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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 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.
**In-Depth Accident Investigation**

This case was initiated because the case vehicle is a gas/electric hybrid vehicle. This crash occurred in March, 2001 at 1210 hours. The crash occurred on a six-lane divided roadway.

The case vehicle, a 2001 Toyota Prius four-door gas/electric hybrid driven by a restrained 46-year-old male, was traveling westbound at a driver reported speed of 56 km/h (35 mph). The front right seat was occupied by an unrestrained 46-year-old female. The first other vehicle, a 1996 Porsche 911 driven by a 36-year-old male, was traveling eastbound, just coming out of a right hand curve. The second other vehicle, a 1986 Nissan pickup driven by a 16-year-old male, was traveling eastbound behind the case vehicle. The front right seat of the Nissan was occupied by a restrained 18-year-old male. The third other vehicle, an unknown year Volkswagen Cabriolet driven by an 18-year-old male, was also traveling eastbound. This vehicle was in the far right hand lane. The driver of the Porsche lost control of his vehicle after hitting a patch of water in the roadway. The vehicle veered to the left, over-rode the center median and struck a narrow tree with its left side. The Porsche continued on and entered the westbound roadway. The rear of the Porsche struck the left front of the case vehicle. The forces were sufficient to deploy both frontal air bags and to fire the driver’s seat belt pretensioner. The case vehicle was pushed to the right and struck the left side of the Volkswagen. The Porsche continued eastbound and contacted the third other vehicle—the Volkswagen Cabriolet. The Volkswagen was diverted to the right, rotated counterclockwise, and struck a curb with its right rear tire.

The driver of the case vehicle sustained a neck strain and a contusion to the right knee. The front right occupant sustained a fractured rib on the left side, abrasions to both hips, a contusion to the right side of the head, a contusion to the right ankle, an abrasion on the left knee, and a contusion on the right knee. The driver of the Porsche complained of pain to the left side of his head. He was transported to a local trauma center. All four vehicles were towed from the scene.
Dynamic Science, Inc.
Accident Investigation
Case Number: DS01-012

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</table>
BACKGROUND:

Description: This hybrid vehicle case was generated by DSI through existing insurance contacts. NHTSA was notified of the case on June 6, 2001. DSI was assigned the case on June 6, 2001. This case was conducted as an on-scene investigation.

Investigation Type: On-scene

Crash Location: California
Crash Date: March, 2001
Notification Date: June 6, 2001
Field Work Completed: June 8, 2001

SUMMARY:

This crash occurred in March, 2001 at 1210 hours. The crash occurred on a six-lane divided roadway. There are three westbound and three eastbound travel lanes. The travel lanes are separated by a raised concrete median. There is parking on both sides of the street. The speed limit is 72 km/h (45 mph). There is a 5% down grade for westbound traffic and a 5% up grade for eastbound traffic.

The case vehicle, a 2001 Toyota Prius four-door gas/electric hybrid driven by a restrained 46-year-old male (180 cm/71 in., 69 kg/152 lbs), was traveling westbound at a driver reported speed of 56 km/h (35 mph). The front right seat was occupied by an unrestrained 46-year-old female (168 cm/66 in., 57 kg/125 lbs.).

The first other vehicle, a 1996 Porsche 911 driven by a 36-year-old male, was traveling eastbound, just coming out of a right hand curve. The second other vehicle, a 1986 Nissan pickup driven by a 16-year-old male, was traveling westbound behind the case vehicle. The front right seat of the Nissan was occupied by a restrained 18-year-old male.
The third other vehicle, an unknown year Volkswagen Cabriolet driven by an 18-year-old male, was also traveling westbound. This vehicle was in the far right hand lane.

The driver of the Porsche lost control of his vehicle after hitting a patch of water in the roadway. The vehicle veered to the left, over-rode the center median and struck a narrow tree with its left side. The Porsche continued on and entered the westbound roadway. The rear of the Porsche struck the left front of the case vehicle (11FLEE9). The case vehicle sustained a longitudinal delta v of -10.9 km/h (-6.8 mph) and a lateral delta v of 6.3 km/h (3.9 mph)\(^1\). The forces were sufficient to deploy both frontal air bags and to fire the driver’s seat belt pretensioner.

The case vehicle was pushed to the right and struck the left side of the Volkswagen (01FREE6). The Porsche continued eastbound and contacted the third other vehicle—the Volkswagen Cabriolet. The Volkswagen was diverted to the right, rotated counterclockwise, and struck a curb with its right rear tire.

