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Dear Mr. Seales:

Re: **Settlement Agreement**
Section B. Fire Safety Research

Enclosed is a publication authored by Robert R. Scheibe of Golder Associates, Inc., Leland E. Shields of Leland E. Shields, Inc., and Timothy E. Angelos of Design Research Engineering, entitled, "Field Investigation of Motor Vehicle Collision-Fires."

This paper relates of Project B.2 (Case Studies of Motor Vehicle Fires). It was included in the proceedings of the 1999 SAE International Congress and Exposition held in Detroit, Michigan, March 2-4, 1999.

Yours truly,

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1999-01-0088

Field Investigation of Motor Vehicle Collision-Fires

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ABSTRACT

Since Federal Motor Vehicle Safety Standard 301 was first issued in 1967, many studies of collision-fires have been conducted. Most of the studies were analyses of motor vehicle crash databases providing little detailed information as to likely fuels involved in ignition, ignition sources, propagation paths and times, and injury mechanisms.

This paper presents the results of case studies and preliminary findings from on-going investigations of motor vehicle collisions involving fire. Twenty one field investigations of incidents involving automobiles, pickup trucks, vans and sport utility vehicles were conducted. Three incidents have been selected for presentation to demonstrate program methodology and characteristic factors of collision-fires.

Results showed that the causes and severities of collision-related fires can vary widely and depend on numerous and complex factors. Field investigations can provide a perspective usually unavailable to fire researchers. The causes of and potential for fire and injury may be characterized through field studies, where the importance of many details in real world events can be weighed.

INTRODUCTION

For many years, automotive collision-fires have been studied to examine trends of such events, their causes and effects, and the effectiveness of Federal Motor Vehicle Safety Standard 301 (FMVSS 301) [1,2,3,4]. FMVSS 301, which regulates only gasoline and diesel fuel leakage in collision and rollover, has been shown in some studies to have been effective in reducing the incidence of collision-fires in general [5,6]. However, other mechanisms for collision-fires not addressed by FMVSS 301 also exist. Motor vehicle incident databases lack detail regarding fire events and often only indicate whether a fire has occurred. Yet there have been very few publicly available studies that included vehicle field inspections so that some conclusions could be drawn as to specific causation and propagation factors of the fires. The few available publications containing case studies of automobile collision-fires have not been extensive or have not included field investigation [7, 8, 9, 10]. While case studies in the field are labor intensive to perform, they are an independent source of specific information about collision-fires.

In this project, researchers are conducting a field study of collision-fire incidents involving passenger cars and light trucks, including pickup trucks, vans, and sport utility vehicles. The goal of the project is to investigate up to 50 incidents though some will be limited in scope. At the time of writing, approximately 21 such investigations have been completed, three of which are presented here in detail. The objective of the program is to compile available information for evaluating the collision severity, fire cause, fire propagation paths and rate, and extent of injuries for each collision-fire incident. The authors expect that results and observations from this study will be useful to designers, regulators, and investigators alike.

For fires to initiate, specific combinations of fuels, oxygen and ignition energy are required. Specific combinations of fuel and oxygen are also again required to promote propagation. Propagation, in turn, depends on the location of the fire, the type and amount of combustible material in the area of ignition, adjacent surface properties for heat reflection, and local air flow and ambient weather conditions. Numerous researchers have demonstrated the difficulty of reenacting realistic vehicle fire scenarios in the laboratory [11, 12, 13]. Many of these attempts to initiate non-collision vehicle fires with only the resources normally available in the vehicle failed to either initiate or propagate the fire. In addition to the numerous variables related to the fire, small differences in crash configuration can make significant differences in the likelihood of a fire. Because of the complexity of collision-fire events, it is difficult to relate the results of controlled laboratory tests to field incidents. Greater value can be gained from case studies by using them in conjunction with laboratory studies so that complementary data may be shared.

Case studies, by nature, do not necessarily define trends in propensity for collision-related fire in specific makes and models. Databases containing thousands of samples are more appropriate for conclusions regarding trends. However, case studies provide the opportunity for a much more detailed examination of individual incidents than is possible through motor vehicle incident databases, hence they provide a deeper understanding of individual events.

Data presented herein illustrate cases that include a wide variety of post-collision ignition times, fluid system breaches, ignition source availability, impact types and impact severity. Photographs, inspection results, witness statements and investigator experience are the bases for the data presented.

The three cases highlighted by the authors demonstrate the value of field investigations developed under the current research program. These examples show that field studies can 1) improve the accuracy of characterization of fire causes, which vary greatly and are difficult to determine, 2) demonstrate that fire propensity and collision severity are not always correlated, and 3) allow better characterization of the potential for injury, which is dependent on many factors.

RESEARCH PARTICIPANTS

The prime contractor for this project is the Washington State Transportation Center (TRAC) at the University of Washington. TRAC is a cooperative transportation research agency with members including the University of Washington, Washington State University, and the Washington State Department of Transportation. From its offices at the University of Washington in Seattle, TRAC coordinates research resources to address multidisciplinary applied research problems. This research was conducted by the authors under subcontract with TRAC.

INVESTIGATIVE TECHNIQUES

An important component of the project was the establishment of a network of contacts at federal, state and municipal levels, in both public and private sectors, to alert the project team of collision-fire events. A considerable expenditure of project resources was and continues to be required to obtain sufficient numbers of events for investigation [14].

Incident samples were selected to identify vehicle and collision factors in fire and injury causation. Cases were drawn from incidents involving 1990 model year design and newer gasoline-powered passenger cars, pickup trucks, sport utility vehicles, and vans, built by various manufacturers. Selection was also based on the extent of impact, fire damage and injury.

It is difficult to determine specific fire causation and propagation factors in vehicles with extensive damage from both impact and fire. To maximize the information learned from each incident selected, samples were taken from three categories:

1) Vehicles with minor fire damage and any degree of impact damage.

2) Vehicles with minor collision damage and any degree of fire damage.

3) Incidents in which fatalities or burn injuries are involved with any degree of collision and fire damage.

For those incidents with either minor impact or minor fire damage, fire causation factors may be identified with a higher degree of confidence. For incidents with both extensive impact and fire damage, investigation still provided insight into causation of injuries, propagation times and entrapment issues.

As secondary selection criteria, various collision impact types, vehicle types, sizes, and manufacturers were sought for investigation. Through the random process of notification, the incidents have been distributed among the secondary selection criteria and it has not been necessary to use any of them for screening during selection. No incident was excluded based on secondary selection criteria.

After selection of an incident, available information was gathered through interviews with police and fire personnel, witnesses, vehicle owners, occupants and family members. Based on these interviews, estimates were made of the time from impact to fire initiation and for propagation times and paths into the passenger compartment. Considering the stressful circumstances, all witness observations were used with caution. Witness time estimates in particular were not relied upon without corroborating information such as police and fire contact logs, concurring witness statements, and approximate time required for described activities.

