Automobile Safety Construction

Robert C. White

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AUTOMOBILE SAFETY CONSTRUCTION

by

Robert C. White

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment
of the
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Robert C. White
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CHAPTER I

AUTOMOBILE SAFETY CONSTRUCTION FOR ACCIDENT AVOIDANCE

The nation's highway death toll for 1970 showed a drop of 2% from 1969 even though the automobile population showed an increase of over 6% for the same period.¹ This compares with an average increase in the death toll of 7% for each year from 1962-1967.² Traffic experts agree that automotive safety construction is beginning to pay dividends in human lives.

Today's automobile offers many safety features that were not in existence five years ago. The biggest task left unfinished, is educating the public to what safety features are now available and how to take full advantage of them. This report will begin with a survey of pre-crash equipment, that is, equipment installed to help prevent accidents from happening.

**Control Location and Identification**

The first item involves the identification and location of controls within the passenger compartment. The driver must be able to reach controls with a seat belt and shoulder harness fastened.³ These controls include; headlight switch, windshield wiper control, driver's sun visor, windshield washer control, and

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numerous obvious controls such as the horn, transmission control, and turn signal control switch. Federal law specifies that some of these controls must be identified by words or symbols. This need for identification is understood by anyone who has attempted to locate these controls in an unfamiliar vehicle. As stated earlier, the purpose of this type of requirement is to help prevent accidents. Imagine a driver drifting towards the road center line while hunting for a windshield washer control switch, that turns out to be on the floor rather than on the dashboard, where most windshield washer controls are located.

Transmission Shift Lever Sequence

A second item now dictated by law is a common shift lever sequence. Basically, it requires the shift lever sequence to be in the same pattern for all makes of automobiles; park, reverse, neutral, drive and low. The law does not state whether the park position must be in the most forward or the most rearward position with a floor shift. Even though the positions are marked, most drivers move a control lever by habit. The existence of the two following sequences provides a confusing move from the neutral position: P R N Dr Lo and Lo Dr N R P.

Starter Interlock

Two other safety features are built into the auto-
mobile concerning the transmission. The first is a safety starter switch, which allows standard transmission cars to be started only when the clutch pedal is depressed. This means the engine and driveline are disconnected while the car engine is started. On automatic transmission cars, the engine can be started only when the shift selector is in the neutral or park position.

**Transmission Braking Effect**

A safety feature has been available for many years although many drivers have been hesitant to make use of it. Federal law now requires all automobiles be provided with a low gear which can be used to slow the vehicle speed anytime below twenty-five miles per hour. This feature is to help prevent the car from building up too much speed while descending a hill, without constant use of the brakes.

**Windshield Defrosting and Defogging**

All vehicles sold in the United States must have a windshield defrosting and defogging system. Normally this system is part of the heater system and uses its temperature and blower speed controls. By directing heated air from the heater to the windshield, the fog or moisture particles on the glass are evaporated. If frost has developed on the glass, the heated air will warm the
windshield glass and it is required to clear 80% of the driver's side in twenty minutes. There are also time requirements for cleaning other parts of the windshield, with all required tests run at 0°F.

**Windshield Wiping and Washing System**

A number of improvements have been made concerning the windshield wiper system. On today's automobiles, the wipers must clear a minimum surface area of approximately 80% of the driver's usable front vision area. The law actually varies with each vehicle, but the details are not within the general interest of this report. The best improvement has been electric-driven windshield wipers in place of vacuum-operated wipers, the advantage being that electric wipers are not affected by engine speed or engine load. Electric wipers are also available on the rear windows of station wagons; what an improvement over the hand-operated wipers of 1912! Another improvement available on windshield wipers is the airfoil windshield wiper blade developed by Chrysler in 1963. The airfoil blade is designed to hold the wiper against the windshield under a high wind or high automobile speeds where normal blades are often lifted off the windshield surface.

Two other modifications to the windshield wiper device are worthy of note. The first involves relocated...
pivot points for the wiper blades. The old method had one blade moving clockwise while the other moved counter-clockwise, both pivots were toward the outside edge of the windshield. The new system locates one of the pivot points near the center of the windshield so that both wiper blades can move clockwise at the same time, and a much wider windshield area is cleared. One foreign-made car has now added a third wiper blade. The second modification was the addition of a built-in circuit breaker which prevents the wiper motor from being damaged when the wiper blades are frozen in position by ice or snow.

A windshield washer system is also a required item on each new car sold since November, 1965. In general terms, it must clear 75% of the wipe pattern in ten wipe cycles and be able to operate without rupture during blocked nozzle or freeze test. It must also be unaffected by a 50% solution of antifreeze added to the washer solution for protection against freezing. There are also numerous temperature test cycles the windshield washing system must be able to pass. Some new model station wagons are also offering the window washer system as an option on the tailgate window.

An experimental windshield device is being studied by Britain's Triumph car designers. The device causes the windshield glass to be vibrated at a frequency such that rain and dirt are thrown off. This type of device
would have two major advantages. First, it would probably keep 100% of the driver's usable vision clear on the windshield instead of the previously mentioned 80%. Second, it would eliminate the ninety times a minute interruption of the driver's vision by the wiper blades, assuming the wipers were traveling at the required forty-five cycles per minute.  

Automotive Brakes

The next topic is automobile brakes. "Brakes are by far the most important safety feature on our automobiles." The brakes are expected not only to stop a car, but to do it smoothly, evenly, and quietly. They must operate in both extreme heat and cold, in rain and snow, on steep grades and sharp turns, and in both forward and reverse directions. The federal safety standards which apply to the automotive brakes are numerous and include regulations concerning the hydraulic brake system, the emergency brake system, the parking brake system, and the hydraulic brake hoses. This report will discuss in addition: disc brakes, power brakes, and anti-skid brake systems.

The hydraulic brake system was developed in 1918 by Lockheed. Previous brake systems had used mechanical means to apply brake shoes against brake drums, usually steel rods or cables connected to the brake pedal.
A hydraulic brake system has many advantages over a mechanically operated system, the basic advantage is that equal pressure is applied to each wheel cylinder without special adjustments. Unequal wheel cylinder pressure causes the car to pull to one side when brakes are applied. The hydraulic system allows the pressure on each side to be equal, and if desired, allows the pressure at the front and rear wheels to be equal. The use of all drum brakes usually required equal pressure to all wheels, with a larger diameter wheel cylinder at the front than at the rear. The larger wheel cylinder is used at the front wheels because the forward momentum of the car throws more of the weight on the front wheels when the brakes are applied. A stronger braking effort at the front wheels is therefore necessary to achieve a balanced braking effort.

Good braking is much more complicated than most persons realize. "Every car driver, even an inexperienced one, is perfectly aware of the steering instability during the braking process." This instability can be divided into two basic groups, those which appear without any wheel-lock and those which exist with locked wheels. The first is defined as instability derived when the vehicle swerves by itself, without any driver action on the steering wheel, with the brakes applied but
not locked. The second case would involve locked wheels on either the front or rear or both. The average driver cannot cope with either of these problems during braking. "It is the engineer's craft to look for the causes of these defects, by means of studies and tests, then to make the necessary arrangements for curing them, if possible with an automatic device."\(^{32}\)

Instability from the first source involves many components of the automobile other than brakes. The main components affecting stability of the car are: suspension, steering, and framework. The ideal solution would be to separate these components from the brakes or at least isolate them where they would have no effect on automobile braking. Brakes themselves have many variable properties such as: coefficient of friction, usually caused by changes in temperature; unequal pressure distributions between lining and drums; and many problems involving the type of brake such as duo-servo, disc-brakes, etc.\(^{33}\)

In addition to the variables among the brakes themselves, research has shown many other variables which affect control of the car during braking. Such variations as tire resistance to slip, weight variations on each wheel, weight transfer during deceleration, highspeed aerodynamics, and vehicle speed all contribute to problems of stability during braking.\(^{34}\) Extensive research has brought forth one fact showing the influence of vehicle
speed on instability during braking. "Due to the
defectiveness of the brakes combined with the "slip"
characteristics of the tires, the result is that on
ground-level, braking creates a pivoting torque that
always tends to make the car pivot during the braking
phase, not only in dependence with brake instability,
but moreover in dependence with the road stability char­
acteristics of the car, and particularly in dependence
with the speed; speed intervenes by its second power in
the formula giving the radius of curvature of the
swerved-out trajectory followed by the car when steering
instability starts."\textsuperscript{35} From this, it can be seen that
suspension, steering, and framework, along with vehicle
speed, are all involved with causing the car to swerve
while braking.

The second problem mentioned earlier, involves
stability during braking with locked wheels. The most
common results show that with only the rear wheels
locked, the automobile tends to spin around with the car
facing backwards.\textsuperscript{36} With the front wheels locked, the
driver loses steering control of the vehicle, and with
all four wheels locked, the car is close to being com­
pletely out of control.\textsuperscript{37} The need for a brake anti­
locking system is evident, as all three of the above
situations are beyond the control of the average driver.

Most experts agree, that locking the rear wheels is
more dangerous than locking the front wheels. Again, many variables enter into the problem, two are certainly worthy of note. Most vehicles are driven by two wheels and yet braked by all four, this produces a discrepancy with braking efforts needed and the difference is not a constant which can be solved easily. The second problem is almost a reverse of the first. Again, all four wheels are involved in braking, but only the two driven wheels are affected by the braking effort of the engine and the transmission.

Another braking test shows some unusual variables relating brake pedal force to brakeline pressure. The test vehicle was a 1967 Ford Country Sedan equipped with power drum brakes. The relationship studied was brakeline pressure versus pedal force characteristics for fast and slow brake pedal application rates. The slow rate was defined as 3.3 seconds to reach maximum pedal force while the fast rate was defined as .21 seconds to reach the same. The brakeline pressure showed almost 700 p.s.i. with a pedal force of 40 pounds using the slow rate to only 20 p.s.i. for the same pedal force at the fast rate. When the pedal force reached 100 pounds, the slow rate showed 850 p.s.i. while the fast rate showed 550 p.s.i. When the pedal force reached 150 pounds both the slow and fast rate showed 1100 p.s.i. in the brakelines. The purpose of this test was not to
determine which rate was best for applying brakes, but to show that the "rate of application" alone affects the resulting brakeline pressure.\textsuperscript{42} It can be safely concluded that designing automotive brakes is one of the most complex problem areas facing automotive engineers.

**Federal Brake Standards**

Brakes must be able to withstand a series of hard stops from various speeds and under different conditions to ascertain performance when hot, cold, wet, or dry.\textsuperscript{43} Details of exact requirements are described in section D of Society of Automotive Engineers Practice J 937, "Service Brake System Performance Requirements - Passenger Car," June 1971.\textsuperscript{44} One of the new additions to automotive brake systems has been the dual master cylinder, developed first by American Motors and available on their 1962 models as standard equipment.\textsuperscript{45} The dual master cylinder, listed as the emergency brake system in the Federal Standards, became mandatory January 1, 1968.\textsuperscript{46} The dual master cylinder is designed with separate hydraulic systems for the front and rear brakes so if a wheel cylinder or brake line should fail, the vehicle can still be brought to a controlled stop. Federal Standard #105 states specifications for stopping of the vehicle if only the front or rear brakes are in operation. If either the front or rear hydraulic system should fail, the remaining portion of the brake system
must stop the vehicle from 60 m.p.h. in 646 feet or less. The standard also gives load requirements and details of the coefficient of surface friction, etc.

In addition, manufacturers must install a red warning light on the instrument panel which turns on before or upon application of the brakes in the event either the front or rear hydraulic system should not be in working order. This gives a signal to the driver that his brake system needs attention immediately. This type of device is advantageous "if" the driver heeds the warning, but there is evidence of driver negligence. In a recent study by the California State Automobile Association and the Southern California Automobile Club, it was found that only in 6% of the fatal accidents a mechanical failure or maintenance defect appeared to be a contributing factor, and in most cases the driver or owner was aware of the defect prior to operating the vehicle on the day of the accident. A second fact was that more than half of the mechanical problems involved braking systems.

The last two federal regulations involving brake systems deal with the parking brake system and the hydraulic brake hoses. The parking brake system must be operated solely by mechanical means and must be able to hold a loaded vehicle in both a forward and reverse direction - within limits of road traction - on a grade.
of 30%. Although the federal standards do not require a "park" position on automatic transmissions, most domestic automobiles now provide such a position which helps to share the load with the parking brake.

The hydraulic brake hose assemblies must provide corrosion protection for the end connections, identify the manufacturers, and meet specified requirements that will reduce the possibility of brake failure due to leakage. Brake hoses must be able to withstand 5,000 p.s.i. pressure, withstand thirty-five hours of continuous flexing without leaking, withstand a 325 pound pull without separating from the fittings, and withstand special tests for cold and salt water.

**Disc Brakes**

Many recently manufactured automobiles are equipped with front disc brakes, and some with disc brakes at all four wheels. Drivers should know how disc brakes operate and what advantages they offer. Instead of a rotating drum with a braking surface perpendicular to the plane of the wheel, the disc brake has a rotating disc in a plane which is parallel to the wheel. The disc brake shoes are located on both sides of the rotating disc and squeeze against the disc whenever hydraulic pressure is applied to the wheel pistons.

Most automobiles with disc brakes have front disc brakes and rear drum brakes. There have been some
problems which have limited the use of disc brakes on rear wheels. Because of rear axle lateral end movement - which would tend to apply the disc brakes - disc brakes are basically limited to automobiles with independent rear suspension, such as the Chevrolet Corvette.\textsuperscript{55} Another problem with rear disc brakes has been the problem of designing a satisfactory parking brake. The mechanically operated system does not supply sufficient pressure to keep the disc brake pads sufficiently tight against the disc to hold the automobile on the required 30\% grade. A solution has been the development of an internal expanding brake system such as regular drum brakes. This is an expensive solution.\textsuperscript{56}

There are additional problems when an automobile has front disc and rear drum brakes. First, disc brakes take almost double the hydraulic pressure of a standard drum brake. With both systems on the same vehicle, some means must provide this pressure differential.\textsuperscript{57} Most automobiles with front disc brakes and rear drum brakes use a proportioning valve. When line pressure exceeds 300 p.s.i., the proportioning valve starts limiting rear line pressure to prevent rear wheel lockup; when the front disc brakes are using a pressure of 900 p.s.i., the rear wheel drum brake pressure will be about 600 p.s.i.\textsuperscript{58}

A second valve, known as the metering valve is used
in some applications. The rear drum brakes must work against the brake shoe return springs while the front disc brake pads have no resistance to overcome before contacting the disc.\textsuperscript{59} The metering valve does not allow any pressure to go to the front wheels until the rear shoe return spring pressure is overcome, which is about 100 p.s.i.\textsuperscript{60} Without a metering valve, the front brakes would be applied first instead of simultaneous application of front and rear brakes.

