DEPARTMENT OF TRANSPORTATION

National Highway Traffic Safety Administration

49 CFR Part 575

[Docket No. NHTSA–2001–9663; Notice 2]

RIN 2127–AI81

Consumer Information Regulations; Federal Motor Vehicle Safety Standards; Rollover Resistance

AGENCY: National Highway Traffic Safety Administration (NHTSA), DOT.

ACTION: Notice of proposed rulemaking.

SUMMARY: The Transportation Recall Enhancement, Accountability, and Documentation Act of 2000 requires NHTSA to develop a dynamic test on rollovers by motor vehicles for the purposes of a consumer information program, to carry out a program of conducting such tests, and, as these tests are being developed, to conduct a rulemaking to determine how best to disseminate test results to the public. In response, this document discusses the results of NHTSA's evaluation of numerous driving maneuver tests for the dynamic rollover consumer information program that Congress mandated for the American public beginning in the 2003 model year. This document also proposes several alternative methods for using the dynamic rollover test results in the agency's consumer information for vehicle rollover resistance.

DATES: *Comment Date:* Comments must be received by November 21, 2002.

ADDRESSES: All comments should refer to Docket No. NHTSA–2001–9663; Notice 2 and be submitted to: Docket Management, Room PL–401, 400 Seventh Street, SW., Washington, DC 20590. Docket hours are 10 a.m. to 5 p.m. Monday through Friday. For public comments and other information related to previous notices on this subject, please refer to DOT Docket Nos. NHTSA–2000–6859 and 8298 also available on the Web at *http://dms.gov/search,* and NHTSA Docket No. 91–68; Notice 3, NHTSA Docket, Room 5111, 400 Seventh Street, SW., Washington, DC 20590. The NHTSA Docket hours are from 9:30 a.m. to 4 p.m. Monday through Friday.

FOR FURTHER INFORMATION CONTACT: For technical questions you may contact Patrick Boyd, NPS–23, Office of Safety Performance Standards, National Highway Traffic Safety Administration, 400 Seventh Street, SW., Washington, DC 20590 and Dr. Riley Garrott, NRD–22, NHTSA Vehicle Research and Test Center, P.O. Box 37, East Liberty, OH 43319. Mr. Boyd can be reached by phone at (202) 366–6346 or by facsimile at (202) 493–2739. Dr. Garrott can be reached by phone at (937) 666–4511 or by facsimile at (937) 666–3590.

SUPPLEMENTARY INFORMATION:

I. Executive Summary

Section 12 of the ''Transportation Recall, Enhancement, Accountability and Documentation (TREAD) Act of November 2000'' directs the Secretary to ''develop a dynamic test on rollovers by motor vehicles for a consumer information program; and carry out a program conducting such tests. As the Secretary develops a [rollover] test, the Secretary shall conduct a rulemaking to determine how best to disseminate test results to the public.'' The rulemaking must be carried out by November 1, 2002.

On July 3, 2001, NHTSA published a Request for Comments notice (66 FR 35179) discussing a variety of dynamic rollover tests that we had chosen to evaluate in our research program and what we believed were their potential advantages and disadvantages. It also discussed other possible approaches we considered but decided not to pursue. The driving maneuver tests to be evaluated fit into two broad categories: closed-loop maneuvers in which all test vehicles attempt to follow the same path; and open-loop maneuvers in which all test vehicles are given equivalent steering inputs. Other potential tests using a centrifuge or computational simulation were discussed but not included in our test plan. This notice discusses the comments we received and the results of our test program to date.

The TREAD Act calls for a rulemaking to determine how best to disseminate rollover test results to the public, and this Notice of Proposed Rulemaking proposes alternatives for using the dynamic tests results in consumer information on the rollover resistance of new vehicles. The resulting rollover resistance ratings will be part of NHTSA's New Car Assessment Program (NCAP). The tests will be carried out and reported to the public by NHTSA. This program places no regulatory requirements on vehicle manufacturers. Past NCAP ratings have been developed using a procedure of public notice and comment, but there was no legal requirement to do so since no regulatory requirements were imposed on any party except NHTSA. Because the dissemination of information will pose no regulatory burden on manufacturers, we provided a brief statement on the potential benefits of this program and no regulatory evaluation.

