902315

# Pedestrian Head Impact Against the Central Hood of Motor Vehicles — Test Procedure and Results

**Thomas F. MacLaughlin**
Vehicle Research and Test Center
National Highway Traffic Safety Administration

**John W. Kessler**
Transportation Research Center of Ohio, Inc.

**ABSTRACT**

This paper describes the development of a pedestrian head impact test procedure which can be applied to central hood regions of motor vehicles. Measurement details are given for locating fourteen impact points in areas where pedestrian head impacts occur and where good performance has been demonstrated on some, but not all, production vehicles. A uniaxial head impactor is used, and HIC values are calculated to evaluate performance.

The procedure was applied to a representative set of nine passenger cars and three light trucks. Percentages of central hood areas over which HIC did not exceed 1000 were determined. Some vehicles were found to provide good pedestrian head protection.

Underhood clearances were measured on a larger set of 36 vehicles (cars, light trucks, and vans) which represents the U.S. vehicle fleet. Based on these measurements, and on clearances measured under those impacts where HIC values were less than 1000 on the twelve-vehicle sample, it is concluded that with little or no additional research and development effort, head injury severity could be reduced in the U.S. by designing all vehicle hoods to have similar impact responses to those of the best performing production vehicles.

**BACKGROUND**

One of the most serious consequences of motor vehicle accidents involving pedestrians is head injury sustained by contact with vehicle hoods, fenders, cowls, and windshields [1][1]. Accordingly, the National Highway Traffic Safety Administration (NHTSA) is conducting research aimed at reducing injury severity from these collisions. This paper describes a test procedure which can be used for research purposes to evaluate regions of motor vehicle hoods in terms of their potential for causing pedestrian head injury [2]. NHTSA may consider using a procedure similar to the described one, in the event the agency decides to explore whether to develop and issue a rulemaking proposal relating to pedestrian head protection. The decision whether to issue a proposal will be made taking into consideration costs, benefits, and other impacts of the proposal, along with factors such as the reliability and validity of the test procedure.

The longitudinal distribution of head impacts over the front surfaces of vehicles was determined from cases contained in the Pedestrian Injury Causation Study (PICS). Figure 1 shows the cumulative frequency of "wrap-around distance" (WAD) for all PICS cases. Distribution is generally uniform from 40 to 90 inches. (WAD, defined in Reference 3, is measured from ground to head impact location, following the vehicle front contour.)

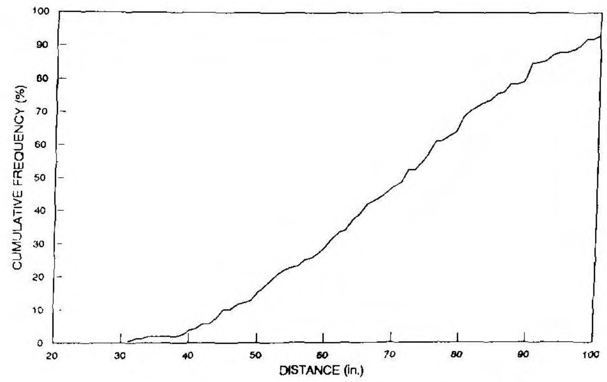



Fig. 1 -- Pedestrian Wrap-around Distance. Source: PICS, All Head and Face Injuries

Lateral distribution was estimated from a random sample of 100 PICS cases. Thirty-four percent of the head impacts occurred on either the right fender or the six-inch boundary along the right side of the hood. Only 14 percent were located on the corresponding region on the left side of the vehicle. The remaining 52 percent were uniformly distributed across the central region of the hood.

[1]Numbers in brackets indicate references.

An impact device capable of simulating pedestrian head impacts on vehicle surfaces was developed [4,5]. A HIC value of 1000, when used with this device, was verified as an accurate indicator of the threshold of serious head injury through experimental reconstruction of real pedestrian accident cases involving adults and children [6,7].

Head impact tests were conducted on hoods, fenders, and cowls of a representative sample of production vehicles [3,7,8]. Head impact velocities were chosen to simulate 30 mph vehicle-to-pedestrian collision speeds. Impacts on hood-fender seam and cowl regions produced predicted levels of severe-to-fatal injury for all the vehicles, indicating the need for additional injury mitigation research, which is under way. However, some of the vehicles yielded excellent results in hood central regions, primarily because of relatively light hood reinforcement structure and sufficient underhood clearance (approximately 2.5 inches or greater). It was concluded from the production vehicle testing that appreciable benefits would be possible over central hood regions having at least 2.5 inches of underhood clearance, by making impact responses of all vehicles as good as the best observed production cars.

This paper describes the development of a test procedure for addressing pedestrian head impacts against motor vehicle hood central regions. The test procedure was applied to a representative sample of nine production cars and three light trucks, and the results are presented and discussed. Results of underhood clearance measurements on a large number of production vehicles are also reported.

## IMPACT TEST ZONE

### Test Zone Boundaries

The boundaries of the impact test zone were determined from accident data analysis (which indicated how frequently head impacts occur in given areas) and from production vehicle test data (which identified those areas where some level of protection already exists on some vehicles).

Figure 1 shows that head impacts occur quite uniformly between WADs of 40 and 90 inches. Accordingly, the forward boundary of the impact test zone was set at the 40-inch WAD for passenger cars. This generally placed the forward boundary at least six inches behind the leading edge of the hood, where good results began to be observed on some of the production cars. For light trucks, the leading hood edge typically is configured differently than for cars. The hood edge is higher, contains relatively sharp curvature as the hood transitions from its essentially horizontal surface to a nearly vertical surface, and is considerably stiffer than the more nearly horizontal region. Therefore, to place the zone in an area where good results have been observed, the forward boundary was set along a line seven inches back from the leading edge of the hood or facia.

Setting the rear boundary at 90 inches would have placed the zone into the cowl or windshield for most vehicles, where good performance has not yet been demonstrated. Furthermore, impact tests conducted on rearmost hood surfaces typically produced much higher HIC values than occurred in hood central regions. This is illustrated in Figure 2, where HIC values are clearly higher within six inches of the rear edge of the hood. The rear boundary of the impact test zone, therefore, was located six inches forward of the rear hood edge, or at a WAD of 90 inches, whichever was the shorter WAD.

