



SURFACE VEHICLE INFORMATION REPORT

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Rollover Testing Methods

RATIONALE

SAE J2926 has been reaffirmed to comply with the SAE Five-Year Review policy.

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INTRODUCTION

At SAE there have been inquiries regarding the common techniques being used for evaluation of rollover crashworthiness. This report contains a brief description of the methods being utilized for rollover crashworthiness evaluation, as well as references for additional follow-up. The materials are organized to reflect:

- Full vehicle testing methods (Section 3)
- Component testing methods (Section 4)
- Computer Aided Engineering (CAE) testing methods (Section 5)

Our work was facilitated by the literature created by Chou, McCoy and Leigh at Ford Motor Company, who graciously have provided their work to us (Chou, 2005b). The literature has been revised to reflect information that has been published or become available since that time. The authors wish to acknowledge our appreciation to the previous authors for sharing their document, which allowed us to expand upon their initial work. The present document cannot include all test methodologies that have been used in the past and does not refer to all published papers that have been written on the subject. Omission of a paper or particular methodology should not be construed as invalidating any work not included, nor is the inclusion of a method intended to endorse or authenticate the use of any particular method. This document is intended to be a living document that evolves as new methodologies are developed.

It is hoped that the current document provides some additional insight into the current state of methods available for use in the development of improved vehicle rollover crashworthiness.

By way of background, there are numerous rollover configurations that occur in the accident environment. For example, Obrien-Mitchell (2007) reported that more than 60% of rollover initiations were tripped as shown in Figure A and Digges (1991) reported that more than 90% of vehicle rollovers occur about the vehicle longitudinal axis.

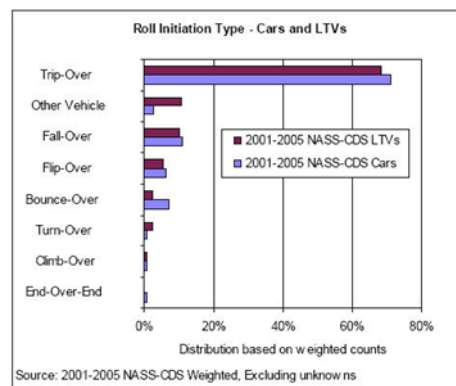


Figure A - Distribution of rollover initiation type in the 2001-2005 NASS-CDS

Viano (2004) reported on a breakdown of test types and their relationship with rollover crashes as shown in Figure B. The study of field crashes involved analysis of databases from crashes in the United States, United Kingdom, Australia and Germany (Parenteau et al. 2001a, 2003). This work provided a global perspective on the relevant rollover crashes. As shown in Figure B, nine laboratory tests cover 93% of the field incidence of rollover crashes for passenger cars and 89% for LTVs. This addressed 84% of serious injury rollovers. Details on the methodology used to determine these fractions are covered in the paper by Parenteau et al. (2001a). The data shown in Figure B involve three columns of frequency percentages. The left represents the NASS-CDS rollover categories used to classify rollover crashes and their field prevalence. The middle column represents the type of laboratory rollover crashes considered. The analysis method determined the fraction of real-world rollovers that would be addressed by these laboratory tests. The right column is the final fraction of field relevance of the laboratory tests. This includes the frequency of rollover crashes and serious injury of belted occupants. The results have been updated with newer NASS-CDS data, but the main conclusion was that a series of rollover tests is needed to cover the majority of real-world injuries in field rollover crashes.

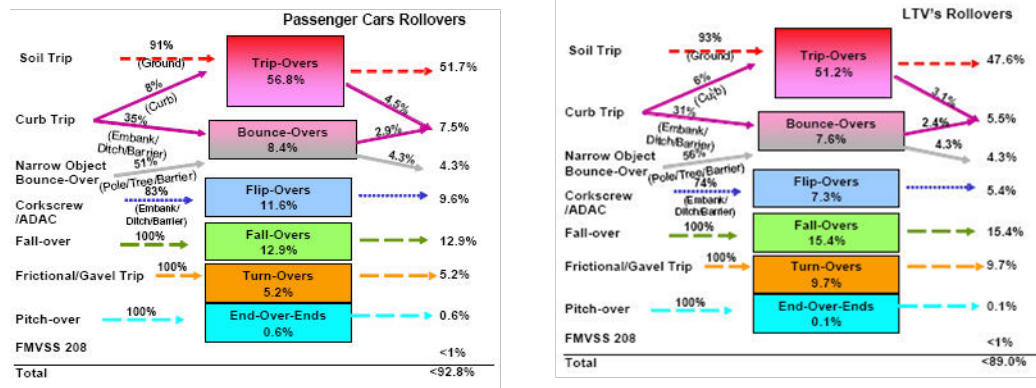


Figure B - Analysis of test types with rollover crash types for passenger cars and LTVs

Numerous papers exist with regard to rollover crash characterization where examination of various aspects of interest has been conducted.

1. SCOPE

The scope of this document is to provide an overview of the techniques found in the published literature for rollover testing and rollover crashworthiness evaluation at the vehicle and component levels. It is not a comprehensive literature review, but rather illustrates the techniques that are in use or have been used to evaluate rollover crashworthiness-related issues.