While the TREAD Act calls for a rulemaking to determine how best to disseminate the rollover test results, the development of the dynamic rollover test is simply the responsibility of the Secretary. Based on NHTSA's recent research to evaluate rollover test maneuvers, the National Academy of Sciences' study of rollover ratings, comments to the July 3, 2000 notice, extensive consultations with experts from the vehicle industry, consumer groups and academia, and NHTSA's previous research in 1997–8, the agency has chosen the J-turn and the Fishhook Maneuver as dynamic rollover tests. They are the limit maneuver tests that NHTSA found to have the highest levels of objectivity, repeatability and discriminatory capability. Vehicles will be tested in two load conditions using the J-turn at up to 60 mph and the Fishhook maneuver at up to 50 mph. Both maneuvers will be conducted with an automated steering controller, and the reverse steer of the Fishhook Maneuver will be timed to coincide with the maximum roll angle to create an objective ''worst case'' for all vehicles regardless of differences in resonant roll frequency. The light load condition will be the weight of the test driver and instruments, approximating a vehicle with a driver and one front seat passenger. The heavy load condition will add additional 175 lb manikins in all rear seat positions.

The National Academy of Sciences recommended that dynamic maneuver tests be used to supplement rather than replace Static Stability Factor (the basis of our present rollover resistance ratings) in consumer information on rollover resistance. This notice proposes two alternatives for consumer information ratings on vehicle rollover resistance that include both dynamic maneuver test results and Static Stability Factor. The first alternative is to include the dynamic test results as vehicle variables along with SSF in a statistical model of rollover risk. This is conceptually similar to the present ratings in which a statistical model is used to distinguish between the effects of vehicle variables and demographic and road use variables recorded for state crash data on a large number of single vehicle crashes. The National Academy of Sciences demonstrated the tight confidence limits that can be achieved using a logistic regression model for this purpose. Such a model would be used to predict the rollover rate in single vehicle crashes for a vehicle considering both its dynamic maneuver test performance and its Static Stability Factor for an average driver population (as a common basis of comparison).

Under the first alternative, the ''star rating'' of a vehicle would be based on the rollover rate in single vehicle crashes predicted for it by a statistical model. The format would be the same as for the present rollover ratings (for example, one star for a predicted rollover rate in single vehicle crashes greater than 40 percent and five stars for a predicted rollover rate less than 10 percent). The present rollover ratings are based on a linear regression model using state crash reports of 241,000 single vehicle crashes of 100 make/model vehicles. We are proposing to replace the current rollover risk model with one that uses the performance of the vehicle in dynamic maneuver tests as well as its SSF to predict rollover risk. The performance of a vehicle in dynamic maneuver tests is simply whether it tipped-up or not in each of the four maneuver/load combinations. The lowest entry speed of maneuvers that caused tip-up will also be used if it improves the predictive fit of the model. In order to compute a logistic model of rollover risk, it is necessary to have large number of state crash reports of single vehicle crashes to establish rollover rates of vehicles for which the dynamic maneuver test performance and SSF are known. The agency is performing dynamic maneuver tests on about 25 of the 100 make/model vehicles for which we have SSF measurements and substantial state crash data. We believe this approach will ensure that the assigned NCAP ratings for rollover resistance correlate to the maximum extent possible with real-world performance. However, since the agency has not finished testing these 25 vehicles, we cannot yet say what the actual coefficients of the model relating dynamic maneuver test performance and SSF to predicted rollover rate will be. We are asking for comments on the validity of this concept only in this notice.

