TRANSPORTATION SCIENCES
CRASH DATA RESEARCH CENTER

General Dynamics
Buffalo, NY 14225

GENERAL DYNAMICS ON-SITE ADVANCED OCCUPANT PROTECTION SYSTEM (AOPS) INVESTIGATION
SCI TECHNICAL SUMMARY REPORT

CASE NO. CA03-039

VEHICLE – 2001 HYUNDAI ELANTRA

LOCATION - STATE OF NEW JERSEY

CRASH DATE – JULY 2003

Contract No. DTNH22-01-C-17002

Prepared for:

U.S. Department of Transportation
National Highway Traffic Safety Administration
Washington, D.C. 20590

DISCLAIMER

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no responsibility for the contents or use thereof.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

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.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. CA03-039	*2. Government Accession No.*	*3. Recipient's Catalog No.*	
4. Title and Subtitle General Dynamics On-Site Advanced Occupant Protection System (AOPS) Investigation Vehicle: 2001 Hyundai Elantra Location: State of New Jersey		*5. Report Date*: October 2004 *6. Performing Organization Code*	
7. Author(s) Crash Data Research Center		*8. Performing Organization Report No.*	
9. Performing Organization Name and Address Transportation Sciences Crash Data Research Center General Dynamics P.O. Box 400 Buffalo, New York 14225		*10. Work Unit No.* C00410.0000.0138 *11. Contract or Grant No.* DTNH22-01-C-17002	
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration Washington, D.C. 20590		*13. Type of Report and Period Covered* Technical Report Crash Date: June 2003 *14. Sponsoring Agency Code*	
15. Supplementary Note On-site investigation of the Advanced Occupant Protection System (AOPS) in a 2001 Hyundai Elantra that was involved in a front-to-rear collision with a parked vehicle. The impact was sufficient to deploy the driver's safety belt pretensioner and front right passenger's air bag and resulted in a minor knee injury to the front right passenger.			
16. Abstract This on-site investigative effort focused on the performance of the Advanced Occupant Protection System (AOPS) and the injury mechanisms for the occupants of a 2001 Hyundai Elantra. The AOPS included dual-stage frontal air bags for the driver and front right passenger positions, retractor-mounted safety belt pretensioners, load limiting retractors, and an occupant sensing system for the front right position. The Elantra was occupied by a restrained 18-year-old female driver, an unrestrained 86-year-old female front right passenger, and an unrestrained 91-year-old female rear left seat passenger. The female driver of the Elantra was initiating a left turn from a local roadway onto a two-lane arterial roadway. As she initiated the left turn and entered the intersection, she noted a vehicle approaching the intersection from the right in the same travel lane. She steered toward the right outboard aspect of the roadway in an attempt to avoid the collision and struck the rear of a parked Chevrolet S-10 Blazer with the front right aspect. The impact was sufficient to deploy the driver's retractor-mounted safety belt pretensioner. The driver's air bag did not deploy, and the firing of the driver's pretensioner was presumed, since the driver's retractor was locked in the used position. The front right passenger's air bag deployed, however the front right pretensioner did not fire, due to the non-use of the safety belt by the front right passenger. The front right passenger sustained a knee sprain, and the driver and rear seat occupant were not injured. The occupants of the Elantra refused treatment at the scene. Approximately one hour after the crash, the front right and rear left seat occupants were transported to the hospital by a family member where they were evaluated for injuries and released.			
17. Key Words Frontal air bag deployment Occupant sensing Retractor pretensioners		*18. Distribution Statement* General Public	
19. Security Classif. (of this report) Unclassified	*20. Security Classif. (of this page)* Unclassified	*21. No. of Pages* 10	*22. Price*

TABLE OF CONTENTS

GENERAL DYNAMICS ON-SITE ADVANCED OCCUPANT PROTECTION SYSTEM (AOPS) INVESTIGATION
SCI TECHNICAL SUMMARY REPORT
CASE NO. – CA03-039
SUBJECT VEHICLE – 2001 HYUNDAI ELANTRA
LOCATION - STATE OF NEW JERSEY
CRASH DATE – JULY 2003

