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CALSPAN ON-SITE HYBRID VEHICLE CRASH INVESTIGATION

SCI CASE NO.:CA09031

VEHICLE: 2006 FORD ESCAPE HYBRID

LOCATION: NORTH CAROLINA

CRASH DATE: MARCH 2009

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The crash investigation process is an inexact science which requires that physical evidence such as skid marks, vehicular damage measurements, and occupant contact points are coupled with the investigator's expert knowledge and experience of vehicle dynamics and occupant kinematics in order to determine the pre-crash, crash, and post-crash movements of involved vehicles and occupants.

Because each crash is a unique sequence of events, generalized conclusions cannot be made concerning the crashworthiness performance of the involved vehicle(s) or their safety systems.

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16. Abstract This on-site investigation focused on the crashworthiness of the hybrid battery system in a 2006 Ford Escape Hybrid. The Ford was equipped with a high-voltage nickel-metal hydride battery pack with a total output rating of approximately 330 volts. The hybrid battery was used for low speed vehicle movement and to assist the 2.3-liter gasoline engine at higher speeds. The battery pack was located in the rear center of the vehicle under the cargo area floor. The Ford was equipped with a regenerative braking system to charge the hybrid battery. A standard 12-volt battery was located in the engine compartment of the vehicle and powered the gasoline engine, lighting and accessories. The Ford was also equipped with a Certified Advanced 208-Compliant (CAC) frontal air bag system, seat back-mounted side impact air bags, and Inflatable Curtain (IC) air bags with rollover sensing. The manufacturer of the Ford has certified that this vehicle is compliant with the advanced air bag portion of Federal Motor Vehicle Safety Standard (FMVSS) No. 208. The CAC system consisted of dual-stage frontal air bags for the driver and front right passenger positions, seat track positioning sensors, safety belt buckle switch sensors and retractor-mounted pretensioners, and a front right occupant presence sensor. The vehicle was traveling through a four-leg signalized intersection when the left front side area of the Ford was impacted by the front of a 2006 Scion tC. The Ford was deflected off-road into a frontal impact sequence with a tree. As a result of the tree impact, the driver's frontal air bag deployed. The left side impact air bag and IC air bags did not deploy in this crash sequence. The restrained 18-year-old male driver of the Ford sustained minor severity injuries and was not medically treated.			
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LOCATION: NORTH CAROLINA
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BACKGROUND

This on-site investigation focused on the crashworthiness of the hybrid battery system in a 2006 Ford Escape Hybrid **(Figure 1)**. The Ford was equipped with a high-voltage nickel-metal hydride battery pack with a total output rating of approximately 330 volts. The hybrid battery was used for low speed vehicle movement and to assist the 2.3-liter gasoline engine at higher speeds. The battery pack was located in the rear center of the vehicle under the cargo area floor. The Ford was equipped with a regenerative braking system to charge the hybrid battery. A standard 12-volt battery was located in the engine compartment of the vehicle and powered the gasoline engine, lighting and accessories. The Ford was also equipped with a Certified Advanced 208-Compliant (CAC) frontal air bag system, seat back-mounted side impact air bags, and Inflatable Curtain (IC) air bags with rollover sensing. The manufacturer of the Ford has certified that this vehicle is compliant with the advanced air bag portion of Federal Motor Vehicle Safety Standard (FMVSS) No. 208. The CAC system consisted of dual-stage frontal air bags for the driver and front right passenger positions, seat track positioning sensors, safety belt buckle switch sensors and retractor-mounted pretensioners, and a front right occupant presence sensor. The vehicle was traveling through a four-leg signalized intersection when the left front side area of the Ford was impacted by the front of a 2006 Scion tC. The Ford was deflected off-road into a frontal impact sequence with a tree. As a result of the tree impact, the driver's frontal air bag deployed. The left side impact air bag and IC air bags did not deploy in this crash sequence. The restrained 18-year-old male driver of the Ford sustained minor severity injuries and was not medically treated.

Figure 1: 2006 Ford Escape Hybrid case vehicle.