2. REFERENCES

Appendix A contains a list of references and other literature on the subject.

3. DEFINITIONS

For ease of discussion the following terms are identified in terms of general usage and in the context of rollover testing:

3.1 LEADING SIDE (sometimes referred to as Near Side)

The side of the vehicle that is initially going into the roll; so a driver side leading roll describes an orientation that in the initial part of the rollover the driver side is starting to move toward the ground (while the passenger side would be moving upward).

3.2 TRAILING SIDE (sometimes referred to as Far Side)

The side of the vehicle that is following the leading side going into the roll; so in driver side leading roll the passenger side would be the trailing side.

3.3 CURB TRIP

A rollover that occurs when a vehicle moving laterally slides into a length of raised curb; the rollover is initiated by the impact of the wheels with a raised curb.

3.4 PITCH-OVER

An end-over-end type of rollover, such as might occur when a vehicle with a longitudinal velocity goes over a drop off.

3.5 SOIL TRIP

A rollover that initiates as a result of the furrowing forces from the buildup of soil by the wheels as the vehicle moves laterally on a dirt surface.

3.6 ON-ROAD ROLLOVER

A rollover that initiates on the road surface.

3.7 UN-TRIPPED ROLLOVER

A rollover that initiates on the road surface as a result of friction forces between the tires and the road surface.

3.8 CORKSCREW

A rollover test where the rollover motion is initiated by a vehicle moving with one side of its wheels on an inclined ramp, resulting in a spiraling-type motion during the rollover.

3.9 TRIP-OVER

When the lateral motion of the vehicle is suddenly slowed or stopped inducing a rollover. The opposing force may be produced by a curb, pothole or pavement that the vehicle wheels dig into.

3.10 TURN-OVER

When centrifugal forces from a sharp turn or vehicle rotation are resisted by normal surface friction (most common for vehicle with higher cg). The surface includes pavement surface and gravel, grass, dirt and there is no furrowing, gouging at the point of impact. If rotation and/or surface friction causes a trip, the rollover is classified as a turn-over.

3.11 FALL-OVER

When the surface on which the vehicle is traveling slopes downward in the direction of vehicle movement so that the center of gravity (cg) becomes outboard of its wheels. The distinction between this code and turn-over is a negative slope.

3.12 FLIP-OVER

When a vehicle is rotated around its longitudinal axis by a ramp-like object such as a turned-down guardrail or the back slope of a ditch. The vehicle may be in yaw when it comes in contact with a ramp-like object.

3.13 BOUNCE-OVER

When a vehicle rebounds off of a fixed object and overturns as a consequence. The rollover must occur in close proximity to the object from which it is deflected.

4. TEST METHODS FOR FULL VEHICLE TESTING

4.1 Dolly Rollover Test Procedure

4.1.1 Background

According to Wilson and Gannon (1972), the Dolly Rollover Test Procedure was introduced by Mercedes-Benz in a presentation to the SAE Impact and Rollover Subcommittee in 1970. The dolly rollover test was incorporated into FMVSS 208 in 1971. SAE Recommended Practice SAE J2114 "Dolly Test Procedure" was adopted in 1993. The SAE J2114 rollover test procedure is shown in Figure 1. A close up of the dolly fixture is shown in Figure 1A. Based on literature review SAE J2114 has been used in evaluation of the following:

- Restraint system performance
- Rollover occupant protection system performance

- Occupant kinematics and ejection
- Vehicle structural integrity such as roof crush performance
- Vehicle rollover kinematics