Field inspections of vehicles were performed to independently evaluate initiation locations, fuel and ignition sources available, and propagation paths. Inspectors were restricted in their authorization to alter the condition of vehicles during inspections, so observations were often limited to exposed components. Additionally, severe impact and fire damage often compromise evidence of fire causation, ignition source, and propagation path. Therefore, inspector evaluations of fuels, ignition sources and times should be considered the authors' appraisal of the most likely conditions involved.

When useful for determination of Delta V[1], crush damage was measured. This calculated value of Delta V was intended to provide an order of magnitude of crash severity. Precision varied depending on the crash configuration and data available.

Nine forms were developed for collection of data related to each of the collision-fire incidents under investigation [14]. The forms are filled out by investigating engineers and medical personnel familiar with their use. A number of the form entries and procedures were based on the National Automotive Sampling System (NASS) developed by the National Highway Traffic Safety Administration (NHTSA). They were kept as similar as possible for data fields that were comparable. The forms included a Case Summary Worksheet, a General Vehicle Form, an Interview Form, Vehicle Exterior and Interior Documentation Forms, a Field Fire Investigation Form, an Incident Site Documentation Form, an Incident Reconstruction Form and an Occupant Injury Assessment Form. At the conclusion of research, a database will be created. Information related to fire cause and propagation, collision severity, and injury mechanisms will be compiled and made publicly available, along with selected photographs of each incident. For privacy considerations, no personal data (names, dates, locations, vehicle identification) will be contained in the database.

FIELD INVESTIGATIONS

Results of the 21 field investigations conducted are summarized in tabular form in the appendix. Three cases were chosen to be highlighted in this paper because they represent a variety of fire causes and severities, impact severities and types, and vehicle types. Note that all sample numbers refer to the table in the appendix.

INVESTIGATION 1: SMALL CAR UNDERCARRIAGE IMPACT AND ROLLOVER

Incident Description

A 1991 Mitsubishi Eclipse (Sample 16) was traveling eastbound on a two-lane road in mid afternoon. There were no known adverse road conditions at the time of the incident. Travel speed estimated by the driver was 113-121 kph (70-75 mph). The driver pulled off to the right gravel shoulder to allow an ambulance the right of way, and lost control of the vehicle at the edge of the roadway. The driver steered left to re-enter the roadway and overcorrected with a right steer resulting in the vehicle leaving the right side of the roadway and striking a culvert. The undercarriage of the vehicle struck the culvert and the vehicle rolled, coming to rest on its roof off the roadway. A passing motorist stopped and informed the driver that the vehicle was on fire. The driver exited the vehicle through the door then walked away from vehicle and lay down due to back pain. The driver was the only occupant in the vehicle.

The driver first observed the fire as he walked approximately 15 to 20 feet away from the vehicle. The fire was seen in the center of the vehicle toward the front of the car. The fire was accompanied by smoke. By the time the driver walked approximately 50 feet and laid down, a passerby with a fire extinguisher extinguished the fire.

[1] Delta V is the change of velocity of the vehicle that takes place during the collision event as a result of impact.

Vehicle Damage

Impact with the culvert and subsequent rollover severely damaged the front suspension, engine oil pan and exhaust system (Figures 1 and 2). The right front suspension strut was pulled from its upper mount. The oil pan was breached and spilled its contents onto the exhaust pipe located adjacent to the oil pan. Black oil was observed on the grass in the culvert two days after the incident. Portions of the exhaust pipe including the catalytic converter were missing and appear to have been separated from the vehicle as a result of the impact with the culvert.

Other collision damage to the vehicle was confined to the front bumper area, rear fenders and tail lamps. The windshield was cracked but remained intact and the roof was depressed approximately four inches at the center of the windshield header. The right rear fixed glass was broken and missing.

The exhaust pipe in the area adjacent to the oil pan was partially enclosed by a metal shield and braided wire covering. The pipe geometry under the braided wire cover was of convoluted/corrugated pipe design.

Because of the nature of this incident, including its undercarriage damage and subsequent rollover, Delta V for this incident could not be calculated with conventional methods and was not relevant to fire causation.

Injuries

This vehicle is equipped with a two-point, motorized shoulder belt and manual lap belt restraint system. The occupant was wearing the shoulder belt portion of the system only at the time of the incident. The driver was taken by ambulance for emergency room treatment and released. Injuries included pulled back muscles, a bruised left knee and scratched left foot.

Fire Damage, Location and Propagation

Post-fire damage on the vehicle was minimal. From witness accounts and inspection of the vehicle, the fire was confined to the area of the exhaust system adjacent to the oil pan (Figure 2). No other heat damage was evident on the vehicle.

Because the vehicle came to rest on its roof, the exhaust system was a high point on the vehicle, with no consumable materials above the fire. Therefore, the fire was sustained by the oil vapor generated by the exhaust pipes, and did not propagate prior to being extinguished. It is unknown if the fire would have propagated or simply used the available fuel supply (oil) and self extinguished. Engine oil appears to have been the only fuel available in this incident. Evidence indicates that the majority of oil was spilled while the vehicle was on its wheels and very little oil was found splattered in the engine compartment that would have facilitated propagation of the fire to other areas of the engine compartment. Even the undercarriage of the vehicle aft of the oil pan exhibited little evidence of oil. The entrapment of the oil in exhaust pipe covers can facilitate autoignition of appropriate concentrations of oil vapor on the hot pipe surface. Additional research is necessary to confirm sufficient temperature in these areas of the exhaust system to support autoignition. The only other potential ignition source for the oil vapor was mechanical spark resulting from interaction between the culvert and undercarriage components. However, a hot surface provides a more continuous ignition source for combustible mixtures. The mechanical sparks due to impact were instantaneous; if a combustible mixture was not present at that precise moment, no ignition would have occurred.

INVESTIGATION 2: SUV SIDE COLLISION FROM SMALL CAR

Incident Description

A westbound 1992 Ford Explorer (Sample 5, "SUV"), carrying three occupants, stopped at a stop sign before a four lane, undivided highway. The SUV driver pulled out in front of a southbound 1991 Toyota Corolla ("car") apparently without seeing it before impact. The driver of the car swerved right and braked, locking the wheels. The front (offset left) of the car struck the right side of the SUV adjacent to and forward of the front wheel. The impact occurred in the outside southbound lane of the highway. Both vehicles came to rest off the southwest corner of the road. The driver of the SUV said she was ejected and landed in the highway.

The driver of the SUV said she immediately got up and ran to the vehicle to assist two children in exiting. By the time either driver observed the SUV, they believe within one minute of impact, flames of 6-15 inches high were observed. Impact damage was limited though the vehicle was eventually totally consumed by fire (Figure 3).

Incident Reconstruction Results and Injuries

Collision damage to the SUV was minimal and was confined to the right front fender, wheel, and suspension area. Crush damage to both vehicles was limited in part by impact to stiff structures supporting the wheels of each vehicle. There was negligible static crush intrusion into the engine compartment (Figure 4). Delta V for the SUV was 31-40 kph (19-25 mph). In the SUV, one child was belted, another in a child safety seat and neither was injured. The driver received cuts and bruises to the legs, head, and arms, a dislocated right shoulder, broken right collarbone, and a broken vertebra in the neck. Delta V for the car was 51-68 kph (32-42 mph). Damage to the car was to the left front bumper, engine, and left wheel area. The left front wheel itself was deformed and pushed rearward. The restrained driver (and sole occupant) of the car received lacerations along the left side, a possible fractured knee, and back pain. Delta V values were calculated using the momentum method.

