILLAR		1.	1.	1.	0.	1.			402
118	HIP PANEL		1.	1.	1.	0.	1.			402
119	WINDOW		1.	1.	1.	0.	1.			402
120	DOOR		1.	1.	1.	0.	1.			402
121	P.ROOF		2.	1.	1.	0.	1.			402
122	P.HEADER		1.	1.	1.	0.	1.			402
123	P.DOOR SILL		1.	1.	1.	0.	1.			402
124	LOW DASH		1.	1.	1.	0.	1.			402
125	P.B-PILLAR		1.	1.	1.	0.	1.			402
126	P.HIP PANEL		1.	1.	1.	0.	1.			402
127	P.WINDOW		1.	1.	1.	0.	1.			402
128	P.DOOR		1.	1.	1.	0.	1.			402
129	FLOOR		1.	1.	1.	0.	1.			402
130	SEAT CUSHION		1.	1.	1.	0.	1.			402
131	PANEL MATERIAL		0.	0.	50.	100.	101.	0.	0.	403
132	PILLAR MATERIAL		0.	0.	50.	100.	101.	0.	0.	403

TABLE 3. ROLLOVER DATA SET INCLUDING ROOF CRUSH (PAGE 3 OF 4).

```
133    DOOR MATERIAL   0.      0.       50.      100.     101.     0.      0.           403
134    FLOOR MATERIAL  0.      0.       50.      100.     101.     0.      0.           403
135    SEAT MATERIAL   0.      0.       50.      100.     101.     1500.   2500.        403
136    GLASS MATERIAL  0.      0.       .001     .5       .6       0.      0.           403
137    PANEL MATERIAL  1.                                 PANEL    ZERO    GRRATIO      404
138    PILLAR MATERIAL 1.                                 PILLAR   ZERO    GRRATIO      404
139    DOOR MATERIAL   1.                                 DOOR     ZERO    GRRATIO      404
140    FLOOR MATERIAL  1.                                 FLOOR    ZERO    GRRATIO      404
141    SEAT MATERIAL   1.                                 SEAT     ZERO    GRRATIO      404
142    GLASS MATERIAL  1.                                 GLASS    ZERO    GRRATIO      404
143    GRRATIO -1.     0.                                                               405
144    GRRATIO -1.     1.                                                               406
145    PANEL    0.     0.                                                               407
146    PANEL    3.     3000.                                                            407
147    PANEL    4.     13000.                                                           407
148    PILLAR  -1.     4000.                                                            407
149    DOOR    -1.     1000.   -562.5   1031.25  -562.5   93.75                         407
150    FLOOR   -1.     860.                                                             407
151    SEAT     0.     0.                                                               407
152    SEAT     2.58   103.                                                             407
153    SEAT     4.     400.                                                             407
154    SEAT     5.     1000.                                                            407
155    SEAT     5.5    2000.                                                            407
156    GLASS   -1.     10000.                                                           407
157    ZERO    -1.     0.                                                               408
158    ROOF EDGE LINE  ROOF             5.       .5       1.       1.                   409
159    ROOF LINE       ROOF             5.       .203     1.       2.                   409
160    HEADERLINE      HEADER           4.5      .5       1.       1.                   409
161    DOOR SILL LINE  DOOR SILL        7.       0.       1.       1.                   409
162    B-PILLAR LINE   B-PILLAR         7.       .284     1.       1.                   409
163    HIP PANEL LINE  HIP PANEL        7.5      0.       1.       1.                   409
164    WINDOW LINE     WINDOW           4.5      0.       1.       1.                   409
165    DOORLINE        DOOR             6.8      0.       1.       1.                   409
166    P.ROOF EDGE LINEP.ROOF           5.       .5       1.       1.                   409
167    P.ROOF LINE     P.ROOF           5.       .203     1.       2.                   409
168    P.HEADERLINE    P.HEADER         4.5      .5       1.       1.                   409
169    P.DOOR SILL LINEP.DOOR SILL      7.       0.       1.       1.                   409
170    LOW DASH        LOW DASH         5.       .5       1.       1.                   409
171    P.B-PILLAR LINE P.B-PILLAR       7.       .284     1.       1.                   409
172    P.HIP PANEL LINEP.HIP PANEL      7.5      0.       1.       1.                   409
173    P.WINDOW LINE   P.WINDOW         4.5      0.       1.       1.                   409
174    P.DOORLINE      P.DOOR           6.8      0.       1.       1.                   409
175    FLOORLINE       FLOOR            4.       0.       1.       1.                   409
176    SEAT CUSHION LN.SEAT CUSHION     7.5      0.       -1.      1.                   409
177    ROOF EDGE LINE  4.                                                               410
178    ROOF LINE       4.                                                               410
179    HEADERLINE      4.                                                               410
180    DOOR SILL LINE  1.                                                               410
181    B-PILLAR LINE   4.                                                               410
182    HIP PANEL LINE  1.                                                               410
183    WINDOW LINE     1.                                                               410
184    DOORLINE        1.                                                               410
185    P.ROOF EDGE LINE4.                                                               410
186    P.ROOF LINE     4.                                                               410
187    P.HEADERLINE    4.                                                               410
188    P.DOOR SILL LINE1.                                                               410
189    LOW DASH        1.                                                               410
190    P.B-PILLAR LINE 4.                                                               410
191    P.HIP PANEL LINE1.                                                               410
192    P.WINDOW LINE   1.                                                               410
193    P.DOORLINE      1.                                                               410
194    FLOORLINE       1.                                                               410
195    SEAT CUSHION LN.1.                                                               410
196    ROOF EDGE LINE  0.      -8.854   -42.881  -6.549   -45.515                       411
197    ROOF EDGE LINE  700.    -8.854   -42.881  -6.549   -45.515                       411
198    ROOF EDGE LINE  800.    -8.854   -35.     -6.549   -38.                          411
```