The second alternative is to have separate ratings for Static Stability Factor and for dynamic maneuver test performance. Dynamic maneuver tests directly represent on-road untripped rollovers. The dynamic maneuver test performance would be used to rate resistance to untripped rollovers in a qualitative scale, such as A for no tip-ups, B for tip-up in one maneuver, C for tip-ups in two maneuvers, etc. Here again the results of ongoing dynamic testing of vehicles with established rollover rates would guide the establishment of a qualitative scale. A statistical risk model is not possible for untripped rollover crashes, because they appear to be relatively rare events and they cannot be reliably identified in state crash reports. The current Static Stability Factor based system would be used to rate resistance to tripped rollovers. Again we are asking for comments on the usefulness and validity of this concept in this notice. Until our testing of the 25 vehicles is finished, we will not know what particular NCAP rating will be assigned to a make/model under either of these two alternatives.

II. Safety Problem

Rollover crashes are complex events that reflect the interaction of driver, road, vehicle, and environmental factors. We can describe the relationship between these factors and the risk of rollover using information from the agency's crash data programs. We limit our discussion here to light vehicles, which consist of (1) passenger cars and (2) multipurpose passenger vehicles and trucks under 4,536 kilograms (10,000 pounds) gross vehicle weight rating.[1]

According to the 2000 Fatality Analysis Reporting System (FARS), 9,882 people were killed as occupants in light vehicle rollover crashes, which represents 31 percent of the occupants killed that year in crashes. Of those, 8,146 were killed in single-vehicle rollover crashes. Seventy-eight percent of the people who died in single-vehicle rollover crashes were not using a seat belt, and 65 percent were partially or completely ejected from the vehicle (including 53 percent who were completely ejected). FARS shows that 53 percent of light vehicle occupant fatalities in single-vehicle crashes involved a rollover event.

Using data from the 1996–2000 National Automotive Sampling System (NASS) Crashworthiness Data System (CDS), we estimate that 274,000 light vehicles were towed from a police-reported rollover crash each year (on average), and that 31,000 occupants of these vehicles were seriously injured (defined as an Abbreviated Injury Scale (AIS) rating of at least AIS 3).[2] Of these 274,000 light vehicle rollover crashes, 221,000 were single-vehicle crashes. (The present rollover resistance ratings estimate the risk of rollover if a vehicle is involved in a single-vehicle crash.) Sixty-two percent of those people who suffered a serious injury in single-vehicle towaway rollover crashes were not using a seat belt, and 48 percent were partially or completely ejected (including 41 percent who were completely ejected). Estimates from NASS CDS indicate that 81 percent of towaway rollovers were single-vehicle crashes, and that 84 percent (186,000) of the single-vehicle rollover crashes occurred after the vehicle left the roadway. An audit of 1992–96 NASS CDS data showed that about 95 percent of rollovers in single-vehicle crashes were tripped by mechanisms such as curbs, soft soil, pot holes, guard rails, and wheel rims digging into the pavement, rather than by tire/road interface friction as in the case of untripped rollover events.

According to the 1996–2000 NASS General Estimates System (GES) data, 61,000 occupants annually received injuries rated as K or A on the police KABCO injury scale in rollover crashes. (The police KABCO scale calls A injuries ''incapacitating,'' but their actual severity depends on local reporting practice. An ''incapacitating'' injury may mean that the injury was visible to the reporting officer or that the officer called for medical assistance. A K injury is fatal.) The data indicate that 212,000 single-vehicle rollover crashes resulted in 50,000 K or A injuries. Fifty-one percent of those with K or A injury in single-vehicle rollover crashes were not using a seat belt, and 23 percent were partially or completely ejected from the vehicle (including 20 percent who were completely ejected). Estimates from NASS GES indicate that 13 percent of light vehicles in police-reported single-vehicle crashes rolled over. The estimated risk of rollover differs by light vehicle type: 10 percent of cars and 10 percent of vans in police-reported single-vehicle crashes rolled over, compared to 18 percent of pickup trucks and 27 percent of SUVs. The percent of all police reported crashes for each vehicle type that resulted in rollover was 1.7 percent for cars, 2.0 percent for vans, 3.7 percent for pickup trucks and 5.4 percent for SUVs as estimated by NASS GES.

