Rollover Investigation
Dynamic Science, Inc. (DSI), Case Number DS09023
2008 Smart Fortwo Coupe
California
February 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 be 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 dynamics of a 2008 Smart Fortwo coupe that was involved in a rollover crash. The crash occurred on a six-lane divided state highway. On the right side of the roadway there was a set of traffic barrels protecting a concrete traffic barrier. North of the barriers was a self-contained speed display that is towed to sites to promote compliance with the speed limit. The Fortwo was being driven northbound by a 64-year-old male. The vehicle drifted to the right and onto the right shoulder. The right front of the vehicle struck the barrel barriers, began a clockwise rotation and, after rotating approximately 45 degrees, impacted the radar trailer. The trailer was displaced forward and the vehicle continued the rotation until reaching a 90 degree angle where it tripped and began a left side leading rollover. The Fortwo rolled two quarter-turns and struck the radar trailer with its right side. The vehicle rolled one additional quarter-turn before coming to rest on its right side. During the crash, the driver's frontal air bag and the left seat-mounted side air bag deployed. The driver sustained a right hip fracture, rib fractures, lacerations to his chin and cheeks, and a liver laceration. The police report stated that the driver was entrapped under the dashboard of the passenger side of the vehicle. The driver was extricated by emergency personnel and transported to a local trauma center by ground ambulance.

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BACKGROUND

This on-site investigation focused on the dynamics of a 2008 Smart Fortwo coupe that was involved in a rollover crash (**Figure 1**). The crash occurred on February 2009 at 0130 hours in California. The crash occurred on a six-lane divided state highway. On the right side of the roadway there was a set of traffic barrels protecting a concrete traffic barrier. North of the barriers was a 2000 Smart Monitoring Awareness Radar Trailer (SMART). The device is a self-contained speed display that is towed to sites to promote compliance with the speed limit.

Figure 1. Right front, Smart Fortwo

The Fortwo was being driven northbound by a 64-year-old male. The vehicle drifted to the right and onto the right shoulder. The right front of the vehicle struck the barrel barriers, began a clockwise rotation and, after rotating approximately 45 degrees, impacted the radar trailer. The trailer was displaced forward and the vehicle continued the rotation until reaching a 90 degree angle where it tripped and began a left side leading rollover. The Fortwo rolled two quarter-turns and struck the radar trailer with its right side. The vehicle rolled one additional quarter-turn before coming to rest on its right side.

The Fortwo was a Certified Advanced 208-Compliant (CAC) vehicle and was equipped with advanced dual stage frontal air bags, seat-mounted side air bags, and safety belt retractor pretensioners. The multi-stage air bags were certified by the manufacturer to be compliant with the advanced air bag requirements of Federal Motor Vehicle Safety Standard (FMVSS) No. 208. During the crash, the driver's frontal air bag and the left seat mounted side air bag deployed.

The driver sustained a right hip fracture, rib fractures, lacerations to his chin and cheeks, and a liver laceration. The police report stated that the driver was entrapped under the dashboard of the passenger side of the vehicle. The driver was extricated by emergency personnel and transported to a local trauma center by ground ambulance.

This on-site rollover investigation was identified by DSI in an internet vehicle auction database. Photos and information about the Fortwo were forwarded to the National Highway Traffic Safety Administration (NHTSA) on April 30, 2009. On May 15, 2009 NHTSA requested that DSI obtain permission to inspect the vehicle. Permission to inspect the vehicle was given on June 6, 2009. DSI was assigned the case on June 8, 2009. The vehicle inspection took place on June 9, 2009. Field work was completed on June 14, 2009.

SUMMARY

Crash Site

It was dark at the time of the crash and the streetlights were illuminated The nearest streetlight was located 28.9 m (95 ft) north of the area of impact. The roadway was configured with three northbound lanes (**Figure 2**) and three southbound lanes that were divided by an unpaved median delineated by double yellow lines. The roadway was bordered on the right by a solid white fog line, a 2.4 m (8 ft) bicycle lane, and on the left by a solid white fog line adjacent to a metal guardrail. The asphalt roadway alignment transitioned from a short straight stretch of highway to a gradual left curve. Profile measurements of the northbound lanes were taken at three intervals. At the area of impact, the grade was a negative 2.5 percent; at 30.4 m (100 ft) from impact, the grade was a negative 2 percent; and at 106.7 m (350 ft) from impact, the grade was a negative 1 percent. The roadway was dry and free of defects at the time of the crash. The posted speed limit was 72 km/h (45 mph).