TABLE 3. ROLLOVER DATA SET INCLUDING ROOF CRUSH (PAGE 4 OF 4).

```
 199   ROOF EDGE LINE  3000.     -8.854    -35.      -6.549    -38.                                411
 200   ROOF LINE       0.        -6.549    -45.515   15.451    -48.015                             411
 201   ROOF LINE       700.      -6.549    -45.515   15.451    -48.015                             411
 202   ROOF LINE       800.      -6.549    -38.      15.451    -41.                                411
 203   ROOF LINE       3000.     -6.549    -38.      15.451    -41.                                411
 204   HEADERLINE      0.        -10.5     -41.      -8.854    -42.881                             411
 205   HEADERLINE      1271.     -10.5     -41.      -8.854    -42.881                             411
 206   HEADERLINE      1600.     -10.5     -41.      -8.854    -42.881                             411
 207   HEADERLINE      1800.     -10.5     -41.      -8.854    -42.881                             411
 208   DOOR SILL LINE  -1.       -15.5     0.        -15.5     -26.                                411
 209   B-PILLAR LINE   0.        -15.5     -26.      -10.5     -41.                                411
 210   B-PILLAR LINE   1271.     -15.5     -26.      -10.5     -41.                                411
 211   B-PILLAR LINE   1600.     -15.5     -26.      -10.5     -41.                                411
 212   B-PILLAR LINE   1800.     -15.5     -26.      -10.5     -41.                                411
 213   HIP PANEL LINE  -1.       -12.5     0.        -12.5     -40.                                411
 214   WINDOW LINE     -1.       -20.      -18.      -9.       -50.                                411
 215   DOORLINE        -1.       -15.5     0.        -15.5     -40.                                411
 216   P.ROOF EDGE LINE0.        39.756    -42.881   37.451    -45.515                             411
 217   P.ROOF EDGE LINE700.      39.756    -42.881   37.451    -45.515                             411
 218   P.ROOF EDGE LINE800.      39.756    -35.      37.451    -38.                                411
 219   P.ROOF EDGE LINE3000.     39.756    -35.      37.451    -38.                                411
 220   P.ROOF LINE     0.        37.451    -45.515   15.451    -48.015                             411
 221   P.ROOF LINE     700.      37.451    -45.515   15.451    -48.015                             411
 222   P.ROOF LINE     800.      37.451    -38.      15.451    -41.                                411
 223   P.ROOF LINE     3000.     37.451    -38.      15.451    -41.                                411
 224   P.HEADERLINE    0.        41.402    -41.      39.756    -42.881                             411
 225   P.HEADERLINE    1271.     41.402    -41.      39.756    -42.881                             411
 226   P.HEADERLINE    1600.     41.402    -41.      39.756    -42.881                             411
 227   P.HEADERLINE    1800.     41.402    -41.      39.756    -42.881                             411
 228   P.DOOR SILL LINE-1.       46.402    0.        46.402    -26.                                411
 229   LOW DASH        -1.       -22.      -16.      52.9      -16.                                411
 230   P.B-PILLAR LINE 0.        46.402    -26.      41.402    -41.                                411
 231   P.B-PILLAR LINE 1271.     46.402    -26.      41.402    -41.                                411
 232   P.B-PILLAR LINE 1600.     46.402    -26.      41.402    -41.                                411
 233   P.B-PILLAR LINE 1800.     46.402    -26.      41.402    -41.                                411
 234   P.HIP PANEL LINE-1.       43.402    0.        43.402    -40.                                411
 235   P.WINDOW LINE   -1.       50.902    -18.      39.902    -50.                                411
 236   P.DOORLINE      -1.       46.402    0.        46.402    -40.                                411
 237   FLOORLINE       -1.       -22.      .00001    52.902    .00001                              411
 238   SEAT CUSHION LN.-1.       -22.      -10.35    52.902    -10.35                              411
 239   1.        1.        .05                                                                     412
 240   0.        43.4      -45.58    0.        -28.5     0.        42.6      0.        2.          601
 241   13.       0.                                                                                602
 242   0.        0.        200.      101.82    400.      190.06    600.      273.46
 243   800.      344.24    1000.     407.27    1200.     448.      1400.     503.27
 244   1550.     536.24    1620.     561.46    1720.     581.82    1960.     607.03
 245   2000.     607.03
 246   20.       0.                                                                                603
 247   0.        -45.58    40.       -45.58    100.      -44.8     225.      -37.24
 248   295.      -35.88    360.      -37.62    500.      -52.75    610.      -55.66
 249   700.      -51.39    780.      -45.77    1010.     -16.1     1070.     -12.61
 250   1120.     -12.61    1185.     -18.23    1400.     -23.37    1625.     -17.36
 251   1725.     -10.76    1785.     -13.87    1935.     -33.45    2000.     -37.33
 252   14.       2.        .1875     5600.                                                         604
 253   0.        -28.5     40.       -28.5     100.      -31.      140.      -31.
 254   275.      -38.      355.      -56.      860.      -214.     1010.     -235.
 255   1360.     -305.     1430.     -310.     1560.     -337.     1710.     -377.
 256   1870.     -379.     2000.     -381.
1000                                                                                             1000
1001   0,1,46-48,10-14,21,22,37,5,38,49,50,15,23-26,2-4,18-20,33-36,30-32,16,                    1001
1002   27-29,39,17,40,45                                                                         1002
1003   1.        1.        -31.      62.       3.        -52.      5.        1.                    1500
1004   21.       0.        0.        1.        1.        0.        1.        0.        0.          1501
1005                                                                                             1600
```

