SAFETY APPURTENANCE DESIGN AND VEHICLE CHARACTERISTICS

Barry D. Stephens
Energy Absorption Systems, Inc.

INTRODUCTION

Energy Absorption Systems, Inc., (EASI) has been designing, testing and manufacturing highway safety appurtenances for over 25 years. The purpose of this discussion is to present some of the observed vehicle characteristics that can directly influence crash test results, especially as they relate to the recent adoption of NCHRP Report 350 testing guidelines versus the previous NCHRP Report 230 guidelines. This 20-minute presentation was originally given at the April 12, 1995, SAE session in Washington, D.C., titled "Roadside Hardware Design Issues and Vehicle Interactions." Specific areas that will be reviewed include

1. Front bumper reinforcement differences between various types of 3/4-ton pickups.
2. Front suspension differences between various types of 3/4-ton pickups.
3. Center-of-gravity location differences between various types of 3/4-ton pickups.
4. Frontal crush differences between 4500S and 2000P vehicles.
5. Bumper height differences between various vehicles.
6. Hood retention characteristics of light-weight vehicles.

NCHRP Report 350 is a comprehensive set of updated procedures for crash testing highway safety appurtenances. Report 350 differs from Report 230 in that it specifies the use of 3/4-ton pickup trucks as the standard passenger vehicle in place of the 4500-lb passenger car. This reflects the fact that almost one-quarter of the passenger vehicles on U.S. roads are in the "light truck" category. "This change was made recognizing the differences in wheel bases, bumper heights, body stiffness and structure, front overhang, and other vehicular design factors."*(1)*

EASI has conducted numerous crash tests using 3/4-ton pickups impacting various types of highway safety hardware at Test Level 3 conditions (100 km/h).

The first three topics detailed below are the result of a comparative evaluation of various types of 3/4-ton pickups.

FRONT BUMPER REINFORCEMENT

The first noteworthy variation between different types of 3/4-ton pickups is the difference in front bumper

FIGURE 1 1990 Ford F250 front bumper reinforcement.

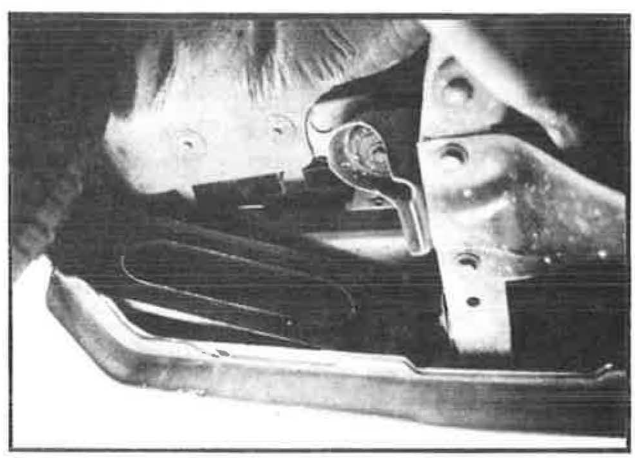


FIGURE 2 1990 Ford F250 front bumper reinforcement.

FIGURE 3 1989 Chevrolet 2500 front bumper reinforcement.

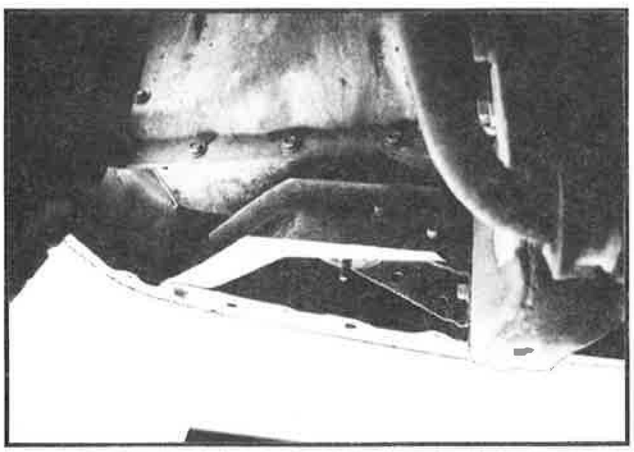


FIGURE 4 1989 Chevrolet 2500 front bumper reinforcement.

reinforcement, depicted in Figures 1, 2, 3, and 4. In this example, a comparison is made between the Ford F250 and the Chevrolet 2500. Both types of front bumpers are equipped with reinforcing braces. The Chevrolet 2500's lateral brace ties into the side of the truck frame. The Ford's reinforcing braces tie back into the bumper itself. The Chevrolet design is inherently stronger due to the triangulation of the bumper, bracket, and truck frame. The Chevrolet's bumper appears to offer more protection for the front wheel of the vehicle. Vehicles with better lateral bracing of the front bumper experience less front wheel snagging during offset and angled impacts.