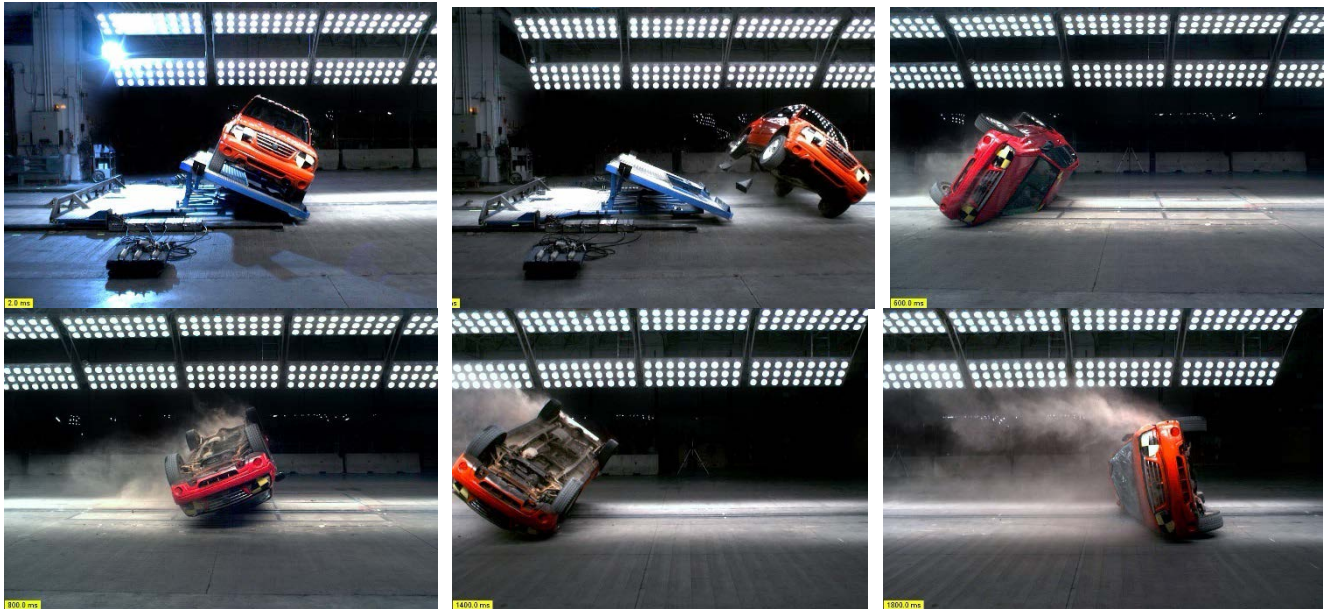


Figure 1 - SAE J2114 Rollover test mode (courtesy of Autoliv)



Figure 1A - Close up of J2114 dolly rollover fixture (courtesy of Exponent)

James et al. (1997) reported that the SAE J2114 rollover test procedure is one of the most widely used rollover test methodologies because it provides a measure of control over the trip location and the vehicle roll direction. In spite of a measure of control over the trip location and vehicle roll direction, they noted that the timing and location of specific vehicle/ground contacts and the resulting roll motion of the vehicle during staged testing are not repeatable. According to James et al., the procedure also does not appear to simulate the occupant motion prior to and during the trip phase.

4.1.2 Test Procedure

The test vehicle is oriented laterally on a rolling cart with a platform at a roll angle of 23 degrees from the horizontal and with the leading side tires against a 4-in (10.16-cm) high rigid flange. The lower-side tires are to be 9 in (22.86 cm) above the ground. The vehicle and rolling cart are accelerated to a constant velocity (30 mph is given as an example in the SAE J2114 procedure, but is required in FMVSS 208) and the cart then is stopped at a distance of not more than 3 ft (0.914 m) without transverse or rotational movement of the platform during its deceleration. The cart deceleration must be at least 20 g's for a minimum of 40 ms. The tire support flange will induce an initial roll velocity of the vehicle, and the leading side tires will most likely impact the ground first, after which the vehicle will continue to roll.

This test procedure was used by NHTSA during the early 1980s for testing numerous passenger cars and trucks, and evaluated by many researchers from the 1970s to the present (Ennos, 1971; Segal and Kamhitz, 1983; Wilson and Gannon, 1972; Cooperrider, 1990). The specified test conditions of 23 degree angle and 30 mph velocity were chosen to ensure that most vehicles would roll on concrete roadways subjected to the aforementioned deceleration pulses. It also has been used for developing, testing and evaluating rollover occupant protection systems. This test method has been used to research rollover mechanics on surfaces other than concrete, including dirt (Croteau 2010).

4.2 Rollover Impact Test Systems Designed for Initial Impact Control

There are at least two rollover test systems designed to control initial impact conditions. The CRIS (Controlled Rollover Impact System) test device utilizes a semi-trailer to deliver a rotating and translating test vehicle onto an outdoor test surface. The JRS (Jordan Rollover System) test device enables control of the vehicle initial rollover impact conditions and the number of impacts with a moving impact surface driven by a pneumatic sled system. The JRS rollover system is suitable for use in a laboratory setting. These systems are described in 3.2.1 (CRIS) and 3.2.2 (JRS).

4.2.1 Controlled Rollover Impact System (CRIS) Test

Cooper et al. (2001) reported on a dynamic rollover test procedure with controlled roof impact, thus the method is referred to as the Controlled Rollover Impact System (CRIS) and is covered by US Patent 6,651,482 assigned to Exponent, Inc. (Moffatt, 2003). This test method releases a rotating vehicle onto the ground from the back of a moving semi-trailer. By controlling the roll, pitch and yaw angles, translation and vertical velocities, and roll velocity of the vehicle, the first roof-to-ground interaction is found to be controllable from test to test. However, the subsequent vehicle dynamics may not be repeatable as the vehicle rolls to rest.

4.2.1.1 CRIS Test Procedure

To achieve this goal, the CRIS procedure involves a moving semi-trailer with a drop fixture that has adjustable-height support pins designed to spin and drop the vehicle at a given roll rate and orientation (see Figures 2 and 3). The towed semi-trailer supports a U-shaped fixture used to allow dropping the vehicle directly onto the ground. This test methodology assures a controllable initial roof-to-ground impact at a given combination of translational, vertical and roll velocities. The fixture is equipped with a motor drive system for rotating the vehicle about its center of gravity (CG), and also is versatile enough to allow testing of different vehicles with identical roof-to-ground impacts. The fixture is movable to allow testing on flat surfaces such as asphalt, dirt, sod, etc., and on other facility locations. Cameras can be mounted on-board and off-board the fixture to cover filming of the event. This methodology can be used with ATDs for research such as occupant excursion and airbag curtain evaluation; the methodology for positioning dummies in the test vehicle was reported by Moffatt et al. (2003). Carter et al. (2002) compared some CRIS test results with SAE J2114 dolly tests and concluded that the dolly and CRIS tests produced two significantly different results, in terms of vehicle dynamics.