BACKGROUND

This on-site investigative effort focused on the performance of the Advanced Occupant Protection System (AOPS) and the injury mechanisms for the occupants of a 2001 Hyundai Elantra **(Figure 1)**. The AOPS included dual-stage frontal air bags for the driver and front right passenger positions, retractor-mounted safety belt pretensioners, load limiting retractors, and an occupant sensing system for the front right position. The Elantra was occupied by a restrained 18-year-old female driver, an unrestrained 86-year-old female front right passenger, and an unrestrained 91-year-old female rear left seat passenger. The female driver of the Elantra was initiating a left turn from a local roadway onto a two-lane arterial roadway. As she initiated the left turn and entered the intersection, she noted a vehicle approaching the intersection from the right in the same travel lane. She steered toward the right outboard aspect of the roadway in an attempt to avoid the collision and struck the rear of a parked Chevrolet S-10 Blazer with the front right aspect. The impact was sufficient to deploy the driver's retractor-mounted safety belt pretensioner. The driver's air bag did not deploy, and the firing of the driver's pretensioner was presumed, since the driver's retractor was locked in the used position. The front right passenger's air bag deployed, however the front right pretensioner did not fire, due to the non-use of the safety belt by the front right passenger. The front right passenger sustained a knee sprain, and the driver and rear seat occupant were not injured. The occupants of the Elantra refused treatment at the scene. Approximately one hour after the crash, the front right and rear left seat occupants were transported to the hospital by a family member where they were evaluated for injuries and released.

Figure 1. Damaged 2001 Hyundai Elantra

This crash was identified by the owner of a repair facility who forwarded the crash information to the General Dynamics SCI team. The notification was forwarded to the Crash Investigation Division of the National Highway Traffic Safety Administration (NHTSA) due to the AOPS present in the Hyundai Elantra. An on-site investigation was initiated on July 14, 2003. The Elantra was inspected at a local body shop. The Chevrolet S-10 Blazer was not towed from the scene and could not be located for inspection.

VEHICLE DATA – 2001 Hyundai Elantra

The 2001 Hyundai Elantra was identified by the Vehicle Identification Number (VIN): KMHDN45001U (production sequence omitted). At the time of the vehicle inspection, the odometer read 371,292 km (146,178 miles). The vehicle was owned by the 18-year-old female driver and was classified by the insurance company as a total loss. The vehicle was four-door sedan equipped with a 2.0 liter, 4-cylinder engine, a front-wheel drive, four-speed, automatic transmission, power front disc/rear drum brakes, power steering, and a tilt steering wheel which was found in the full-up position at the time of the inspection. The Elantra was equipped with a Futura 2000 Radial LTE P195/65R15 tire on the left front position and Innovation Jetzon P195/65R15 tires on the remaining OEM steel wheels. The vehicle manufacturer's recommended tire pressure for each tire was 210 kpa (30 psi). The specific tire data is as follows:

Tire	Measured Pressure	Maximum Pressure	Tread Depth	Restricted	Damage
LF	203.4 kpa (29.5 psi)	303.4 kpa (44.0 psi)	6.4 mm (8/32")	No	None
LR	206.8 kpa (30.0 psi)	241.3 kpa (35.0 psi)	7.1 mm (9/32")	No	None
RF	193.1 kpa (28.0 psi)	241.3 kpa (35.0 psi)	5.6 mm (7/32")	No	None
RR	220.6 kpa (32.0 psi)	241.3 kpa (35.0 psi)	7.9 mm (10/32")	No	None

The Elantra was configured with front bucket seats with adjustable head restraints. The driver's seat track was adjusted to 2.5 cm (1.0") forward of full-rear and 21.6 cm (8.5") rear of full forward. The front right passenger's seat track was adjusted to the full-rear track position at the time of the inspection, although the towing company stated the seat was moved by rescue personnel post-crash. The rear seating positions were configured with a bench seat with a 60/40 split folding back.