noted. Even though there are more contacts of the head with the roof in the case of roof crush, their level of force is no larger than those contacts observed when the roof remained intact.

The appendix to this report contains the bulk of printout from the roof crush simulation based on the data set contained in Table 3. Although printout is at 10 millisecond intervals in the printout, actual values were computed at 0.5 millisecond intervals. These last values would be the most appropriate for use in a computer-generated display of the results. In fact, because of the bulk of the output, graphical displays are the only practical method for handling most of the variables.

Figure 21 shows the second parameter variation where the passenger door is to presumed to be forced open near the end of the exercise. This was accomplished in the data set (411 cards) by moving the passenger door and window contact surfaces away from the vehicle when the vehicle finishes its roll to land upright during a forcible lateral interaction between the vehicle tires and the ground (1700 milliseconds). The occupant is shown being ejected at the end of the simulation while still moving at close to 15 mph. It should be noted that all interactions with the passenger door and window structures were the same as in the baseline case until 1700 milliseconds.

Figure 22 shows the third parameter variation which simulated the case where there was no passenger door at anytime during the simulation. Ejection occurred shortly after 500 milliseconds while the vehicle was in a primarily rotational mode. The result was that the occupant was flipped up into the air as the result of head and shoulder contacts with the roof structures near the passenger door. By 2000 milliseconds the duration of the simulation, the occupant is beginning to fall toward the ground.

