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ON-SITE ADAPTED CONTROL VEHICLE INVESTIGATION

VERIDIAN CASE NO: CA99-008

VEHICLE: 1995 PLYMOUTH VOYAGER/BRAUN CONVERSION

LOCATION: VIRGINIA

CRASH DATE: MAY, 1999

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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 of the involved vehicle(s) or their safety systems.

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17. *Abstract*

This on-site investigation focused on the single vehicle/median barrier crash of a modified 1995 Plymouth Voyager/Braun Conversion and the injuries and injury mechanisms of the 36 year old disabled female driver. The vehicle was equipped with a wheel chair lift, tri-pin steering control device, modified chest restraint, and associated adaptive controls to meet the needs of the incomplete quadriplegic driver. The Plymouth was also equipped with a Supplemental Restraint System (SRS) that consisted of driver and front right passenger air bags that deployed as a result of the crash. The female driver sustained a right forearm fracture, rib fractures, pneumothorax, liver laceration, multiple lower extremity fractures and a forehead laceration as a result of the crash.

The Field Operations Branch of the National Highway Traffic Safety Administration (NHTSA) was informed of the crash on May 10, 1999. NHTSA in-turn assigned an investigation of the crash to the Special Crash Investigation team at Veridian/Calspan on the same day. Cooperation with the local authorities was established and the vehicle was quarantined pending SCI investigation.

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BACKGROUND

This on-site investigation focused on the single vehicle/median barrier crash of a 1995 Plymouth Voyager/Braun Conversion and the injuries and injury mechanisms of the 36 year old disabled female driver. The vehicle was equipped with a wheel chair lift, Tri-pin steering control device, modified chest restraint, and associated adaptive controls to meet the needs of the incomplete quadriplegic driver. The Plymouth was also equipped with a Supplemental Restraint System (SRS) that consisted of driver and front right passenger air bags that deployed as a result of the crash. The female driver sustained a right forearm fracture, rib fractures, pneumothorax, liver laceration, multiple lower extremity fractures and a forehead laceration as a result of the crash.

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SUMMARY

Crash Site

This single-vehicle crash occurred during the early morning hours of May 1999. At the time of the crash, it was dark; the area was not lighted by overhead street lights. The weather was clear and not a causative factor in the crash. The crash occurred in the eastbound lanes of a limited access toll road in the Commonwealth of Virginia. The eastbound roadway was level and consisted of 4 traffic lanes. There was a shallow curve to the right. **Figure 1** is a view of the crash site**.** A Jersey type median barrier ran parallel to and was located approximately 0.3 m (1 ft) in-board of the left most lane. The speed limit in the area of the crash was 89 km/h (55 mph).

Figure 1: Easterly view of the crash scene.

Pre-crash

The driver of the 1995 Plymouth Voyager (post-manufacture modified) was a 36 year old handicapped female. She reportedly was a C5/C6 incomplete quadriplegic. She had the use of her biceps and some upper torso mobility. She reportedly sustained her spinal injury in the summer of 1994 and had been driving an adapted controlled vehicle since late 1995/early 1996.

Crash

A witness traveling behind the Plymouth recalled the vehicle traveling in the left center lane. Due to a probable combination of alcohol and drowsiness, the driver relinquished directional control and allowed the vehicle to drift to the left. Post-crash police investigation determined the driver's Blood Alcohol Content (BAC) was above the legal limit. The van drifted through the in-board lane and sideswiped the median barrier with the vehicle's left side. The driver probably was awakened by the contact and reacted by steering to the right and then over-corrected back to the left. The crash occurred with the left frontal area of the van striking the median barrier. The delta V of the impact was determined to be approximately 27 km/h (17 mph). The force of the impact caused the deployment of the vehicle's driver and front right passenger air bags. The location and extent of the vehicle's damage indicated the Plymouth departed the road at a heading angle of approximately 15-20 degrees (relative to the road). After the impact, the van rotated approximately 180 degrees, while sliding eastward approximately 23 m (75 ft) to rest. The police officer indicated the van came to rest facing southward, under the overpass in Figure 1. **Figure 2** is a schematic of the crash scene.