VEHICLE DATA – 1993 Chevrolet S-10 Blazer

The 1993 Chevrolet Blazer was identified by the VIN on the Police Report as follows: 1GNDT13W9P2 (production sequence omitted). The vehicle was a four-door, 4 x 4, S-10 Blazer that was equipped with a 4.3 liter, V-6 engine, and a driver's air bag. The vehicle was not towed from the crash site, and could not be located for inspection.

Figure 2. Overall view of the intersection - lookback view from the location of the parked Blazer

CRASH SITE

This two-vehicle crash occurred during the daylight hours of July 2003 in the state of New Jersey. At the time of the crash, the weather was clear and the asphalt roadway surface was dry. The crash occurred at a four-leg intersection of a two-lane arterial roadway and a two-lane local roadway **(Figure 2)**. The north/south arterial roadway was configured with one travel lane in each direction separated by a double-yellow centerline

and bordered by concrete curbs. The travel lanes measured 6.2 m (20.3') in width and were wide enough to accommodate parallel curbside parking. The two-lane east/west roadway consisted of one travel lane in each direction and was bordered by concrete curbs. The concrete curbs exhibited yellow paint on the curb faces adjacent to the intersection corners, which identified 'no parking' zones. Both roadways were bordered by concrete sidewalks and residential properties. Traffic flow through the intersection was controlled by stop signs for east and westbound traffic. The posted speed limit for both roadways was 40 km/h (25 mph). The scene schematic is included as **Figure 12** at the end of this report.

CRASH SEQUENCE

Pre-Crash

The 18-year-old female driver of the Elantra was operating the vehicle in an eastbound direction on the two-lane roadway on approach to the four-leg intersection **(Figure 3)**. The driver brought the Elantra to a controlled stop at the stop sign with the intent to initiate a left turn onto the northbound travel lane. The police reported that as the Elantra proceeded into the intersection **(Figure 4)**, the female driver detected a non-contact vehicle approaching at a high rate of speed in the northbound lane. She stated to police that the driver of the northbound vehicle sounded the horn as the Elantra was in the intersection. The driver of the Elantra steered right toward the curb in an attempt to clear the travel lane as the non-contact vehicle approached. She did not detect the 1993 Chevrolet S-10 Blazer that was parked parallel to the right curb of the northbound lane.

Figure 3. Eastbound approach to the intersection for the Elantra

Figure 4. Approach view for the Elantra as it entered the intersection

Crash

The front right aspect of the Elantra struck the rear left aspect of a parked 1993 S-10 Blazer. The direction of force was in the 12 o'clock sector for the Elantra. The Missing Vehicle algorithm of the WinSMASH program computed a total delta-V of 18.0 km/h (11.2 mph) for the Elantra and 14.0 km/h (8.7 mph) for the Blazer, based on the Elantra's frontal crush profile. The impact resulted in minor damage to the Elantra and was sufficient to deploy the front right passenger's air bag and driver's safety belt pretensioner. Given the existence of buckle switches and the Passenger Presence Detection System, the AOPS system most likely suppressed the front right pretensioner and deployed the front right passenger's air bag due to the presence of the front

right occupant combined with the non-use of the safety belt. The impact displaced the Blazer slightly forward, and the Elantra came to rest in the northbound lane adjacent to the Blazer.

Post-Crash

The driver and the rear seat passenger exited the vehicle under their own power. The front right occupant remained in the vehicle until it could be moved, as there was not sufficient space between the vehicles (in the final rest positions) to allow her to exit the vehicle. Once the Elantra was moved rearward, the front right passenger exited the vehicle under her own power. All of the occupants refused medical treatment at the scene. Approximately one hour after the crash, the 86-year-old female and 91-year-old female were transported by a family member to the hospital for evaluation and released.