Figure 23 shows yet another case of ejection by eliminating the driver door. In this case the driver is ejected at 1200 milliseconds. This occurs as the vehicle becomes airborne after roof and driver side contact with the ground. The driver is literally dumped out onto the ground and could be trapped under the vehicle as both entities continue their simulated movement.

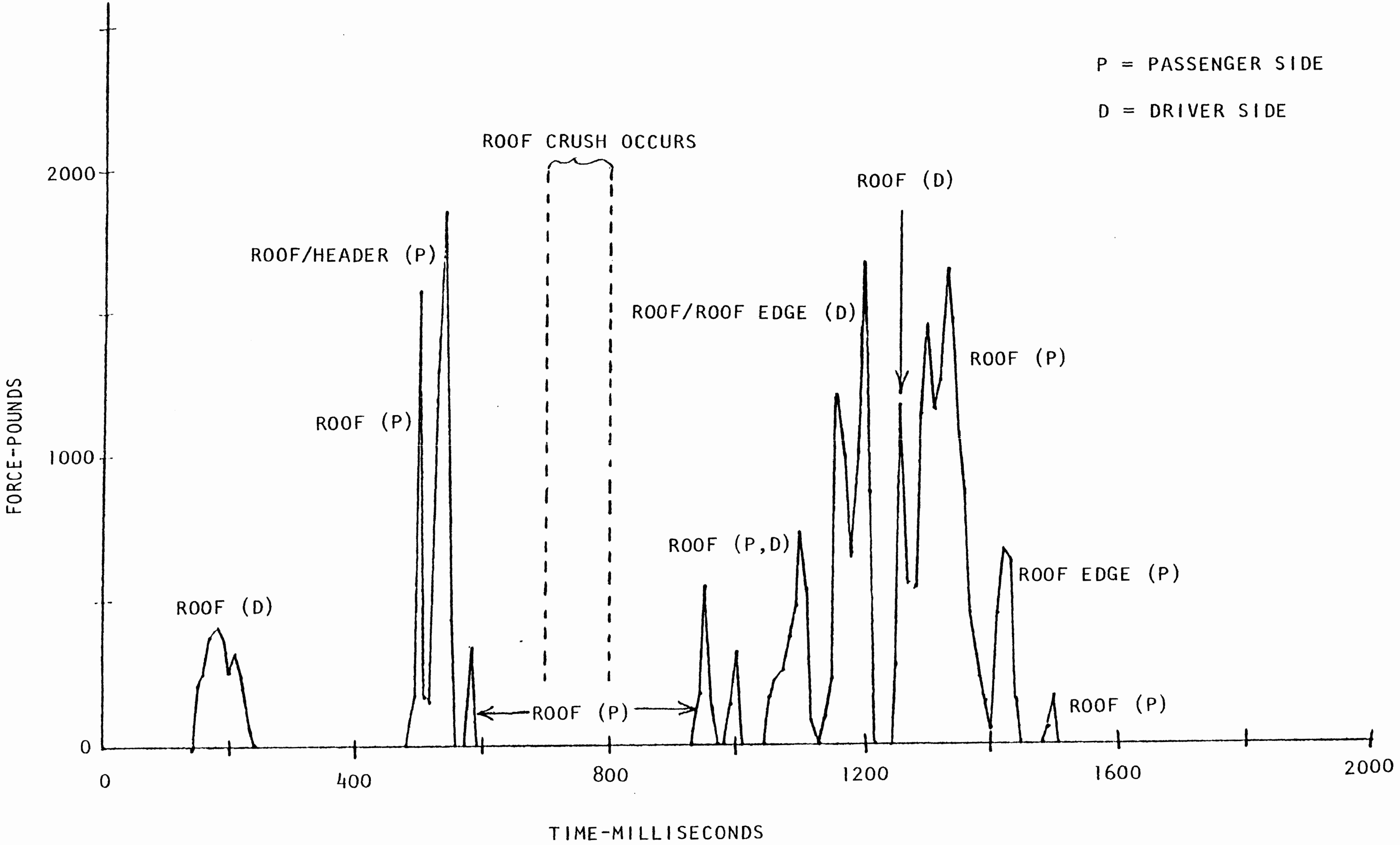


FIG. 19. CONTACTS OF HEAD WITH VEHICLE INTERIOR (ROLLOVER WITH ROOF CRUSH).

