

Forensic physics of vehicle accidents

The reconstruction of accidents and the analysis of the mechanisms of injury are the focuses of an emerging interdisciplinary field that is leading to safer vehicle design.

Arthur C. Damask

Accidents are the third largest cause of death in America, taking 140 000 lives per year.¹ Only heart attacks and cancer kill more people. Vehicular accidents such as the one shown in figure 1 account for 44 000 of the accidental deaths and cause 80 000 permanent disabilities through trauma to the brain or spinal cord. The direct and indirect costs of all automobile accidents run close to \$60 billion per year.²

For many years Arthur Paskin and I have been using vehicular accidents as examples in our first-year physics courses at Queens College, both to bring added interest to the courses and, indirectly, to educate drivers about vehicular dynamics. In addition I have included topics on injury dynamics in my course on medical physics. A few years ago Paskin and I compared notes and decided that we should create an academic course on accidents and injuries, but thought it would be best to base the course on case studies to avoid being too abstract. Often an analysis of injuries can be used together with the

dynamics of an accident to unravel its causes (see the box on page 40). Although our studies have been largely of auto accidents, we have also examined other types of accidents such as slip-and-fall, bicycle, train, truck, subway, work place and construction site accidents.

This article is a broad overview covering the reconstruction of vehicular accidents, the causation of injury, developments in safety, the process of litigation and a new government initiative to support research on the prevention and control of injury. Of course a single article cannot cover the thousands of publications on these topics, but this brief survey should introduce the subject and direct the interested reader to the literature.

Vehicle-pedestrian collisions

In 1984 about 122 000 pedestrians were injured or killed in automobile accidents. Here we look at a few of the many factors that determine the fate of the pedestrian.

A pedestrian hit by the front of a car will follow a trajectory that depends principally on the height of the pedestrian's center of mass, the height of the front of the vehicle and the speed of the vehicle. Let us consider two extremes: an adult struck by a car and a child struck by a truck.

Americans and Europeans have done much research on injuries to adult pedestrians struck by cars. The Society of Automotive Engineers has published a series of papers—with a 234-entry bibliography—on studies of the epidemiology of injuries, studies of collisions with cadavers and dummies, and studies using computer modeling.³ The results of these studies have motivated manufacturers to reduce frontal projections and to make hood ornaments flexible to reduce lacerations. They have standardized the bumper height so that bumpers will strike an adult pedestrian below the knees—broken legs will heal but knee injury can leave one crippled for life. Impacts with adult male cadavers have shown that the bumper breaks one or both lower legs starting at speeds of 25–30 mph.

Leg injuries, however, are not very serious compared with head injuries. High-speed photography with cadavers and dummies shows that the head strikes the hood or windshield quite violently. Figure 2 shows a series of stills from a computer-graphics animation based on the equations of motion. Here one can see that at lower speeds the head strikes the hood, most of which is not rigid, whereas at higher speeds or with a smaller car the head strikes the windshield or its frame, which are more rigid. Studies are

Arthur Damask is a professor of physics at Queens College of the City University of New York, and author of the books *Medical Physics*, volumes I and II, and with Charles E. Swenberg, volume III (Academic, New York, 1978, 1981, 1984).



Vehicle-vehicle collision. The tractor-trailer truck crossed the concrete median barrier and collided head-on with the car. The truck's center of mass was higher than the barrier. (Photograph by Richard A. Retting, New York City Department of Transportation.) Figure 1

under way to compare the damage to the head caused by sheet metal with that caused by breakable glass. A recent report concluded that the hood is a good energy absorber but that it cannot go lower than elevated engine parts; the report suggests that car hoods be designed with greater engine clearances.⁴

The problem of a child's being struck by a car is quite different because the child's center of mass is at the level of the bumper or the lower grill. In this situation the child is usually projected forward at the car's speed. In every case that we have examined the car began braking before striking the child, so that the speed v_0 of the car was readily determinable. The horizontal distance that the child will travel before hitting the street is approximately $v_0(2h/g)^{1/2}$, where h is the initial height of the center of mass. After striking the street the body slides a distance $v_0^2/2\mu g$, for a total distance S of $v_0(2h/g)^{1/2} + v_0^2/2\mu g$. The coefficient of friction μ is not completely determinable and must be approximated. Drag tests on humans in various types of clothing and on various road surfaces give values of μ of 0.6–0.8. But the human body also tumbles with

arms flung out. Its tumbling and sliding motion is similar to that of a sack of flour,⁵ so that for large total distances S the effective coefficient of friction μ is 0.8–1.0, or even higher in certain circumstances. As this example illustrates, there are no exact solutions in accident reconstruction, only a bracketing of values.