FIGURE 5 1990 Ford F250 front suspension.

FIGURE 6 1990 Ford F250 front suspension.

FRONT SUSPENSION

The second variation between different types of 3/4-ton pickups is the differences in front wheel suspensions,

FIGURE 7 1989 Chevrolet 2500 front suspension.

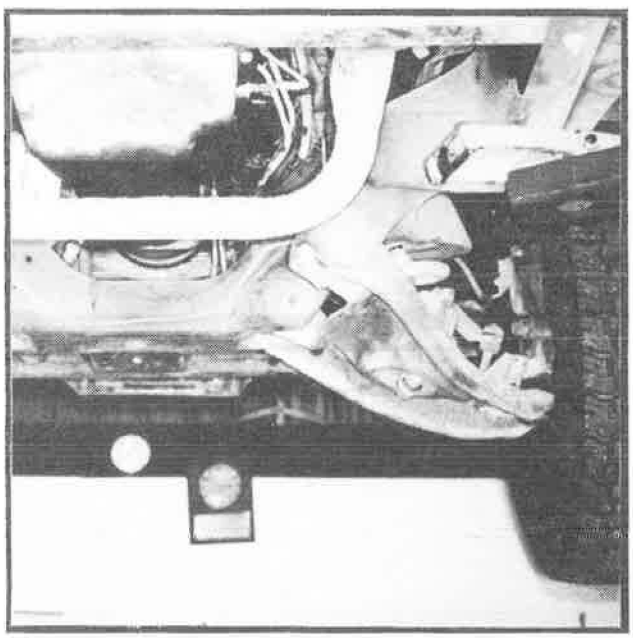


FIGURE 8 1989 Chevrolet 2500 front suspension.

depicted in Figures 5, 6, 7, and 8. In this example, a comparison is made between "I-beam" and "Wish-bone" suspensions. Experience has shown that when the "I-beam" suspension's vertical strut fails during severe front-angled impacts, upward loading can be imparted into the truck through the still-connected "I-beam," creating a potential upward loading condition. When the "Wish-bone" suspension fails, it typically fails in a horizontal plane, which reduces the likelihood of upward loading on the truck. These failure modes are presented graphically in Figures 9, 10, 11, and 12. Thus, during severe lateral or angular nose impacts that cause suspension failure, pickups with "I-beam" suspensions may experience a higher tendency to climb or ramp than the pickups equipped with "Wish-bone" suspensions.

CENTER-OF-GRAVITY LOCATION

The third variation between different types of 3/4-ton pickups is the general location of the center of gravity (CG) above the ground and from the front of the vehicle. The actual CG location varies from vehicle to vehicle depending on model, wheel diameter, gas tank fill level, etc. In this example, a comparison is made between the Ford F250 and the Chevrolet 2500*(2)*. Typically, Ford F250s have CG locations that average up to 6.4 cm (2.5 in) higher than the Chevrolet 2500s. The Ford F250s also have CGs that are located up to 17 cm (6.7 in) closer to the front bumper than the Chevrolet 2500s. This information is shown graphically in Figure 13.

A vehicle's CG location affects how it interacts with highway safety hardware. Vehicles with higher CGs have a greater tendency to ramp over some highway appurtenances, especially during frontal impacts. Also, if vehicle rolling is induced during the impact, higher CG vehicles have a greater tendency to roll over.

Vehicles that have CGs located closer to the front have a greater tendency to counter rotate instead of being smoothly redirected during lateral impacts into longitudinal barrier, see Figures 14 and 15. The logic behind this is depicted graphically in the free-body diagram shown in Figure 16. As the CG location moves rearward, the "redirection moment arm" increases which increases the likelihood of smooth redirection. Thus, vehicles with CGs located further back on the vehicle have a higher chance of being smoothly redirected.

