A. Basics and Overview of Accident Reconstruction

Vehicle Accident Reconstruction is the technical evaluation of a vehicle accident using the principles of science and engineering. It begins with an assessment of the available physical and documentary evidence. This may include firsthand measurements and
photographs or it may involve building upon the foundation of other investigators. After the basic evidence is established, the principles of physics and engineering are used to analyze the accident. This may lead to additional documentation and further refinement in an iterative process towards the final result. In an investigation and reconstruction, one of the first issues that must be addressed is what technical questions will likely be of concern. The documentation necessary to evaluate a vehicle’s speed is substantially different than that required to evaluate whether the lights were in use. Fortunately, in most cases the areas of interest are relatively obvious. These may include speed, position, mechanical condition, visibility and evasive actions.

The typical reconstruction analysis proceeds in reverse order from the sequence of the accident. The reconstruction will begin at the “end of the accident” where the vehicles came to a stop. The first analytical work evaluates the distance, time and speeds from collision to rest. The next evaluates the collision itself and the last phase analyzes the events prior to collision.

Accidents occur for a variety of reasons. Some are more obvious than others. In vehicle accidents, it can be helpful to break the potential areas into groups such as the following:

1. Vehicle – Obviously, blown tires, failed brakes and broken steering can cause an accident. But so can worn windshield wipers, fogged windows, misaligned headlights, poor acceleration, mismatched tires or bad suspension? Under the right circumstances, any of these could be a major factor in the accident.

2. Roadway – We could quickly point out a pothole or a section of “ponded” water which caused an accident. Identifying a poorly positioned sign, conflicting speed limit or reverse banking on a curve might take a little more effort.
3. Environmental – Snow and rain are obvious. Just as important are the setting sun, deep shadows, background lighting and that “FOR SALE” sign that blocked the view out of the window.

4. Driver – Drivers can certainly cause accidents. They sometimes fail to see the obvious. They misjudge the speed or the distance of an approaching vehicle and they frequently travel too fast or change lanes without checking all the mirrors. They also, read maps, eat, talk on the cell phone, and dig through the glove compartment trying to find a CD. Drivers almost never say they were doing anything other than “paying strict attention, facing forward with both hands on the wheel” when the accident developed. We understand that this is the story and the driver will be sticking to it.

VEHICLE

The modern vehicle is a technological wonder. It is also a compilation of compromises. As a technological wonder, it has well designed and tested machine components, electronically controlled and monitored engines, drive trains and suspensions as well as numerous gadgets for our pleasure and convenience. As a compilation of compromises, parts are supplied by the lowest bidder, it must comply with marketing conditions, a myriad of state and federal laws, and manufacturing costs must be held to a minimum. Most of the time we operate safe, reliable vehicles. Unfortunately, on occasion, design, maintenance, manufacturing, age or abuse act singly or in combinations to create a vehicle problem. Of the accidents caused by vehicle problems, only a small portion are caused by sudden catastrophic failure. Many more are caused by reduced capabilities from aged or worn components.

With a heavily damaged vehicle, it may be difficult to differentiate a pre-impact problem from the collision damage. This task is much easier if the range of possibilities can be narrowed. In this process, driver or witness statements, roadway evidence and other indications of the sequence of events can be extremely critical to the
successful analysis of the problem. While it is possible to examine vehicles without knowledge of the accident, the chances of finding a problem are diminished and the time involved usually increases significantly.

A driver, passenger or witness will typically be the first source for a potential problem. They should be queried about repairs, changes and problems. There are, however, many problems that could be significant that would not be identified by these individuals.

**ROADWAY**

Generally we look for a potential roadway problem if the vehicle would up where it should not have been. In these types of accidents, we are concentrating not so much on where the collision took place as much as where the vehicle left the normal path of travel. Is there a curve? What is the banking? Is the posted speed correct? Are there any drop-offs or potholes? Could a domestic or wild animal have been a problem? Modern roadways facilitate high speed travel. However, many have their origins as dirt paths for pedestrians and horse drawn wagons. Others were restricted by buildings, railroads and landholders. Still others have compromises created by rivers, hills, and rock outcroppings. Even if properly laid out and constructed, roadways require maintenance, reassessment and modification to handle increased traffic density or flow patterns. As a result, many roadways are too narrow, have poor shoulders, inadequate sight distance or speed limits incompatible with current traffic densities and conditions.

Important clues to a roadway problem are the presence of any new construction, repairs or recent maintenance. Be sure to check for evidence of other accidents at the same location. Damaged trees, collision debris, gouges, older skids can all indicate that other drivers have had similar problems.
Shoulder drop-off on U.S. Highway 17 near Georgetown, South Carolina. Note the scrape at the pavement edge.

Shoulder “drop-off” is 5 inches. Many drivers would have trouble if they left the pavement in this area.

ENVIRONMENTAL

Environmental concerns include the weather but also other factors such as ambient or background lighting, other traffic, pedestrians, parked vehicles, etc. In short, anything that could change and affect an operator’s view of the scene or the ability to perceive the situation properly. For example, many failure to yield accidents are readily
explained with the presence of intervening traffic or visual problems from a parked vehicle.

Check to see how the site is oriented. Could a rising or setting sun influence visibility? At night, what is the background lighting? How would the roadway geometry effect high or low beam light distributions? What are the traffic patterns? Look for any situation that could affect a driver’s perception or visibility.

The truck driver turned left in front of an oncoming motorcycle. The accident was at night. A witness was following behind the motorcycle.
Three headlights viewed at night. One is 150 feet from the camera. The other two are 300 feet away. The motorcycle is easy to see.

Three headlights viewed at night. One is 150 feet from the camera. The other two are 300 feet away. Can you see the motorcycle?
DRIVER

Driving is a relatively easy task most of the time. It can, however, get very complex in a hurry. Imagine tossing a baseball a few feet in the air and catching it. Easy, right. Now imaging doing it for a few hours. Chances are that you will drop it once or twice. While driving, we make similar mistakes. Most of the time there is no conflict. We recover and proceed on. Occasionally, there is conflict and an accident develops. Trying to figure out exactly what caused you to miss the baseball that one time can be difficult. So can trying to figure out how you made the driving error.

Driver error generally comes in one of three ways. These are:

Inattention – reading a map, talking on the cell phone, daydreaming, etc. which causes us to miss a stop light, wander out of the lane or fail to note the stopped vehicle ahead.

Aggressive Driving – Speeding, approaches which require hard braking, taking risks in crossing maneuvers, etc.

Perception and Identification – In general, drivers can only respond to things that they can “see”. However, they do not always see things that are visible. For example, at an intersection a driver may not “see” an approaching vehicle for many reasons. The vehicle could be behind a curve or hidden by a parked vehicle, advertising sign or even a roof support. Even if the driver “sees” the vehicle, the driver has to evaluate its speed, direction of travel and the time available to conduct a maneuver. There are many opportunities to get this wrong. If the incident is at night and the headlights of the approaching vehicle are close together, as on a jeep, the offending driver may “see” a vehicle that is closer than he thinks.
Examples of Less than Obvious Problems:

Vehicle:
- Different tire types or sizes. Creates handling difficulties.
- Speedometer error from oversize tires. Indicated speed is less than actual speed.
- Low air pressure in tires. Increases potential for hydroplaning.
- Add-on tinted windows. Reduce visibility especially at night.
- Misadjusted headlights. Give driver inadequate nighttime illumination.

Roadway:
- Quick yellow light. Inadequate time to complete crossing or turning maneuver.
- Stop sign poorly positioned. Driver does not notice in time to stop.
- Driveway drains across the roadway. Increases chance of hydroplaning and encountering ice.
- Background lighting confuses driver. Common in construction zones.
- Foliage, signs obstructing portions of the sight triangle. Reduces opportunity to assess approaching traffic.

Environmental:
- Objects, animals or people in the road, on the shoulder or in the vehicle. Potential to create distraction or reason to deviate from normal path.
- Visibility restrictions e.g. sun visors, passengers, dirty windows, or decals and stickers on the windows. Provide opportunity to miss or misinterpret another vehicle’s position.
- Blind Spots. All vehicles have blind spots over the front, on the sides, and at the rear.
- Traffic. Other traffic and its movement control our actions and what we can see.

Driver:
- Nighttime vision reduces significantly with age.
- Older drivers may have trouble turning their head and shoulders sufficiently to see at an acute intersection.
- Younger drivers may have less experience with a different vehicle or a manual transmission.
- Is the driver familiar with the vehicle? Particularly in rental vehicles, the driver may have problems with the signals and controls.
- Driver familiarity with the area. Has it changed? A new stop sign may not be “seen” by drivers accustomed to another condition.

This driver floored the accelerator and drove off a parking garage. This type of accident is common. It is known as a Sudden Acceleration Incident (SAI).
If the driver momentarily confuses the pedal position, the accelerator is depressed and not the brake. Unfamiliarity is a major cause.

INVESTIGATING AND DOCUMENTING THE ACCIDENT

The first step required in an accident reconstruction is measurement and photography of the accident site and the involved vehicles. Ideally, this process should begin before the vehicles are moved from the scene. Reconstructionists seldom have access to the scene at this stage. Therefore, it is important that on scene personnel have some familiarity with the documentation and preservation of evidence available at the scene.

Photographs - 35 mm or High resolution digital (retain the negatives or electronic files)

(a) Take shots from all angles.
(b) Elevate the camera (if possible) for overall site views.
(c) Get the horizon/background in the picture.
(d) If you take a close-up, take a matching overall photo.
(e) Take a picture of the accident site, all sides of all vehicles including undamaged trailers.
(f) Take pictures of cargo prior to unloading.
(g) Take close-ups of broken parts, tie-downs, failed tire, etc.
(h) Take pictures of any personnel with cameras or measuring devices.
(i) Videotape is fine but it is not a substitute for still photos,
(j) If you shoot pictures at night, return in daylight and shoot the same angles,
(k) Photograph lighting, drop-offs, potholes, roadwork, debris, etc.