[1] For brevity, we use the term ''light trucks'' in this document to refer to vans, minivans, sport utility vehicles (SUVs), and pickup trucks under 4,536 kilograms (10,000 pounds) gross vehicle weight rating. NHTSA has also used the term ''ALTVs'' to refer to the same vehicles.

[2] A broken hip is an example of an AIS 3 injury.

III. Background

Section 12 of the ''Transportation Recall, Enhancement, Accountability and Documentation (TREAD) Act of November 2000'' directs the Secretary to ''develop a dynamic test on rollovers by motor vehicles for a consumer information program; and carry out a program conducting such tests. As the Secretary develops a [rollover] test, the Secretary shall conduct a rulemaking to determine how best to disseminate test results to the public.'' The rulemaking must be carried out by November 1, 2002.

On July 3, 2001, NHTSA published a Request for Comments notice (66 FR 35179) discussing a variety of dynamic rollover tests that we had chosen to evaluate in our research program and what we believed were their potential advantages and disadvantages. It also discussed other possible approaches we considered but decided not to pursue. The driving maneuver tests to be evaluated fit into two broad categories: closed-loop maneuvers in which all test vehicles attempt to follow the same path; and open-loop maneuvers in which all test vehicles are given equivalent steering inputs. Other potential tests using a centrifuge or computational simulation were discussed but not included in our test plan. This notice discusses the comments we received and the results of our test program to date.

The TREAD Act calls for a rulemaking to determine how best to disseminate rollover test results to the public, and this Notice of Proposed Rulemaking proposes several alternatives for using the dynamic tests results in consumer information on the rollover resistance of new vehicles. The resulting rollover resistance ratings will be part of NHTSA's New Car Assessment Program (NCAP). The tests will be carried out and reported to the public by NHTSA. This program places no regulatory requirements on vehicle manufacturers. Past NCAP ratings have been developed using a procedure of public notice and comment, but there was no legal requirement to do so since no requirements were imposed on any party except NHTSA.

NHTSA's NCAP program has been publishing comparative consumer information on frontal crashworthiness of new vehicles since 1979, on side crashworthiness since 1997, and on rollover resistance since January 2001. The present rollover resistance ratings are based on the Static Stability Factor (SSF) which is the ratio of one half the track width to the center of gravity (c.g.) height. (see *http://www.nhtsa.dot.gov/hot/rollover/* for ratings and explanatory information).

SSF was chosen over vehicle maneuver tests in the present ratings system because it represents the first order factors that determine vehicle rollover resistance in the 95 percent of rollovers that are tripped by impacts with curbs, soft soil, pot holes, guard rails, *etc.* or by wheel rims digging into the pavement. In contrast, untripped rollovers are those in which tire/road interface friction is the only external force acting on a vehicle that rolls over. Driving maneuver tests directly represent on-road untripped rollover crashes which are about 5 percent of the total, and test performance can be improved by vehicle changes that may not improve resistance to tripped rollovers. Other reasons for selecting the SSF measure are: driving maneuver test results are greatly influenced by SSF; the SSF is highly correlated with actual crash statistics; it can be measured accurately and inexpensively and explained to consumers; and changes in vehicle design to improve SSF are unlikely to degrade other safety attributes.