FRONTAL CRUSH DIFFERENCES BETWEEN 4500S AND 2000P VEHICLES

As stated earlier, NCHRP Report 350 differs from Report 230 in that it specifies the use of 3/4-ton pickup trucks (2000P) as the standard passenger vehicle in place of the 4500-lb passenger car (4500S). In the past, highway safety hardware designers could rely on the front end crush of the 4500S car to safely dissipate

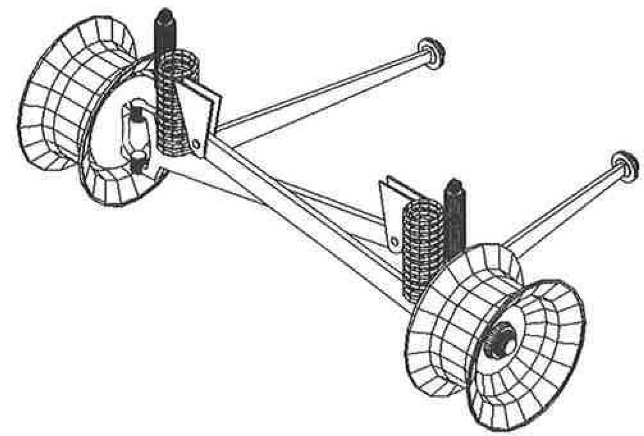


FIGURE 9 Ford F250 dual I-beam suspension.

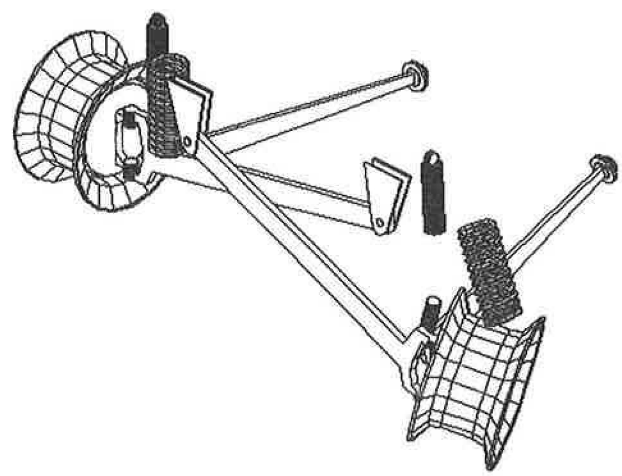


FIGURE 10 Ford F250 dual I-beam suspension failure.

approximately 5% of the vehicle's kinetic energy. Using the crush of the 4500S vehicle plus the stroke of the attenuator, a designer could design the shortest practical system to meet the occupant risk criteria recommended by NCHRP 230. The front ends of 2000P vehicles are much stiffer and do not have as much overhang as the 4500S cars. Thus, they do not have the ability to safely absorb as much kinetic energy. Consequently, to meet the new NCHRP 350 standards, attenuators will need to be made longer or collapse more efficiently to dissipate the extra energy not safely absorbed by the crush of the 2000P vehicle. The variations in the front end crush between the 4500S and the 2000P vehicles can be seen in Figures 17 and 18.

BUMPER HEIGHT DIFFERENCES BETWEEN VARIOUS VEHICLES

Figures 19 and 20 represent a picture study of typical vehicles placed immediately in front of typical highway appurtenances. The depicted vehicles include a 1988 Ford Festiva, a 1990 Ford F250 pickup, a 1994 Dodge Intrepid, and a 1991 Dodge Stealth. The highway appurtenance shown in Figure 19 is a cut away of a typical 320 kg (700 lb) inertial barrel showing the proper fill height for the sand. The highway appurtenance shown in Figure 20 is a typical guardrail end terminal.

