ROLLOVER RESISTANCE TEST PROCEDURE INVOLVING MAXIMUM ROLL MOMENTUM

Brian Kebschull
Dynamic Research, Inc.
USA
Keisuke Ishii
Honda R&D Co., Ltd.
Japan
Marc Ernst
Honda R&D Americas, Inc.
USA

Paper Number 321

ABSTRACT

A procedure that was developed by Honda R&D to measure and evaluate vehicle rollover resistance is described and compared to the NHTSA Roll Rate Feedback Fishhook Test. The Honda procedure, known as the AVC Reverse Steer Test, incorporates the use of an automatic vehicle controller (AVC) for precise and repeatable steering inputs and to allow the use of sensor feedback in the control algorithm. The procedure is intended to induce "worst-case" dynamic roll response for each vehicle, by using the vehicle's roll momentum. A distinguishing feature of the AVC Reverse Steer Test is the algorithm used to determine when the steering reversal is to occur. The reversal occurs at a time corresponding to the second local maximum value of roll rate, following the initial steering input. It was found that this algorithm provided a reversal timing that induced worst-case roll response for a variety of vehicles.

INTRODUCTION

Rollover resistance has been a topic of interest for vehicle manufacturers for many years. Over the last several decades, however, this interest has intensified, as sales of vehicles with higher centers of gravity (e.g., sport utility vehicles and pickup trucks) have greatly increased.

Honda and Dynamic Research, Inc. (DRI) began work to develop a new dynamic rollover resistance test in 1996. The result of this effort, which concluded in 1998, was the AVC Reverse Steer Test, described herein. Since then, the test procedure has been used extensively as a method of comparing vehicles' rollover resistance.

The test is of the "fishhook" type. The name "fishhook" is used because the path of a vehicle looks similar to a fishhook when viewed from above during a low-severity test. However, the path does not generally resemble a fishhook during high-severity tests. Other vehicle manufacturers that are known to employ fishhook-type tests include Toyota and Nissan.

In recent years, the U.S. National Highway Traffic Safety Administration (NHTSA) has had an active role in rollover resistance test development, and has made it a priority to investigate and inform the public about the risks of vehicle rollovers and the relative rollover resistance levels of the vehicles currently in the market. In response to a petition from Consumers Union, NHTSA began to develop what it then called an "emergency handling" test in 1997. This multi-phase effort included investigation of several fishhook-type test methods, in addition to investigation and consideration of many other types of tests.

In June 2000, NHTSA proposed to include the Static Stability Factor (SSF) as a rollover resistance rating of all new vehicles in its New Car Assessment Program (NCAP). The rating system was then implemented, beginning with the 2001 model year.

In November 2000, the U.S. Congress passed the Transportation Reporting Enhancement, Accountability, and Documentation (TREAD) Act. One element of the TREAD Act required NHTSA to develop a dynamic rollover resistance test by November 2002. In July 2001, NHTSA published a Request for Comments notice (Ref 1) that discussed in some detail the dynamic test procedures that were being considered, including several types of fishhook tests.

In October 2002, NHTSA published a Notice of Proposed Rulemaking (Ref 2) that proposed two specific tests to be used to assess dynamic rollover resistance, and to supplement the SSF ratings in the NCAP. The two tests included a J-Turn test and a fishhook-type test, which NHTSA called the Roll Rate Feedback Fishhook test (RRFF; NHTSA suggested that it be also called the "Road Edge Recovery Maneuver"). The RRFF test has some similarities and some differences with the AVC Reverse Steer Test, and these are discussed below.

AVC REVERSE STEER TEST DEVELOPMENT

Goals

The primary goal of the effort described herein was to develop a dynamic test procedure that would provide a basis for evaluating the relative rollover resistance of passenger vehicles. Of particular interest were sport utility vehicles and other light trucks. A test procedure was sought that would:

- Have good repeatability
- Provide steering inputs that would induce a "worst-case" response, while also being representative of real-world inputs by human drivers
- Be objective, such that different results would not be obtained for different test drivers
- Be equitable (e.g., providing equally severe inputs for different vehicles)

- Be applicable to assessment of possible untripped rollover for passenger vehicles operating on flat and level paved surfaces

Test Selection and Development

Several types of tests were considered as candidates during rollover resistance test development, in addition to the fishhook. These included the J-Turn test, tangent circle test, various sinusoidal steering tests, and tests involving closed loop steering, such as the Consumers Union short course maneuver and the ISO 3888-2 severe lane change (also known as the VDA course). The AVC Reverse Steer Test was selected because it best met the criteria listed above, namely, it can be performed with good repeatability; it induces worst-case vehicle roll response; it is objective; it is an "equitable" test; and it is applicable to assessment of untripped rollover.

After the form of the test had been selected, additional development was done to select the test parameters. The primary goals of this effort were to select parameters that were as severe as possible, while remaining within the capabilities of human drivers; would be equitable for different vehicles; and that would induce worst-case response for each vehicle.