Measurements

(a) Use actual measurements (tape, rolling measuring device, auto odometer, surveying equipment). Estimate only as a last resort. Even heel-to-toe method is better than estimating, especially if you later calibrate this method.
(b) Record all measurements in a single document.
(c) Prepare a sketch or drawing illustrating what was measured.
(d) Measure overall length, wheelbase, damaged areas of vehicles; measure distances between vehicles if they are still at the scene; at the scene measure at least two reference points which are unlikely to be moved or changed

Documentation

(a) Statements of drivers, passengers and witnesses.
(b) Maintenance records, registration, inspection (tractor and trailer).
(c) Post accident maintenance check (conditions of tires, brakes, steering, lights, etc.).
(d) Driver records, driver training.
SPEED EVALUATION

In vehicle accident reconstruction, the speed of the vehicle is often of primary importance. Speed becomes a factor because of its:

- legal significance relative to the posted speed limit,
- physical role in the damage to the vehicles and the injuries to the occupants,
- effects on the movement and maneuvering of the vehicles,
- effect on a driver’s visibility, perception and response to the developing accident.

There are a variety of ways a reconstructionist can evaluate a vehicle's speed. Different mathematical formulas are used in these methods. While these may at first appear intimidating, the actual math is usually basic algebra and geometry. The greater difficulty is understanding the underlying physics and deciding exactly how the equations are applied to a particular situation.

The evaluation of speed will usually be conducted with one or more of the following methods:

1. Momentum/Energy Analysis
2. Damage/Energy Analysis
3. Centrifugal Force Analysis
4. Launch, Fall or Vault Analysis
5. Geometry and Timing Analysis
6. Event Data Recorders

(e) Cargo records.
(f) Accident reports (state, federal, company).
Each of the methods will be outlined briefly along with some of the restrictions and limitations.

1. **Momentum/Energy Analysis**

For our purposes, linear momentum can be defined as the vehicle weight multiplied by the vehicle speed in a certain direction. The basic premise of a momentum analysis is that the linear momentum immediately following a collision is the same as the linear momentum immediately preceding a collision. Any momentum "lost" by one vehicle is "gained" by the other. The application of these principals can be observed in any billiard game. Each vehicle has a weight, speed, and a direction going into the collision and a weight, speed, and direction coming out of the collision. There are a total of 12 numerical values in the two vehicle, two dimensional momentum analysis. The analysis will solve for any 2 of the 12. The other 10 variables must be assumed or evaluated by some other means.

The typical linear momentum/energy analysis has the following phases:

- The reconstructionist must obtain the weights of the vehicles both before and after the collision. Since, in most cases the weight of the vehicles will not change appreciably during the collision, this information is sufficient for 4 of the 10 required values.

- The impact location and rest position of the vehicles is determined.

- The post-impact direction is obtained from the physical evidence, e.g. tire marks, gouges at the accident site or the general direction from impact to rest.

- The decelerations from impact to rest are evaluated. The evaluation is based on post-impact braking, rotation, terrain, contact with
brush, etc. encountered from impact to rest. The post-impact speeds can then be determined from the evaluated decelerations and the travel distance to rest. This is the energy portion of the analysis.

- At this point, if the pre-impact direction for both vehicles is "known", the momentum equations can be solved to yield the speed for each vehicle. Alternatively, if the incoming speed and direction for one vehicle is "known", the speed and direction for the second can be calculated.

- The final portion of the analysis is another energy phase (braking or skidmark length) which takes into account any pre-impact deceleration.

Accidents where the momentum analysis has limited or no applicability include:

- head-on or rear-end collisions (In these cases the analysis reduces to one dimension and can only solve for one unknown speed or direction.)
- collisions with fixed objects or between vehicles with large weight differences (such as a loaded tractor trailer with a small automobile)
- collisions where deceleration values cannot reasonably be determined
- collisions which are not short in duration such as sideswipe of a trailer

Although, it is not used as frequently, angular momentum is also conserved during a collision. Therefore, any angular momentum lost by one vehicle is gained by the other. The principles of angular momentum can also be observed in a billiard game. When "English" is imparted to a ball, it is given a spin. When it subsequently strikes another ball, some of the spin will be transferred to the struck ball. Also like "English" in billiards, angular momentum is more difficult to apply to reconstruction than linear momentum. There are two basic reasons for this difficulty. First, while linear momentum requires the weight of a vehicle, angular momentum requires the rotational inertia. Rotational inertia values are significantly more difficult to obtain than weights. In addition, the angular deceleration must be evaluated. Reasonable values for the rotational deceleration can be very difficult to obtain and usually require extensive computation. The easy way to handle the computation is with a computer and angular momentum is evaluated in some reconstruction software.

2. Damage/Energy Analysis

The basic premise in a damage analysis is that the forces causing the collision damage can be evaluated analytically by comparing the damage profile of the accident vehicle with the damage profile produced by a controlled test. Verification of the basic premise is well documented. The difficulties lie in three general areas.

a) Staged tests are usually conducted with a collision into the proverbial "brick wall". This produces a nice flat damage profile which is easy to measure. Real collisions may involve profiles which are more difficult to measure.
b) The vast majority of staged tests are frontal collisions at 30 or 35 mph. Real accidents involve a variety of angles and speeds. Impact areas are often on the side or rear where the comparison data is sparse.

c) Real collisions usually involve another vehicle. The data on staged collisions with another vehicle is also sparse.

Even with these complications, analysis from damage data is often superior to the momentum analysis and has wider application. Damage analysis can be applied to collisions with fixed objects such as large trees or bridge columns. It is also very useful when analyzing collisions between automobiles and large trucks.

A point of considerable confusion over this type of analysis is that the damage analysis only evaluates the change in velocity (speed and direction) of a vehicle during the collision. The post-impact speed and the speed prior to impact must be calculated independently. Usually, these calculations are made with energy methods in the same manner as outlined for the momentum analysis.
3. Centrifugal Force Analysis

The forces generated as the tractor trailer rounded a curve dislodged the load.

Centrifugal forces are created whenever a vehicle is not traveling along a straight path. Therefore, this analysis technique is usually applied in accidents which occur on curves or as a result of evasive maneuvering. As a vehicle travels along a curved path, the centrifugal forces increase as the speed increases or the radius decreases. This type of analysis could be used for a truck overturn or to evaluate speed from "yaw marks". It is very useful for establishing a maximum speed around a curve. The important points to remember here are that steering, braking and suspension components can significantly effect the speed at which control is lost or a vehicle overturns. A sudden steering input can reduce the radius of the turn. It will also create a "weight shift" which may initiate an overturn. Braking will reduce the speed at which the tires begin to leave "yaw marks". Also, when braking is involved, it is important to distinguish between skidmarks that curve as a result of vehicle rotation and yaw marks which are created by lateral movement.
4. Launch, Fall or Vault Analysis

When a vehicle or an object loses support from the ground it is "launched". It then travels horizontally at the same horizontal speed at which it was "launched" until it "falls" back to the ground. The "fall" may start as an initial upward, level or downward movement.

These techniques are a favorite of the reconstruction schools. The principal reasons are: the equations can be readily set up and solved; the principles can be easily demonstrated and the solutions can be very accurate. Unfortunately, the amount of effort and time associated with the equations in the schools is far out of proportion to their actual utility in speed evaluation. Relatively few accidents involve significant "flights" of vehicles or objects. However, there are occasions where this type of analysis is useful. These include a) pedestrian impact, b) motorcycle/rider separation, c) vehicle travel over an embankment or into a body of water, d) travel over a ditch or a steep grade, and e) rollovers. The basis of the analysis is that once a vehicle or object separates from the ground, it will follow a ballistic arc while in the air. All that is required to calculate the speed at which it left the ground are:

- Identification (measurement) of the point where it was "launched" and the point it first contacted following the "fall". This provides the horizontal travel distance.

- Difference in elevation of the launch and contact points.

- The angle of launch.
A fall from this height is readily analyzed

As typically used, these equations make several assumptions which may influence the results. The equations ignore the effects of wind and air resistance. In most cases these effects will be negligible but they may be significant for very high speed accidents or objects which are not as dense as vehicles and people. A factor which will likely be significantly greater is the accuracy of the launch angle and the horizontal distance. If the vehicle left the ground while traveling over uneven terrain or as a result of contacting an object such as a curb or guardrail, the launch angle may be difficult to evaluate. Vehicle rotation and suspension movement can also effect the evaluation of the distance from launch to contact. These will be especially important if the horizontal travel is not several times the length of the vehicle.
5. Geometry and Timing Analysis

With the advent of antilock braking systems, the traditional momentum analysis combined with pre-impact skidmark evaluation is not as reliable as in the past. Skidmarks from ABS are much fainter or non-existent. Analysts are relying more heavily on visibility and timing considerations to evaluate speed. To illustrate the application of these techniques, consider an accident in which an automobile driver rounds a curve and observes a tractor trailer backed across the roadway. The driver of the automobile states, "as soon as he came around the curve, he saw the trailer, applied brakes and skidded to impact". If the automobile left 150 feet of skidmarks prior to impact, a damage analysis could be used to determine the speed at collision and an energy analysis (skidmark length) to determine the speed at the start of braking. However, if the automobile had antilock brakes there may be little or no skids to measure. In this situation, the speed at impact could still be evaluated with a damage analysis but the speed at the start of braking would have to be evaluated on the basis of the available visibility and the timing considerations of perception/reaction and deceleration.

You may note that it appears the result will be less accurate than the analysis with the measured skidmark. However, it is possible that it will be more accurate. One of the principal problems with the skidmark is that, when it is present, it tends to become the controlling factor in the analysis. Many accidents involve significant braking before any skidding occurs. This results in a general trend toward the conservative evaluation of a vehicle's speed. If we reconsider the speed analysis with the skidmark and also perform a visibility and timing analysis, it may indicate that the driver of the automobile could have begun braking 300 feet prior to impact. Therefore, it could be concluded that the automobile was either traveling faster than the damage and 150 feet of skidmarks would suggest, or the driver was not paying attention as he rounded the curve. Visibility and timing considerations may therefore be important even in situations where there is sufficient information to evaluate speed by other methods.
6. Engine Control Modules and Event Data Recorders

Engine control modules (ECM) were placed on truck engines to monitor the engine operation to reduce maintenance and increase service life. Many now also provide some speed and braking monitoring that captures data in the hard brake applications that accompany many accidents. Air bags and stability control systems are beginning to appear in trucks. These will further increase the data available for reconstruction.