The conclusion that can be drawn from Figures 19 and 20 is that highway appurtenance designers must

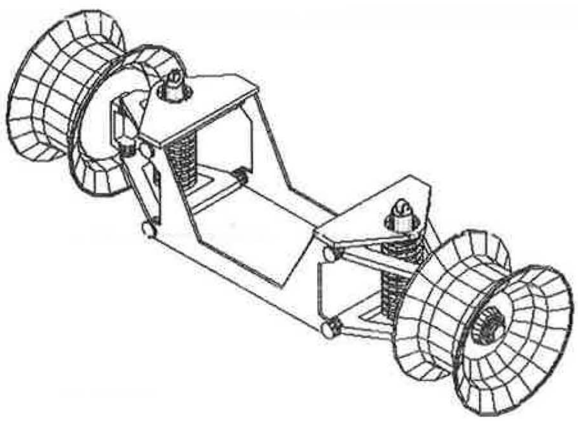


FIGURE 11 1989 Chevrolet 2500 suspension.

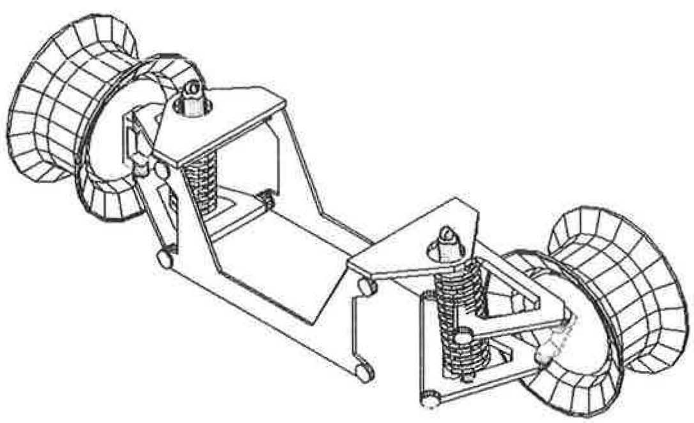


FIGURE 12 1989 Chevrolet 2500 suspension failure.

optimize their designs to accommodate a wide range of front bumper heights as well as vehicle shapes. The height of the front bumpers, measured to the center, ranges from 41.9 cm (16.5 in) for the Intrepid to 65.4 cm (25.75 in) for the Ford F250. Vehicles with low bumper heights combined with the currently popular aerodynamic wedge shape have a greater tendency to "nose dive" under some devices. "Nose-diving" can lead to possible windshield penetration and, because the safety device's energy dissipation capabilities are not efficiently utilized, the vehicle may impact the hazard at a higher-than-normal rate of speed. Vehicles designed to have high ground clearance combined with high front bumpers have a greater tendency to ramp. A ramping vehicle will not be decelerated efficiently by highway appurtenances, which can result in possible high-speed impacts into the hazard. Vehicle trajectory can also be a problem.

HOOD RETENTION CHARACTERISTICS OF LIGHT-WEIGHT VEHICLES

NCHRP Report 350 includes a set of safety criteria to evaluate the relative performance of highway safety hardware. The three primary evaluation criteria include 1) structural adequacy, 2) occupant risk, and 3) post impact response. A subset to the occupant risk criteria is listed as follows:

"Detached elements, fragments or other debris from the test article, or *vehicular* damage should

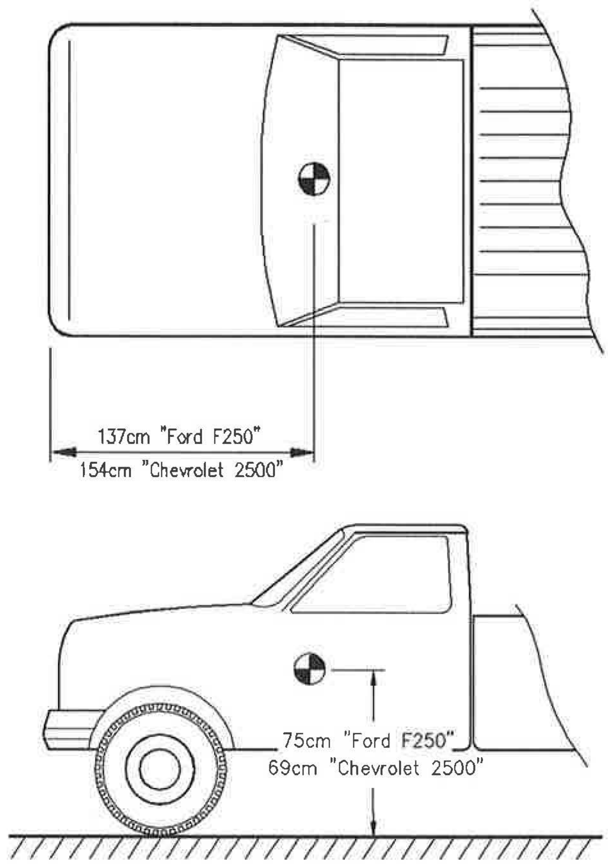


FIGURE 13 Ford F250 versus Chevrolet 2500 center of gravity location.