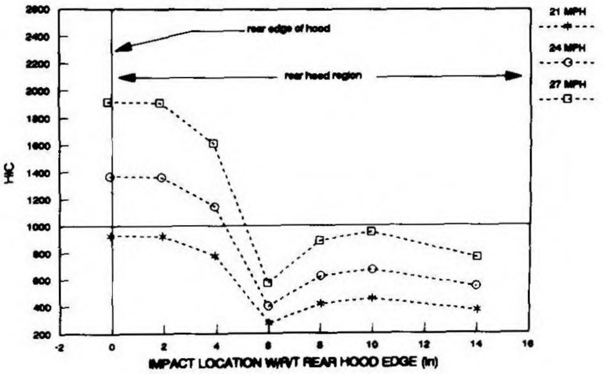



Fig. 2 -- HIC Versus Impact Location on Hood - 1985 Oldsmobile Cutlass Ciera

It was also observed that impacts within six inches of the side edges of hoods generally produced unacceptably high HIC values. Figure 3 shows the results of 35 impact tests conducted at 23 mph on an Oldsmobile Ciera hood. Although this hood performed well in the central region, with several HIC values in the 400s, most of the outermost impacts, which were located six inches from the hood edges, resulted in HICs greater than 1000. Consequently, the side boundaries of the impact test zone were located six inches from the hood side edges. As stated earlier, more than half of pedestrian head impacts occur uniformly between the two side boundaries of the zone.

Figure 4 shows the impact test zone. For passenger cars, the front boundary is a curved line defined by measuring a 40-inch WAD at several locations across the width of the vehicle's front surface. For light trucks, the forward boundary is located seven inches behind the leading hood or facia edge. The rear boundary is a curve parallel to the front boundary, passing through the point on the centerline of the hood which is either six inches forward of the hood's rear edge or at a WAD of 90 inches, whichever is the shorter WAD.

Production car testing indicated that, in general, the hood area (and substructure less than 2.5 inches below the hood) within a 6 to 8 inch radius of the impact location influences the headform response. Further experimentation showed that a test scheme using between 10 and 15 impacts could be distributed across the impact test zone and enable the impacts to be 12 to 16 inches apart, depending on the size of the vehicle. This allowed

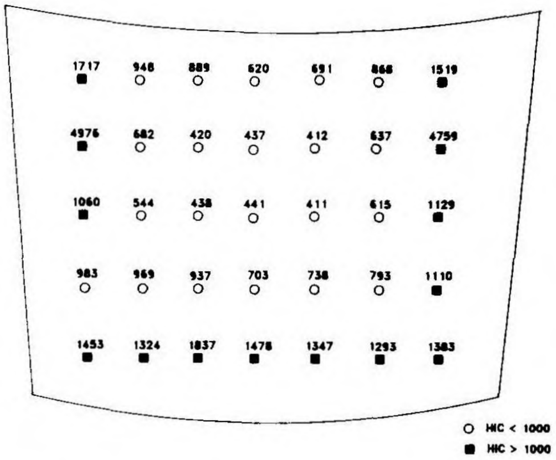



Fig. 3 -- HIC Values From Tests on 1985 Oldsmobile Ciera, 23 mph

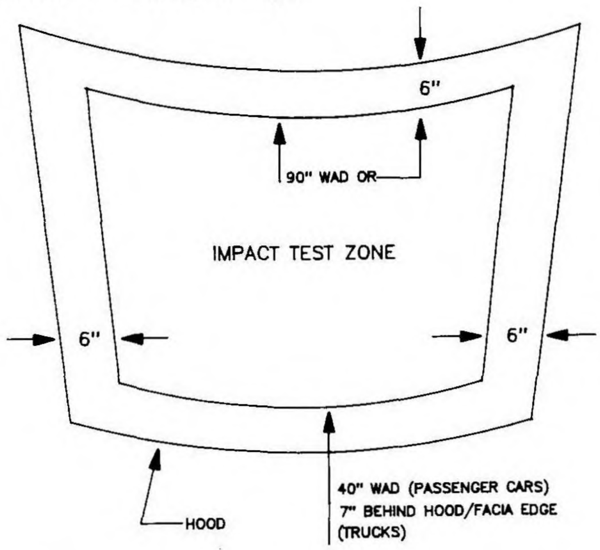



Fig. 4 -- Impact Test Zone

**Impact Test Locations**

reasonably full and uniform coverage of the zone, assuming the response from each impact represents an area with a 6 to 8 inch radius. Also, to provide reasonable assurance that protection extended to the boundaries of the zone, it was desired that tests be conducted close to, but not on, the boundaries.

Figure 5 shows the layout of impact test locations that was decided upon. Eleven equal spaces were measured along the hood's centerline, between front and rear boundaries of the zone. Curves parallel to the front and rear boundaries were then drawn through these points. Next, the front and rear boundaries each were divided into 14 equal spaces, and the points representing these spacings were connected by straight lines, defining the grid as shown. Fourteen impact locations were placed at grid intersections as shown in Figure 5, forming four staggered rows in a 3-4-3-4 pattern, front to rear, across the zone. Appropriate grid intersection points have been connected to form hexagons, approximating circular areas surrounding

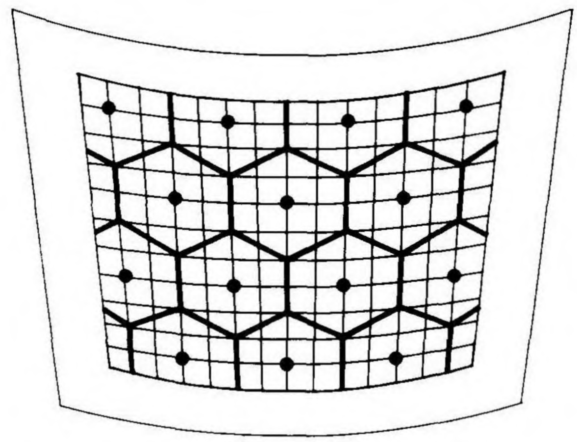


Fig. 5 -- Impact Test Grid and Locations

each impact point, to illustrate that this matrix of impact points, although somewhat arbitrary, fulfills the desired objectives of providing uniform coverage over the entire impact test zone.

Examples of this test pattern are shown in Figures 6 (passenger car) and 7 (light truck). The measurement procedure has been applied to a large number of vehicles, representing a variety of sizes and styles, and appears easy and straightforward to perform.