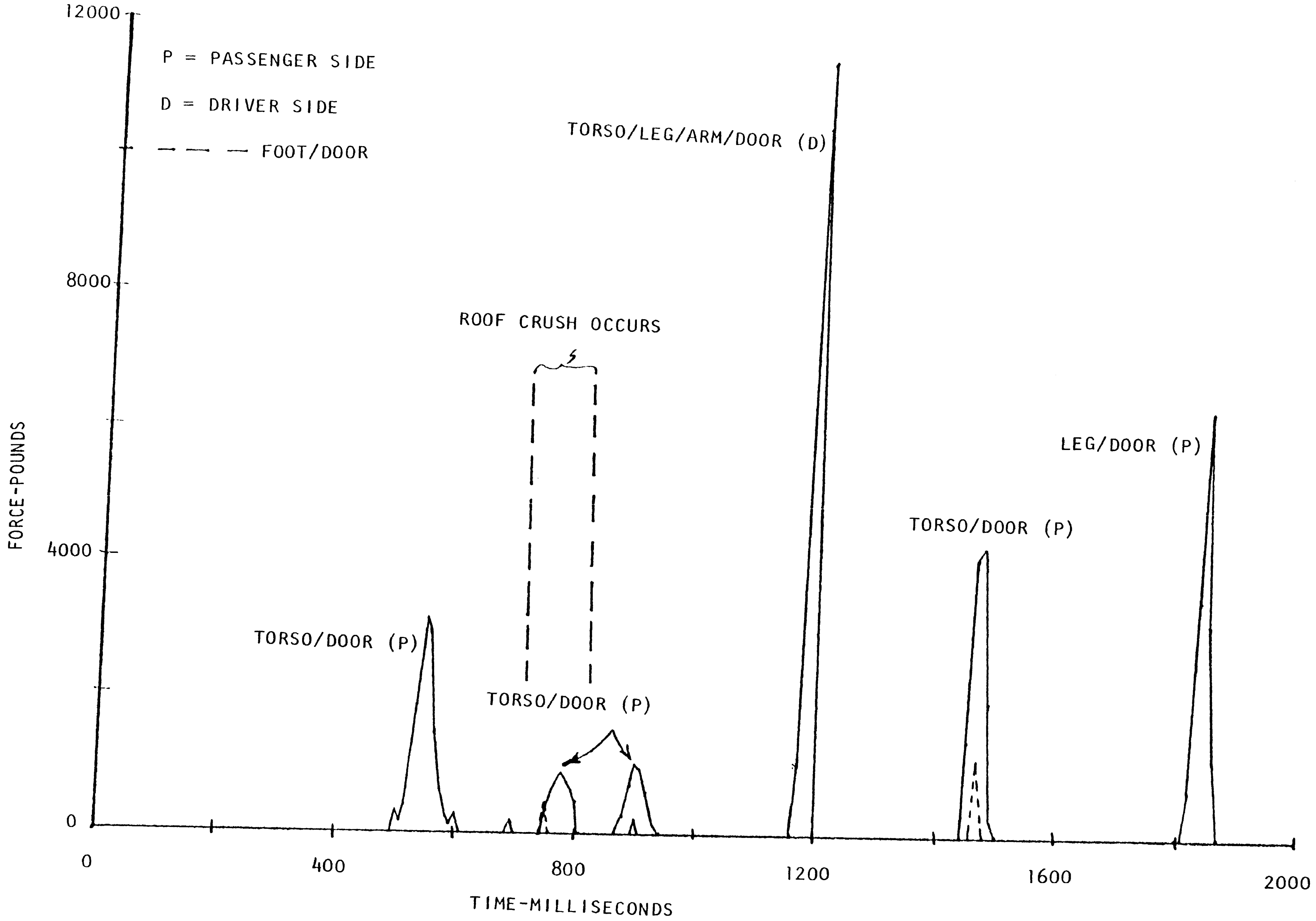
