Fire Occurrence in Crashes Based on NASS/CDS

Kennerly H. Digges

MVFRI Report –

August 2009

Table of Contents

List of Figures

Fire Occurrence in Crashes Based on NASS/CDS

Kennerly H. Digges

MVFRI Report – August 2009

INTRODUCTION

The research reported in this paper is a follow-on to projects reported in earlier papers [Digges and Stephenson 2003, 2004, 2005, 2006 and 2007]. Some of the data is based on studies funded by MVFRI [Bahouth, 2006, Kildare, 2006]. This paper presents the results of a continuing analysis of two national data systems – the FARS and the NASS/CDS. This paper examines the crash factors that are associated with fires that occur after crashes. The crash modes are separated into the following categories: frontal, side, rear and rollover.

The Fatality Analysis Reporting System (FARS) is a database maintained by the US Department of Transportation. It contains records of all fatal crashes that occur on public roads in the United States. The FARS database has been used to document fatal injuries annually since 1975.

The FARS database documents all fatalities that occurred as a result of the crash including those where a fire resulted. In this paper, the term "FARS Fatalities" designates the fatalities in which a fire occurred in the vehicle, regardless of whether or not the fire caused the fatality. Since 1979, FARS also coded the "most harmful event" (MHE). If the fire event has been coded as the most harmful event, burn or inhalation injuries are the most likely cause of the fatality. In many crashes, it may be difficult to discern the cause of the fatality (biomechanical trauma vs. fire trauma). This distinction was not investigated and the coding was taken directly from FARS. This paper uses FARS to indicate historical trends in fire cases with regard to crash mode.

This paper uses the (NASS/CDS) National Automotive Sampling System/Crashworthiness Data System data to examine the crash factors that are associated with crash induced motor vehicle fires. NASS/CDS is a sample of tow-away crashes that occur on US roads each year. The sample is stratified by the severity of the crash. The sample rate for minor crashes is much lower than for severe crashes. In order to expand the stratified sample to the entire population it represents, an inflation factor is assigned to each case in the NASS/CDS sample. When the data are processed using the actual number of cases investigated, the sample is referred to as "unweighted" or "raw." When the data are processed using the total of the inflation factors, the results should represent the total population of vehicles and the sample is referred to as "weighted."

SUMMARY OF FIRE OCCURRENCES- FARS

An earlier analysis of FARS data examined changes in the rates of fatal crashes with fires over the time period 1979-2000 [Digges, 2003]. The figures presented in the earlier paper showed that the fire rates of vehicles generally decreased during the decade of the 1980's but have remained relatively constant since 1990. To further examine these trends, the FARS years were averaged over a five year period. The figures to follow show the five year moving averages for the FARS years beginning in 1979 and ending in 2005. Figure 1 shows the FARS fire rate and FARS MHE fire rate using billions of annual vehicle miles traveled (VMT) as the denominator.

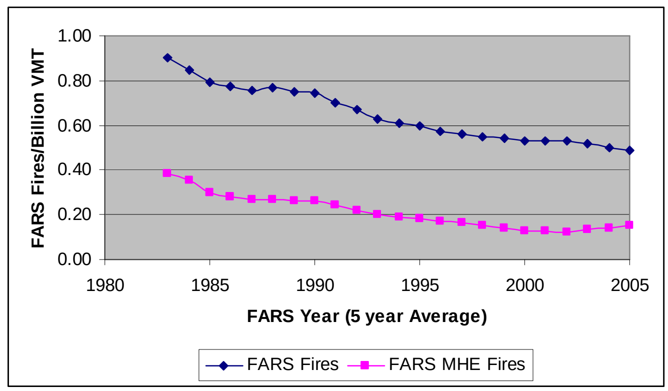

Figure 1. Fatalities in Vehicles with Fires and in Vehicles with Fire as the MHE per Billion Vehicle Miles Traveled Annually - FARS

FARS does not record the direction of force in the crash. However, the location of principal damage is coded. In this coding, rollovers with damage from impacts with fixed objects or with other vehicles are coded according to the location of the damage. If the damage comes from ground contact, the crash is classified as a non-collision. Rollovers are classified according to the event during which the rollver occurred (ie. non-rollover, rollover during 1st harmful event, or rollover during subsequent events). Most of the rollovers have damage to the front or sides of the vehicle. This damage may have been caused by impacts with fixed or non-fixed objects before or during the rollover. In some cases, these impacts may have been the cause of the fatality. In the analysis to follow, all rollovers are grouped together, regardless of the area of damage. No crashes with rollover are included in the groupings of front, side or rear damage areas.

The distributions of annual fatalities and fatalities where fire was the MHE are shown in Figures 2 and 3.

The rate of fire occurrence in fatal frontal crashes versus vehicle age is shown in Figure 4 [Fell 2007]. The graph shows an upward trend after twelve years. In the case analysis to follow, only vehicles less than ten years old will be included.

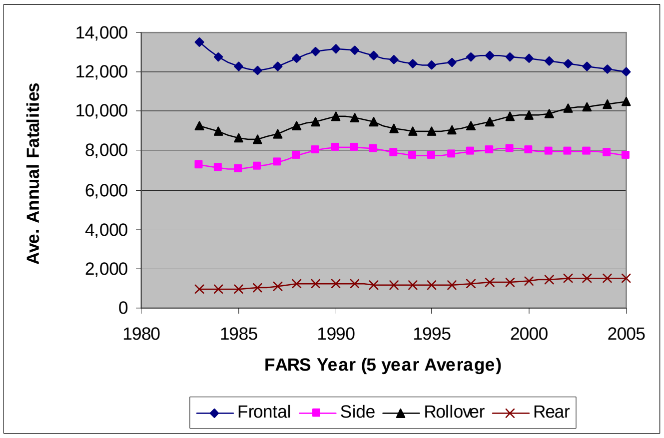

Figure 2. Average Annual Fatalities by Crash Damage Location – FARS 1979 to 2005

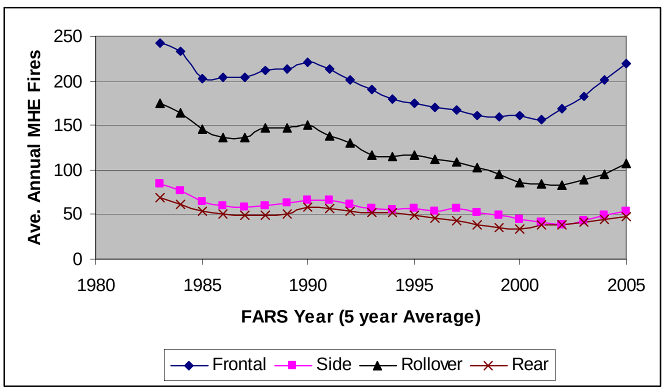

Figure 3. Average Annual Fatalities when Fire was Most Harmful Event by Crash Damage Location – FARS 1979 to 2005

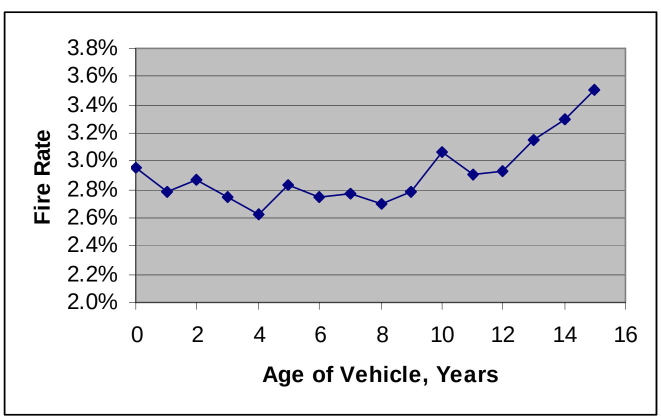

Figure 4. Fire Rate (Fires per Crash Involved Vehicle in FARS) vs. Age of Vehicle – FARS 2000 to 2002

Table 1 shows the damage distribution for the subset of cases with fire as the most harmful event. The data is separated into cases with and without rollovers. The damage in rollover may be caused by the rollover or by objects impacted before or during the rollover. Table 2 shows similar data for entrapment cases where fire was the most harmful event.

Table 1. Distribution of Average Annual Fatalities when Fire was Most Harmful Event by Crash Type and Damage Location – FARS 2000 to 2005

Damage Location	No Rollover	Rollover	Total
Non-Collision	2.1%	3.3%	5.4%
Front	45.8%	14.5%	60.3%
Right	5.8%	2.5%	8.3%
Rear	9.4%	2.0%	11.4%
Left	5.6%	2.1%	7.8%
Top	0.4%	1.4%	1.9%
Undercarriage	1.0%	0.6%	1.6%
Unknown	1.7%	1.7%	3.4%
Total	71.8%	28.2%	100.0%

Table 2. Entrapment Percentage for each Crash Type when Fire was Most Harmful Event by Damage Location and Rollover Presence– FARS 2000 to 2005

Damage Location	No Rollover	Rollover	Total
Non-Collision	18%	23%	21%
Front	23%	25%	23%
Right	21%	22%	21%
Rear	28%	28%	28%
Left	27%	20%	25%
Top	22%	19%	20%
Undercarriage	21%	18%	20%
Unknown	15%	15%	15%
Average of All	23%	23%	23%

METHODOLOGY – NASS/CDS ANALYSIS

NASS/CDS classifies fires as either Major or Minor. These fire severities are defined as follows:

A Minor Fire is a general term used to describe the degree of fire involvement and is used in the following situations:

- Engine compartment only fire
- Trunk compartment only fire
- Partial passenger compartment only fire
- Undercarriage only fire
- Tire(s) only fire

A Major Fire is defined as those situations where the vehicle experienced a greater fire involvement than defined under “minor” above, and is used in the following situations:

- Total passenger compartment fire
- Combined engine and passenger compartment fire (either partial or total passenger compartment involvement)
- Combined trunk and passenger compartment fire (either partial or total passenger compartment involvement)
- Combined undercarriage and passenger compartment (either partial or total passenger compartment involvement)
- Combined tire(s) and passenger compartment (either partial or total passenger compartment involvement).

DERIVED VARIABLES

Variables such as Crash Direction, Vehicle Body Type and Final Rest Position are not directly provided in the NASS/CDS database. Below is a discussion of each of the derived variables used in the analysis.

<u>Crash Mode</u>

One of the most significant variables in the analysis of fire occurrence is crash direction (mode); namely whether a crash is frontal, near side, far side, rear or rollover. Crash direction, however, is not a variable provided in the NASS database but it is a combination of principal direction of force (PDOF), general area of damage (GAD1), Occupant Seating location (SEATPOS), and rollover (ROLLOVER). The following criteria were used to establish crash direction.

Frontal - Frontal crashes were determined to be any crash where the PDOF was 1, 11, or 12 o'clock or was at either 10 or 2 o'clock with the highest deformation location coded as front (F).

Far Side - All side impact crashes were determined with respect to the driver seating position. Far Side crashes were determined to be any crash where the PDOF was 3 or 4 o'clock or was at 2 o'clock with the highest deformation location not coded as front (F).

Near Side - All side impact crashes were determined with respect to the driver seating position. Near Side crashes were determined to be any crash where the PDOF was 12 or 1 o'clock or was at 11 o'clock with the highest deformation location not coded as front (F).

Rear - Rear crashes were determined to be any crash where the PDOF was 5, 6 or 7 o'clock.

Rollover - Rollover crashes were determined to be any crash where a rollover was indicated by the variable ROLLOVER. It is important to note that crashes with any involvement of rollover were included as a rollover crash; hence multiple impacts with any other planar impact occurring first would also be included as a rollover crash. A classification of rollover indicates that a rollover event was involved in the crash at some point.

Other - All Crashes not meeting the criteria of the other aforementioned crash directions was labeled as 'Other. These crashes include under-rides, object penetrations, emersions, and undercarriage impacts.'

<u>Number of Quarter-turns</u>

For rollovers, data from groups of four quarter-turns were aggregated and the results were reported as the number of complete revolutions.

<u>Final Rest Position</u>

A variable for final rest position was developed based on the coded number of quarter-turns. For this variable, the following final positions were established:

Side - A final rest position of side was determined to be when 1, 3, 5 or any odd numbers of quarter-turns occurred.

Roof - A final rest position of roof was determined when the number of quarter-turns were equal to 2, 6, 10 or any even number not divisible by 4.