Witness Accounts (Related to Fire)

The driver of the SUV was reportedly ejected, and observed red flames she estimated to be 15 inches high when she first looked up from the pavement toward her vehicle within one minute of impact. The flames were located in the right-rear corner of the engine compartment by the windshield and right-front mirror. She made these observations from the driver's side, behind the vehicle. She then ran to get her child out of the right-rear passenger seat. The driver of the car was still in his vehicle when she approached the right side of the SUV. She couldn't open the right-rear door (it may have been locked) so she ran around the car to the left-rear door. Opening the left-rear door, she unbuckled the belt of a nine year-old child and he exited immediately. She unbuckled the car seat (in the right-rear position) of a seven month-old baby and carried it out. After taking about ten steps from the car, she collapsed. At that time she heard a "real loud, muzzled pop."

The driver of the car said he saw fire within 30 seconds of his vehicle coming to rest. As he described the sequence, his vehicle stopped on the shoulder after impact and he looked through his windshield at the incident scene. The SUV was at rest directly in front of him and was reportedly already on fire with flames 6-12 inches high when he first observed it. He said the fire was in the rear of the engine compartment near the hinges to the hood. His point of view was from his driver's seat, facing the passenger side of the SUV. He could see the top of the front-right wheel well and did not recall seeing fire there in the early stages. He exited the rear-passenger door and moved around the front of the SUV. As he did so, he indicated that the fire may have been in the center of the engine compartment (right-left) but he could not be sure whether the fire was centered (fore and aft) or at the rear of the engine compartment. By that time the flames were estimated to be 18-24 inches high. Seeing that everyone in the SUV was taken care of, he walked away from the vehicles. Within approximately two to four minutes of rest and while he was walking away, he heard a "loud explosion" involving the sound of breaking glass, then he noted that flames engulfed the interior of the SUV.

Fire Location

The SUV was fully consumed, therefore the burn pattern did not indicate the origin of the fire. Burn patterns from complete burns do not necessarily yield reliable origin information because of possible involvement of intense heat from secondary fuels in regions distant from the actual fire origin. Witness statements and the location of likely fuels were the most reliable means by which the area of origin could be identified in this case. They suggest that the fire originated in the right rear of the engine compartment. The viewpoint of the witness positioned on the left side of the vehicle would provide a clear perspective on the absence of flames on the left side and therefore supports initiation on the right, in the region of impact damage. And the driver of the car expressed greater confidence in his observation of fire toward the rear of the engine compartment while including the possibility that it could have been farther forward. Witness statements in this case are likely more useful for identifying the general area of fire origin rather than its specific location, because the deformed, closed hood would have restricted visibility into the engine compartment.

Fuel(s)

There was static crush distortion to the bulkhead in the blower housing mount location (Figure 4). Leftward dynamic crush likely caused contact between the blower housing and the cooling hose connection at the bulkhead because of the close proximity of these components (Figure 5). This could possibly have caused rupture of the cooling hose connection near the bulkhead, though physical evidence was destroyed in the fire. Figures 4 and 5 show the right rear of the engine compartment in incident and exemplar vehicles, respectively. Substantial impact damage to the right front wheel suggests that the right front brake hose may have ruptured but there was likely no brake fluid leakage communicated to the engine compartment beyond the fender skirt. The fender skirt was totally consumed in the subsequent fire and was not evident at the time of inspection. There were no other liquid fuels routed in or near the impact area of the engine compartment.

Since a power distribution box was located on the right-front inner fender well in the area of impact, the box and wiring were considered as potential sources of both fuel and ignition. Resistance heating of shorted wires could ignite the polymeric box and wiring insulation. It is the experience of the authors that such fires take a period of time to initiate and propagate that would be far longer than the almost immediate 6-15 inch high flames described by the witnesses in this case. Given the reported rate of fire propagation, the fact that the coolant was the only fluid in the engine compartment likely subject to release from impact damage, and the witness accounts, it was concluded that the initial fire was most likely fed by coolant.

Coolant as an initiating fuel source has been confirmed by the authors in numerous full-scale vehicle tests and laboratory tests. In these tests, pure coolant and 50-50 mixtures of coolant with water have both readily ignited on hot surfaces and due to sparks. Once ignited, flames spread throughout the available mist or vapor clouds. Propagation may then occur through continued leakage of coolant mist or vapor (and its consequent combustion), and/or the involvement of solid or liquid secondary fuels.

Ignition Source(s)

The most likely ignition source was concluded to be electrical sparks in the area of the power distribution box on the right-front fender or resistance heating due to an electrical short. The power distribution box and associated wiring were the only electrical sources disturbed in the zone of impact damage. High-current cables and contacts were present after the fire and showed no evidence of arcing as would be expected in high-current shorts. The possibility of more limited and potentially undetectable electrical shorts remained. An exhaust manifold was on the same (right) side of the engine, and was shielded, increasing the possibility of autoignition. However, it is less likely that the exhaust system would have been hot enough to result in autoignition of coolant, though it likely provided adequate heat for vaporization of coolant.

In reviewing the detailed observations and deductions, perspective on simple facts should not be lost. However unlikely the circumstances seem, there is no doubt that a fire occurred. Impact damage was extremely limited; systems disturbed were few. Because of the extent of the fire, there was no direct evidence remaining to positively confirm the fuel or ignition sources. It is most likely that the fire was related to disturbed systems, though other possibilities remain. This case exemplifies the difficulty in investigating post-collision fires, and ultimately, in limiting such events.

Propagation

Given the extensive burn damage to the vehicle, the burn pattern was not informative as to the relative contributions of various fire pathways. Consumables were almost totally burned except for the spare tire under the rear deck. It was noted that the ventilation system, which was likely to have been disturbed during dynamic crush, included openings in the metal bulkhead between the engine and passenger compartments. Given observable impact damage and witness statements, it was not likely that the windshield was broken in the crash. However, the windshield may have served as a large pathway for propagation once it had broken from heat.

The two primary witness statements were consistent as to the time elapsed from rest to fire initiation and propagation to the interior. In determining propagation times, investigators consider witness estimates, but also use witness descriptions of activities to help confirm times. In this case, it appears that fire initiation was almost immediate. Both witnesses also describe activities leading to the sound they characterized as an initial "pop" or "explosion." This event is linked by both witnesses with the time fire was observed in the passenger compartment. The estimates and activities are consistent with elapsed times of 2-4 minutes from rest to propagation to the passenger compartment. If there had been a subtle incursion of fire into the passenger compartment prior to two minutes, it may not have been observed.