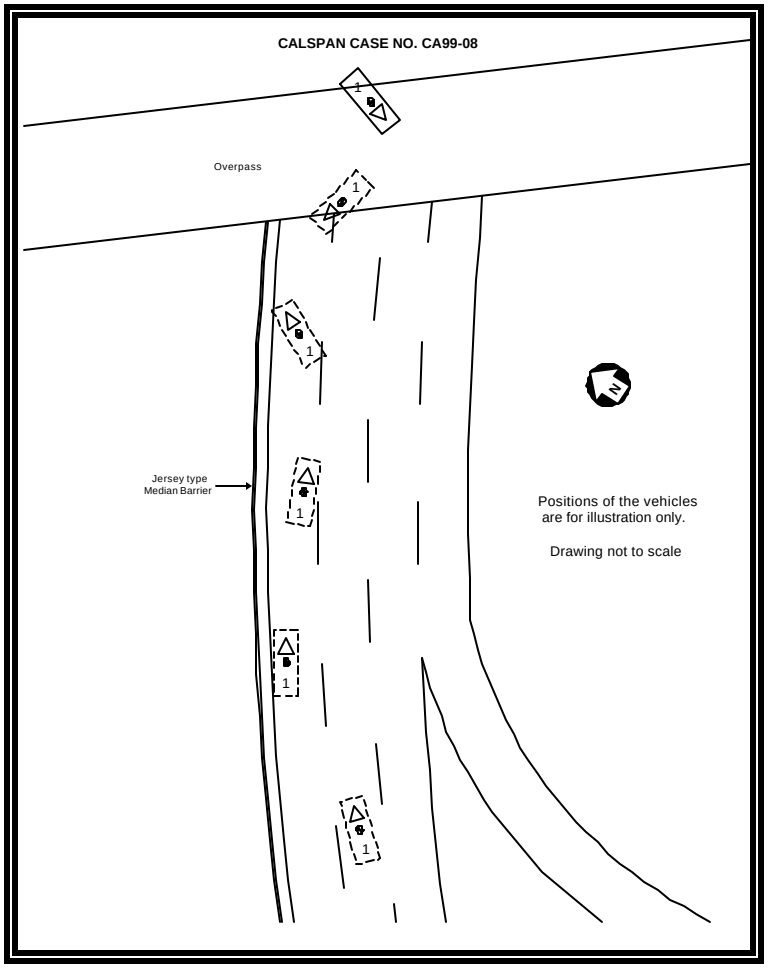

Figure 2: Crash Schematic.

Post-crash

The police officer investigating the crash was on-scene within 2 minutes of notification. Upon her arrival, she found the driver to be in a semi-conscious state slipping in and out of consciousness. The driver was being tended to by a medical doctor, who reportedly was a passer-by and stopped to render assistance. The police officer secured the scene and set-up flares to alert on-coming traffic to the disabled van. The ambulance arrived approximately 2 minutes after the police and began administering aid. The EMS personnel removed the right front seat to access the driver through the right front door. The driver was removed from her wheelchair and placed on a back board. The driver was transported in critical condition to the emergency room of a level 1 trauma center. The trauma center was located within 10 miles of the crash. The driver was admitted and placed in the intensive care in critical condition.

ADAPTIVE CONTROL VEHICLE

The 1995 Plymouth Voyager was identified by a Vehicle Identification Number (VIN): 1P4GH54R7SX (production sequence deleted). The Plymouth was badged the Grand Voyager and was configured with the extended wheelbase. The gross vehicle weight rating was 2,359 kg (5,200 lb). The power train consisted of a 3.3 liter, V6 engine linked a 4-speed automatic transmission. The Plymouth was equipped with a Supplemental Restraint System that consisted of driver and front right passenger air bags that deployed as a result of the above threshold crash. The date of vehicle manufacture was August 1994. The odometer read 62,326 km (38,729 miles) upon inspection.