Wheels - A final rest position of on wheels was determined to be when 4 quarter-turns, or any multiple of this number of quarter-turns occurred.

End-over-end - The determination of end over end is not necessarily a final rest position but was used to indicate those cases where an end-over-end roll was coded as having occurred. In these cases, no number of quarter-turns was provided. The final rest position was determined by reviewing the scene diagram and other information in the case documentation.

Unknown - A rollover case was listed as unknown when the variable for rollover was coded as '99' indicating unknown in the data set.

SUMMARY OF ALL FIRE OCCURRENCES – NASS/CDS

Table 3 shows the summary of the complete NASS data set after initial preprocessing as discussed in an earlier section. In total, over the 8 year period from 1997-2004, 431 fire cases were recorded in NASS/CDS, representing 54,053 actual cases. The cases were approximately evenly distributed between minor and major fire occurrences (47% / 53%).

The research contained in this report was conducted over a period of several years. Consequently, additional NASS years past 2004 will be used as they became available.

Table 3 – Distribution of Fire Cases in NASS/CDS 1997/2004 – Weighted and Unweighted Data

	Fire Severity				
Data Type	Minor	Major	Unk.	All Fires	No Fire
Unweighted	201	227	3	431	51,991
Weighted	25,939	27,998	116	54,053	26,044,625

Body type

Table 4 shows the distribution of all fires cases using the 'Body Type' variable to classify the vehicle involved in each crash. The current classification groupings were developed based upon earlier work [Bahouth 2002]. Variations in methods of grouping vehicles by 'Body Type' may lead to slight variations in data, but should not affect overall results.

Table 4 - Distribution of No Fire and Fire Cases in NASS/CDS by the Fire Severity and Vehicle Body Type for Weighted and Unweighted Data

Unweighted	**Fire Severity**		**Distributions**	
Body Type	Minor	Major	All Fire	No Fire
Car	34%	35%	69%	68%
Pickup	4%	8%	13%	15%
SUV	5%	6%	11%	10%
Van	4%	4%	8%	7%
Totals	47%	53%	100%	100%
Weighted	**Fire Severity**		**Distributions**	
Body Type	Minor	Major	All Fire	No Fire
Car	31%	30%	61%	70%
Pickup	4%	10%	14%	14%
SUV	3%	8%	11%	10%
Van	10%	4%	14%	7%
Totals	48%	52%	100%	100%

The data in Table 4 is based on 52,422 raw cases with 431 fires. These cases expand to 26,103,409 cases and 54,053 fires when weighted. For both weighted and unweighted data, about 52% of the fires are classified as major. The distribution of fires by body type is generally similar to the distribution of crash involved vehicles with no fires. However, the weighted data indicates that vans tend to have fewer major fires than other body types. SUV's and pickups appear to have more major fires, based on the weighted data.

CRASH MODE

Table 5 shows the distribution of all fires cases using the 'Crash Direction' variable to classify the crash mode.

For both weighted and unweighted data, it was found that frontal crashes were the most prevalent type of crash with fire occurrence, producing about half of all fire cases. However, this is not surprising given that frontal crashes are the most frequent crash type recorded. What is more interesting is that crashes involving rollover contributed to 24% (unweighted) and 30% (weighted) of fire cases while this mode is much less prevalent in terms of all crashes.

Table 5 shows that across almost all identified directions, the distribution of minor and major fires was approximately 50/50 with the exception of rear impacts which appear to show a prevalence of resulting in a major fire.

Table 5 - Distribution of No Fire and Fire Cases in NASS/CDS by the Fire Severity and Crash Mode for Weighted and Unweighted Data

Unweighted	**Fire Severity**		**Distributions**	
Crash Mode	Minor	Major	All Fire	No Fire
Frontal	27%	27%	55%	46%
Far Side	3%	3%	5%	6%
Near Side	3%	3%	5%	7%
Rear	2%	5%	6%	5%
Rollover	11%	12%	24%	11%
Other	1%	3%	4%	25%
All	47%	53%	100%	100%
Weighted	**Fire Severity**		**Distributions**	
Crash Mode	Minor	Major	All Fire	No Fire
Frontal	24%	29%	53%	43%
Far Side	1%	1%	2%	5%
Near Side	1%	1%	3%	7%
Rear	2%	4%	5%	5%
Rollover	12%	16%	28%	11%
Other	8%	1%	9%	30%
All	48%	52%	100%	100%

NASS DATA ON FRONTAL CRASHES

Figure 5 provides a comparison of crash damage location for FARS cases with fire as MHE and NASS cases with major fires. The NASS data is weighted so that it represents the distribution that occurs in tow-away crashes on the US highways. It is not possible to determine the fire origin from the FARS data, but it is sometimes available from the NASS data. A study of the NASS cases with major fires provides insights into crashes that present fire injury risks to occupants.

Figure 6 displays a comparison of the distribution of all crashes in NASS/CDS and those with major fires, by crash direction. About 25% of the NASS weighted cases display complexities of the crash mode so that they do not fit into the categories of frontal, side, rear and rollover. These cases were excluded from the data in Figure 6 and the totals add to 100%. In view of the high frequency of fires in frontal crashes, that crash mode was selected for further analysis using NASS. In the analysis to follow, only frontal crashes without rollovers will be considered.

Earlier studies have found that the rate of crash induced fires increases with vehicle age [Fell 2007]. The analysis by Fell indicates that fire rates in FARS crashes increases with vehicles age past nine years, as shown in Figure 4. To reduce the influence of vehicle age, this paper analyzes cases of major fires in frontal crashes in vehicles that were less than 10 years old..

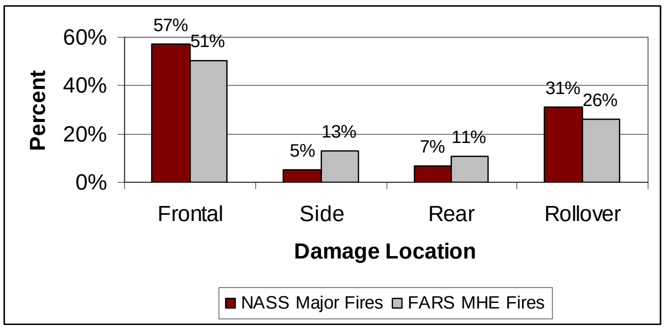

Figure 5. Distribution of Crashes with Fires by Damage Location for Major Fires in NASS/CDS and MHE Fires in FARS 1997- 2005

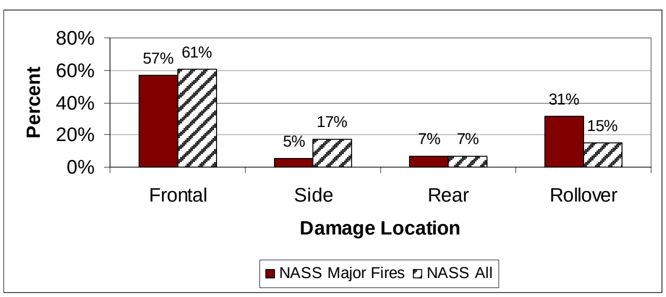

Figure 6. Distribution of Crashes and Crashes with Major Fires by Damage Location in NASS/CDS 1997-2004

Figures 7 through 12 present distributions of frontal crash data on fire origin, fuel leakage location, entrapment, object contacted, extent (depth) of vehicle damage and type (width) of vehicle damage. The data is based on NASS/CDS 1997 to 2005 and it contains 87 cases of major fires in vehicles less than 10 years old. When weighted, these cases expand to 10,337. The standard error for this size NASS population is about 2,300 or 23% [NHTSA 2001].

The data set contains 29 fatalities that expand to 1,386 when weighted. Fatalities are rare events that are difficult to capture in a limited sample such as NASS. A comparison of fatalities in frontal crashes with major fires in NASS and FARS for the time period 1997 to 2005 found that NASS predicted only 85% of the fatalities that were predicted by FARS. A review of FARS procedures suggests that FARS may further under-count fatalities with fires [Fell, 2007]

Figures 7 through 12 show the distributions of vehicles in frontal crashes with major fires and with major fires and fatalities, based on NASS.

Figure 7 shows that the engine compartment is the fire origin for more than 80% of the fires. Figure 8 shows that no fuel leakage could be found in most cases, but the fuel tank was implicated in many of the fatalities. Over half of the fatalities were entrapped, as shown in Figure 9.

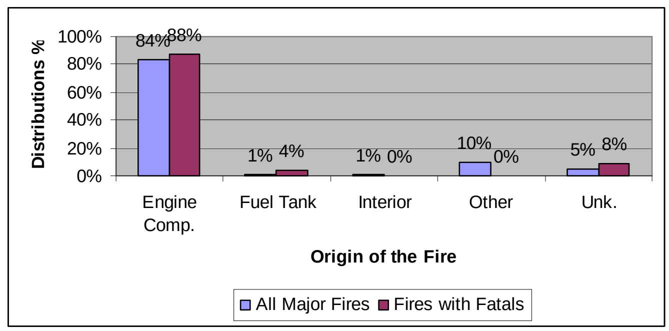

Figure 7. Distribution of Fire Origin for All Major Fires and Major Fires with Fatalities that Occur in Frontal Crashes – Vehicles Less than 10 Years Old

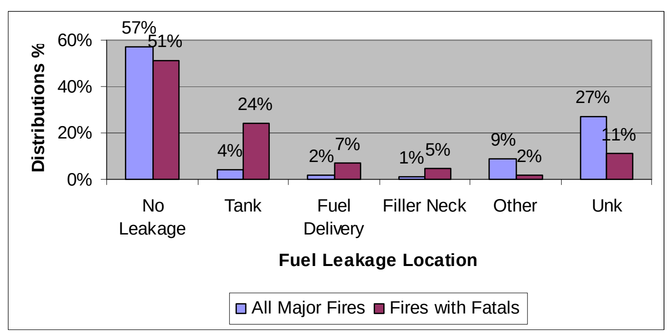

Figure 8. Distribution of Fuel Leakage Location for All Major Fires and Major Fires with Fatalities that Occur in Frontal Crashes– Vehicles Less than 10 Years Old

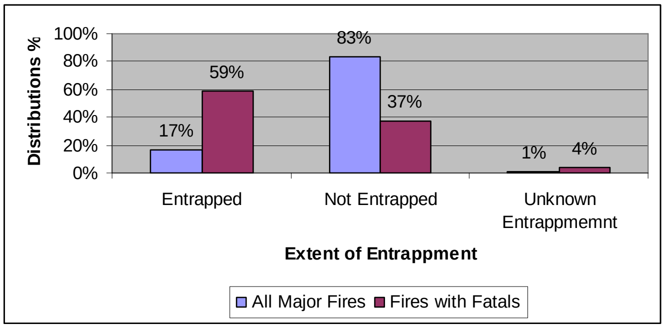

Figure 9. Distribution of Entrapment Types for All Major Fires and Major Fires with Fatalities that Occur in Frontal Crashes– Vehicles Less than10 Years Old

Figure 10 shows the objects contacted that caused the most damage. Large fixed objects were the most frequently objects contacted. In 39% of the crashes, multiple impacts were involved. About 30% of the crashes involved a second impact with a fixed object. For the crashes with fatalities, 66% involved multiple impacts. Ditches and culverts were the source of secondary damage in 25% of the crashes with fatalities.

Figures 11 and 12 use the Collision Damage Classification (CDC) method of accounting [SAE J224] to display the extent and type of damage (See Figure 37). The measurement for extent of damage ranges from 1 to 9. For frontal damage, the distance from the bumper to the windshield is divided into 5 equal zones. Zone 6 encompasses the horizontal depth of the windshield. Zone 7 and above indicate that the damage has penetrated the occupant compartment to a depth beyond the windshield. It should be noted that occupant compartment intrusion generally occurs before the damage extent reaches Zone 5.