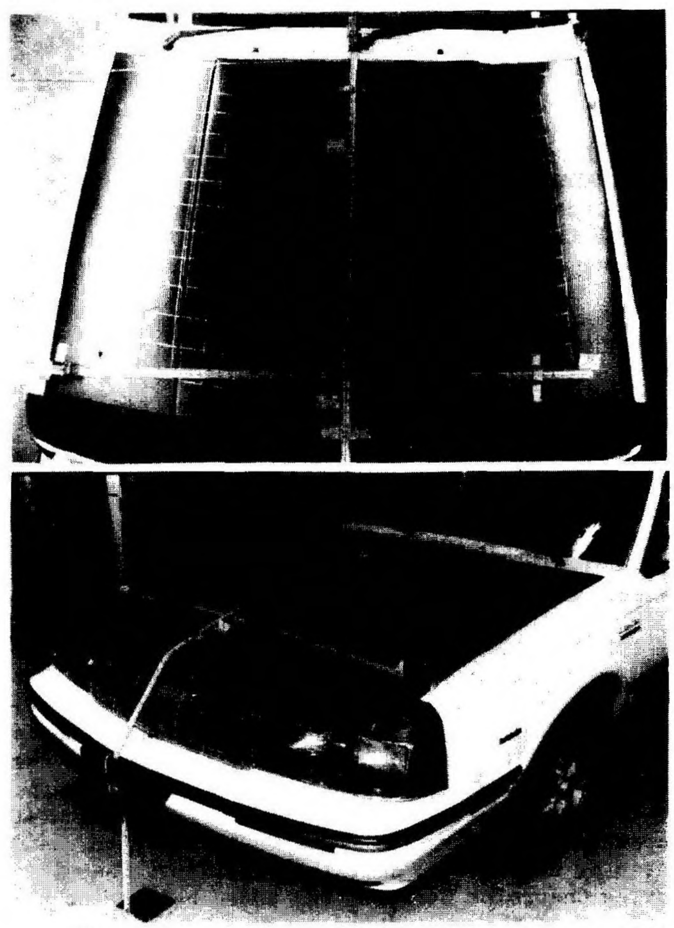


Fig. 6 -- Impact Test Pattern on 1985 Oldsmobile Ciera

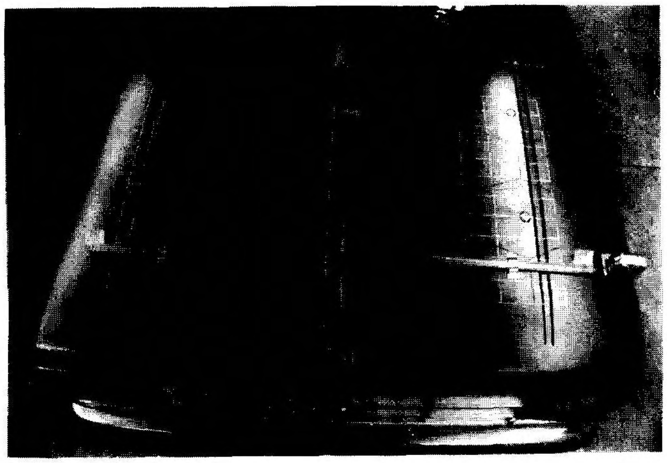


Fig. 7 -- Impact Test Pattern on 1990 Ford Ranger

By making the following assumption and approximation, the percent of the impact test zone area over which HIC does not exceed 1000 can be determined:

1) Assumption: The HIC value for a particular impact is representative of the HIC values which would be measured over the entire area encompassed by the hexagon around that impact point.

2) Approximation: Each impact point is representative of impacts over an area which is one-fourteenth the area of the total impact test zone.

Thus, if seven of the fourteen tests result in HICs below 1000, it is assumed that 50 percent of the impact test zone would produce HICs below 1000; if eight HICs below 1000 are obtained, 57 percent of the zone would result in HICs under 1000; and so on.

## IMPACT TEST DEMONSTRATION

The head impact test procedure was applied to a sub-set of nine passenger cars and three light trucks in order to establish its viability and determine what percent of the impact test zone produces HIC values of less than 1000 on current production vehicles.

### Vehicle Selection

Eleven of the twelve test vehicles were chosen from a representative sample of 36 vehicles (27 passenger cars, six light trucks, and three vans) used in a study of pedestrian head impact zones [7,9]. The 36-vehicle sample was selected on the basis of 1987 sales figures, and represented the U.S. vehicle fleet in terms of manufacturer representation, vehicle size distribution, and ratio of domestic to imported vehicles. The ninth car, a Chevrolet Corsica, was added because of the 1988 sales figures posted by the Beretta/Corsica models (over 400,000 units sold), and its contemporary sloping hood design.

### Test Procedure

Impact test grids were laid out on the vehicle hoods as previously described. For each vehicle, fourteen impact tests were conducted nominally at 23 mph (simulating a vehicle-to-pedestrian collision speed of 25 mph) normal to the hood at the point of impact. Impact speed was controlled to 23 ± 0.4 mph. Before HIC was computed, the impactor acceleration-time response was normalized to exactly 23.0 mph by multiplying the acceleration magnitude by the ratio, 23.0/measured velocity. Dynamic displacement of the impactor was measured with a linear potentiometer. Hoods were examined after each test; if excessively damaged, they were replaced with new hoods. Typically, two tests per hood were conducted.

Figure 8 shows pre- and post-test photographs for an impact on the Nissan Sentra hood. Hood damage is extensive, giving evidence of the test severity. This test provided "good" results: approximately 3 inches of dynamic deflection, and a HIC value of 516.