Figure 2 - Test vehicle and fixture for CRIS procedure test

The fixture accommodates pitch angles of $\pm 15^\circ$ and yaw angles of $\pm 15^\circ$. Test conditions have been reported from 13 to 80 kph (8 to 50 mph) translation velocity, 25 cm (10 in) and larger drop heights, roll rates of 220 to 450 degrees/s, with the yaw angle typically at 90° and the pitch angle typically at 5° .

4.2.2 Jordan Rollover System (JRS)

4.2.2.1 Background

The Jordan Rollover System (JRS) is a physical test apparatus which evaluates vehicle-rollover-protection performance by dropping a rotating vehicle with a horizontally stationary CG position onto a moving road bed and is covered by US Patent 7,373,801 assigned to Safety Testing International. This test configuration permits control and monitoring of the rollover impact conditions, and allows the rollover test to be conducted in a limited space.

4.2.2.2 Test Procedure

A pictorial sequence of a JRS test is shown in Figure 3. The system consists of a pneumatic dynamic impact sled that is mounted a platform, which represents an impacted road surface. The pneumatic system propels two pistons connected to cables that pull the platform, which is mechanically coupled to a driveshaft that rotates the test vehicle. The pistons are disconnected from the rotational drive system before impact, allowing the vehicle to roll freely during impact. The initial impact conditions are controlled by mechanical adjustments in the rotational drive system and the pneumatic system. The vehicle initially is positioned to have the desired vertical velocity at impact and is suspended by a fixture as illustrated. The vehicle release is electromechanically controlled to ensure that the desired impact location and angle are obtained. The translational impacting velocity is controlled through the pneumatic sled system. During the impact event, the vehicle remains connected to the fixture via the cradle and its rotating axis, and the vehicle is free to move vertically and to rotate about its rotational axis and in the plane of the fixture. Once the vehicle impacts the platform and the platform passes out from under the vehicle, the vehicle is kept from falling onto the tracks by a built-in arresting system, thus preventing any further contacts with the vehicle roof.

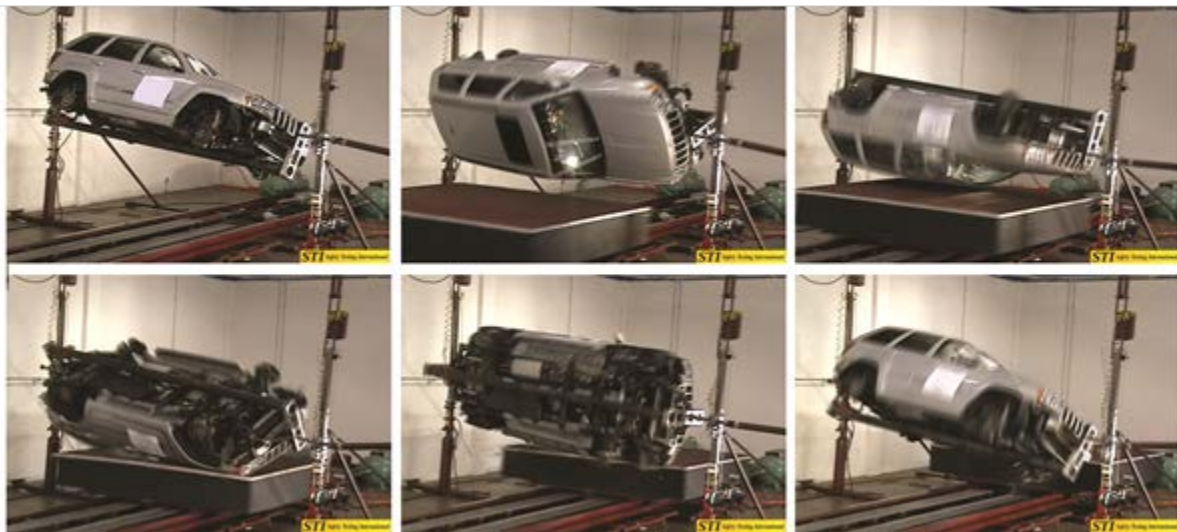


Figure 3 - Jordan rollover system test (courtesy Safety Testing International)

The sequence above shows a vehicle in a pitched and yawed orientation rotating and falling against a moving surface, allowing a controlled initial impact of the vehicle. The vehicle impacts the surface and the surface then moves out of the way to preserve the resulting damage. Subsequent impacts can be run on the same vehicle under controlled impact conditions to continue evaluation of the effects of interest. The moving surface is instrumented to provide measurement of impact loads, and instrumentation on the test device provides measurements of the impact conditions, including rotational and vertical velocity, and velocity of the impacted surface. Instrumentation and video on-board the vehicle record the metrics of interest associated with a given study. Anthropometric dummies routinely are incorporated for evaluation of restraint and structural performance evaluations.

A number of sensors provide data of the actual impact conditions. For example, direct recording of the velocity at the front and back of the vehicle is provided by potentiometers mounted on the vertical rails. The rotational velocity of the vehicle is measured directly with an angular rate sensor mounted inside the vehicle. A roll encoder mounted to the cable drive system measures the roadway velocity at impact.