The crash was identified by the National Highway Traffic Safety Administration's Crash Investigation Division (CID) by accessing the online records of a nationwide salvage company and searching for vehicle crashes of interest to the agency. The salvage details were forwarded to the Calspan Special Crash Investigations (SCI) team on May 15, 2009 and assigned for on-site investigation. The PAR was obtained from the police agency and the on-site investigation was conducted on May 21-22, 2009. This investigation involved the inspections of the Ford and the Scion, an interview with the mother of the driver of the Ford, and documentation of the crash scene. The mother of the driver requested that her son not be contacted regarding this research.

SUMMARY

Crash Site

This crash occurred during the evening hours of March 2009 in the signalized intersection of two one-way urban roadways. Both roadways consisted of three travel lanes that were 3.3 m (10.8 ft) in width with parallel parking permitted along the curb line at the right side. The roadways were surfaced with asphalt. The roadsides were bordered by concrete barrier curbs that were 17 cm (6.7 in) in height. The police reported conditions at the time of the crash were clear, dry, and dusk. The southwest corner of the intersection was an active construction work zone at the time of the crash. Beyond the curbline at the northwest corner of the intersection, the sidewalk was surfaced in brick, with trees planted in brick lined planters north of the roadway. Beyond the curblines at the northeast and southeast corners of the intersection were narrow strips of grass followed by concrete sidewalks, with trees planted north and south of the roadway. The posted speed limit on both roadways was 48 km/h (30 mph). The Crash Schematic is included as **Figure 9** of this report.

Vehicle Data

2006 Ford Escape Hybrid

The case vehicle was a 2006 Ford Escape Hybrid four-door Sport Utility Vehicle (SUV). The SUV was manufactured in March 2006 and was identified by the Vehicle Identification Number (VIN): 1FMCU95H16K (production number deleted). The vehicle was purchased new in 2006 by the current owner.

The front-wheel drive Ford was powered by a 2.3-liter inline 4-cylinder gasoline engine and a 330-volt electric motor linked to a Continuously Variable Transmission (CVT) with a console mounted shift lever. The hybrid electric motor was powered by a 330-volt sealed nickel-metal-hydride battery with alkaline electrolyte. This battery and motor was used for low speed vehicle movement and to assist the gasoline engine in higher speed movement. The battery compartment was located aft of the second row bench seat within the cargo area floor. The hybrid battery was concealed by an aluminum cover with a circular disconnect relay on the rear right aspect of the battery. This disconnect was rotated counterclockwise and removed to safely disconnect the high-voltage battery during the SCI inspection. The braking system consisted of front and rear disc brakes with four-wheel antilock, brake assist, and electronic brakeforce distribution. The Ford was equipped with a regenerative braking system to assist in charging the hybrid battery. The front and rear windows were closed at the time of the crash. The windshield was OEM AS-1 laminated glass. The front side windows were AS-2 tempered glass. The rear side windows and backlight were AS-3 deep tint. The Ford was equipped with four Michelin Cross Terrain tires with a Tire Identification Number (TIN) of B37P PA7X mounted on five-spoke alloy wheels. The tire size was P235/70R16. The vehicle manufacturer recommended tire size was P235/70R16 with a recommended cold tire pressure of 241 kPa (35 PSI), front and rear. The specific tire data at the time of the SCI inspection was as follows:

Position	Measured Tire Pressure	Measured Tread Depth	Damage
Left Front	Tire flat	9 mm (11/32 in)	Unknown
Left Rear	200 kPa (29 PSI)	6 mm (8/32 in)	None
Right Front	Tire flat	9 mm (11/32 in)	Sidewall cut 6 cm (2.4 in)
Right Rear	207 kPa (30 PSI)	6 mm (8/32 in)	None

The interior of the Ford was configured with cloth-surfaced five-passenger seating. The front bucket seats were separated by a center console and equipped with adjustable head restraints. Both front head restraints were adjusted 4 cm (1.6 in) above the full-down position at the time of the SCI inspection. The front left seat track was adjusted 3 cm (1.2 in) forward of the full-rear position. The front left seat back angle was measured at 27 degrees aft of vertical. The front right seat track was found in the full-rear position. The front right seat back angle was measured at 25 degrees aft of vertical. The second row seat was a split bench seat (60/40) with forward folding seat cushions and seat backs. The second row seat was equipped with three adjustable head restraints; all adjusted 3 cm (1.2 in) above the full-down position.