The OEM vehicle was modified in September 1994 by the Braun Corporation of Winimac, Indiana. These modifications included the installation of the Braun's Entervan II Conversion that included:

- 25 cm (10 in) lowered floor, firewall to rear axle;
- Power kneeling system with locking out feature;
- Power entrance ramp;
- Power sliding door, with manual release;
- Remote control for kneeling, door and ramp;
- (1) wheelchair & occupant belt system;
- Quick release front driver seat;
- Quick release front passenger seat;
- 3-passenger rear bench seat.

The Entervan II Conversion was identified by the Model No: 52000A, Engineering Series No: 02, Serial No: 1834, Engineering Ramp Series No: 03, Door Operation Series No: 02, (52000A-02-1834-03-02). The post-manufacturer's label, affixed to the left B-pillar, indicated the altered vehicle conformed to all applicable Federal Motor Vehicle Safety Standards in effect as of October 1994.

The vehicle was further modified in April 1996 to meet the specific needs of the quadriplegic female driver to include:

- Tri-pin steering device;
- Steering column extension;

- Low-effort steering;
- EGB II (Electronic Gas Brake Control) hand control;
- Digi pad electronic engine and accessory controls;
- EZ-lock wheelchair hold down
- Chest restraint (refer to *Manual Restraint System* page 5 for detail)
- Instructors training brake.

Refer to the Adaptive Controls Section on Page 7 for further detail of these features.

Exterior Damage

The left side of the Plymouth, **Figure 3**, sustained longitudinal scratches and abrasions consistent with sideswiping contact to the Jersey median barrier. The damage was centered primarily about the left rear wheel well, began 49.0 cm (19.3 in) forward of the left rear axle and extended 141.7 cm (55.8 in) rearward to the left rear corner. There also was a 7.6 cm (3.0 in) wide band of scratches located 129.5 cm (51.0 in) forward of the left rear axle, immediately aft of the left door. There was no measurable lateral deformation associated to the left side damage, only surface (paint) scratches and abrasions. The damage occurred in the front to rear direction. The Collision Deformation Classification (CDC) of the contact was 12-LZES-01.

Figure 3: View of the left side scratches/abrasions.

The vehicle's frontal plane sustained direct and induced damage across the its entire 138.4 cm (54.5 in) frontal end width, **Figure 4**. The width of the direct contact damage measured 38 cm (15 in), began 21.6 cm (8.5 in) left of center and extended to the left front bumper corner. The crush profile measured as follows: C1=61.0 cm (24.0 in), C2=30.5 cm (12.0 in), C3=19.1 cm (7.5 in), C4=10.2 cm (4.0 in), C5=2.5 cm (1.0 in), C6=10.7 cm (4.2 in). The bumper fascia was displaced from the reinforcement bar by the impact. The left front fender deformed laterally and buckled rearward into contact with the left door. The left door also was buckled. The door was operational, but very restricted. The forward left aspect of the roof buckled above the driver's position. The lower left aspect of the windshield was fractured by the frontal deformation. The left front and middle side glazings disintegrated. The left wheelbase was foreshortened approximately 23 cm (9 in). The left front wheel rim

Figure 4: Left front view of the frontal damage.

was bent and the tire had aired out. The CDC of the impact was 11-FLEW-3. The Barrier Equivalent Delta V calculated by the WINSMASH model was 26.5 km/h (16.5 mph). The longitudinal and lateral components of the velocity change were -23.0 km/h (-14.3 mph) and 13.3 km/h (8.3 mph), respectively.

Interior Damage

The interior damage to the Plymouth Voyager was associated to both the intrusion caused by the exterior crash forces and the occupant contacts within the compartment. The intrusion into the vehicle consisted of 15-20 cm (6-8 in) of rearward deformation of the left toe pan. The brake pedal was bound by the deformation and would not move. The deformation also caused a rotation of the auxiliary stepper motor which applied the brakes. The driver's bolster exhibited a contact from the right lower extremity. The contact was located approximately 7 cm (3 in) right of the steering column centerline and measured approximately 18 cm x 3 cm (7 in x 1 in). The contact occurred due to the driver's forward kinematic pattern in response to the impact. The tilt steering wheel/column, **Figure 5**, was in the full up position at inspection and appeared to have been loaded forward and left, consistent with the 11 o'clock direction of the impact force. The right shear capsule displacement measured approximately 1.5 cm (0.6 in). The left shear capsule was not accessible.