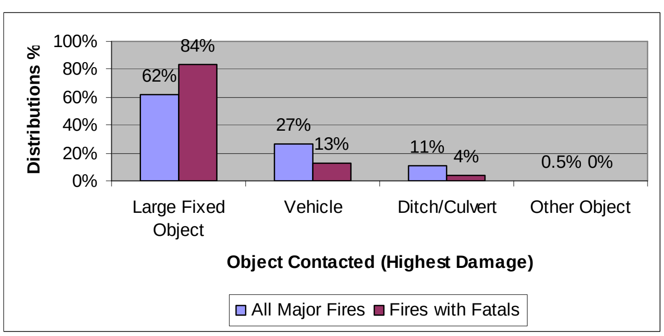

Figure 10. Distribution of 1st Object Contacted for All Major Fires and Major Fires with Fatalities that Occur in Frontal Crashes– Vehicles Less than10 Years Old

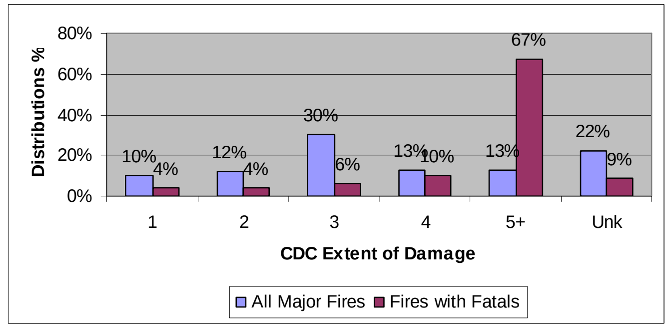

Figure 11. Distribution of Deformation Extent for All Major Fires and Major Fires with Fatalities that Occur in Frontal Crashes– Vehicles Less than 10 Years Old

An analysis of the pre-crash factors provides added insights into the cause of the damage patterns presented in Figures 10 through 12. About 73% of the crashes involved single vehicles. Run-off-the-road crashes comprised about 63% and 37% occurred on curves. Braking and/or steering avoidance maneuvers were documented in 25%. In 36%, accident avoidance maneuvers could not be determined.

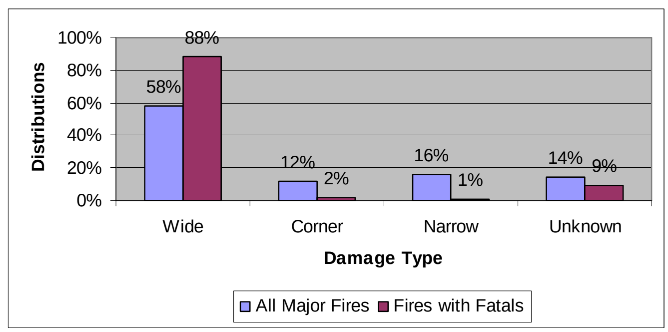

Figure 12. Distribution of Damage Type for All Major Fires and Major Fires with Fatalities that Occur in Frontal Crashes– Vehicles Less than 10 Years Old

Within the 87 NASS cases with major fires and frontal crashes, there were 25 cases of entrapment and 19 of these were also fatalities.

Case Review of Fatalities In NASS Frontal Crashes with Fires

In NASS 1997-2005 there were 29 cases of fires in frontal crashes with fatalities in vehicles less than 10 years old. Twenty impacted large trees, poles or bridge supports with significant frontal damage; 1 involved a severe car-to-car frontal impact; 4 crashes involved under-rides with larger vehicles; 2 involved crashes in which the fire may have originated in the other vehicle; and 2 involved multiple impacts that may have damaged the vehicle underside.

Nineteen occupants were coded as entrapped, one occupant was ejected, one vehicle broke apart, and two vehicles were destroyed so that entrapment could not be determined.

Twenty-four of the crashes had an extent of damage CDC of 5 or greater. However, 33% of these crashes did not involve fatalities. There were 13 crashes with CDC of 4, and 9 of them had no fatalities.

NASS Frontal Crashes in Which Fire May Have Contributed to the Fatality

Of the 87 NASS cases with major fires in frontal crashes, there were 29 with fatalities. In most of these cases, the crash related injuries were coded as the most severe injury by the NASS investigator. There were eight cases in which burns were coded as severe or fatal injuries. Consequently, the fire may have contributed to the fatal injury. Table A1 in the Appendix contains a summary of these cases.

Since weighing factors were not applied to this data, the individual cases are not representative of national statistics on fires. The raw NASS has a strong bias toward high severity crashes. Harmful events that occur in lower severity crashes are difficult to obtain from NASS. However, the raw cases can provide insights into the causes of casualties and of possible countermeasures. The following discussions deal with patterns in the raw data. These patterns have the restrictions discussed above.

Figure 13. Damaged Vehicle with Fire Related Fatalities – Case 1997-11-146

Figure 14: Damaged Vehicle with Fire Related Fatalities – Case 2004-43-343

There were four vehicles that departed the roadway to the right and impacted large trees. These vehicles, shown in Figures 13 through 16, sustained extent of damage ranging from 4 to 7. All the fires originated in the engine compartment and entrapment occurred in all cases. Tank leakage was documented in a vehicle that impacted a ditch/culvert prior to the tree impact. Another case documented fuel leakage from the line/pump/filter.

Figure 15: Damaged Vehicle with Fire Related Fatalities – Case 2005-12-160

Figure 16: Damaged Vehicle with Fire Related Fatalities – Case 1997-48-129

Figure 17: Damaged Vehicle with Fire Related Fatalities – Case 1998-6-139

The vehicle in Figure 17 reported a fuel tank fire origin and occupant entrapment (1998 6 139). This departed the road to the right and mounted a concrete barrier. The reported fuel tank puncture may have occurred during an undercarriage contact with a fixed object on the top of the barrier.

Three cases involved crashes with other vehicles. In two of the cases (2005 81 63 and 2002 49 61), the fire may have originated in the other vehicle.

Figure 18: Damage to Rear of Struck Vehicle – Case 2002-49-61

Figure 19: Damaged Vehicle with Fire Related Fatalities – Case 2002-49-61

The fire in vehicle 2002 49 61 was initiated after a moderate impact with the rear of a van shown in Figure 18. The rear impact caused a fire origin at the van's fuel tank and the van experienced a major fire, but with no injuries to its occupant. The vehicles separated after impact and the case vehicle contacted a barrier before coming to rest. Fire was coded as the cause of two fatalities in the vehicle. This vehicle had a fiberglass body that was consumed by the fire, as shown in Figure 19.

The fire in vehicle 2005 81 63 was initiated after a frontal impact with the side of a pickup. The side damage extended past the centerline of the pickup as shown in Figure 20. A major fire resulted. Both vehicles remained together after the impact and both experienced major fires. The injuries in the vehicle impacted in the side were attributed to the crash forces. The driver of the vehicle involved in the frontal impact was entrapped and his fatal (AIS 6) injury was attributed to the fire. The frontal damaged vehicle is shown in Figure 21.

Figure 20: Damage to Struck Vehicle – Case 2002-81-63

Figure 21: Damaged Vehicle with Fire Related Fatalities – Case 2002-81-63

The third case involving a vehicle-to-vehicle crash was 2003 78 31. In this front-to-side crash with a tractor-trailer, only moderate frontal damage occurred. The forward velocity of the impacted vehicle caused a lateral shift in the case vehicle structure and induced a side-slap. The partially ejected driver suffered moderate (AIS 2) level crash induced injuries but critical (AIS 5) level burns. The damaged vehicle is shown in Figure 22.

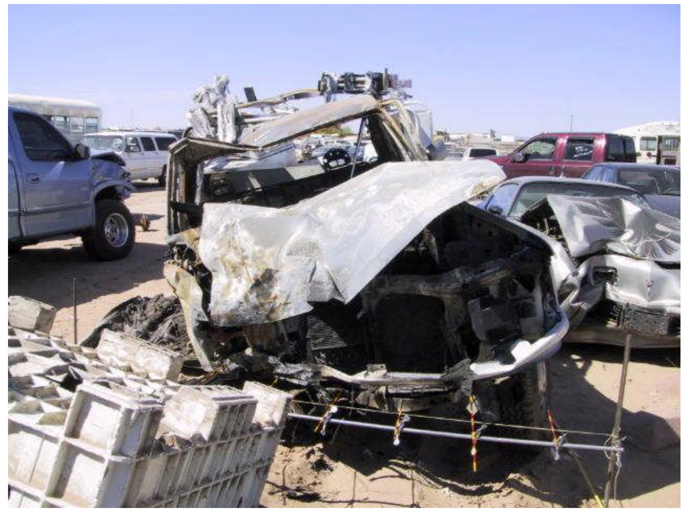

Figure 22: Damaged Vehicle with Fire Related Fatalities – Case 2003-78-31

Discussion – Frontal Crash Fires

Figure 1 indicates that the fire rate in FARS where fire was coded as the most harmful event decreased by about 50% between the 1979-1985 time period and the 1994-2000 period. It has remained relatively constant since 2000.

Figures 2 and 3 compare the annual fatalities with the fire MHE fatalities by direction of damage. In recent years, the overall number of fatalities in frontal crashes has been decreasing, but the numbers of fire MHE fatalities has been increasing. These trends suggest the need for research to better understand how to reduce fires in frontal crashes.

Figure 4 shows that the rate of fire in FARS increases after the vehicle age exceeds 12 years. This data formed the basis for examining NASS cases with vehicles less than 10 years old.

Tables 1 and 2 provide data to assist in the examination of the frequency of entrapment by crash direction. The entrapment rate is about 23% for both rollover and non-rollover fatalities where fire is the MHE. Rear crashes and left side crashes have the highest rate of entrapment at 28% and 27%, respectively.

Figure 5 compares FARS fatalities where fire was MHE with NASS cases that sustain major fires. Although the NASS under-predicts the number of fires with fatalities, the distributions by crash direction are generally similar. Frontal crashes account for over half of both populations.

Figure 6 compares the overall distribution of NASS exposed occupants with the occupants exposed to major fires by crash direction. The comparison shows that frontal fires occur in about the same proportion as frontal crashes.

Figures 7 through 12 present distributions of weighted NASS data for frontal crashes with major fires in vehicles less than 10 years old.

Figures 7 and 8 show distributions of crashes with major fires and with major fires that also have fatalities. More than 80% of the major fires and major fires with fatalities originate in the engine compartment. No fuel leakage could be observed in more than half of these fires. For many of the vehicles (27%) fuel leakage could not be determined. The fuel tank is rarely the origin of the fire in frontal crashes. However, as shown in Figure 8, fuel tank leakage is present in a much larger fraction of the fires with fatalities.

Figure 9 shows the distribution of entrapment for vehicles in frontal crashes with major fires. Entrapment did not occur in 83% of the cases. However for the fatalities, 59% were documented as being entrapped.

Figure 10 shows the objects contacted prior to the fire. The most frequent contact was a large tree, bridge abutment or other large fixed object. This category accounted for 62% of the crashes with fires and 84% of the fires with fatalities. In about 39% of the cases, two or more objects were contacted during the crash. Again, a tree or large fixed object was the most frequent second contact. However, for cases with fatalities, a ditch or culvert was the most frequent other contact. These latter type contacts may have produced damage to the underside of the vehicle.

Figures 11 and 12 display the depth and the width of damage incurred during the frontal crash. About 52% of the crashes have an extent of damage of 3 or less. However, for the fatalities, 67% have an extent of damage of 5 or more. Extensive occupant compartment intrusion would be expected at this extent of damage. The damage width is classified as wide in 56% of the fire crashes and 88% of the fires with fatalities.

The vehicle damage analysis indicates that most of the fatalities with fires occur in crashes with fixed objects and involve severe damage to the front of the vehicle. The engine compartment was by far the most common fire origin. Earlier fire tests of crashed vehicles found that, in the absence of fuel tank leakage, the time for an engine compartment fire to penetrate the occupant compartment was in the order of 10 to 24 minutes. However, in the case of pool fires from spilled gasoline, the fire penetration time was generally less than 3 minutes [Digges, 2006]. It may be noted from the NASS data that while 88% of the fatalities were in vehicles with engine compartment fire origin, about 25% also had leakage from the fuel tank. These results indicate that prevention of fuel leakage continues to be an important safety feature in frontal crashes. The results of the fire tests of crashed vehicles suggests that for many fires that originate in the engine compartment there is time to exit the vehicle, providing entrapment or disabling injuries do not occur.

Table 2 shows that entrapment occurred in about 23% of the FARS fatalities where fire is the most harmful event. For NASS major fires in frontal crashes, entrapment occurred in 17% of the weighted cases. However, when a fatality occurred, entrapment was present in 59% of the weighted NASS cases.

Technologies such as automatic crash notification that can reduce rescue time could be beneficial in cases with entrapment or disabling injuries. Also, technologies to permit rapid egress of from crashed vehicles and to increase the time that the occupant compartment remains tenable would be beneficial.

Eight cases from NASS/CDS provide insight into some crash factors associated with fires that may have contributed to a fatal injury.