VEHICLE DAMAGE

Exterior Damage – 2001 Hyundai Elantra

The 2001 Hyundai Elantra sustained moderate frontal damage as a result of the impact with the Blazer. The direct damage on the top aspect of the bumper and leading edge of the hood began 40.0 cm (15.3”) to the right of the centerline and extended laterally 31.1 cm (12.3”) to the front right corner. The top surface of the bumper fascia was scuffed, fractured, and partially separated on the right side aspect. The headlamp was fractured and separated. The hood was crushed and buckled rearward and the right front fender was crushed rearward and buckled outward. Scuffs and paint transfers extended longitudinally on the right front fender. The upper radiator support was crushed rearward **(Figure 5)**. The maximum crush was located at the right corner of the upper radiator support and measured 18.0 cm (7.0”). The combined direct and induced damage measured 142.2 cm (52.0”) and involved the entire frontal width of the vehicle. As a result of the above-bumper crush, the engine was displaced rearward. The rearward displacement resulted in the fracture of the front right motor mount at the bolt **(Figure 6)**. Direct contact scuffs were present on the upper aspect of the firewall from contact with engine components located in the rear aspect of the engine compartment. Six crush measurements were documented along the upper radiator support and were as follows: C1 = 0.0 cm, C2 = 0.0 cm, C3 = 5.1 cm (2.0”), C4 = 10.2 cm (4.0”), C5 = 15.2 cm (6.0”), C6 = 18.0 cm (7.0”). Bumper crush was present only at C6 (right corner), and measured 2.5 cm (1.0”). Since the above-bumper crush exceeded the bumper crush, the bumper-level crush was used for C1 – C4, and the above-bumper and bumper crush were averaged for C5 and C6, per NASS measurement protocols. The resulting average crush profile used for the WinSMASH

Figure 5. Overhead image of the frontal damage to the Elantra

Figure 6. Close-up of fractured motor mount

calculation was as follows: C1 = 0 cm, C2 = 0 cm, C3 = 0 cm. C4 = 0 cm, C5 = 10.7 cm (4.2”), C6 = 10.5 cm (4.1”). The Collision Deformation Classification (CDC) for the impact with the Blazer was 12-FREE-2.

Interior Damage – 2001 Hyundai Elantra

The Elantra sustained minor interior damage **(Figure 7)** as a result of the impact with the Blazer. There were no passenger compartment intrusions. The windshield was fractured from crash forces and from contact with the front right passenger’s air bag and air bag cover flap. A scuff that measured 2.5 x 2.5 cm (1.0 x 1.0”) was located 3.8 cm (1.5”) left of the steering column on the bottom aspect of the knee bolster from probable contact with the driver’s lower leg. The rear view mirror was separated from the windshield. The windshield exhibited white fabric transfers from the front right passenger’s air bag expansion against the interior aspect of the windshield.

Figure 7. Interior view from left side

MANUAL RESTRAINT SYSTEMS – 2001 Hyundai Elantra

The Hyundai Elantra was configured with manual 3-point lap and shoulder belts for each seating position in the vehicle. The front safety belts **(Figures 8 and 9)** were configured with sliding latch plates and adjustable D-rings that were in the full-up positions. The driver’s safety belt had an Emergency Locking Retractor (ELR) and the front right safety belt had a switchable ELR/Automatic Locking Retractor (ALR). At the time of the vehicle inspection, the driver’s safety belt retractor was locked in the used position. The driver’s safety belt exhibited stretch marks in the webbing that began 47.0 cm (18.5”) above the anchor and extended 82.6 cm (32.5”) upward. Abrasions were present on the plastic D-ring as a result of occupant loading and the retractor pretensioner actuation. A diagonal transfer was present on the safety belt webbing 157.5

Figure 8. Driver's safety belt

Figure 9. Front right passenger's safety belt

cm (62.0”) above the anchor from engagement with the D-ring. Since the front right passenger was unrestrained, the front right safety belt did not exhibit any stretch marks in the webbing and the retractor remained functional. Minor abrasions were present on the front right plastic D-ring from historical use.

