

Motorcycle Rider Trajectory in Pitch-Over Brake Applications and Impacts

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ABSTRACT

Pitch-over events are common in motorcycle accidents, and can be caused by impact to the front wheel and occasionally by hard brake application. In either case, the rider of the motorcycle can be propelled over the handlebars as the motorcycle pitches rear-end up. In accidents caused by pitch-over braking, the accident investigator may be faced with limited evidence and then must rely on analyzing the throw distance of the rider in attempting to reconstruct the pre-accident speed of the motorcycle. This analysis can be complicated by the presence of a second rider (the passenger) on the motorcycle. Pitch over caused by front wheel impact can be similarly complex. Although motorcycle deformation as a result of front wheel impact has been studied [1], circumstances surrounding the nature of the deformation, or the impact itself, may require that the trajectory of the rider be analyzed in order to determine the pre-impact motorcycle speed.

A series of sled tests was conducted to analyze rider and passenger motion during pitch-over events to develop a more complete understanding of how deceleration and initial speed affect the occupant trajectory and velocity. Brake stops were simulated on the sled as well as front wheel impacts. A full-scale crash test was also conducted and compared against the results of the sled simulations. High-speed video footage was analyzed to develop an understanding of the pitch-over dynamics as well as rider/passenger trajectories and velocities. This paper presents the results of this study and offers a method for accident reconstructionists to employ as they examine motorcycle accidents that involve pitch-over events.

INTRODUCTION

The field of Accident Reconstruction has long used pedestrian travel distance, or throw distance, to determine vehicle speed in vehicle-pedestrian collisions. Numerous publications document the research in this area and the assumptions that are common for reconstructions of these accidents. Far less research effort has been expended in understanding occupant kinematics in motorcycle accidents, and even a smaller amount in understanding kinematics associated with single-vehicle motorcycle accidents. Such single-vehicle motorcycle accidents include those caused when heavy braking leads to rear-end-up pitch (pitch over) of the motorcycle and subsequent rider/passenger ejection.

Early motorcycle brake designs were influenced by brake designs of the bicycles that had preceded them. Since bicycles had been in existence for some time prior to the invention of the motorcycle, bicycle braking systems had been significantly refined and became the starting point for early motorcycle brake system designs. Therefore, one of the early brake designs for motorcycles was a "stirrup" design that has evolved to the design still used on many bicycles today. Another early design was the use of a "coaster brake" on motorcycles and motor-bicycles. This was similar to the "coaster hub" design commonly used on bicycles where a rearward pressure applied by the rider to the pedal disengaged the chain and forced a cone against the outside hub. This design did not adequately dissipate heat and was rather abrupt for motorcycles. Other designs included various friction blocks and contracting metal bands. To this point in motorcycle brake design history the brakes were present only on the rear wheel.

A significant design change occurred with the advent of the use of an internal expanding brake, commonly known as a brake drum. This design is still used on some modern motorcycles as a rear brake. This design change led to motorcycles having front brakes, and by the 1920's motorcycle regulations requiring that motorcycles have both front and rear brakes were in place. Some early British designs had linked braking systems, where a foot pedal controlled both the front and rear brakes. The 1958 Harley-Davidson Duo Glide made use of a hydraulic actuator for the rear brake drum.

Another concept that had been developing was an external exposed disc, which would cool quickly. In 1969 Honda released the CB750 with a hydraulically actuated front disc brake. This basic design progressed from a rotor being compressed in a caliper consisting of a single "live" friction pad and a static friction pad to the designs we see today that involve multiple opposing-piston calipers. These designs utilize floating discs along with the multiple opposing-piston calipers to maintain proper alignment. Currently, many sport bikes have dual front brakes and single rear brakes to achieve shorter stopping distances and reduce brake fade. Some modern designs also include linked front and rear brakes.

As motorcycle performance was improved and top speeds increased, the need to more aggressively slow and stop them became important. As described in McKibben [4], during high braking deceleration a motorcycle transfers a large portion of the motorcycle and rider weight to the front wheel. This weight transfer, along with the relatively short wheelbase and high center of gravity, causes a substantial increase in the normal road force experienced by the front tire as well as a substantial decrease in the normal road force experienced by the rear tire. Due to this load-transfer effect, the majority of a motorcycle's braking capacity comes from the front tire. Many modern sport bikes employ two front disc brakes to make use of this transfer of brake capacity to the front wheel.