Event Data Recorders (EDR) were introduced into automobiles as a byproduct of airbag implementation. The airbag has to deploy in time to protect an occupant during a collision. A variety of sensors collect information which is processed in an electronic module. When some combination of the inputs exceeds the designated threshold, the airbags are activated. The systems are designed to retain portions of the input data in electronic memory. Following an accident, the automobile manufacturer can download the data. Some manufacturers are pursuing at least some public access to this information. Equipment to download and electronically interpret the data from some of the vehicles of the following manufacturers is now commercially available.

- General Motors
- Ford
- Chrysler
- Isuzu
- Mitsubishi
- Sterling
- Suzuki

The type of information stored will depend upon the vehicle model and the nature of the accident. Useful information for reconstruction is unlikely in vehicles earlier than the mid 1990's. As an example, late model General Motors' vehicles store information on the engine speed, vehicle speed, brake status and throttle position for up to 5 seconds before the airbag deployment. The accelerometer data is converted to a delta V for the event. The status of the airbag warning indicator and the driver's seat belt is also included.
ECMs and EDRs are essentially storage devices for the measuring instruments the manufacturer has chosen. These can provide an accurate description of the accident. However, there are a number of limitations. The limitations include:

- Acceleration data is usually limited to the longitudinal axis, therefore the delta V’s only reflect the component parallel to the vehicle.
- Because of the limited storage space, storage occurs at discrete intervals. What happened between the storage intervals could be important.
- The stored data is a reflection of the sensor readings. These may or may not be accurate. Bad sensors will give bad data.
- The sensor data may be accurate, but not a reflection of what is really happening to the vehicle. For example, the speed data would presumably come from the drive train. If a drive wheel left the ground it could provide a falsely high speed to the sensors.
- Much of the sensor data simply reflects an on/off condition.
- The devices are electronic with some mechanical interfaces. Electronics can be influenced by age, contamination, deterioration, electromagnetic fields, etc. In most cases, this would produce no results. However, inaccurate results are possible. The results should be consistent with the other aspects of the accident. A traditional reconstruction is required to confirm or refute the recorded data.
HEADLAMPS AND OTHER LIGHTING

Have you ever noticed someone driving at night without headlights? This occurs frequently when a driver travels from a lighted area, such as a convenience store, and forgets to turn on the lights. Drivers also neglect to use their headlights under reduced visibility conditions of fog, dusk, and rain. But then, on the other hand, other drivers just simply don't see a well lighted vehicle. Following a collision it is often possible to determine whether a vehicle was driven with its headlights illuminated.

First, it is usually easier to demonstrate that the lights were in use than it is to demonstrate that they were off. Usually, one positive indication that a headlight was illuminated is sufficient to conclude that the headlights were "on". However, this conclusion must be exercised with some caution, since it is possible for some of the lights to be burned out, missing, or otherwise damaged prior to the collision. To demonstrate that the headlights were off, requires either very positive evidence or an accumulation of "off signals" from a number of bulbs.

Headlights, or headlamps as they are technically referred to, generally are of two basic types, sealed beam or halogen. Both consist of a coiled tungsten filament surrounded by a glass envelope. The glass envelope of the sealed beam lamps is large, 4 to 6 inches across and shaped like a small TV picture tube. The air inside is removed and the glass envelope is "sealed" so that the tungsten filament is heated in a vacuum. In contrast, the filaments in halogen headlamps are surrounded by a small cylindrical glass envelope, approximately ½ inch in diameter and 1 inch long. They are called halogen headlamps, because the glass is filled with an inert halogen gas. The halogen bulbs also have an outer glass or plastic covering which provides additional protection and focuses the emitted light. In the sealed beam headlamps, all of these functions are provided by the glass envelope.
Undamaged Headlamp Filaments

When a headlamp is illuminated, the coiled tungsten filament is heated by electrical resistance to a temperature of 4500 degrees F. At this temperature, the filament emits radiation in the form of white light. If the glass covering is broken during a collision, several things are likely to happen. The "shock" or impact which breaks the glass will cause the headlamp to move violently. When this occurs, there will be inertial loads imposed on the filament coils. If the filament is cold, it will sustain very high inertial loads without deforming the filament coils. However, when the filament is white hot, the metal is relatively malleable and most impacts which break the glass will also deform the filament. This results in a filament which has bends, bows or other non-uniformity in the coils.

When the glass covering breaks, in a sealed beam bulb, the vacuum is lost and in a halogen bulb, the halogen gas dissipates. In either case, the hot filament is exposed to the atmosphere which contains oxygen. Oxygen will chemically combine with the hot tungsten to form tungsten oxide on the surface of the filament. This changes the color of the filament from a shiny silver color to a blue/black color. If the filament remains
energized, the filament metal will continue to combine with oxygen, producing a yellow green powder of tungsten oxide. The filament will continue to decompose until it separates and the electric circuit is broken. Where it separates, the ends of the filament will taper down to the separation.

When the glass envelope is broken, the breaking glass will generate many small fragments. These small fragments are swirled around and may contact the tungsten filament. If the filament is cold, the glass particles simply bounce away. However, if the filament is hot, the glass melts onto the surface of the filament, forming little glass nodules. This effect is usually more pronounced with a sealed beam headlamp, because the air rushes inward to fill the vacuum carrying the glass particles toward the filament at the center.

*Hot Filament Deformed by Inertial Forces Generated During Impact
Notice the Adjacent Undefomed Filament*
In some situations, the headlamps may be turned on after the collision. These filaments will exhibit oxidation but none of the other conditions. Careful examination will usually allow a determination of whether the lights were on, off, or turned on after the collision.

**TIRE MARKS**

Tire marks are a frequent part of a vehicle accident. When, where, and how they are made provide important clues to the analysis of an accident. Reconstructionists classify tire marks by the manner in which they are made. "Skidmarks" are made by a tire which is "locked" or rotating slower than the vehicle is moving. "Acceleration marks" are somewhat opposite since they are made by a tire which is rotating faster than the vehicle is traveling. A tire can also leave a mark if it is slipping perpendicular to the direction of travel. These are typically referred to as "yaw marks". Additionally, tires may leave marks if something unusual is occurring to create a wobbling of the tire tread. This can occur with a flat tire or a suspension problem. Tires leave marks as a result of movement during a collision. These are sometimes referred to as "collision scrubs".
The nature of the tire mark can provide useful information about an accident. A skidmark with bold outside edges is an indication of an overloaded tire. This occurs on the front tires because of the weight shift during hard braking. Skidding rear tires would more likely exhibit a bold center, a characteristic of an underloaded tire.

Similarly, a vehicle which is simultaneously braked and turned will skid the inside tires first. It takes less brake torque because the turn has reduced the load on the inside tires. However, a vehicle turning hard without braking will leave "yaw marks" on the outside tires because the tire flexes more under the heavier load.

Tire marks also are very important in establishing the area of the collision. A vehicle will leave tire marks which are straight lines or smooth arcs until it strikes another object. At that point the path can deviate sharply. Any sharp deviation in a tire mark indicates a sudden event, either a collision or a major mechanical failure. Careful tire mark analysis is essential during vehicle accident analysis. It is often the most critical evidence of the accident speeds, timing and sequence.
B. Engine Control Modules and Event Data Recorders

As everyone knows, aircraft crash analysis usually involves locating and analyzing data from “black boxes” which record cockpit conversations, flight controls and a variety of parameters associated with the aircraft’s operation. Not as well known is that most modern vehicles store diagnostic and troubleshooting information associated with the Supplemental Restraint System (SRS or air bag), emissions control, powertrain and braking systems. This data can be retrieved with a variety of proprietary and commercial equipment usually in the form of a “scan tool” or a computer interface.

Earlier systems varied tremendously but in the early 1990’s, the Society of Automotive Engineers released standards to promote more commonality among the vehicle interfaces and the equipment used to retrieve the data. The current interface is referred to as the “OBD II” (On Board Diagnostics Version II). This interface has 16 pins and is located in the passenger compartment near the center console or below the dash on the driver side. For automobile or small truck accidents, the most useful information is usually obtained with the air bag or “Supplemental Restraint Systems”. Large trucks have similar systems with a different type of common interface. The large truck systems were developed around maintenance requirements for the engines and therefore concentrate predominately on engine operating conditions.

Event Data Recorders (EDR) were introduced into automobiles as a byproduct of airbag implementation. Air bag patents date back at least to 1952. The first commercial air bags were introduced in 1974 as an option on certain General Motors vehicles. They were available for three model years and then dropped, presumably for lack of sales. Air bags were effectively reintroduced by Mercedes in 1985 and then by all manufacturers beginning in 1989 to meet the passive restraint requirements of Federal Motor Vehicle Safety standard 208. The airbag has to deploy in time to protect an occupant during a collision. A variety of sensors collect information that is processed in an electronic module. When some combination of the inputs exceeds the designated threshold, the airbags are activated. The systems are designed to retain
portions of the input data in electronic memory. Following an accident, the automobile manufacturer can download the data. Some manufacturers are pursuing at least some public access to this information.