AVC REVERSE STEER TEST EQUIPMENT, PARAMETERS, AND PROCEDURES

Equipment and Data Collection

The equipment required for the AVC Reverse Steer Test includes an AVC, sensors, signal conditioning, and outriggers.

The AVC used for test development (Fig 1) was developed by DRI and is described in Ref 3. It features a servomotor and power system to control steering angle, and is able to provide high rates and high levels of torque. As a result, steering inputs are accurate and repeatable.

Figure 1. AVC Servomotor Assembly.

Another important feature of the AVC is that it allows the use of sensor feedback in control algorithms.

The AVC was also used for data acquisition, and includes A/D, D/A, and digital encoder capabilities. The AVC Reverse Steer Test requires sensors to measure:

- Steering wheel angle
- Roll rate
- Lateral acceleration
- Vehicle speed

Additional sensors are typically used to measure:

- Yaw rate
- Sideslip angle
- Roll angle

The AVC steering control loop cycles at 500 Hz. Data are also collected at 500 samples/sec. Anti-alias and digital filters are used to condition the roll rate data (which are used in the reversal timing algorithm, as discussed below).

Outriggers are used to maintain driver safety. The outriggers that Honda currently uses are of a carbon fiber-reinforced aluminum design, and weigh a total of approximately 44 kg, including the mounts. They are mounted such that they extend laterally from beneath the vehicle at approximately the longitudinal cg location, as shown in Fig 2. In general, they contact the pavement at a body roll angle of approximately 15 deg.

Figure 2. Vehicle with Outriggers Mounted.

AVC Reverse Steer Test Parameters and Procedures

As discussed, the AVC Reverse Steer Test is of the "fishhook" type of rollover resistance tests. The general form of the steering input of the test is shown in Fig 3. Generally speaking, the test involves a rapid turn to an initial steering wheel angle. Steering is maintained at this angle for a short time (called the "dwell time"). Following this the steering is rapidly reversed to the reversal angle, which is then maintained for approximately 4 seconds.

Test parameters include these five steering parameters (initial angle, reversal angle, initial rate, reversal rate, and dwell time), as well as specifications for initial vehicle speed, throttle, and gear.

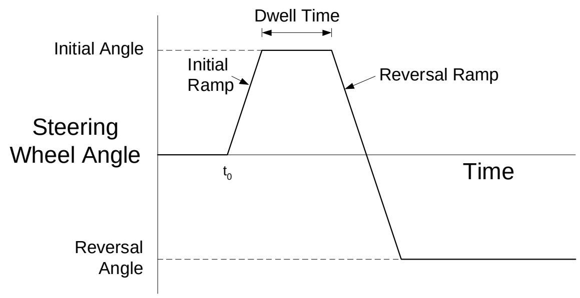

Figure 3. General Form of Steering Input for Fishhook Tests.

Initial Vehicle Speeds

Two initial vehicle speeds, 60 km/h and 90 km/h, are used. This was done because of a requirement that the test be applicable to vehicles traveling at typical urban and highway speeds (testing at higher speeds was considered but ultimately rejected, due to concerns about test driver safety).

Throttle

The throttle is closed approximately 0.5 to 1.0 sec before the initial steering input. This is done in order to be representative of typical evasive maneuvering situations and for optimum repeatability.

Brakes

The brakes are not used until the test has been completed. It was noted that NHTSA and other researchers have attempted to use pulse braking in order to increase the severity of the test. However, NHTSA found that it decreased the repeatability of the test. Also, pulse braking would require additional test complexity (i.e., additional test parameters would include pulse timing, duration, and magnitude), and a short-duration pulse may not be representative of typical evasive maneuvering. In addition, the test results would typically be highly sensitive to the exact values of these parameters.

Gear

Highest gear is used if the vehicle has an automatic transmission. For vehicles with manual transmission, third gear is generally used for the 60 km/h tests, and highest gear is used for the 90 km/h tests (the clutch remains engaged throughout the test). As a result, engine speeds are relatively low during the maneuver, and engine braking effects are minimal.

Initial Steering Wheel Angle

The initial and reversal steering wheel angles are increased from run to run. The lowest initial steering wheel angles (also called the "level 1" steering wheel angles) are determined from Slowly Increasing Steer pre-tests conducted at 60 and 90 km/h. In this test (Fig 4), the steering wheel angle is slowly increased, with vehicle speed maintained at a constant. The relationship between steering wheel angle and lateral acceleration is then determined. As shown in Fig 4, the lowest initial steering wheel angle to be used in the AVC Reverse Steer Test is that which corresponds to 90% of the maximum lateral acceleration in the Slowly Increasing Steer pre-test. The 90% level was selected in order that the testing begins at a relatively severe level. At the same time, the 90% value can be obtained with good repeatability. Note that the steering wheel angle corresponding to 100% of maximum lateral acceleration cannot be obtained repeatably, due to various non-linearities and other conditions that make achieving steady state conditions at the limit very difficult.