As the brake application increases and braking deceleration increases, either by application of the front or rear brakes or both brakes, weight transfer to the front wheel increases and the weight on the rear wheel decreases. Provided there is sufficient tire/road friction, at the limit of the braking capacity of the motorcycle the weight on the rear tire is zero. Though not inevitable, this is the point at which the motorcycle can pitch-over. Riders do not normally brake at this limit; however, motorcycle braking research has shown that controlled braking decelerations on the order of about 1.1 g are possible, and experienced riders can achieve controlled braking decelerations above 1.0 g and as high as 1.2 g, again provided there is sufficient tire/road friction [5,6,7]. Braking the motorcycle past this limit however, puts the motorcycle in a pitch-over condition and can happen very quickly if the rider panics and over-brakes during the developing weight transfer.

Motorcycles have also significantly evolved with respect to shape and size. Classic multipurpose motorcycles of the 1950s through the 1970s have been replaced with styles that range from large touring motorcycles to sport bikes. For this research a motorcycle was chosen that represented an average of both the sport-touring and sport-racing motorcycle. A 1985 Kawasaki Ninja was chosen as a representative for the shape and size of a motorcycle in the middle of this design range.

Eighteen sled tests were conducted to evaluate the trajectory and velocity of riders and passengers on motorcycles when subjected to pitch-over braking events and braking events that end with collisions. Ten of the tests were conducted with a rider only, with pre-braking speeds ranging from 19 mph to 33 mph. Eight tests were conducted with both a rider and passenger using speeds in the same range. Braking deceleration was varied as well, using a range of decelerations that resulted in tip-up. Two of the tests were designed to have some braking followed by a significant impact event, simulating an impact with an automobile.

A motorcycle-to-car crash test was also conducted, wherein no pitch due to braking was induced prior to impact. In addition to tracking the occupant kinematics of this test, the crash pulse was used to develop the impact portion of the final two sled tests.

CRASH TEST

TEST DESIGN

The Exponent Test and Engineering Center in Phoenix, Arizona was the site of the crash and sled testing. For the crash test, a 1985 Kawasaki Ninja motorcycle was guided into impact with a 1996 Honda Prelude 2-door coupe. A Hybrid II 50th-percentile-male anthropomorphic test device (ATD) was positioned as the rider on the motorcycle, and a Hybrid III 5th-percentile-female ATD was positioned behind the rider as the passenger. The motorcycle was guided into impact using the Exponent Motorcycle Dolly. A trailing brake system on the dolly was activated when the motorcycle was about 30 feet from impact, arresting the dolly. The motorcycle then rolled unguided into impact with the stationary Prelude. The target impact point on the Prelude was the left front A-post, at the front door seam, and the target speed was 35 mph. The impact configuration is depicted in Figure 1.

The motorcycle was instrumented with two triaxial accelerometer sets – one located under the seat at the rider position (the primary accelerometer set) and the other on the steering head (the secondary set). A two-axis rotational rate sensor was also placed under the rider seating position and was oriented to measure motorcycle pitch and yaw rates. Three real-time video cameras and four high-speed video cameras were used to record the test. The high-speed camera data was also used to determine ATD trajectories and velocities.

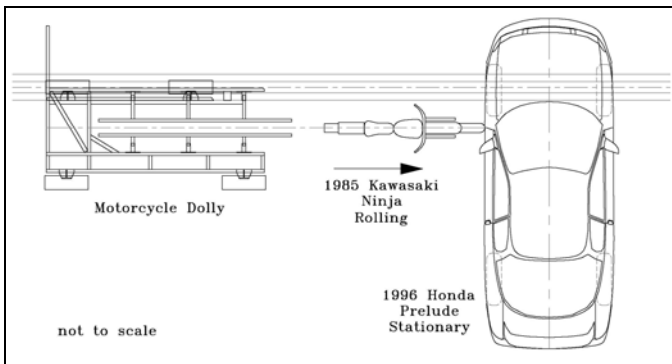


Figure 1 – Motorcycle crash test impact configuration.

RESULTS

The measured velocity of the motorcycle as it impacted the car was 35.1 mph. Data collected by the primary accelerometer set is provided in Figure 2. The longitudinal acceleration peaked at 52.4 g with a pulse duration of approximately 80 milliseconds. The resulting change of velocity was 33.8 mph. A failure with the pitch rate measurement required that video analysis be used to analyze the motorcycle pitch. This pitch rate and pitch angle data are provided in Figure 3.

The ATD in the rider position traveled mostly horizontally following the impact, hitting the left side of the Prelude's windshield before tumbling over the hood. The ATD in the passenger position was projected over the car, vaulting approximately 25 feet before impacting the ground. Although the initial trajectory of the passenger appeared to be mostly horizontal, the presence of the rider ATD forced the passenger to develop a vertical velocity component as well. Portions of the ATD motion are depicted in Figure 4.