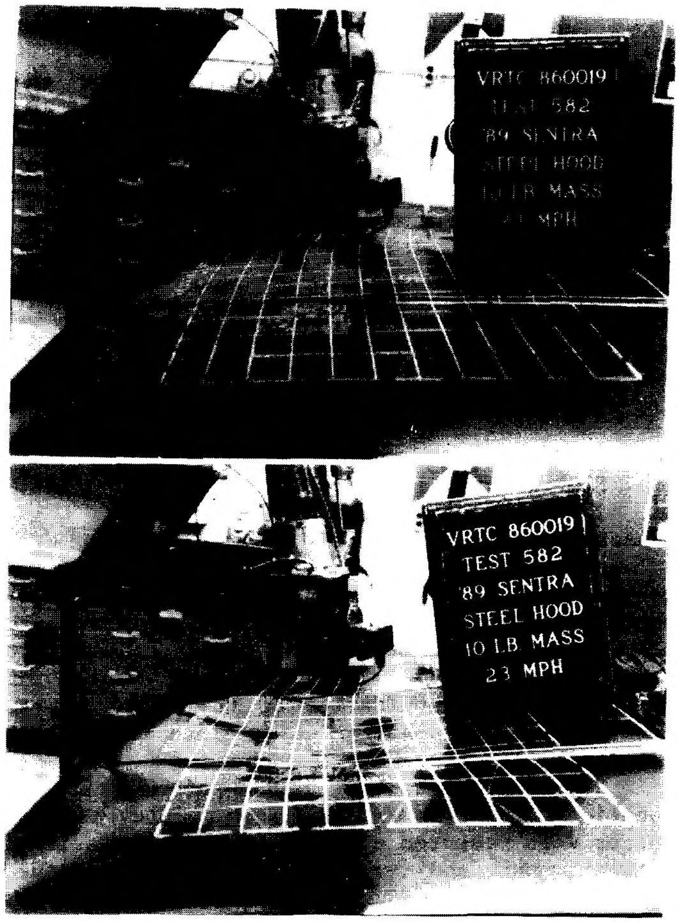
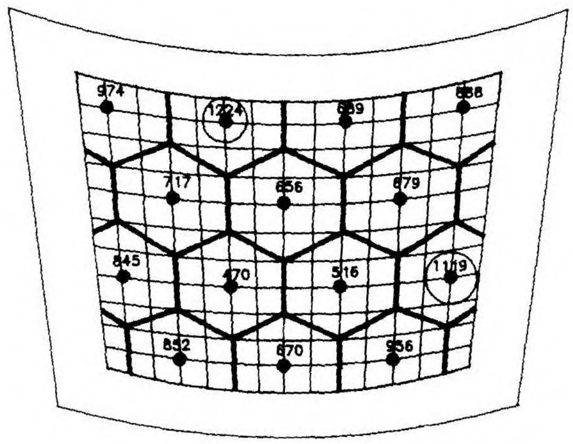



Fig. 8 -- Pre- and Post-Test Views - Nissan Sentra Hood

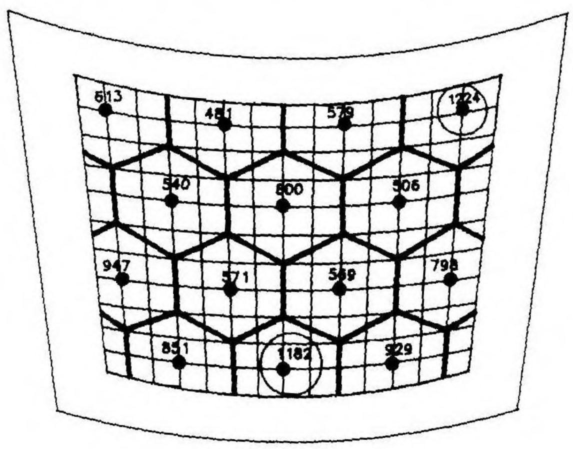
### Test Results

All of the test results are presented in Figures 9-20. For each vehicle, the number of tests yielding HIC values below 1000 was divided by the total number of tests (14) to produce an estimate of the percentage of the impact test zone