Figure 2. North approach at 106.6 m (350 ft) from impact

Figure 3. Approach to impact with traffic barrels

A concrete barrier was located 4.8 m (16 ft) east of the roadway edge (**Figure 3**). The distance between the road edge and the barrier gradually narrowed in the northerly direction. There was a set of eleven traffic barrel protecting the southern end of the concrete barrier. The barrels were arranged with three barrels in a line followed by four sets of two barrels side by side. This layout was designed for roadways with vehicle speeds of 72 km/h (45 mph). The distance from the barrier to the first barrel was 6.7 m (22 ft). Each barrel was yellow in color, filled with sand, and covered with a black lid. The barrels each measured 99 cm (38.9) in width at the top, 84 cm (33.0 in) in width at the bottom, and 90 cm (35.4 in) in height. They had a sand capacity of 635 kg (1400 lbs). The lead barrel was configured with a black and yellow striped reflective warning sign.

Pre-Crash

The Fortwo was traveling northbound in the first lane from the right at an unknown speed. The driver's daughter stated to the police that her father did not recall the crash but was very tired on his way home from work and may have fallen asleep. She also advised that her father had just returned from overseas and was recovering from jet lag. The vehicle was negotiating a left curve and for unknown reasons departed the roadway on the right side.

Crash

The right front of the Fortwo impacted the first and probably the second barrel (**Figure 4**). The Damage algorithm of the WinSMASH program computed a Total Delta-V of 23 km/h (14.3 mph). The longitudinal and lateral components were -23 km/h (-14.3 mph) and 0 km/h, respectively. The results were borderline because of the yielding nature of the traffic barrels. The driver's frontal air bag deployed during the impact. The Fortwo began a clockwise rotation and, after rotating approximately 45 degrees, it impacted the radar trailer. The driver's seat-mounted side air bag deployed during this impact. The trailer was displaced forward and the Fortwo continued the rotation until reaching a 90 degree angle relative to its original path of travel where it tripped and began a left side leading rollover. The Fortwo rolled two quarter-turns and struck the radar trailer with its right side. The vehicle rolled one additional quarter-turn before coming to rest on its right side.

Figure 4. Area of impact with barrels and rollover

Post-Crash

The driver sustained a right hip fracture, rib fractures, lacerations to his chin and cheeks, and a liver laceration. The police report stated that the driver was entrapped under the dashboard of the passenger side of the vehicle. The driver was extricated by emergency personnel and transported to a local trauma center by ground ambulance. It is not known if he was released or hospitalized.

The Fortwo was towed from the scene due to damage was later declared a total loss by the insurance company.

Vehicle Data - 2008 Smart Fortwo Coupe

The 2008 Smart Fortwo coupe was identified by the Vehicle Identification Number (VIN): WMEEJ31XX8Kxxxxxx. The vehicle's date of manufacture was February 2008. There was no power to the instrument panel and the vehicle mileage was not known. The Fortwo was a 3-door hatchback that was equipped with a 1-liter, 3-cylinder engine, an automated manual 5-speed transmission, rear wheel drive, anti-lock brakes, and electronic stability and traction control. The Fortwo was 270 cm (106 in) in length and 156 cm (61 in) in width. The vehicle was designed with a panoramic roof module made of silicon hardcoated polycarbonate. The vehicle was configured with Continental Contiprocontact 155/60R15 tires on the front and 175R15 tires on the rear. The tire manufacturer's recommended maximum pressure was 303 kPa (44 psi). The vehicle manufacturer's recommended cold tire pressure was 200 kPa (29 psi) for the front and 248 kPa (36 psi) for the rear. The specific tire information was as follows:

Position	Measured Pressure	Measured Tread Depth	Restricted	Damage
LF	Tire Flat	8 mm (10/32 in)	No	De-beaded
LR	172 kPa (25 psi)	7 mm (9/32 in)	No	None
RR	186 kPa (27 psi)	9 mm (11/32 in)	No	None
RF	Tire Flat	6 mm (7/32 in)	Yes	None

The seating in the Fortwo was configured with front bucket seats with integral head restraints. Both seats were adjusted to the rear most track positions at the time of inspection. By design, the front right seat is positioned slightly rearward of the driver seat to optimize shoulder room. With the seats in the rear most position, the front right seat was located 9 cm (3.5 in) aft of the driver's seat.

Vehicle Damage - 2008 Smart Fortwo Coupe

Exterior Damage

The Fortwo sustained moderate front end damage as a result of the initial impact with the traffic barrels (Event 1). The damage began at the right front bumper corner and extended 70 cm (27.5 in) to the left (**Figure 5**). The right side wheelbase was shortened by 14 cm (5.5 in). The right front wheel was damaged; 7 of the 9 spokes on the aluminum wheel were fractured. Six crush measurements were taken at the bumper level as follows: C_1 = 0 cm, C_2 = 1 cm (0.4 in), C_3 = 4 cm (1.6 in), C_4 = 10 cm (3.9 in), C_5 = 20 cm (7.9 in), C_6 = 29 cm (11.4 in). The Collision Deformation Classification (CDC) for the impact with the barrels was 12FZEW4.