Disc brakes do have advantages. They cost less per mile to maintain than drum brakes and they have much more resistance to "fade" because they dissipate heat better; this is because of the large disc surface area exposed to the air and because of the fins built into the disc.\textsuperscript{61} Disc brakes also have greater braking power, have a self-cleaning action, and require no adjustment.\textsuperscript{62}

**Power Brakes**

Power brakes are designed to increase or boost the braking force of the automobile brake system.\textsuperscript{63} Although there are different makes and designs, they all operate in basically the same manner. Because the physical strength of the driver limits the force which can be applied to the brake pedal, some device is needed to help make braking easier. The brake booster consists of an enclosed diaphragm with vacuum on one side and
atmospheric pressure on the other side. The diaphragm will move towards the side with vacuum. The movement of the diaphragm is applied to the master cylinder push rod to provide the necessary increase in force over foot pressure. The larger the area of the diaphragm, the more help it provides the driver. If this same diaphragm has manifold vacuum or atmospheric pressure on both sides at the same time, there will be no movement because pressure will be equal on the two sides of the diaphragm. When the driver pushes on the brake pedal, he moves a valve which admits atmospheric pressure to one side of the diaphragm. The diaphragm and linkage move towards the master cylinder to help apply the brakes. A diaphragm of 50 square inches, with atmospheric pressure on one side and a partial vacuum of 15 inches of mercury on the other side, would develop a force of almost 370 pounds to "help" the driver apply the brakes.\(^{64}\) The other parts of the brake system are the same as conventional brakes. The power brake unit involves only the master cylinder and linkage.\(^{65}\)

**Anti-Skid Brake Systems**

"Analysis of automobile accidents involving one or more fatalities by Dr. Moseley and his team at Harvard Medical School shows that, in most situations, both steering and braking are critical."\(^{66}\) "When the driver can maintain vehicle control through steering, both
prior to and during panic brake application, he stands an excellent chance of avoiding an accident or reducing its severity.\(^6\)

There is a common misunderstanding that the anti-skid or anti-lock brake system is a device designed solely to bring the automobile to a stop in a shorter distance than if the wheels are in a locked-up position. Conditions exist where the anti-skid device will actually take a longer distance to stop the automobile than if the wheels were locked. However, the vehicle will be under the driver's control rather than be in an uncontrolled skid.

"The operating environment with which anti-lock systems must contend is broad and encompasses almost an infinite number of combinations of road surfaces constructions, road surface contaminants, tire designs, tire tread wear and vehicle parameters."\(^6\) It is important that testing of prototype anti-lock systems be done very carefully before the systems are released to the driving public. There are many performance tests that anti-lock brakes should pass, these include: (1) panic stops on dry pavement, wet pavement, gravel road surface and ice; (2) panic stops from high speed on low coefficient surface; (3) braking on ice with fast and slow brake pedal application rates; (4) panic braking on a
non-uniform ice/dry pavement surface such that the vehicle travels from ice to dry pavement during the stop; (5) panic braking on a non-uniform ice/dry pavement surface such that the vehicle travels from dry pavement to ice and back to dry pavement during the stop; (6) panic stops on dry pavement with built-in bumps; (7) panic stops on the multi-friction lane with the car straddling ice on one side and dry pavement on the other side; (8) and maneuverability on wet pavement and ice for four wheel anti-lock systems.69

There are rear wheel anti-skid brake systems available to the public, but at the time this paper is being written, no four wheel anti-skid brake systems have been released for public use. A typical anti-lock brake system would have three main components, a device to sense wheel speed, a device to regulate brake hydraulic pressure going to the wheel brake cylinder, and a device which can take information coming from the wheel speed sensor and convert it to the signals which control the valving system to regulate the brake hydraulic fluid pressure.

The speed sensor is a pulse generator which induces an AC voltage in the pick-up coil with a frequency directly proportional to the wheel speed.70 The device which controls the brake hydraulic pressure is known as a pneumatic actuator.71 The pneumatic actuator operates
somewhat like a power brake unit; a diaphragm unit has
engine vacuum on both sides and atmospheric pressure is
admitted to one side of the diaphragm whenever the com-
puter receives the signal that wheel speed approaches
lockup. The diaphragm moves towards the side which
still has vacuum. Hydraulic pressure to the wheel cy-
linger is blocked by a ball check valve. As the diaphragm
keeps moving towards the vacuum side, the closed volume
of the brake fluid is expanded and the brake pressure
drops. "From the point where the wheel speed starts to
recover, the computer, through the control valving, mod-
ulates brake pressure so as to maintain wheel speed at
its optimum slip valve." 72

The anti-skid brake system has a serious challenge
to providing a panic stopping distance equal to or
shorter than a locked-wheel stop basically because of
the wide range of road surface friction coefficients. 73

Special test road sites located at the General
Motors Proving Ground, Stevens Point, Wisconsin and
Dunnellon Airport, Marion County, Florida revealed that
anti-lock brake systems will not significantly reduce
stopping distances on dry asphalt and concrete at
60 m.p.h. 74 The second test surface was a gravel road.
"Each rear wheel tracks in the path left by a sliding
front tire; since the locked front wheel plows aside
most of the loose gravel, the rear tire is in contact
with a gravel road surface having little or no loose gravel cover.\textsuperscript{75} Anti-lock brake systems used on gravel roads revealed the difference between four wheel anti-lock systems and rear wheel anti-lock systems. Because of the problem mentioned concerning tracking, the four wheel anti-lock test showed longer stopping distances than either the rear wheel anti-lock brake system or the locked wheels.\textsuperscript{76} With the four wheel anti-lock brake system, the front wheels roll over loose gravel leaving the surface almost undisturbed; this leaves almost the same road surface for rear wheel traction.\textsuperscript{77} It is, without question, easier to stop an automobile on a gravel road where loose gravel has been removed than where the loose gravel has not been removed. On the rear wheel anti-lock brake system, it is the front wheels which are removing loose gravel for the rear wheels.

The third test surface was a wet pavement. Anti-lock brake systems provide significant improvement in braking performance on wet pavements, with a greater reduction in stopping distance over conventional brakes as vehicle speed increases.\textsuperscript{78}

Tracking plays an important role in the operation of the anti-lock system. The front tire squeezes the water out of the track for the rear wheel, so the water depth will be less when the rear wheel reaches that point.\textsuperscript{79} Since the water depth affects the friction
ratio, the rear wheels will do a better job of braking if the front wheels have traveled the same path. On a wet pavement, a four wheel anti-lock system produces the shortest stopping distance, second best is the rear wheel anti-lock system, and last is the conventional brake system with no anti-lock features.

Another fact helps to show the advantage of the anti-lock brake system on a wet pavement. On wet pavement, the locked wheel stopping distances increase with increasing water cover depth. However, the ability of anti-lock brakes to reduce stopping distances on wet smooth-textured road surfaces is not markedly affected by water cover depth. The anti-lock control provides a constant percent reduction in stopping distance as compared with the locked wheel stopping distance over a wide range of water cover depth, therefore the absolute stopping distance with the anti-lock braking system increases with the water cover depth.

The fourth surface tested was an icy surface, and, as was true with dry pavement, the anti-lock system had trouble obtaining panic stopping distances shorter than locked brakes. The amount of information available concerning the performance of anti-lock brake systems on ice was limited, but it did conclude that a locked wheel had the shortest stopping distance, second best was the anti-lock brake on rear wheels only, and the longest
stopping distance was with the four wheel anti-lock system. Stopping distance alone is not the only important factor when considering the braking process on an icy pavement; directional control is more important. It will be shown later that the four wheel anti-lock brake system with studded tires will give both the directional control and stopping distance desired. If the road surface is snow covered, again the locked wheel showed an advantage over an anti-lock brake system, considering only the stopping distance. This is based on the fact that a locked wheel brakes through the snow and grips the underlying pavement while the anti-lock brake system just rolls over the snow. Again, the anti-lock brake on the rear wheels only will give a shorter stopping distance than the four wheel anti-lock system, because the front wheels will scrub a clear path for the rear wheels, provided the automobile is tracking.

Information as to the effect of tire design on ice anti-lock performance is limited. Radial, belted, cross-ply, snow and studded tires were each tested. The main objective was to determine if torsional dynamic properties of different tire constructions affected the operation of the anti-lock brake system. Oscillographic records did not show that different types of tire construction had any adverse effect on anti-lock operation although the tire torsional dynamics differed for each
Also, the number of studs per tire as related to its ability to reduce stopping distance was studied, and tires tested with 108 studs showed a brake friction coefficient of .4 while the tires with 200 studs per tire showed a friction coefficient of .9. This gives a shorter stopping distance to the car with the 200 studs per tire. On ice, studded tires offer the greatest potential for improved braking performance, and when used with the anti-lock brake system, it gives the best steering control and the shortest stopping distance.

The last variable tested in relationship to the efficiency of the anti-lock brake system was tire tread wear. It must be noted that stopping distance with locked wheels increases as tire tread wear increases; this is due to the decrease in friction coefficient of a tire as the tread wears. Stopping distance with an anti-lock brake system also increases as tire tread wear increases, but the increase in distance is less with the anti-lock brake system than with locked wheels. With a bald tire, the anti-brake system will reduce stopping distance as compared with a locked wheel, but the absolute stopping distance with the anti-lock brake and a bald tire, is still longer than the locked wheel which has full-treaded tires.

Directional control of the vehicle during panic
braking is more critical than the actual stopping distance. It was found that with the four wheel anti-lock braking system in operation, the changing of lanes and tracking while taking a curve were almost equal to the same maneuvers during no braking at all. On wet pavement, lane changes could be readily made when panic braking from 60 to 70 miles per hour. When equipped with bald tires, the same maneuvers could be made up to 45 miles per hour with anti-lock braking assisting directional control.

"One commonly encountered road condition during winter driving is where the wheels on one side of the car are on ice or snow and the other side is on dry or wet pavement." The test condition used had a friction coefficient of .6 for the left wheels and .2 for the right wheels. At 30 miles per hour with locked wheels, the vehicle will rotate counterclockwise approximately 100 degrees while sliding forward. With a good rear anti-lock brake system, the vehicle will drift towards the side with the higher friction coefficient but it will not spin out. With the four wheel anti-lock brake system, the vehicle will not drift at all so long as the driver makes the necessary steering correction; but if the driver freezes at the steering wheel, then the car will spin out in a manner similar to what happens with locked wheels. Therefore, even with the
four wheel anti-lock brake system, the driver plays an important role in preventing a skid; he must make the necessary steering correction.

The final test also provided evidence that anti-skid braking systems are a must for automotive safety. This test was conducted to compare locked wheel braking, rear anti-lock braking, and four wheel anti-lock braking under a condition that is frequent in all parts of the country, the operation of a car equipped with tires that do not have uniform wear. The results included total stopping distance, yaw angular deviation, and drift of the car when a panic stop was made from 55 miles per hour on wet asphalt with non-uniform tire wear. One side of the car had bald tires and the other side of the car had tires with full tread. With no anti-lock brake system, the total stopping distance was 360 feet, the yaw angular deviation was 180 degrees, and the lateral drift was 4 feet towards the side with the full tread. With a rear anti-lock brake system, the total stopping distance was 293 feet, the yaw angular deviation was 5 degrees, and the lateral drift was 15 feet towards the side with the full tread. With the four wheel anti-lock brake system, the total stopping distance was reduced only 3 feet from the rear anti-lock brake system, but there was an absolute zero degrees yaw angular deviation and no lateral drift. Although
there are still problems to be solved, the prototype anti-lock braking systems has a high performance acceptability based on the tests reviewed for this report.

**Reflective Surfaces**

Drivers have experienced, at some time in their driving, the bright reflection of the sun from some part of the car. One of the most recent federal safety standards deals with this problem. It states that reflective coefficient of the surface of materials used for certain bright metal components shall not exceed specific limits. The components include windshield wiper arms and blades, inside windshield mouldings, horn ring and hub of the steering wheel assembly, and inside rearview mirror frame and mounting bracket. Additional steps have been taken by the automotive industry to help reduce glare in non-required areas. Chrysler and other manufacturers have sprayed special lacquers on the top of the instrument panel and the steering column which diffuses the light striking these surfaces. The instrument panels also have a dull non-reflective finish.

**Lamps and Reflective Devices**

Part of accident avoidance involves effective communication among drivers. A major portion of inter-vehicular communication is provided by the lighting and signaling system. Rear-end collisions account for 49
percent of all accidents and 10 percent of the fatal accidents. There was no question that most of the drivers in the rear car did not know what the driver in the front car was about to do.\textsuperscript{106} All new vehicles sold in the United States must have a specified number and type of lamps and reflective devices placed at specific heights where they can be seen during darkness or during poor visibility.\textsuperscript{107} The hazard warning system (four-way flasher) must operate independently of the ignition switch; there must be an indicating light or device on the dashboard to tell the driver his high beam headlamps are on, and a number of other special wiring requirements are included in the federal standards.\textsuperscript{108}

All passenger cars sold in the United States must be equipped with two white 7-inch or four white 5 3/4-inch headlamps and two amber parking and turn signal lamps at the front. Each side must have an amber front marker lamp and reflector and a red rear marker lamp and reflector. At the rear requirements include two red tail lamps, two red or amber stop lamps, two red or amber turn signal lamps, one white license plate lamp, one white back-up lamp, and the vehicle must be equipped with flashing turn signals and the four-way emergency flasher unit.\textsuperscript{109} Many performance tests are also required for these components following designated S.A.E. standards.\textsuperscript{110}
"The fact that the traffic accident death rate at night is considerably greater than in daytime--by a factor of 2.6 in 1968--seems to indicate that visibility is a problem, assuming, of course, that the driving population at night constitutes the same cross section as during the day." Some of the major problems in the lighting area include forward lighting and glare, rear lighting arrangements, visibility of vehicles under adverse weather conditions, and maintenance of lighting equipment.