Equipment to download and electronically interpret the data from late model General Motors, Ford, Chrysler, Isuzu, Mitsubishi, Sterling and Suzuki vehicles is commercially available from Bosch Corporation (www.boschdiagnostics.net). Other manufacturers are likely to follow the trend. The Bosch equipment (formerly Vetronix Corp) is called the "Crash Data Retrieval System" (Fig 1). It consists of an interface module, connectors, and a software package to allow a portable computer to store and present the data. The raw data is retrieved in hexadecimal format (Fig 2). The manufacturers have not released the information necessary to directly confirm or translate the raw data. For commercial motor vehicles, the primary data of interest is in the Engine Control Module (ECM). The major engine manufacturers, Cummins, Detroit Diesel, Caterpillar, Mack and Volvo all capture and record data that can sometimes be extensive. Knowing a vehicle's speed, engine rpm, brake effort, throttle position and other parameters in detail for the time frame before, during and after a collision can be extremely helpful in any accident analysis.
First generation airbags deployment systems typically consisted of one or more forward placed discriminating sensors and a more centrally located arming sensor. Each of these acts as an inertia activated switch. When a forward discriminating sensor closes, it completes a portion of the firing circuit. If the arming sensor also closes, the firing circuit is complete and airbag deployment is initiated. The sensitivity of the sensors is controlled both by their basic design and adjustment controls on the individual sensors. The air bag module for these systems predominately acts as an energy reserve source in case of loss of vehicle power and a malfunction indicator if the system detects an out of limits condition in the circuit. There is no logic routine and little or no data is permanently recorded. An example of this type of module is the General Motors “Diagnostic Energy Reserve Module” or DERM introduced for the 1990 model year.

In addition to providing an energy source for deployment, the DERM provides diagnostic monitoring of the system components and activation of the malfunction warning indicators. It provides very limited event data most of which directly involves the supplemental restraint system. The data available includes the following:

1. Status of warning indicator - on/off
2. Length of time the warning indicator was illuminated
3. Crash sensing activation times or the crash sensing criteria was met
4. Time from vehicle impact to deployment initiation
5. Diagnostic trouble codes present at the time of the event
6. Ignition cycle count at the time of the event
Hexadecimal Data
This page displays all the data retrieved from the air bag module. It contains data that is not converted by this program.

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$3F  3D 3D 3D 3D 3D 3D

Printed hexadecimal data from a 2003 Chevrolet Van
Second generation systems introduced a logic routine into the firing circuit. In a typical example, a longitudinal accelerometer provides data which is checked against a preprogrammed algorithm. When the deployment criteria is met or exceeded and a discriminating sensor is activated, deployment is initiated. The General Motors version of the module is called an SDM for “Sensing and Diagnostic Module”. It was introduced into the 1994 model year. This version of the SDM provides all of the previous data plus the following:

7. Maximum delta V for a near deployment event
8. Delta V versus time for a deployment event
9. Time from impact to time of maximum delta V
10. Status of drivers seat belt switch
11. Time between near deploy and deployment event if within 5 seconds

The delta V recorded is the change in longitudinal speed undergone by the vehicle in the time period under consideration. It is calculated from the accelerations measured by the accelerometer. The device has the capability to record two separate events. There is a threshold, below which no information is captured. Once the threshold is exceeded, a near deployment is recorded. The near deployment could be as simple as striking a pothole or running into a curb. Any event which is greater than the first one will overwrite the data in this field unless the first event was followed within five seconds by a deployment level event. In this case, the data fields are locked together. If there is no near deployment event within five seconds before deployment, a second deployment level event may be recorded into the near deployment field.

Beginning in 1999, General Motors began adding additional data to include:

12. Passenger airbag enabled/disabled status
13. Engine speed in second increments for five seconds prior to impact (algorithm enable)
14. Vehicle speed in second increments for five seconds prior to impact (algorithm enable)
15. Brake status (on/off) in second increments for five seconds prior to impact (algorithm enable)
16. Throttle position in second increments for five seconds prior to impact (algorithm enable)

Non-deployment pre-crash graph

This type of data is useful in accident reconstruction. However, its usefulness comes with a number of caveats.

- First, the ability to record data is very limited. The typical General Motors SDM has 32 kilobytes of ROM (read only memory) for program code. It has 512-640 bytes of RAM (random access memory) and 512 bytes of EEPROM (electronically erasable programmable read only memory). All the data stored is limited to the 512 bytes of EEPROM. To appreciate the small amount of storage, consider that a single letter such as “B” is one byte of information.
- Acceleration data may be limited to the longitudinal axis, therefore the delta V’s only reflect the component parallel to the vehicle.

- Because of the limited storage space, storage occurs at discrete intervals. What happened between the storage intervals could be important.

- The stored data is a reflection of the sensor readings. These may or may not be accurate. Bad sensors will give bad data.

- The sensor data may be accurate, but not a reflection of what is really happening to the vehicle. For example, the speed data comes from the drive train. If a drive wheel left the ground it could provide a false speed to the sensors.

- Portions of the sensor data simply reflect an on/off condition.

- In order to save memory space, the acceleration data is not stored. A delta V is calculated from the data. Only the resultant calculated values are actually stored.

Supplemental Restraint Module Installed in Vehicle Under the Seat
Problems with the data occur with the manner in which it is captured. The vehicle speed is captured from the rotational speed of the drive train. This is influenced by the size of the tires, whether or not they are inflated, and whether they are rolling in line with the path of travel. A vehicle which has tires spinning, leaving the ground or traveling partially sideways will be unlikely to reflect its true speed. The data is also a "snapshot" of the status in one second intervals. Nominally it begins one second before algorithm enable. The one second designation is therefore at the extreme upper limit of the actual time period. The one second intervals are also problematic in the sense that it does not report what occurs between intervals. For example, an operator who "pumps his brakes" could cycle the pedal such that either a) no brake application was recorded or b) it appeared to be a continuous application. Even then, the brake status actually represents the status of the brake light circuit, that is, "on or off". It tells nothing about the extent the brakes were applied nor whether they were operating properly. Further complications arise when it is recognized that the delta V may be only representative of the single longitudinal axis at the location of the module. Recorded values will be influenced both by non longitudinal accelerations and by rotation about any axis. Some systems employ dual axis accelerometers. With the increasing use of side impact airbags, it is likely that most new systems will employ either biaxial or triaxial accelerometers. Access to this type of data will allow significantly more direct comparison with reconstruction values.

Other limitations are associated with the focus of the system on the airbag deployment. Frontal airbags are designed to deploy in collisions where the occupants would move forward relative to the automobile. The sensor data is concentrated on the detection of a frontal event. If the accident under consideration is a rollover, it is unlikely that the data would contain much useful information. Further advances such as side airbags require additional sensors that may provide more useful data for this type of accident.
### DDEC® Reports - Last Stop Record

**Print Date:** 02:28 PM (EST)

- **Trip:** 06/03/2001 to 01/04/2003 (EST)
- **Vehicle ID:** [redacted]
- **Driver ID:** [redacted]
- **Odometer:** 725440.1 mi

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- **Fuel Consumption:** 5.84 gal/h
- **Idle Time:** 3732:58.23
- **Idle Percent:** 45.37%
- **Idle Fuel:** 1405.13 gal

**Last Stop Time:** 11/20/2002 07:09:00 (EST)

**Last Stop Odometer:** 725440.1 mi

#### Vehicle Speed (mph)

![Vehicle Speed Graph]

#### Engine RPM

![Engine RPM Graph]

#### Percent

![Percent Graph]

#### Brake Applied

![Brake Applied Graph]

#### Clutch Engaged

![Clutch Engaged Graph]

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W Poplin Engineering LLC  Post Office Box 210  Wadmalaw Island, SC 29487  
(843) 559-8801  Fax (843) 559-8802  wpoplin.com
### DDEC® Reports - Last Stop Record

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**Vehicle ID:**

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**Last Stop Time:** 11/20/2002 07:09:00 (EST)

**Last Stop Odometer:** 725440.1 mi

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C.  Problems Unique to Trucking Accidents

Commercial vehicles are just like automobiles except for a few small details. They can be 5 times as long, 1.5 times wider, 30 times heavier, take 50% longer time and distance to stop, take 3 times longer to turn or cross an intersection and have only side mirrors for a rear view. In addition, they may articulate in the middle, have a high center of gravity and be relatively noisy. These differences can make for some interesting accidents.

Post accident examination of a commercial motor vehicle is similar to any other vehicle. The general condition and damage must be documented. Details of lights, mirrors, tires, etc. are similar. Probably the largest difference is the brake system. Air braked vehicles typically require more maintenance than hydraulic brakes. Older vehicles require routine adjustment of the brakes, typically every few weeks or several thousand miles. Newer vehicles have self adjusting brakes, but it is not unusual to find brakes out of adjustment even with these mechanisms. There are additional federal and state regulations that trucks must meet. The current (October 1, 2007) inspection
requirements from 49CFR are listed in Appendix I. These guidelines provide a summary of items to consider in a vehicle inspection.

One type of accident that is almost exclusively associated with tractor trailers is the side underride collision. These accidents typically occur at night when a tractor trailer backs across a roadway or turns left from a driveway. The elevated structure of a trailer can peel back the roof and crush the passenger compartment of an automobile even at slow speeds. Most of these collisions involve three factors:

1. A poorly illuminated trailer.
2. A truck tractor position on the oncoming shoulder or the oncoming lane of travel with its headlights pointed toward approaching traffic.
3. An approaching driver who observes the truck but does not realize there is a trailer stretched across the roadway.

The typical trailer is illuminated with three side marker lights, an amber light on the side near the front, an amber light in the middle and a red marker light on the side at the rear. In addition, a similar color reflector must be located adjacent to the side marker light. On most trailers both the marker lights and the reflectors are small. When located behind the glare of oncoming headlights, the side lights can be somewhat difficult to see under the best of circumstances. However, there are a variety of conditions which can further decrease the visibility of the trailer. These include:
1. The lights may be burned out or otherwise damaged.
2. The jackknifed truck tractor will hide the forwardmost side marker light of a flatbed or similar trailer.
3. Dirt and dust from the road will reduce the conspicuity of low mounted marker lights. Diesel exhaust may cover the high mounted lights.
4. Straps, load binders or other tie down materials may block visibility of the side marker lights.
5. A mailbox, brush or parked vehicle may block the rear side marker light.