INVESTIGATION 3: VAN REAR END COLLISION FROM PICKUP TRUCK

Incident Description

A 1992 Chevrolet Sportvan (Sample 15, "van") was southbound in the center lane of a three-lane highway. It was mid-afternoon, traffic was heavy, and there were no known adverse environmental conditions. The right lane of travel was eliminated ahead due to construction and the highway narrowed from three lanes to two lanes. According to the driver of the van, she braked to approximately 89 kph (55 mph) to allow a vehicle to enter her lane of travel, but she was unable to avoid it side swiping her. Seconds after this collision, the van was struck from behind by a 1993 Chevrolet Silverado pickup truck (Sample 14, "pickup"). The pickup traveled into the center median after impact and came to rest. The van continued across the median and across the northbound lanes and across a parallel access road where it came to rest in the east ditch of the access road.

Indications are that the collision resulted in a fire after impact and prior to rest. The fire initiated in the rear of the van and then progressed to the interior and engine compartment. A small, unrelated fire occurred in the engine compartment of the pickup truck.

Vehicle Damage and Incident Reconstruction Results

The front bumper of the pickup truck (Figure 6) contacted the lower edge of the rear bumper of the van (Figure 7). The pickup front bumper rotated approximately 90 degrees and under-rode the van while the van's bumper also rotated approximately 90 degrees and crushed the front structure and engine compartment of the pickup, primarily above the pickup bumper. The front license plate of the pickup was found lodged between the forward edge of the van rear bumper and the fuel tank approximately 15 inches to the right of the van longitudinal centerline, indicating an offset collision occurred.

The underride by the pickup caused damage to the van fuel tank (Figure 8) and resulted in three breaches in the fuel tank. The largest opening was approximately 2 inches by 1.5 inches, located in the forward right lower corner of the tank (Figure 9). This hole was adjacent to the brake line distribution tee mounted to the rear axle. The other two openings in the tank were in the area of direct impact to the right rear of the fuel tank and were each approximately 1.5 inches by 0.25 inch in size. The exact cause of these two breaches is not known. However, one appeared to be the result of direct impact from some component of the striking vehicle and the other appeared to be due to excessive deformation of fuel tank material. An additional tear in the filler hose was noted but there was not burn damage in the area.

The rear doors were damaged at impact resulting in separations between the body and door frame and between the doors. At the time of inspection, the left door moved freely and the right door was jammed shut. While fire damage destroyed the physical evidence, the possibility remained that glass in the rear doors was broken at impact. The right rear taillight was damaged in the collision, resulting in an opening to the passenger compartment. There were no separated seams identified in the body panels.

Approximate maximum crush of the front of the pickup ranged from 22 inches at the bumper plane to 40 inches at the plane of the front edge of the hood. Maximum crush of the van at the rear bumper plane was approximately 17 inches. Collision profile measurements for both vehicles were used in EDCRASH to calculate Delta V for both vehicles. There was no detailed information available about the post-impact trajectories of the vehicles. Due to the underride/override nature of this collision, a wide Delta V range was calculated. The pickup Delta V was 34-56 kph (21-35 mph); the van Delta V was 23-35 kph (14-22 mph). Further refinement of the Delta V would require additional information beyond the scope of this project.

Injuries

The driver of the pickup was fatally injured in the collision. His death and trauma were unrelated to fire. Although the police report did not indicate whether the driver of the pickup was restrained, severe distortion to the steering wheel, along with other evidence of occupant contact, suggested he was unbelted.

The van contained four occupants including the driver, right front passenger, first rear seating row occupant and second rear seating row occupant. The driver and right front occupant were belted and the rear seat passengers were unbelted. The driver of the van reportedly sustained a concussion, facial bruising, swelling to the right rear of the head, injured ligaments in the back, and a burn to one arm. Her rest position after the incident was with her upper torso between the two front seats. The driver was treated and released from the hospital. The right front occupant sustained a sore leg but was not treated. The first seating row passenger fractured a kneecap. The second rear seating row passenger sustained minimal injuries and, with the help of a bystander, reportedly assisted the unconscious driver from the vehicle.

Fire Location and Propagation

Van

Impact damage to the fuel tank of the van caused leakage in the right rear of the vehicle. Mechanical sparks from the collision, electrical sparks from the rear lamps of the van, and electrical components in the engine compartment of the pickup were possible ignition sources. Breaches in the fuel tank suggested that large amounts of fuel were dropped to the ground from the fuel tank as the vehicle traveled to its rest position, possibly leaving little or no remaining fuel to pool under the vehicle. The exterior post-fire damage pattern indicates higher heat intensity on the rear and right side of the vehicle. Both right side tires were completely consumed while both left side tires maintained inflation.

After the impact, the unconscious driver of the van was removed by one of the other van occupants with assistance. The occupant reportedly exited the van, ran up to a road, called and gestured for help for some time. The occupant and a passerby then returned to assist the driver. The fire propagated from the rear and was "over" the driver by the time she was removed. Fire department personnel arrived on the scene approximately 11 minutes after the incident. By then, all the van occupants were outside the vehicle and the vehicle was fully involved in fire. At the time of their arrival, the entire vehicle, including its engine compartment and interior, was on fire.

Gasoline released from the fuel tank during the collision most likely ignited vehicle components in the rear of the vehicle while causing only minimal heat damage to the undercarriage. Lack of undercarriage heat damage suggested a pool fire under the vehicle was unlikely to be the source of the original fire. This was supported by the police report that stated the vehicle was on fire before it came to rest. The fire most likely propagated into the passenger compartment through body panel openings surrounding the tail lights, crush-induced opening in the rear doors, or the broken windows in the rear doors. No evidence existed of openings in the floor that allowed propagation of the fire into the passenger compartment from under the vehicle. The second rear seating row occupant was not injured from the fire indicating that the components that were initially on fire were confined to the rear-most areas of the occupant compartment.

Pickup

Impact damage evident to the front of the pickup caused breach of the cooling system and brake master cylinder reservoir. Collision damage prevented examination of other potential liquid fuel sources. Fire damage was extremely limited and confined to the upper rear left corner of the engine compartment. The heat-damaged areas were all within the upper engine compartment (above the region of direct contact with the van gasoline tank) and covered by the hood. Crush damage to the hood confined its movement indicating the hood was not open even during the dynamic crush phase. There was no evidence of heat damage in areas consistent with gasoline released from impact with the van; therefore, it was concluded that the pickup fire was due to an independent fuel. The burn pattern indicated that the fire originated outboard of the brake master cylinder; heat and impact damage to the power distribution box were noted in the same area. Little else was located between the master cylinder and the fender. Based on location of heat damage, the released fluids were unlikely to be the originating fuels for the fire. The damage was consistent with electrical ignition. There was evidence that dry chemical fire suppression was used to extinguish the fire, however, there were no witnesses interviewed including fire personnel that knew of the fire in the pickup. Fire personnel reported that a large number of passing motorists were on site to assist, including truck drivers who generally carry fire extinguishers. Such participants usually are not listed on police reports unless they were also witnesses to the crash event.