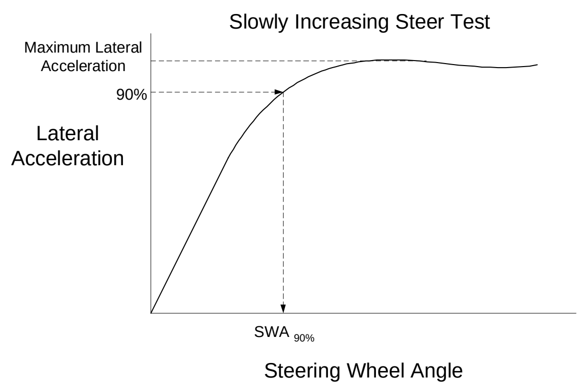

Figure 4. Measurement of Lowest Initial Steering Wheel Angle.

Note also that the level 1 steering wheel angle differs, in general, from vehicle to vehicle. The selection procedure accounts for vehicle-to-vehicle differences in steering ratio, steering compliance, etc. This helps to ensure fairness. That is, the inputs are of the same relative severity across all vehicles. For vehicles tested to date, level 1 steering wheel angles typically range from 120 to 200 deg at 60 km/h, and 80 to 155 at 90 km/h.

Reversal Steering Wheel Angle

The reversal angle is the simply the opposite of the initial angle (e.g., if the initial angle is 190 deg to the right, the reversal angle is then 190 deg to the left). Larger reversal angles (e.g., 600 deg, as used in the NHTSA Phase I testing) were investigated. However, they were not found to increase test severity, in general, and they tended to increase tire wear noticeably during testing.

Steering Wheel Angle Increments

The AVC Reverse Steer Test uses run-to-run increments of steering wheel angle. The increments are 30 deg each. Up to 4 increments in each turn direction (right-then-left and left-then-right) are performed. Therefore, the highest initial steering wheel angle (i.e., level 5) is 120 deg greater than the lowest angle. This procedure ensures that steering wheel angles associated with 90% to 100% maximum lateral acceleration are used.

Initial and Reversal Steering Rates

The steering rate is 720 deg/sec for both the initial and reversal steering ramps. In general, for fishhook tests, a higher rate will induce a more severe vehicle response. Research has shown that steering rates greater than 1400 deg/sec can be achieved by human drivers for steering angle rotations that do not require a repositioning of the hands on the steering wheel (e.g., less than 180 deg). However, accomplishing steering wheel rotations of larger angles requires that the hands be repositioned, which substantially lowers the maximum achievable rate. A review of test data collected during tests using the Consumers Union short course (which in many cases requires relatively large steering wheel angles and maximum rates) showed that the maximum steering rates across several drivers was in the range of 600 to 800 deg/sec. 720 deg/sec (2 revolutions/sec) was selected as a convenient representative value within this range.

Primary Reversal Criterion

The reversal timing of the AVC Reverse Steer Test is determined using roll rate feedback. The reversal occurs at a time corresponding to the second peak roll rate, as shown in Fig 5. In practice, the AVC computer detects the second zero crossing of roll rate and then delays the reversal by a short pre-programmed period of time. This delay time is typically short (e.g., 0.10 sec), and is a function of known filter delays (from both the anti-alias filter and digital filter) and measured roll natural frequency of the vehicle. Note that the second zero crossing of roll rate corresponds to the third zero crossing of roll acceleration.

It was recognized early in test development that the reversal timing needed to be "tuned" for, or to take into account the unique characteristics of each vehicle, according to some response measure, in order to take advantage of the energy stored in the vehicle's suspension and the resulting roll momentum, and thereby induce worst-case response. However, it was not clear which vehicle response measure or measures (and what values of those measures) would be best suited for that purpose. Experiments involving the use of feedback of lateral acceleration, yaw rate, and roll angle (and combinations of these) were done, in addition to experiments with roll rate. In the end, roll rate was selected because of its direct relationship to roll momentum and because it is convenient to measure (e.g., sensor availability, ease of filtering high frequency modes, etc), which is helpful for detection of, for example, threshold crossings.

