

Vertical Impact to an Open Wheel Race Car and Development of a Crash Test to Simulate Driver Response

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ABSTRACT

The Indy Racing League (IRL) continuously strives to improve safety for drivers of open wheel racecars. As part of a comprehensive engineering effort, the IRL carefully investigates crashes that occur to understand crash causation, the vehicle dynamics involved and driver outcome. Over time, these investigations lead to improved facilities, vehicle design and restraint system performance.

One of these investigations involved an open wheel racecar that struck a barrier and became airborne. Without the benefit of an intact suspension, the bottom of the vehicle struck the ground with significant vertical deceleration, leading to driver injury. The vehicle's onboard event data recorder captured the event.

Working with the IRL, the Center for Advanced Product Evaluation (CAPE) developed a dynamic sled test to recreate this specific event. The test involved design of a sled buck to simulate the key elements of the racecar's seating system, restraint system and interior. The buck was oriented on the sled platform such that the vehicle's vertical axis was aligned with the sled's horizontal axis of motion. Unique facility adaptations were required to duplicate the deceleration pulse from the event data recorder.

The IRL's THOR anthropomorphic test device (ATD) was seated inside the sled buck to measure biomechanical response during the tests. Results were compared against known human response in the actual event. Several energy absorbing design alternatives were explored to mitigate injury in this vertical impact.

INTRODUCTION

The Indianapolis Motor Speedway and the Indy Racing League have a long history of safety research and innovation. Since the inception of the IRL in 1996, there has been continuous research done towards the improvement of driver safety. The goal is to improve the survivability for the 50+ drivers in the Indy Car and Firestone Indy Lights series.

The exciting pace of open wheel racing in the IRL also makes it a dangerous occupation. Highly competitive and skilled drivers race close together at speeds exceeding 200 miles per hour, on lightly banked oval tracks, driving within inches of exterior walls. This combination of factors makes safety research particularly important for the IRL.



FIGURE 1: INDY CAR RACING

The IRL uses many avenues for safety research including sled testing, full size car testing, accident simulation, and crash data analysis. Some of the results from this research include design improvements to the rear attenuator and transmission stiffness to reduce the severity of rear impacts, Zylon panels on the car sides to reduce intrusion during side impacts and modifications to the head surround thickness and attachments to reduce head injury potential. When combined with the semi-reclined seating position of the driver, tight fitting six-point restraint systems, energy absorbing seats and other factors, IRL drivers can walk away from crash events that would be devastating in other vehicle types².

The IRL maintains a very thorough accident investigation process in both series. The key elements of the investigation process are as follows:

Accident Scene – One of the on-track paramedics records skid marks, impact angle and object impacted, and initial driver health. All of this information is entered into a database.

Post accident – A small team of people record all of the damaged parts of the race car, download the ADR3 data, draw several graphs and post information on a secure web site. They inspect the seat and head surround for damage, and look for root cause of accidents if necessary. All of this information is then entered into a database.

Driver Condition – The driver is evaluated upon arrival to the medical center and status is entered into a database.

All of the above databases can be queried together to identify trends, target research areas and design meaningful test programs. With nearly 1,000 entries, the database indicates meaningful conclusions and research directions.

Each car in both series is equipped with a crash recorder and each driver has instrumented ear sensors. The crash box is an ADR3, which is designed and built by Delphi motor sports. The crash box is mounted on the tub floor below and slightly forward of the dash bulkhead. The ADR3 has 3 internal accelerometers that record the chassis longitudinal, lateral, and vertical accelerations at 1000HZ. The driver ear sensors measure 3 axis of acceleration in each ear and are also recorded at 1000HZ by the ADR3. The ADR3 continuously monitors these input channels. When a crash event occurs, it records one minute of pre-crash data and 30 seconds of post-crash data. This long record time enables the ADR3 to capture pre-crash vehicle dynamics as well as secondary or tertiary collisions.

SUBJECT CRASH

Ongoing analysis of the IRL crash /injury database identified an increased incidence of spinal fracture over the past 10 years.¹ Forty-four instances of spinal fracture have been identified, five of which were the result of primarily vertical input. In two cases an object fell from a height directly onto the driver's head resulting in fracture of the upper thoracic spine in both. The other three sustained a spinal fracture when a car became airborne and landed on the bottom of the tub (monocoque). Fracture levels in these 3 drivers were in the upper thoracic spine in two (T3 and T5 ;T9 above a previous T10 – L2 fusion;), and at thoracolumbar junction (T12) in the third.