Forward Lighting Systems

The forward lighting system involves a unique problem. It must project sufficient light ahead of the vehicle to reveal the roadway and objects on or near the roadway, and at the same time it must not interfere with the vision of a driver of an approaching vehicle or with the vision of the driver directly ahead. In the United States automobiles have been equipped with high and low beam headlamps. The former distributes a high intensity region for distance viewing and a broad low intensity for the foreground. The latter distributes light quality based upon glare limitations for the oncoming and leading vehicles.

These limitations have produced problems on which research has been conducted. Studies have been made
regarding optimum size of headlamps, shifting of light filaments in relation to the focal point, the use of halogen bulbs, the addition of an interstate highway beam to high and low beam (a special beam for interstate highway driving only--a third beam in addition to the present two), the shape of headlamp bulbs to change optical characteristics, and a study involving "selected yellow light," "interrupted light," and "polarized light." There are hundreds of pages of research reports available regarding the use of polarized light for automobile forward lighting. Much of it is beyond the level of layman understanding. The concept of polarized lighting seems to offer an ideal solution to provide all the light needed while offering glare relief to the drivers of approaching or leading vehicles. However, the idea of polarized headlighting has been thoroughly considered by the United States auto industry, and so far it has been set aside. Technical problems have been found to be extremely difficult to solve in regard to depolarization of light by surfaces and by atmospheric conditions, to conditions where the polarizer is not needed (such as city driving), to the problem of hidden vehicles in dips or around turns in the road, and to problems of "ghost" images in windshields. It has been concluded at this time that a practical polarized headlighting system for automobiles
Another experimental forward lighting system uses an elliptical optical system and a projection lens. The projection lens collects the light passing through the secondary focus and forms the beam ahead of the lighting unit.\textsuperscript{123} In the United States this lighting system was manufactured and used as original equipment on the Dodge Polara and Monaco under the name "Superlite."\textsuperscript{124}

Two other forward lighting system adaptations have been tried to add safety to night driving. The first is a headlamp with an integral aiming and inspection gauge which has been tried experimentally by General Motors.\textsuperscript{125} The horizontal aiming is done by mounting the two headlamps on each side on a mounting plate and then adjusting the plate according to a mechanical aimer incorporated into the headlamp construction. The vertical aimer is a bubble gauge, also incorporated into the construction, which can be adjusted with a single screw. Claimed benefits are: headlamp mounting that permits lamps to be replaced without necessity of re-aiming, quick factory inspection at production, minimized field inspection problems such as safety inspection stations, and car owners who pull boat trailers or otherwise have heavy rear end loading can quickly readjust their own headlight aim.\textsuperscript{126}

The self-leveling headlamp has also received
attention from researchers. The purpose of the self-leveling headlamp is to improve the accuracy of aim under all conditions, especially under acceleration, braking, load variations, and wind sway. The basic self-leveling headlamp system consists of three components: a sensing unit which measures the inclination variations of the vehicle in relation to the ground, a device to transmit this signal, and an operating unit that modifies the headlamp position according to the signal it receives from the sensing unit. The basic difference in the systems developed is the method of transmitting linear or angular motion from the sensing unit to the operating unit. The best method to this time is an electrical transmission, such as that used in aircraft. Cost has eliminated this solution. Three alternate solutions used have been mechanical cables used by Citroen, a pneumatic device used by D.B.A. Company, and a hydraulic device designed by the Projeteurs Cibie Company.

Although the design of self-leveling devices for headlamps involves some complications, the following requirements should be fulfilled: acceleration and deceleration must not change headlamp orientation by more than 1/4° (without actuating the self-leveling device, acceleration could easily raise the light beam 2 or 3°), when submitted to aerodynamic pressure of wind velocity,
self-leveling headlamps must withstand a 10 kg strain, beam orientation change must not exceed $1/4^\circ$ for any load on the vehicle, and temperature variations must not affect headlamp aiming.\textsuperscript{131}

**Automobile Rear Lighting**

Rear-end collisions account for approximately half of all automobile accidents, and the driver of one of the vehicles is usually at fault.\textsuperscript{132} The most common errors are following too closely, driving too fast for conditions, driving while intoxicated, and driver inattention. A question has been raised regarding the feasibility of some change in vehicle design to reduce rear-end collisions.\textsuperscript{133}

The main functions of rear lighting systems are to indicate: stopping, turning, tail or presence lights, hazard warning, and back-up lamps.\textsuperscript{134} It is generally agreed by lighting experts that stop lamps and turn signal lamps should be separated. There is less general agreement that there should be separate turn signal lamps and tail lamps.\textsuperscript{135} Most lighting experts agree that red is the best color for the stop lamps, but the best color for the tail and turn signal lamps has been debated. Research studies recommended the use of red stop lamps, amber turn signal lamps, blue-green tail lamps, and white back-up lamps.\textsuperscript{136} Blue-green provides
good discrimination from white and is easily discriminated from red lights by color-blind drivers. Blue-green also suffers relatively no loss in transmission through fog when compared to red.

Under normal conditions at night driving against low-beam headlamps, the recognition distance of different color rear lamps was tested. The following median distances were found for 0.7 candlepower lamps; red = 3,000 feet, green-blue = 2720 feet, and amber = 2500 feet. These results reinforce the recommendations mentioned previously, using the strongest color for the stop lamps, second strongest for tail or presence lamps, and the third color for the turn signal lamps.

The intensity of each rear lamp is also of great importance. It should be noted that one of the greatest problems is that lights which are visible at night without glare do not provide adequate visibility in daytime. This is one problem to which no evident solution has been found. The following minimum and maximum recommended candlepower values for a lamp 12 square inches in area were found for red: night minimum = 80 c.p., night maximum = 185 c.p., day minimum = 300 c.p., day maximum = 2400 c.p. This raises the question, how can an automobile stop lamp meet both night and day recommendations? One possibility would be to have the intensity depend on whether the headlamps were on, that
is, the voltage applied to the stop lamp bulb would be dependent on whether the headlamps were on or off.

The location of each of the rear lamps in relation to the other rear lamps was also studied. The recommendation was to have the tail lamps furthest outboard, the turn signal lamps next to the tail lamps, and the stop signal lamps inboard of the turn signal lamps. Another recommendation in the same study was to have additional tail lamps above the rear window and as far outboard as possible, as a combined horizontal-vertical lamp array can provide better information for the perception of a change in headway than a horizontal array.

Experts agree that deceleration of an automobile should be indicated to the driver behind; at the present time, there is no signal for deceleration of an automobile. Several proposals have been made for signaling vehicle deceleration. One method would be to use different colors to indicate the rate of deceleration, green for light deceleration, amber for medium deceleration, and red for a maximum deceleration rate or panic stop. Another proposal is to have an amber lamp turn on whenever the accelerator pedal is released and a red lamp turn on whenever the brake pedal is used. A third proposal is to have the stop lamps flash at an increasing rate as the rate of deceleration increases.
One research reports a warning that actual road testing must be intermixed with laboratory testing while evaluating lighting systems.\textsuperscript{147} A deceleration light study was made with rear mounted amber lights which would light up whenever driveshaft speed was reduced. There was also a control in the system which indicated the rate of deceleration.\textsuperscript{148} It was observed that many people tend to let up on the accelerator when approaching a curve or a rise in the road and it was felt that the car was "crying wolf" too much of the time; the driver of the following car began to ignore the warning light signals.\textsuperscript{149} It must be mentioned that there is a measurable reduction in the time available for a following driver to react to the deceleration of the lead car.\textsuperscript{150} A solution to the present problem of deceleration lighting lies somewhere close to this lighting arrangement.

The use of side turn signals in addition to front and rear turn signals has also been suggested by many experts. Some recommendations propose completely separate side turn signal lamps because they feel that the current front and rear turn signal lamps are mounted too low to be effective as side turn signals.\textsuperscript{151} The advantage of having the additional turn signal lamps on the side would be in freeway traffic where lane changes occur when the car in the adjacent lane does not have
the rear turn signal lamps within view. Another recom-
mendation concerning turn signals is to require separate
pilot indicators for left and right and to require the
flasher unit to be loud to attract the driver's atten-
tion when he is giving a false signal to the driver
behind. 152

"Motor vehicle inspection reports indicate 10 per-
cent of the vehicles checked have one or more of the
required lamps inoperative." 153 The drivers usually are
not aware that the light is not functioning because of
the lack of suitable lamp-failure indicators. Some of
the present models, such as Chevrolet Corvette, use
fiber-optic dashboard indicators to show if the lamps
are working. 154 This solution again depends upon the
driver. Many are too careless to notice the indicators.
Some are too careless to have the bulb replaced even if
they know it is burned out.

The final recommendation concerning rear lighting
is to require the stop lamps to stay on when the engine
is running with the vehicle at rest. 155 Unless the
driver keeps his foot on the brake pedal when the vehi-
cle comes to a rest, the present stop lamps are not
lighted. It is especially important that stop lamps be
on when the vehicle is stopped in fog or in other poor
visibility conditions, because the high intensity red
stop lamp is visible further than any of the other rear
lamps. 156

"Since the evaluation of signaling systems is complex and over 100,000,000 drivers will be affected by any changes, some of the recommended changes require considerably more research than has been accomplished and reported." 157

**Tires and Rims**

The federal standards which regulate tires and rims extend for sixty pages. Only a summary will be given. Some basic terms or definitions need to be given with the summary of testing by the automotive industry.

The following definitions have been selected from the federal standards to clarify the terms used when discussing tires. 158 The "carcass" is the tire structure excluding the rubber tread and sidewall. The "bead" means that part of the tire made of steel wires, wrapped or reinforced by ply cords, that is shaped to fit the rim. "Ply" means a layer of rubber-coated parallel cords. "Cord" means the strands forming the plies in the tire. A "bias ply tire" means a pneumatic tire in which the ply cords that extend to the beads are laid at alternate angles substantially less than 90 degrees to the centerline of the tread. A "radial ply tire" means a pneumatic tire in which the ply cords which extend to the beads are laid at 90 degrees to the centerline of
the tread. "Tread separation" is the tread pulling away from the tire carcass.

The tires on today's automobile must be tested to be sure they meet minimum performance requirements for strength, endurance, high speed performance, and resistance to bead unseating.\textsuperscript{159}

The strength test consists of forcing a 3/4 inch steel plunger into the periphery of a tire inflated to a specified pressure until the plunger reaches the wheel rim. This is done at five points equally spaced around the tire circumference.\textsuperscript{160} Results must meet federal requirements for minimum breaking energy.

The endurance test uses a flat faced steel wheel, which is pressed against the tire and wheel assembly at a specified test load and driven at 50 m.p.h. for 4, 6, and 24 hour periods at 100° F.\textsuperscript{161} After completion of the laboratory wheel endurance test, federal standards specify that the tire shall have no tread, ply, cord, or bead separation; chunking; or broken cords.

The high speed performance test uses the same steel wheel as the endurance test. The tire is tested at 50 m.p.h. for two hours, 75 m.p.h. for thirty minutes, 80 m.p.h. for thirty minutes, and 85 m.p.h. for thirty minutes.\textsuperscript{162} After completion of the laboratory high-speed performance test, federal standards specify that the tire shall have no tread, ply, cord, or bead
separation; chunking; or broken cords.

The bead unseating test uses a wedge-shaped block which is forced against the outer sidewall of the tire. The test is repeated at four equally spaced points at the rate of two inches per minute until the bead unseats from the tire rim. Unseating loads are then compared against load ratings specified in the federal standards.

The federal standards include maximum tire load ratings and inflation pressures, minimum physical dimensions, and specific labeling instructions are given for the various types and sizes of tires. All tires manufactured on or after August 1, 1968, must incorporate a tread wear indicator that will provide a visual indication that the tire has worn to a tread depth of 1/16 inch. When the tire wears to a tread depth of approximately 1/16 of an inch, a strip of rubber extends across the width of the tread surface without the normal groove between treads; these wear indicator strips extend around the tire circumference at about six-inch intervals. The federal standards require specifications on which tire selection is based to be permanently displayed on the glove box door or other accessible location. These specifications include vehicle capacity weight, designated seating capacity, vehicle manufacturer's recommended cold tire inflation pressure for a maximum loaded vehicle weight, and the vehicle
manufacturer's recommended tire size designation\textsuperscript{166}.

All of the domestic auto manufacturers have their own tire test facilities in addition to those owned by the tire manufacturers. One of the most comprehensive facilities is at the General Motors Proving Ground in Milford, Michigan. Known as the Tire Performance Evaluation Facility, it provides indoor facilities and equipment to complement extensive tire road testing at General Motors Desert Proving Ground at Mesa, Arizona, on public highways, and on the Milford installation's road system\textsuperscript{167}.

To test tire endurance, three two-station dynamometers and two four-station dynamometers are used. These dynamometers can test tires at speeds up to 200 m.p.h. - federal standards only require 85 m.p.h. - and at loads up to 10,000 pounds\textsuperscript{168}. These machines can be programmed to run unattended. Speed, load, and tire inflation pressure are changed automatically according to predetermined schedules\textsuperscript{169}.

Dynamometers are used to test tire endurance and high speed performance of tires. Other laboratory tests are used to measure carcass strength and bead unseating resistance. The carcass strength is tested by using a steel plunger under compression and a plotter to compute the tire's resistance to breaking. The bead unseating tester measures the ability of a tire-wheel combination...
to sustain high side loads encountered by striking a curb or during severe maneuvers. Strain gauge type load cells in the base of the tire-mounting fixture measure the vertical force applied to the tire throughout the test.

There are other factors that affect tire ride quality. Two separate machines are located at the General Motors Tire Performance Evaluation Facility for studying tire ride quality. A tire uniformity machine measures radial and lateral force variations in tires with fixed loaded rolling radius, with results monitored on display meters. The machine is also used to spot-test tires General Motors purchases from tire manufacturers for their five automobile divisions and for investigating other tire non-uniformity induced vehicle vibration problems.

The spring rate machine is used in ride performance evaluation and for computerized suspension design problems. Tire spring rate is one of the factors that controls the tire's response to road bumps longer than the tire contact patch length. Research has revealed that the relationship between the spring rate and inflation pressure can change significantly with different tire construction. Spring rate data must be evaluated at more than one inflation pressure.