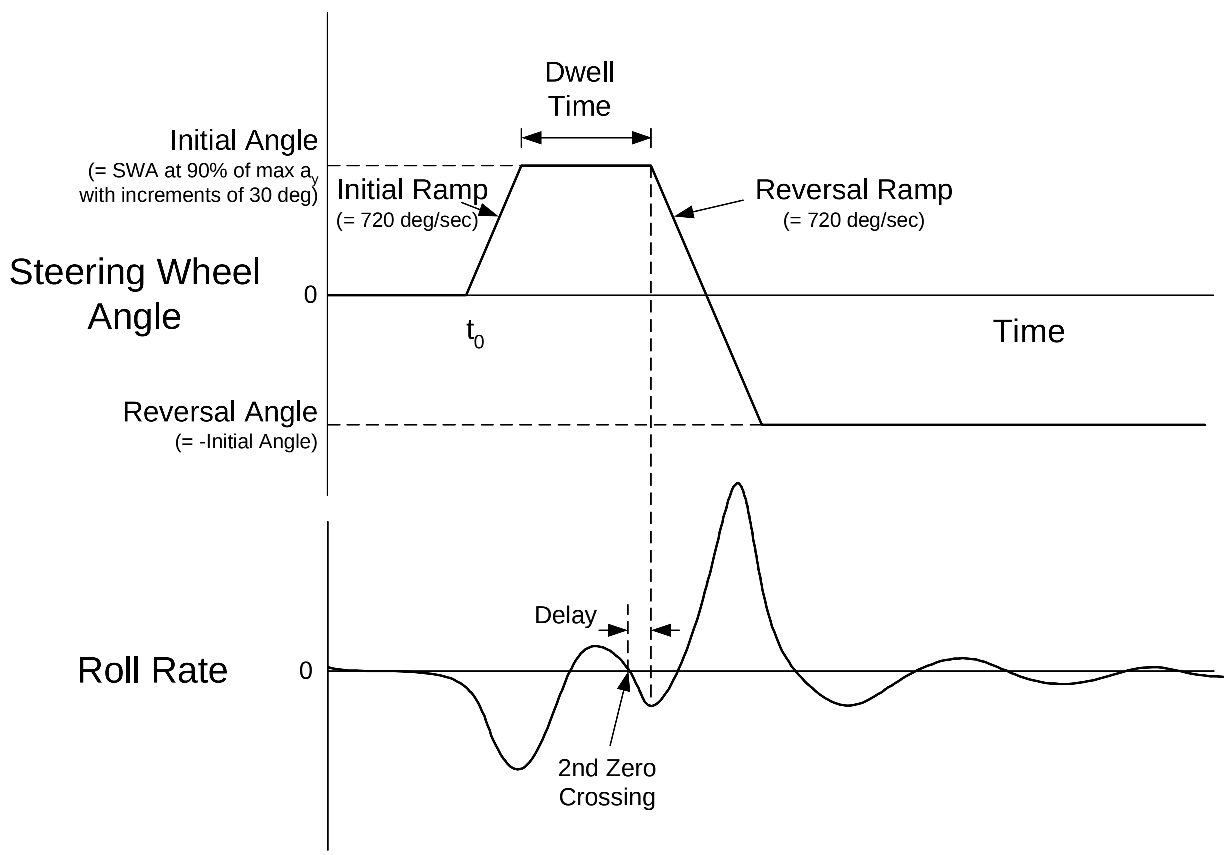

Figure 5. Determination of Steering Reversal in AVC Reverse Steer Test

The reversal timing strategy was developed based on experiments with various sport utility vehicles (SUVs), which involved determining which dwell times were most effective in inducing worst-case response. First, informal tests were conducted with various loading conditions, speeds and dwell times in order to identify cases that resulted in a tip-up (note that tip-up was considered to have occurred if the end of the outriggers contacted the pavement). Then, the dwell time was varied on successive runs.

In most cases, it was found that there was a range of dwell times that resulted in tip-up. That is, dwell times that were too short or too long did not result in tip-up. It was concluded that, at least for some vehicles, dwell times that are too short do not allow lateral acceleration to build to sufficiently high levels, or induce sufficiently large sideslip angles. On the other hand, dwell times that are too long may not induce tip-up due to tire scrub and a corresponding loss of vehicle speed (i.e., kinetic energy).

Figure 6 shows the results of the dwell time experiments for 6 example SUVs. For some vehicles (E and F), the range of dwell times that resulted in tip-up was relatively large, and included a dwell time of zero. For other vehicles, the range was relatively small. In large part, the “second roll rate peak” reversal strategy was selected based on these results. The timing provided by this strategy was found to be near the middle of the range for most vehicles. For these vehicles, the average dwell time provided by the AVC Reverse Steer Test, using the “roll rate second peak” criterion, was 0.49 sec.

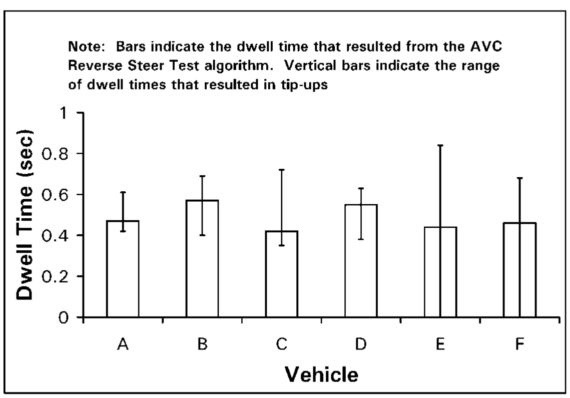

Figure 6. Dwell Times Resulting in Tip-up.