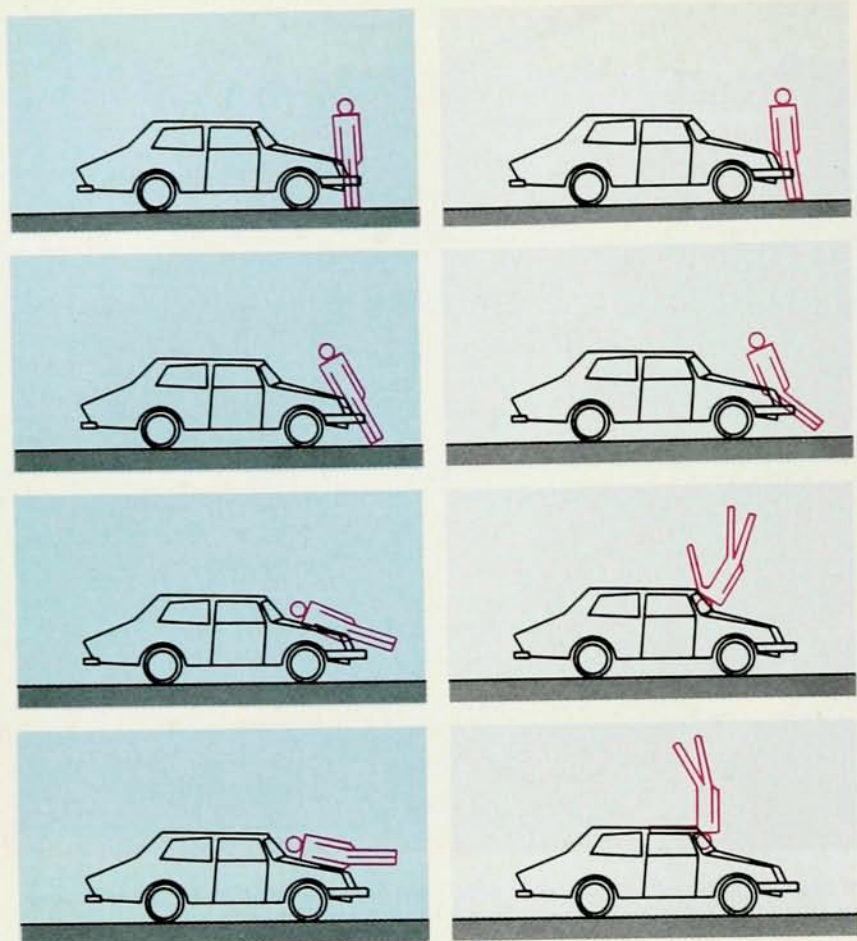
As an example of a vehicle-child collision let us consider an accident that Paskin and I reconstructed in which a truck on a city street struck a boy who dashed out between parked cars while chasing a skateboard. The driver saw the boy and locked his brakes, leaving a long pair of skid marks in an arc that stopped just before reaching the curb. We measured the coefficient of friction of a comparable tire on the street and found it to be somewhat higher where the right truck tire was than where the left tire was. This difference accounts for the truck's skidding in an arc. From the length of the skid marks we could determine the truck's speed at all points on its path. We located six boys of comparable height, size and age to the injured boy and measured their speed in chasing a skateboard.

Knowing this speed, the contribution

of the boy's momentum to the caroming angle of his body from the bumper, the speed of the truck at various positions, the range of possible angles between the parked cars from which the boy emerged into the street, and the reaction time of the driver upon first seeing the boy, we calculated a series of solutions for various paths of the boy and truck positions at impact. None of the solutions yielded the actual final body position! We returned to the area and watched streetwise boys at play. When they ran into a street with traffic they ran across a lane, slowed while a vehicle passed, then ran across the next lane. When we put in this slowing we obtained a correct solution and realized how the tragedy had occurred. The boy apparently chased his skateboard at sprinting speed, saw the truck and slowed before the truck's lane to allow it to pass. The truck driver, seeing the boy rush out and not realizing that the boy would not run into his lane, locked his brakes. The unevenness of the street caused the truck to skid in an arc and strike the boy, who was not in the truck's lane.

Car-car collisions

The physics of car-car collisions is



Car-pedestrian collisions at 25 mph (left) and 35 mph (right). These are tracings of stills from a computer animation based on equations of motion of limbs and torso derived from high-speed photographs of car-cadaver impacts. (Computer graphics by Jay Damask and the author.)

Figure 2

not that of the nearly elastic collision between two billiard balls. Cars must be treated as extended masses that are deformable and somewhat elastic. The momentum and energy equations contain unknowns that can be evaluated only through controlled crash tests. Let us look first at how the elasticity, or coefficient of restitution ϵ , is involved.

Consider two cars of masses m_1 and m_2 with velocities v_1 and v_2 before the collision and v'_1 and v'_2 after the collision. The velocity of their center of mass is

$$v_c = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2}$$

If there were a single mass $m_1 + m_2$ moving with velocity v_c its kinetic energy would be

$$E_c = \frac{1}{2} (m_1 + m_2) \left[\frac{m_1 v_1 + m_2 v_2}{m_1 + m_2} \right]^2$$

This is the kinetic energy after impact in a totally inelastic collision. The

energy remaining for the deformation of metal is the difference between the sum of the cars' individual initial kinetic energies, $\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$, and E_c . This difference is

$$\frac{1}{2} \frac{m_1 m_2}{m_1 + m_2} (v_1 - v_2)^2$$

This is the maximum kinetic energy that can be lost in the collision. Often only a fraction of it goes into metal deformation and heat. The remaining fraction goes into elastic recoil, which is measured by the coefficient of restitution.

When similar equations are written for the cars after impact, the result is

$$\frac{1}{2} \frac{m_1 m_2}{m_1 + m_2} (v'_1 - v'_2)^2$$

This is the energy that is not part of the center-of-mass energy; it is available, but not used up, in the collision. The coefficient of restitution ϵ relates this unused kinetic energy to the maximum

kinetic energy that can be lost:

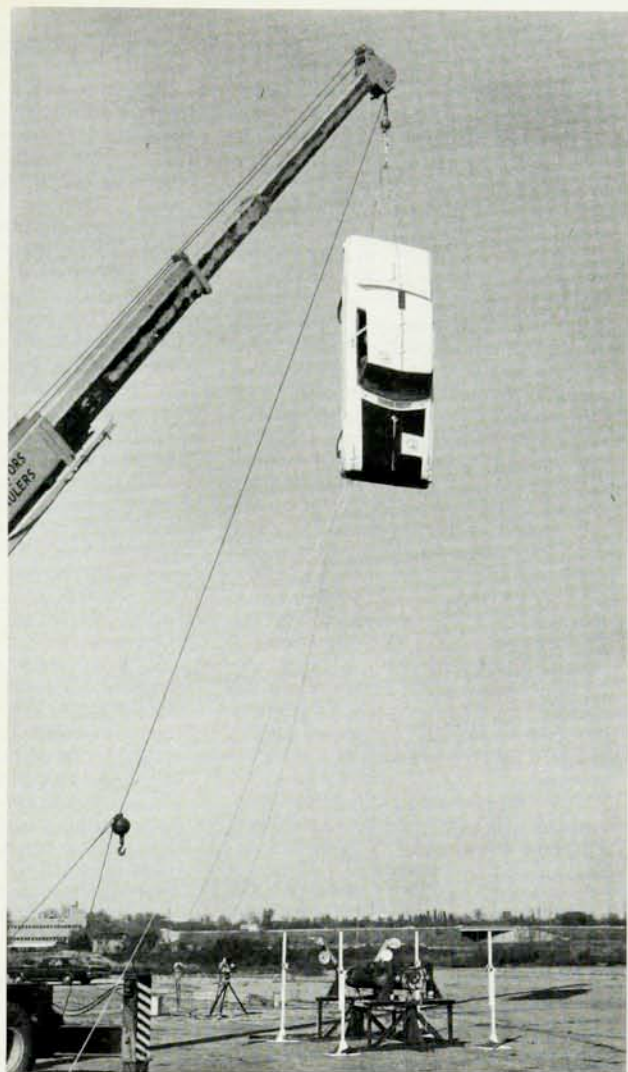
$$(v'_1 - v'_2)^2 = \epsilon^2 (v_1 - v_2)^2$$

The coefficient is 1 for completely elastic collisions and 0 for completely plastic collisions. Estimates of the coefficient ϵ from controlled collisions range from 0.84 at 10 mph to 0.47 at 20 mph to 0 at 25 mph and above.⁵

The above equations are based on simple physical principles, but there are many unknowns, including the velocities of the two cars before and after the collision and the energy lost in the impact. There are several possible ways to reduce the number of unknowns. Conservation of momentum will eliminate one variable, and knowledge of the positions of the vehicles before, during or after the collision will eliminate others. In some cases one must use an iterative method in which one assumes a series of reasonable velocities for one vehicle and seeks self-consistent solutions. It is clear, however, that this method can solve only a fraction of collisions if there are no reliable estimates of the crush energy—the energy that goes into damaging the cars.

The Department of Transportation's National Highway Transportation Safety Administration has supported controlled crash experiments in an attempt to estimate vehicle crush energies. The first type of experiment, done in the 1960s, involved hoisting cars with a derrick and dropping them onto instrumented rigid targets, as shown in figure 3. The result of such dynamic crushing is not the same as that of static crushing. The data on static crushing for the comparison shown in figure 4 come from an experiment done on a large-scale press used by the scrap metal industry for baling scrap vehicles.⁶ The oscillations in the dynamic results are expected because steel exhibits higher strength when subjected to dynamic loads. The dynamic measurements also reflect the impulsive momentum changes of large masses

Drop test. The car is hoisted by a derrick and dropped onto an instrumented rigid target. This kind of test, developed in the 1960s, is no longer used. Instead, remotely controlled cars containing dummies are driven into barriers, as figure 5 shows. (Courtesy of Calspan Corp, Buffalo, New York.) Figure 3



such as the engine and transmission, which do not crush; in the static tests the engine and transmission mounts yield continuously. Although the dropping tests yielded useful data, there was considerable variation with speed of impact. Comparison of dynamic and static crushing continues, although the drop test is no longer used. Instead, cars containing anthropoid dummies wired with up to 70 accelerometers are automatically driven into barriers, as shown in figure 5.

In reconstructing accidents, one wants to be able to estimate from the damage the energy of crushing. In the late 1970s NHTSA sponsored 27 controlled collisions at various speeds and angles. The 53 vehicles involved covered six classes of wheelbases. The experimenters measured the depths of indentation at six positions and used numerical integration with a trapezoidal approximation to determine the energy of crushing. Two constants convert the crush area to the crush energy: a spring preload constant and a linear spring constant.⁷

Of course not all vehicles in a given wheelbase class will be damaged identically. Some investigators claim that the error is only 10–12% when one uses damage alone to estimate closure velocities, or relative speeds. Others claim that one cannot achieve this accuracy with only five trapezoids of damage. Another source of error is variation in the way cars are built. In the 1970s many American cars still had frames and steel bodies, while today the norm is unit body construction, which eliminates the frame and includes generous amounts of fiberglass.

Intervehicle friction augments the normal force of deformation in cars colliding at an angle. The energy of deformation is increased by a factor $1 + \tan^2 \alpha$, where α is the angle between the line of force and the axis of the car—front to rear for frontal collisions and transverse for side collisions. The research that produced the crush ener-

gy results discussed here was conducted by the Calspan Corporation of Buffalo, New York, and led to the development of a computer program called Calspan Reconstruction of Accident Speeds on the Highway. Originally developed for a large computer, CRASH is now available for PCs. Raymond R. McHenry largely developed the mathematical analysis that led to the program, which is summarized in reference 8. Other researchers have introduced further refinements.⁹

Injuries

There have been many accident injury studies using cadavers and dummies. Reference 10 is a good tabulation of the results of cadaver tests on the forces required to fracture various bones. Reference 11 summarizes bone strength measurements for long bone fracture in various directions. Reference 12 gives the tearing or breaking strengths of materials such as cartilage, tendon and soft tissue.