Lane departure to the right occurred in 5 of 8 cases and was the pre-crash pattern that predominated. In 4 of these 5 cases with lane departure, the impact was with a large tree, resulting in a damage that extended beyond 60% of the hood length. Entrapment occurred in all five of these cases.

However, there were also cases that involved lower severity frontal damage. These lower severity cases involved a variety of crash factors and no clear patterns were evident. In two of the four lower severity cases the fire may have originated in the vehicle struck in the side or rear, not the striking vehicle. Entrapment was recorded in two of the vehicles with a level 3 CDC extent of damage. This level of damage is no greater than that typically caused by a 35 mph barrier crash.

Running off the road and impacting a fixed object was the most common pre-crash pattern observed in both fatal and non-fatal cases. Technology to prevent this type of crash could be beneficial to the prevention of fires.

It should noted that electrical arcing and/or leakage of engine fluids can not be easily determined from the evidence that remains after a vehicle has been totally consumed by fire. However, damage that caused leakage of power steering fluid was reported to cause engine compartment fires in two identical frontal crash tests [Santrock, 2005]. In these crash tests, the exhaust manifold was at operating temperature and the engine was running. In another series of crash tests, an engine compartment fire was caused by electrical fault [Jensen, 1998]. The fire was unrelated to spilled gasoline or other engine compartment fluids, except battery acid. The fuel for the fire was provided by the plastic materials near the battery. These test results suggest that factors that can not be identified by the NASS investigators may be associated with the large number of fires in which no fuel leakage was observed. Technology to prevent electrical faults and leakage of underhood fluids should be beneficial in reducing the incidence of engine compartment fires.

NASS DATA ON SIDE CRASHES

A query of NASS/CDS 1997 to 2006 for major fires in side crashes (CDC damage R or L) produced 27 left side and 33 right side cases. Of these 60 cases 37 involved vehicles less than 10 years old.

Twenty-two of these cases involved fatalities. Eleven of the vehicles had fatalities coded as AIS 6 attributed to burns and without crash injuries more severe than AIS 4. Seven of the vehicles had fatalities that were attributed only to crash forces. Four cases with fatalities involved severe crash injuries with burns that may have contributed to the fatality.

Upon examining the 11 vehicles with fatalities attributed to burns, it was found that three cases involved crashes with fuel trucks or trailers. In these cases, the fire did not originate from the crashed vehicle. These three cases were eliminated from the analysis. The final population analyzed consisted of 34 cases, 19 of which contained fatalities.

Since this NASS data reported here is not weighted, the individual case data is not representative of national statistics on fires. The following figures present distributions of raw (unweighted) NASS data. The patterns observed have the restrictions discussed previously in the report.

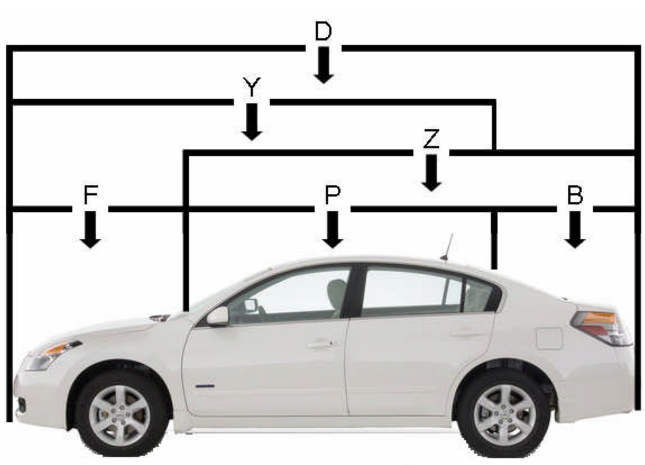

Figure 23. CDC Damage Horizontal Location

In describing the damage to the vehicles, two elements of the Collision Deformation Classification (CDC) were used [SAE J224]. The first element was the location of horizontal damage. The CDC coding for side damage horizontal location is shown in Figure 23. The second element was the extent of damage. This element describes the maximum penetration of the damage into the side of the vehicle and its coding is shown in Figure 24.

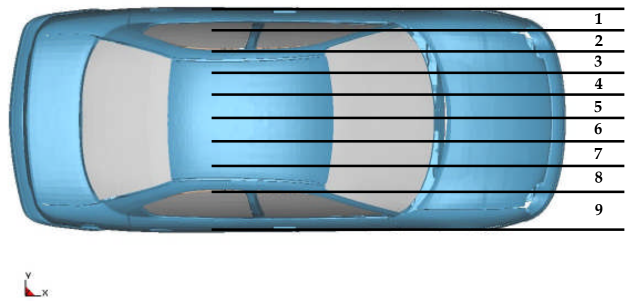

Figure 24. CDC Extent of Damage

Figures 25 through 29 present distributions of side crash data on fire origin, fuel leakage location, object contacted, horizontal distribution of vehicle damage and extent of damage. The data is based on NASS/CDS 1997 to 2006 and it contains 34 cases of major fires in vehicles less than 10 years old. The graphs compare all 34 cases with major fires and 8 cases with fires and fatalities that were coded as having been caused by the fire. Cases where the cause of death was coded as uncertain or caused by crash forces were not included in the fatality group. In view of the small sample size, the data presented in the figures is unweighted.

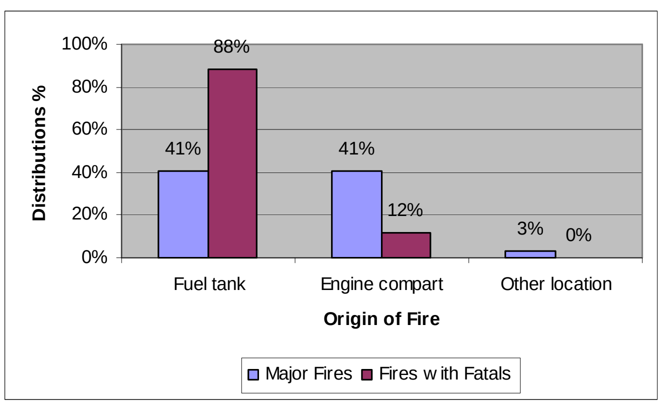

Figure 25. Distribution of Fire Origin for All Major Fires and Major Fires with Fatalities that Occur in Side Crashes – Vehicles Less than 10 Years Old

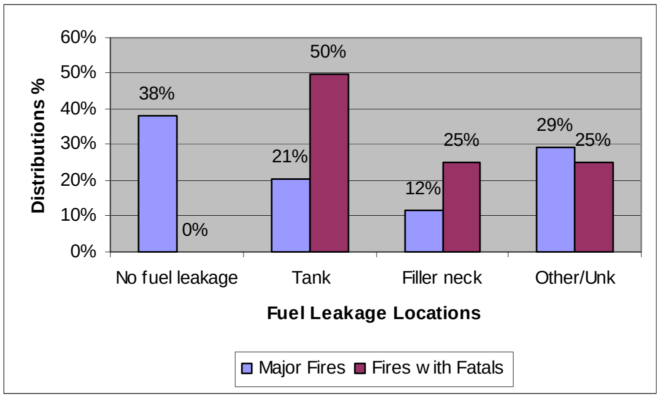

Figure 26. Distribution of Fuel Leakage Location for All Major Fires and Major Fires with Fatalities that Occur in Side Crashes– Vehicles Less than 10 Years Old

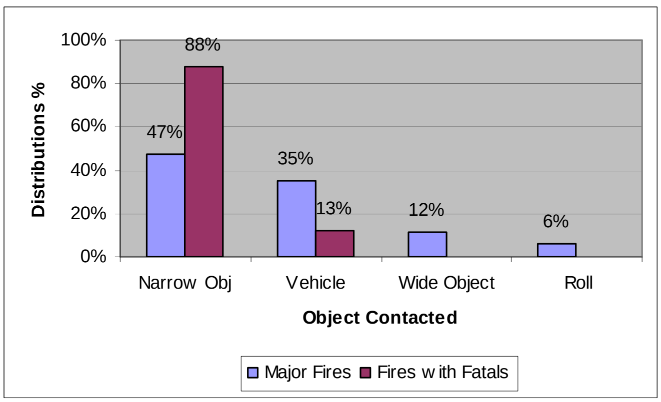

Figure 27. Distribution of 1st Object Contacted for All Major Fires and Major Fires with Fatalities that Occur in Side Crashes– Vehicles Less than10 Years Old

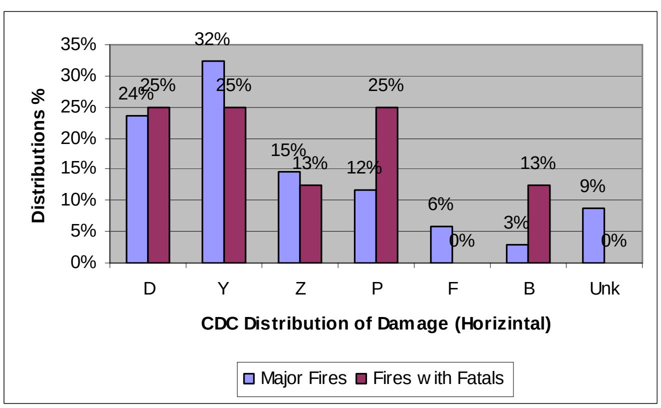

Figure 28. Distribution of Damage Horizontal Location for All Major Fires and Major Fires with Fatalities that Occur in Side Crashes– Vehicles Less than 10 Years Old

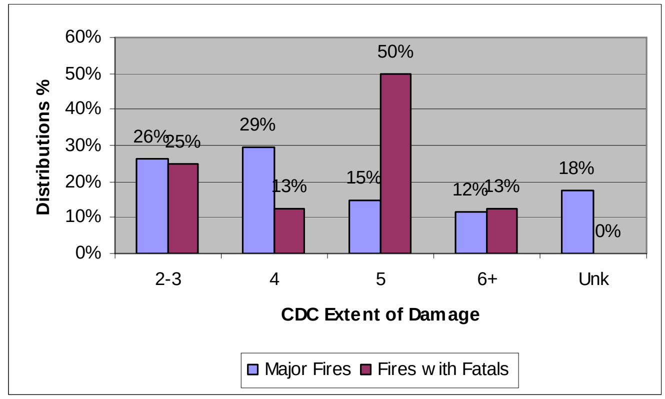

Figure 29. Distribution of CDC Extent of Damage for All Major Fires and Major Fires with Fatalities that Occur in Side Crashes– Vehicles Less than 10 Years Old

Among the 8 vehicles with fire related fatalities, 7 of the fuel tanks were located in front of the rear axle and one behind the rear axle. In the latter case, a side impact damaged the area behind the rear axle to the extent of damage CDC 5.

SIDE CRASH ENTRAPMENT

Entrapment was coded in twelve of the 34 vehicles with major fires after side impacts. In Figures 30 and 31, the damage for the vehicles with entrapment is compared with the damage in the 34 vehicle population.

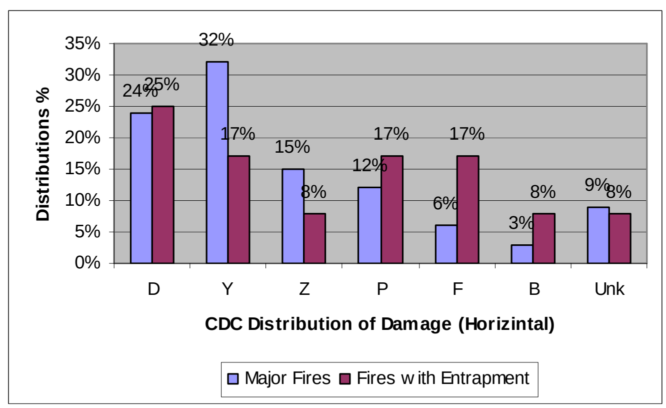

Figure 30. Distribution of Damage Horizontal Location for All Major Fires and Major Fires with Entrapment that Occur in Side Crashes– Vehicles Less than 10 Years Old

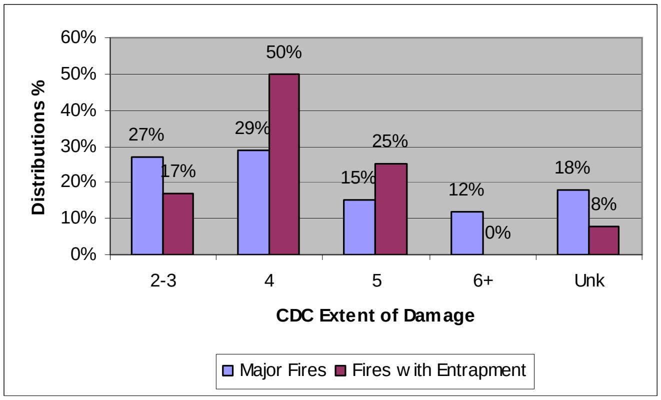

Figure 31. Distribution of Extent of Damage for All Major Fires and Major Fires with Entrapment that Occur in Side Crashes– Vehicles Less than 10 Years Old

NASS Side Cases in Which Fire May Have Contributed to the Fatality

Of the 34 NASS cases with major fires in side crashes, there were 19 cases with fatalities. There were eight cases in which burns were coded as the most severe injury. Consequently, the fire may have contributed to the fatal injury. Table A2 in the Appendix contains a summary of these cases. In the table, CDC extent of damage 4 or greater was categorized as severe.