The system design approach can accommodate yaw attitudes of at least $\pm 30^\circ$, and the vehicle can be pitched at selectable angles ranging from 0 to 10 degrees. The JRS has a provision for recording the loads on the roof through load cells mounted between the moving platform and the carrier system mounted on the rails (Jordan 2010). The JRS design approach supports various road platform sizes and provides for vehicles weighing up to 2727 kg (6000 lb). The JRS can control the number of impacts that occur during a given test by adjusting the length of the platform and the initial contact location (Jordan 2010).

Impact velocity control is provided through two mechanisms. The translational impacting velocity is controlled through a pneumatic sled system. The drop height of the vehicle is positioned to produce the desired impact velocity.

Variability analyses of the system with regard to initial impact conditions have been reported (Bish, 2008; Chirwa, 2010; Friedman, 2010).

Test conditions typically reported in the literature are translation velocities from 24 to 34 kph (15 to 21 mph), 5 or 10 pitch, 80° yaw, 10 to 15 cm (4 to 6 inches) drop height and 180 to 270 degrees/s at first side contact.

4.3 Ramped Rollover Tests

4.3.1 Background

Unlike the SAE J2114 test methodology where a vehicle is moving laterally at the initiation of the test, ramp or corkscrew tests take a portion of a vehicle's forward (longitudinal) momentum and translate it into roll motion. This typically produces a rollover with significant longitudinal velocity and relatively low roll rates. Depending on the vehicle's forward velocity and ramp configuration, both roll and non-roll cases can be generated, thus providing roll rate data in both roll and non-roll for rollover sensing algorithm development. In Europe, Allgemeiner Deutscher Automobil Club (ADAC) developed this test mode as a consumer information test, thus it sometimes is referred to as "ADAC Corkscrew" or "ADAC ramp test" in the literature (Viano and Parenteau, 2004). Figure 4 shows various ramp configurations with different height, width and length that have appeared in the literature. One type shown in Figure 4 is a straight-up-flat-surface ramp, while the other is a curved surface (sometimes referred to as a spiral ramp). These are described in 3.3.1.1 and 3.3.1.2.

4.3.1.1 Straight-Up-Flat-Surface Ramp

The straight-up-flat-surface ramp is designed in such a way that the bottom of the test vehicle does not contact the side edge of the ramp. This eliminates one source of possible test variations, but as ramp height increases the risk of vehicle underbody interaction increases. Switching to a curved-surface corkscrew ramp alleviates this condition (3.3.1.2). A ramp that is designed to serve this purpose for testing vehicles ranging from small-sized cars to light trucks and SUVs is shown in Figure 4(d).

An early straight ramp test was incorporated into SAE Recommended Practice J857 (now canceled). According to Wilson and Gannon (1972), this procedure, developed by Chrysler, uses a curved guide-rail to direct the test vehicle up the ramp (see Figure 5) high enough to initiate vehicle roll. Sakurai et al. (1991) used the SAE J857 ramp for their rollover study by conducting a series of 12 ramp rollover tests at 50 km/h (31 mph) as shown in Figure 6. The roll motion was developed by driving the right-side tires onto the ramp while quickly turning the steering wheel to the right, resulting in a left-side-leading vehicle rollover.

During a straight ramp test, a vehicle with longitudinal velocity runs over a ramp; initially wheels from one side of the vehicle contact the ramp, while wheels on the other side are in contact with the ground. As the vehicle continues to move up the ramp, it experiences a high asymmetric acceleration from the z-direction causing it to rotate along its longitudinal axis. When it leaves the ramp, the vehicle continues to rotate along its longitudinal axis until it contacts the ground.

Issues pertaining to this test mode may include: (1) getting the test vehicle on the ramp in the same manner every time, and (2) whether or not the steering wheel on the test vehicle should be locked in position during the test. The ramps shown in Figures 4(b) and 4(c) were used by TUV Rheinland. Figure 4(b) shows a corkscrew ramp and test. The ramp shown in Figure 4(c) consists of four segments: The first three segments of lower heights are an integral part (referred to as a three-segment ramp), while the fourth segment can be separated from the entire fixture (referred to as a four-segment system). Given a forward velocity, the three-segment ramp can be used for non-roll tests, while the four-segment ramp can be used for roll cases. A ramped test from the 1930s is shown in Figure 7.