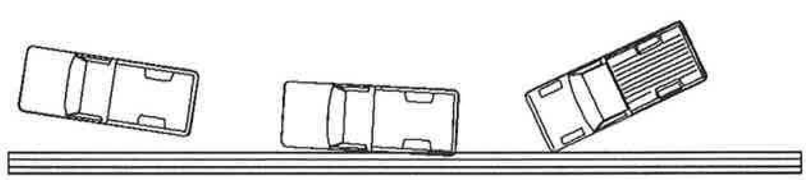


FIGURE 14 Lateral impact into longitudinal barrier with "smooth redirection."

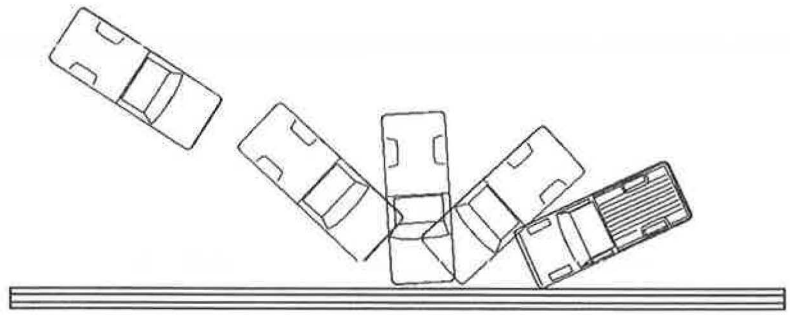


FIGURE 15 Lateral impact into longitudinal barrier with "counter rotation."

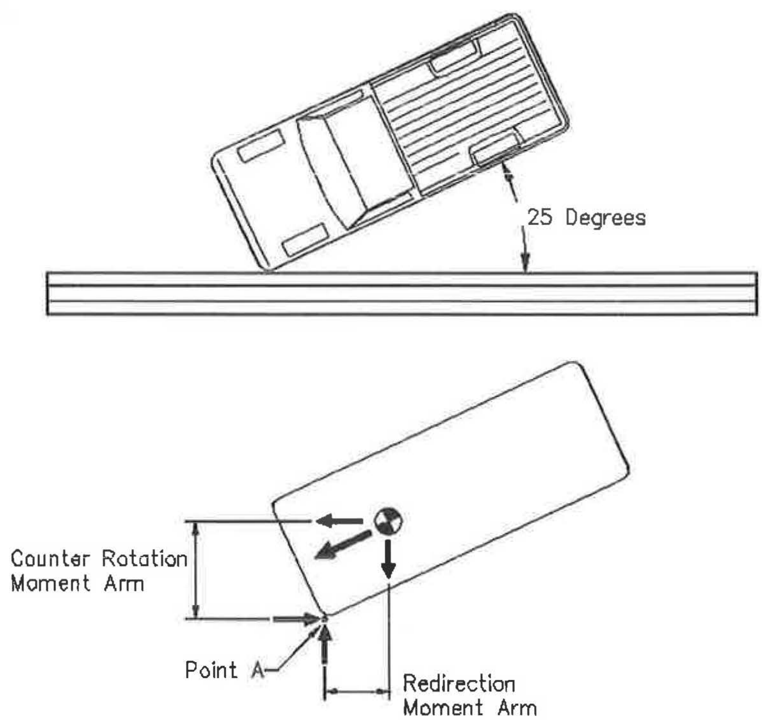


FIGURE 16 Lateral impact into longitudinal barrier with free-body diagram.

not block the driver's vision or otherwise cause the driver to lose control of the vehicle."