The initial four cases in Table A2 involve side impacts with narrow objects resulting in wide damage with an extent of 4 or 5. These crashes all involved lane departure. Two crashes were caused by loss of control and excessive speed. One was caused by hydroplaning. One involved an unexplained lane departure off the right side of the road and then back across four traffic lanes.

Case 1998 49 95 involved a right side impact with a utility pole. The utility pole was located on the left side of the road and the impact was preceded by a complex lane departure. The police reported no alcohol presence. The vehicle damage pattern is shown graphically in Figure 32.

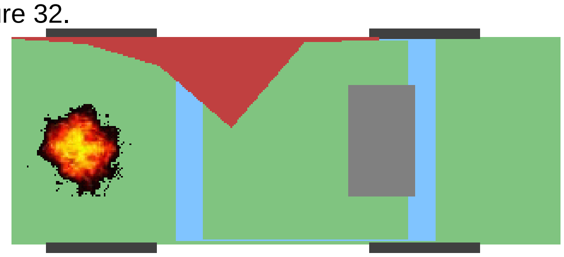

Figure 32. Damage Pattern – Case 1998 49 95

In this case, the damage included the engine compartment region behind the front wheels. The engine compartment was coded as the fire source. The 52 year old driver sustained AIS 3 chest, pelvic and inhalation injuries. He also sustained AIS 6 burn injuries. Entrapment was coded as unknown.

Case 1997 9 20 involved a right side impact with a tree that was approximately 2 feet in diameter. The 26 year old driver lost control after hydroplaning. He suffered AIS 4 chest injuries and AIS 6 burn injuries. Police reported no alcohol presence and no entrapment. The fire source was coded as the fuel tank. The extensive side damage is shown graphically in Figure 33.

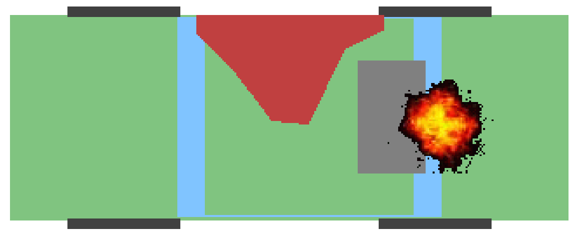

Figure 33. Damage Pattern – Case 1997 9 20

Figure 34. Damaged Vehicle – Case 2003 8 227

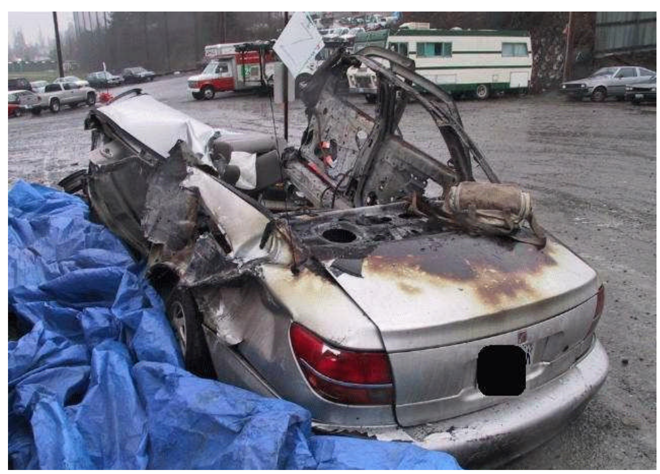

Figure 35. Damaged Vehicle – Case 2003 82-501

Cases 2004 45 219 (Figure 34) and 2003 82 501 (Figure 35) involved multiple single vehicle impacts that included severe side impacts with narrow objects. Catastrophic vehicle damage resulted. Both vehicles had two occupants. The maximum crash injury recorded was AIS 3. One driver escaped with AIS 1 injuries. The other three occupants sustained AIS 6 burn injuries. The fuel tank was coded as the fire origin. Loss of vehicle control occurred prior to both crashes.

Case 2003 8 227 involved a severe left side impact with the front of another vehicle followed by a 5 quarter-turn rollover. The side impact was at the occupant compartment and severe (CDC 7) damage resulted. The driver suffered crash injuries in addition to the AIS 6 burn injury. The crash injuries included AIS 5 chest and AIS 4 head injuries. The fuel tank was coded as the fire origin.

Case 2006 41 65 involved a left side impact from a vehicle front. The impact induced spin, resulting in two narrow object side impacts with the right front and right rear. The latter appears to have caused damage to the fuel tank. Four of five occupants were coded as entrapped and fatally injured. The fifth was ejected and sustained AIS 2 injuries. The four entrapped occupants suffered AIS 4 crash injuries and AIS 6 burn injuries.

The 200 49 134 involved a frontal angular crash with a concrete traffic barrier that caused only moderate damage. However, the impact induced a vehicle rotation and rollover that exposed the left side to a collision with a light post that may have exposed the fuel tank to damage. The driver and right front passenger suffered crash injuries at the AID 5 and AIS 4 levels, respectively. Degree of entrapment was unknown. Figure 36 shows the damage to the vehicle.

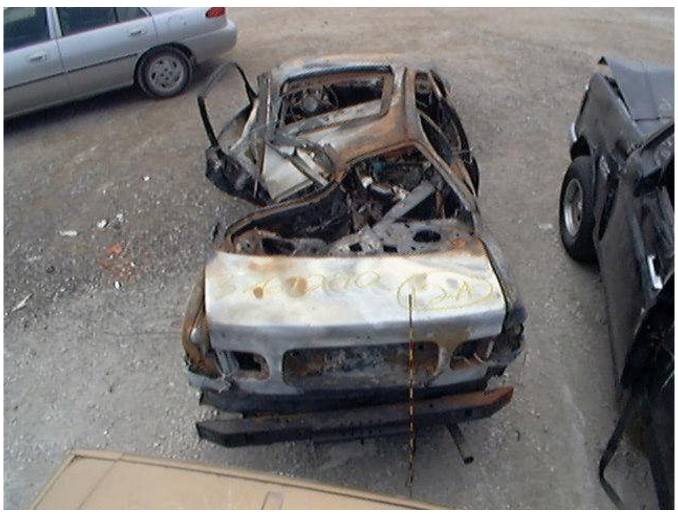

Figure 36. Damaged Vehicle– Case 2000 49 134

Case 2006 82 68 was a multiple impact event initiated by a corner impact with an impact attenuator and concrete guardrail barrier. The impact initiated a two quarter-turn rollover and a side impact with a jersey barrier. The fuel tank was the fire origin. The crash investigators reported that the damage to the fuel system occurred during the rollover rather than during the side impact. The driver and right front passenger sustained crash injuries at the AIS 3 severity. They both suffered AIS 6 burn injuries. Entrapment was coded as doors jammed.

Discussion – Side Crash Fires

In frontal crashes the engine compartment was coded as the origin of 82% of the major fires in weighted NASS [Digges 2008]. In the 34 side impact cases analyzed in this study, the engine compartment and the fuel tank contributed about equally as the fire origin. However, in the case of fire related fatalities 88% of the major fires in side impact were coded as having a fuel tank origin.

Figures 25 and 26 show that while the fuel tank was the fire origin in 8 of 9 cases with fire related fatalities, the filler neck was identified as the leakage source in two of the cases.

Figure 27 shows that a fixed narrow object was the most frequent object contacted. Five of eight cases with fire related fatalities impacted a narrow object.

Figures 28 and 29 show the horizontal damage location and extent of damage, respectively. The two vehicles with the low extent of damage were involved in rollovers that exposed the fuel tank to damage. All six of the vehicles not involved in rollovers suffered extent of damage in of CDC 4 or greater. In five of these cases the damage was at the location of the fuel tank.

Entrapment occurred in 12 of the 34 cases in the study. Among the cases with fire related fatalities, entrapment could be documented in 6 of the 8 cases. The other two were documented as entrapment unknown. It is instructive to examine the entire group of cases where entrapment occurred to determine the damage characteristics of these crashes. Figures 28 and 29 indicate a wide distribution of the horizontal damage areas, but with a high extent of damage – CDC level 4 and greater.

It is evident from the data in Table A2 that the fuel tank was the most frequent fire origin for the NASS cases of side impacts with fire related fatalities. The one case with an engine compartment fire origin was involved in a pole impact that damaged the front half of the right side of the vehicle. The other vehicles in the table had severe damage in the region of the fuel tank or they experienced rollovers that may have contributed to tank damage.

Rollovers were present in three of the eight cases and multiple impacts were present in five of eight cases.

NASS DATA ON REAR CRASHES

A query of NASS/CDS 1997 to 2006 for major fires in rear crashes produced 36 cases, 20 of which were in passenger vehicles less than 10 years old. Eight of these cases involved fire related fatalities.

Since this NASS cases for rear crashes are not weighted, they are not representative of national statistics on fires. The raw NASS has a strong bias toward high severity crashes. Harmful events that occur in lower severity crashes are difficult to obtain from NASS. However, the raw cases can provide insights into the characteristics of the crashes that have major fires. The following figures present distributions of raw (unweighted) NASS data. The patterns observed have the restrictions discussed above.

In describing the damage to the vehicles, two elements of the Collision Deformation Classification (CDC) were used [SAE J224]. The first element was the location of horizontal damage. The CDC coding for rear damage horizontal location is shown in Figure 23, presented earlier. The cases in this study have CDC damage coded "B".

Another CDC element was the extent of damage. This element describes the maximum penetration of the damage into the side of the vehicle and its coding is shown in Figure 37. Note from Figure 37 that the rear damage elements are generally smaller than the frontal elements. Consequently, for passenger cars, lower crash severity is needed to produce the same extent of damage.

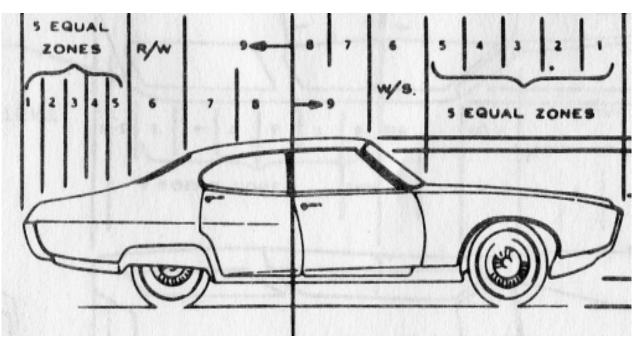

Figure 37. CDC Extent of Damage

Figures 38 through 40 present distributions of rear crash data on fire origin, fuel leakage location, and extent of damage. The graphs compare all 20 cases with major fires and 8 cases with fires and fatalities that were coded as having AIS 6 fire related injuries. Cases where the cause of death was coded as caused by crash forces were not included in the fatality group. In view of the small sample size, the data presented in the figures is unweighted.