VIDEO ANALYSIS

The high-speed video was analyzed with motion tracking software for the purpose of documenting rider and passenger velocities and trajectories as the impact progressed. For the purpose of this research, targets placed on the hips of the dummies were used as the center of mass location. The hip is not only very near the actual center of mass, the center of mass being approximately at the intersection of the lower torso and hip, but it is also a wide, flat, vertically-oriented surface on the ATD that facilitates adhesive target placement and video tracking. The tracked motion of the two ATDs is depicted in Figure 5.

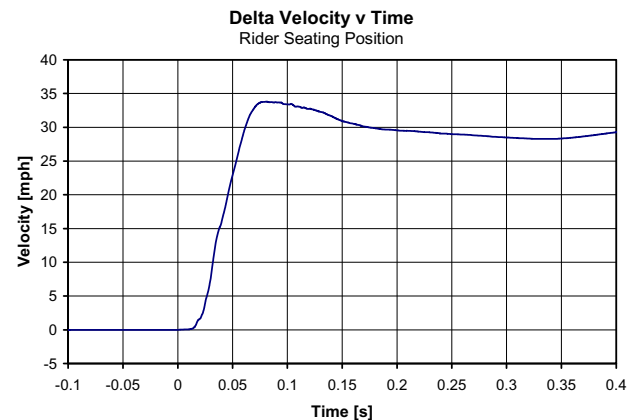
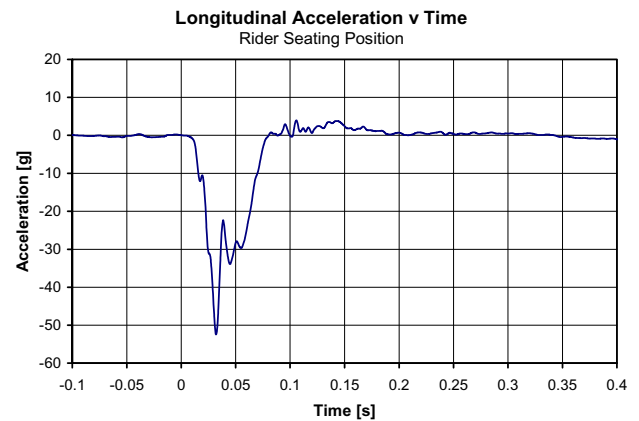


Figure 2 – Acceleration and velocity data.

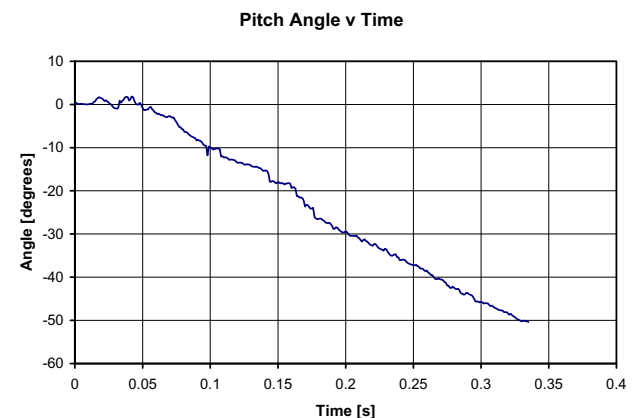
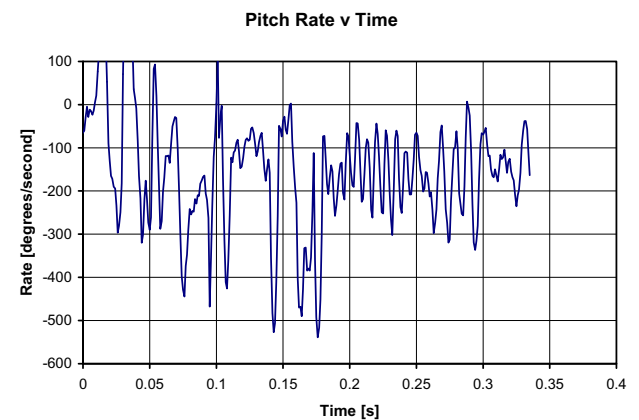


Figure 3 – Pitch data from video analysis.