The driver of the case vehicle sustained a neck strain and a contusion to the right knee. He was transported by ambulance to a local hospital where he was treated and then released two hours later. The neck pain continued for several weeks. The front right occupant sustained a fractured rib on the left side, abrasions to both hips, a contusion to the right side of the head, a contusion to the right ankle, an abrasion on the left knee, and a contusion on the right knee. She was transported by ambulance to a local hospital where she was treated and then released two hours later.

The driver of the Porsche complained of pain to the left side of his head. He was transported to a local trauma center.

All four vehicles were towed from the scene.

\(^1\)Calculated using WinSmash version 2.06, stiffness values calculated from NCAP test results. Results appear low. Damage was likely altered by the second impact.
Scene Diagram

Figure 3. Scene diagram
<table>
<thead>
<tr>
<th>Data Point</th>
<th>Distance and Direction from RP</th>
<th>Distance and Direction from RL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ft</td>
<td>m</td>
</tr>
<tr>
<td>End skid A (Porsche)</td>
<td>56</td>
<td>17</td>
</tr>
<tr>
<td>Tree 1</td>
<td>59</td>
<td>17.9</td>
</tr>
<tr>
<td>Start skid A (Porsche)</td>
<td>74</td>
<td>22.5</td>
</tr>
<tr>
<td>End skid B (Porsche)</td>
<td>84</td>
<td>25.6</td>
</tr>
<tr>
<td>Tree 2</td>
<td>89</td>
<td>27.1</td>
</tr>
<tr>
<td>Start skid B (Porsche)</td>
<td>120</td>
<td>36.6</td>
</tr>
</tbody>
</table>
DETAILED INFORMATION

Vehicles

Case vehicle
Description: 2001 Toyota Prius four-door hybrid electric
VIN: JT2BK12U0100xxxxxx
Odometer: Unknown
Engine: Engine: 1.5 L 4 cylinder gasoline
Traction battery: Nickel hydride metal
Reported Defects: None
Cargo: None
Damage Description: Moderate crush to left side beginning at left front corner and extending to driver’s door. Driver’s door jammed shut. Moderate crush to right side beginning at front corner and extending along most of the fender. Vehicle declared a total loss by insurance company.

CDC: Impact 1 (Porsche): 11FLEE9
Impact 2 (Volkswagen): 01FREE6

Delta V (Impact 1): Total 12.6 km/h (7.9 mph)
Longitudinal -10.9 km/h (-6.8 mph)
Latitudinal 6.3 km/h (3.9 mph)
Energy 14,152 joules (10,438 ft-lbs)

Figure 4. Front left, showing first impact.
Figure 5. Right side, case vehicle, showing second impact.
**Prius hybrid-electric system discussion**

The Toyota Prius is one of the world's first standard-production hybrid-electric vehicles. The name Prius is Latin for “to go before”. The Prius' hybrid powertrain consists of a 70 horsepower 1.5 litre four cylinder gasoline-fueled internal combustion engine, a 33 KW (44 horsepower) permanent magnet electric motor, a generator, a 274 volt nickel metal-hydride battery, an electronic controller, and a 'power split device' which functions as a continuously variable (automatic) transmission. The Prius operates on both the engine and electric motor/battery - one or both of these power sources can drive the Prius depending on load and road conditions - the electronic controller makes that decision with no input from the driver.

**System modes**

The Prius system works in six main modes:

1. When accelerating from a stop, the Prius is powered by the battery/electric motor only.
2. As more acceleration is needed, the engine will turn on automatically and run by itself or in conjunction with the electric motor and the battery.
3. Under full acceleration, the electric motor is supplemented by power from the battery. At high speeds the gas engine is the primary source of power. The electric motor will assist to varying degrees.
4. When the engine is running it uses a generator to charge the battery, and when braking, a regenerative braking system also charges the battery, so there is never a need to recharge the battery separately. When the vehicle is coasting or the brakes are applied, the motor is turned into a generator, capturing energy that would normally be lost as heat or kinetic energy and transforming it into electricity to recharge the batteries.
5. The battery is regulated to maintain a constant charge. When the charge is low, the electric generator routes power to charge the battery.
6. During coasting or braking, the electric motor functions as a generator to charge the battery. When the vehicle is stopped, the gas engine shuts off automatically and the electric motor stands ready to power up the Prius. This conserves fuel and eliminates exhaust emissions caused by idling.

**Specifications**

Standard equipment includes ABS brakes, thermostat-controlled air conditioning, power windows, door locks and mirrors, an cassette stereo, an eight-year/100,000-mile battery and hybrid-related component warranty, roadside assistance and three-year basic maintenance programs.