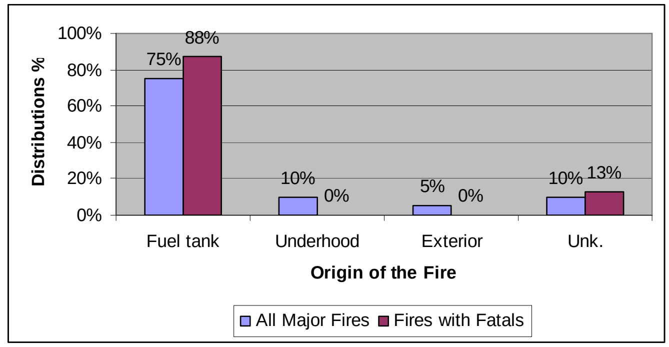

Figure 38. Distribution of Fire Origin for All Major Fires and Major Fires with Fatalities that Occur in Rear Crashes – Vehicles Less than 10 Years Old

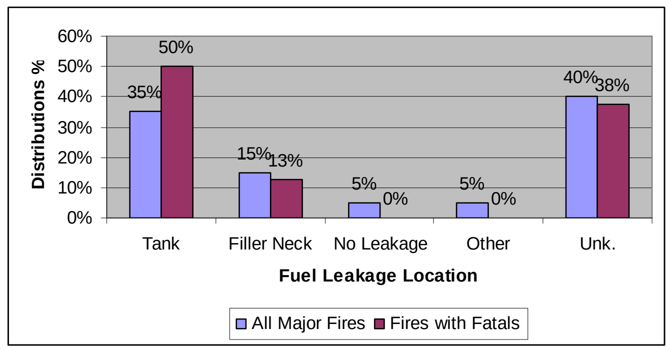

Figure 39. Distribution of Fuel Leakage Location for All Major Fires and Major Fires with Fatalities that Occur in Rear Crashes– Vehicles Less than 10 Years Old

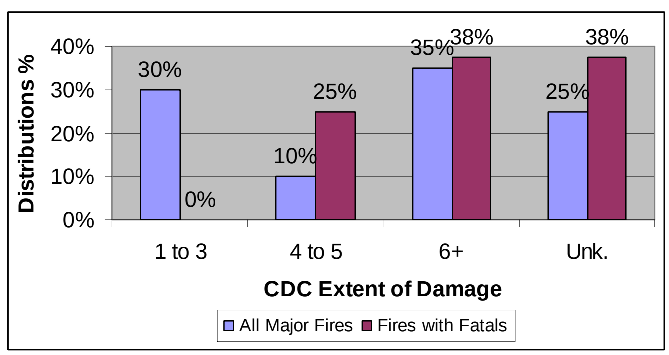

Figure 40. Distribution of CDC Extent of Damage for All Major Fires and Major Fires with Fatalities that Occur in Rear Crashes– Vehicles Less than 10 Years Old

Among the 8 vehicles with fire related fatalities, 5 of the fuel tanks were located in front of the rear axle and 3 behind the rear axle. Vehicles that were either stopped in lane, decelerating, or traveling at well below the speed limit were involved in all the crashes with fatalities.

REAR CRASH ENTRAPMENT

Entrapment was coded in eight of the 20 vehicles with major fires after rear impacts. Among the 8 cases of fatalities with fires, entrapment was coded in 6 and unknown was 1.

NASS Rear Cases in Which Fire May Have Contributed to the Fatality

Of the 20 NASS cases with major fires in rear crashes, there were eight cases in which burns were coded as the most severe injury. Consequently, the fire may have contributed to the fatal injury. Table A3 in the Appendix contains a summary of these cases. All fatal cases sustained a CDC extent of damage of 5 or greater

Upon examining the eight vehicles with fatalities attributed to burns, it was found that three cases involved rear impacts by large trucks and three were impacted by pickups or SUV's. The two remaining cases involved passenger cars impacting pickups or SUV's. Under-ride may have been involved in these cases.

All these crashes were characterized by a severe rear impact from an aggressive vehicle or an impact that may have induced under-ride. In six of the eight cases, the impacted vehicle was stopped in the traffic lane. The reasons for stopping included making a left turn, a traffic bottleneck and disabled vehicles due to a crash or for unknown reasons. These conditions made the struck vehicle vulnerable to impact from following vehicles that did not adjust speed in time to prevent the collision. Tractor trailers or heavy trucks were bullet vehicles in three of the eight cases. A consequence of this type of crash was the involvement of multiple vehicles in the line of traffic. Subsequent front-to-rear impacts and rollovers were common. These subsequent impacts sometimes contributed to the severity of the collision and to the occupant entrapment.

Cases 1998-45-128 and 2001-45-197 are shown in Figures 41 and 42. Both involved severe rear impacts of passenger cars by tractor trailers. Both crashes occurred on interstate highways where traffic was slowed or stopped due to construction. Multiple vehicles and multiple impacts were involved in both of the Figure 41 and 42 cases. The burn injuries were coded as AIS 6. However, other severe crash related injuries may have occurred but were undocumented. Occupants were entrapped in both cases.

Figure 41. Scene Picture - Case 1998-45-128

Figure 42. Scene Picture - Case 2001-45-197

Case 2005-74-48 involved a rear impact of a utility vehicle by a dump truck. The struck vehicle was on a two lane road and was slowing to make a left turn. Subsequent to the rear impact, the vehicle rolled on its roof. The only injuries coded for the driver were AIS 6 burns and AIS 3 inhalation. The damaged vehicle is shown in Figure 43. The fire origin was the fuel tank located behind the rear axle. Entrapment was coded as doors jammed.

Figure 43. Damaged Vehicle - Case 2005-74-48

Case 2006-2-12 was a rear impact of a utility vehicle by a large pickup truck. The struck vehicle was stopped on a two lane road while waiting to make a left turn. The driver sustained AIS 3 chest injuries and AIS 6 burn injuries. The damaged vehicle is shown in Figure 44. The fire origin was the fuel tank located behind the rear axle. Entrapment was coded as doors jammed.

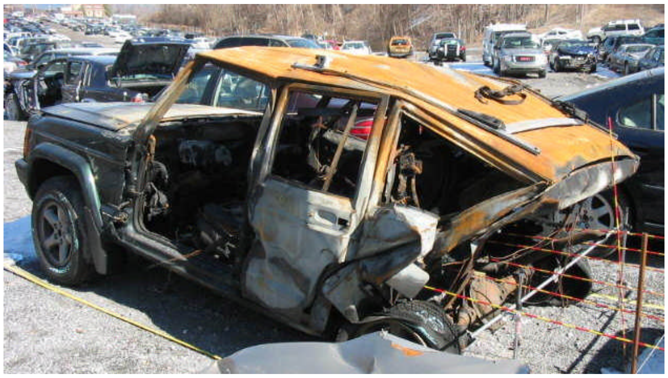

Figure 44. Damaged Vehicle - Case 2006-2-12

Case 2002 49 174 was a police car that was impacted in the rear by a utility vehicle. The struck vehicle was on a 4-lane divided highway traveling at a very low speed while serving as an escort for a highway paint crew. The driver was entrapped and fatally injured due to the fire. The damaged vehicle is shown in Figure 45. The fire origin was the fuel tank located behind the rear axle. Entrapment was coded as doors jammed.

Figure 45. Damaged Vehicle - Case 2002-49-174

Case 2005-79-105 was a rear impact of a pickup by a passenger car. The pickup was stopped behind a vehicle that had stopped in the fourth lane of a five lane highway. The front-to-rear crash resulted in under-ride and a subsequent frontal crash and a rollover. Final rest for the pickup was on its roof. The pickup driver sustained minor injuries but the passenger was fatally injured due to burns. The damaged vehicle is shown in Figure 46. The fire origin was the fuel tank located on the left side, forward of the rear axle. Entrapment was coded as unknown.

Figure 46. Damaged Vehicle - Case 2005-79-105

Case 2006-45-180 was a rear impact of a pickup truck by a utility vehicle. The pickup was stopped in the right lane of a three lane highway. The damaged pickup is shown in Figure 47. The driver was fatally injured due to burns. The fire origin was the fuel tank located on the left side, forward of the rear axle. Entrapment was coded as doors jammed.

Figure 47. Damaged Vehicle - Case 2006-45-180

Case 2006-3-49 was a multi-vehicle crash in which the source of the fire was unknown. The scene was a three lane divided highway. Two utility vehicles were stopped one behind the other in the center lane. A third vehicle impacted the rear of the exposed utility vehicle, driving it into the vehicle in front. A fourth vehicle impacted the rear of the third vehicle and the second, third and fourth vehicle all caught fire. The driver of the third vehicle sustained an AIS 6 burn injury and an AIS 4 head injury. The occupants of the other vehicles had 0 or MAIS 1 injuries. The origin of the fire could not be determined. The fuel tank for the utility vehicle was located behind the rear axle. The fuel tank for the vehicle with the fatality was located forward of the rear axle. This case illustrates a difficulty in determining the source of fires after a crash. The crash involved multiple vehicles, multiple impacts of the individual vehicles, and fire that destroyed three vehicles.

NASS Rear Fire Cases with Fuel Tanks Behind the Rear Axle

Seven of the 20 rear damage cases with fuel tank fire origin were in vehicles with tanks located behind the rear axle. Three of these cases were fatalities – 2002 49 174; 2006 2 12; and 2005 74 48. All three of these crashes involved rear impacts with the impacted vehicle stopped or moving slowly in the lane of traffic. Other impacts, if they occurred were minor and did not influence the outcome.

One case, 1998 45 147, involved a vehicle spinning before a rear impact with an embankment and a subsequent rollover occurred. Figure 48 shows the damaged vehicle. The rear impact was with a rock embankment that most likely damaged the fuel tank. The extent of rear damage was CDC 2. Both occupants were ejected and were not exposed to the vehicle fire.

Figure 48. Damaged Vehicle - Case 1998 45 147

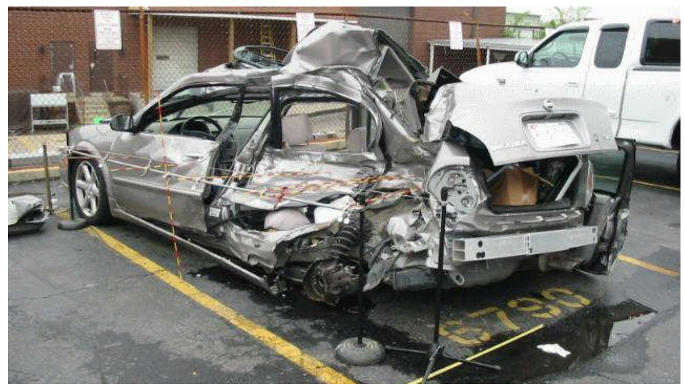

Figure 49. Damaged Vehivle - Case 2003 9 90

The case vehicles shown in Figures 49 and 50 (2003 9 90 and 2003 41 54) sustained a low CDC damage extent (CDC 2) and no entrapment occurred. No significant injuries were documented. The fire origin was the fuel tank.

Figure 50. Damaged Vehicle - Case 2003 41 54

The vehicle in case 2001 41 31 sustained a more severe rear impact that produced an extent of damage CDC 6. The damage is shown in Figure 51. Fuel leakage from the filler tube was documented and the fire origin was the fuel tank. In spite of the high level of damage the occupant injuries were minor and no entrapment occurred.

Figure 51. Damaged Vehicle - Case 2001 41 31

Discussion – Rear Crash Fires

In the 20 rear impact cases analyzed in this study, the fuel tank was the fire origin in 75% of the cases. Among the 8 cases with fire related fatalities, 7 (88%) had fuel tank origin. Unknown fire origin was coded in 10% of the 20 rear fire cases and 1 of the fatal cases. See Figure 38.

As shown in Figure 39, the fuel tank was the most frequent source of fuel leakage.

Figure 40 shows that subset of crashes with fires and fatalities involved severe rear damage for the cases where damage measurement was possible.

Entrapment occurred in 8 of the 20 cases in the study. Among the cases with fire related fatalities, entrapment could be documented in 6 of the 8 cases. One was documented as entrapment unknown.

An examination of the seven cases with fuel tanks behind the rear axle showed that for the lower severity events, entrapment did not occur there were no fire injuries. All the fire injuries occurred in the vehicles with jammed doors.

It is evident from the data in Table A3 that the fuel tank was the most frequent fire origin for the NASS cases of rear impacts with fire related fatalities. It is also evident most cases involved multiple vehicles and multiple impacts of the struck vehicle.

NASS DATA ON ROLLOVER CRASHES

The analysis presented here is of rollover cases of fire occurrence. Table 6 shows a summary of all rollover fire cases that were recorded by NASS/ CDS as having occurred on US roads between 1997 and 2004.

Since there were only 53 cases of major fires in rollovers, only unweighted data was considered in the analysis of rollover fires. The application of NASS weighting factors produced unrealistic distortions when such a small data set was disaggregated. Unweighted data can not be used to extrapolate the cases to national distributions. However, it is useful for examining the presence or absence of crash factors. It can serve as the basis for developing hypotheses to apply when more robust data sets become available.