Often one may calculate the force on a bone from the mass and the deceleration. The deceleration can be estimated by assuming a reasonable deceleration distance, which can be taken from references. The thoracic compression prior to rib fracture, for example, is about 2 inches,¹³ although if the torso strikes the steering wheel one must include an additional yielding distance.¹⁴ In contrast, the skull can yield only 0.01–0.025 inches prior to fracture under static loading, although dynamic tests show that the skull can tolerate much higher loads for short durations. Biophysical calculations of this type can often be used to establish a minimum speed of collision and thereby confirm the vehicle speed calculation. Attorneys for New York City have asked me on occasion to render an opinion in cases of alleged police brutality by showing with similar calculations how an injury could or could not have occurred.

The knees of unbelted front seat

A parkway accident

On a rainy night in winter, five youths were returning home in a 1973 Mustang after having consumed some beer. They rounded a left-hand curve in the dark because the two lights that should have illuminated the curve had been knocked down in previous accidents and not replaced. The car went onto a grassy shoulder 12 feet wide, bordered on the right by trees. It struck the corner of a 3-foot-high concrete guard rail at the passenger door hinge. The car split in two, with only some sheet metal attachment remaining. As figure A indicates, the front of the car ended up on the road side of the concrete wall about 24 feet beyond the beginning of the wall, while the rear part lay more to the left, rotated about 200° clockwise. The passenger door was molded about the end of the wall with its outside against the wall. A police drawing showed the vehicle and bodies scattered on the road as in the figure. Occupant A was alive but was unable to recall any details of the crash or who was driving. Occupants B, C, D and E were all dead at the scene.

Arthur Paskin and I reconstructed the accident at the request of the attorneys for occupant A, who was charged with vehicular homicide. The jury acquitted him of this charge.

The outside of the right front wheel rim had a deep dent at an angle of 40°–45° with the plane of the wheel. The shaded rectangle in the lower right corner of figure A represents a 2×3-foot electrical utility vault with a steel cover. Electrical work had been done during the day and the cover of the vault had been left off. A 1×2-inch chip was missing somewhat to the left of the midpoint of the vault's north rim. Because of the location of the Mustang's center of mass, for the car to rotate counterclockwise about its right front wheel its orientation would have to have been about 35°–40° with respect to the road. Figure B shows the direction of the center of mass and the seating arrangement determined from the injuries. Occupant E had multiple fractures of both sides of his body as well as his jaw. Occupant D had multiple fractures of only the right side of his body while C had no body fractures, only a broken neck from severe whiplash. Evidently the corner of the wall pushed into the back seat to the middle of occupant D. This geometry indicates that the axis of the car had an orientation angle of 60°–65° as it encountered the wall, different from the velocity vector of the center of mass.

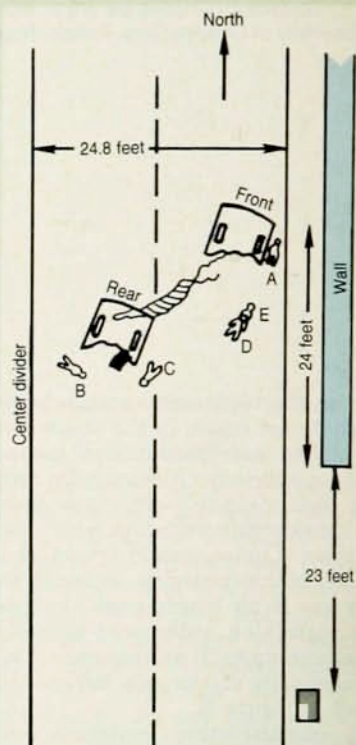
Our interpretation is that the car was heading about 35°–40° northwest when its

front right wheel went into and struck the open vault, caught in the corner and rolled out again. This collision created a torque, causing the car to rotate an additional 30° while traveling 23 feet on wet grass to the wall.

We used two methods to estimate the speed. First, there was no damage to the trees, which were 12 feet to the east of the curb. The car therefore had a maximum arc in which it could turn to the 35° angle. We measured the coefficient of friction of wet grass, and using the sports car correction factor for the maximum speed of turn,⁵ we calculated a maximum speed of 37 mph. In other words, our reconstruction showed that the car did not succeed in making the full left turn in the dark, so it went up the shoulder and the driver was turning the car back to the road when the right front wheel struck the open vault.

The second estimate of the speed used the skid distance of the car between the electrical vault and the wall, the skid distances of the front and rear of the car after the impact, and the crush energy. The Mustang has unit body construction rather than a frame. It is reasonably crush resistant to a head-on collision, but has minimal strength in a side collision. It is much like an egg—strong axially but extremely crushable laterally. In a side collision of this severity, the CRASH program method described in the text for determining the crush energy is not on sound experimental grounds. The most direct way to get the crush energy is to measure the energy for tearing sheet metal and shearing bolts. One may use metallurgical data to add a correction for dynamic instead of static metal shearing. When we added the skid energy from the vault onward, the skid energies of the two sections after the collision and the tearing energy of the sheet metal after the collision, we found that the speed of the car could not have exceeded 35 mph.

We calculated the injuries that one would expect the driver to have suffered during the violent deceleration indicated by the data discussed earlier. Experiments have shown that while an unbelted driver on a bench seat will slide up the steering wheel, in a bucket seat such as the Mustang's the driver's hips will slide forward and the driver will suffer knee injury against the dash panel. As mentioned in the text, in many cases the right knee wedges under the dash, which exerts a downward force on the tibia, fracturing it and the fibula near the ankle. Furthermore, the skull and torso of a driver in a bucket seat will



Accident scene according to police drawings. The sketch shows the positions of the two halves of the car and the five occupants after the car hit the end of the wall. Figure A

generally strike the steering wheel, which can cause skull or brain injury as well as internal injuries. The table shows the injuries to the driver expected in this particular accident.