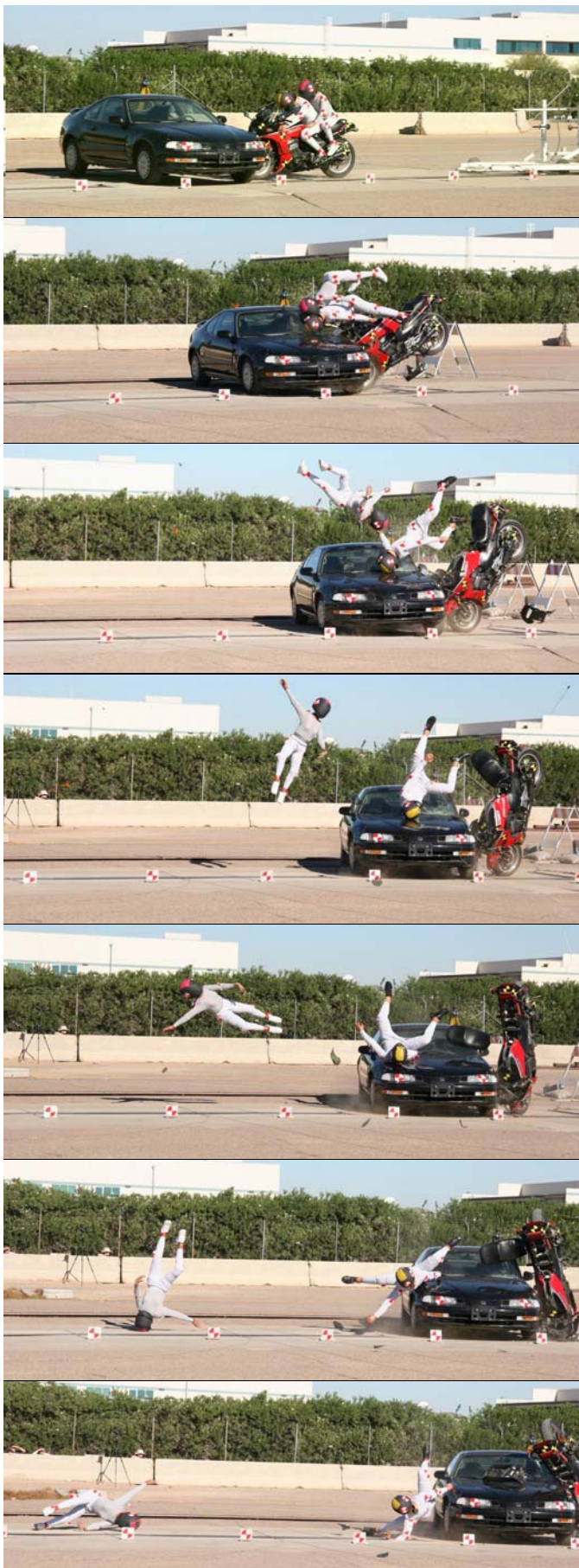
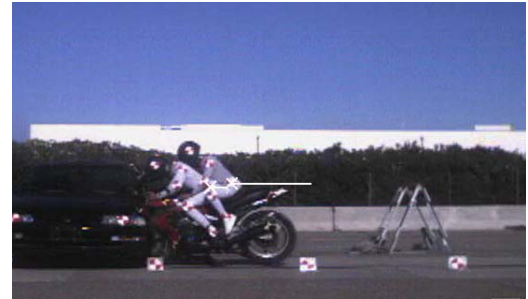


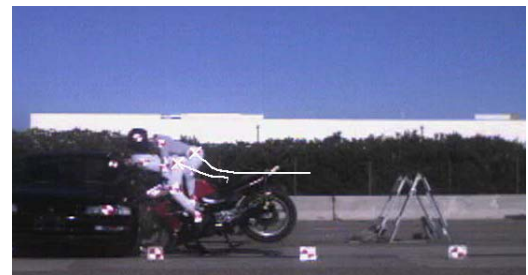
Figure 4 – Crash test ATD motion.



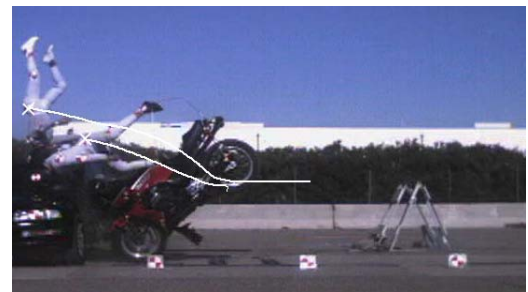
Impact



50 milliseconds post-impact



90 milliseconds post-impact



300 milliseconds post-impact

Figure 5 – Video tracking of ATD motion in crash test.

Initially, the motion of the rider post-impact is directly forward, and as the ATD interacts with the fuel tank and windscreen, its center of mass develops an upward component of velocity. At approximately 50 milliseconds after initial contact, the rider has visibly left the motorcycle seat and is interacting with the fuel tank. At this point, the rider's trajectory is 16.7 degrees above the horizontal, and the velocity of its center of mass is 23.8 mph. The passenger has also moved forward and is developing an upward velocity as a result of using the rider as a "ramp". The presence of the rider causes the passenger to move up the rider's back, and when the passenger leaves the seat of the motorcycle its trajectory is 8.4 degrees above the horizontal. The velocity of the passenger's center of mass at this point is 28.4 mph.