Blind spots of trucks can also set up accidents. The two areas with the greatest potential are directly behind the rear and at the passenger front. In either of these positions, an automobile or pedestrian can be completely hidden from the driver.

All vehicles have blind spots. This automobile cannot be seen from the cab of the truck.
Tractor Trailer and Heavy Truck Acceleration

A series of tests were conducted at a South Carolina weigh station to evaluate the acceleration characteristics of large trucks. The tests were arranged with the cooperation of The Coastal MAIT unit of the South Carolina Highway Patrol. A flat lot adjacent to the weigh station terminal provided a straight flat acceleration lane. The trucks were stopped as part of the normal inspection procedure. A Stalker radar was positioned adjacent to the exit route from the terminal. Once released, the truck drivers accelerated along the straight path to the exit. The operators were free to conduct an exit in any manner in which they desired. The truck weights were obtained from the weigh station scales. The weights were recorded along with the data from the Stalker radar. The objective was to obtain acceleration data from a variety of trucks of known weight. As would be expected, the accelerations varied significantly based on not only the capabilities and weight of the truck but the desires of the driver as well. The radar and radar operator were visible to the truck drivers. This clearly offered some distraction. However, even with these limitations, the accelerations fell in a relatively narrow range.

The accelerations of a total of 40 trucks were tested. All except one were tractor trailers or large straight trucks. Of the 40, the data from 4 were rejected. Of the four, one was a small straight truck. The others either stopped or were slowed by preceding traffic. The remaining 36 trucks were divided into three categories. A truck weighing 35000 pounds or less was considered either empty or lightly loaded. There were a total of 17 trucks in this category. Trucks weighing more than 35000 pounds but less than 60000 pounds were considered moderately loaded. Eight trucks fell in this category. The remaining 11 trucks weighed more than 60000 pounds and were categorized as heavily loaded. The measurements were taken over a distance of approximately 300 feet. The trucks all reached speeds between 9 and 23 mph.

The Stalker radar has very limited capability at speeds below 6 mph. The instrument reading jumps from 0 to 6 mph. The Stalker software plots the data assuming a constant acceleration from 0 to 6 mph. This introduces some error at very low speeds,
but with any appreciable acceleration, there is little effect on the movement over that derived from the linear acceleration extrapolation. Another source of difficulty with the radar is the sensitivity to other signal sources. Once a truck begins to accelerate, the radar correctly identifies the target of interest. However, prior to movement, weaker return signals from roadway or other weigh station traffic was often recorded in the data. Typically, the extraneous signals reflected speeds outside of the range under consideration and could therefore be readily recognized and filtered from the test data.

The data was examined and evaluated as a constant acceleration. For the lightly loaded trucks, weights ranged from 25100 pounds to 34960 pounds with an average of 30654 pounds. The accelerations varied from a low of 0.7 ft/s$^2$ to 3.2 ft/s$^2$. The moderately loaded trucks were slower with a range of 0.4 to 2.2 ft/s$^2$. The moderately loaded trucks averaged 42330 pounds with the lightest at 35020 pounds. The heaviest weighed 52660 pounds. The heavily loaded trucks averaged 74607 pounds with the lightest at 62050 pounds and the heaviest at 79220 pounds. As expected, the heaviest trucks had the lowest accelerations which ranged from 0.4 to 1.9 ft/s$^2$. A summary of the data is provided in Table 1.
## Table 1

<table>
<thead>
<tr>
<th>Weight Type</th>
<th>Less than 35000 #</th>
<th>35000-60000#</th>
<th>Above 60000#</th>
</tr>
</thead>
<tbody>
<tr>
<td>weight</td>
<td>mph/s ft/s²</td>
<td>weight</td>
<td>mph/s ft/s²</td>
</tr>
<tr>
<td>28780</td>
<td>0.50 0.7</td>
<td>42000</td>
<td>0.30 0.4</td>
</tr>
<tr>
<td>31580</td>
<td>0.50 0.7</td>
<td>35020</td>
<td>0.40 0.6</td>
</tr>
<tr>
<td>27940</td>
<td>0.50 0.7</td>
<td>48240</td>
<td>0.50 0.7</td>
</tr>
<tr>
<td>34960</td>
<td>0.50 0.7</td>
<td>52660</td>
<td>0.60 0.9</td>
</tr>
<tr>
<td>33360</td>
<td>0.70 1.0</td>
<td>39120</td>
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<tr>
<td>33040</td>
<td>0.75 1.1</td>
<td>38500</td>
<td>0.80 1.2</td>
</tr>
<tr>
<td>34340</td>
<td>0.80 1.2</td>
<td>43500</td>
<td>1.50 2.2</td>
</tr>
<tr>
<td>25100</td>
<td>0.90 1.3</td>
<td>39600</td>
<td>1.50 2.2</td>
</tr>
<tr>
<td>33440</td>
<td>0.90 1.3</td>
<td>35020</td>
<td>0.30 0.4</td>
</tr>
<tr>
<td>29460</td>
<td>0.90 1.3</td>
<td>35020</td>
<td>0.30 0.4</td>
</tr>
<tr>
<td>33460</td>
<td>1.00 1.5</td>
<td>35020</td>
<td>0.30 0.4</td>
</tr>
<tr>
<td>25700</td>
<td>1.25 1.8</td>
<td>35020</td>
<td>0.30 0.4</td>
</tr>
<tr>
<td>27220</td>
<td>1.30 1.9</td>
<td>35020</td>
<td>0.30 0.4</td>
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<td>0.30 0.4</td>
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<td>34100</td>
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<td>35020</td>
<td>0.30 0.4</td>
</tr>
<tr>
<td>33000</td>
<td>1.70 2.5</td>
<td>35020</td>
<td>0.30 0.4</td>
</tr>
<tr>
<td>26780</td>
<td>2.20 3.2</td>
<td>35020</td>
<td>0.30 0.4</td>
</tr>
</tbody>
</table>

### Minimum (min) Values
- Less than 35000 #: 25100 mph/s, 0.50 mph/s, 0.7 ft/s²
- 35000-60000#: 35020 mph/s, 0.30 mph/s, 0.4 ft/s²
- Above 60000#: 62050 mph/s, 0.25 mph/s, 0.4 ft/s²

### Maximum (max) Values
- Less than 35000 #: 52660 mph/s, 2.20 mph/s, 3.2 ft/s²
- 35000-60000#: 52660 mph/s, 1.50 mph/s, 2.2 ft/s²
- Above 60000#: 79220 mph/s, 1.30 mph/s, 1.9 ft/s²

### Average (avg) Values
- Less than 35000 #: 30654 mph/s, 1.02 mph/s, 1.5 ft/s²
- 35000-60000#: 42330 mph/s, 0.79 mph/s, 1.2 ft/s²
- Above 60000#: 74607 mph/s, 0.68 mph/s, 1.0 ft/s²
A typical acceleration vs. time graph for one of the trucks is shown above. The accelerations vary substantially with time. Because the acceleration varies widely, it is difficult to determine an average value for use in calculations.
It is much easier to examine the velocity vs. time curves and evaluate the accelerations as the slope of the curve. The velocity vs. time curves for the lightly loaded trucks are shown in the next two graphs.
The graphs for the moderately loaded trucks are shown above and for the heavily loaded trucks below.
Summary

The basic relationships of time, distance, velocity and acceleration have been used to evaluate data produced by heavy trucks accelerating from a South Carolina weigh station. The exit path was straight and level. There were no external urgencies for the drivers. The vehicles accelerated from a stop on the basis of the equipment limitations and operator desires. All of the trucks reached speeds between 9 and 23 mph. Trucks 35000 pounds and under were considered empty or lightly loaded. Their accelerations varied from a low of 0.7 ft/s² to 3.2 ft/s². The moderately loaded trucks were slower with a range of 0.4 to 2.2 ft/s². Their weight varied from 35020 pounds to the heaviest at 52660 pounds. The heavily loaded trucks averaged 74607 pounds with the lightest at 62050 ponds and the heaviest at 79220 pounds. They had the lowest accelerations which ranged from 0.4 to 1.9 ft/s².
APPENDIX I

Minimum Periodic Inspection Standards

(49 CFR 399.211 - APPENDIX G)

A vehicle does not pass an inspection if it has one of the following defects or deficiencies:

1. Brake System.

   (a) Service brakes.—

      (1) Absence of braking action on any axle required to have brakes upon application of the service brakes (such as missing brakes or brake shoe(s) failing to move upon application of a wedge, S-cam, cam, or disc brake).

      (2) Missing or broken mechanical components including: shoes, lining, pads, springs, anchor pins, spiders, cam rollers, push-rods, and air chamber mounting bolts.

      (3) Loose brake components including air chambers, spiders, and cam shaft support brackets.

      (4) Audible air leak at brake chamber (Example: ruptured diaphragm, loose chamber clamp, etc.).