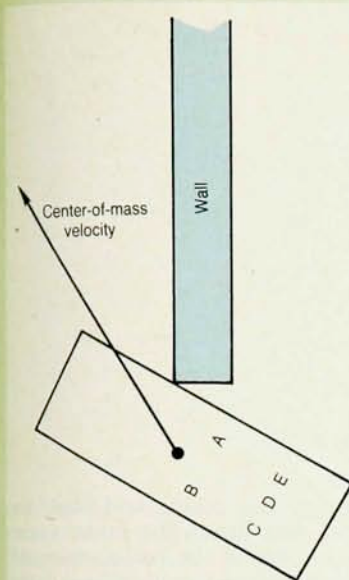
Occupant A, the survivor, had only one of the expected injuries, while B had all. Note that all occupants but A had ruptured aortas and that figure 6 indicates that this occurs at decelerations above about 110 g. Why didn't A have this injury? Detailed analysis showed that the corner of the wall that penetrated the car just grazed the right rear of the front passenger seat; as the car split in two and decelerated, all occupants continued forward, colliding in various ways with the car interior. In the right front passenger's forward direction there was no car interior, just the gap left by the removed door. He went in a forward trajectory, landed on the road and slid to the position marked A in figure A. He did not move from that position until the police arrived because he was immobilized by a fractured right rib, right shoulder and left wrist. His shallow angle upon striking the road allowed his deceleration to be small enough not to rupture his aorta. Through this analysis we demonstrated to the jury that A was the front seat passenger, not the driver.

We felt that it would be difficult to explain the complex rotations of the car to a jury,

Expected injuries

Rib fracture
Skull fracture
Brain damage
Facial lacerations
Aortic tear
Knee injury
Fracture of right lower tibia and fibula

Occupant				
A	B	C	D	E
•	•		•	
	•			
	•			
	•	•		
	•		•	•
	•			
	•			



Velocity vector of the car's center of mass and orientation of its axis as it struck the wall. Figure B

so in collaboration with my son Jay Damask we used an Apple computer to create a rather primitive two-dimensional animated graphic display of the car's motion. We encountered an unexpected obstacle: None of the attorneys could find any legal precedent for this. A reporter visiting the courtroom learned that a scientific legal decision was to be made and gave word to the press, and soon reporters, TV newspeople and courtroom artists filled the court. With the jury out of the courtroom, the lawyers presented their arguments for and against this new type of evidence. The prosecutor objected because anyone with a computer could draw any picture desired; he argued that if the jury members saw the animation, it would fix in their minds that the accident happened in the way shown. In the hearing I explained to the judge that the graphics were not drawn but computed from the equations of motion of both translation and rotation of the car.

New York Supreme Court Justice John Collins ruled in our favor, saying, in part: Every new development is entitled to its first day in court. A computer is not a gimmick, and a court should not be shy about its use when proper. In this case the graphics can help the jury understand the defense's case.

We chose not to bring the computer into the courtroom because of fear of mechanical or electrical failure. Instead, we filmed the screen with a video camera and used a VCR and monitor in court.

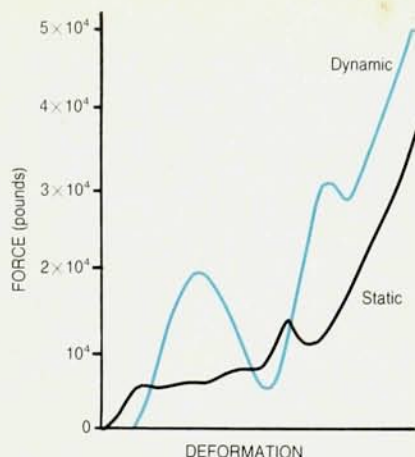
With this legal precedent obtained, Paskin, Jay Damask and I have created graphics on more sophisticated computers. The introduction of computer graphics into court is described and illustrated in reference 21.

occupants are particularly vulnerable to serious damage through collision with the dash panel. A characteristic additional injury for the driver is a fracture of the right tibia and fibula just above the ankle. This apparently occurs because the heel is trapped at the base of the accelerator and the wedging of the right knee under the dash panel causes a downward force on the tibia. Research is in progress with both cadavers and dummies to design a soft bolster under the dash,¹⁵ but a universal bolster to accommodate occupants of all heights has yet to be achieved.

Detailed studies on animals indicate that head injury, which is of particular concern, is a function of the area under the acceleration-time curve. Studies initiated at Wayne State University on intercranial pressure in animals and cadavers for pulses of similar shapes but different impulse times show that the longer the duration the less intercranial pressure can be tolerated. Human tolerance experiments by NASA involving the acceleration and deceleration of volunteers in sleds show a similar functional behavior. A head injury severity index based on these results takes the form of a pulse integral:

$$(t_2 - t_1) \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) dt \right]^{2.5}$$

If a is the acceleration in units of g and t is time in seconds, then a severity value that exceeds 1000 is life threatening. The exponent 2.5 is an approximation that may differ somewhat according to age and sex, and, of course, the threshold of 1000 is not a rigid number. One



Dynamic versus static crushing. This plot of force as a function of deformation for a 1963 Ford shows different relationships for dynamic and static crushing. (From reference 6.) Figure 4

may use exponents other than 2.5 and still match the range of the data, and thereby obtain different maximum values of injury tolerance even within a single population group.¹⁶

The US Air Force was interested in knowing the effects of extreme acceleration on the spinal column so that it could set limits on the explosive ejection of pilots from disabled planes. Experiments involved dropping primates strapped into chairs and performing autopsies to examine not only the spinal column but also the aorta, lung, liver and spleen. The results given in figure 6 for some primate tissues may be used for humans because masses and strengths of tissues generally scale appropriately. A monkey's heart, for example, requires less tissue to hold it in place than does a human heart.