"All forces, excluding the aerodynamics which
affect the directional control of a vehicle are applied at and through the tire-road contact patch."\textsuperscript{176} It is desirable to be able to study these forces to know how they affect vehicle directional behavior. The General Motors facility has two separate machines for studying the tire and its relationship to the directional control of the automobile. The first, known as the Flat Bed Tire Force and Moment Machine, provides for a tire to be supported in an assembly whereby vertical load, camber, slip angle, and wheel torque can be controlled and forces recorded.\textsuperscript{177} The second machine is a trailer-type test machine; the tire is mounted on a test trailer and the same tests are made as are made with the Flat Bed Tire Force and Moment Machine.\textsuperscript{178} These machines allow engineers to study new tire construction and to study the directional behavior of the vehicle using new tire designs.

It is important that tires being tested are a true sample of normal tire production and that some unknown flaw does not exist in the tire. The tires are inspected before they are used for any testing, not only to detect flaws but to give a base for comparison after the tire has been tested to see what changes, if any, have taken place. One method of inspection utilizes a mechanical tire inspector with hydraulic assists. The tire is spread at the bead and rotated to enable careful
visual inspection. A more thorough inspection is done with a tire x-ray machine which can penetrate up to three inches of tire carcass.

In order to make a complete evaluation of tire performance, actual road testing must be added to the laboratory machine testing. One road testing device used at the General Motors Proving Grounds is a friction test trailer. This friction test trailer is towed behind a truck equipped with instruments to record brake torque, vertical force, longitudinal force, braked wheel speed, unbraked wheel speed, and vehicle speed. A sliding wheel takes a longer distance to stop than a wheel which is braked but still has traction. The friction test trailer is used to find the percent of wheel slip under different loads and different road conditions. A free rolling wheel is operating at 0% slip and a locked or sliding wheel is operating at 100% slip. Water from the truck is used to wet the testing surface to conduct wet traction test. A similar vehicle is used to measure tire driving traction capability. Rather than testing the slip involved when brakes are applied to the wheel, it measures the tire slip involved when a vehicle is under acceleration.

It is necessary to conduct traction tests on several different types of surfaces to correctly evaluate the traction ability of a tire. A wet smooth surface would
best evaluate the ability of tire tread design to remove water from a surface while a textured surface would be best to evaluate the traction differences caused by changes in tread rubber compounds. A number of different surfaces are available at the two General Motors test facilities for tire traction evaluation. Most of the tire traction test surfaces are a part of the regular test tracks. This allows for testing on turns as well as straight ahead, and for checking traction on both up and down grades. In actual customer usage, tires will be operated over a wide range of road surface types. It is not possible to perform tests on every type of surface that exists, so the most common surfaces are used. These include: asphalt, concrete, polished concrete, traffic painted asphalt, Jennite, plus water and snow covered surfaces. Test surfaces also provide the necessary environment for high speed testing, braking and cornering maneuvers.

A very important advancement in tire testing has been the development of several devices which can rapidly deflate a tire on a moving vehicle. A number of versions have been developed using blasting caps to rupture the tire. Probably the least expensive device involves using a short piece of sharpened 2 1/2" pipe to cut the tire, the disadvantage being that it requires skill on the part of the driver to strike the pipe which
is located on the road surface. A unique device has been developed for driver training use which can be reused and does not damage the tire. The teacher in the driver training car can release the air pressure from a front tire while the car is in motion. A supply tank carried in the car is used to reinflate the tire. All these devices are used to evaluate vehicle and driver response to loss of tire inflation pressure and to work with the federal standards involving tire and tire rim requirements.

**Rearview Mirrors**

Vision accounts for more than 90% of the information a driver receives. The vision to the rear is provided by mirrors. All automobiles today are equipped with inside and outside rearview mirrors. Some vehicles are also equipped with an outside rearview mirror on the passenger side of the car.

The federal standards list basic requirements for both rearview mirrors. The outside rearview mirror on the driver's side must provide a view of the road at least 8 feet wide 35 feet behind the driver's eyes, and extending to the horizon. The driver must be able to adjust the mirror from his seated position. The outside rearview mirror and its mounting must not have sharp points or edges, and it may not project beyond the
widest point of the vehicle unless it is necessary to do so to meet visibility requirements. The mirror must meet the minimum reflectance value of 35%. A deflecting or breakaway inside rearview mirror with vertical and horizontal adjustment must provide a 20% horizontal field of view and sufficient vertical angle to see the road extending from 200 feet behind the car to the horizon. If the inside rearview mirror cannot meet specifications, the car must have an outside rearview mirror on the passenger side.

The evolving trend in rearview mirrors has been to provide the driver with a larger mirror to help increase his vision both alongside and behind the vehicle. The area of greatest importance to the driver is the horizontal view and the standard 8-inch mirror has been replaced by 10 and 12-inch mirrors. There are a number of factors which determine the effective field of vision, such as the distance between the mirror and the driver's eyes, but the effective view of an 8-inch mirror is about 17 inches. Rear vision not only is limited by the mirror and the driver's eyes, but also by the rear window opening and the distance from the mirror to the rear window.

The width of the inside rearview mirror must be limited so that it does not sacrifice too much forward vision, therefore some alternate ideas have been studied.
concerning driver rear vision. One of these ideas has been the periscope which has been considered since 1941. There are numerous problems concerning the periscope. The greatest problem is the large vertical head and eye movement required which is difficult and objectionable for the driver. A second problem is that it presents additional difficulty for the driver who wears glasses. A more complex periscope system has been proposed which displays the rear view on the dashboard through an optical path. The basic periscope system is designed to display the rear view high in the windshield area. This also presents serious problems, because in folding the optical path, mirrors and lenses are required to provide the necessary image uprighting and reversals for normal display of objects in the rear field of view. Still another factor is that the vertical vantage point with the periscope is at roof level or higher while the present mirror system provides the driver with a rear vertical vantage point just slightly higher than that for the front. It is easier for the driver to have approximately the same vertical vantage point for the front and rear vision so that no difference exists in references and orientation between forward and rear vision.

Another proposal has been to use closed circuit television; the image display and optical problems are
the major drawbacks. 208 "Extremely wide angle lenses, with their inherent distortion, are required to provide a wide-angle field with a rear mounted device." 209 Other problems involve magnification and distance judgment, focusing, and the high cost. 210

Some modifications to our present mirrors include the use of convex mirrors and the Wink wide-angle mirror. The convex mirror provides a large field of view but has focusing and demagnification problems with resulting difficulty in judgment of distances. 211 The Wink wide-angle mirror claims up to 300% more rear view vision than with normal mirrors and also claims to be distortion free. 212 The added vision includes the area along both sides of the car as well as the blind spots found between outside and inside rearview mirrors. 213

**Headlamp Concealment Devices**

Several models of new vehicles are equipped with hidden or concealed headlamps. Headlamps are concealed during the day for protection and for automotive design purposes. They open for night use. The federal standards require the headlamps to remain fully open if there is any power loss or malfunction in the system. 214 If either a malfunction or a power loss occurs when the headlamps are in the concealed position, there must be an automatic or manual assist to bring the headlamps to
the open position and keep them open without the use of any tools.215 On some of the older models, concealed headlamps were opened by a switch separate from the headlamp switch, and it was possible to drive with the headlamps on but in the closed position. The federal standards now require a single control which must operate both the concealment device and the headlamp illumination, and also requires the headlamps to reach the full open position in three seconds or less.216 No part of the concealment device may be removed when replacing or aiming headlamps and the headlamps must not cast a beam to the left or above the normal beam position while opening or closing.217

Hood Latch Systems

Only one requirement is spelled out in the federal standards involving hood latches; each front opening hood must have a latch with a primary and a secondary latch system or two separate hood latches.218 Other safety items involving hoods and hood latches include the hood hinged at the front and inside hood locks. The hoods with hinges at the front allow for an emergency such as the hood latch becoming released. Because of the air flow over the hood, this type hood stays in the lowered position which does not block the driver's vision. The inside hood locks, while not preventing
Theft, do help reduce the theft of parts from under the hood.

**Theft Protection**

"Stolen cars are 200 times more likely to be involved in accidents than other cars." In 1968 there were 153,000 accidents involving stolen cars; 21,000 persons were injured and 600 persons were killed in these accidents. "The chances are better than one in 100 that your car will be stolen this year." These facts help point out why theft protection is considered a part of automobile safety. The federal standards require each passenger car to have a key-locking system which will deactivate the engine, lock the steering wheel, and lock automatic transmissions in park and standard transmissions in reverse when the key is removed. Also, anytime the driver's door is opened when the key has been left in the ignition switch, the automobile must have a warning device which sounds a buzzer to remind the driver that the key is in the ignition switch. The key cannot be removed unless the engine has been turned off and the transmission has been placed in the correct position—park for automatic transmissions and reverse for standard transmissions. Federal standards also require at least 1,000 different key combinations or at least as many different keys as
cars manufactured if total production for a company falls below 1,000 cars. 224

Vehicle Identification

To reduce the number of accidents involving stolen cars, vehicle numbers must be displayed inside the car near the left front pillar where they can be easily read by outside observers such as law enforcement officers. 225 The numbers must be recessed in or embossed on a permanent part of the vehicle or a permanently fixed plate, excluding the glass. 226 A derivative of the vehicle identification number is also imprinted on the engine and transmission of the automobile. 227

Brake Fluids

A new federal standard has been added to existing standards, controlling the quality of brake fluids. Requirements are given for the boiling point, viscosity, corrosion, evaporation, effect on rubber, and other properties of the brake fluid. 228 The standard also requires labeling of all hydraulic brake fluids. 229

All material presented to this point in the report is contained under the heading of "accident avoidance" construction of the automobile. A number of additional features available on automobiles are related either directly or indirectly to helping the vehicle operator drive more safely. "These allow the driver to devote
more attention to the road, provide him with the means to respond more quickly to hazardous situations, and greatly add to his control of the automobile.\(^2\)\(^3\)\(^0\)

Power steering, power seats, power windows, and air conditioning all improve the driver's environment. Automatic speed control units enable the driver to select a speed at which he would like to travel, and once he has driven his automobile to that speed, the speed control unit will automatically maintain it without any further assistance.\(^2\)\(^3\)\(^1\) The driver can override the speed control by pressing down on the accelerator pedal or by stepping on the brake pedal. Other aids to driver safety, comfort and convenience will become available as automotive technology solves design, production and cost problems.
CHAPTER II

AUTOMOBILE SAFETY CONSTRUCTION FEATURES FOR OCCUPANT PROTECTION DURING INTERIOR IMPACT

This section of the paper treats safety construction features of the automobile which relates to the "secondary crash;" that is, the impact of the passenger against interior parts of the vehicle. This aspect of automobile safety construction is of great interest because it will be directly responsible for the chances of occupant survival during an automobile accident.

The relationship of passenger-to-vehicle velocity and vehicle-to-ground velocity must be understood. The car first collides with an object and then, as the car stops, the occupant moves inside the vehicle and collides with the interior of the car. "If the occupant is unrestrained and the car completely stops before the occupant collides with the interior of it, the occupant then hits the car at the same speed as the car was traveling initially." The survivability of the occupant can be increased by reducing the speed at which he strikes the vehicle interior, by construction materials used in the vehicle interiors and by the design of the passenger compartment. The problem of automotive interior construction for safety is very complex because
passenger size and weight, vehicle speeds, direction of impact, type and size of the object hit, the construction, and the size of the automobile are all variables.

Two terms which must be understood to research and study automobile collision are "crush rate" and "ride down." Most lay people are not aware that an automobile front end should not be as "sturdy as possible." If the automobile front end would not compress, the vehicle would reach zero velocity a split second after collision, and the passenger deceleration rate would therefore be extremely high. With a stopped vehicle and a high passenger velocity, the secondary collision would be critical. The automobile front end is designed to compress or collapse at a given rate; this is known as the "crush rate." This requirement will be discussed in more detail later in this section of the report.

If an occupant can slow down with the vehicle, his chances for survival are improved. The term "ride down" refers to the occupant slowing down while the vehicle is slowing down. The purpose again is to have as low a passenger-to-vehicle velocity as possible before the secondary impact takes place. The two methods used to accomplish "ride down" are a seat belt and a shoulder harness combination, and placement of the instrument panel closer to the occupant. These methods of "ride down" will be discussed in the
following section of the paper.

One other fact must be understood before studying the details of vehicle interior safety design. "Subjective evidence indicates that exceedingly few vehicle occupants solidly strike any interior component faster than 30 m.p.h., regardless of the vehicle impact speed."\textsuperscript{235} The exact percentage of accidents where the passenger-to-vehicle speed at impact exceeds 30 m.p.h. is only 2.5\%.\textsuperscript{236} Tests show that in controlled intersection-type crashes, dummy occupants of the impacting vehicles strike the vehicle interior at between 1/3 and 1/2 the impact speed; the difference depends upon the amount of spin each vehicle makes after the primary impact.\textsuperscript{237} In a documented highway accident that occurred several years ago,\textsuperscript{238} two vehicles met head-on with about a one-foot offset at a closing speed of 100-110 m.p.h.; there were eleven unrestrained people (no seat belts or shoulder harnesses in use) in the two vehicles. The one-foot offset was sufficient to cause both vehicles to spin and the maximum occupant-to-vehicle interior impact speed was about 20 m.p.h.; only one occupant was killed and one moderately injured, all the others only had minor injuries. If the two vehicles would have met without the one-foot offset, the passenger-to-vehicle interior impact speed could have surpassed the 30 m.p.h. figure. The fatality total for
this accident would have been higher. To design energy-absorbing interior components to function effectively beyond a 30 m.p.h. occupant impact speed is wasteful of both manpower and money. An accident of severity beyond 30 m.p.h. occupant impact speed does not leave much remaining in the structure of the impacting vehicles.  

This is the philosophy of researchers in the automotive industry; to design vehicle interior safety construction which will prevent serious injury or death in an occupant-to-vehicle impact velocity below 30 m.p.h.  

Although all sources do not fully agree, the following statistics concern the types of accidents and the percent of fatalities each produces. The largest number of accidents are rear impact (52.5%), although they only produce 15.6% of the fatalities. The second most frequent accident (21.5%) is the side impact which also ranks second in fatalities with 20.3%. The third most common accident is the head-on collision, yet it ranks first in fatalities with 54.4%. Other miscellaneous accident types such as rollovers comprise the remaining percentages (7.2%) and 9.7% of the fatalities. Although automotive engineers are concerned with the number of accidents, their main concern is to design the vehicle to reduce the occupant injuries and fatalities during a collision. Therefore, the frontal or head-on accident is of greatest concern to automotive design.
engineers.