Figure 5: View of the steering wheel/column.

Manual Restraint System

The driver's position of the altered Plymouth Voyager was equipped with a modified chest restraint, in addition to the OEM 3-point lap and shoulder belt system. The OEM lap and shoulder belt system would typically have been used when the standard OEM driver's seat was installed. When the OEM driver's seat was removed, the OEM 3-point lap and shoulder belt would remain stowed within the retractor and not used by the disabled driver. The modified chest restraint was be utilized.

Figures 6 and 7 are views of the modified chest restraint used by the disabled driver. The upper outboard anchor of the chest restraint was fastened to the adjustable D-ring, (attached using the same fastener as the OEM belt). The belt webbing was attached to the floor of the van via a modified floor anchor. Refer to **Figure 8**. The anchor consisted of a formed steel section that was spot-welded to the floor. The section measured 130 cm (51 in) and spanned the width of the vehicle. There were thirteen 1 cm x 5 cm (0.5 in x 2.0 in) slots to allow for the adjustment of the lateral position of the inboard anchor. The third slot, approximately 33 cm (13 in) from the vehicle's right side, was the inboard anchor location. The webbing was worn across the driver's chest and was routed over the inboard side of the wheelchair. The total length of the webbing section measured 173 cm (68 in) in the buckled condition. The length of the restraint

was adjusted on the inboard aspect of the webbing with a locking latch plate. Duct tape had been used to secure the adjusted (loose) end of the webbing. It could not have been easily re-adjusted. Refer to Figure 8. Due to the chest restraint's overall length and geometry, belt slack was in this restraint system. This belt slack reduced the efficiency of the restraint. It should be noted, there was no lap belt available for the wheel-chaired driver. The modified chest restraint would typically be left in the buckled condition, such that the handicapped driver could simply enter the vehicle and lock the wheelchair in the driver's position and the chest restraint would already be positioned - ready for use.

The belt webbing was cut 34.3 cm (13.5 in) from the D-ring, by the EMS personnel, during driver extrication. A 15 cm (6 in) transfer was identified on webbing from driver inertial loading. The transfer began approximately 41.9 cm (16.5 in) from the upper outboard anchor, (8 cm (3 in) from the cut end of the webbing).

Figure 6: View of the modified chest restraint.

Figure 7: Right interior view of the chest restraint.

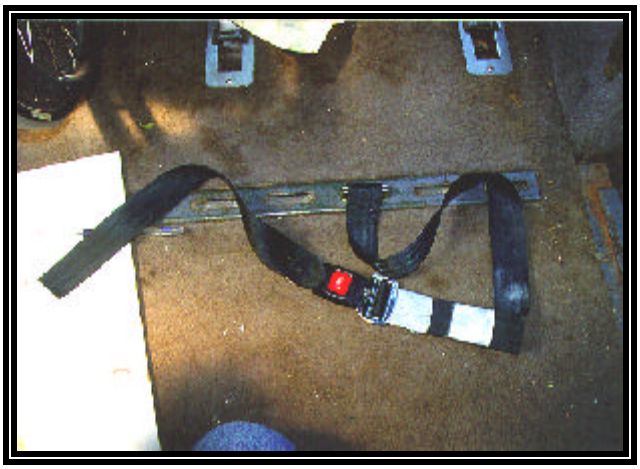

Figure 8: View of the cut restraint and inboard anchorage.