One measure that does not scale readily is rotational acceleration of the brain. Concussive brain injury is one of the more serious injuries. If the human skull accelerates or decelerates abruptly, the brain, being without cartilage, impacts against the inside of the skull and also shears itself, causing contusions, breaking blood vessels or creating lesions in the brain or brain stem. Although the result is sometimes only a mild concussion, there has been no study of possible long-term effects on postconcussive patients.

By combining data on human and animal experiments, researchers at Wayne State University in 1960 developed an impact tolerance curve. This plot of translational acceleration versus time of impulse, shown in figure 7, is now referred to as the Wayne State University concussion tolerance curve.



Car-barrier collision test. Dummies in such tests are wired with up to 70 accelerometers. (Courtesy of Ford Motor Company Auto Safety Center.)

Figure 5

Human volunteers have survived without concussion frontal crash simulations involving accelerations in excess of 45 g; this has led some researchers to recommend¹⁸ that the asymptote in the concussion tolerance curve be raised to about 80 g.

Concussion studies have also focused on the role of whiplash and rotational acceleration of the head. As early as 1943, A. H. S. Holbourn examined the fracture of gels of various spherical

sizes under comparable rotational accelerations. He proposed that for similar radial accelerations, parts of the brain far from the axis of rotation would suffer damage more readily than those closer to the axis because the moment of inertia varies with the radius. This is now called Holbourn's rule or law.

Ayub K. Ommaya and his coworkers at NIH, noting that the moment of inertia of a sphere varies with the

square of the radius and that the volume, and hence the mass, varies with the cube of the radius, showed¹⁹ that if the torque is proportional to the mass (but not to the distance from the axis of an applied force) Holbourn's rule may be written for the comparison of two brains of different sizes as

$$\ddot{\theta}_1 = \ddot{\theta}_2 \left(\frac{m_2}{m_1} \right)^{2/3}$$

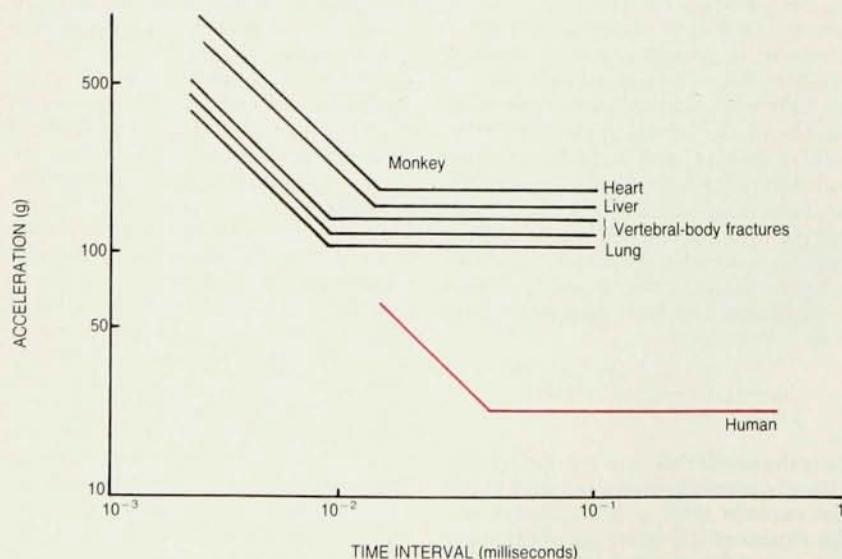
Here m_i and $\ddot{\theta}_i$ are the masses and radial accelerations of the two brains. For example, if brain 1 is that of a human, brain 2 is that of a rabbit and the ratio m_1/m_2 is 64, then

$$\ddot{\theta}_1 = \ddot{\theta}_2 \left(\frac{1}{64} \right)^{2/3} = \frac{\ddot{\theta}_2}{16}$$

Therefore a concussion in a human can be produced with $1/16$ the radial acceleration that it would take to produce a concussion in a rabbit. Figure 8 shows the scaling relationship between humans and other primates. It should be noted that the restrictive assumption on the torque may be an oversimplification if applied to blows on the head. A computer model of the brain could give a more precise solution to this problem.

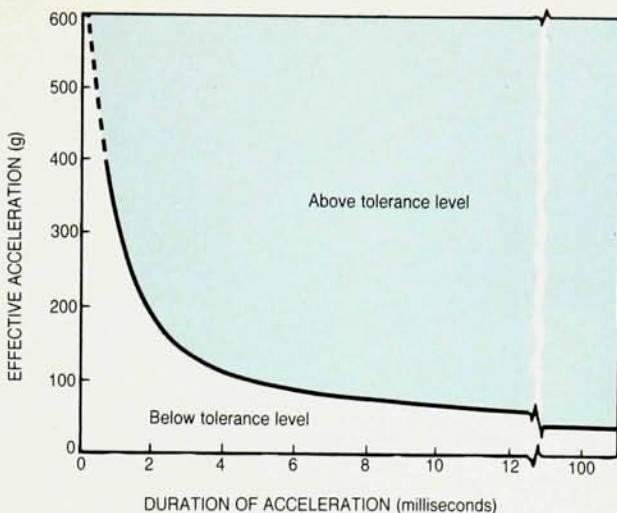
From these primitive beginnings, investigators, beginning with Carley Ward at the University of California, San Diego, in the early 1970s, have used rather sophisticated finite-element models of the brain and skull in computer simulations of impacts and whiplash, and have matched the results to cadaver studies.