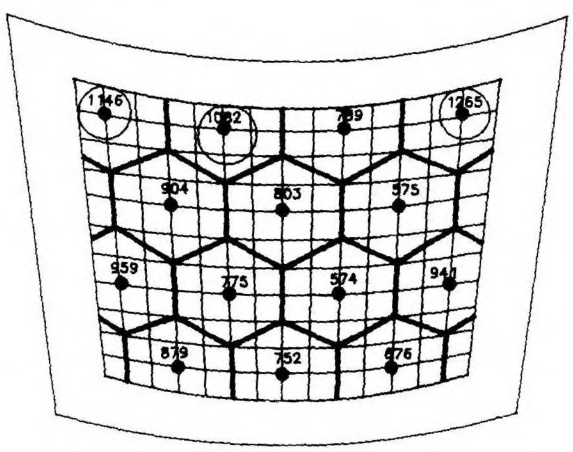

HIC < 1000 PERCENTAGE = 86%

Fig. 9 -- Impact Test Results - 1989 Nissan Sentra



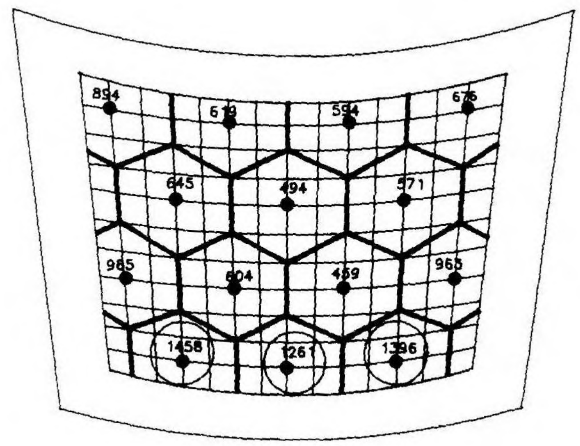

HIC < 1000 PERCENTAGE = 86%

Fig. 10 -- Impact Test Results - 1986 Toyota Pickup



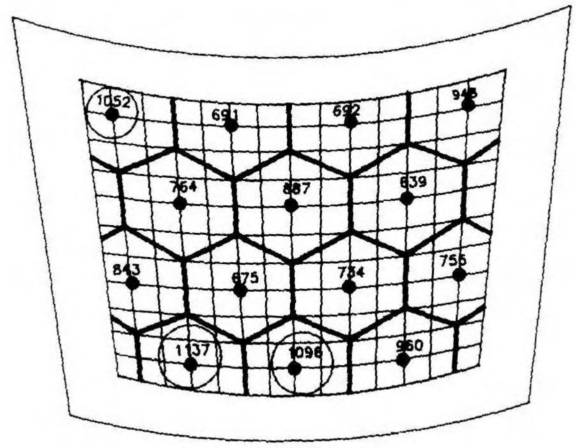

HIC < 1000 PERCENTAGE = 79%

Fig. 11 -- Impact Test Results - 1989 Ford Escort



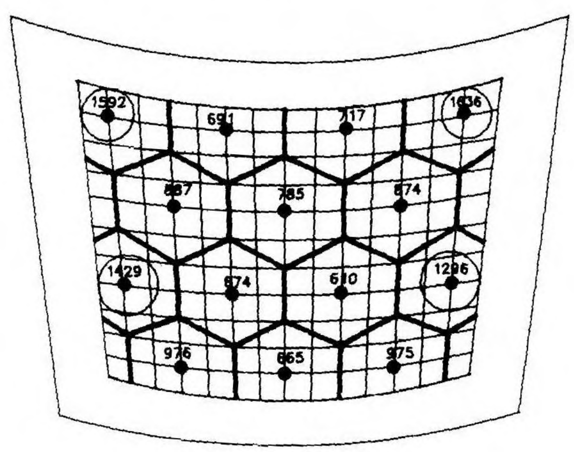

HIC < 1000 PERCENTAGE = 79%

Fig. 12 -- Impact Test Results - 1990 Ford Ranger Pickup



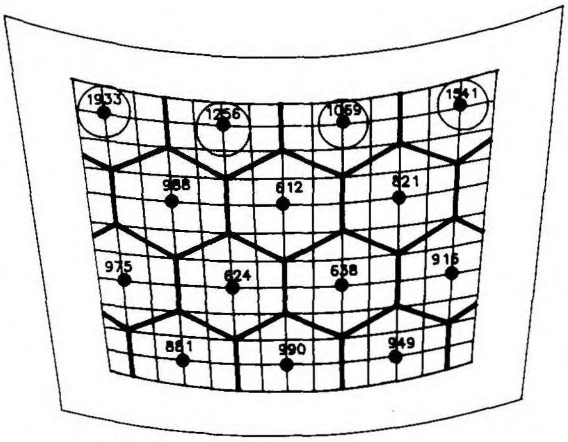

HIC < 1000 PERCENTAGE = 79%

Fig. 13 -- Impact Test Results - 1989 GMC Sierra Pickup (Full-size)