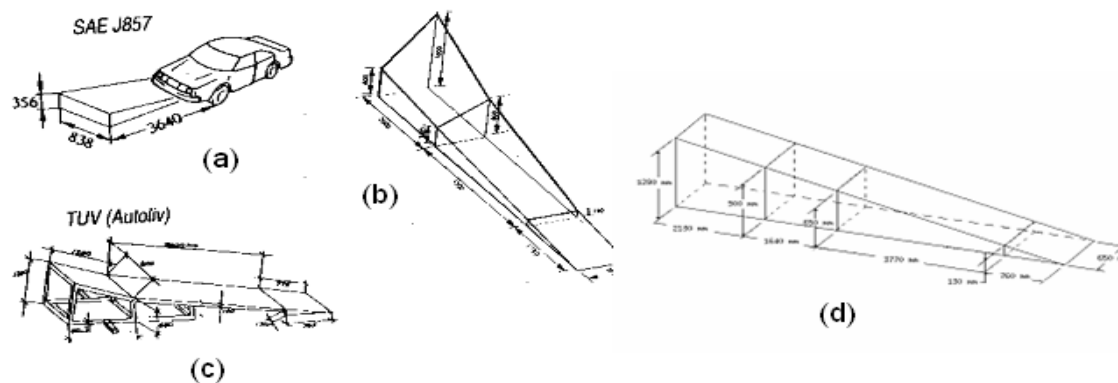


Figure 4A - 4D - Various ramp configurations

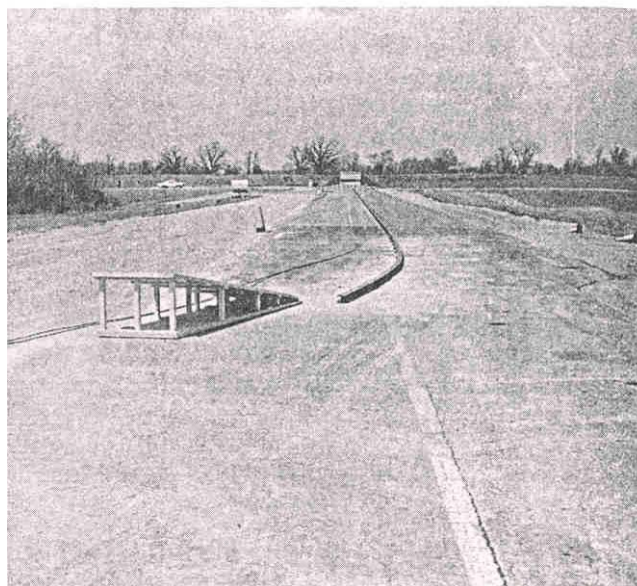


Figure 5 - Use of SAE J857 ramp (now canceled)

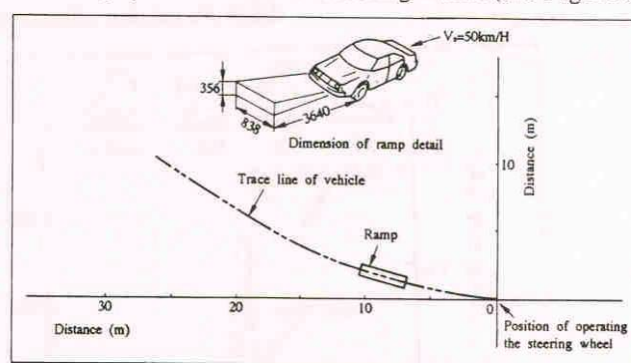


Figure 6 - Corkscrew ramp tests (Sakurai et al., 1991)

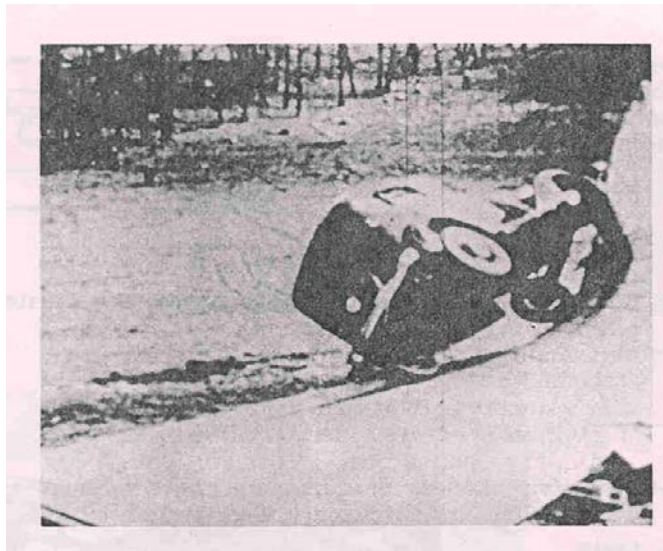


Figure 7 - GM test in early 1930s

4.3.1.2 Curved-Surface (Corkscrew) Ramp

Another type of test ramp is a curved or spiral ramp, which provides the ability to introduce an inclination angle as the vehicle travels up the ramp. Figure 7 shows an early corkscrew rollover test done at General Motors (GM) in the 1930s. The test, as reported by Wilson and Gannon (1972), was done by driving a vehicle onto a spiral ramp located at the top of a hill. Figure 8 shows a spiral ramp used for corkscrew tests conducted by DEKRA as reported by Berg et al. (2002). Typically, a corkscrew test produces one or two quarter-turn vehicle rolls; i.e., 90° and 180°, respectively.