Figure 21 depicts the after test results of a subcompact vehicle impacting an inertial barrel array at 100 kph (60 mph). Note that the vehicle's hood is missing. Experience has shown that some vehicles, especially low-cost, light-weight, subcompacts have hood latches and hinge mechanisms that are not structurally adequate enough to keep the hood attached during certain types of relatively safe, low g impacts. This characteristic is not so much a flaw of highway safety hardware, but instead, is an undesirable characteristic of the impacting vehicle. This is a problem that needs to be addressed by the automotive design engineers.

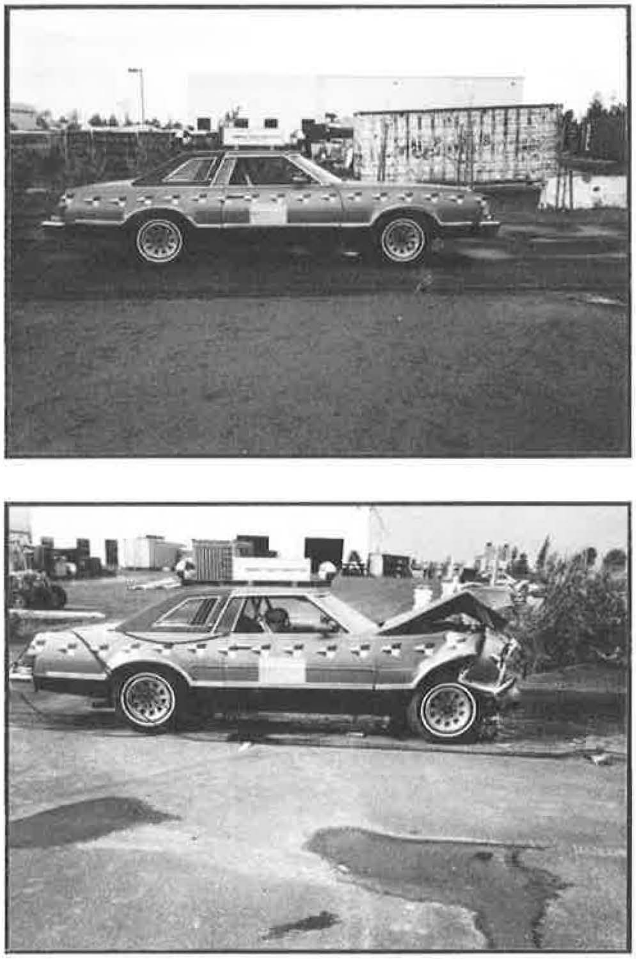


FIGURE 17 Before and after front end crush of a 4500S vehicle.

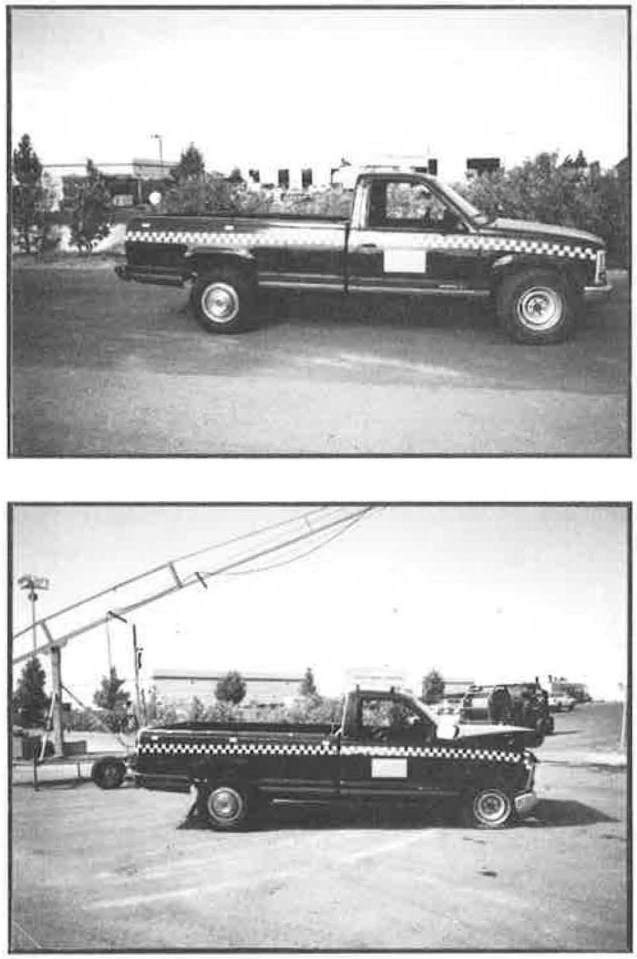
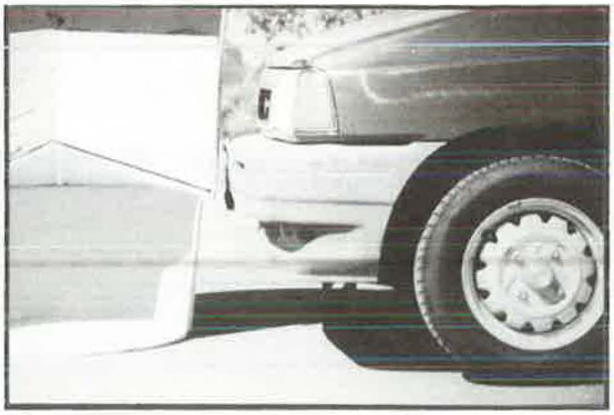