Secondary Reversal Criterion

NHTSA, in its October 2002 Notice of Proposed Rulemaking (NPRM, Ref 2), noted that, “Occasionally, when performing this maneuver, the measured roll rate does not return to zero for a substantial period of time (1 to 2 seconds) resulting in a greatly delayed countersteer and an invalid test. However, this happens quite rarely…”

This type of vehicle behavior was also observed during the development of the AVC Reverse Steer Test, and in many cases since then. In these cases, the roll rate does not cross zero (or 1.5 deg/sec, as in the NHTSA protocol) within a “reasonable” amount of time for many heavily loaded vehicles and vehicles with high suspension damping. The result is that speed (and hence, kinetic energy) reduces during the relatively long period prior to the steering reversal, and the event cannot be characterized as being “worst-case”. As mentioned, our experience is that this does not occur “quite rarely”, but rather it is a repeatable phenomenon that occurs for some combinations of vehicle and loading condition.

Because the primary reversal criterion could not be used, a secondary criterion was implemented. The secondary criterion involves a so-called “timeout” of the dwell time, based on a pre-measured value of the roll natural frequency of the sprung mass. Recalling that the primary reversal criterion is the second roll rate peak, the algorithm for the secondary criterion identifies the first roll rate peak (in real time) and then waits for a time equal to one cycle of the pre-measured roll natural frequency. If the reversal has not already occurred (due to the primary criterion), then the algorithm times out, and the reversal is applied.

For cases in which the reversal was initiated according to the primary criterion, it was found that the secondary criterion generally would have resulted in initiation of the reversal approximately 0.1 to 0.2 sec later.

Note that it is likely in cases in which roll rate “lingers” above zero, that small variations in reversal timing will not substantially affect the outcome of the run, since the situation is less dynamic (in roll, i.e., roll acceleration and velocity, and therefore roll momentum, are approximately zero). So, the slight delay involved when the secondary reversal criterion feature is used would not be expected to substantially influence the outcome of the run.

Loading Conditions

The test protocol typically includes testing at 2 or 4 loads. “Standard” load includes the vehicle, driver, AVC, instrumentation, and outriggers. “Heavy” load includes the Standard load plus additional weight in the form of water dummies placed in the rear seats and sandbags (if necessary) placed in the cargo area, to bring the total load to GVWR.

Investigations also typically included adding a load to the roof for both the Standard and Heavy loads, bringing the number of possible loading conditions to four. The roof load was vehicle-dependent, and typically in the range of 32 to 75 kg.

Tire Wear

Some of the concerns about fishhook-type tests that some researchers have discussed (e.g., Ref 4) have centered on repeatability issues regarding tire wear. Tires tend to wear quickly and unevenly (the shoulders tend to wear the fastest). It has been shown that extensive shoulder wear can increase a tire's coefficient of friction significantly.

The protocol of the AVC Reverse Steer Test has been to change tires when shoulder wear reduces the tread depth in the shoulder to one half of the original height. Although this issue was not extensively investigated during test development, test results in terms of trends have been found to be generally repeatable. That is, the tip-up/no tip-up boundary has generally been found to be stable when worn tires have been replaced by new (broken in) tires.

Test Series

Testing begins at steering wheel angle level 1 and proceeds from run to run until either level 5 has been completed, or until a tip-up occurs. If a tip-up occurs, then one additional run is conducted at the next lower "half level". For example, if a tip-up does not occur at level 2, but does occur at level 3, then one additional run is conducted at level 2.5 (i.e., the steering wheel angle 15 deg below level 3). Testing is generally not conducted at any steering wheel angle larger than that which first resulted in a tip-up, since it was shown that larger angles generally also result in tip-ups.

Vehicle Evaluation

The tests enable vehicle-to-vehicle or vehicle-to-group comparisons based on the steering wheel angle level at which tip-ups occurred (if any). Note that the evaluations include data from two initial vehicle speeds, both right-then-left and left-then-right turns at both speeds, and from two to four loading conditions.

Electronic Stability Control Systems

The procedure is compatible with and can be used to evaluate the effectiveness of various electronic stability control systems. This is also mentioned as being one of NHTSA's goals.

Comparison with NTHSA-Proposed Roll Rate Feedback Fishhook Test

As discussed above, NHTSA's October 2002 NPRM proposed two rollover resistance tests for use in its NCAP ratings. One was the J-Turn and the other was the Roll Rate Feedback Fishhook. The Roll Rate Feedback Fishhook bears many similarities to (and some key differences with) the AVC Reverse Steer Test.