**Progressive Collapse of Front Ends**

Progressively collapsing automotive front ends involve the "crush rate" and its affect on making the passenger compartment safer during collision. The collision of the vehicle with an object is called the "first collision." The collision of the occupant with the vehicle interior is called the "second collision." The "crush rate" of the vehicle will help determine the deceleration rate of the passenger. A poor "crush rate" will increase the velocity of the secondary collision, increasing the chances of injury or fatalities.

The most important function of vehicle structure during collision is to dissipate vehicle kinetic energy with minor deformation of the passenger compartment.\(^{242}\) It must also "crush" at such a rate that the passenger reaches vehicle velocity before the vehicle stops. If the "crush" ends too quickly, passenger velocity against the vehicle interior can be greater than the first collision.\(^{243}\) The distance from the passenger to the vehicle interior must be less than the "crush distance," that is, the amount the front end of the vehicle is able to compress.\(^{244}\)

The greatest problem in designing the automobile front end "crush rate" is the variable loading condition

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of the vehicle. In a standard-size sedan passenger car, vehicle weight may vary by 1,500 pounds (30%), depending on the number of persons and amount of loading. Vehicle deceleration will vary inversely to the mass and the energy-absorption requirement will vary directly to the mass. The loading of the vehicle must therefore be known. Since this factor cannot be known prior to crash time, the average load of 2 or 3 persons is used, and any loading difference will produce "ride down" which varies from exact design purposes.

If it is desirable to increase speed limitations of survivable impacts, the front end of the automobile will have to become significantly longer. The tolerance of the occupant to deceleration is limited and the only way to change "ride down" velocity is to increase the "crush distance" to allow more "ride down."

Another factor affecting "ride down" is the design of the interior including the dash, the steering column, restraint systems, etc.

**Instrument Panels**

One method of providing "ride down" is to move the instrument panel closer to the occupant. Much "ride down" research concerning the instrument panel could be ended if the occupants of the vehicle would use the seat belt and shoulder harness combination. The restraint
system provides the same "ride down" while keeping the occupant from contacting the instrument panel. Recent data shows that only 30% of those who have seat belts in their automobile use them, and only about 3% use the shoulder harness.\textsuperscript{249} This means the majority rely on the instrument panel and steering wheel for "ride down" during an accident.

The first problem concerning instrument panel safety design is the difference in height and weight of the occupants. As an example, the head of a 5th percentile female is about seven inches closer to the instrument panel than that of a 95th percentile male when both are seated in normal positions.\textsuperscript{250} Other variables affect the "ride down," such as a driver leaning forward or backward against the seat in his normal driving position and whether he has applied the brakes which would move him forward before the collision took place.\textsuperscript{251} Because these factors cannot be known when the instrument panel is made, it is assumed that no "ride down" will occur, and the design of the instrument panel is based on this assumption. If "ride down" does occur, it will provide a plus to the survivability built into the instrument panel.\textsuperscript{252}

Currently available research reveals that 80 g's (80 times the acceleration rate of gravity; 32 feet/sec./sec.) can be tolerated by the human head for short
periods of time.\textsuperscript{253} Deceleration of the occupant's head at the instrument panel must be accomplished by the use of materials which permanently deform or fracture.\textsuperscript{254} Foam coverings on the dashboard actually have little effect on energy absorption capabilities as the velocity of impact increases.\textsuperscript{255} The critical items for instrument panel safety construction would include the supporting structures, the materials used for the cross section, the vinyl skin used over the foam padding, and most critical, the absorption capability of the total instrument panel.\textsuperscript{256} The structural framework should be designed and located to support the necessary controls and instruments and yet provide "crush space" for deceleration of the head. The materials used must provide both a soft surface for low-speed occupant impacts and the required "crush rate" to protect the occupant's head during high-speed impacts. Most instrument panels are made up of steel .024" thick and have varying amounts of plastic used in combination with the steel.\textsuperscript{257} The underside is either filled with low density rigid foam or left empty so it can compress to produce the needed "crush." The foam and vinyl skin on the outside is not used for energy absorption but to prevent bruises at low speed occupant impacts. The vinyl skin also helps spread the load over a larger surface area of the dashboard and keeps the plastic base members from separating
Motor Vehicle Safety Standard #201 contains the requirements for the instrument panel. It requires that when a 15-pound, 6 1/2-inch diameter head form impacts the instrument panel at a relative velocity of 15 m.p.h., the deceleration of the head form shall not exceed 80 g's continuously for more than three milliseconds. As with most standards, it does not dictate how that requirement must be met; that responsibility belongs to the automotive industry and each company may choose how it will meet the requirement.

Sun Visors and Armrests

Standard #201 also lists the requirements for the seatbacks, sun visors, and arm rests which all contribute to the interior construction for automotive safety. Sun visors must be made of or covered by energy absorbing materials and the top of the seatback must be able to decelerate a headform at a specified rate. Armrests must meet certain dimensional requirements for load distribution or be constructed of energy absorbing materials that meet specified performance requirements. Interior compartment doors in seats, side panels and instrument panels must remain closed during required tests.
Seatbacks and Head Restraints

Seatbacks and head restraints provide the restraint system necessary to protect occupants during rear impact.\textsuperscript{262} During a rear impact, the differential of velocities between the two vehicles involved causes the struck vehicle to be abruptly accelerated forward. The force necessary to accelerate the occupant of the struck vehicle is transmitted to him through the seatback, making the strength of the seatback essential.\textsuperscript{263} The seatback resistance to rearward rotation has a significant influence on the effective head support height; as the seatback rotates rearward, the occupant tends to slide up the ramp created by the yielding seatback.\textsuperscript{264} A yielding seatback would have the same effect as a yielding seat belt in a frontal collision; it would not provide the restraint necessary for good occupant protection during the secondary collision.

Most seatbacks are terminated at the occupant's shoulder height which allows the head to rotate rearward during severe rear impact.\textsuperscript{265} This rearward head rotation produces an injury to the cervical spine referred to as "whiplash."\textsuperscript{266} Two methods have been used to deter whiplash: the vertical extension of the seatback, and the addition of a head restraint to the seat. Automobiles using a bucket seat have extended the seatback vertically instead of adding the head restraint. The
head restraint is positioned a few inches behind the head where it won't interfere with hats or hairstyles, and where it cannot be comfortably used for a headrest. The head restraint was not designed to be used as a headrest. The head restraint is adjustable and should be positioned to meet the middle of the back of the occupant's head during rear impact.

Federal specification #202 lists requirements head restraints must meet. The head restraints are required only for the two outboard front seat positions. The test requirement for the head restraint is to withstand a load of 200 pounds while in the fully extended position; the load is applied by a 6 1/2-inch headform. Also, the headform must not be displaced rearward beyond 4 inches from a predetermined line.

**Energy Absorbing Steering Columns**

Although the seat belt and shoulder harness are the best deterrents to secondary collision, another deterrent is the energy absorbing steering column. Only deaths resulting from ejection exceed driver deaths caused by steering assemblies. As with the seat belt and shoulder harness, industry developed the energy absorbing steering column before required or suggested legislation. Energy absorbing steering columns were incorporated in all 1967 cars manufactured by General
Motors, Chrysler, and American Motors.²⁷⁰

Two federal regulations, #203 and #204,²⁷¹ now relate to the steering control system. They contain requirements for impact protection for the driver from the steering control system, and regulations for the rearward displacement of the steering control respectively. The steering control system must fulfill specific requirements to minimize chest, neck, and facial injuries to the driver due to impact. The impact force developed by a test dummy torso striking a steering control assembly at 15 m.p.h. must not exceed 2,500 pounds.²⁷² This means that when an automobile is in an accident, the steering control assembly must not allow more than 2,500 pounds to be applied to the driver's torso. It must absorb any force beyond this point. The steering control system must be constructed such that no components or attachments, including horn actuating mechanisms and trim hardware, can catch the driver's clothing or jewelry during normal driving maneuvers.²⁷³

Not only can the driver be injured by hitting the steering assembly; he can have the steering assembly pushed back into him. In a 30 m.p.h. frontal impact into an immovable barrier (equivalent to a 60 m.p.h. impact into a parked car), the upper end of the steering column and shaft must not be pushed back more than 5 inches.²⁷⁴
All research completed to and including early 1968 reported only two driver fatalities from impact in vehicles with the energy absorbing steering columns.\textsuperscript{275} One of these fatalities involved a violent head-on collision where impact forces exceeded the limits of the energy absorbing column which caused the column to compress its total distance.\textsuperscript{276} The second fatality involved a vehicle which hit the rear of a tractor trailer at a high rate of speed; in both cases the driver was not wearing a seat belt or a shoulder harness.\textsuperscript{277} From second highest cause of fatalities to two "reported causes" of fatalities is a very significant improvement in driver safety.

Basically, the energy absorbing steering column acts as a telescope from either or both ends. If the driver's body exerts 2,500 pounds or more on the steering assembly, it will telescope to a maximum of 8 1/4 inches.\textsuperscript{278} The telescoping section is located beneath the dashboard. This telescoping section consists of concentric tubes which resist each other when they telescope axially.\textsuperscript{279} This resistance is caused by rows of steel balls separated in the annular space between the tubes; the diameter of the balls is larger than the distance across the space between the tubes. When the steering column is telescoped during impact, the balls must form a groove in the outer surface of the inner
tube and the inner surface of the outer tube as they roll.

One advantage of the design is the simplicity of changing the column collapse load. The standard balls used have an average of .0075 interference; they are .0075 larger than the space they occupy. If it is desirable to decrease the collapse load of the column, then the assembly is fitted with smaller diameter balls. For each .001 decrease in diameter of the balls, the average collapse load will drop 70 pounds. To increase the collapse load, a change is made to either larger balls or an increase in the number of balls.

Desired placement of the balls is also advantageous; since most loads which tend to cause column bending or shake are in the vertical plane, a greater number of balls are in the area of six and twelve o'clock positions and less at three and nine o'clock positions.

In addition, those models with a forward-mounted gear box have a second telescoping section inside the engine compartment which allows the steering shaft to reduce in length an additional 9 1/2 inches. The underhood section is not energy absorbing to the driver, but allows for more vehicle exterior front-end "crush" before the column is loaded rearward towards the driver. If the lower section is completely collapsed and the
upper section has not telescoped completely, the upper
energy absorbing section will then telescope from the
impact of the object hit as well as from the impact of
the driver's torso.

Significant engineering problems were solved before
the energy absorbing steering column was made available
on the passenger car. Although the 1967 models were the
first to offer the energy absorbing steering column,
design activities began in the late fifties. It took
about five years to design, construct, and test the
assembly, and almost two years "lead time" to incorpor­
ate the vehicle changeover from the standard steering
column. 284

One of the most difficult problems was that of
determining the maximum tolerable load on the human
chest; this determined the collapse load for the steer­
ing system. Since most crash testing involves the use
of "test dummies," these limits have been derived from
the work of various biomechanics laboratories. The
maximum load tolerable on the chest over a 30 square
inch area is 1,200 pounds. 285 However, it was found that
all the energy of the upper torso need not be trans­
ferred through the chest to the wheel hub. Additional
load can be absorbed through other areas such as arms
and shoulders; therefore, it is possible to increase the
column collapse loads. 286 This permits a driver to
survive a higher velocity collision.

Most injuries from the steering assembly are to the face and are caused by the steering wheel rim.\textsuperscript{287} The steering wheel rim must be weak enough to allow the driver's arms to deflect the rim forward and absorb energy in the process, and yet not too weak or it will place too much of the load directly on the driver's chest.\textsuperscript{288} The height and size of the driver and the speed of the vehicle at impact are other variables which must be considered when designing the steering wheel rim.\textsuperscript{289} Seat belts do not necessarily prevent these facial injuries—they do prevent ejection which is far more important—but such injuries could be prevented by a shoulder belt worn in combination with a seat belt.\textsuperscript{290} Another engineering problem is the angle at which the steering column is mounted. If it were mounted horizontal and the driver moved horizontally forward during impact, the load would be applied directly along the steering column centerline.\textsuperscript{291} If the steering column is mounted at a 25° angle from horizontal, it will require a 10° increase in pressure to collapse the same column; this is a result of both the geometry and the increased friction between the sliding elements of the steering assembly.\textsuperscript{292}

If the driver is wearing a seat belt, his upper body will rotate so that, at the time he contacts the
steering wheel, his direction of applied force will be more closely aligned with the column centerline.\textsuperscript{293} This serves a double advantage, it lowers the force needed to initiate column collapse and the seat belt has also reduced the total energy which is applied to the steering system.\textsuperscript{294} With the addition of a shoulder belt, the driver decelerates with the vehicle and is essentially immobile with respect to the vehicle.\textsuperscript{295} This was termed earlier as "ride down." Depending upon the speed at impact, the driver will either never meet the steering assembly or will have lost most of his inertia energy before he contacts the steering system.\textsuperscript{296} Seat belts and shoulder harnesses make possible survival under many varying and increasingly severe accident conditions.

Special considerations have also been given to optional tilt and tilt-telescoping steering columns. They have a greater mass to be supported and also change the angle at which the driver will contact the steering wheel rim.\textsuperscript{297} With the addition of the ignition switch to the steering column for the anti-theft design, additional special design problems have required solving.\textsuperscript{298}

Since the human chest is essentially convex, increasing the diameter of the steering wheel hub will not increase the effective contact area in proportion to the increase of the actual hub area.\textsuperscript{299} A future
consideration is the adding of a small air bag located in the steering wheel hub to the existing system to help reduce chest injuries or increase the ability to survive higher velocity collisions. This air bag would inflate at primary impact and provide protection to the driver's chest during secondary impact. The air bag in the steering wheel hub is similar in design and operation to the large "passenger air bag" which will be reported later in this section.

Windshields

All automobiles manufactured in or imported into the United States and Canada must have laminated windshields. Most automobiles sold elsewhere in the world are fitted with tempered windshields. This report will make objective comparisons of these two different windshields and also report some engineering problems concerning windshield design.

Laminated glass consists of two layers of glass with a plastic interlayer. The outer layer, which faces the outside of the car, is unstrengthened and is about .125 of an inch thick. The plastic interlayer is about .030 of an inch thick and the inside glass is between .070 and .125 of an inch thick, sometimes strengthened and sometimes not strengthened.