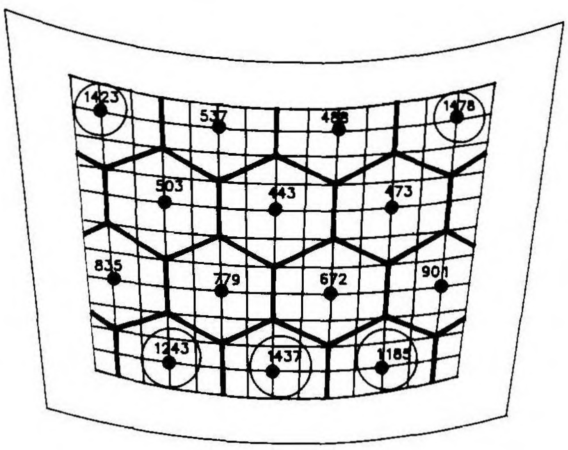

HIC < 1000 PERCENTAGE = 71%

Fig. 14 -- Impact Test Results - 1989 Ford Taurus



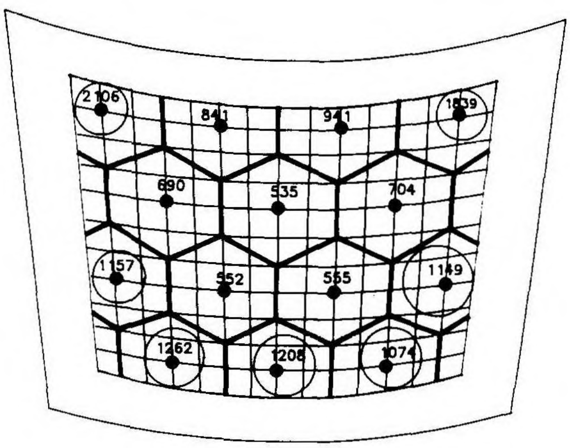

HIC < 1000 PERCENTAGE = 71%

Fig. 15 -- Impact Test Results - 1989 Plymouth Reliant



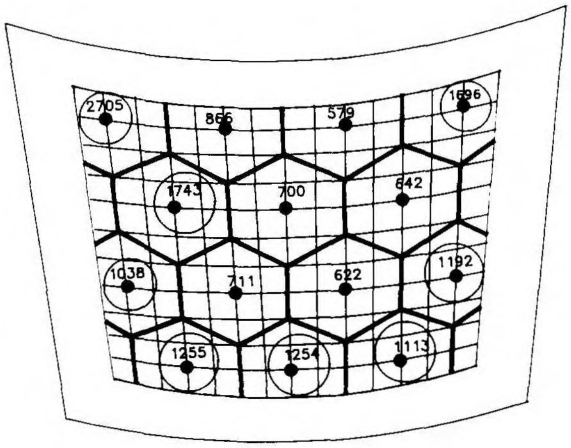

HIC < 1000 PERCENTAGE = 64%

Fig. 16 -- Impact Test Results - 1989 Oldsmobile Ciera



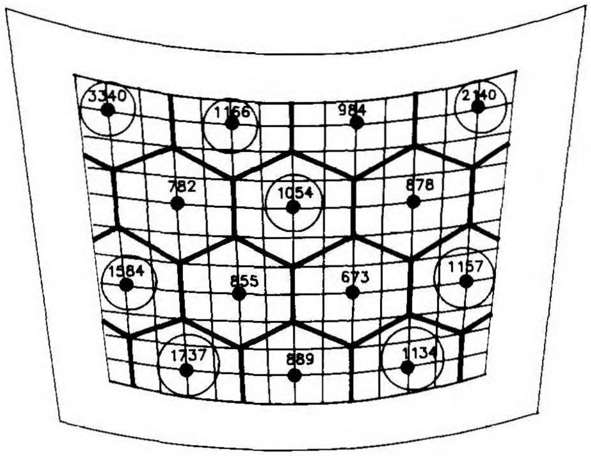

HIC < 1000 PERCENTAGE = 50%

Fig. 17 -- Impact Test Results - 1989 Buick LeSabre



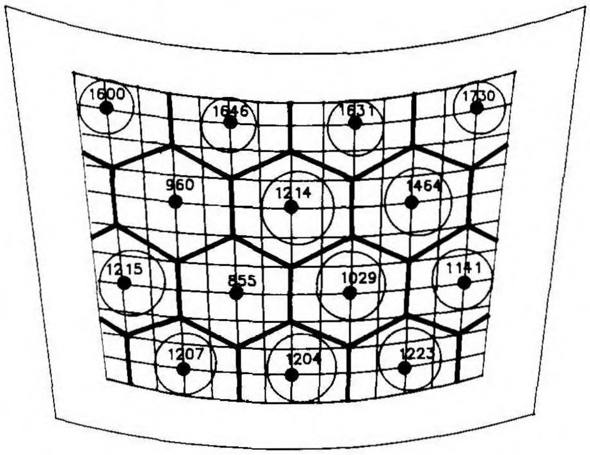

HIC < 1000 PERCENTAGE = 43%

Fig. 18 -- Impact Test Results - 1988 Chevrolet Celebrity




HIC < 1000 PERCENTAGE = 43%

Fig. 19 -- Impact Test Results - 1989 Chevrolet Corsica




HIC < 1000 PERCENTAGE = 14%

Fig. 20 -- Impact Test Results - 1989 Hyundai Excel

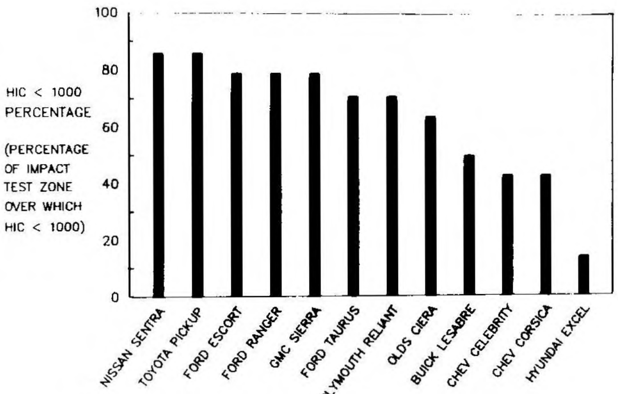



Fig. 21 -- Impact Test "HIC" < 1000 Percentages" - Nine-car and Three-truck Test Sample

area over which HIC < 1000. These percentages appear on the figures, and are presented in the bar chart of Figure 21. Large variation occurred among the vehicles; "HIC < 1000 percentages" ranged from 86 percent to 14 percent.

In general, HIC values exceeding 1000 were not excessively high. Only 17 of the 168 tests (10 percent) produced HICs exceeding 1500. All of them were on passenger cars; 12 were located in the rear corners of the impact test zones, and probably occurred from suspension system tower contact. Similarly, many of the sub-1000 HIC values were just barely below 1000, especially for the cars. For example, each of the four best performing cars had four to six impacts which produced HIC values between 850 and 990; thus, the "good performance" demonstrated by each of these four cars was achieved by a rather narrow margin.

Figure 22 presents a summary of tests on all nine cars, showing locations where HICs exceeded, or were less than, 1000. Only one car produced a HIC < 1000 in each rear corner of the impact test zone (designated by the circled ratio, 1/8), but most of the cars performed well in the central region of the zone (where ratios are enclosed in rectangles). Along the front of the zone and the forward part of the sides of the zone, chances for exceeding HIC of 1000 were approximately 50 percent. A similar presentation for the three light trucks is contained in Figure 23. HICs were generally lower in the rear corners of the zone due to the absence of suspension towers, but were somewhat higher at the front edge of the zone.

Production vehicle test results [3,7,8] have shown that a strong relationship exists between injury prediction (HIC) and dynamic deflection of the impacted vehicle surface. That relationship is apparent in these test results also, as is shown in Figure 24. An exponential curve fits the data well, producing a coefficient of determination, R-squared, of 0.83. The curve crosses the HIC = 1000 line at a dynamic deflection value of 2.3 inches, suggesting that, on average, HIC values below 1000 can be obtained when as few as 2.3 inches of stroking distance under the hood are available. In the next section, this information will be used with underhood clearance measurements to illustrate the potential for improved protection in the U.S. vehicle fleet.

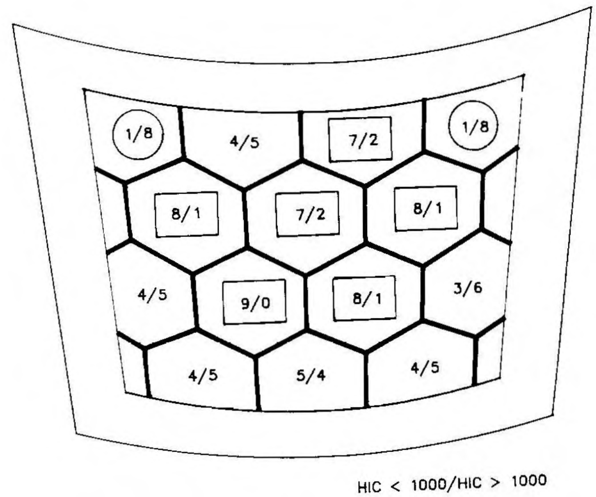



Fig. 22 -- Summary of Tests on Nine Cars, Showing Locations Where HIC < 1000 and HIC > 1000

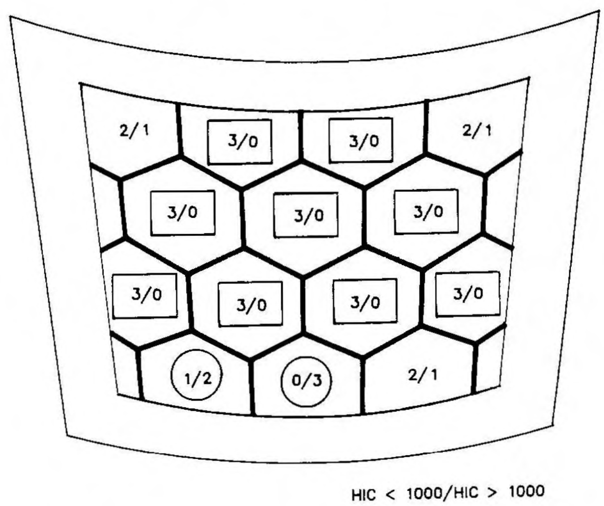



Fig. 23 -- Summary of Tests on Three Trucks, Showing Locations Where HIC < 1000 and HIC > 1000