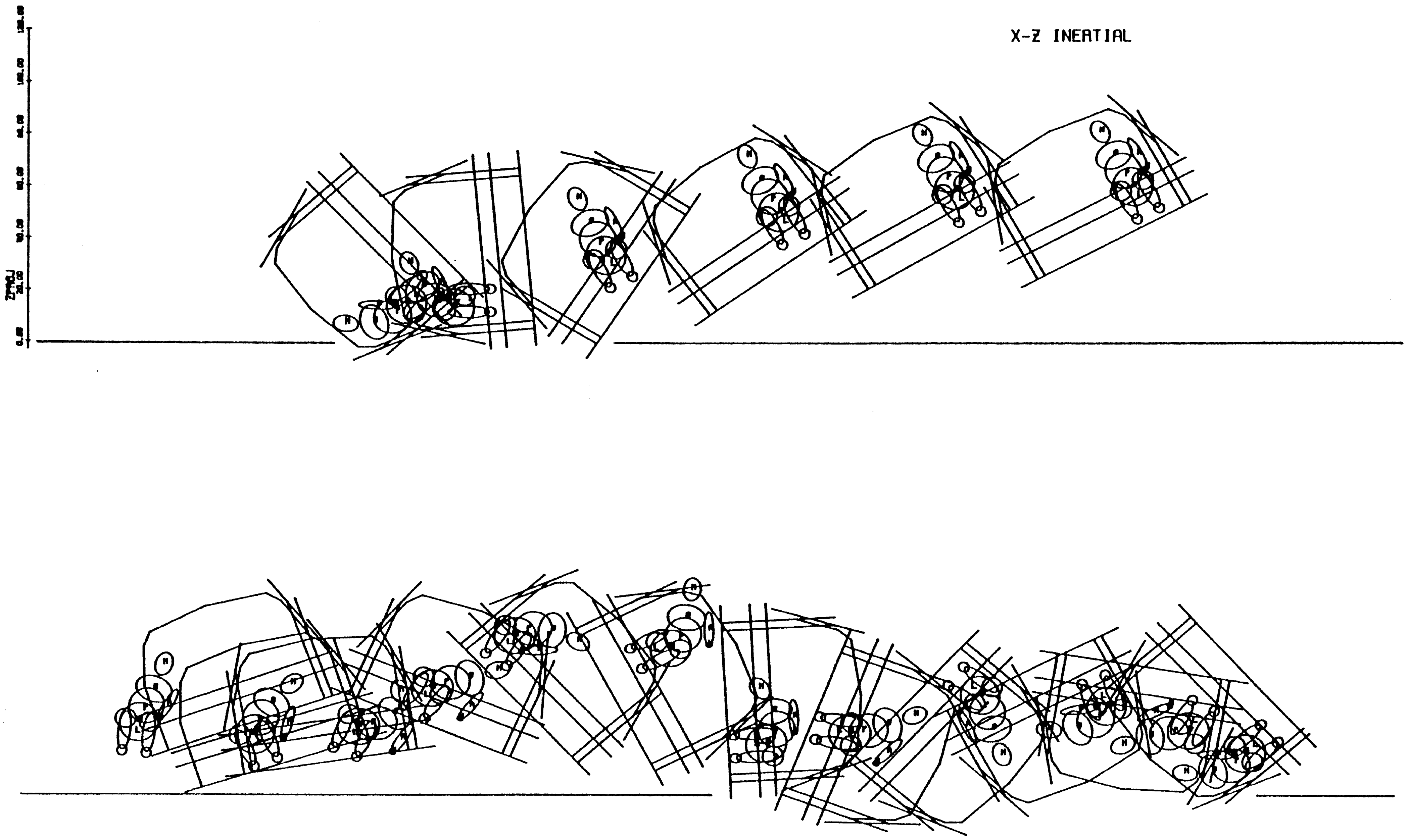