Tempered windshields are "toughened glass" which
is produced by controlling the cooling rate on the surface by air blasts; this results in the surface being in compression to a depth of a few thousandth of an inch.\textsuperscript{305} Tempering can also be accomplished by chemical treatment of the windshield glass.\textsuperscript{306}

A number of factors must be considered when studying effects of windshield construction design during impact. First, if the glass is too hard and has no "give," it increases the chances for facial bone fractures.\textsuperscript{307} Second, if the glass breaks, the bluntness or sharpness of fragments formed will partially determine the seriousness of lacerations.\textsuperscript{308} A third consideration results from a windshield being broken from the outside. Not only the amount of flying glass entering the passenger compartment must be considered but the vision available to the driver through the glass is important so he can maintain control of the vehicle.\textsuperscript{309} A fourth but important factor is that the windshield may be considered as part of the restraint system for the front seat occupants—the importance of using the seat belt and shoulder harness appears again—and must be able to absorb energy.\textsuperscript{310}

Testing windshields, like barrier crash testing of automobiles, must make use of "dummies" to obtain required information during impact. The windshield is tested by impacting it with the face and skull of the
dummy which is thrown against the windshield as the car is suddenly stopped. The tests for both laminated and tempered windshields are conducted at a variety of speeds on a vehicle accelerator. A vehicle accelerator is basically an automobile body, on its own wheels, which can be rapidly accelerated to any speed up to 70 m.p.h., and then stopped in a manner that closely simulates a barrier crash.\(^3\)\(^1\)\(^1\)

The dummy head cavity is fitted with accelerometers to measure the impact velocity required to crash the glass. This data is very important to safety performance of windshields. If head impact velocity is high enough, concussion and bone fracture can occur before the windshield breaks.\(^3\)\(^1\)\(^2\) The windshield is designed to break and prevent concussion and bone fracture, and yet, after it breaks it must restrain the occupant and absorb his inertial energy. One important finding is that the penetration velocity and break velocity is the same for tempered glass; while for laminated glass, the penetration velocity is much higher than the break velocity required to crack the glass.\(^3\)\(^1\)\(^3\) The highest head-to-glass velocity at which a fracture did not occur for the laminated windshields was 13.1 m.p.h. while for tempered windshields two tests reached 30 m.p.h.\(^3\)\(^1\)\(^4\) The definite advantage for the laminated windshield is that by fracturing at 13 m.p.h. it prevents any chance of concussion.
It also prevents head penetration beyond the break and penetration velocity of a tempered windshield. The tempered windshield fracture velocity is higher and offers little resistance after breakage; this exposes the head to further injury from the hood, cowl, and windshield frame. If a tempered windshield is made strong enough to prevent breakage, the likelihood of brain damage is increased during the initial impact.

To obtain information concerning laceration injuries, the dummy head is covered with two layers of moist cod oil, tanned sheep skin, or chamois to provide a means for recording and evaluating lacerations. A ten-point scale is used to measure the quantity and severity of lacerations. Because the impact velocity required to crack the glass is higher for tempered windshields than it is for laminated windshields, the lacerations are dependant on head-to-glass impact velocity. At velocities below tempered glass breakage velocities, it is possible to have lacerations from a laminated windshield, although they rate low on the severity scale. The overall comparison gives a definite advantage to laminated windshields over tempered windshields. During extensive tests, laminated glass did not exceed six on the ten-point scale while tempered glass reached ten on head-to-glass impact velocities between 25 m.p.h. and 30 m.p.h.
Testing has shown the problem of loss of vision with laminated windshields after stone impact is minor and the possibility of eye damage from flying glass particles is remote. With tempered glass the problem is not one of controlling a vehicle with a few cracks in the windshield, but one of controlling a vehicle with an almost opaque windshield and as much as 15 to 20 pounds of flying glass, most of which will come into the vehicle. This increases the chances of severe lacerations. The tested advantages of laminated windshields over tempered windshields have provided the strong evidence needed to require laminated windshields in all American automobiles.

Corning Glass Company in conjunction with American Motors Corporation has developed a new laminated windshield with the express purpose of reducing the danger of lacerations to a vehicle occupant who is thrown into the windshield. This is accomplished by using a thin, chemically strengthened sheet of glass for the inside layer. This inside layer is provided with stress raisers that will cause it to break before excessively high concussion forces can be developed in the occupant's skull. With the conventional laminated windshield, the inside glass layer is broken when contacted by the occupant's head while the improved version will bend as the windshield is flexed. If the blow is mild, the
inside layer will not break at all. In a more severe impact, the inside layer will bend until it develops a bending stress high enough to break. The broken fragments are blunt and have dull edges because of the chemically induced residual stress pattern in the body of the glass. The Corning safety windshield was first available in 1970 on all AMX and Javelin models.

One of the greatest variables in designing windshield construction for impact is the passenger compartment configuration. The two factors having greatest effect are the horizontal distance between the nose of the instrument panel and the lower edge of the windshield, and the slope of the windshield at the point of occupant impact. If the instrument panel projects out toward the front seat far enough, it can catch the chest of the occupant before his head impacts the windshield. If the car has a narrow instrument panel, the glass will be required to handle the brunt of the impact. Test results did not disclose any appreciative difference in lacerations from windshields mounted at different angles although the windshield with the smallest angle from horizontal did show more frequent tears in the plastic interlayer and also showed a slightly greater tendency to pull out of the windshield frame.
Other conditions facing engineers in windshield impact construction design have effects about which little research data is known. The effects of temperature, abrasion, glass thickness, and the differences which must exist between test dummies and humans are all subjects for further investigation. 333

Performance tests which automobile windshields and windows must meet are listed in Federal Standard #205. 334 To provide good optical quality, windshields and windows must be exposed to simulated sunlight, tropical temperatures, humidity and abrasion. To test impact strength, penetration resistance, and fragmentizing, one-half pound and five-pound steel spheres and an eleven-pound leather bag full of shot must be dropped from varying heights on test specimens. A seven-ounce dart is also included to check penetration resistance of a sharp object. In case an emergency exit had to be made through a closed window, the breakability of the window is tested by dropping a 15-pound, 6-ounce bag of shot onto the glass from varying heights. Plastic windows, such as those used in convertible tops, must pass additional tests for weathering, chemical resistance, warpage, flexibility and flammability. Exposed glass edges must be rounded and smooth except on school buses where they must be banded. A new standard, Federal Standard #212, requires 75% windshield perimeter...
retention on each side of the car centerline during a 30 m.p.h. frontal barrier impact test.

**Side Impact Construction**

"In an injury study presented at the 10th Stapp Conference by the University of California, Los Angeles, accident investigators listed the door region as the fourth leading area of significant injury." The actual percentage of accidents where the principal impact was from the side is 15%, 6% on the driver's side and 9% on the passenger's side. Three areas are strengthened to reduce injuries from side impact: door latches, door hinges, and the addition of side structures to resist penetration. Federal Standard #206 lists the load limits which door latches and door hinges must meet. Door latches must withstand longitudinal loads of 2,500 pounds when fully latched and 1,000 pounds in the secondary latch position. They must withstand transverse loads of 2,000 pounds when fully latched and 1,000 pounds in the secondary latch position. The latches must also withstand inertia loads of 30 times the weight of the door in both directions. Hinges must support 2,500 pounds longitudinally and 2,000 pounds transversely.

The last requirement of Federal Standard #206 specifies that all doors must have an inside locking
mechanism. When the inside locking mechanism is engaged on the front doors, it must make the outside release inoperable. When the inside locking mechanism is engaged on the rear doors, it must make outside and inside releases both inoperable.

At this time, no Federal regulation exists which defines any specifications on side structures used to resist penetration. All work done in the area of improved side structures is voluntary by automobile manufacturers.

Because of the generally severe nature of the consequences of side impacts, increased attention has been focused on the improvement of crashworthiness in this type of impact. Side impacts present some problems different from frontal impact. The two most important problems are the differences in the role of the restraint system and the increased penetration by the striking vehicle. During side impact, the occupant tends to follow a trajectory in line with the impact while the vehicle rotates. Lateral "ride down" is not provided by the restraint system; the design for "lateral ride down" is much different than for "frontal ride down."

Experimental research is being conducted with a variety of "integrated seat" concepts. An integrated seat would "pocket" the body, absorbing a portion of the
direct intrusion force in addition to displacing the motorist away from the intruding door structure. The seat bottom would also contain lateral compression tubes to absorb the energy of impact much like the compression absorption of the steering column. This "integrated seat" would therefore serve as the restraint necessary to provide "lateral ride down."

The second problem most common to side impacts is the intrusion of the hitting vehicle into the hit vehicle's passenger compartment. General Motors researched two approaches to reduce this penetration and most American automobiles built today have the steel side beam within the door which resulted from that research. The door beam, located inside the door, is installed at the necessary height to meet the bumper and fender of the striking car and is designed to prevent them from riding up over the beam and into the passenger compartment. The steel beam is approximately 2 inches deep, 8 inches high, and is box-like in design. It is mounted in a horizontal position within each door. The beam is reinforced by properly structured body supports and previously strengthened door hinges and latches. The most important supporting structure is a reinforced pillar support at the floor area. The weight and dimensions of the door beams vary with each body style, with an addition of approximately 48 pounds to a
two-door vehicle.\textsuperscript{348}

The second approach GM researched was to increase the height of the floor rocker panel and frame structure to align with the bumper of the striking car to prevent it from penetrating.\textsuperscript{349} This approach was dropped after impact testing because it was believed that the raised rocker panel principle was undesirable for passenger convenience during entering and leaving the passenger compartment.\textsuperscript{350}

There are other variables affecting the performance of vehicles in side impacts. Included are: the weight of both the struck and striking vehicles, the friction between the ground and the struck vehicle, the shape and design of the striking vehicle front end, the angle of impact, and the velocity of impact.\textsuperscript{351}

One study shows that the relative velocity between a dummy's head and the inside of the car is basically the same with or without the special side impact structure.\textsuperscript{352} In the case of the car without the improved side structure, the energy is absorbed in the collapsing door and deforming sheet metal of both the striking and struck cars. In the case of the car with the improved side structure, the same amount of energy absorption is accomplished with a greater amount being absorbed in the front end of the striking car and less in the side of the struck car.\textsuperscript{353}
Automobile Roof Construction

The earliest impact tests involving automobiles took place in the 1930's and were full-scale rollover tests. General Motors' tests were accomplished by driving the car onto a spiral ramp located at the top of a hill while Chrysler Corporation conducted end-over-end rolls by pushing the car off a steep cliff near Pontiac, Michigan. At the time of these tests no instrumentation or dummies had yet been developed. Only regular speed motion pictures were available. Roof construction was known to be an important factor in automotive safety at that time. Even today the importance of roof design is evident from the fact that the fifth and sixth leading causes of significant injury are the windshield pillar and the roof header.

Percentages of accidents involving rollover vary greatly depending upon the type of roadway environment. In the United States, a research study by the Automotive Crash Injury Research Program of Cornell Aeronautical Laboratory during the years 1956-1959 verified rollover accounted for 23% of all accidents. Research by Motors Insurance Corporation of accident cases involving 1968 GM cars showed only 2.5% of the accidents involved rollover.

In England, 6% of urban accidents involved rollover, 12% of rural accidents involved rollover, and 32%
of expressway accidents involved rollover. The total average percentage of all accidents which involved rollover was 8%. Over one-half (55%) of these rollovers were simple rolls involving no substantial impact with either another car or any other object. Over one-third (35%) of these rollovers were caused by impact.

The restraint system is needed in a rollover accident, not so much for "ride down" as in a frontal accident, but to prevent ejection. This is especially true for the passengers as ejection is the most frequent source of rollover injury. The driver is somewhat restrained by the steering assembly. A restraint system is essential, since 95% of all occupants receive a head or face injury, usually from impact with the roof or door frame.

Tests conducted on the conventional header construction—the header is the area just above the sunvisor where the windshield and roof meet—of automobiles showed that the rear wall of the header was an obstruction interrupting the occupant's head movement toward the windshield. In a frontal crash, and in some rollovers, the occupant's body is accelerated forward toward the windshield. With the conventional header, the occupant's head catches on the rear wall of the header surface and is rotated abruptly rearward because the occupant's body is still moving forward. The new
header design consists of a simple rearward extension of the existing header surface to form a "ramp." This ramp approach has greatly reduced the rearward head rotation by skidding or deflecting the occupant's head up the ramp and into the windshield glass which is designed to absorb the energy without concussion.

Roof construction was previously tested by a full-scale rollover test with both prototype and production cars. This method has been replaced by an improved test method known as a static roof crush. The rollover test presented three basic problems: each single test could only check one "severity level," evaluation of results was limited because the tests were not always reproducible, and a complete vehicle including the engine, chassis and body had to be used each time which was extremely expensive.

The new method, using the static roof crush, is accomplished by using a large steel pad to apply the load to the roof structure. An automobile body without the engine, drive-line suspension, and front-end sheet metal is impacted by the large (14" X 74") steel pad and the deflection of the structure is recorded and plotted against the load magnitude.

A second test used by the automotive industry is the inverted vehicle drop test. The vehicle is positioned to fall free under conditions of pitch and roll
angle to simulate a rollover. The drop occurs upon a 6-inch reinforced concrete surface which is covered by 3/4-inch thick plywood. The initial force is applied to one side of the roof structure located over a windshield pillar. The structural deformation resulting from the drop test is evaluated and necessary structural changes or modifications are made. Research is presently being conducted to cross-check the validity of this test with accident data.

Restraint System

Evidence has shown that ejection is the leading cause of death and injury in automobile accidents, and that secondary impact of the occupant against the car interior, after the car stops, is the second leading cause of injury.\(^{368}\) Seat belts and shoulder belts are the most reliable solutions to both of these problems. U.S. Government representatives agree with automotive engineers that belts are better than the proposed "air bags."\(^ {369}\) In a study of 28,000 accidents, there was not a single fatality to occupants wearing seat belts and shoulder belts at accident speeds below 60 m.p.h. Non-belted occupants sustained fatal injuries throughout the entire speed-scale.\(^ {370}\) Accident studies conducted by a University of Michigan medical team show that 40% of the people killed in accidents would have been saved had
they been wearing seat belts.\textsuperscript{371} This means that more than 20,000 people per year might still be alive if they had "buckled-up."