Vehicle roll and non-roll conditions can be generated using different ramp configurations, such as:

- Ramp length
- Ramp height
- Ramp surfaces: flat versus spiral
- Longitudinal velocity
- Entrance: straight-in versus curved-in



Figure 8 - Corkscrew test mode using spiral ramp

4.4 Curb Trip Methodologies

4.4.1 Critical Sliding Velocity Mode

The Critical Sliding Velocity Mode (CSVM) test method, shown in Figure 9, has been reported by Chou (2005a). The CSVM test is a quasi-static test condition, and is relatively easy to perform. In this test mode, the test vehicle is placed at the top of a ramp, which can be adjusted to any angle smaller than the angle that the vehicle will roll over by itself under static conditions. The wheels of the vehicle sit on a "frictionless pad" and are guided on the ramp. The vehicle slides laterally down the ramp when released and initiates rollover when the tires impact the flange located at the bottom of the ramp, provided that the speed and angle are sufficient, as shown. This test mode has been shown to be capable of generating low to midrange lateral acceleration levels depending on the ramp angle (for a given ramp length and curb height) for both roll and non-roll conditions. Some sensor suppliers and test institutions have adapted this test methodology as a means to generate low lateral g's and vehicle roll rates for rollover sensor/algorithm development. However, signals generated from this mode may pose some difficulty to sensor engineers in discriminating rolls from non-roll conditions.

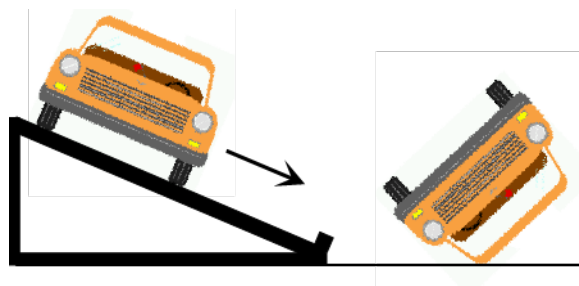


Figure 9 - Ramp curb impact test mode

4.4.2 Lateral Curb Tripping

A Lateral Curb Trip test involves propelling a vehicle sideways, with no longitudinal velocity, into a curb-type structure. In a pure lateral side curb test mode, as shown in Figure 10A, the vehicle is placed on a sled against a curb of about 6 inch (15 cm) high, or high enough to allow rim interaction with the curb. The sled is then towed to a predetermined velocity (which can be determined by a CAE rollover model of the specific vehicle or via trial-and-error method) and released from the tow device prior to impact with the curb. In general, the vehicle will experience a lateral acceleration of approximately 7 to 12 g, thus producing high roll rate and high lateral acceleration signals (Chou, 2005b). Another method used for conducting this type of test is to tow the vehicle sliding sideways on a low-friction surface into the curb, such as utilizing a layer of soap to allow the vehicle to slide sideways. The curb height and lateral velocity are parameters that affect the roll condition in a lateral curb impact. It has been reported that curb trip tests generate occupant head lateral movement that is the fastest to close the gap between the occupant head and the side glass, thus requiring an earlier time-to-fire for a rollover occupant protection system (Werner, 2002). Thomas and Cooperrider (1989, 1990, and 1998) presented this test procedure using passenger cars and utility vehicles; analyzed vehicle kinematics results including time histories of displacement, velocity and energy; and compared results with those from dolly tests at similar speeds with a similar vehicle.

Hare et al. (2002) and Hughes et al. (2002) presented a lateral curb trip test methodology that utilized an SAE J2114 dolly, but with the vehicle support platform horizontal, to launch the vehicle into an aluminum honeycomb-cushioned curb (honeycomb often is utilized to ensure a rollover occurs rather than have the vehicle wheel/axle separate without a rollover occurring) Figure 10B. In this testing the vehicle came off the dolly platform 18.5 inches (47 cm) above the ground and impacted a 6 inch (15 cm) tall curb that was placed approximately 13 feet (4 m) downrange from the launch point. The authors noted that this methodology provided an alternative to the FMVSS 208 rollover dolly procedure in a limited area of evaluating dummy kinematics and restraint performance. Dummy head movement in response to the trip differed from that shown in FMVSS 208 rollover dolly testing.

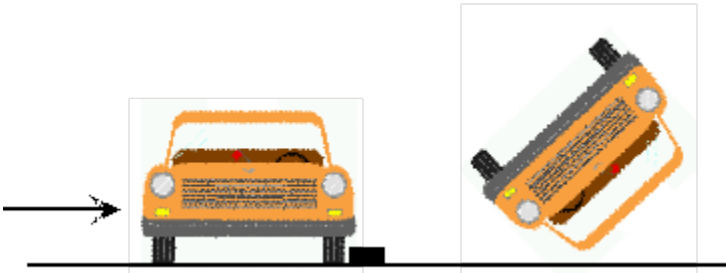


Figure 10A - Perpendicular side curb tripping



Figure 10B - Example of tripped rollover procedure runs

Figure 10

4.4.3 Oblique Curb Trip

Curb trip tests alternatively can be run in an oblique configuration, as shown in Figure 11, in which the vehicle has a forward velocity component, with and without a yaw rate, impacting the curb with a prescribed incident angle. The benefit to this type of procedure could be to more closely replicate the configuration of a specific accident scenario, but the cost would be in the repeatability of the resulting vehicle behavior. The pure lateral variation sometimes is referred to as an "aggressive" side curb trip, and could be considered for some research to be a worst-case condition. In addition to curb height and lateral velocity, forward velocity and side-slip angle is a controlling factor in an oblique mode. An example of oblique curb trip testing is the test series conducted by the University of Missouri Columbia where vehicles were driven via remote control into a curb in three different ways: driving straight, cornering, and cornering and spinning (Nalecz 1994).