CONCLUSIONS

1. Field investigations enhance the characterization of post-collision fire causation. Untangling the complexity of collision-fires in the field can only be done through detailed inspection and sound deduction. In certain cases, field investigations may not provide conclusive evidence of post-collision fire causation. Fires following collisions tend to be dependent on transient events (such as fuel/air mixture, surface temperature, sparks, etc.), with subtle evidence that is often obscured or destroyed by fire. However, even when precise causation cannot be determined, such field investigations provide automotive engineers valuable insight into vehicle design issues related to both collision and non-collision-fires.

2. In this study, it was shown that coolant, oil(s) and gasoline were all identified as liquid fuels with the potential to initiate fire. Damage to the electrical system also provides a potential source of both fuel and ignition. In what may be contrary to common understanding of collision-fires, a large percentage of the frontal impacts investigated did not initially involve gasoline leakage.

3. Detailed investigations illustrated that factors which may initially seem important may, upon a deeper study, not be related to the cause of fire. For example, in the case of the rollover/fire event, the fire was caused by undercarriage damage rupturing the oil pan. In this case, the fire cause was unrelated to rollover, and in fact, the rollover may have actually reduced the potential for fire propagation.

4. Identified propagation times, paths, and initiating fuels varied considerably among incidents. In the rear collision case detailed herein, even gasoline, the most volatile and plentiful on-board fuel, initiated a fire in which the incapacitated driver received only minor burn injuries. Non-incapacitated occupants who were closer to the point of fire initiation exited without burn injuries. Fire propagation and hence potential for injury are dependent on the nature of tank rupture, the integrity of the surrounding structure, occupant incapacitation, and a host of other factors. Field investigations allow consideration of such detailed factors, which enhance the evaluation of fire cause and injury potential.

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REFERENCES

1. Malliaris, A.C., "Impact Induced Car Fires, a Comprehensive Investigation," 1991.
2. McCarthy, G, et al., "The Impact of the 1968 Evaporative Loss Standard on Automotive Fire Risk," American Society of Mechanical Engineers, 1989.
3. Flora, J.D., "Automobile Fires in Traffic Crashes," DOT HS-036 241, 1983.
4. Johnson, N.B., "An Assessment of Automotive Fuel System Fire Hazards," DOT HS-800 624, 1971.
5. Parsons, G.G., "Motor Vehicle Fires in Traffic Crashes and the Effect of the Fuel System Integrity Standard," DOT HS-807 675, 1990.
6. Parsons, G.G., "Evaluation of Federal Motor Vehicle Safety Standard 301-75, Fuel System Integrity: Passenger Cars," NHTSA Technical Report, DOT HS 806 335, 1983.
7. Cole, L.S., A Survey of Vehicle Fire Causes, Lee Books, 1988.
8. Cooley, P., "Fire in Motor Vehicle Accidents," Highway Safety Research Institute 32949, DOT HS-801-745, 1975.
9. Gesac, Inc., "Fuel System Integrity Upgrade - NASS & FARS Case Study," USDOT Contract DTNH-22-92-D-070604.
10. Habberstad, J.L., Collins, J.C., Investigation of Collision-Related Vehicle Fires, Highway Collision Reconstruction, American Society of Mechanical Engineers, 1980.
11. "A Study of Vehicle Fires of Known Ignition Source," International Association of Arson Investigators Alberta Chapter, 1983.
12. Cole, L.S., Investigation of Motor Vehicle Fires, Third Edition, Lee Books, 1992.
13. Patal, A., et al, "A Study of Six Automotive Fires of Known Ignition Source," Saskatchewan Government Insurance Office, 1978.
14. Shields, L., Scheibe, R., Angelos, T., "Motor-Vehicle Collision-Fire Analysis Methods and Results," National Fire Protection Association, 1998.

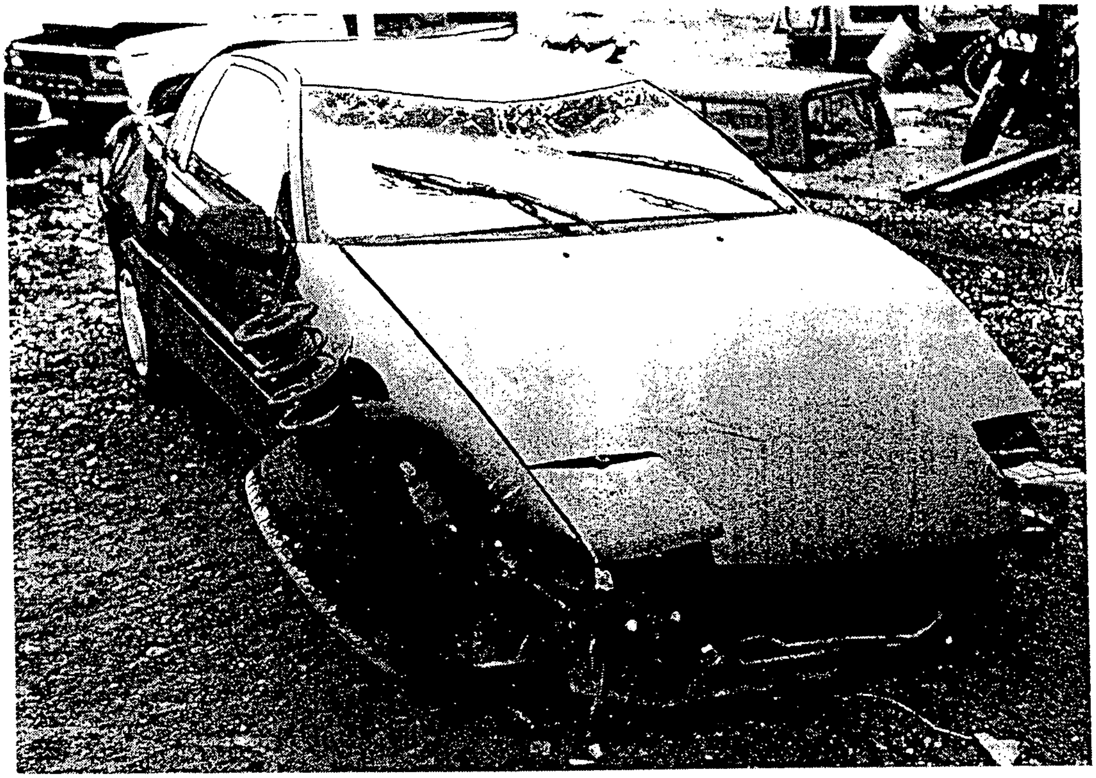

Figure 1. Investigation 1 small car, showing rollover damage and no fire damage to exterior