The interior occupant safety systems consisted of 3-point lap and shoulder belt systems for the five designated seating positions, front safety belt retractor and buckle pretensioners, dual-stage frontal air bags, front seat back mounted side impact air bags, and IC air bags that provide protection for the four outboard seating positions. The Ford was equipped with rollover sensing for the IC air bags.

2006 Scion tC

The other vehicle was a 2006 Scion tC 3-door hatchback. The Scion was manufactured in March 2006 and was identified by the VIN: JTKDE177560 (production number deleted). The front-wheel drive Scion was powered by a 2.4-liter inline 4-cylinder transverse mounted engine linked to a 4-speed automatic transmission. The braking system consisted of front and rear disc with four-wheel antilock and electronic brakeforce distribution. The Scion was also equipped with an indirect Tire Pressure Monitoring System (TPMS). The Scion was equipped with Bridgestone Potenza tires on the front and Primewell P2-900 tires on the rear. All tires were size P215/45R17, consistent with the manufacturer recommendations. The manufacturer recommended cold tire pressure was 220 kPa (32 PSI) for the front and 200 kPa (29 PSI) for the rear. The specific tire data at the time of the SCI inspection was as follows:

Position	Measured Tire Pressure	Measured Tread Depth	Damage
Left Front	207 kPa (30 PSI)	6 mm (7/32 in)	None
Left Rear	186 kPa (27 PSI)	7 mm (9/32 in)	None
Right Front	214 kPa (31 PSI)	6 mm (7/32 in)	None
Right Rear	193 kPa (28 PSI)	7 mm (9/32 in)	None

Crash Sequence

Pre-Crash

The restrained 18-year-old male driver of the Ford was on a westbound approach to the signalized four-leg intersection. The driver was traveling to a routine destination in the center lane of a three-lane, one-way roadway. The interviewee stated that he regularly traveled this route. The 21-year-old female driver of the Scion was on a northbound approach to the same signalized four-leg intersection. The driver was traveling in the center lane of a three-lane, one way roadway. Both vehicles entered the intersection, attempting to travel through on a straight path.

Crash

The front of the Scion impacted the left side area of the Ford. The directions of force for this initial impact were within the 11 o'clock sector for the Ford and 2 o'clock for the Scion. The damage algorithm of the WinSMASH program calculated a total delta-V of 16.0 km/h (9.9 mph) with longitudinal and lateral components of -12 km/h (-75 mph) and 10 km/h (6.2 mph), respectively for the Ford. The total delta-V for the Scion was 20 km/h (12.4 mph) with a longitudinal component of -13 km/h (-8 mph) and lateral component of -15 km/h (-9.3 mph). The vehicles were redirected in a northwest trajectory by the force of the impact. The Ford was redirected approximately 20 degrees north from its original westbound heading. The Ford departed the roadway at the northwest corner of the intersection and impacted a 30 cm (11.9 in) diameter tree with its center frontal area. The driver's retractor and buckle mounted pretensioners actuated. The driver's frontal CAC air bag in the Ford deployed as a result of the impact with the tree. The direction of force for the impact with the tree was within the 12 o'clock sector. The calculated delta-V for the tree impact was 34.0 km/h (21.1 mph). The longitudinal and lateral components were -34 km/h (-21.1 mph) and 0 km/h, respectively. The Ford came to rest against the tree, facing west on the northwest roadside. The Scion came to rest on the roadway in the northwest corner of the intersection.

Post-Crash

The driver of the Ford called the 9-1-1 emergency response system for assistance on his cellular telephone. Police, emergency medical, and tow personnel responded to the crash site. Both drivers exited their vehicles unassisted after the vehicles had come to rest. The driver of the Ford sustained minor severity injuries and refused medical treatment. The driver of the Scion sustained police reported minor severity injuries and was transported to a local hospital center by ambulance for treatment. Both vehicles were towed from the scene due to disabling damage. The Ford was towed on a rollback-type truck. The tow truck driver stated that he did not know the Ford was a hybrid vehicle and he did not take any precautions beyond that of a normal tow procedure. The Ford was transferred to a regional salvage facility where it was inspected. The Scion remained at a local tow yard where it was inspected.