The rear seat was configured with manual 3-point lap and shoulder belts for each rear seating position. Each safety belt was configured with a sliding latch plate and a switchable ELR/ALR retractor. The rear left passenger was not restrained by the safety belt in this crash.

ADVANCED OCCUPANT PROTECTION SYSTEM (AOPS) – 2001 Hyundai Elantra

The AOPS in the Elantra included dual-stage frontal air bags for the driver and front right positions, retractor-mounted safety belt pretensioners, load limiting retractors, and a Passenger Presence Detection (PPD) system for the front right position. The PPD consisted of a sensor located in the front right seat cushion designed to detect occupant presence and prevent the unnecessary deployment of the front right passenger’s air bag if the seat was unoccupied.

The logic of the AOPS in the Elantra was not known with regard to pretensioner actuation and air bag deployment. Based on information contained in a monthly Hyundai Technical Service publication and electrical diagrams of the AOPS, the frontal air bags and front safety belt pretensioners operated independent of each other. In addition, the wiring diagram identified the presence of buckle switches for both front seat positions. Based on a diagram of the pretensioner present in the Elantra, the pretensioners were configured with multiple aluminum balls in a tube which, when propelled through the tube by a gas generator, engaged the outer teeth of the pretensioner gear which rotated the safety belt retractor. The driver’s frontal air bag did not deploy in this crash. The driver’s retractor pretensioner activated, evidenced by the locking of the retractor in the used position. The front right pretensioner did not appear to have fired during the crash, as the retractor remained functional at the time of the vehicle inspection. Based on the vehicle inspection and AOPS system technical data, it appears that the AOPS system detected a threshold deployment pulse. Given the safety belt usage by the driver, the system determined that since the driver was restrained, the driver’s pretensioner was sufficient and did not deploy the driver’s air bag. However, the deployment of the front right passenger’s air bag and lack of pretensioner firing suggest that the front right passenger was unrestrained, the AOPS detected occupant presence, and the AOPS provided the air bag (most likely a single stage) in lieu of the pretensioner since the buckle switch was not engaged. The Elantra was not equipped with an Event Data Recorder (EDR) to verify the safety belt logic and deployment thresholds.

Figure 10. View of cover flap, fractured windshield, and transfer area

The front right passenger’s air bag deployed from a top-mount module configured with a single rectangular cover flap hinged at the forward aspect that measured 33.0 cm (13.0”) in width and 15.2 cm (6.0”) in height. The cover flap struck and fractured the windshield **(Figure 10)** as the air bag deployed. Air bag transfers

were present on the right aspect of the interior windshield. The transfer area measured 43.8 cm (17.3”) in width and 40.6 cm (16.0”) in height and was located directly over the air bag module. The transfers were longitudinal in orientation and radiated outward on the outboard aspects of the transfer area. Due to the top-mount nature of the air bag module, it appeared that the air bag deployed vertically and was directed rearward (with respect to the vehicle) by the windshield as it expanded. There were no injuries to the front right occupant to support occupant interaction with the air bag during expansion.

The deployed front right passenger’s air bag **(Figure 11)** measured 45.7 cm (18.0”) in width and 55.9 cm (22.0”) in height. It was vented by two circular ports located on the top aspects of the left and right side panels. The vent ports measured 5.1 cm (2.0”) in diameter and were located 17.8 cm (7.0”) aft of the face of the air bag. The air bag was tethered by two straps that were horizontally centered and located 19.1 cm (7.5”) and 36.8 cm (14.5”) from the top aspect of the air bag. Each tether measured 20.3 cm (8.0”) in width. A faint scuff mark was located on the top left quadrant of the air bag that measured 2.5 x 1.3 cm (1.0 x 0.5”) and was located 7.0 cm (2.5”) left of the vertical centerline and 17.1 cm (6.8”) above the horizontal centerline. A second faint scuff mark was located on the bottom right quadrant of the air bag that measured 5.1 x 3.2 cm (2.0 x 1.3”). The scuff mark was located 1.3 cm (0.5”) right of the vertical centerline and 10.8 cm (4.3”) below the horizontal centerline.