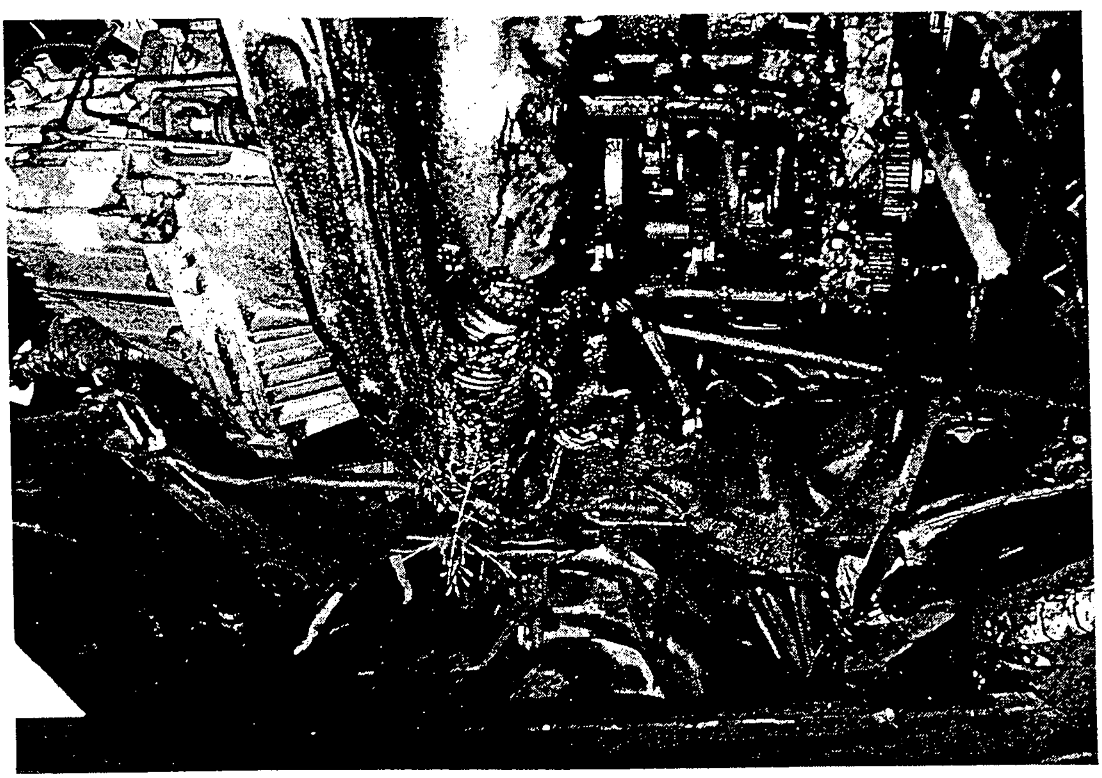

Figure 2. Investigation 1 small car, undercarriage, showing minimal fire damage to exhaust system adjacent to oil pan

Figure 3. Investigation 2 SUV, showing impact to right front and overall fire damage

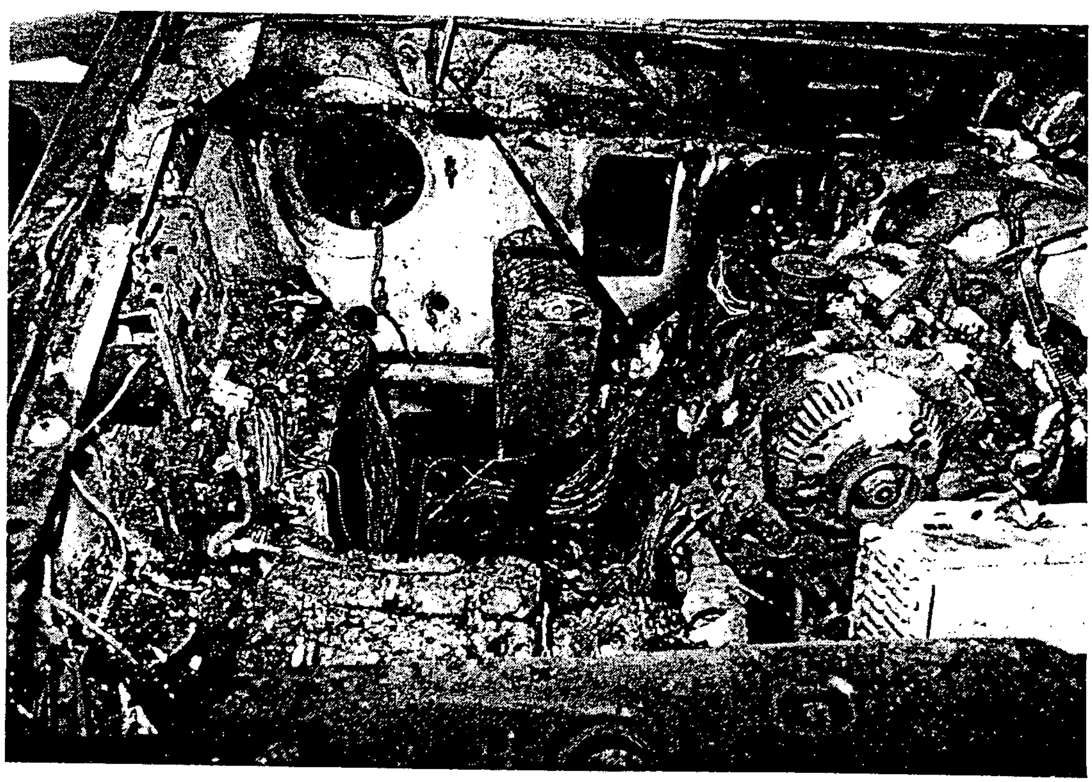

Figure 4. Investigation 2 SUV, looking rearward, showing fire damage to passenger side of engine compartment