      (5) Readjustment limits. The maximum stroke at which brakes should be readjusted is given below. Any brake ¼ inch or more past the readjustment limit or any two brakes less than ¼ inch beyond the readjustment limit shall be cause for rejection. Stroke shall be measured with engine off and reservoir pressure of 80 to 90 psi with brakes fully applied.
Bolt Type Brake Chamber Data

<table>
<thead>
<tr>
<th>Type</th>
<th>Effective area (sq.in.)</th>
<th>Outside dia. (in.)</th>
<th>Maximum stroke at which brakes should be readjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>12</td>
<td>6-15/16</td>
<td>1-3/8</td>
</tr>
<tr>
<td>B</td>
<td>24</td>
<td>9-3/16</td>
<td>1-3/4</td>
</tr>
<tr>
<td>C</td>
<td>16</td>
<td>8-1/16</td>
<td>1-3/4</td>
</tr>
<tr>
<td>D</td>
<td>6</td>
<td>5-1/4</td>
<td>1-1/4</td>
</tr>
<tr>
<td>E</td>
<td>9</td>
<td>6-3/16</td>
<td>1-3/8</td>
</tr>
<tr>
<td>F</td>
<td>36</td>
<td>11</td>
<td>2-1/4</td>
</tr>
<tr>
<td>G</td>
<td>30</td>
<td>9-7/8</td>
<td>2</td>
</tr>
</tbody>
</table>
Rotochamber Data

<table>
<thead>
<tr>
<th>Type</th>
<th>Maximum stroke at Effective area (sq. in.)</th>
<th>Outside dia. (in.)</th>
<th>which brakes should be readjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>9</td>
<td>4-9/32</td>
<td>1-1/2</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>4-13/16</td>
<td>1-1/2</td>
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<td>16</td>
<td>5-13/32</td>
<td>2</td>
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<td>20</td>
<td>20</td>
<td>5-15/16</td>
<td>2</td>
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<tr>
<td>24</td>
<td>24</td>
<td>6-13/32</td>
<td>2</td>
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<tr>
<td>30</td>
<td>30</td>
<td>7-1/16</td>
<td>2-1/4</td>
</tr>
<tr>
<td>36</td>
<td>36</td>
<td>7-5/8</td>
<td>2-3/4</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>8-7/8</td>
<td>3</td>
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</tbody>
</table>
Clamp Type Brake Chamber Data

<table>
<thead>
<tr>
<th>Type</th>
<th>Effective area (sq. in.)</th>
<th>Outside dia. (in.)</th>
<th>Which brakes should be readjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>6</td>
<td>4-1/2</td>
<td>1-1/4</td>
</tr>
<tr>
<td>9</td>
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<td>5-11/16</td>
<td>1-3/8</td>
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<td>1-3/4</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>6-25/32</td>
<td>1-3/4</td>
</tr>
<tr>
<td>24</td>
<td>24</td>
<td>7-7/32</td>
<td>1-3/4 (1)</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
<td>8-3/32</td>
<td>2</td>
</tr>
<tr>
<td>36</td>
<td>36</td>
<td>9</td>
<td>2-1/4</td>
</tr>
</tbody>
</table>

(1) (2” for long stroke design).

Wedge Brake Data--Movement of the scribe mark on the lining shall not exceed 1/16 inch.

(6) Brake linings or pads.

(a) Lining or pad is not firmly attached to the shoe;
(b) Saturated with oil, grease, or brake fluid; or
(c) Non-steering axles: Lining with a thickness less than 1/4 inch at the shoe center for air drum brakes, 1/16 inch or less at the shoe center for hydraulic and electric drum brakes, and less than 1/8 inch for air disc brakes.
(d) Steering axles: Lining with a thickness less than 1/4 inch at the shoe center for drum brakes, less than 1/8 inch for air disc brakes and 1/16 inch or less for hydraulic disc and electric brakes.

(7) Missing brake on any axle required to have brakes.

(8) Mismatch across any power unit steering axle of:

(a) Air chamber sizes.
(b) Slack adjuster length.

b. Parking Brake System. No brakes on the vehicle or combination are applied upon actuation of the parking brake control, including driveline hand controlled parking brakes.

c. Brake Drums or Rotors.

(1) With any external crack or cracks that open upon brake application (do not confuse short hairline heat check cracks with flexural cracks).
(2) Any portion of the drum or rotor missing or in danger of falling away.

d. Brake Hose.

(1) Hose with any damage extending through the outer reinforcement ply. (Rubber impregnated fabric cover is not a reinforcement ply). (Thermoplastic nylon may have braid reinforcement or color difference between cover and inner tube. Exposure of second color is cause for rejection.
(2) Bulge or swelling when air pressure is applied.
(3) Any audible leaks.
(4) Two hoses improperly joined (such as a splice made by sliding the hose ends over a piece of tubing and clamping the hose to the tube).
(5) Air hose cracked, broken or cramped.

e. Brake Tubing.

(1) Any audible leak.
(2) Tubing cracked, damaged by heat, broken or cramped.

f. Low Pressure Warning Device missing, inoperative, or does not operate at 55 psi and below, or \$1/2\$ the governor cut-out pressure, whichever is less.

g. Tractor Protection Valve. Inoperable or missing tractor protection valve(s) on power unit.
h. Air Compressor.
   (1) Compressor drive belts in condition of impending or probable failure.
   (2) Loose compressor mounting bolts.
   (3) Cracked, broken or loose pulley.
   (4) Cracked or broken mounting brackets, braces or adapters.

i. Electric Brakes.
   (1) Absence of braking action on any wheel required to have brakes.
   (2) Missing or inoperable breakaway braking device.

   (1) Master cylinder less than 1/4 full.
   (2) No pedal reserve with engine running except by pumping pedal.
   (3) Power assist unit fails to operate.
   (4) Seeping or swelling brake hose(s) under application of pressure.
   (5) Missing or inoperative check valve.
   (6) Has any visually observed leaking hydraulic fluid in the brake system.
   (7) Has hydraulic hose(s) abraded (chafed) through outer cover-to-fabric layer.
   (8) Fluid lines or connections leaking, restricted, crimped, cracked or broken.
   (9) Brake failure or low fluid warning light on and/or inoperative.

k. Vacuum Systems. Any vacuum system which:
   (1) Has insufficient vacuum reserve to permit one full brake application after engine is shut off.
   (2) Has vacuum hose(s) or line(s) restricted, abraded (chafed) through outer cover to cord ply, crimped, cracked, broken or has collapse of vacuum hose(s) when vacuum is applied.
   (3) Lacks an operative low-vacuum warning device as required.
2. Coupling devices.

a. Fifth Wheels.

(1) Mounting to frame.

(a) Any fasteners missing or ineffective.
(b) Any movement between mounting components.
(c) Any mounting angle iron cracked or broken.

(2) Mounting plates and pivot brackets.

(a) Any fasteners missing or ineffective.
(b) Any welds or parent metal cracked.
(c) More than 3/8 inch horizontal movement between pivot bracket pin and bracket.
(d) Pivot bracket pin missing or not secured.

(3) Sliders.

(a) Any latching fasteners missing or ineffective.
(b) Any fore or aft stop missing or not securely attached.
(c) Movement more than 3/8 inch between slider bracket and slider base.
(d) Any slider component cracked in parent metal or weld.

(4) Lower coupler.

(a) Horizontal movement between the upper and lower fifth wheel halves exceeds 1/2 inch.
(b) Operating handle not in closed or locked position.
(c) Kingpin not properly engaged.
(d) Separation between upper and lower coupler allowing light to show through from side to side.
(e) Cracks in the fifth wheel plate.

Exceptions: Cracks in fifth wheel approach ramps and casting shrinkage cracks in the ribs of the body of a cast fifth wheel.

(f) Locking mechanism parts missing, broken, or deformed to the extent the kingpin is not securely held.
b. Pintle Hooks.

(1) Mounting to frame.
   (a) Any missing or ineffective fasteners (a fastener is not considered missing if there is an empty hole in the device but no corresponding hole in the frame or vice versa).
   (b) Mounting surface cracks extending from point of attachment (e.g., cracks in the frame at mounting bolt holes).
   (c) Loose mounting.
   (d) Frame cross member providing pintle hook attachment cracked.

(2) Integrity.
   (a) Cracks anywhere in pintle hook assembly.
   (b) Any welded repairs to the pintle hook.
   (c) Any part of the horn section reduced by more than 20%.
   (d) Latch insecure.

c. Drawbar/Towbar Eye.

(1) Mounting.
   (a) Any cracks in attachment welds.
   (b) Any missing or ineffective fasteners.

(2) Integrity.
   (a) Any cracks.
   (b) Any part of the eye reduced by more than 20%.

d. Drawbar/Towbar Tongue.

(1) Slider (power or manual).
   (a) Ineffective latching mechanism
   (b) Missing or ineffective stop.
   (c) Movement of more than 1/4 inch between slider and housing.
   (d) Any leaking, air or hydraulic cylinders, hoses, or chambers (other than slight oil weeping normal with hydraulic seals).

(2) Integrity.
   (a) Any cracks.
(b) Movement of 1/4 inch between subframe and drawbar at point of attachment.

e. Safety Devices.
   (1) Safety devices missing.
   (2) Unattached or incapable of secure attachment.
   (3) Chains and hooks.
      (a) Worn to the extent of a measurable reduction in link cross section.
      (b) Improper repairs including welding, wire, small bolts, rope and tape.
   (4) Cable.
      (a) Kinked or broken cable strands.
      (b) Improper clamps or clamping.

f. Saddle-Mounts.
   (1) Method of attachment.
      (a) Any missing or ineffective fasteners.
      (b) Loose mountings.
      (c) Any cracks or breaks in a stress or load bearing member.
      (d) Horizontal movement between upper and lower saddle-mount halves exceeds 1/4 inch.

3. Exhaust System.
   a. Any exhaust system determined to be leaking at a point forward of or directly below the driver/sleeper compartment.
   b. A bus exhaust system leaking or discharging to the atmosphere:
      (1) Gasoline powered--excess of 6 inches forward of the rearmost part of the bus.
      (2) Other than gasoline powered--in excess of 15 inches forward of the rearmost part of the bus.
      (3) Other than gasoline powered--forward of a door or window designed to be opened. (exception: Emergency exits).
c. No part of the exhaust system of any motor vehicle shall be so located as would be likely to result in burning, charring, or damaging the electrical wiring, the fuel supply, or any combustible part of the motor vehicle.


a. A fuel system with a visible leak at any point.

b. A fuel tank filler cap missing.

c. A fuel tank not securely attached to the motor vehicle by reason of loose, broken or missing mounting bolts or brackets (some fuel tanks use springs or rubber bushings to permit movement).

5. Lighting Devices.

All lighting devices and reflectors required by Section 393 shall be operable.


a. Part(s) of vehicle or condition of loading such that the spare tire or any part of the load or dunnage can fall onto the roadway.

b. Protection Against Shifting Cargo--Any vehicle without a front-end structure or equivalent device as required.

7. Steering Mechanism.

a. Steering Wheel Free Play (on vehicles equipped with power steering the engine must be running).