Figure 11. Deployed front right passenger's air bag

OCCUPANT DEMOGRAPHICS – 2001 Hyundai Elantra

Driver

Age/Sex:	18-year-old/Female
Height:	157 cm (62”)
Weight:	46 kg (102 lb)
Seat Track Position:	2.5 cm (1.0”) forward of full-rear and 21.6 cm (8.5”) rear of full-forward
Manual Restraint Use:	Manual 3-point lap and shoulder belt
Usage Source:	Vehicle inspection, interview
Eyewear:	None
Type of Medical Treatment:	Did not receive medical treatment

Driver Kinematics

The 18-year-old female driver of the Elantra was seated in an upright posture and was restrained by the manual 3-point lap and shoulder belt. At impact, the retractor-mounted safety belt pretensioner fired and the driver initiated a forward trajectory. She loaded the manual restraint and her left lower leg probably contacted the plastic knee bolster, evidenced by a faint scuff mark. She rebounded rearward and came to rest in the driver’s seat. The driver exited the vehicle

under her own power through the driver's door. She did not sustain injury and did not receive medical treatment.

Front Right Passenger

Age/Sex:	86-year-old/Female
Height:	160 cm (63")
Weight:	64 kg (140 lb)
Seat Track Position:	Unknown (moved post-crash)
Manual Restraint Use:	Unrestrained
Usage Source:	Vehicle inspection
Eyewear:	Prescription eyeglasses
Type of Medical Treatment:	Refused treatment at the scene, but transported to a local hospital an hour after the crash by a family member for evaluation

Front Right Passenger Injuries

Injury	Injury Severity (AIS 90/Update 98)	Probable Injury Mechanism
Knee sprain (NFS)	Moderate (850826.2,9)	Toe pan (indirect)

Injury source: Interview with family member

Front Right Passenger Kinematics

The 86-year-old female front right passenger was seated in an upright posture. Although safety belt use was maintained by a family member, the non-actuation of the pretensioner and the deployment of the front right passenger's air bag suggest the front right passenger was unrestrained. There was no loading evidence on the safety belt webbing consistent with restraint usage, however, it should be noted that this minor severity crash would most likely not produce significant loading evidence on the webbing.

At impact, the front right passenger's air bag deployed. The unrestrained front right passenger initiated a forward trajectory and loaded the deployed air bag. She sustained an unspecified knee sprain as a result of transmitted crash forces from the probable bracing of her feet against the toe pan. The deployed air bag provided additional protection to the unrestrained front seat occupant from the frontal crash forces and contact with the instrument panel. She rebounded rearward and came to rest upright in the seat. She was unable to exit the vehicle immediately after the crash because there was not sufficient space between the vehicles to open the door fully. The Elantra was pushed rearward to provide adequate space for the right front door to be opened fully, and the front right passenger exited the vehicle under her own power. She did not receive medical treatment at the scene, but was transported by a family member to a local hospital approximately one hour post-crash for a complaint of knee pain. She was treated and released.

Rear Left Passenger

Age/Sex:	91-year-old/Female
Height:	152 cm (60”)
Weight:	57 kg (125 lb)
Seat Track Position:	Fixed
Manual Restraint Use:	Unrestrained
Usage Source:	Vehicle inspection, interview
Eyewear:	None
Type of Medical Treatment:	Refused treatment at the scene, but transported to a local hospital an hour after the crash by a family member for evaluation

Rear Left Passenger Kinematics

The 91-year-old female rear left passenger was seated in an upright posture. She was not restrained by the available manual 3-point lap and shoulder belt. At impact, she initiated a forward trajectory and struck the rear aspect of the driver’s seat back. She loaded the seat back and rebounded rearward. The 91-year-old female exited the vehicle through the left rear door under her own power. She did not sustain injury and refused medical treatment at the scene. She was transported to a local hospital by a family member with the front right passenger approximately one hour after the crash for evaluation and released.