Public acceptance of seat belts and shoulder belts has been very slow even though the need for them is well established. Even though seat belts have been available in automobiles for fifteen years and the shoulder belts for six years, recent studies indicate that less than 30\% of the motorists who have seat belts in their car use them regularly and shoulder belt usage is something less than 4\%.\textsuperscript{372} A University of Michigan survey showed that the better educated a person is the more likely he is to use a seat belt.\textsuperscript{373} Seventy-five percent of persons with post-graduate work used seat belts as compared to 30\% of the total drivers. The use of the restraint system should be improved by the recent decision of the California Supreme Court holding that failure to wear lap belts may deprive an otherwise innocent accident victim of his right to receive the full amount of any monetary settlement made on his behalf.\textsuperscript{374}

The alibis of many people about non-use of restraints are based on the assumption that if they have a seat belt on and their car catches fire or is under water after a collision and they are unconscious, they would not be able to get out. Mr. Leonard Baker, Assistant Chief Engineer of Automotive Safety for Chrysler
Corporation, answered that alibi quickly. "If someone was unconscious, they couldn't get out with or without a seat belt on, and if they had the seat belt on, their chance of being conscious is much greater." 375

Another common complaint is that seat belts are uncomfortable; it is surprising how many people have tried to get out of a car without unfastening the seat belt. They couldn't have been too uncomfortable if they forgot the belt was latched! Those that worry about the wrinkle that might be left in their clothes from a seat belt should think about the scar that might be left on their face without it. This might sound like a calloused view, but the factless rejection of the present restraint system is forcing "extremely expensive" alternate restraint systems on everybody including those who use the belts.

The first "alternate" restraint system, which will become effective by law on January 1, 1972, will require a three-point lap-shoulder belt system for the driver and front outboard passenger. 376 This belt system is inferior to the existing four-point lap-shoulder belt system but would provide for one-hand operation of the driver's lap belt. It will also require a warning light and buzzer which will operate any time the ignition is on, and the driver and/or right front seat passenger do not have belts fastened about them. "Even if a
sophisticated system could be developed to sense occupant size, presence and seat adjustment range, we believe it would be extremely complex and present excessive reliability problems at a substantial cost to the customer," General Motors said. 377

It is obvious that many motorists will not wear belts under any circumstances, and no type of warning system will change them. They will just disconnect the warning system. The cost of the "warning system" will be exceptionally high because this system will be used only until the "air bag" requirement becomes effective; a year and a half under present proposed standards (1972). 378

It is important to understand the basic concepts of three-point and four-point restraint and seat belt and shoulder belt systems. The seat belt "must" be worn as snug as possible and be positioned as low as possible on the occupant's hip. 379 This allows a large portion of the force necessary to decelerate the occupant to be applied to the pelvic structure. The pelvic bone is capable of withstanding a load in excess of 5,000 pounds. 380 If the belt is worn too loose or is forced upward, damage can be done to the lower spine and internal injuries suffered in the abdominal area from the belt. 381 The shoulder belt should not be as tight as the seat belt, a fist should fit sideways between the
occupant's chest and the belt. With only a seat belt in use, the body will "jackknife" and injury to the head and chest can result from striking the steering wheel, instrument panel, and other surfaces directly in front of the driver and front seat passenger. The shoulder belt minimizes the likelihood of these injuries and also provides restraint of the occupant so as to reduce the risk of knee impact during a forward collision.

The four-point restraint system is considered to be superior to the three-point restraint system. A four-point restraint system has a separate anchor point for each end of the seat belt and for each end of the shoulder belt. Both seat belt anchors and the inboard shoulder belt anchor are located in the floor pan. The outboard shoulder belt anchor is attached to the roof structure midway between the front and rear seat. In convertibles, where a fixed roof structure is not available, the outboard shoulder belt anchor is attached to the floor pan at the rear seat lap belt anchor point or at the rear wheel-well. Either structure is sufficiently strong to take the load. The three-point restraint system differs only in that it does not use the inboard floor pan anchor for the shoulder belt; instead it is anchored to the seat belt at the seat belt buckle. This allows the occupant to fasten only one buckle to obtain use of the seat belt and shoulder belt.
This single advantage is offset by a number of more important disadvantages.

The first of these disadvantages is extremely important. Because of the normal "jackknife" motion forward during a frontal impact, the first force is applied to the shoulder belt. This pull on the shoulder belt is independent of the seat belt on a four-point restraint system because the two belts each have their own anchors. But on a three-point restraint system, the inboard end of the shoulder belt is attached to the seat belt buckle and this "pull" is transferred directly to the seat belt. The seat belt "can" be pulled upward and over the hip bone into the abdominal area by this pull on the shoulder belt. In this position, the seat belt can cause severe damage in the abdominal area if heavily loaded.

There are other disadvantages of the three-point restraint system, or advantages for the four-point restraint system. An occupant can wear only the seat belt if he is not yet convinced of the importance of the shoulder belt. On most three-point restraint systems, this option is not available. It is also evident that a shoulder belt anchored to the seat belt will increase the load on the seat belt anchors. The four-point system uses separate anchors for the two belts. "With regard to the question of rapidity of release, it is
obvious that two buckles take twice as long as one to release."\textsuperscript{388} Certainly, the advantage in design more than compensates for the few seconds it takes to unlatch the two buckles.

The Automotive Crash Injury Research Group of Cornell Aeronautical Laboratory has studied the effectiveness of seat belts in reducing risk of injury. Their research included 50,000 vehicle cases in 31 states and the cooperation of specially instructed teams of state police and medical personnel.\textsuperscript{389} From these 50,000 accident cases, 1,055 occupants were found to be wearing a seat belt at the time of the accident. The belt-wearing occupant was matched with a non-belt-wearing occupant when another accident case was found to be sufficiently similar; a person of the same sex, approximately the same age, height, and weight occupying the same seated position in a car of the same make and model year.\textsuperscript{390} The accident also had to be similar in type, in severity, in direction, and in area of severest impact to complete the match.\textsuperscript{391} Matching was successful in 651 cases; 492 driver pairs and 159 pairs of right front seat passengers.

Results showed that unbelted occupants received dangerous or fatal injuries 50\% more frequently than did belted occupants. Unbelted drivers received dangerous or fatal injuries 70\% more frequently than did belted
drivers. The seat belt advantage was greatest in reducing injury to the chest area. Unbelted drivers received dangerous or fatal injury almost three times as frequently as drivers wearing belts. One fact found in the study might convince those people who wear their seat belts and not their shoulder belt to wear both belts. The right front seat passenger "might" actually be less well protected against "head injury" while wearing a seat belt than without it. This fact should not be interpreted that the seat belt isn't necessary, but rather that the shoulder harness is also necessary to reduce head injury. The seat belt and shoulder belt should both be used, and used correctly.

Incorrect use of either belt can cause injuries to the occupant. The most common error in seat belt usage, is the occupant's failure to adjust the belt to take up the slack. This failure is particularly hazardous with seat belts having the spring-wound nonlocking retractors; the motorist might not realize that the belt has not been pulled all the way out. In the event of an accident, this loose belt can ride up over the crests of the pelvic bones and into the soft abdominal area. Some motorists fasten the safety belt around the abdominal area originally; it belongs as low as possible on the hips with the lower edge of the belt resting on the thighs.
A phenomena known as "submarining" can occur if the seat belt is too loose or the shoulder belt is too tight. "Submarining" occurs when the occupant's body slides downward and underneath the seat belt in a forward direction during a frontal impact. If the shoulder belt is too tight—a fist should fit sideways between the occupant's body and the belt—then the normal "jackknife" forward motion is blocked. Research has shown that completely blocking the "jackknife" motion tends to induce "submarining;" this action is reenforced if the seat belt is worn loose.

Research has developed a number of improvements for the restraint system which have not been adopted for public use because they lack acceptability to the customer. One example is the symmetric belt systems such as the double shoulder harness and the inverted Y-yoke harness. Both of these harness systems provide improved performance during side impact and lack the unsymmetric motions and rotations of the body found with the use of the single diagonal shoulder harness. If only 4% of the motorists are using the present shoulder harness then the intended benefits are lost; there is no need to spend more money on an item people will not use.

**Integrated Seats**

Another example has been the development of the
integrated seat at the University of Michigan and the University of California. Funded by the National Highway Safety Bureau, a series of integrated seat prototypes have been developed and tested which perform much better than current systems. An integrated seat is specially designed to withstand body decelerations from front, side and rear impacts, and has a contour opposite the head and neck to support them during rear-end collision. The harness system included self-retracting inertial lock devices which allow convenient access and comfortable usage; the harness is secured directly to the seat. The integrated seat also provides energy absorption in the seat belt and shoulder harness materials and allows for better seat belt mounting angles. The seat is also designed to reduce the side-impact intrusion of the striking vehicle and the torso-ramping during rear impact. Torso-ramping is the tendency of the body to slide up the seat back incline as the seat back gives or bends rearward from the weight of the occupant's body. "The integrated safety seat provides more protection for the motorist than the combination of all other protective measures yet devised for passenger compartment safety." The integrated seat is more scientifically designed and more appropriately constructed than any type of present restraint system. Like many other safety items, it seems
Children Restraint

The problem of restraining children has been studied since the beginning of automotive safety research. "Children constitute a special problem for restraint in that they are not miniature adults but differ significantly both anatomically and psychologically from the adult passengers." Children have a different anatomical structure than adults, basically a smaller pelvis and a larger head. Because the seat belt applies much of the load to the pelvis, an alternate restraint is needed for small children. A child's pelvis is not strong enough to support this load. The child restraint system should also compensate for the larger head to weight ratio found in children.

One further problem is the variety of devices which are currently offered for sale as restraint devices. Many such devices provide nothing more than a platform for the child to allow him to see out while riding in the vehicle, contributing little or nothing in terms of safety. One of the best child safety seats is the Tot-Guard designed and sold by Ford.

The Tot-Guard is a removable padded plastic shield designed to increase protection for children in
collision impacts from any direction.\textsuperscript{416} It consists of three pieces; a hollow-molded polyethylene shield, a polyethylene seat, and a removable foam pad for the inside of the shield. The child is placed on the seat, the shield is slipped over his legs and body, and the regular lap belt then is buckled around the outside of the shield. The shield allows moderate "jackknife" motion forward, which is normal in a frontal impact. The child's head contacts the foam pad mounted inside the shield. The shield is designed so that the child can see over the top while in a normal sitting position.

The Tot-Guard is designed around the 35-pound child but also provides protection for smaller and larger children.\textsuperscript{417} This child safety seat has been tested in laboratory and proving-ground experiments which simulate head-on, side and rollover crashes at highway speeds.\textsuperscript{418} The suggested retail price is $19.95.\textsuperscript{419}

**Passive Restraints**

A passive restraint is one which does not require any overt action on the part of the user to obtain its benefits.\textsuperscript{420} Both the energy absorbing steering column and the "air bag" are examples of passive restraints. Only the energy absorbing steering column is currently available to motorists.

An air bag is a gas-inflated impact bag which
cushions the occupant as he decelerates along with the vehicle during a frontal collision. In an air bag system, a stop caused by a collision actuates a sensor which, in 30 milliseconds, explodes air into the bag. The air bag inflates itself in front of the occupant and absorbs the crash impact. Studies have shown that the occupant receives a very soft ride during frontal collision and that his deceleration performance is very close to the deceleration of the vehicle. When the vehicle deceleration is quicker than the occupant deceleration, the occupant collides with the vehicle interior.

"Air bags are baloney!" Those are the words of Henry Ford II and the exact feeling of many automotive people who have knowledge of restraint systems, air bags, and auto safety in general. There are many unsolved problems concerning air bags and yet July 1, 1975 is the deadline to have them all worked out. Three of the most difficult problems have not been solved as yet and less than two years exist to have them solved or to develop an alternate solution. The occupant position prior to air bag inflation, the noise level associated with inflating the air bag, and the reliability of the inflation of the air bag present the largest challenges to be solved.

The occupant's position prior to the air bag inflation affects the efficiency of the restraint. The
driver's position is fairly constant but the position of the passenger is not. If the passenger is not met head-on by the air bag or if a car window is open when the impact occurs, the bag might fail to do an adequate job of cushioning; some dummy tests have found the occupant thrust out of the open window by the bag impact. The impact of an inflating air bag designed for adults might be fatal to youngsters.

The noise produced during air bag inflation is as loud as a gun discharged close to the eardrum. The noise level inside a closed car during inflation of one air bag has been measured between 153 and 160 decibels by General Motors; it is generally accepted that sound levels above 160 decibels are capable of producing some permanent ear damage in a significant number of people.

Reliability of the air bag is crucial since by the present plan seat belts will not be installed in conjunction with the air bag. Inadvertent inflations or failure to inflate are a certainty for any production item, especially with 200,000 installations per week. Unwanted or unexpected actuation could cause momentary loss of vehicle control while failure to inflate could cause many deaths and lawsuits. Another factor affecting reliability is the long period of time the air bag could rest undisturbed before it is summoned into use by
an accident. This period could easily reach ten years. Considering the fact that no maintenance will have been required, the chance of still having 100% reliability after ten years of storage is questionable.

Other questions concerning the air bag also exist. There is the possibility that the driver or passenger could be smoking a pipe or cigarette; in either case the object could be driven down their throat. Eyeglasses could be shattered against the eyes although general tests made at Holloman Air Force Base showed that an inflating air bag would not break a person's glasses.

Air bags offer little or no protection in side impacts and rollovers. With side impacts as the fourth leading area for serious injury, it does not stand to reason that good protection could be obtained by using only contoured seats and side cushioning; with the air bags this would be the only means of protection during side impact. Ejection is common in rollover accidents, and again, the only plans are to strengthen the roof and provide cushioning. A stronger roof and padding won't prevent ejection!

Closed windows pose another problem. Testing has caused the side windows to be blown out by the sudden air pressure of the inflating bag. In rollover tests, the blown-out windows have been exit corridors for dummy test victims. One suggested solution is
the addition of flapper vents or other types of pressure relieving mechanisms. Another expected change to reduce the chances of ejection from side windows is to replace the present safety glazing with laminated windows.

The air bag will not provide any protection during rear impact. Although the main restraints during rear impact are the seat back and head restraint, some device is needed in case the car is forced into a spin. With the seat belt and shoulder belt removed and with the sensors for the air bag in the front of the automobile, nothing is available to protect the occupants from colliding with the automobile interior. One suggestion has been to use inflatable head restraints on the front seats which would serve to keep the rear seat passengers somewhat protected.