Exterior Damage

2006 Ford Escape

Figure 2: Initial and sideslap impact damage to Ford Escape.

The left and front planes of the Ford Escape were damaged in this multiple impact crash. The initial impact involved moderate severity damage to the left front side area of the Ford **(Figure 2)**. The direct contact damage began 108 cm (42.5 in) forward of the left rear axle and extended 169 cm (66.5 in) forward to the left front wheel area. Lateral crush was present to the left front door, A-pillar and fender. A crush profile capturing the residual crush from the impact with the Scion was documented along the left side, forward of the B-pillar. The combined direct and induced damage (Field L) began 108 cm (42.5 in) forward of the left rear axle and extended forward 169 cm (66.5 in). The residual crush profile was measured at the lower door elevation and was as follows: C1 = 0 cm, C2 = 10 cm (3.9 in), C3 = 18 cm (7.1 in), C4 = 6 cm (2.4 in), C5 = 2 cm (0.8 in), C6 = 0 cm. The maximum crush was located on the left front door, 199 cm (78.3 in) forward of the left rear axle and measured 20 cm (7.9 in). The elevation of the maximum crush was 45 cm (17.7 in), consistent with the front bumper height of the Scion that was 39 cm (15.4 in) above ground level. The Door Sill Differential (DSD) was 13 cm (5.1 in). The Collision Deformation Classification (CDC) of this impact was 11-LYEW-2.

The left front and left rear door hinges were intact and remained attached to the A- and B-pillars, respectively. Both left side door latches remained engaged and both left side doors remained closed during the crash. The left front door was jammed closed as a result of damage. The left rear and right side doors remained operational. The front left tire and wheel were engaged by the Scion; however, the suspension components remained attached to the Ford.

Figure 3: Overall view of the frontal damage to the Ford Escape.

The left and center aspects of the frontal plane sustained moderate severity damage as a result of the impact with the tree **(Figure 3)**. The direct contact damage began 19 cm (7.5 in) left of the vehicle's centerline and extended left 37 cm (14.6 in). A crush profile was documented along the full frontal width of the bumper beam. The crush profile was as follows: C1 = 13 cm (5.1 in), C2 = 35 cm (13.8 in), C3 = 28 cm (11 in), C4 = 18 cm (7.1 in), C5 = 8 cm (3.1 in), C6 = 0 cm. The maximum crush for this impact was located 21 cm (8.3 in) left of the centerline of the vehicle and was 36 cm (14.2 in). The CDC for this impact was 12-FYEN-2. This impact actuated the driver's pretensioners and deployed the driver's frontal CAC air bag.

2006 Scion tC

The front and right side planes of the Scion were damaged in this multiple impact crash. The initial impact involved moderate severity damage to the front of the Scion **(Figure 4)**. The direct contact damage began 20 cm (7.9 in) left of the centerline of the vehicle and extended 90 cm (35.4 in) to the front right bumper corner. Longitudinal crush was present to the bumper beam. The lateral component of the 2 o'clock impact force displaced the frame rails to the left 27 cm (10.6 in). The bumper fascia was separated from the vehicle. **Figure 5** depicts the separated bumper fascia, with a rubber transfer from direct contact with the left front tire of the Ford. A crush profile was documented along the full-width of the bumper beam and was as follows: C1 = 5 cm (2 in), C2 = 16 cm (6.3 in), C3 = 15 cm (5.9 in), C4 = 16 cm (6.3 in), C5 = 18 cm (7.1 in), C6 = 9 cm (3.5 in). The maximum crush was located 1 cm (0.4") right of the centerline and was 18 cm (7.1 in) in depth. The CDC assigned for this impact was 82-FZEW-1 with a shift increment value of 80.