FIGURE 18 Before and after front end crush of a 2000P vehicle.

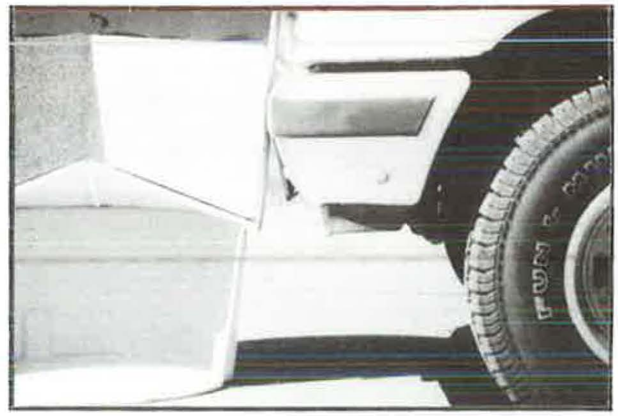
CONCLUSIONS

This presentation has reviewed just a few of the vehicle characteristics that can directly influence the overall outcome of impacts into highway safety appurtenances. Energy Absorption believes that new highway safety appurtenance designs need to keep pace with the changes in the nation's vehicle fleet. When the motoring public chooses to buy vehicles that range from light-weight subcompacts to 3/4-ton pickups, any new highway appurtenance designs need to safely accommodate these vehicles. At some point, however, the appurtenance designer may ask himself, "When am I measuring a characteristic of my highway safety device and when am I measuring a design flaw in the impacting vehicle?"

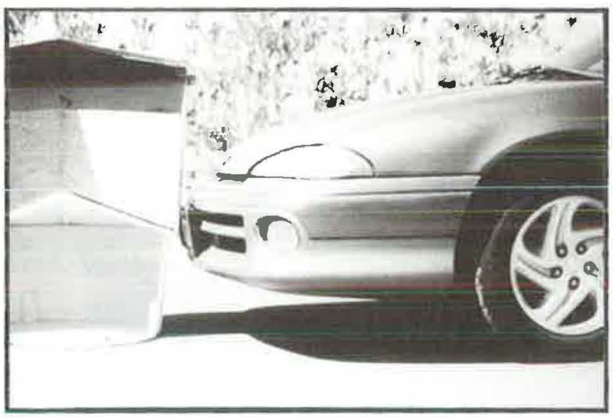
Automobile designers have continued to make tremendous strides toward designing forgiving vehicles as evidenced by padded interiors, steering wheel impact protection, head restraints, seat belts, air bags, side door impact protection, etc. Perhaps it's time to educate the automobile designer on the substantial time, effort, and expense that's gone into the design of the nation's "forgiving" highways. Highway appurtenance designers, researchers, and government officials have access to valuable information dealing with various types of vehicle interaction with highway appurtenances that needs to be shared with automobile designers. A forum, perhaps through NHTSA, SAE or TRB, needs to be established to allow for the exchange of this information, with the ultimate goal being the design of a forgiving highway that works well with a future fleet of forgiving vehicles.