Honda conducted testing during November and December 2002. This was done in part to investigate the effects of the differences between the AVC Reverse Steer Test and the Roll Rate Feedback Fishhook.

A summary of the AVC Reverse Steer Test and Roll Rate Feedback Fishhook test parameters is shown in Table 1. Among the similarities between the two tests are:

- The basic form of the maneuver is the same
- Selection of steering wheel angle is based on lateral acceleration measured in the Slowly Increasing Steer pre-test
- Steering rate (720 deg/sec)
- Use of roll rate feedback to determine reversal timing
- Reversal steering wheel angle is opposite of initial steering wheel angle
- Loading conditions

Among the differences are:

- The use of initial vehicle speed as a run-to-run increment, rather than steering wheel angle. This difference is not seen as important, however, but rather simply a difference in style and emphasis.
- The selection of initial steering wheel angle (NHTSA uses 6.5 times the value for steering wheel angle associated with 0.3g lateral acceleration. A typical value that results from this would be 270 deg). The NHTSA October 2002 method results in steering wheel angles generally similar to the higher angles used in the AVC Reverse Steer Test. In some cases, however, recent testing showed that the NHTSA procedure could result in substantially higher values (e.g., 390 deg).
- Reversal timing. The RRFF performs the steering reversal when roll rate first dips below (the absolute value of) 1.5 deg/sec, as shown in Fig 7. In our recent testing, typical dwell times that resulted from this strategy were generally in the range of 0.20 to 0.25 sec. This is substantially shorter than the reversal timing with the AVC Reverse Steer Test. As shown in Fig 6, the shorter dwell times of the RRFF would not have resulted in "worst-case" response for several of the vehicles and therefore would not be an "equitable" test. The late 2002 investigation, however, which involved 6 different vehicles, did not show the same trend. In those tests, the outcome (tip-up or no tip-up) was not very sensitive to reversal timing, within the range of approximately 0 to 0.6 sec, for all 4 of the vehicles that experienced a tip-up in at least one of the test conditions (2 vehicles did not have any tip-up). Rather, the outcomes were observed to be more sensitive to initial vehicle speed. That is, for boundary and near boundary cases, a change of 2 mph was more likely to change the outcome from no tip-up to tip-up

Table 1. Comparison of Honda and NHTSA Rollover Resistance Test Parameters

Test Parameter	AVC Reverse Steer Test	NHTSA Roll Rate Feedback Fishhook
Run-to-Run Increments	Steering wheel angle, increments of 30 deg, tip-up cases resolved to 15 deg	Initial speed, increments of 5 mph, tip-up cases resolved to 1 mph
Initial Speeds	60 km/h (37 mph) and 90 km/h (56 mph)	56 km/h (35 mph), up to 80 km/h (50 mph)
Initial Steering Wheel Angle(s)	Angle (SA1) that corresponds to 90% of the maximum lateral acceleration, up to SA1 + 120 deg	6.5 times the angle that corresponds to 0.3g lateral acceleration
Reversal Steering Wheel Angle(s)	Opposite of the Initial Steering Wheel Angle	Opposite of the Initial Steering Wheel Angle
Primary Steering Reversal Criterion	2nd roll rate peak	1st crossing of 1.5 deg/sec roll rate
Secondary Steering Reversal Criterion?	Yes	No
Steering Rate	720 deg/sec	720 deg/sec
Throttle	Closed prior to initial steering input	Closed prior to initial steering input
Brakes	None	None
Gear	Highest, typically	Highest, typically
Vehicle Loading*	Standard, Standard plus roof load, Heavy, Heavy plus roof load	Standard, Heavy