Prius' primary power is provided by an all-aluminum 1.5-liter 4 cylinder gasoline engine with a peak 70 horsepower at 4,500 rpm and peak torque of 82 lb./ft. at 4,200 rpm. Variable valve timing maximizes efficiency. The 11.9 gallon gas tank has a plastic bladder which reduces gasoline vapors. The EPA fuel
economy is 52 miles per gallon for the city and 45 miles per gallon for the highway.

The electric drive motor is a permanent-magnet design. It produces its maximum power of 33 kW (44 horsepower) from 1,040-5,600 rpm, and maximum torque of 350 N-m (258 lb./ft.) from 0-400 rpm.

Prius' lightweight battery pack is comprised of 38 sealed Nickel-Metal Hydride modules with a nominal voltage of 274 volts. For matters of safety, it is completely sealed in a carbon composite case and positioned behind the rear seat within the protective unibody of the car. It is also a safer alternative to lead-acid batteries because it is essentially inert, non-flammable and non-caustic.

Recalls
There is one recall in place that might affect this vehicle (NHTSA Campaign ID Number: 00V285000). This potentially affects 1,772 vehicles manufactured between May 2000 and July 2000. On certain passenger vehicles, insufficient electrical contact can occur in the torque sensor that controls the power assist operation of the electric power steering gear box. The torque sensor could output improper electrical signals. If this occurs, the power steering warning icon will be displayed on the center panel, and the driver could experience higher than normal steering effort depending upon vehicle speed.
Compliance with Sec.571.305 Standard No.305: Electric-powered vehicles: electrolyte spillage and electrical shock protection

The case vehicle was examined to determine compliance with the 305 standards.

1. There were no indications of electrolyte spillage from the propulsion battery.
2. There was no movement of the battery module.
3. The electrical isolation test was partially conducted. There is a circuit near the power cable that prevents access to power unless the ignition switch is in the “ON” position and the vehicle is running. In this case, the initial impact had gone through the left hand fuse block and there was no internal 12v power available. There was also no key available. The net result was that there was no propulsion battery voltage external of the battery system. There were no indications of any arcing, fire, or component meltdown.

An overview of the electrical isolation test is included as Attachment 1.
Responding agency training

The responding police agency was contacted. Responding officers had received academy training with regard to issues related to hazardous material spillage.

Safety features discussion

The case vehicle was equipped with driver and front right passenger air bags. According to data found in the NCAP test files, these are not advanced, multistage air bags. The case vehicle was also equipped with 3-point seat belts in all five seating positions. The drivers belt was equipped with an emergency locking retractor while the other seat positions are equipped with switchable retractors. The driver and front passenger seat belts are equipped with pretensioners with force limiters.

In this crash, the driver was wearing the lap and shoulder belt but the front right passenger was not. At impact, the pretensioner for the driver’s belt fired. Since the front right passenger was not belted, the pretensioner on the right side did not fire.
Other vehicle 1

Description: 1996 Porsche 911
VIN: Unknown
Odometer: Unknown
Engine: Unknown
Reported Defects: None noted
Cargo: Unknown
Damage Description: Moderate lateral crush along entire rear bumper. Moderate lateral crush to left side, primarily the driver’s door. According to interviewee, vehicle was declared a total loss.

CDC: Impact 1 (tree): 09LFEN1
Impact 2 (Prius): 07BDEW1
Impact 4 (Nissan): 09LPEW1

Delta V (Impact 2):

<table>
<thead>
<tr>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>12.5 km/h (7.8 mph)</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>8.9 km/h (5.5 mph)</td>
</tr>
<tr>
<td>Latitudinal</td>
<td>8.9 km/h (5.5 mph)</td>
</tr>
<tr>
<td>Energy</td>
<td>19,081 joules (14,073 ft-lbs)</td>
</tr>
</tbody>
</table>

**Figure 9.** Exterior, rear and right side.
Other vehicle 2

Description: Unknown year Volkswagen Cabriolet
VIN: Unknown
Odometer: Unknown
Engine: Unknown
Reported Defects: None noted
Cargo: Unknown
Damage Description: Light contact damage to left side. Right rear wheel pushed inward due to contact with the curb.

CDC:
Impact 3 (Prius): 07LPEW1
Impact 5 (curb): 02RPWN1

Delta V:
Total Unknown
Longitudinal Unknown
Latitudinal Unknown
Energy Unknown

Figure 10. Exterior, left side.