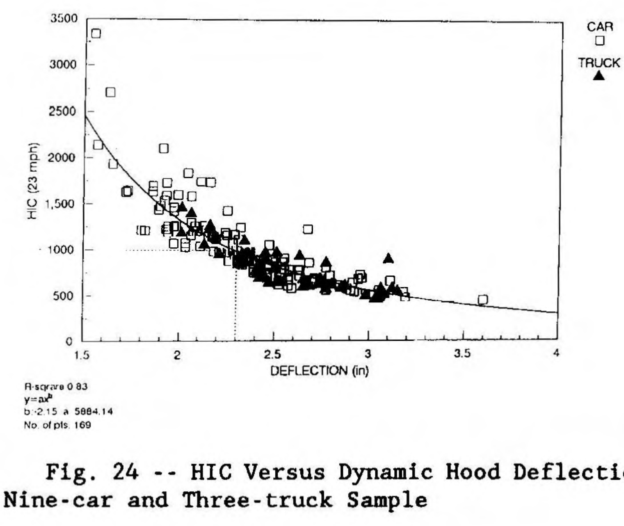



Fig. 24 -- HIC Versus Dynamic Hood Deflection - Nine-car and Three-truck Sample

## UNDERHOOD CLEARANCE MEASUREMENTS

At a pedestrian head-to-hood impact site, the amount of clearance between the underside of the hood and hard engine compartment substructure is very important in determining how much protection is possible. In order to estimate percentages of impact test zone areas over which HIC responses of less than 1000 are possible, underhood clearances of a representative sample of 36 late model passenger cars, light trucks, and vans were measured.

### Vehicle Selection

The vehicles measured were identical to the set of vehicles referred to previously (and described in References 7 and 9), except that the Chevrolet Corsica and Geo Prizm replaced the Chevrolet Nova and Yugo.

### Measurement Technique

A grid of two-inch by two-inch squares was laid out on the hood surface of each vehicle. At the center of each square the vertical distance from the underside of the hood to the nearest hard structure was measured. Longitudinal and lateral distances between measurement points were measured in a horizontal plane. This procedure produced a three-dimensional coordinate system (x,y,z), illustrated in Figure 25. For vans, whose hood surfaces generally were not close to horizontal, the x-y plane was established to be approximately parallel to the hood, and underhood distances were measured normal to this plane (approximately normal to the hood surface) rather than vertically. If hood reinforcement structure lay beneath a data point, its depth was subtracted from the underhood distance (hood underside to nearest hard structure).

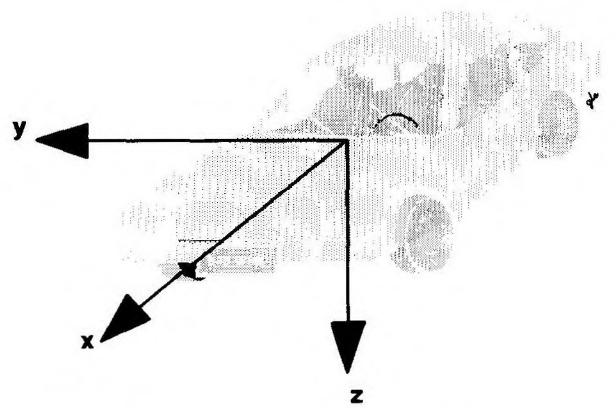



Fig. 25 -- Coordinate System Used for Underhood Clearance Measurements

The equipment used in this study is shown in Figure 26. Coordinates in the x direction were recorded manually and coordinates in the y and z directions were recorded automatically by an ITEK digital measuring device. All data were then

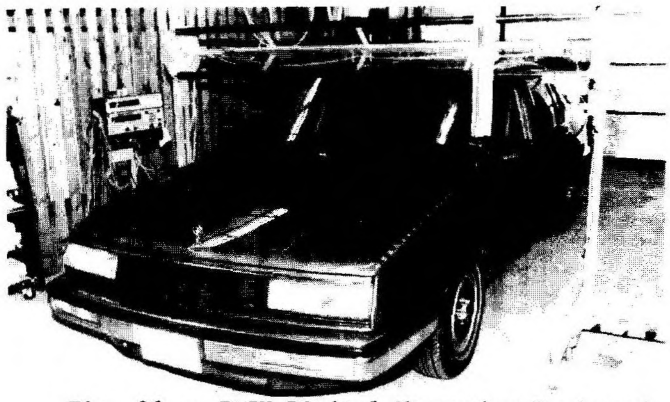


Fig. 26 -- ITEK Digital Measuring Equipment

stored on a computer disk for use in subsequent data processing. Two sets of measurements were made, one with the hood in place, and the other with the hood removed. Each pair of measurements had identical x and y coordinates and the difference between the z coordinates was recorded. Hood reinforcement locations were noted and coded, and the depth of the reinforcement was subtracted from the z coordinate difference to produce the clearance distance.

### Measurement Results

Percentages of hood impact test zones under which clearances were 2.3 inches or greater are presented in Table 1. The value of 2.3 inches was chosen because, as was shown in Figure 24, average HIC values of 1000 or less were obtained in the demonstration tests when deflections were 2.3 inches or greater. On average, 73.9 percent of the impact test zones of the passenger cars had underhood clearances exceeding 2.3 inches. For the light trucks and vans, the average was close to 90 percent. Averages for the nine cars and three trucks used in the demonstration tests were very similar to those in the larger samples.

In Figure 27, the 2.3-inch clearance percentages for the twelve demonstration test vehicles are plotted along with percentages over which HIC < 1000 (shown in Figure 21). The four best performing cars (Sentra, Escort, Taurus, and Reliant) and the three trucks used available underhood clearance effectively, as evidenced by the fact that percentages over which HIC < 1000 generally agreed with, or exceeded, clearance percentages. (The Escort result, where the "HIC < 1000" percentage exceeded the clearance percentage, seems anomalous. However, five impacts produced HIC values from 876 to 959, barely under 1000, with corresponding deflections between 2.2 and 2.6 inches. If three of these tests had produced HICs over 1000, the two percentages would have agreed closely.) The remaining five cars had clearance percentages generally as high as the better performers. This suggests that their poorer performance was not the result of lack of underhood clearance, but was due to poorer impact response of the hoods themselves. In particular, the Hyundai Excel has a very heavy hood reinforcement, which likely is responsible for its inferior performance.