Supplemental Restraint System

The Plymouth Voyager was equipped with a Supplemental Restraint System (SRS) that consisted of driver and front right passenger air bags. The air bags deployed as a result of an above threshold crash. The driver air bag was configured in the typical manner and located in the center hub of the steering wheel. The H-configuration cover flaps of the air bag module were symmetrical and measured 17.8 cm x 6.4 cm (7.0 in x 2.5 in). The exterior surface of the lower flap was scuffed from contact with the Tri-pin steering device. This contact occurred during the deployment sequence as the flap rotated open. The driver air bag measured 61 cm (24 in) in diameter in its deflated state and was not tethered. The bag was vented by two - 3 cm (1 in) diameter vents located in the 1/11 o'clock sectors on the back side of the bag. The 2 to 5 o'clock sectors of the driver air bag were blood stained from post-crash driver contact.

The deploying driver air bag contacted the tri-pin steering device mounted to the 5 o'clock sector of the steering wheel rim. There was no mechanical damage to the device or the air bag, however the contact caused the device to rotate about its attachment to the rim. The contact between the deploying bag and the steering device altered the normal deployment path of the bag.

The front right passenger air bag module was a top mount design located in the right aspect of the instrument panel. The module cover flap was rectangular and measured 33.0 cm x 14.0 cm (13 in x 5.5 in), width by height. The face of the passenger air bag measured 48 cm x 61 cm (19 in x 24 in). It was tethered by a single strap and was not vented. The fabric of the bag was blood spattered as a result of contact during driver extrication.

Adaptive Controls

The 1995 Plymouth Voyager was equipped with adaptive controls used by of the 36 year old quadriplegic female driver. These controls included: a Tri-pin steering control, Low-effort steering, EGB II electronic speed control (brake/accelerator), 2 Digi-pad II electronic touch pad controls, and an elbow touch pad, in addition to the Braun Entervan II conversion/modification referenced above (page 3). An instructors training brake installed on the vehicle's right side was disconnected. **Figures 9 and 10** are overall views of the driver's position depicting adaptive control location.

A Tri-pin steering control device was attached to the 5 o'clock sector of the steering wheel rim. The device was fastened to the rim by a band clamp. During installation the device was mounted to the steering wheel rim with its base plane parallel to the plane of the rim. At inspection, the device was rotated approximately 23 degrees counterclockwise relative to the steering wheel, Figure 10. The rotation occurred due to a combination of loading caused by the deployment of the air bag and the occupant. It was also noted during the inspection, the finishing grommet on top of the "palm grip" pin was missing. The grommet was found on the floor and had been displaced by contact with the occupant's head. The driver sustained a forehead laceration consistent with this contact.

Figure 9: Rear view of the driver's position.

Figure 10: Right view of the driver's position.

The vehicle was modified with a steering column extension that allowed for the incorporation of the adaptive controls. A Low-effort steering system was installed in the Plymouth. Reportedly, this system reduced the effort required by the driver to steer the vehicle. Redundant power to the steering system was supplied by battery and served as a back-up to the Low-effort system.

The Plymouth Voyager's power train and electrical accessories were controlled electro-mechanically by the EGB II control system, manufactured by EMC Incorporated. The Central Processing Unit (CPU) for the EGB II was mounted under the left aspect of the instrument panel, behind the bolster panel, **Figure 11**. The CPU controlled and integrated the functions of the individual EGB components.

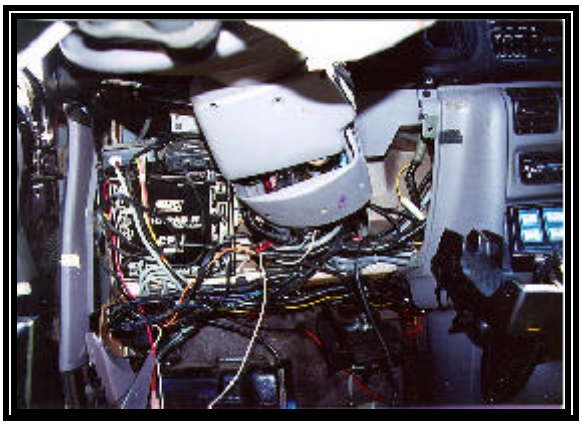

Figure 11: View of the adaptive controls CPU location.