Table 6 – Distribution of Rollover Fire and No Fire Cases in NASS/CDS 1997/2004 – Weighted and Unweighted

	Fire Severity - Rollover Crashes				
Data Type	Minor	Major	Unk.	All Fires	No Fire
Unweighted	49	53	1	103	5,766
Weighted	6,523	9,432	1	15,956	2,184,898

BODY TYPES INVOLVED IN ROLLOVER FIRES

Table 7 shows the distribution of 102 rollover fire cases by the vehicle body type. These are the cases listed in Table 6 with known fire severity. The distribution of rollover cases without fires is also included in the table. Similar to all fire cases, it was found that the most frequent body type in rollover crashes and in rollover crashes with fires is passenger cars (50% unweighted).

Table 7 - Distribution of No Fire and Fire Cases in NASS/CDS Rollovers by Fire Severity and Vehicle Body Type – Unweighted Data

Body Type	Minor	Major	All Roll Fires	No Fire
Car	23%	27%	50%	43%
Pickup	10%	9%	18%	24%
SUV	8%	12%	20%	26%
Van	7%	4%	11%	7%
Total	48%	51%	100%	100%

FIRE ORIGIN

Table 8 shows the distribution of the 102 rollover cases with fires of known severity by fire origin and severity. As observed earlier, the most frequent origin of fires in rollover is the engine compartment (63%). The second most frequent fire origin was the fuel tank (20%).

Table 8 - Fire Origin in Rollovers by Fire Severity – 102 Cases

Fire Location	Minor	Major	All
Unknown Origin	3%	6%	9%
Exhaust System	1%	0%	1%
Fuel Tank	3%	17%	20%
Engine Compartment	36%	27%	63%
Cargo / Trunk Area	1%	0%	1%
Instrument Panel	1%	2%	3%
Other Location	3%	0%	3%
Total	48%	52%	100%

FUEL LEAKAGE LOCATION

Table 9 – Fuel Leak Location in Rollovers by Fire Severity – 102 Cases

Fuel Leak Location	Minor	Major	All
Unknown	2%	16%	18%
No Fuel Leakage	42%	22%	64%
Tank	1%	4%	5%
Filler Neck	2%	6%	8%
Cap	1%	2%	3%
Line/Pump/Filter	0%	2%	2%
Other	0%	1%	1%
Total	48%	52%	100%

Table 9 shows the distribution of the 102 cases of rollovers with fires by the fuel leakage location. The tank and filler neck were the two most frequent fuel leakage location when leakage occurred and its source could be identified.

Table 10 shows the distribution of fuel leakage location in major fires by crash mode. Table 3 indicated that NASS contained 227 cases with major fires. Of these cases, 53 were in rollovers and 174 were in planar crashes – front, side and rear. The columns in Table 8 show the distributions for the 53 rollover cases, and the 174 planar cases. Frontal crashes are the largest component of the planar crashes and the distribution for the 118 frontal cases is shown in the center column.

Table 10- Fuel Leak Location in Major Fires by Crash Mode

Fuel Leak Location	Rollover	Frontal	All Planar
Unknown	28%	16%	22%
No Fuel Leakage	43%	72%	53%
Tank	8%	6%	13%
Filler Neck	11%	2%	5%
Cap	4%	0%	0%
Line/Pump/Filter	4%	3%	3%
Other	2%	1%	5%
Number of Cases	*53*	*118*	*174*

NUMBER OF VEHICLE REVOLUTIONS

Table 11 shows the distribution of rollover fire cases by the number of complete vehicle revolutions involved in the rollover. The last two columns in Table 9 display the fire rates for all fires and major fires, based on the raw data. The fire rate is the number of rollovers with fires and a given number of revolutions per 100 vehicles with rollovers and with the same number of revolutions.

Table 11 – Distributions and Fire Rates and Fire Severity by Number of Rollover Revolutions–102 Cases

Number of Revolutions	Fire Type %		Fire Rates per 100	
	Minor	Major	All	Major
1	36%	35%	1.32	0.66
2	4%	10%	1.06	0.76
3+	5%	6%	3.96	2.15
End over End	3%	1%	4.28	1.19
Total	48%	52%	1.42	0.74

FINAL REST POSITION

Table 12 – Frequency and Fire Rates for Vehicle Final Rest Position by Fire Severity - 102 Cases

Final Rest Position	Fire Severity		Fire Rate per 100	
	Minor	Major	All Fires	Major
Side	21%	12%	1.48	0.56
Roof	14%	24%	1.31	0.81
Wheels	13%	16%	1.50	0.81
All	48%	52%	1.42	0.70

Table 12 shows the distribution of rollover fire cases by the final rest position of the vehicle after rollover. The most prevalent final rest position was on the roof of the vehicle (38% of rollover fire cases, unweighted). The fire rate is the number vehicles with fires in a final rest position per 100 vehicles with rollovers that end in the same final rest position.

Rollover Cases with Major Fires

To further understand the nature of fires in rollover crashes, a case by case study of the rollover crashes with major fires that were documented in NASS/CDS was undertaken. Complete documentation was not available in electronic format for the 2003 and 2004 NASS files, so the review was undertaken for 1997-2002 cases. Cases with occupant ejection and unknown fire origin were excluded. The remaining data set contained 24 cases with vehicles model year 1990 and later with major fires and with recorded fire origins. The cases of model year 1990 and later vehicles were examined in detail to determine patterns for the rollover characteristics. The cases are listed along with summary data in Table A-4. The engine compartment was coded as the fire origin in 17 of these cases. Other fire origin locations were: the fuel tank – 5 and instrument panel - 2.

For the five cases with fuel tank as the fire origin, the source of fuel leakage was examined. There were two cases with filler tube leakage and one case with tank leakage. For the other two cases the source of fuel leakage was unknown. All five of these cases involved severe impacts with fixed objects or other vehicles prior to the rollover. Undercarriage damage may have been present in four of the cases that involved climbing or bouncing over fixed objects such as guardrails and concrete roadside fixtures.

Of the 17 cases with fire origin in the engine compartment, 10 were listed as having no fuel leakage and 5 had unknown fuel leakage. The two remaining cases documented leakage from the fuel cap separation. In one case there was a side impact prior to roll that might have damaged the filler tube area. The other case was a tripped rollover with no prior side impact.

Table 13 – Categories of Rollovers with Major Fires Originating in the Engine Compartment – 17 Cases with Documented Fire Origin

Contact Prior to Roll	Number	Percentage
Tripped Roll	8	47%
Front & Undercarriage	6	35%
Rear, Side	3	18%
Total	17	100%

The characteristics of the rollover crashes that produced engine compartment fires were examined. NASS/CDS characterizes rollovers according to the rollover initiation mechanism. The most common rollover mechanism is tripped rollover. In this category, the rollover is initiated by lateral forces applied at the wheels or rims. Over 50% of rollovers with fires fall into this category. For the rollovers with underhood fires, 53% were categorized as trip-over. However, two of these trip-over's involved impacts to the undercarriage or engine compartment. Consequently, the rollover contacts were reclassified to separate crashes that were simple tripped rollovers from those that had more complex impacts. The results of the reclassification are shown in Table 13.

Figures 52 and 53 show the vehicles from cases 1997-41-126 and 2001-13-58, respectively. These cases are of the tripped rollover category. The fire originated in the engine compartment and spread to the occupant compartment. Except for the roof, the body damage is minor. Table 13 indicates that this type of crash occurred in 45% of the cases with engine compartment fire. This result suggests the value of containment of all flammable fluids and isolation of electrical sources in rollovers.

Figure 52. Major Fire after Rollover with Engine Compartment Origin – NASS Case 1997-41-126

Figure 53. Major Fire after Rollover with Engine Compartment Origin – NASS Case 2001-13-58

Discussion – Rollover Fires

The 1994-2004 NASS/CDS contains 431 cases with fires, 52% of which are classified as major fires. The weighted and unweighted distribution of fires by vehicle type was found to be generally similar to the distribution of crashes without fires.

Table 5 shows that for the combined fleet, about 50% of the fires result from frontal crashes. Rollovers account for 8% to 11% of the crashes and 24% to 30% of the fires.

Fires and rollovers are generally rare events in NASS/CDS. From 1997-2004 there were only 103 cases of rollovers with fires. About half were major fires. One case was of unknown fire severity and the following analysis of rollover fires was based on 102 cases.

In view of the small number of cases, only unweighted data was used in the analysis of rollover crash fires. When unweighted data is used, the results can not be extrapolated to the general population. However, the unweighted data is useful in examining the combination of factors that contribute to fires in the known rollover cases.

Data from Table 7 is unweighted and can not be used to assess the relative fire rates by vehicle type. An earlier analysis of police reported crashes in Illinois and Pennsylvania found no difference between cars and light trucks in the fire rates when rollover crashes occur [Friedman 2003].

Table 8 shows that in the 102 NASS/CDS rollover crashes, the engine compartment is the most frequent fire origin (63%), followed by the fuel tank (20%).

Table 9 shows that the most frequent source of fuel leakage for the 102 cases is the filler neck, followed by the tank, the filler cap and the fuel lines. No fuel leakage was reported in about 64% of the cases with rollovers and fires. Fuel leakage was recorded in 19% of the cases with fires. In another 18% it was unknown if fuel leakage occurred.

Table 10 compares unweighted data for fuel leakage location by crash mode. When considering only major fires, no fuel leakage occurred in 43% of the cases with rollover fires compared to 72% of the cases with fires after frontal impacts. The uncertainty regarding fuel leakage was higher for rollovers with major than for frontal crashes with major fires.

Based on 102 rollover cases summarized in Table 11, the distribution of fires by rollover severity shows that most of the fires occurred in rollovers with four quarter-turns or less. The fire rate increased for rollovers with three or more revolutions or with end-over-end motion. These more severe rollovers account for a small fraction of the rollover fires in NASS/CDS and carry fire risks higher that of rollovers with no more than one revolution.

The most frequent final rest position is on the roof (38%). This position tends to have a higher percentage of major fires. However, as shown in Table 12, the overall fire risks do not appear to be strongly influenced by the final rest position.

In the1997-2002 NASS/CDS, there were 24 cases of major fires in rollovers that involved vehicles model year 1990 and later and with known fire origins. These cases were examined in detail in an attempt to better understand the characteristics of fires in rollovers for recent model vehicles. An analysis of the 24 cases indicated that planar impacts to the vehicle front, side, rear or undercarriage frequently occurred prior to the rollover. All five of the rollovers that had major fires originating at the fuel tank had impacts prior to the rollover. These impacts may have contributed to a loss of integrity of the fuel system. It is difficult to assess the causes of the fire in these cases because of a major fire destroys most of the evidence.

Table A-4 provides a summary of the 24 rollover cases with major fires. Seventeen of the cases had underhood coded as the fire origin. It may be noted that 8 of the cases with underhood fire and 2 cases with instrument panel fires involved rollovers in which forces on the tires and wheels were the cause of the rollover. Frontal and/or undercarriage damage may have been present in six of the cases with underhood fires.

Overall, 10 of 24 major fires in rollovers did not involve major impacts prior to the rollover. The remaining 14 crashes involved pre-crash events that may have caused damage that contributed to the loss of integrity of fluid containment or electrical isolation.

CONCLUSIONS - FRONTAL

For major fires in NASS and fatalities in FARS with fire as the most harmful event, frontal crashes represent more than half of the populations. In recent years, the number of fatalities in frontal crashes has been decreasing while the number of fatalities in these crashes where fire is the most harmful event has been increasing.

The engine compartment is by far the most frequent source of NASS major fires that occur in frontal crashes (84%). Most of these fires do not have known fuel leakage. These NASS major fires are most frequently associated with impacts with large fixed objects. About 30% of the frontal crashes with major fires involve multiple impacts. About half of the cases with major fires have a wide damage area and an extent of damage of 3 or less.

An examination of raw NASS frontal crash cases in which fires may have contributed to the fatality indicated that lane departure to the right was the most common pre-crash factor. Entrapment after severe impacts with trees was an associated crash factor. However, entrapment was also observed in two crashes with the extent of frontal damage no greater than that experienced in a 35 mph frontal barrier crash.

Entrapment occurred in 23% of FARS frontal crashes with fire as the most harmful event and in 17% of NASS major fires. However, entrapment was present in 59% of the weighted NASS frontal crashes with major fires and fatalities.