Figure 11. Exterior, right side.
Other vehicle 3

Description: 1986 Nissan pickup
VIN: Unknown
Odometer: Unknown
Engine: Unknown
Reported Defects: None noted
Cargo: Unknown
Damage Description: Moderate frontal contact to bumper and grille.
Towed from the scene.

CDC: Impact 4 (Porsche): 12FDEW1

Delta V: Total Unknown
          Longitudinal Unknown
          Latitudinal Unknown
          Energy Unknown

Figure 12. Exterior, front left.
### Occupants

<table>
<thead>
<tr>
<th><strong>Case vehicle</strong></th>
<th><strong>Occupant 1</strong></th>
<th><strong>Occupant 2</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age/Sex:</strong></td>
<td>46/Male</td>
<td>46/Female</td>
</tr>
<tr>
<td><strong>Seated Position:</strong></td>
<td>Front left</td>
<td>Front right</td>
</tr>
<tr>
<td><strong>Seat Type:</strong></td>
<td>Fabric covered bucket seat, adjusted to between middle and rear most track position.</td>
<td>Fabric covered bucket seat, adjusted to rear most track position.</td>
</tr>
<tr>
<td><strong>Height:</strong></td>
<td>180 cm/71 in.</td>
<td>168 cm/66 in.</td>
</tr>
<tr>
<td><strong>Weight:</strong></td>
<td>69 kg/152 lbs</td>
<td>57 kg/125 lbs</td>
</tr>
<tr>
<td><strong>Occupation:</strong></td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td><strong>Pre-existing Medical Condition:</strong></td>
<td>None noted</td>
<td>None noted</td>
</tr>
<tr>
<td><strong>Alcohol/Drug Involvement:</strong></td>
<td>None</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Driving Experience:</strong></td>
<td>Unknown, presumed to be greater than 20 years</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Body Posture:</strong></td>
<td>Normal, upright</td>
<td>Normal, upright</td>
</tr>
<tr>
<td><strong>Hand Position:</strong></td>
<td>Both on steering wheel, unknown placement</td>
<td>Unknown</td>
</tr>
<tr>
<td><strong>Foot Position:</strong></td>
<td>Right on accelerator, left on floor</td>
<td>Unknown</td>
</tr>
<tr>
<td><strong>Restraint Usage:</strong></td>
<td>Lap and shoulder belt available, used</td>
<td>Lap and shoulder belt available, not used</td>
</tr>
<tr>
<td><strong>Air bag:</strong></td>
<td>Steering wheel mounted driver’s air bag deployed</td>
<td>Top mounted front right passenger’s air bag deployed</td>
</tr>
</tbody>
</table>
Other vehicle (Porsche)

Age/Sex: 36/Male
Seated Position: Front left
Seat Type: Bucket
Height: 183 cm (72 in)
Weight: 84 kg (185 lbs)
Occupation: Unknown
Pre-existing Medical Condition: None noted
Alcohol/Drug Involvement: None
Driving Experience: Unknown
Body Posture: Unknown
Hand Position: Unknown
Foot Position: Unknown
Restraint Usage: Lap and shoulder belt used, per police report
Other vehicle (Volkswagen)

Age/Sex: 28/Male
Seated Position: Front left
Seat Type: Unknown
Height: 178 cm (70 in)
Weight: 75 kg (165 lbs)
Occupation: Unknown
Pre-existing Medical Condition: None noted
Alcohol/Drug Involvement: None
Driving Experience: Unknown
Body Posture: Unknown
Hand Position: Unknown
Foot Position: Unknown
Restraint Usage: Lap and shoulder belt used, per police report
Other vehicle (Nissan)

Age/Sex: 16/Male
Seated Position: Front left
Seat Type: Unknown
Height: 170 cm (67 in)
Weight: 64 kg (142 lbs)
Occupation: Unknown
Pre-existing Medical Condition: None noted
Alcohol/Drug Involvement: Unknown
Driving Experience: Unknown
Body Posture: Unknown
Hand Position: Unknown
Foot Position: Unknown
Restraint Usage: Lap and shoulder belt used, per police report
### Injuries and Injury Mechanisms

Case vehicle (Toyota Prius)