We need further data on concussions in humans. Obviously we cannot obtain these data from human volunteers. However, now that collision velocity calculations are in fairly good shape, we can estimate the translational and rotational decelerations of heads striking interior objects and ex-



Accelerations and times that expose a rhesus monkey to a 99% probability of injury. The lower curve (red) is that for 5% probability of injury to humans. (From reference 17.) Figure 6

Impact tolerance for the human brain when the forehead hits an unyielding plane surface. This curve is known as the Wayne State University concussion tolerance curve. Figure 7



periencing whiplash. Such estimates will allow us to use large-scale epidemiological statistics to see if there are sex or age group differences (neuronal integration is known to change with age²⁰). This may lead to refinements in the concussion tolerance curve of figure 7.

Litigation

Lawyers generally like to settle cases between themselves rather than submit to an imponderable jury. Because of this desire to settle, only about 10% of vehicle accident cases go to trial.

Who are the "experts" on accident reconstruction who are called upon to testify in court? Very few physicists seem to have entered this field, possibly because they deem it not to be on the frontier of knowledge. The failure of physicists to take up this social role has left a vacuum that has been strangely filled by a few very good engineers and a mixed lot of persons who are only partly qualified to reconstruct accidents. Most of the United States is served in this capacity by graduates of a three-month course on traffic accident investigation. Unfortunately, some graduates of such courses believe that they are able to reconstruct any accident, and courts usually accept their credentials from the course as sufficient to qualify them as reconstruction experts.

Physicists trying to aid society with their skills face difficulty because so few physicists appear in court that neither lawyers nor judges nor juries know what they do or what they can do. Although a physicist may do an expert reconstruction of an accident and the opposing "expert" may be violating the laws of physics, if the physicist cannot convince the jury of nonscientists that his or her reconstruction is the correct one, the case will be lost. I recently lost a case in which I had programmed a

computer to calculate the trajectories of objects and bodies ejected from an open car and showed the results diagrammatically to the jury. I learned later that in his summation the opposing attorney had told the jury that "the laws of physics are obeyed in the laboratory but not in rural New Jersey." Perhaps physicists should begin to tithe their knowledge to society to dispel such misconceptions.

How does one cope with this pedagogical problem? First one must face the issue of credentials and credibility. A PhD in physics is generally more impressive than a certificate from a three-month course, but it is not that simple. Someone who has analyzed 100 to 1000 accidents, even if every analysis was wrong, appears more credible than a physicist who has analyzed 0 to 10 or 20 accidents. So it is difficult to get accepted by a jury. The second problem is educating the jury. This might be likened to teaching a class of non-science students who can't ask questions and end up grading the teacher. All of the skills of an experienced physics teacher are required—using models and diagrams and repeating concepts in several different ways, all the while scanning the student's (or juror's) eyes for a glimmer of understanding.

The above problems are not a deterrent but a challenge. More physicists should get into the courtroom as experts. As more do, lawyers, judges and juries will no longer find our presence and abilities so strange and the path will be smoothed for future forensic physicists.

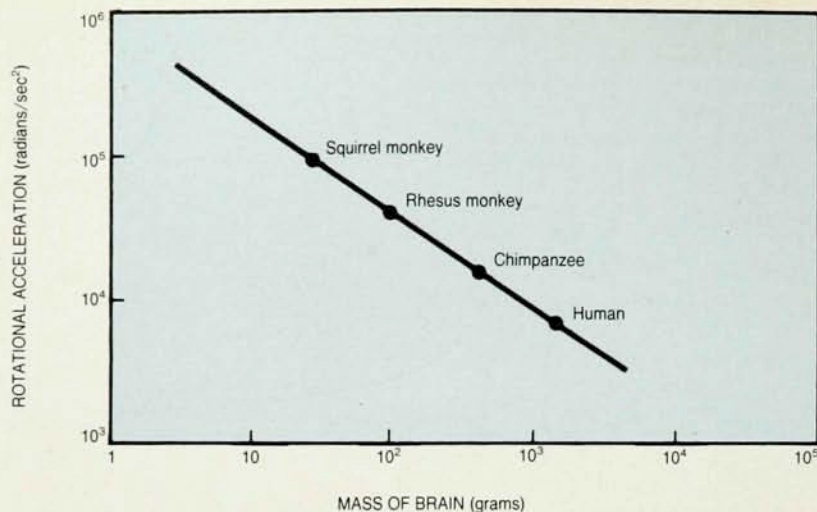
Safety developments

Numerous statistical studies have focused on car crashes and the ensuing injuries to occupants and pedestrians. The results have led to improvements

in safety design. Some improvements, such as anti-skid brakes, are obvious; others are more subtle. Studies of pedestrian injuries have led to standardized low bumpers to protect the knees of pedestrians and to less lacerating projections on the fronts and sides of cars. Occupant injury studies have led to nonprojecting door handles, the removal of projecting knobs on the dash panel, padding on the edge of the dash, padding of the A columns on either side of the windshield, headrests to reduce retroflex whiplash injury, and three-point (shoulder harness) seat belts. For driver protection there are the energy-absorbing or collapsible steering column and the air bag. A European auto company has just announced an accessory in which the motor is attached by cables to the driver's seat belt and to the steering column. In a frontal collision the momentum of the motor tightens the seat belt and pulls the steering column out of the way.