Figure 5. Frontal damage and crush measurement

The Fortwo sustained moderate left side damage from the initial impact with the radar trailer (Event 2). Along the left roof side rail, there was a 20 cm (7.9 in) area of contact that began 99 cm (38.9 in) aft of the front axle. The left door panel was not present during the inspection but probably sustained damage from trailer impact. The rear aspect of the left door reinforcement beam was deformed laterally 3 cm (1.2 in). The CDC for the impact with the trailer was 10LPAN3.

The vehicle sustained direct and induced damage to the left and right sides and the roof during the

rollover (Event 3). The direct contact to the left side of the vehicle began at the front bumper corner and extended 71 cm (27.9 in) rearward to the door opening (**Figure 6**). There was 90 cm (35.4 in) of direct contact that extended from the A-pillar into the roof side rail. On the right side of the vehicle, there were scratches that began 23 cm (9.0 in) forward of the rear bumper corner and extended 37 cm (14.6 in) forward. The scratches extended to a height 89 cm (35.0 in) above the ground. There was also 51 cm (20.0 in) of direct contact along the right A-pillar. The roof damage began at the right windshield header and measured 51 cm (20.0 in) in width by 21 cm (8.3 in) rearward (**Figure 7**). The transparent polycarbonate roof was cracked. The crack was L-shaped and measured 85 cm (33.5 in) along the left roof side rail and 68 cm (26.8 in) laterally from left to right. The crack formed an opening 56 cm (22.0 in) in length and 9 cm (3.5 in) in height. The maximum vertical crush was located at the right A-pillar and measured 2 cm (0.8 in). The CDC for the rollover was 00TPZO1.

Figure 6. Left side damage

Figure 7. Top rollover damage

The right side of the vehicle also sustained direct damage from the second impact with the radar trailer (Event 4). The damage began 92 cm (36.2 in) forward of the rear axle and extended 22 cm (8.7 in) forward along the sill (**Figure 8**). The damage was located 36 cm (14.2 in) above the ground and was deformed upwards. The direct damage probably also extended into the right door but this could not be verified. The CDC for the impact with the trailer was 00RPLN1.

Figure 8. Right side damage

Interior Damage

The Fortwo sustained moderate interior damage as a result of intrusions and occupant contacts. Both doors were jammed shut. The windshield was cracked and holed and the side glazing was disintegrated. The hole in the windshield measured 51 cm (20.0 in) in width by 14 cm (5.5 in) in height. The rear view mirror was displaced from the windshield.

The passenger compartment sustained vertical, lateral, and longitudinal intrusions. The specific intrusions were as follows:

Row/Position	Intruded Component	Magnitude of Intrusion	Direction
Front left	Seat back	12 cm (4.7 in)	Lateral
Front left	Roof side rail	7 cm (2.8 in)	Lateral
Front right	Toe pan	7 cm (2.8 in)	Longitudinal
Front left	Center tunnel	5 cm (1.9 in)	Lateral
Front right	Floor	4 cm (1.6 in)	Vertical
Front left	B-pillar	4 cm (1.6 in)	Lateral
Front left	Door, rear upper quadrant	4 cm (1.6 in)	Lateral

Manual Restraints

The Fortwo was configured with 3-point manual lap and shoulder belts for the two seating positions. Both safety belts were equipped with retractor pretensioners. The driver's safety belt was configured with a sliding latch plate and an Emergency Locking Retractor (ELR). The passenger safety belt was configured with a sliding latch plate and a switchable ELR/Automatic Locking Retractor (ALR). There were no indications of usage related to this crash for the driver's belt. There was no scratching to the latch plate and no stretch marks to the webbing and the pretensioner did not actuate, which was indicative of non-use.

Supplemental Restraint System

The Fortwo was equipped with advanced occupant protection systems including multi-stage driver and front right passenger air bags. The driver's frontal air bag deployed as a result of the longitudinal deceleration of the Fortwo during the traffic barrels impact. The front right passenger's air bag did not deploy and the retractor pretensioners did not actuate for either seat. The Fortwo was also equipped with seat-mounted side air bags. The driver's seat-mounted side air bag deployed at impact with the radar trailer.

The driver's frontal air bag deployed from the center of the steering wheel hub through asymmetrical I-configuration module cover flaps (**Figure 9**). The left flap measured 8 cm (3.1 in) along the top and 8 cm (3.1 in) vertically to a 4 cm (1.6 in) offset. The right flap measured 3 cm (1.2 in) along the top and 8 cm (3.1 in) vertically to a 4 cm (1.6 in) offset. The air bag measured 45 cm (17.7 in) in diameter in its deflated state. The air bag was tethered by a single internal strap. Circular stitching on the face of the air bag measured 15 cm (5.9 in) in diameter.