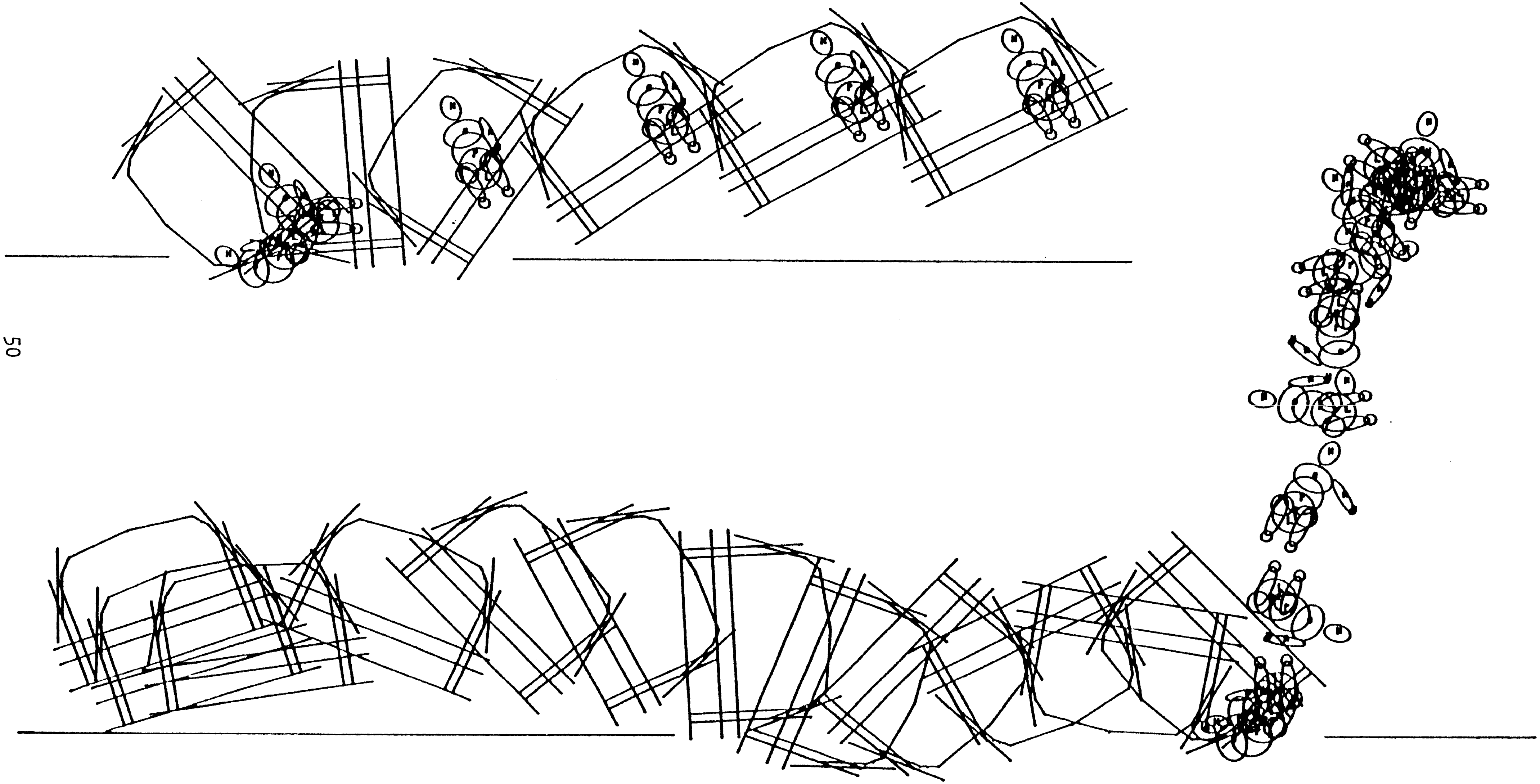