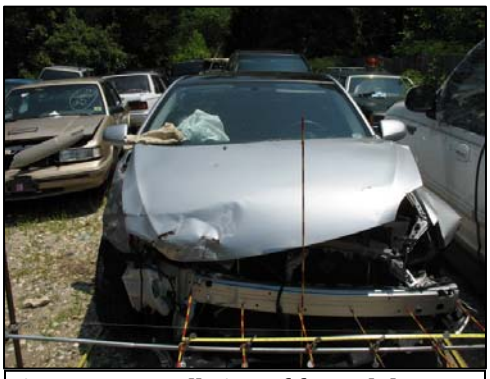

Figure 4: Overall view of frontal damage to the Scion.

Figure 5: Damaged front bumper fascia of the Scion.

Interior Damage

2006 Ford Escape

The Ford Escape sustained minor interior damage attributed to passenger compartment intrusion and occupant contacts. The Ford sustained minor left side intrusion in the front left seating position as a result of the impact. The left B-pillar cover was displaced laterally and was engaging but not compressing the front left seat back. The lower aspect of the left front door, the left A-pillar and the left side panel forward of the A-pillar intruded laterally.

The intrusion to the Ford is listed on the following table:

Position	Component	Direction	Magnitude
Row 1 Left	Side panel forward of the A-pillar	Lateral	8 cm (3.1 in)
Row 1 Left	Lower left A-pillar	Lateral	10 cm (3.9 in)
Row 1 Left	LF door panel, forward lower quadrant	Lateral	9 cm (3.5 in)
Row 1 Left	LF door panel, rear lower quadrant	Lateral	4 cm (1.6 in)

There was a scuff mark on the left front door armrest that was attributed to the driver's left elbow. This scuff was located 8–17 cm (3.1–6.7 in) forward of the rear of the armrest, and 0–5 cm (0–2 in) below the top of the armrest.

Manual Restraint Systems

2006 Ford Escape

The manual restraint systems in the Ford Escape consisted of 3-point lap and shoulder belts in all five seating positions. The driver's restraint utilized continuous loop webbing, an Emergency Locking Retractor (ELR), a sliding latch plate and a height adjustable D-ring located 3 cm (1.2 in) below the full-up position. This restraint utilized retractor and buckle-mounted pretensioners which actuated during the crash. There was 2 cm (0.8 in) of distance remaining in the front of the pretensioner piston tube. The driver's safety belt was not locked in place by the actuation of the retractor pretensioner. There were two areas of loading on the belt webbing. A 4 cm (1.6 in) frictional abrasion attributed to the latch plate was located 87-91 cm (34.3-35.8) above the floor anchor, and a 9 cm (3.5 in) frictional abrasion attributed to the D-ring was located 165-174 cm (65-68.5 in) above the floor anchor. The driver was restrained at the time of the crash based on the loading evidence on the belt system.

The front right and second row safety belt systems consisted of 3-point lap and shoulder belts in all four positions. These restraints utilized continuous loop webbing, switchable ELR/Automatic Locking Retractors (ALR), sliding latch plates, and fixed height D-rings for the second row outboard seats. In addition, the front right restraint system contained retractor and buckle-mounted pretensioners which did not actuate in this crash and a height adjustable D-ring that was in the full-down position. The webbing of the second row outboard belts measured 227 cm (89.4 in) fully extended and the second row center belt webbing was 240 cm (94.5 in) fully extended.

Frontal Air Bag System

2006 Ford Escape

The Ford was equipped with a CAC frontal air bag system for the driver and front right passenger positions. The driver's frontal air bag deployed during the crash sequence.

The driver's air bag was concealed within the center hub of the four-spoke steering wheel by two asymmetrical cover flaps. The upper flap measured 15 cm (5.9 in) in width at the horizontal tear seam and 7 cm (2.8 in) in height. The lower flap measured 14 cm (5.5 in) in width at the horizontal tear seam and 5 cm (2.0 in) in height. The air bag (**Figure 6**) measured 60 cm (23.6 in) in diameter in its deflated state. The air bag was vented by two vent ports located at the 3 and 9 o'clock positions on the rear aspect of the air bag. The air bag was tethered by two tethers located at

Figure 6: Deployed driver's frontal air bag of the Ford Escape.

the 12 and 6 o'clock positions on a 9 cm (3.5 in) diameter circular seam sewn to the center face of the air bag. There were no occupant contacts to the driver's frontal airbag.