CONCLUSIONS - SIDE

In NASS 1997-2006 there were 34 cases of major fires originating in vehicles that had been subjected to a side impact. Of these cases, there were 19 fatalities, 8 of which were documented as fire related.

When weighted, the 34 cases expanded to 3,216. The fuel tank was the fire origin in 41% of the weighted cases.

For fatalities in FARS with fire as the most harmful event, side crashes represent 16% of the population. About 29% of these crashes also involved a rollover. For the 8 unweighted NASS side crashes with fire related fatalities, 2 involved rollovers after a side impact.

The most frequent crash condition for vehicles with a side impact and a major fire was a collision with a narrow object that produced severe side damage. A CDC extent of damage of 4 or greater occurred in most of these cases. Lower damage extent was observed in cases that involved both a side impact and a rollover. Rollovers were present in 3 of 8 cases (37%) with fire related fatalities. An examination of FARS indicates that rollovers are involved in 24% of the side impacts with fire as the most harmful event.

Entrapment occurred in about 32% of the cases in the study. This compared to an entrapment rate of about 23% for FARS cases where fire is the most harmful event.

CONCLUSIONS - REAR

The fuel tank was the fire source in 75% rear impact with major fires in NASS. Entrapment was documented in 40% of the 20 rear cases reported in NASS.

An examination of 8 cases with fire related fatalities found for all cases with the outcome known and documented the fuel tank was the fire source and entrapment occurred. All of these cases involved severe rear impacts.

An examination of 7 cases with the fuel tank behind the rear axle, found that fires with fuel tank origin can occur at relatively low damage severity. However, in these cases the crash injury was minor and entrapment did not occur.

The location of the fuel tank behind the axle exposes the tank to damage in relatively low severity rear impacts. However, in the study cases, no entrapment or incapacitating injuries occurred in these lower severity crashes and no burn injuries were observed. At crash severities that produced entrapment and incapacitating crash injuries, fatal burn injuries occurred.

CONCLUSIONS - ROLLOVERS

Fires in rollover crashes are second to fires in frontal crashes in frequency. In the sample of cases examined in this research, most fires in rollovers occurred in crashes less severe than five quarter-turns. The most frequent final rest position for rollovers with fires is on the roof. However, the final rest position did not strongly influence the risk of a fire.
In NASS/CDS cases, the majority of rollover fires originate in the engine compartment. No fuel leakage was noted for most rollover fires.

An examination of 24 cases with major fires in rollovers found 58% of the cases involved impacts with the vehicle front rear, side or undercarriage prior to the rollover. For the 17 cases with fire with fire origin in the engine compartment, 53% may have suffered damage prior to the rollover. In two of these cases, the crash investigator also documented leakage from the filler cap. The remaining 15 cases had no fuel leakage or unknown fuel leakage. In most cases, the cause of the rollover fires could not be determined from the available case documentation. However, in many of these cases the vehicle damage was relatively minor except to the roof. The lack of vehicle damage suggests that the engine compartment fires may have originated from leakage of flammable fluids or from electrical faults.

REFERENCES

Bahouth, G., "Post Crash Exterior Crush Patterns and Motor Vehicle Fire Occurrence", SAE 2006-01-0789, 2006.

Bahouth , G., "Analysis of Fire Related Crash Fatalities and Crashed Vehicle Rescue Times", Report prepared for MVFRI, March 30, 2007. www.mvfri.org

Digges, K., Stephenson, R., and Bedewi, P., "Fire Safety Performance of Motor Vehicles in Crashes", Proceedings of the 18th Conference on Enhanced Safety of Vehicles, Paper ESV 03-422, May 2003.

Digges, K., Stephenson, R., and Bedewi, P., "A Research Program in Crash-Induced Fire Safety", SAE 2004-01-0475, March, 2004.

Digges, K., Stephenson, R., and Bedewi, P., "Research Programs in Crash-Induced Fire Safety", SAE 2005-01-1425, April, 2005.

Digges, K., and Stephenson, R., "Summary of Recent Research in Crash-Induced Vehicle Fire Safety", SAE 2006-01-0551, April, 2006.

Digges, K., and Stephenson, R., "Recent MVFRI Research in Crash-Induced Vehicle Fire Safety", SAE 2007-01-0880, April, 2007.

Digges, K., and Kildare, S., “Fire Occurrence in Rollover Crashes Based on NASS/CDS”, SAE 2007-01-0875, April, 2007.

Digges K., “Fire Occurrence in Frontal Crashes Based on NASS/CDS,” SAE 2008-01-0256, April, 2008.

Digges K., “Fire Occurrence in Side Crashes Based on NASS/CDS,” SAE 2009-01-0008, April, 2009.

Fell, J., Tippets, A., and Bahouth, G., “An Analysis of Fire Rates in Fatal Crashes: Is There an Indication of Underreporting?”, SAE 2007-01-0876, April 2007.

Jensen, J. and Santrock, J., ‘Evaluation of Motor Vehicle Fire Initiation and Propagation – Part 2 Crash Tests on a Passenger Van”, General Motors Report submitted to NHTSA Docket, September, 1998, www.mvfri.org

Kildare, S. and Digges, K., “Analysis of Fire Occurrence in Automotive Crashes Using NASS CDS Data (1994-2004)”, GW University Report prepared for MVFRI, October 2006, www.mvfri.org

National Highway Traffic Safety Administration, “1995-1997 National Automotive Sampling System – Crashworthiness Data System”, DOT HS 809 203, February, 2001.

SAE J224, “Collision Deformation Classification”, SAE Standard J224, 1980.

Santrock, J. and Hodges, S., “Evaluation of Automatic Fire Suppression Systems in Full Scale Vehicle Fire Tests and Static Vehicle Fire Tests”, SAE paper 2005-01-1788, April, 2005.

ACKNOWLEDGEMENT

The author would like to recognize that funding for this research was provided by General Motors in accordance with the White, Monson and Cashiola vs. General Motors Settlement Agreement.

The author would also like to recognize the contributions of several researchers and/or organizations that provided technical input to this paper. These include: Dr. George Bahouth of the Pacific Institute for Research and Evaluation; Mr. Shaun Kildare and Mr. Tobias Bick of the George Washington University.

APPENDIX

Table A1. NASS Cases of Frontal Crashes with Coding Indicating Fire May Have Contributed to a Fatality

Year	PSU	Case	Origin of Fire	Leakage Location	Damage Extent	Damage Width	Entrapment	Object Contacted	2nd Object Contacted
1997	11	146	Eng. Comp	Line/Pump/Filter	4	Wide	Door Jammed	Large Tree	
2004	43	343	Eng. Comp	No Fuel Leak	4	Wide	Door Jammed	Large Tree	
2005	12	160	Eng. Comp	No Fuel Leak	7	Corner	Entrapped	Large Tree	
1997	48	129	Eng. Comp	Tank	5	Wide	Entrapped	Ditch/Culvert	Large Tree
1998	6	139	Fuel Tank	Tank	3	Wide	Door Jammed	Jersey Barrier	Top of Barrier
2003	78	31	Eng. Comp	No Fuel Leak	2	Wide	Not Entrapped	Vehicle Side	Sideslap
2005	81	63	Unknown	Unknown	3	Wide	Door Jammed	Vehicle Side	
2002	49	61	Eng. Comp	Unknown	Unk	Unk.	Unknown	Vehicle Rear	Jersey Barrier

Table A2. NASS Cases of Side Crashes with Coding Indicating Fire May Have Contributed to a Fatality

Year	**PSU**	**Case**	**Origin of Fire**	**Objects Contacted**	**Damage Severity**	**Comments**
1998	49	95	Engine Comp	Narrow Object	Severe	Impact near front wheels
1997	9	20	Fuel tank	Narrow Object	Severe	Hydroplaned; Impact at occ. comp
2004	45	219	Fuel tank	Narrow Object	Severe	Impact at occupant compartment
2003	82	501	Fuel tank	Narrow Object	Severe	Barrier sideswipe+ pole impact
2003	8	227	Fuel tank	Vehicle front to side	Severe	Impact at occupant compartment
2006	41	65	Fuel tank	1 Vehicle + 2 Narrow Object	Severe	Impact near rear fuel tank
2000	49	134	Fuel tank	Traffic Barrier/Light Pole	Moderate	Rollover followed impact
2006	82	68	Fuel tank	Impact Attinuator	Moderate	Fuel system damage during rollover

Table A3 NASS Cases of Rear Impact with Coding Indicating Fire May Have Contributed to a Fatality

Year	PSU	Nr.	Fire Origin	Leakage Location	Damage Extent	Entrapment	Pre-Crash Event	Object contacted (highest)	Impacting Vehicle	Object contacted (2nd highest)	Tank Location Relative to Rear Axle
1998	45	128	Fuel tank	Filler neck	99	Yes	STOPPED IN LANE	VEH NO. 5	Tractor Trail	VEH NO. 1	Front/Centered
2001	45	197	Fuel tank	Tank	7	JAMMED	STOPPED IN LANE	VEH NO. 3	Tractor Trail	ROLLOVER	Front/Centered
2005	74	48	Fuel tank	Unknown	5	JAMMED	DECELER IN LANE	VEH NO. 2	Dump Truck	ROLLOVER	Behind/Left
2006	2	12	Fuel tank	Unknown	6	JAMMED	STOPPED IN LANE	VEH NO. 2	Pickup	1 IMPACT	Behind/Centered
2002	49	174	Fuel tank	Tank	7	JAMMED	LOW SPEED IN LANE	VEH NO. 2	SUV	1 IMPACT	Behind/Centered
2005	79	105	Fuel tank	Tank	99	Unknown	STOPPED IN LANE	VEH NO. 3	Pass Car	ROLLOVER	Front/Centered
2006	45	180	Fuel tank	Tank	5	JAMMED	DISABLED IN LANE	VEH NO. 2	SUV	1 IMPACT	Front/left
2006	3	49	Unknown	Unknown	99	No	STOPPED (Crash)	VEH NO. 2	Multiple	VEHI. NO. 4	Uncertain

Table A4. Cases in NASS with Rollovers and Major Fires in Vehicles MY 1990 and Later

Year	PSU	Case #	Fire Origin	Leakage Location	Rollover Type	Qtr-Turns	Impact Locations
2002	75	502	Fuel tank	Filler neck	BOUNCE-OVER	1 to 4	Front/Side
2001	45	197	Fuel tank	Tank	BOUNCE-OVER	1 to 4	Front/Rear
1998	78	83	Fuel tank	Filler neck	BOUNCE-OVER	1 to 4	Front/Undercarriage
2002	2	81	Fuel tank	Unknown	CLIMB-OVER	1 to 4	Front/Undercarriage
1997	75	145	Fuel tank	Unknown	COLLISION W/VEH	1 to 4	Rear
2000	12	198	UndrHood	Unknown	BOUNCE-OVER	1 to 4	Front/Undercarriage
1999	49	134	UndrHood	None	BOUNCE-OVER	1 to 4	Rear
2002	43	108	UndrHood	Filler cap	BOUNCE-OVER	5 to 8	Front/Undercarriage
2000	49	32	UndrHood	None	BOUNCE-OVER	1 to 4	Undercarriage
2000	78	501	UndrHood	Unknown	TURN-OVER	1 to 4	Wheels/Overturn
1999	76	101	UndrHood	None	FLIP-OVER	5 to 8	Front/Undercarriage
2000	78	502	UndrHood	Unknown	FLIP-OVER	1 to 4	Rear
1997	12	66	UndrHood	None	FLIP-OVER	9+	Rear
2001	81	502	UndrHood	None	TRIP-OVER	1 to 4	Wheels
2001	12	100	UndrHood	None	TRIP-OVER	5 to 8	Wheels
1997	41	120	UndrHood	None	TRIP-OVER	1 to 4	Wheels
2002	9	103	UndrHood	None	TRIP-OVER	1 to 4	Front/Undercarriage
2001	13	58	UndrHood	None	TRIP-OVER	1 to 4	Wheels
1997	78	135	UndrHood	Filler cap	TRIP-OVER	5 to 8	Wheels
1998	45	117	UndrHood	None	TRIP-OVER	1 to 4	Wheels
1998	78	102	UndrHood	Unknown	TRIP-OVER	9+	Wheels
2000	48	106	UndrHood	Unknown	TRIP-OVER	1 to 4	Front/Wheels
1999	12	55	Inst Panl	None	TRIP-OVER	5 to 8	Wheels
2000	81	118	Inst Panl	None	TRIP-OVER	1 to 4	Wheels