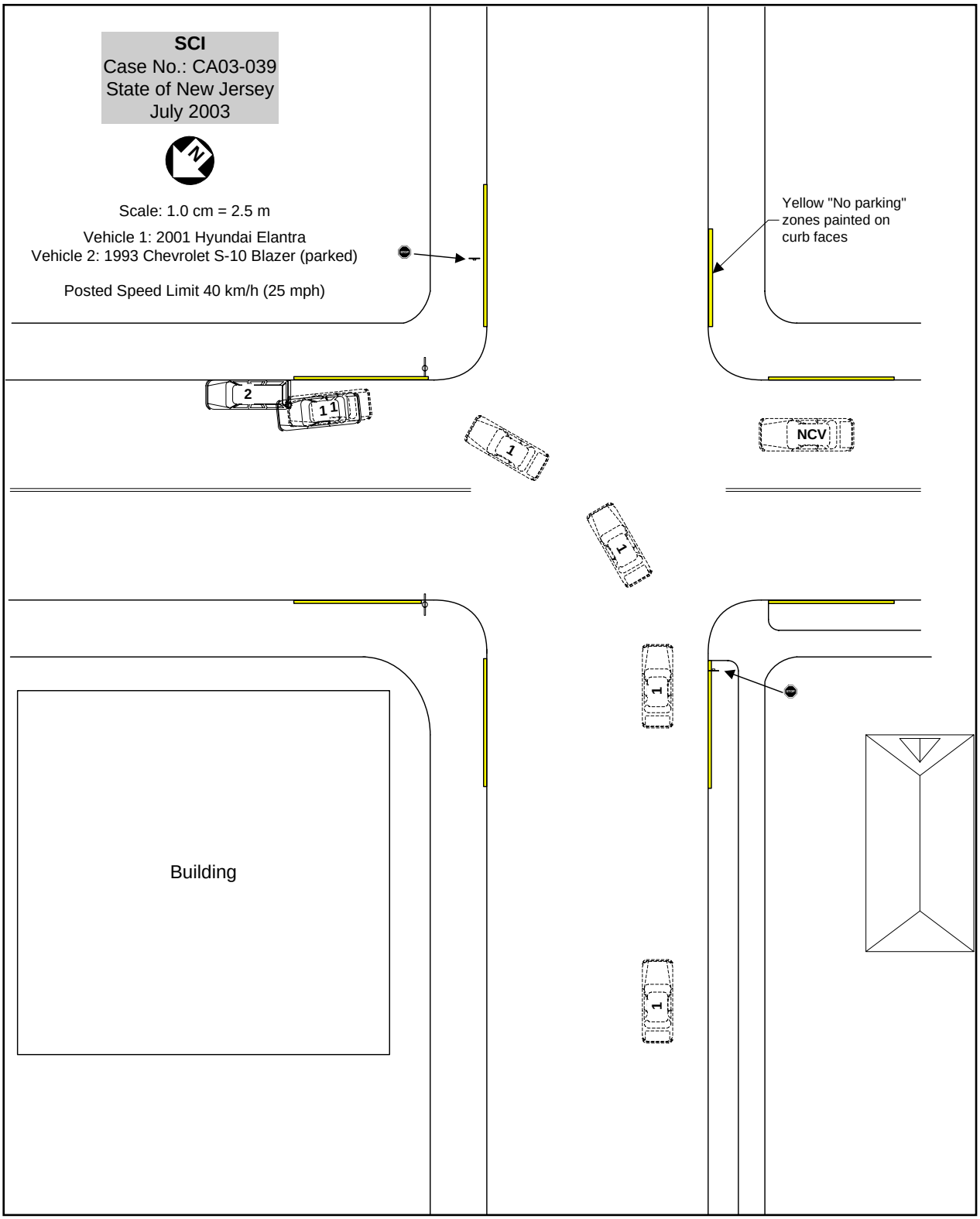

Figure 12. Scene schematic