The front right seat was unoccupied at the time of the crash; therefore, the CAC system suppressed the deployment of the front right air bag.

Side Impact / Rollover Air Bag System
2006 Ford Escape

The Ford Escape was equipped with driver and front right passenger side impact air bags mounted in the upper outboard aspect of the front seat backs. IC air bags were mounted in the roof side rails and provided coverage to the four outboard seat positions. The Ford was equipped with rollover sensing for the IC air bags. The seat back mounted side air bags and the IC air bags did not deploy in this crash.

Hybrid Vehicle Battery System
2006 Ford Escape

The 2006 Ford Escape Hybrid was equipped with a hybrid battery system used to drive an electric motor that assists the gasoline engine. This system improved fuel efficiency while the gasoline engine was in use, and to provide power for vehicle movement at lower speeds without the use of the gasoline engine. The standard battery is a Sanyo Metal Case Module consisting of 250 cells in 50 modules. It has a nominal voltage of 330 V with a capacity of 5.5 Ah using nickel-metal hydride cells and a potassium hydroxide electrolyte. The battery compartment and the battery were inspected for damage due to the crash. The hybrid battery was centered under the rear cargo area of the Ford. The top aspect of the hybrid battery compartment formed the floor of the cargo area of the Ford and was covered with carpeting. There was a circular disconnect switch located at the rear right aspect of the top of the battery. This disconnect switch was found in the "Lock – For Operation" position at the start of the SCI inspection. The switch was turned counterclockwise to the "Unlock" position and was placed in the "Service/Shipping – No Voltage" position for the safety of the researcher during the inspection **(Figure 7)**. The salvage yard was notified of this change. **Figure 8** depicts the hybrid battery in the rear of the Ford.

Figure 7: Hybrid battery disconnect switch in the Ford Escape.

Figure 8: Hybrid battery centered over rear axle and behind rear seat of the Ford Escape.

There was no intrusion rearward of the left B-pillar to the vehicle. The Hybrid battery was not damaged. The individual cells were covered by aluminum covers at the forward and rear aspects. The battery was examined with the covers in place for leakage of fluid or corrosion. No damage to the battery was found.

Occupant Demographics/Data
2006 Ford Escape

Driver Age/Sex:	18-year-old/Male
Height:	183 cm (72 in)
Weight:	82 kg (180 lb)
Eyewear:	None
Seat Track Position:	Rear-track, 3 cm (1.2 in) forward of full-rear
Manual Safety Belt Use:	Lap and shoulder belt
Usage Source:	Vehicle inspection
Egress from Vehicle:	Exited the vehicle unassisted
Mode of Transport from Scene:	None
Type of Medical Treatment:	Treated self at home with ice and ibuprofen

Driver Injuries
2006 Ford Escape

Injury	Injury Severity (AIS 90/Update 98)	Injury Source
Left neck abrasion	Minor (390202.1,2)	Safety belt webbing
Left hand contusion, dorsal aspect	Minor (790402.1,2	Left front door panel (left upper quadrant)
Abdominal contusion	Minor (590402.1,8)	Safety belt webbing

Source - Interview with driver's mother

Driver Kinematics
2006 Ford Escape

The 18-year-old male driver was seated in a rear-track position and was restrained by the manual 3-point lap and shoulder safety belt system. In response to the initial left side impact, the driver initiated a left and forward trajectory within the front left seating position. The driver's chest and abdomen loaded the safety belt and his left hip loaded the left front door panel, evidence by a scuff on the armrest.

The Ford was redirected off the roadway at the northwest corner of the intersection. The front center area of the Ford impacted a tree on the north roadside. This impact actuated the driver's buckle and retractor-mounted pretensioners and deployed the driver's frontal air bag. The deployment of the frontal air bag displaced the driver's left hand from the steering wheel rim. His left hand impacted the left upper quadrant of the left front door panel resulting in the contusion and swelling to the dorsal aspect of his left hand. The driver subsequently initiated a forward trajectory within the front left seating position. As a result of safety belt loading during the crash, the driver sustained an abrasion of the left lateral neck and an abdominal contusion.