Indy Car cockpits are very tight, and drivers prefer to sit low in the vehicle. As a result, there is no energy absorbing material between the driver's bottom and the vehicle chassis in the vertical direction, as shown in figure 2. However, a narrow gap exists in this region that could be used to reduce injury in this type of crash mode. The combination of spinal injuries and an opportunity to mitigate that type of injury led to research and testing of vertical impacts.



FIGURE 2: INDY CAR COCKPIT WITH SEAT REMOVED

A representative crash was selected from the crash database. In this event, the driver's throttle appeared to stick when entering a turn. The car drove through the turn and approximately 75 feet of sand trap and collided with a tire barrier at a 70° angle. This initial impact destroyed the front suspension on both sides of the car. The impact lifted the car into the air several feet and rotated it 150° clockwise. The vehicle landed upright with a "pancake" impact between the skidpan and sand. The car left no skid marks in the sand from impact with the tire barrier to its final rest position.

The driver in this representative crash sustained a compression fracture of T12 Gertzbein Type A,1,1.³ This was sub classified as a type 3 fracture ($>10\%$ to $<30\%$ compression and $>15^\circ$ to $<30^\circ$ angulation) according to the severity scale in our previous publication.¹ The injury is noted by increased signal intensity (bright) along the anterior superior vertebral endplate and the wedge deformity shown in figure 3.



FIGURE 3: MRI ILLUSTRATING T12 TYPE A SEVERITY TYPE 3 COMPRESSION

ADR output from this event, shown in figure 4, identified the vertical deceleration from the pancake impact as the most harmful event. As a result of this crash, the IRL medical staff checks for similar spinal injuries of all drivers involved in a crash with high vertical deceleration.

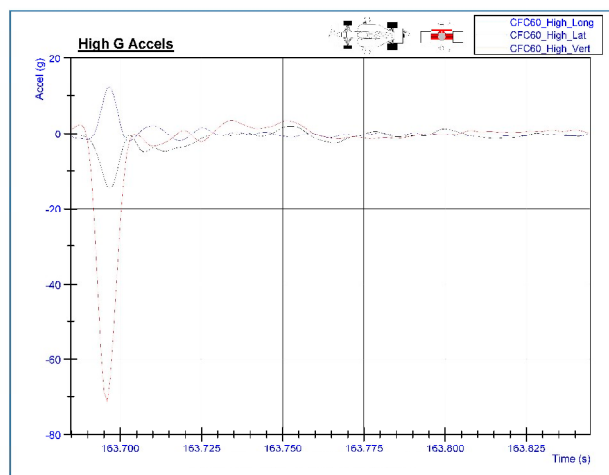


FIGURE 4: ADR3 OUTPUT FROM SUBJECT CRASH

The spinal injury causation from this vertical input is fundamentally different than in a rear impact¹. In the vertical event, the inertia from the driver's head, helmet and upper torso apply a compressive load into the spine. Restraint systems do not engage in this direction and the occupant does not ramp up into the seat as in a rear impact.

DYNAMIC SLED TEST

Several test options were considered to create a test that would mimic the vertical response of the subject crash. A vertical drop test was considered since it would be visually and operationally similar to the subject crash. Ultimately, this approach was rejected due to concerns about repeatability of impact speed, deceleration pulse and cross axis signal sensitivity. To maximize consistency, a dynamic sled test format was chosen for the test.

CAPE includes a full-scale vehicle barrier crash test facility, and has experience crashing open wheel racecars. One such test has been reported in prior literature¹. When not used for full scale crash tests, the facility can be equipped to conduct dynamic sled testing, by connecting a moving platform to the facility propulsion system and attaching a decelerator to the face of the barrier. CAPE's electric propulsion system features closed loop controls and excellent speed accuracy. Similarly, CAPE's decelerator systems enable consistent duplication of crash pulses, including the high deceleration levels seen in open wheel racecar crashes.

However, the sled's motion is directed along a horizontal axis. To produce input into the vertical direction of the vehicle coordinate system, CAPE designed and fabricated the sled buck shown in figure 5 to align the vertical axis of the vehicle's coordinate system with the sled's horizontal direction of motion. The team agreed that the snug, six-point, non-retractable restraint system would securely position in the ATT