One of the most important questions to the consumer is the cost of the "air bag" system, if and when all problems mentioned are solved. Estimates available cover a wide range, from a total cost of $50 per car (government estimate) to $100 per car (industry estimate). When all air bag problems are solved, $100 per car will probably be a conservative estimate.

Alternate passive restraint systems have been researched. One alternate system is a passive type safety belt that does not require occupants to fasten it.
Once the passenger enters the car and closes the door, he is automatically belted in. Other passive restraint systems include the articulated dash, the cushion car, and the retractable dash. All are special automotive interiors designed to provide the needed occupant restraint during impact. A number of experimental net systems have also been studied which deploy in a crash to provide a restraint to the occupant.

If the present proposals are followed, the first change will include required light and buzzer system to remind the driver and passengers to fasten safety belts. One such device has been demonstrated by Irvin Industries, Inc., Greenwich, Connecticut. The device is designed to prevent a car from being started until all occupants have fastened seat belts. A special sensing device in the buckle can determine by elevation and angle if the seat belt is actually being worn. The device is currently undergoing testing in Washington by the Department of Transportation.

The "air bag" seems to be the passive restraint the government and the auto industry will provide for the 1974 models. No positive predictions can be made at this time. Breakthroughs and changes in Federal Standards are both possibilities.

Present regulations on seat belts and shoulder belts are included in Federal Standards #208, #209, and
Seat belts are required for each permanent seating position and shoulder belts for front seat outboard positions in hardtop automobiles. Convertibles are not required to have the shoulder belts. Required seat belt assemblies must meet minimum requirements for webbing, assembly performance, and hardware. Belt webbing must pass a performance test for breaking strength and elongation. In addition, belts must retain a minimum of 75% original breaking strength after an abrasion test, 85% after a micro-organism test, and 60% after light exposure tests. Full belt assemblies must also meet requirements for loop strength and elasticity.

All the attaching hardware used with seat belts and shoulder belts must pass corrosion, strength, and tensile force tests. Retractors must meet requirements for regular occupant use and performance while buckles must comply with specified maximum release and adjustment forces, latch strength, and design requirements.

Seat belt and shoulder belt anchorages have specific location and strength requirements to provide effective restraint and reduce the chance of failure during impact. Each pair of seat belt anchorages must be as near as possible to 15 inches apart and be able to withstand a 5,000 pound test load applied through a
body block. The angle formed by a seat belt extending from the anchorage to the occupant's seating reference point must be as near as practicable to 45 degrees. The upper outboard shoulder belt must be within an 80 degree angle above horizontal when extended through a point six inches vertically above the shoulder reference point on an S.A.E. mannikin. If the anchor is below the shoulder reference point, it must be within an angle of 40 degrees below horizontal from the reference point. With a 3,000 pound test load applied simultaneously to both the pelvic portion and the upper torso portion of a body block, the anchorages for the seat belts and shoulder belts must hold.

**Pedestrian Hazards**

Federal Standard #211 precludes the use of any winged projections on wheel nuts, wheel discs, or hub caps to eliminate hazards to pedestrians and cyclists.

All preceding sections of this report have reviewed injury reduction equipment being used on automobiles; that is, equipment installed to reduce injury to the passenger once the accident has already occurred. A review of future considerations for injury reduction equipment and the present Federal Standards which apply to this equipment has also been included. Many of the
devices have been developed without government mandate. These represent an honest effort on the part of the automobile industry to provide a safer automobile for the motoring public.
"The post-collision phase of vehicle impact has received much less attention historically than pre-collision or collision phases." The main topic of this chapter of the report will be fire after impact, submersion after impact, departing or exiting from vehicle after impact and post-impact vehicle control.

Presently only the fuel tank, fuel tank filler pipe, and fuel tank connections are regulated by the Federal Standards. With the fuel tank filled to at least 90% capacity, and the vehicle run forward into an immovable barrier at 30 m.p.h., there must not be more than one ounce of gasoline spilled during impact or more than one ounce per minute following impact. The barrier test must also be made in a rearward direction at 20 m.p.h. and the same spill standards are required. These regulations on fuel tanks are incorporated to reduce the chance of fire after a collision. Less than one tenth of one percent of cars involved in accidents severe enough to injure people have fuel tank related fires. The number of cars which are actually destroyed by fire varies from 0.9% to 2.0%
depending upon the make of the car. A higher fire rate exists for vehicles with fuel tanks located at the front because of the higher frequency of front-end collisions.

Fire Considerations

To prevent a fire after collision, it is necessary to eliminate either the igniting spark or the accessibility of the fuel. Although a number of devices have been developed which stop the current flow from the battery when a given deceleration value is reached, more attention has been given to fuel tank construction. One suggestion has been to equip automobile fuel systems with breakaway valves and fitting. Another suggestion has been to equip cars with fire extinguishers, but this does not seem to be adequate for post-crash fires. A better solution seems to be improvement of the present fuel tanks to reduce leakage and to increase their crush resistance.

Fuel Tank and Connections

Research studies include the possibilities of using foam-filled fuel tanks, bladders, sprayable urethane coatings, plastic tanks and heavier gauge metal tanks. To evaluate the effect of foam inside the fuel tank, blocks of foam were installed prior to welding the fuel tank halves together. The foam, weighing 1.8 pounds per
cubic foot, had ten pores per square inch, was compatible with gasoline, and had a melting point of 500° F. Instead of using the rear-impacting test of 20 m.p.h., the fuel tank was impacted by a moving barrier without the protection of the rest of the automobile; the energy absorbed by the fuel tank is many times that absorbed in the 20 m.p.h. required government test. This type of testing allows fuel tanks to be tested without wrecking the rear-end of an automobile each time a test run is made. Test results showed that foam did not alter the energy absorbing properties of the fuel tank and no reduction in fuel spray was found when compared to the conventional fuel tanks.

Foam has also been tested to check its ability to reduce the leakage rate of fuel. The leakage rate is important because it affects the amount of time available for the automobile occupant to either escape from a post-crashed automobile or for him to be rescued from the wrecked automobile. Although a small differential was found in the leak rate, the foam-filled tank leaked about 8 seconds per minute slower than a tank without foam. No practical advantage was found for foam in preventing or significantly reducing static fuel leakage from automobile fuel tanks.

All Indianapolis race cars use the bladder type fuel tanks which consist of a rubber liner inside a
metal skin; the most common skin being aluminum. These tanks have worthwhile protective advantages for high-speed collisions, but the cost is about $155.00 per fuel tank. The cost is questionable since the problem of fire after highway collisions constitutes only 1% of all accidents.

A urethane coated tank has a soft plastic coating applied in a 1/8" thick external layer. No improved rupture protection is found with the urethane coated fuel tank although it does possess better puncture resistance than the conventional tank. Plastic fuel tanks, like conventional tanks, pass both the rear-impact and side-impact tests. Both the plastic and the conventional fuel tanks ruptured and sprayed fuel at approximately the same impact force when tested.

Steel tanks usually fail adjacent to the seam weld that secures the tank halves. Increasing the thickness of the metal used for fuel tanks construction does increase the required impact speed necessary to rupture the tank, but the difference is small. While it would appear that rubber-lined, plastic-coated, and heavier-gauge metal fuel tanks at present do not offer means of improving crush resistance or fuel spillage, many possibilities have yet to be evaluated to provide improvement in fuel tanks, and help reduce the possibility of fire during and after impact.
Submersion Considerations

Submersion of a vehicle after impact is most common in areas along the coastlines or in areas with numerous lakes and rivers. The submersion conditions are dependent on vehicle speed, load distribution and the obstacle encountered in running off the road. The vehicle might come to rest in any position from upside-down to right-side-up. The depth will depend upon the water penetration resistance of the automobile. It is uneconomical to build an unsubmersible car considering the low rate of automobiles involved in submersion; but, the car should be sealed well enough to increase the time available for the occupant to evacuate if submersed.

Submersion of a vehicle is an extremely serious event which allows very few possibilities of escape. The occupants of the car will be mainly responsible for their own escape. The most important problem to be solved is the equalization of pressure inside the vehicle. An automobile submerged in water five feet deep has over one ton of pressure holding the door closed. Nobody would be able to open the door. The only solution is to let the inside of the car fill with water and equalize the pressure so the door can be easily opened. The time it takes the water to fill the car, which depends upon whether any windows are open and
how tightly sealed the vehicle is, will provide the time necessary to recover from fright and unfasten seat belts. A driver or passenger wearing a seat belt has a much higher chance of being conscious so that he may rescue himself. Manual windows allow the occupants to somewhat control the filling rate while power windows will probably short-circuit. A short-circuited power window circuit could cause the window to either open or stay closed depending upon the wiring circuit. Once the vehicle is nearly full of water, the occupants should get a breath of air from the air pocket near the inside of the roof and swim to the water surface.

Post-Collision-Exit From Vehicle

In most cases, if the occupant suffers no more than minor injuries or momentary unconsciousness, he can usually exit from a crashed vehicle under his own mobility provided the vehicle impact speed was under 25 m.p.h. An impact speed of 25 m.p.h. varies greatly from a vehicle traveling 25 m.p.h. Very few accidents occur without some braking effort on the part of the driver. The weight of a vehicle as well as its type of construction will affect the chances of the occupant to exit on his own mobility. Larger vehicles over 2,500 pounds will increase the chances of self exit. Roll-over certainly could prevent exiting if severe roof
collapse occurred. It is possible that the doors cannot be opened if the roof does collapse. This condition would require exit through either a side window or the windshield. Both the windshield and the side windows present problems. The increased strength of the high penetration resistant interlayer of the windshield and the great resistance to fracture of the side tempered glass both delay the exit time.\textsuperscript{499} This is of special concern if fire occurs, and it may prevent the use of the glass areas for exit. One suggestion has been to add a ballistic device within the glass at manufacture which would intentionally break when triggered by vehicle occupants.\textsuperscript{500}

Another problem of concern during post-crash situations is door jamming due to impact. Tridimensional locks and structure strengthening are advantageous in keeping the doors closed in a crash but they may also prevent the doors being opened after a crash for exit purposes.\textsuperscript{501} It is desirable for doors to remain closed during impact and still retain good maneuverability after the crash. This compromise has not yet been reached. Experimental testing has shown that very seldom do all the doors become jammed after a crash.\textsuperscript{502}

\textbf{Post-Collision-Loss of Control of Vehicle}

Post-impact control of a vehicle is essential to
avoid a second collision. The two most common courses of losing vehicle control after impact are driver shift and mechanical loss of control. Post-impact research has strengthened the argument for restraint system usage. The automotive restraint system is essential for keeping the driver in his seated position, and will also maintain passengers in their original seated positions. This will reduce occupant-to-occupant contact injuries. Lateral impact or sideswipe collisions frequently cause a shift in driver position and leaves the vehicle "driverless." The result is sometimes a much worse secondary collision with another vehicle or the vehicle leaves the roadway and strikes pedestrians.

The most common mechanical failure causing loss of control involves the steering system. The steering column flexible coupling can be damaged during initial impact and cause loss of vehicle control. Also, the failure of wheels and suspension parts during initial impact has caused secondary collisions. Brake line failure can also cause loss of control of a vehicle, but the dual master cylinder has reduced the chance of this cause of control loss. Mechanical loss of control of a vehicle can be avoided or reduced by considering the design location of a component, such as the steering box, and by evaluating the results of barrier impact.
Post-collision vehicle factors can be hidden by the necessity of rapid occupant removal, the need for vehicle movement and the need to prevent traffic tie-up. Because it is not always possible to accurately reconstruct the role of post-collision factors, only careful analysis of accident results will bring about an improvement in construction which will provide adequate post-collision protection for automobile occupants.
Automotive safety involves the vehicle, the driver, and the roadway. Statistics show the driver to be at fault in the majority of accidents. Even the roadway ranks ahead of the vehicle in being responsible for automobile accidents. Emphasis has been given to accelerating the auto industry's program to improve the safety construction of the automobile. The federal government has written standards which are issued by the National Highway Safety Bureau. Research has confirmed that the automotive industry is making an honest effort to go beyond the scope of these requirements wherever it has been practical to do so.

Mr. Ralph Nader and others have made valuable contributions in helping the consumer obtain a safer automobile. The consumer must be represented by the federal government to keep a "balance of power" with the automotive industry. The federal government also has a responsibility to work with the automotive industry in determining the standards to be incorporated for new automobiles. There are many serious questions concerning the "air bag" regulations, and most experts blame...
government for moving too quickly without research to back their mandate. Errors of this type could prove to be a costly hoax to both the consumer and the automotive industry.

Significant advances in automotive safety construction are achieved through scientific research and strong engineering programs. Most of the work is complex, costly, and time consuming and it is tragic for developments like the present restraint systems to be rejected by the majority of the public. Even education has not convinced the public to take advantage of the safety provided in their automobiles. A recent ruling of the Supreme Court in California, holding that failure to wear lap belts may deprive an otherwise innocent accident victim of his right to receive the full amount of any monetary settlement made on his behalf, is a step in the right direction to force people to take advantage of the safety provided.

The federal government should also mandate vehicle inspection laws to force careless drivers to maintain their vehicles in safe operating condition. The time has come to quit protecting the "right" of one person to endanger the lives of many, including himself. State legislators are often too concerned about individual rights and not concerned enough about the safety of the population as a whole. The federal government can and
should withhold funds for highway construction from states who refuse to pass the needed vehicle inspection laws.

Most important is the need for stiffer control of drivers. It has been a known fact for years that over half of all highway accidents and fatalities are caused by intoxicated drivers. Thousands of dollars are being spent to design an automobile to prevent intoxicated drivers from driving. The automobile is not responsible. The driver is responsible. To compound the problem, courts are too lenient with drunk drivers. In Marin County, California, a man with two drunk driving arrests within six months was found guilty of drunk driving by a jury. A judge overruled the jury decision even though the man refused to take a sobriety test as required by California state law. It does not make sense to spend millions of dollars a year to build a "safer vehicle" which is at fault for less than 5% of all automobile accidents, while allowing the largest contributor to automobile accidents and fatalities to go unchecked.

Automotive safety construction must advance as fast as knowledge will safely allow it, but it must be kept constantly in mind that the vehicle is only as safe as the driver behind the wheel.
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