TABLE 1 -- Underhood Clearance Measurement Results

| MAKE | MODEL | % OF IMPACT TEST ZONE UNDER WHICH CLEARANCE IS 2.3" OR GREATER |
|---|---|---|
| ACURA | INTEGRA | 57.5 |
| BUICK | CENTURY | 91.4 |
| BUICK | LESABRE * | 79.1 |
| CADILLAC | SEDAN DEVILE | 70.8 |
| CHEVROLET | CAPRICE | 77.1 |
| CHEVROLET | CAVALIER | 72.1 |
| CHEVROLET | CELEBRITY * | 66.9 |
| CHEVROLET | FULL-SIZED PICKUP* | 94.6 |
| CHEVROLET | S-10 | 92.3 |
| CHRYSLER | LEBARON J | 73.3 |
| DODGE | CARAVAN | 100.0 |
| DODGE | SHADOW | 68.9 |
| FORD | AEROSTAR | 81.7 |
| FORD | ESCORT * | 59.9 |
| FORD | FULL-SIZED VAN | 81.4 |
| FORD | F-SERIES | 99.8 |
| FORD | RANGER* | 77.3 |
| FORD | TAURUS * | 76.7 |
| FORD | TEMPO | 60.8 |
| HONDA | ACCORD | 72.8 |
| HYUNDAI | EXCEL * | 67.4 |
| JEEP | CHEROKEE | 77.3 |
| LINCOLN | TOWN | 85.5 |
| MAZDA | 323 | 84.6 |
| MERCURY | COUGAR | 57.5 |
| MERCURY | GRAND MARQUIS | 76.0 |
| NISSAN | SENTRA * | 86.0 |
| OLDSMOBILE | CUTLASS CIERA * | 89.0 |
| OLDSMOBILE | DELTA 88 | 83.6 |
| PLYMOUTH | RELIANT * | 77.1 |
| PONTIAC | 6000 | 81.5 |
| PONTIAC | GRAND AM | 72.2 |
| TOYOTA | CAMRY | 78.0 |
| TOYOTA | PICKUP* | 91.6 |
| CHEVROLET | CORSICA * | 58.0 |
| CHEVROLET | GEO PRIZM | 70.8 |

* VEHICLES USED FOR TWELVE-VEHICLE IMPACT TEST SAMPLE

| | | AVERAGES | |
|---|---|---|---|
| ALL PASSENGER CARS | - | 73.9% | (n=27) |
| NINE-CAR IMPACT TEST SAMPLE | - | 73.3% | |
| ALL LIGHT TRUCKS (1) | - | 88.8% | (n=6) |
| THREE-TRUCK IMPACT TEST SAMPLE | - | 87.8% | |
| VANS | - | 87.7% | (n=3) |

(1) INCLUDES JEEP CHEROKEE

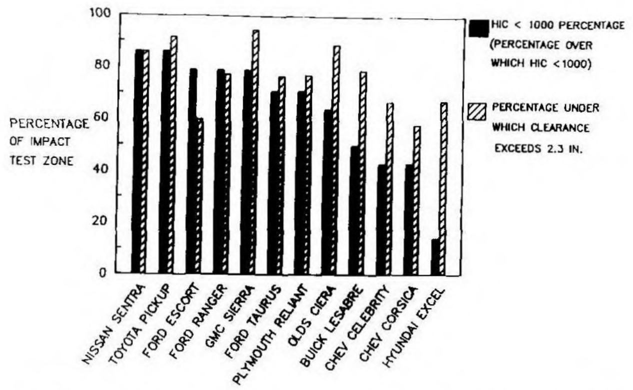



Fig. 27 -- Impact Test "HIC" < 1000 Percentages" and Under Hood Clearance -- Nine-car and Three-truck Test Sample

## CONCLUSIONS

The test procedure described in this paper can be used to evaluate central regions of automobile and light truck hoods in terms of their potential for causing pedestrian head impact injury.

Some production vehicles provide good pedestrian head protection in central hood regions. Reduction in pedestrian head injury severity in the U.S. may be possible with little or no additional research and development effort, by designing central hood impact responses for all vehicles to be similar to those of the best performing production vehicles.

## REFERENCES

1. MacLaughlin, T.F., Hoyt, T.A., and Chu, S., "NHTSA's Advanced Pedestrian Protection Program," 11th International Technical Conference on Experimental Safety Vehicles, Washington, D.C., May 1987.

2. MacLaughlin, T. F., and Kessler, J. W., "Development and Assessment of a Test Procedure for Pedestrian Head Impact Against Central Hoods," NHTSA Final Report, to be published.

3. Kessler, J. W., "Development of Countermeasures to Reduce Pedestrian Head Injury," 11th International Technical Conference on Experimental Safety Vehicles, Washington, D.C., May 1987.

4. Pritz, H.B., "Experimental Investigation of Pedestrian Head Impacts on Hoods and Fenders of Production Vehicles," SAE Paper No. 830055, February 1983.

5. Brooks, D., L., Collins, J., A., and Guenther, D., A., "Experimental Reconstructions of Real World Pedestrian Head Impacts," Final Report for DOT/NHTSA Basic Agreement No. DTNH22-83-A-072779, VRTC Task Order No. OSU-84-4059, College of Engineering, The Ohio State University, Columbus, Ohio, March 1985.

6. Hoyt, T. A., MacLaughlin, T. F., and Kessler, J., W., "Experimental Pedestrian Accident Reconstructions -- Head Impacts," Final Report No. DOT HS 807 288, NHTSA, June 1988

7. Kessler, J. W., and Monk, M. W., "NHTSA Pedestrian Head Injury Mitigation Research Program -- Status Report," 12th International Technical Conference on Experimental Safety Vehicles, Goteborg, Sweden, May 1989.

8. Kessler, J. W., Hoyt, T. A., and Monk, M. W., "Pedestrian Head Injury Reduction concepts," Final Report No. DOT HS 807 432, NHTSA, June 1988.

9. Kessler, J. W., Stoltzfus, D., and Monk, M. W., "Pedestrian Head Impact Zones on Late Model Cars and LTVs, "Interim Report No. DOT HS 807 477, NHTSA, August 1989.

10. "Scaling Pedestrian Head Injury for Changes in Impact Velocity," Progress Report, Project VRTC-86-0019, Vehicle Research and Test Center, November 1988.