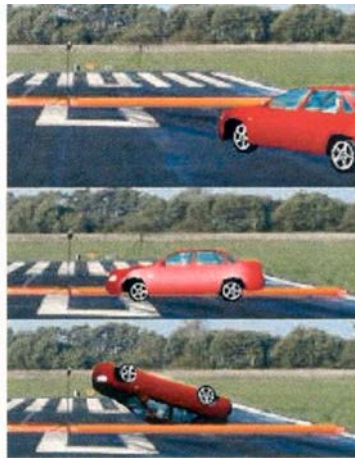


Figure 11 - Oblique side curb tripping

4.5 Deceleration Rollover Sleds

The deceleration sled test is a methodology developed to allow for controlled 90° tip-up events. The methodology was developed as the Deceleration Rollover Sled (DRS) Patent 6,622,541 is described by Stein (2003) for use in occupant protection development (Rossey, 2001) and as the Dynamic Rollover Test (DRT) for use in rollover resistance measurement (Larson, 2001). This methodology consists of a sled that runs on a rail and a method of applying a deceleration force in the range of lateral tire friction or furrowing forces. The DRS method uses a series of pulse-generating brakes to provide the deceleration force, as shown in Figure 12, and the DRT method uses a linear brake fin that is mounted to the ground, to which brake pads on the sled clamp. A test vehicle can be positioned laterally on the platform of the sled. On the leading side of the platform, a set of tire stops are bolted to the surface of the platform. The wheels are placed against the edge of the stops. The sled accelerates in the direction of the sled track until it reaches a constant predetermined velocity; brakes are used in such a manner as to decelerate the sled to a desired "g" level. A system of tether straps can be used to stop the vehicle from rolling onto its side or traveling off of the sled. The vehicle then can be saved for reuse in subsequent tests. Examples of the DRS and DRT are shown in Figures 13A and 13B respectively.

The DRS can provide a wide range of "g" levels from slow (1 to 2 g) to fast roll (8 to 10 g), so it can be adapted for furrow-type and aggressive curb-trip-type simulations. Stopping distance, deceleration velocity and deceleration g's are parameters that affect the performance of this test mode.

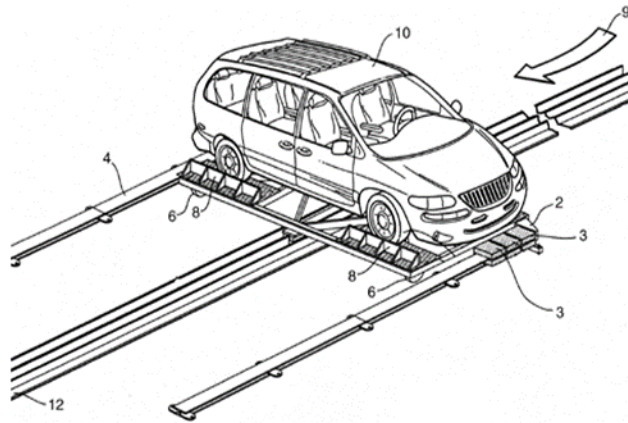


Figure 12 - Deceleration rollover test sled (leading side)

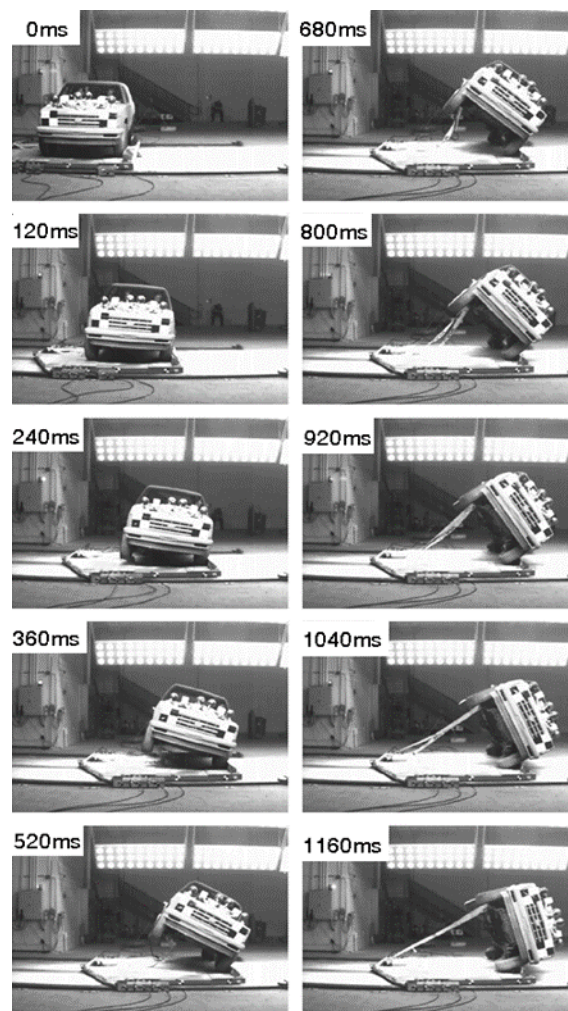


Figure 13A - Vehicle rollover sequence using the Autoliv drrs decel-sled test