Immediately following the crash, the driver exited the vehicle from the right front door. He refused medical treatment at the scene and was transported home by his parents. At home, his injuries were treated with ice and ibuprofen.

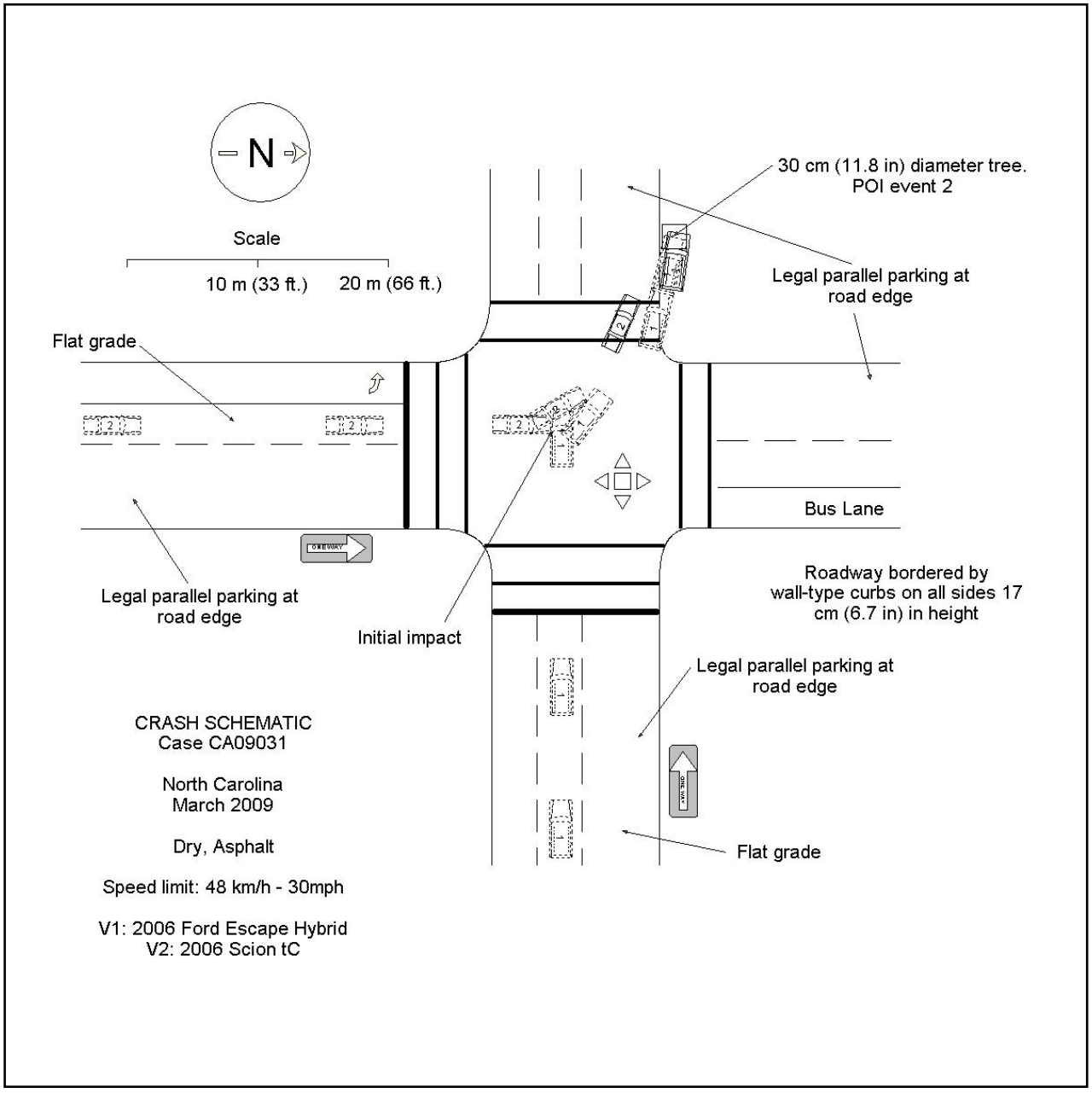

Figure 9: Crash Schematic