Figure 9. Driver's air bag

A single 3 cm (1.2 in) circular vent port was located at the 12 o'clock aspect on the rear of the air bag. A black 3 x 2 cm (1.2 x 0.8 in) scuff was located 6 cm (2.4 in) to the right of bag centerline and 8 cm (3.1 in) above the bag centerline.

Figure 10. Seat-mounted side air bag

The driver's seat-mounted side air bag deployed forward from a triangular-shaped cover flap (**Figure 10**). The flap measured 33 cm (12.9 in) along the rear seat back, 37 cm (14.5 in) along the forward seat back, and 11 cm (4.3 in) along the base. The air bag extended forward 52 cm (20.5 in) and was 34 cm (13.3 in) in height at the rear and 31 cm (12.2 in) at the front. On the inboard panel of the air bag, there was a 19 x 13 cm (7.5 x 5.1) red transfer on the rear aspect and a 21 cm (8.3 in) long red transfer along the lower forward edge. The transfer was probably related to contact between the door panel and the air bag as the air bag unfolded during deployment. On the outboard panel of the air bag, there was a 21 x 13 cm (8.3 x 5.1 in) area of scuffing on the rearward portion of the bag.

Rollover Discussion

The Fortwo had a Static Stability Factor (SSF) of 1.16. The SSF of a vehicle is an at-rest calculation of its rollover resistance, which is based on its track width and center of gravity. The vehicle had a rollover resistance rating of 3 out of 5 stars, and had a 21% chance of rollover[1]. The vehicle was equipped with anti-lock brakes, brake force distribution, and electronic stability and traction control.

At impact with the traffic barrels, the Fortwo initiated a clockwise rotation. The left side of the Fortwo impacted and displaced the radar trailer. The vehicle continued the clockwise rotation approximately 90 degrees to a point at which the roadway's opposing forces against the left side tires induced a trip rollover, left side leading. The vehicle rolled about its longitudinal axis for two quarter-turns before impacting the radar trailer with its right side the third and final quarter- turn. The vehicle came to rest on its right side west of the barrels facing east. The estimated roll distance was 4 m (13 ft).

There was insufficient time and distance between the initial impact and roll for the stability control technology to counteract the vehicle's lateral movement.

Occupant Demographics

	Driver
Age/Sex:	64/Male
Seated Position:	Front left

[1] www.safercar.gov

Seat Type:	Bucket
Seat track position:	Middle track
Height:	168 cm (66 in)
Weight:	73 kg (160 lbs)
Alcohol/Drug Involvement:	None
Body Posture:	Unknown
Hand Position:	Unknown
Foot Position:	Unknown
Restraint Usage:	None
Air bags:	Steering wheel mounted frontal air bag deployed. Seat-mounted side curtain air bag deployed.

Occupant Injuries

Driver: Injuries obtained from police and interviewee.

Injury	AIS Code	Injury Mechanism	Confidence Level
Liver laceration	541820.2,1	Steering wheel rim	Possible
Right hip fracture	852600.2,1	Center console/shifter	Possible
Rib fractures, left	450220.2,2	Left door	Probable
Chin laceration	290600.1,8	Driver air bag	Probable
Bilateral cheek abrasions	290202.1,1 290202.1,2	Driver air bag	Probable

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Driver Kinematics

The 64-year-old male driver was seated in an unknown posture and was not using the vehicle's 3-point manual lap and shoulder belt. The cloth-covered bucket seat was set to the middle track position and the seat back was slightly reclined. At impact with the traffic barrels, the driver was displaced forward in response to the 12 o'clock direction of force. He engaged the deployed frontal air bag with his face and torso, possibly causing the lacerations to his chin and cheeks. He possibly engaged the lower steering wheel rim and the deployed air bag with his abdomen, causing a liver laceration. His left knee engaged the lower instrument panel and the metal bracket just below the panel (**Figure 11**). The Fortwo initiated a clockwise rotation and the driver was displaced to the right in response to the vehicle's rotation. At impact with the trailer, the driver was displaced sharply to the left and probably contacted the door and the side air bag and caused the left rib fractures. As the vehicle tripped, the driver was still in contact with the left door as the vehicle began its first quarter-turn. The driver was displaced from his seat as the vehicle rolled onto the roof and was displaced to the right during the final quarter turn. His right hip and thigh engaged the center console mounted shift and the ignition key (**Figure 12**), probably causing the right hip fracture. He came to rest trapped between the right instrument panel and the seat. The vehicle was rolled back onto its wheels and the right door was removed to extricate the driver. The driver was transported to a local trauma center by ground ambulance. It is not known if he was released or admitted.

Figure 11. Lower instrument panel knee contact

Figure 12. Shifter and key contacts

Attachment 1. Scene Diagram