The vehicle's acceleration/brakes operated via a hand shuttle control located on the left side of the driver position. The control was adjacent to the arm rest, 47.0 cm (18.5 in) forward of the door striker. The U-shaped shuttle control was approximately 72.4 cm (28.5 in) above the floor. The control was fastened to 3 cm x 3 cm (1 in x 1 in) steel box tube section. The box tube was mounted concentric with a 2 cm x 2 cm (3/4 in x 3/4 in) box tube attached to the vehicle's floor and left side wall. The tube-in-tube construction allowed for height adjustment of the control. The directional control of the shuttle was not labeled. Presumably, it was mounted in the typical forward brake/aft accelerate configuration.

Mechanical brake action was achieved via the stepper motor mounted to the left toe pan, **Figure 12**. The brakes operated through movement of the hand shuttle, which in-turn activated the operation of the stepper motor. The lever mounted roller, on the inboard side of the motor, engaged the modified brake pedal. The rotation of the lever caused the brake pedal to depress. The brake pedal was modified by the addition of a steel section welded to the pedal's left side. The flat surface of the steel section was the reactive surface for the stepper motor. The pedal was also modified by the addition of the cable-activated instructor's training brake. This cable modification is depicted in the right center aspect of Figure 12. The opposite end of the cable was attached to a brake pedal that was fastened to the toe pan in the front right passenger location. The training brake was disconnected at the time of the inspection.

The toe pan deformed rearward as a result of the impact. This deformation caused the stepper motor to rotate away from the brake pedal as depicted in figure 12. The brake pedal was jammed by the deformation.

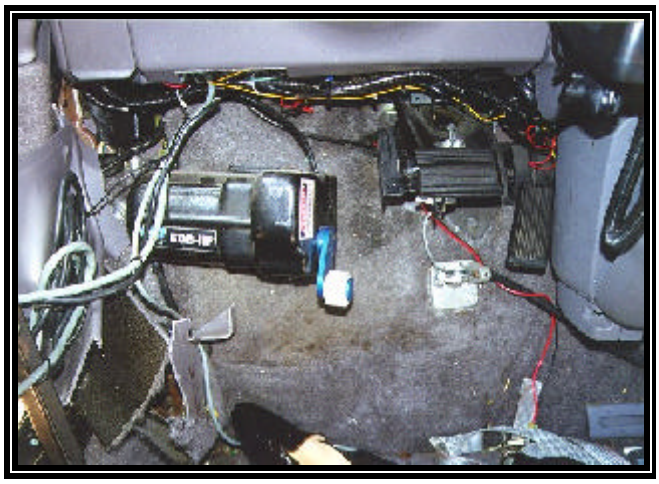

Figure 12: View of the modified brake actuation.

Two Digi-pad electronic touch pads were located on the driver's right. The pads were mounted on sliding tubular box sections (described above). The height of the touch pads was adjusted to approximately 61 cm (24 in) above the floor. The forward pad controlled the following: headlights, wipers/washer, front fan, interior dome light and cruise controls. The aft pad controlled the following functions: engine ignition and start, parking brake, transmission shift, EZ lock tie down windows and an auxiliary input. A Digi-tone elbow pad was fastened to the interior left door panel, above the arm rest. Reportedly, the elbow pad controlled the functions of the horn and headlights hi/lo beam.

The wheel chair was held stationary in the driver's position by EZ Lock Inc. model number 6_90 (the second digit in the model number was illegible). The lock was electronically operated via the Digi-pad. A manual/emergency release was located on the forward aspect of the lock. The lock was fastened to the floor by four 10 mm (3/8 in) diameter grade 5 bolts. The lock latched about a 2.5 cm (1 in) diameter pin attached to the rear aspect of the wheelchair. The EZ Lock was located 81 cm (32 in) rearward of the toe pan.