<table>
<thead>
<tr>
<th>Steering wheel diameter</th>
<th>Manual</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>2&quot;</td>
<td>4-1/2&quot;</td>
</tr>
<tr>
<td>18</td>
<td>2-1/4&quot;</td>
<td>4-3/4&quot;</td>
</tr>
<tr>
<td>20</td>
<td>2-1/2&quot;</td>
<td>5-1/4&quot;</td>
</tr>
<tr>
<td>22</td>
<td>2-3/4&quot;</td>
<td>5-3/4&quot;</td>
</tr>
</tbody>
</table>
b. Steering Column.
   (1) Any absence or looseness of U-bolt(s) or positioning part(s).
   (2) Worn, faulty or obviously repair welded universal joint(s).
   (3) Steering wheel not properly secured.

c. Front Axle Beam and All Steering Components Other Than Steering Column.
   (1) Any crack(s).
   (2) Any obvious welded repair(s).

d. Steering Gear Box.
   (1) Any mounting bolt(s) loose or missing.
   (2) Any crack(s) in gear box or mounting brackets.

e. Pitman Arm. Any looseness of the pitman arm on the steering gear output shaft.


g. Ball and Socket Joints.
   (1) Any movement under steering load of a stud nut.
   (2) Any motion, other than rotational, between any linkage member and its attachment point of more than \( \frac{1}{4} \) inch.

h. Tie Rods and Drag Links.
   (1) Loose clamp(s) or clamp bolt(s) on tie rods or drag links.
   (2) Any looseness in any threaded joint.

i. Nuts. Nut(s) loose or missing on tie rods, pitman arm, drag link, steering arm or tie rod arm.

j. Steering System. Any modification or other condition that interferes with free movement of any steering component.

8. Suspension.

a. Any U-bolt(s), spring hanger(s), or other axle positioning part(s) cracked, broken, loose or missing resulting in shifting of an axle from its normal position. (After a turn, lateral axle displacement is normal with some suspensions. Forward or rearward operation in a straight line will cause the axle to return to alignment).

b. Spring Assembly.
   (1) Any leaves in a leaf spring assembly broken or missing.
(2) Any broken main leaf in a leaf spring assembly. (Includes assembly with more than one main spring).
(3) Coil spring broken.
(4) Rubber spring missing.
(5) One or more leaves displaced in a manner that could result in contact with a tire, rim, brake drum or frame.
(6) Broken torsion bar spring in a torsion bar suspension.
(7) Deflated air suspension, i.e., system failure, leak, etc.

c. Torque, Radius or Tracking Components. Any part of a torque, radius or tracking component assembly or any part used for attaching the same to the vehicle frame or axle that is cracked, loose, broken or missing. (Does not apply to loose bushings in torque or track rods.)


   a. Frame Members.
      (1) Any cracked, broken, loose, or sagging frame member.
      (2) Any loose or missing fasteners including fasteners attaching functional component such as engine, transmission, steering gear, suspension, body parts, and fifth wheel.

b. Tire and Wheel Clearance. Any condition, including loading, that causes the body or frame to be in contact with a tire or any part of the wheel assemblies.

c. (1) Adjustable Axle Assemblies (Sliding Subframes). Adjustable axle assembly with locking pins missing or not engaged.

10. Tires.

   a. Any tire on any steering axle of a power unit.
      (1) With less than 4/32 inch tread when measured at any point on a major tread groove.
      (2) Has body ply or belt material exposed through the tread or sidewall.
      (3) Has any tread or sidewall separation.
      (4) Has a cut where the ply or belt material is exposed.
      (5) Labeled ```Not for Highway Use``` or displaying other marking which would exclude use on steering axle.
(6) A tube-type radial tire without radial tube stem markings. These markings include a red band around the tube stem, the word “radial” embossed in metal stems, or the word “radial” molded in rubber stems.

(7) Mixing bias and radial tires on the same axle.

(8) Tire flap protrudes through valve slot in rim and touches stem.

(9) Regrooved tire except motor vehicles used solely in urban or suburban service (see exception in 393.75(e).

(10) Boot, blowout patch or other ply repair.

(11) Weight carried exceeds tire load limit. This includes overloaded tire resulting from low air pressure.

(12) Tire is flat or has noticeable (e.g., can be heard or felt) leak.

(13) Any bus equipped with recapped or retreaded tire(s).

(14) So mounted or inflated that it comes in contact with any part of the vehicle.

b. All tires other than those found on the steering axle of a power unit:

(1) Weight carried exceeds tire load limit. This includes overloaded tire resulting from low air pressure.

(2) Tire is flat or has noticeable (e.g., can be heard or felt) leak.

(3) Has body ply or belt material exposed through the tread or sidewall.

(4) Has any tread or sidewall separation.

(5) Has a cut where ply or belt material is exposed.

(6) So mounted or inflated that it comes in contact with any part of the vehicle. (This includes a tire that contacts its mate.)

(7) Is marked “Not for highway use” or otherwise marked and having like meaning.

(8) With less than 2/32 inch tread when measured at any point on a major tread groove.

11. Wheels and Rims.

a. Lock or Side Ring. Bent, broken, cracked, improperly seated, sprung or mismatched ring(s).

b. Wheels and rims. Cracked or broken or has elongated bolt holes.
c. Fasteners (both spoke and disc wheels). Any loose, missing, broken, cracked, stripped or otherwise ineffective fasteners.

d. Welds.
   (1) Any cracks in welds attaching disc wheel disc to rim.
   (2) Any crack in welds attaching tubeless demountable rim to adapter.
   (3) Any welded repair on aluminum wheel(s) on a steering axle.
   (4) Any welded repair other than disc to rim attachment on steel disc wheel(s) mounted on the steering axle.

12. Windshield Glazing.
   (Not including a 2 inch border at the top, a 1 inch border at each side and the area below the topmost portion of the steering wheel.) Any crack, discoloration or vision reducing matter except: (1) coloring or tinting applied at time of manufacture; (2) any crack not over \(\frac{1}{4}\) inch wide, if not intersected by any other crack; (3) any damaged area not more than 3/4 inch in diameter, if not closer than 3 inches to any other such damaged area; (4) labels, stickers, decalcomania, etc. (see 393.60 for exceptions).

   Any power unit that has an inoperative wiper, or missing or damaged parts that render it ineffective.

The vehicle portion of the FMCSA's North American Uniform Driver-Vehicle Inspection Procedure (NAUD-VIP) requirements, CVSA's North American Commercial Vehicle Critical Safety Inspection Items and Out-Of-Service Criteria and Appendix G of subchapter B are similar documents and follow the same inspection procedures. The same items are required to be inspected by each document. FMCSA's and CVSA's out-of-service criteria are intended to be used in random roadside inspections to identify critical vehicle inspection items and provide criteria for placing a vehicle(s) out-of-service. A vehicle(s) is placed out-of-service only when by reason of its mechanical condition or loading it is determined to be so imminently hazardous as to likely cause an accident or breakdown, or when such condition(s) would likely contribute to loss of control of the vehicle(s) by the driver. A certain amount of flexibility is given to the inspecting official whether to place the vehicle out-of-service at the inspection site or if it would be less hazardous to allow the vehicle to proceed to a repair facility for repair. The distance to the repair facility must not exceed 25 miles. The roadside type of inspection, however, does not necessarily mean that a vehicle has to be defect-free in order to continue in service. In contrast, the Appendix G inspection procedure requires that all items required to be inspected are in proper adjustment, are not defective and function properly prior to the vehicle being placed in service.

Differences Between the Out-of-Service Criteria & FMCSA's Annual Inspection

1. Brake System.

The Appendix G criteria rejects vehicles with any defective brakes, any air leaks, etc. The out-of-service criteria allows 20% defective brakes on non-steering axles and a certain latitude on air leaks before placing a vehicle out-of-service.

2. Coupling Devices.
Appendix G rejects vehicles with any fifth wheel mounting fastener missing or ineffective. The out-of-service criteria allows up to 20% missing or ineffective fasteners on frame mountings and pivot bracket mountings and 25% on slider latching fasteners. The out-of-service criteria also allows some latitude on cracked welds.

3. Exhaust System.

Appendix G follows Section 393.83 verbatim. The CVSA out-of-service criteria allows vehicles to exhaust forward of the dimensions given in Section 393.83 as long as the exhaust does not leak or exhaust under the chassis.


Same for Appendix G and the out-of-service criteria.

5. Lighting Devices.

Appendix G requires all lighting devices required by Section 393 to be operative at all times. The out-of-service criteria only requires one stop light and functioning turn signals on the rear most vehicle of a combination vehicle to be operative at all times. In addition one operative head lamp and tail lamp are required during the hours of darkness.


Same for both Appendix G and the out-of-service criteria.

7. Steering Mechanism

Steering lash requirements of Appendix G follows the new requirements of Sec. 393.209.

8. Suspension

Appendix G follows the new requirements of Sec. 393.207 which does not allow any broken leaves in a leaf spring assembly. The out-of-service criteria allows up to 25% broken or missing leaves before being placed out-of-service.

9. Frame

The out-of-service criteria allows a certain latitude in frame cracks before placing a vehicle out-of-service. Appendix G follows the new requirements of 393.201 which does not allow any frame cracks.

10. Tires

Appendix G follows the requirements of 393.75 which requires a tire tread depth of 4/32 inch on power unit steering axles and 2/32 inch on all other axles. The out-of-
service criteria only requires 2/32 inch tire tread depth on power unit steering axles and 1/32 inch on all other axles.

11. Wheel and Rims

The out-of-service criteria allows a certain amount latitude for wheel and rim cracks and missing or defective fasteners. Appendix G meets the requirements of the new 393.205 which does not allow defective wheels and rims non-effective nuts and bolts.

12. Windshield Glazing

The out-of-service criteria places in a restricted service condition any vehicle that has a crack or discoloration in the windshield area lying within the sweep of the wiper on the drivers side and does not address the remaining area of the windshield. Appendix G addresses requirements for the whole windshield as specified in 393.60.