<table>
<thead>
<tr>
<th>INJURY</th>
<th>OIC CODE</th>
<th>ICD-9</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver: Neck strain</td>
<td>640278.1,6</td>
<td>847.0</td>
<td>Air bag</td>
</tr>
<tr>
<td>Contusion, right knee</td>
<td>890402.1,1</td>
<td>924.11</td>
<td>Left lower instrument panel</td>
</tr>
<tr>
<td>Front right occupant: Rib fracture, lower left side</td>
<td>450212.1,2</td>
<td>807.01</td>
<td>Unknown</td>
</tr>
<tr>
<td>Bilateral hip abrasions</td>
<td>590202.1,1</td>
<td>916.0</td>
<td>Center console / right door</td>
</tr>
<tr>
<td></td>
<td>590202.1,2</td>
<td>916.0</td>
<td></td>
</tr>
<tr>
<td>Contusion, right side of head</td>
<td>190402.1,1</td>
<td>920.0</td>
<td>Side glass</td>
</tr>
<tr>
<td>Contusion, right ankle</td>
<td>890402.1,1</td>
<td>924.21</td>
<td>Right door, near base</td>
</tr>
<tr>
<td>Abrasion, left knee</td>
<td>890202.1,2</td>
<td>916.0</td>
<td>Right lower instrument panel</td>
</tr>
<tr>
<td>Contusion, right knee</td>
<td>890402.1,1</td>
<td>924.11</td>
<td>Right lower instrument panel</td>
</tr>
</tbody>
</table>
Other vehicle (Porsche)

<table>
<thead>
<tr>
<th>INJURY</th>
<th>OIC CODE</th>
<th>ICD-9</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver: Complained of pain to left side of head</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Other vehicle (Nissan)

<table>
<thead>
<tr>
<th>INJURY</th>
<th>OIC CODE</th>
<th>ICD-9</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver: Complained of pain to back</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Other vehicle (Volkswagen)

<table>
<thead>
<tr>
<th>INJURY</th>
<th>OIC CODE</th>
<th>ICD-9</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver: Complained of pain to head</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Occupant Kinematics

The 46-year-old male driver of the case vehicle was seated in the front left position. He was seated in a bucket seat in a normal, upright position. The seat was adjusted to the rear-most track position. He was wearing the available lap and shoulder belt. Both of his hands were on the steering wheel. His right foot was on the accelerator. The 46-year-old female occupant was seated in the front right position. She was seated in a bucket seat in a normal, upright position. The seat was adjusted to between the middle and rear-most track position. She was not wearing the available lap and shoulder belt. The seat belt anchorage was adjusted to the full up position.

At the first impact, the restrained driver responded to the 11 o’clock direction of force by moving forward and to the left. The seat belt pretensioner fired. The driver engaged the deployed air bag with his face–causing the neck strain. His right knee contacted the lower instrument panel–causing a small contusion. At the second impact, he responded to the 1 o’clock direction of force by moving forward and to the right.

At the first impact, the unrestrained front right occupant responded to the 11 o’clock direction of force by moving forward and to the left. Her left side contacted the center console, causing the left hip abrasion and possibly the rib fracture on the left side. At the second impact, she responded to the 1 o’clock direction of force by moving forward and to right. Her right side contacted the door and right side glass, causing the head contusion and right hip abrasion. As she moved forward, both knees struck the instrument panel, causing the abrasion to the left knee and the contusion to the right knee.
Attachment 1. Electrical Isolation Test
REMOVAL

1. REMOVE SERVICE PLUG (See page HV-1)
2. DRAIN HV COOLANT (See page HT-6)
3. REMOVE COWL TOP PANEL (See page BO-27)

4. VERIFY 0 V

NOTICE:
- Before starting step (a), 5 minutes or more should be passed after removing the service plug.
- Be careful to prevent foreign matter from entering the inside of connector cover.

(a) Disconnect the connector of the battery power cable and insulate it with packaging tape.

(b) Using a 10x socket wrench (T30), remove the 4 screws and inverter terminal cover.

(c) Using a 10x socket wrench (T40), remove the 2 screws, circuit breaker sensor and connector cover.

HINT:
Slide the connector cover to disconnect the circuit breaker sensor connector.

(c) Using a voltmeter, measure the voltage between terminals of 3 phases (U-V, V-W, U-W) and each terminal and body ground to verify them to be approx. 0 V.

5. REMOVE CONVERTER & INVERTER ASSEMBLY

(a) Remove the 6 belts and 3 power cables for MG2.

NOTICE:
Be careful to prevent foreign matter from entering the inside of connector cover.

(c) Remove the 3 belts and power cable for MG1.

NOTICE:
- Remove the power cable for MG1 together with converter & inverter assembly.
- Be careful to prevent foreign matter from entering the inside of connector cover.
- Remove the bolt and ground cable.