FIG. 20. CONTACTS OF TORSO AND LEGS WITH VEHICLE INTERIOR (ROLLOVER WITH ROOF CRUSH).



PASSENGER DOOR OPENS AT END

FIGURE 21. OCCUPANT MOTIONS WITH PASSENGER DOOR OPEN AT END.



NO PASSENGER DOOR

FIGURE 22. OCCUPANT MOTIONS WITH NO PASSENGER DOOR.

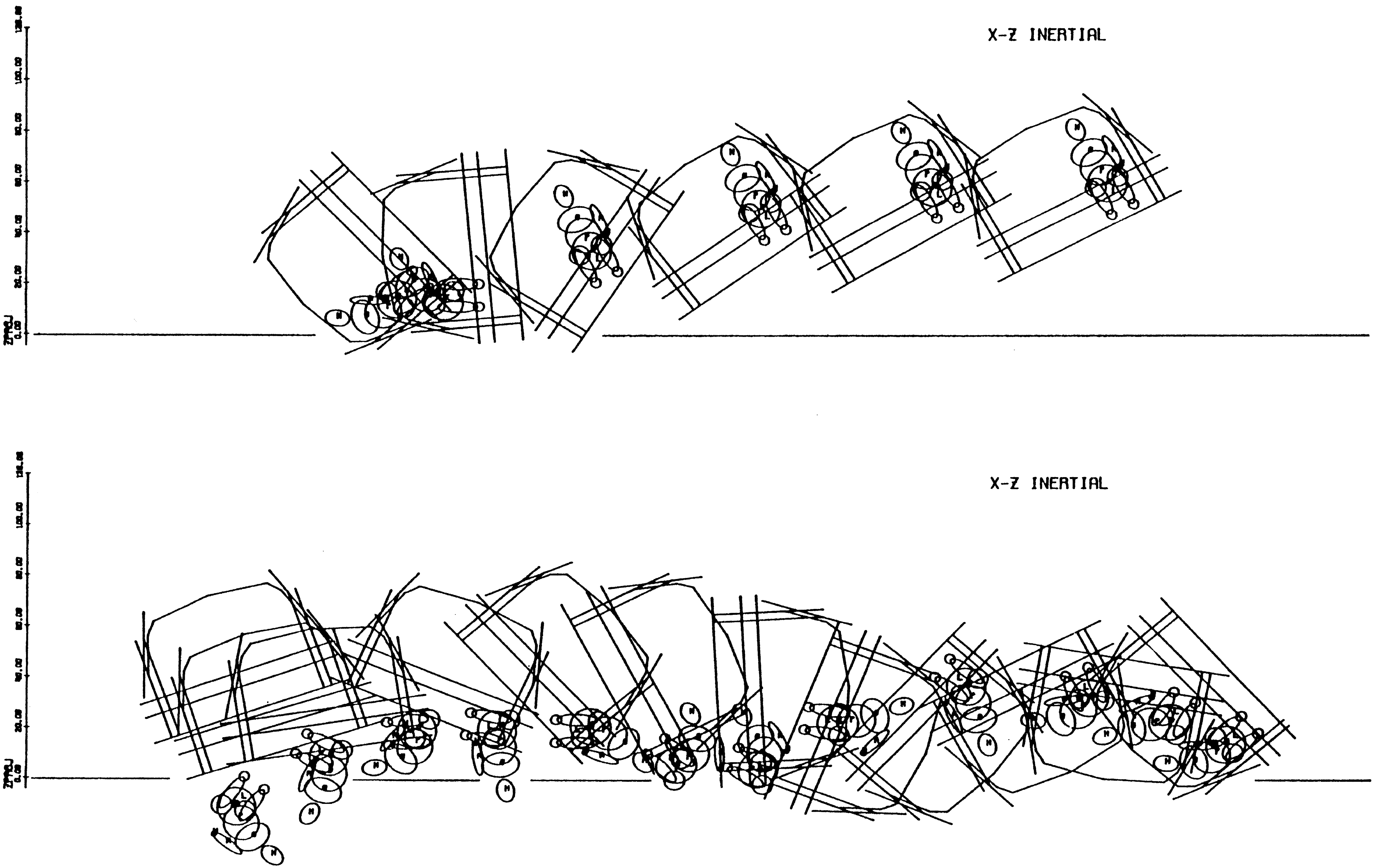


FIGURE 23. OCCUPANT MOTIONS WITH NO DRIVER DOOR.

NO DRIVER DOOR

3.0 REFERENCES

1. Robbins, D.H. and Becker, J.M., "Baseline Data for Describing Occupant Side Impacts and Pedestrian Front Impacts in Two Dimensions," Report No. UM-HSRI-81-29, University of Michigan Transportation Research Institute, Ann Arbor, June 1981.

2. Robbins, D.H., Becker, J.M., Bennett, R.O., and Bowman, B.M., "Accident Data Simulation: Pedestrian and Side Impact, 3-D," Report No. UM-HSRI-80-75, University of Michigan Transportation Research Institute, Ann Arbor, December 1980.

APPENDIX

EXAMPLE OF TABULAR OUTPUT.
ROLLOVER WITH ROOF CRUSH.