* Note: NHTSA definition of "Heavy" is slightly different than Honda definition

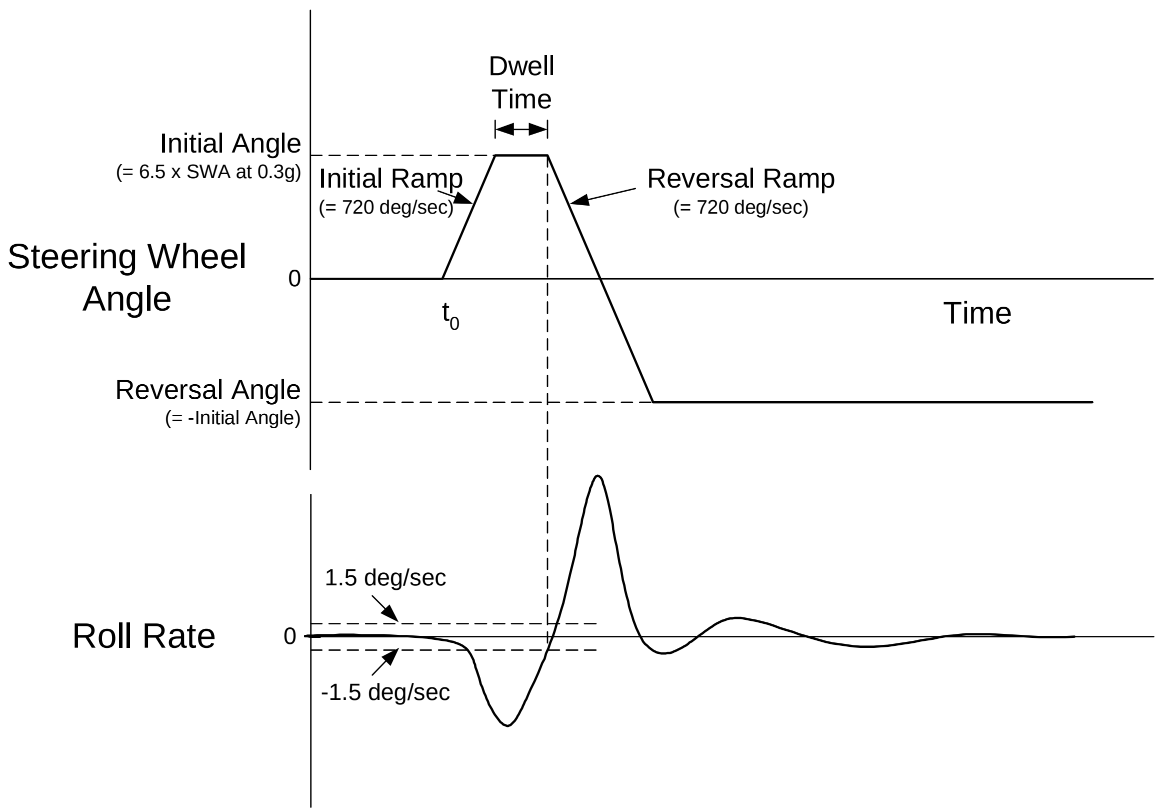

Figure 7. Determination of Steering Reversal in NHTSA Roll Rate Feedback Fishhook Test

than was a change of, for example, 0.2 sec in dwell time. Overall, therefore, the data suggest that the timing of the steering reversal may be more critical for some vehicles than for others, in terms of generating worst-case response. For those vehicles that showed a greater sensitivity to reversal timing, the later reversal of the AVC Reverse Steer Test, as compared to the RRFF, induced a more severe response (i.e., a truer "worst-case").

- The NHTSA October 2002 procedure lacks a secondary reversal criterion, such as the timeout feature of the AVC Reverse Steer Test. As discussed above, a secondary reversal criterion is needed for some combinations of vehicles and loading conditions. Figure 8 illustrates the effect of the lack of a secondary reversal criterion. As shown in this example, the vehicle response can be heavily damped, and roll rate “lingers” below -1.5 deg/sec for an extended period of time. Meanwhile, the vehicle slows somewhat, and the eventual reversal typically does not induce worst-case response. Our recent tests have confirmed NHTSA’s finding that, in some cases, the reversal only occurs after a dwell time of 1 to 2 sec. In some of these tests, no tip-up occurred, while tip-up did occur in tests in which the reversal was forced to occur after a shorter dwell time (e.g., 0.5 sec), using the same initial vehicle speed.

DISCUSSION AND CONCLUSIONS

Honda and DRI developed a dynamic rollover resistance test method, known as the AVC Reverse Steer Test. The test is applicable to assessment of untripped rollover for passenger vehicles operating on flat and level paved surfaces. The test has been shown to:

- Have good repeatability
- Provide steering inputs that induce “worst-case” response
- Be equitable (e.g., providing equally severe inputs for different vehicles)

It should be noted that the tests were specifically designed as a method of evaluating vehicle rollover resistance and comparing the rollover resistance of different vehicles. The steering angles and rates, while achievable by human drivers, were not designed or intended to be representative of normal