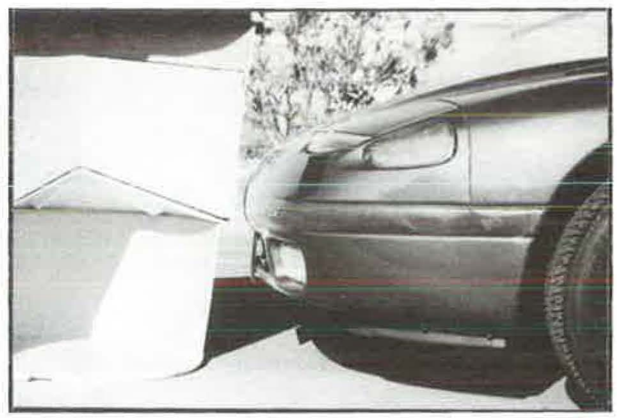
1988 Ford Festiva



1990 Ford F250



1994 Dodge Intrepid

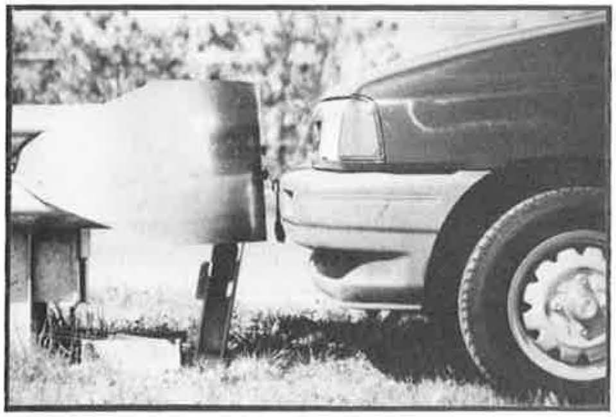


1991 Dodge Stealth

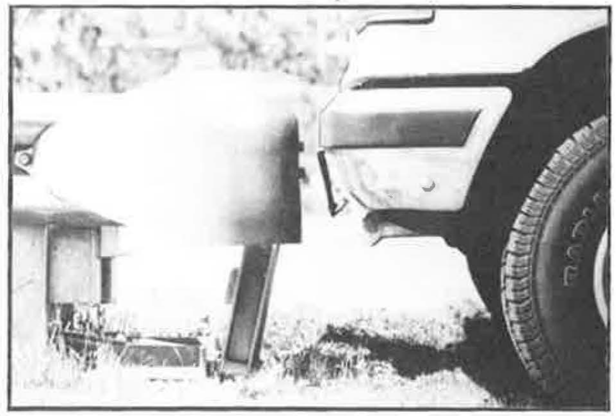
FIGURE 19 Variation in vehicle bumper heights.

REFERENCES

1. H. E. Ross, Jr., D. L. Sicking, R. A. Zimmer, and J.D. Michie, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 350, Transportation Research Board, Washington, D.C. (1993).
2. W. Riley Garott, "Measured Vehicle Inertial Parameters - NHTSA's Data Through September 1992," Society of Automotive Engineers Technical Paper 930897, March 1993.

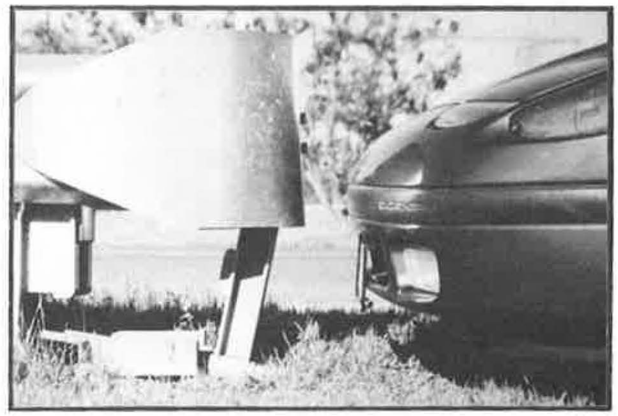


1988 Ford Festiva



1990 Ford F250

1994 Dodge Intrepid



1991 Dodge Stealth

FIGURE 20 Variation in vehicle bumper heights.

FIGURE 21 1988 Ford Festiva with missing hood after impact into inertial barrel array.