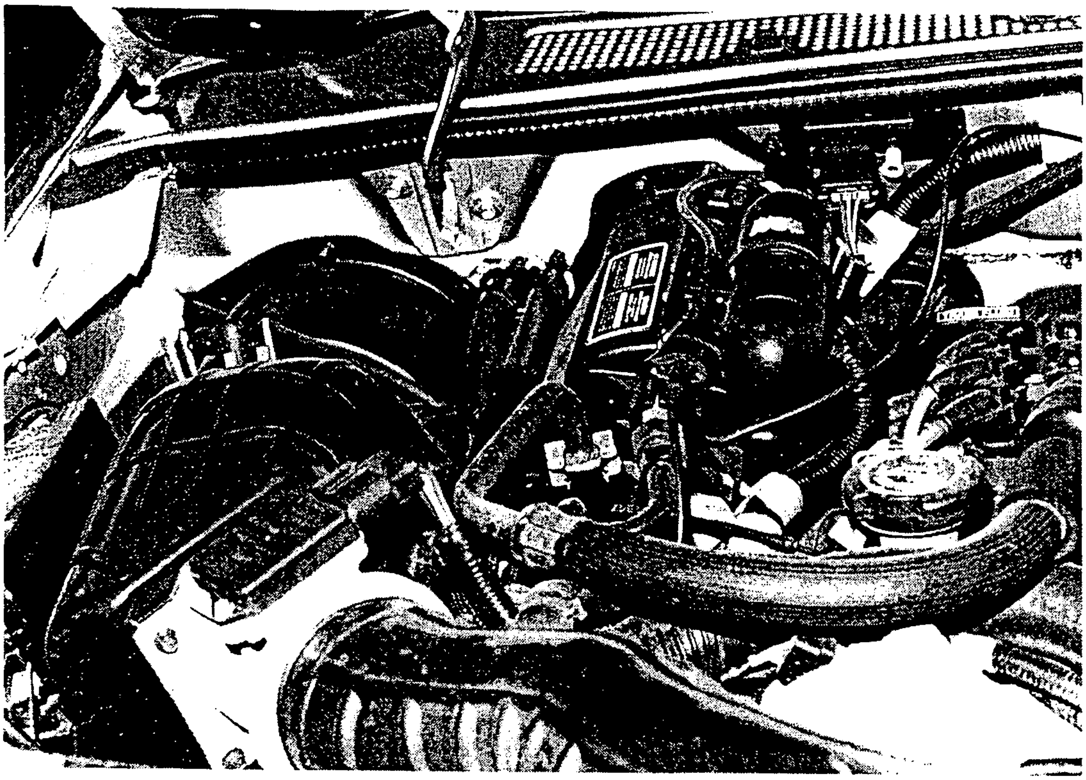

Figure 5. Investigation 2 exemplar SUV, looking rearward, showing passenger side of engine compartment

Figure 6. Investigation 3 pickup truck, showing frontal override collision damage

Figure 7. Investigation 3 van, showing rear underride collision damage and overall fire damage