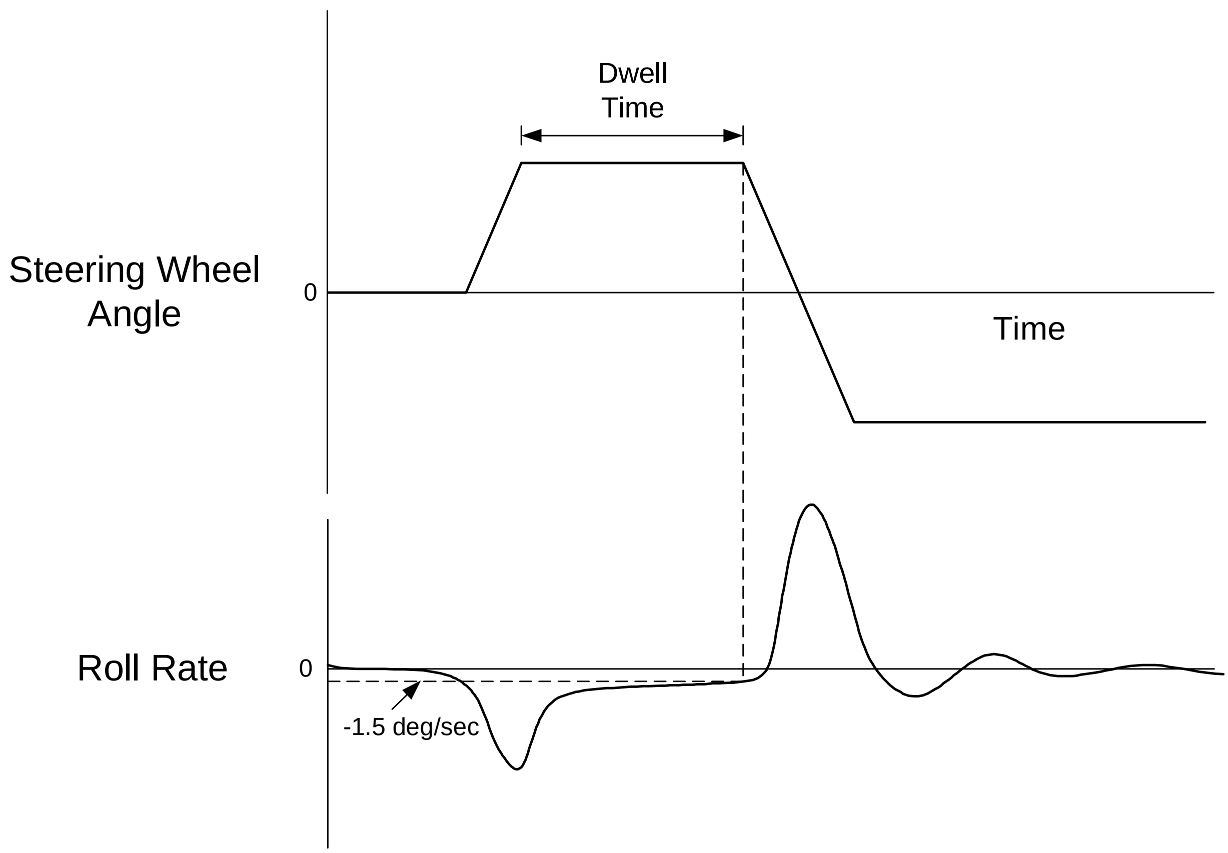

Figure 8. Effect of the Lack of a Secondary Reversal Criteria

driving or even of typical driving during extreme accident avoidance situations. Rather, the steering angles and rates are far more severe than what most people would use even in extreme accident avoidance situations.

The AVC Reverse Steer Test was compared to the recently proposed NHTSA Roll Rate Feedback Fishhook. A number of similarities were noted, as well as a few differences. The primary differences were the primary reversal timing strategy, and the noted lack of a secondary reversal strategy in the NHTSA October 2002 method.

As discussed, the AVC Reverse Steer Test primary reversal strategy results in a somewhat later reversal than does the RRFF test. In one set of tests, conducted in 1997, the later reversal time resulted in more severe outcomes for some vehicles. However, a more recent set of evaluations showed no significant differences in the outcomes produced by the two reversal strategies (for the vehicles tested, the outcomes were found to be more substantially affected by initial vehicle speed). It was concluded that the timing of the steering reversal may be more critical for some vehicles than for others. For those vehicles for which reversal timing is a significant factor, the later timing of the AVC Reverse Steer Test appears to be preferable to the RRFF timing. Honda's comments to NHTSA (Ref 5) in response to the NPRM therefore included the recommendation that NHTSA should continue to check a range of reversal timings to confirm that the agency's method generates the worse case for each vehicle.

Another recommendation was that NHTSA establish a secondary reversal criterion in the control algorithm similar to that used in the AVC Reverse Steer Test in order to ensure that the steering reversal occurs within a short period of time after the "expected" reversal time.

REFERENCES

[1] Anon., Request for Comments; Rollover Resistance, U.S. Docket NHTSA-2001-9663-1, 3 July 2001.

[2] Anon., Notice of Proposed Rulemaking; Rollover Resistance, U.S. Docket NHTSA-2001-9663-35, 7 October 2002.

[3] Kebschull, B. K., A. J. Arencibia, J. M. Brubacher, "An Automatic Vehicle Controller for Stability and Handling Tests", Society of Automotive Engineers, Paper No. 2000-01-1627, 2000.

[4] Anon., Comments on Notice for Proposed Rulemaking; Rollover Resistance, U.S. Docket NHTSA-2001-9663, Documents 2 through 34, 24 July 2001 to 18 July 2002.

[5] Anon., Comments on Notice for Proposed Rulemaking; Rollover Resistance, U.S. Docket NHTSA-2001-9663-51, 21 November 2002.