The left front and right front seating positions were equipped with floor anchors for the attachment of a standard seat. Each seat was attached at 4 anchorage points. The anchors were arranged in a rectangular pattern that measured 40.6 cm x 31.0 cm (16.0 in x 12.2 in), laterally by longitudinally. The anchors can be seen in Figures 7 and 9. The OEM seat was installed in the vehicle's right front at the time of the crash. Kinedyne wheelchair restraints were utilized to anchor the wheelchair when it was in the right front position.

The Plymouth was also modified with a 25 cm (10 in) drop floor which extended from the firewall to the rear axle. A power sliding right door, power lift and kneeling feature allowed wheelchair access by the driver.

DRIVER DISABILITY CHARACTERISTICS

The driver of the 1995 Plymouth Voyager (post-manufacture modified) was a 36 year old female with a C5/C6 incomplete quadriplegic disability. The driver's height and weight were not known. Reportedly she had very limited torso and upper extremity mobility. She only had use of her biceps. Her disability resulted from an accident that occurred in the summer of 1994. While still in rehabilitation, this individual began driving lessons in the September/October 1994. She began driving solo in late 1995/early 1996.

DRIVER INJURY

Injury	Severity (AIS update 98)	Injury Mechanism
Forehead laceration	Minor (290600.1,7)	Tri-pin steering device
Multiple rib fractures with pneumothorax, NFS	Serious (450211.3,9)	Inertial contact to modified chest restraint
Liver laceration, NFS	Moderate (541820.2,1)	Inertial contact to modified chest restraint
Right forearm fracture	Minor (751900.2,1)	Tri-pin steering device
Right elbow dislocation	Minor (750630.1,1)	Tri-pin steering device
Pelvic fracture - right side	Moderate (852600.21)	Induced fracture from the driver's knee bolster
Bilateral tibia/fibula fractures, NFS	Moderate (853404.2,1) Moderate (853404.2,2) Moderate (851605.2,1) Moderate (851605.2,2)	Intruding toe pan / foot controls / stepped motor

The above injuries were identified through an interview with the driver's father.

DRIVER KINEMATICS

Immediately prior to the crash, the driver relinquished directional control of the vehicle and drifted to the left. The left side of the Plymouth contacted the median Jersey type barrier. The driver probably was startled awake by the vehicle's sideswiping contact. Realizing her error, the driver steered the vehicle clockwise (right) and then over-corrected counterclockwise (left). These steering maneuvers resulted in the left aspect of the vehicle's frontal plane impacting the barrier. The above threshold force of the 11 o'clock impact caused the deployment the Supplemental Restraint System (air bags). The delta V of the crash was determined to be approximately 27 km/h (17 mph).

The driver was only restrained during the crash by the modified chest restraint. No lap belt was available. The restraint was positioned diagonally across the driver's chest and measured approximately 173 cm (68 in) in length. The webbing was anchored at the modified inboard floor anchor, extended over the inboard side of the wheelchair and anchored to the outboard OEM D-ring. Belt slack was inherent in this restraint system due in part to its length and lack of a pre-tensioning device. The slack in the system reduced the restraint's efficiency.

Upon impact, the driver initiated a forward trajectory in response to the 11 o'clock direction of force. As she translated forward, the driver's torso contacted and loaded the chest restraint. As her forward momentum became restrained, her inertial loading of the restraint resulted in multiple rib fractures and pneumothorax. The driver began to submarine the chest restraint, thus allowing the webbing to slip under the rib cage lacerating the liver. The driver's head/neck complex flexed forward and down resulting in contact with the inflated air bag. The air bag was backed up by the Tri-pin steering control in the region of this contact. The contact resulted in the driver's forehead laceration. The driver used her right arm to steer the vehicle. The right forearm fracture and elbow dislocation occurred as a result of an interaction with the Tri-pin steering control, her forward kinematic pattern and probable feedback through the steering linkage. The driver submarined the chest restraint. Her right knee contacted and loaded the bolster panel evidenced by the identified scuff mark. This contact loaded the pelvis through the right femur resulting in pelvic fracture. The driver's ankle fractures resulted from contact with the intruding foot controls and stepper motor of the adaptive controls.