These are just a few of the safety features that have been developed. The world of auto owners and manufacturers is becoming more safety conscious and we can expect new developments.

New government initiative. In 1966 the National Research Council issued a report, *Accidental Death and Disability: The Neglected Disease of Modern Society*, indicating that little progress had been made from the time that cars had been introduced. Since that report, more than 2.5 million Americans have died from injuries. In 1983 Congress enacted a law authorizing the Secretary of Transportation to ask the National Academy of Sciences to conduct a study on injury to determine what is known, what research should be done and what the Federal government can do to increase and improve



Scaling relationship between nonhuman primates and humans for concussive levels of rotational acceleration. The points for the squirrel monkey, chimpanzee and human are theoretical. (From reference 19.)

Figure 8

knowledge of injury. The National Research Council's Commission on Life Sciences, in collaboration with the Institute of Medicine, established a committee on trauma research. The numbers in the first paragraph of this article suggest that the incidence of injury has epidemic proportions, and it is fitting that William Foege of the Center for Disease Control chaired the committee on trauma research. The committee's report, *Injury in America*,¹ was published in 1985. It summarizes the causes of injury and recommends that injury prevention and research centers be established, that more scientists, especially biophysicists, be attracted to injury research and that graduate students be trained in the multidisciplinary aspects of the field.

In the 1986 budget, Congress made available \$7.8 million for grants to support injury control research and demonstration projects and to establish injury prevention and research centers. These centers will be organizational units within academic institutions and will work toward developing an interdisciplinary, comprehensive approach to the problem. They will involve physicians, epidemiologists, engineers, biophysicists, behavioral scientists, public health workers and others. Although there is sentiment for continuing this approach, future budgets are always uncertain.

As Paskin and I have pursued our scholarly effort to develop an academic course on accidents and injuries we have learned that there have been many others with similar concerns but with grander visions. What we thought was a backwater scientific activity may soon become the main-

stream of a new interdisciplinary academic field of study, training and research.

References

1. *Injury in America*, National Academy Press, Washington, DC (1985).
2. *The Economic Cost to Society of Motor Vehicle Accidents*, report no. DOT-HS-806-342, National Highway Transportation Safety Administration, US Department of Transportation (1983).
3. *Pedestrian Impact Injury and Assessment*, pub. no. P-121, Society of Automotive Engineers, Warrendale, Pa. (1983).
4. H. B. Pritz, in *Pedestrian Impact Injury and Assessment*, pub. no. P-121, Society of Automotive Engineers, Warrendale, Pa. (1983), p. 67.
5. J. C. Collins, *Accident Reconstruction*, Charles C. Thomas, Springfield, Ill. (1979).
6. R. R. McHenry, D. J. Segal, N. J. Deleys, in *Proc. 11th Stapp Car Crash Conference*, Society of Automotive Engineers, Warrendale, Pa. (1967), p. 8.
7. K. L. Campbell, *Energy Basis for Collision Severity*, paper no. 740565, Society of Automotive Engineers, Warrendale, Pa. (1974).
8. R. R. McHenry, *Extensions and Refinements of the CRASH Computer Program, Part II: User's Manual for the CRASH Computer*, pub. no. PB-252 115, National Highway Transportation Safety Administration, US Department of Transportation (February 1976). R. R. McHenry, B. G. McHenry, in *Proc. 30th Stapp Car Crash Conference*, Society of Automotive Engineers, Warrendale, Pa. (1986), p. 333.
9. *Field Accident Data Collection, Analysis, Methodologies, and Crash Injury Reconstructions*, pub. no. D-159, Society of Automotive Engineers, Warrendale, Pa. (1985).
10. *Human Tolerance to Impact Conditions as Related to Motor Vehicle Design*, pub. no. J885, Society of Automotive Engineers, Warrendale, Pa. (1980).
11. A. C. Damask, *Medical Physics, Vol. I: Physiological Physics and External Probes*, Academic, New York (1978).
12. H. Yamada, *Strength of Biological Materials*, Williams and Wilkins, Baltimore (1970).
13. *The Human Thorax—Anatomy, Injury and Biomechanics*, pub. no. P-67, Society of Automotive Engineers, Warrendale, Pa. (1976).
14. *Occupant Crash Interaction with the Steering System*, pub. no. SP-507, Society of Automotive Engineers, Warrendale, Pa. (1982).
15. D. C. Viano, C. C. Culver, R. C. Haut, J. W. Melvin, M. Bender, R. H. Culver, R. S. Levine, in *Proc. 22nd Stapp Car Crash Conference*, Society of Automotive Engineers, Warrendale, Pa. (1978), p. 401.
16. J. Versace, in *Proc. 15th Stapp Car Crash Conference*, Society of Automotive Engineers, Warrendale, Pa. (1971), p. 771.
17. L. E. Kazarian, J. W. Hahn, H. E. von Gierke, in *Proc. 14th Stapp Car Crash Conference*, Society of Automotive Engineers, Warrendale, Pa. (1970), p. 121.
18. L. M. Patrick, H. R. Lissner, E. S. Gurdjian, in *Proc. Seventh Stapp Car Crash Conference*, Charles C. Thomas, Springfield, Ill. (1965).
19. A. K. Ommaya, P. Yarnell, A. E. Hirsch, E. H. Harris, in *Proc. 11th Stapp Car Crash Conference*, Society of Automotive Engineers, Warrendale, Pa. (1967), p. 73.
20. A. C. Damask, C. E. Swenberg, *Medical Physics, Vol. III: Synapse, Neuron, Brain*, Academic, New York (1984).
21. T. Harper, *Am. Bar Assoc. J.* **70**, 80 (November 1984). □