13. Windshield Wipers

Appendix G requires windshield wipers to be operative at all times. The out-of-service criteria only requires that the windshield wiper on the driver's side to be inspected during inclement weather.
APPENDIX II

W POPLIN RECONSTRUCTION THUMB RULES

1. Convert mph to ft/s by multiplying by 1.5 (1½).
   The actual conversion factor is (5280 ft/mile) divided by (3600 sec/hr)
   \[(60 \text{ mph})(5280 \text{ ft/mile})/(3600 \text{ sec/hr}) = 88 \text{ ft/sec}\]
   using 1.5
   \[(60 \text{ mph})(1.5 \text{ ft-hr/mile-sec}) = 90 \text{ ft/sec}\]
   which is close and easy to apply when thinking about an accident.

2. Accelerations and decelerations can be expressed in units of ft/s\(^2\) or miles per hour per second (mph/s)

   On dry level pavement, maximum braking will typically decelerate vehicles at the following levels:

<table>
<thead>
<tr>
<th>Type</th>
<th>Acceleration</th>
<th>Deceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automobiles/Pickup/Vans/SUVs</td>
<td>15 - 18 mph/s</td>
<td>22 - 26 ft/s(^2)</td>
</tr>
<tr>
<td>Tractor Trailers/Heavy Trucks</td>
<td>10 - 12 mph/s</td>
<td>15 - 18 ft/s(^2)</td>
</tr>
</tbody>
</table>

   Therefore from 60 mph:

   - **Automobile**: 60 mph / 15 mph/s = 4 sec to stop
     - 1 sec = 45 mph; 2 sec = 30 mph; 3 sec = 15 mph; 4 sec = 0 mph

   - **Tractor Trailer**: 60 mph / 10 mph/s = 6 sec to stop
     - 1 sec = 50 mph; 2 sec = 40 mph; 3 sec = 30 mph
     - 4 sec = 20 mph; 5 sec = 10 mph; 6 sec = 0 mph
3. Travel distance during a stop can be calculated using the time to stop and the average speed that is \( \frac{1}{2} \) of the starting speed.

   \[
   \text{From 60 mph} = \frac{90}{3600} \times 60 = 90 \text{ ft/s}
   \]

   \[
   \text{Automobile stop} = (90/2 \text{ ft/s}) (4 \text{ sec}) = 180 \text{ feet}
   \]

   \[
   \text{Tractor Trailer} = (90/2 \text{ ft/s}) (6 \text{ sec}) = 270 \text{ feet}
   \]

4. Skids from modern automobiles typically begin with the front tires. Skids from trucks typically begin with the drive or trailer axles.

5. Tire marks left by a turning vehicle begin with the outside tires if there is no braking. Tire marks from a turning and braking vehicle typically begin with the inside tires. Inside and outside refer to the center of the turn. On a vehicle turning right and being braked, the right side tires would typically skid first.

6. It takes traction to turn and traction to decelerate. A turning vehicle cannot decelerate as rapidly as one braking in a straight line, because some of the available traction is used to keep the vehicle in a turn.

7. Vehicles of all types braking off road, on firm level soil, grass or gravel decelerate at approximately 10 mph/sec.

8. Vehicles of all types rolling, sliding on the sides or roof and rotating (without braking) on level terrain or pavement all decelerate at approximately 10 mph/sec.
9. During a collision (other than a sideswipe or similar event), the contacting areas of the vehicles reach a common velocity, that is, these parts are traveling at the same speed in the same direction.

10. The portion of a rolling tire in contact with the pavement is not moving. The top of the same tire is moving at twice the speed of the vehicle. The same concept applies to the sides and roof of a vehicle in a pure roll. An object or occupant ejected from the vehicle on the low side will remain close to the point of separation. The same object separating on the high side will tend to travel farther than the vehicle.
APPENDIX III

BASIC EQUATIONS OF MOTION

The relationships of time, distance, speed and acceleration are important to the reconstruction of most accidents involving a moving heavy truck. In order to take advantage of the data available with limited testing, it is important to understand the relationships of the equations of motion. These can then be applied to the development of test data and reconstructions of heavy truck accidents.

Reconstruction of accidents involves analysis using fundamental equations of motion. As typically used in reconstruction, the parameters involve time, position, velocity, and acceleration. Concepts of time and position are well understood. Velocity and acceleration are not as easily grasped. In the English measurement system, time, length and force are the three fundamental units of measure. All other units of measure are derived from these three. Therefore, when we discuss time or length, a single value and unit will suffice. We refer to 10 seconds (sec or s) or 5 feet (ft). These are scalar quantities, that is, they need only a single value to be completely defined. Force, position, velocity, and acceleration are vector quantities. Vectors require two values, a magnitude and a direction, to be fully described.

The magnitude of the velocity and acceleration are combinations of the fundamental units of measurement. We define these as:

\[
\text{velocity} = \frac{\text{position}}{\text{time}} \quad (1)
\]

\[
\text{acceleration} = \frac{\text{velocity}}{\text{time}} \quad (2)
\]

We can express a velocity in any convenient combination of position (length) units and time units. Therefore, velocities are given values of 10 feet per second (ft/s) or 50 miles per hour (mph). Accelerations are similarly expressed as velocities per unit of time. Typical values are 5 feet per second per second (5 ft/s^2) or 5 meters/sec/sec. We can even use such combinations as 15 mph/sec.
There is also a gravitational acceleration produced by the mass of two objects. For reconstruction purposes, this is limited to the earth and all objects on or near its surface. The actual attraction is influenced by the mass of the objects and their distance from one another. However, for our purposes, the mass of the earth is so much larger than the other objects that we evaluate, that we take the gravitational acceleration as a constant. It is always directed toward the center of the earth and to three significant digits, its value is 32.2 ft/s\(^2\). It is interesting to note that there is no way to distinguish between the acceleration caused by a change in motion from the acceleration caused by a gravitational attraction. A convenient unit of acceleration measurement is obtained by comparing the acceleration to that produced by the gravitational attraction between an object and the earth. This acceleration is given the symbol of “g”. Accelerations are referred to as fractions or multiples of a g. Accelerations of 16.1 ft/s\(^2\) or 64.4 ft/s\(^2\) would be called \(\frac{1}{2}\) g and 2 g’s respectively.

As an object moves, it changes position with time. The change in position with time is the velocity. Note that because the velocity is defined by both a magnitude and a direction, the velocity is changing if the direction or the magnitude is changing. A vehicle traveling around a curve has a changing velocity even if the magnitude or “speed” remains constant. Similarly, acceleration is the rate of change of the velocity. Most equations developed for accident reconstruction assume that the acceleration is constant. If we plot a typical movement of an automobile from a stopped position to highway speed, we might get a curve like the following:
The slope of the curve at any point is the velocity. The velocity curve for the same movement is:

![Velocity vs. Time Graph]

And the acceleration curve:

![Acceleration vs. Time Graph]
If we can define the movement with an equation, then we can obtain the slope of the equation by taking the mathematical derivative of that equation. For example, the equation for the first graph (distance vs. time) is:

\[ s = s_0 + v_0 + \frac{1}{2}at^2 \]

where \( s, s_0, v_0, a, \) and \( t \) are the position at time \( t \), original position, original velocity, acceleration and time. \( (3) \)

\[ v = v_0 + at \]

is the derivative of the first equation and the plotted curve. \( (4) \)

\[ a = \text{constant} \]

is the derivative of equation 4 and the second derivative of equation 3. \( (5) \)

Alternatively, if we start with an acceleration curve, we can integrate it to obtain the velocity curve and integrate it once again to obtain the motion curve.
Integration is a mathematical concept which calculates the area under the curve. For example, in the example above, the acceleration is 3 ft/s\(^2\). To calculate the velocity after 4 seconds, it is simply 3 ft/s\(^2\) times 4 seconds or 12 ft/s.

To obtain the distance we find the area under the velocity curve. For the triangular velocity curve, the area is half of the equivalent rectangle. For 4 seconds, this is 0.5 times 4 seconds times 12 ft/s or 24 ft.
The graph below shows an acceleration curve for a standing start of a 1998 Toyota 4-runner sport utility vehicle. The data was obtained from a Vericom VC2000 accelerometer:
The graph below shows a velocity curve for a standing start of a 1998 Toyota 4-runner sport utility vehicle. The data was obtained from a Vericom VC2000 accelerometer. The graph is actually a representation of the area under the acceleration vs. time curve, since the Vericom 2000 is only capable of measuring acceleration as a function of time. It cannot directly measure velocity or distance.
The graph below shows a distance curve for a standing start of a 1998 Toyota 4-runner sport utility vehicle. The data was obtained from a Vericom VC2000 accelerometer. The graph represents the area under the velocity curve.
The curve below is an acceleration curve produced by a tractor trailer:

So far we have discussed acceleration as a concept of straight line motion. However, these equations can be calculated independently for each axis of interest. For example, the ballistic equations used for falls, vaults, etc. are developed using a horizontal and vertical axis. The rise and fall times associated with a gravitational acceleration are independent of the horizontal motion. The concepts are also not limited to linear movement. The equations for angular rotation are identical if the following substitutions are used:

<table>
<thead>
<tr>
<th>Linear</th>
<th>Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>Moment of inertia</td>
</tr>
<tr>
<td>Distance</td>
<td>angular displacement</td>
</tr>
<tr>
<td>Velocity</td>
<td>angular velocity</td>
</tr>
<tr>
<td>Acceleration</td>
<td>angular acceleration</td>
</tr>
</tbody>
</table>
The rotational equations of motion for a constant angular acceleration are therefore given by:

\[ \theta = \theta_0 + \omega_0 + \frac{1}{2} \alpha t^2 \]

where \( \theta \), \( \theta_0 \), \( \omega_0 \), \( \alpha \), and \( t \) are the position at time \( t \), original angle, original rotational velocity, angular acceleration and time. 

\[ \omega = \omega_0 + \alpha t \]

is the angular velocity at time \( t \)

\[ \alpha = \text{constant} \]

is a constant angular acceleration