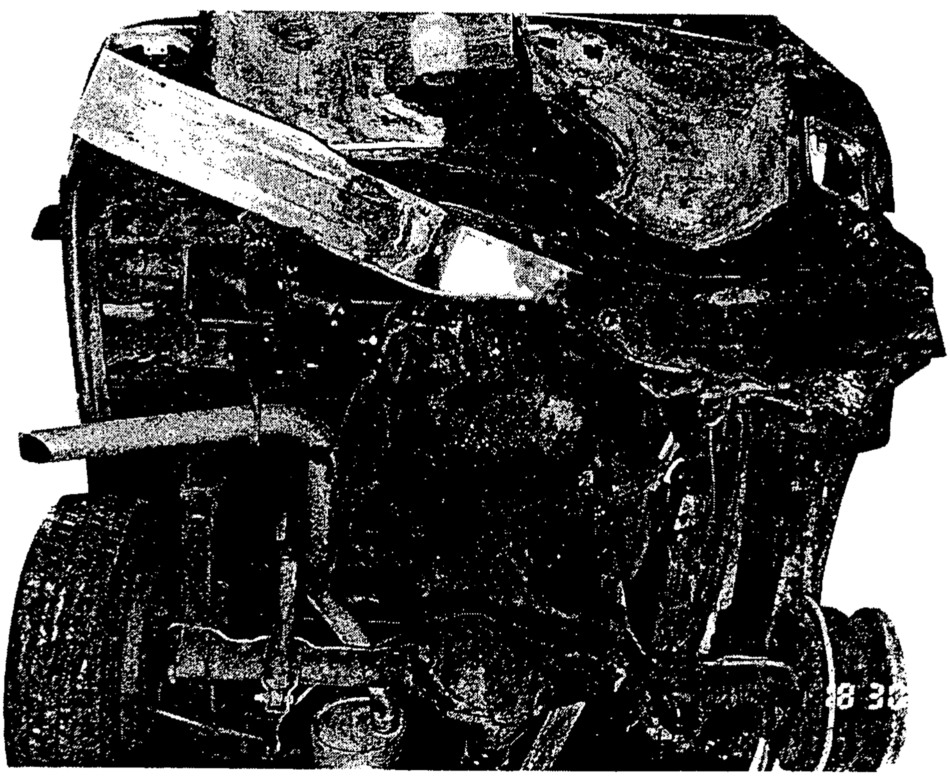

Figure 8. Investigation 3 van, showing damage to rear underside

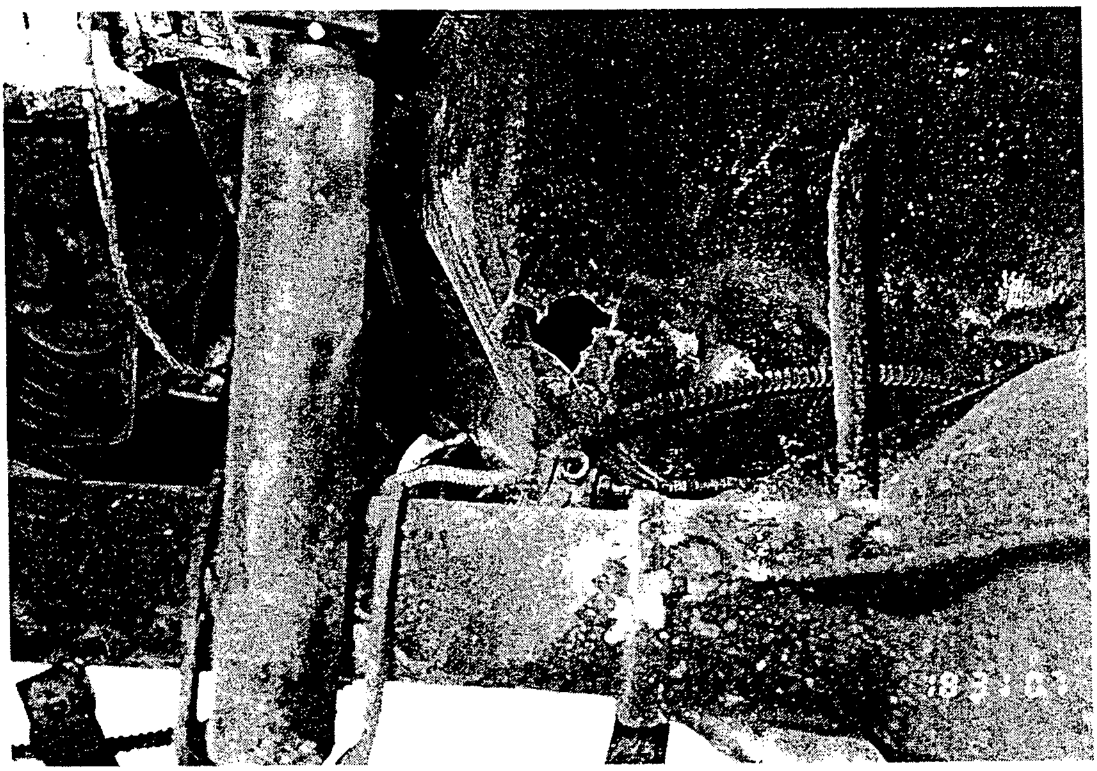

Figure 9. Investigation 3 van, showing largest breach in fuel tank

Appendix
Summary of Investigator Evaluations
Detailed Investigations

Sample No.	Fire Vehicle	Impact Description	Estimated Delta V kph/ mph	Most Likely Fuel/Ignition Source(s)[2]	Estimated Time to Ignition/Time to Interior[3] (minutes)	Initial Location of Fire	Reported Injuries: Fire Vehicle (Other Vehicle)	Assistance in Egress (Fire Veh.)
1	1995 BMW 525i	Frontal with barrier, narrow	47-63/ 30-40	Gasoline*, coolant/ electrical spark, hot manifold surface	2-3/4-6	Engine compartment	Driver: unconscious, passenger: spinal injuries	Yes
2	1997 Plymouth Voyager	Frontal with side of van, underride	19-27/ 12-17	Gasoline*, other fluids/ electrical spark, hot exhaust manifold	Immediate/4-7	Engine compartment	Driver: broken hand (Driver: cut to head)	No
3	1992 Mitsubishi Eclipse	Frontal with front of pickup	47-53/ 29-33	Engine oil*, coolant/ hot exhaust manifold*, elec. spark	Immediate/ 5-8	Engine compartment	Minor (none)	Yes
4	1995 Ford Escort	Frontal with rear of pickup	9-15/ 6-10	Engine oil* and coolant/exhaust manifold* and electrical	<2/extinguished within 5 min. with no spread to interior	Engine compartment	None	No
5	1992 Ford Explorer	Right side with front of car	31-40/ 19-25	Coolant/electrical spark	Immediate/ 2-4	Engine compartment	Driver: ejected, broken vertebra (Driver: cuts, broken knee, back pain)	Yes (for children)
6	1991 Plymouth Acclaim	Frontal with side of pickup	3-8/ 2-5	Coolant/ electric motor	8-10[4]/extinguished 9-11 with no spread to interior	Engine compartment	None	No
7	1988 Plymouth Sundance	Undercarriage impact and rollover	Minor	Unknown fluid(s)/ Unknown	<5[4]/ fully engulfed within 10	Between front wheels on inverted car	Driver: non-incapacitating	Yes
8	1990 Dodge Caravan	Frontal impact with tree	64-80/ 40-50	All fluids/ electrical, hot exhaust manifold	Immediate/5-10	Engine compartment	Driver: burns. Passengers: one fatal, two seriously injured, one with burns	Yes

[2] * Asterisk indicates one or more fuels or ignition sources are believed to be more likely than others present.
[3] Times estimated from witness descriptions of events and responder logs. High estimates of propagation time used. Times are with respect to rest after impact.
[4] Engine reported to be on after impact.

Appendix (Continued)
Summary of Investigator Evaluations
Detailed Investigations

Sample No.	Fire Vehicle	Impact Description	Estimated Delta V kph/ mph	Most Likely Fuel/Ignition Source(s)[5]	Estimated Time to Ignition/Time to Interior[6] (minutes)	Initial Location of Fire	Reported Injuries: Fire Vehicle (Other Vehicle)	Assistance in Egress (Fire Veh.)
9	1996 Chrysler Sebring	Side with side of tractor-trailer	8-21/ 5-13	Coolant, engine oil, power steering & transmission fluids/ electrical, hot exhaust manifold	3-5[4]/4-6	Engine compartment	Driver: lacerations	No
10	1993 Honda Prelude	Frontal with utility pole	37-45/ 23-28	Coolant, power steering fluid/ mechanical or electrical spark	5/<10	Engine compartment	Driver: incapacitating injuries	Yes
11	1994 Toyota Camry	Frontal with narrow object	50-63/ 31-39	Coolant*, brake fluid/exhaust manifold, elec. or mech. spark*	1-2/<5	Engine compartment	Driver: bruised chest	Yes
12	1995 Toyota Camry	Frontal with guard rail	34-42/ 21-26	Coolant, transmission fluid/ electrical spark, hot exhaust manifold	1-4/ fully engulfed within 9	Engine compartment	Driver, passenger both had "other visible injuries"	Yes
13	1995 Chevrolet K-15 Pickup	Frontal with tree	35-42/ 22-26	Coolant, brake fluid/electrical spark*, exhaust manifold	Unknown/3-7	Engine compartment	Driver: fatal, cause unknown	Driver remained in vehicle
14[7]	1993 Chevrolet Silverado Pickup	Frontal with rear of van	34-56/ 21-35	Power distribution box*, coolant, brake fluid/ electrical heating* or spark	Unknown/ extinguished with no spread to interior	Engine compartment	Driver: fatal from impact (see sample 15)	Driver remained in vehicle
15[7]	1992 Chevrolet Sportvan	Rear by front of underriding pickup	23-35/ 14-22	Gasoline from tank/ electrical or mechanical spark	Immediate/ fully engulfed within 11	Rear end	Driver: concussion, back injuries, burned arm. 3 passengers: minor injuries	Yes

[5] * Asterisk indicates one or more fuels or ignition sources are believed to be more likely than others present.
[6] Times estimated from witness descriptions of events and responder logs. High estimates of propagation time used. Times are with respect to rest after impact.
[7] Samples 14 and 15 both involved in same incident; fires began independently.

Appendix (Continued)
Summary of Investigator Evaluations
Detailed Investigations

Sample No.	Fire Vehicle	Impact Description	Estimated Delta V kph/ mph	Most Likely Fuel/Ignition Source(s)[8]	Estimated Time to Ignition/Time to Interior[9] (minutes)	Initial Location of Fire	Reported Injuries: Fire Vehicle (Other Vehicle)	Assistance in Egress (Fire Veh.)
16	1991 Mitsubishi Eclipse	Override of culvert, rollover	Minor	Engine oil/exhaust pipe*, mechanical spark	~Immediate/ extinguished without spread to interior	Exhaust system, car inverted.	Driver: back pain, bruises, scratches	No
17	1994 Mazda 323	Rear-end by front of passenger car	66-69/ 41-43	Gasoline from tank/ electrical or mechanical spark	Immediate/<2	Rear end and/or interior	Driver: fatal, cause(s) unknown. (Minor injuries)	Driver remained in vehicle
18	1990 Lincoln Town Car	Rear-end by front of 3/4 ton van	80-97/ 50-60	Gasoline from tank/ electrical or mechanical spark	Immediate/ fully engulfed within 9	Rear end and/or interior	Driver and passenger fatal, causes unknown. (Driver: none, four passengers: minor and major injuries)	Driver and passenger remained in vehicle
19	1991 Toyota Previa	Override of tow dolly	Minor	Gasoline from tank/ mechanical spark	Immediate/immediate to exit paths	Pool fire under driver door	Driver and passenger burn injuries	No
20	1994 Dodge Caravan	Override of steel road plate	Minor	Gasoline from tank/ mechanical spark	Immediate/immediate to exit paths	Pool fire under pass. compartment	Driver and passenger burn injuries	Unknown
21	1994 Saturn	Rear by front of passenger car	68-77/ 42-48	Gasoline from tank/ mechanical or electrical spark	Immediate/1-3	Passenger compartment	Driver: fatal, cause unknown	Driver remained in vehicle

NOTE: Entries in the table that refer to "electrical spark" as an ignition source may include the possibility of electrical resistance heating as well. Burn injuries are listed only in the affirmative; annotation was not provided if there were no burn injuries.

[8] * Asterisk indicates one or more fuels or ignition sources are believed to be more likely than others present.

[9] Times estimated from witness descriptions of events and responder logs. High estimates of propagation time used. *Times are with respect to rest after impact.*