Vehicle manufacturers generally oppose the present rollover resistance ratings because they believe that SSF is too simple since it does not include the effects of suspension deflections, tire traction and electronic stability control (ESC) and because they believe that the influence of vehicle factors on rollover risk is too slight to warrant consumer information ratings for rollover resistance. In the conference report dated October 23, 2000 of the FY2001 DOT Appropriation Act, Congress permitted NHTSA to move forward with the rollover rating proposal and directed the agency to fund a National Academy of Sciences study on vehicle rollover ratings. The study topics are ''whether the static stability factor is a scientifically valid measurement that presents practical, useful information to the public including a comparison of the static stability factor test versus a test with rollover metrics based on dynamic driving conditions that may induce rollover events.'' The National Academy's report was completed and made available in pre-publication form on February 21, 2002. Section IV discusses the findings and recommendations of the study.

IV. Comments to the Previous Notice

In its July 3, 2001 Request for Comments notice (66 FR 35179), NHTSA solicited comment on the development of a dynamic test for vehicle rollover resistance and identified a number of tests it planned to evaluate. The notice posed the following five sets of questions for comments. Most commenters either supported one of the tests being evaluated, suggested another test, or described elements the commenter believed to be important for any test chosen for rollover resistance. In this way, most commenters responded to the substance of question 1. While only a few commenters responded specifically to the other questions, parts of the general comments of other commenters are discussed in the context of the questions.

Question 1: NHTSA has decided to devote its available time and resources under the TREAD Act to develop a dynamic test for rollover based on driving maneuver tests. Is this the best approach to satisfy the intent of Congress in the time allotted? Are there additional maneuvers that NHTSA should be evaluating? Which maneuver or combination of maneuvers do you believe is the best for rollover rating? Are these other approaches well enough developed and validated that they could be implemented 18 months from now?

Comments: In answer to this question many commenters either voiced a preference for one of the maneuvers in the test plan NHTSA announced in its July RFC Notice or made specific suggestions for other tests. Daimler-Chrysler (D–C), Continental-Teves, BMW, Mitsubishi and Volkswagen (VW) supported the use of the ISO 3388 Part 2 double lane change test (developed by VDA, the German vehicle manufacturers' association) as the dynamic rollover test. VW suggested that the ratings should include three components: (a) SSF for general overall rating of static stability, (b) the ISO 3388 Part 2 test with minimum entry of 60 kph without 2 wheel lift, and (c) a dynamic handling test that gives credit to ESC.

Several commenters supported the variations of the fishhook test. Toyota suggested a fishhook test with fixed timing using the LAR (lateral acceleration at rollover [tip-up]) criterion as test for untripped rollover. Toyota's recommendation also suggested using the ISO 3388 PART 2 test as a stability/controllability test, with entry speed and peak to peak yaw rate as the measured criteria. Toyota also offered a hypothetical star rating breakdown for LAR as a rollover rating and a star rating chart relating entry speed and peak to peak yaw rate in the ISO 3388 PART 2 test as a separate controllability rating. TRW stated that rollover test maneuvers should excite worst case roll dynamics, but that some conditions on the vehicle path should be observed to keep handling tradeoffs in check. It expressed the opinion that a fishhook test with steering based on roll rate best approached the stated goal but that future developments in simulation could also be useful for rollover resistance ratings. Honda recommended a fishhook maneuver with a protocol for optimizing to the worst case timing for each vehicle as a test for untripped rollover resistance combined with the basic quasi-static centrifuge test to measure tripped rollover resistance. Nissan had previously suggested a fishhook test and its own optimization protocol, but in its comment to this notice, Nissan changed its position stating that the fishhook may be too severe for consumer information and that it has no data correlating it to real world accidents. It suggested that NHTSA should test for handling properties instead of rollover resistance.

NHTSA's July RFC Notice announced a research plan that excluded the centrifuge test on the basis that it was not deemed sufficiently ''dynamic'' for the requirements of the TREAD Act and for concern that a vehicle optimized for the centrifuge test may have more oversteer than the manufacturer would otherwise choose. Nevertheless, a number of commenters were in support of rollover resistance tests that included centrifuge testing. Ervin and Winkler of UMTRI suggested a number of possible test modes using a centrifuge including a basic quasi-static mode which adds suspension roll and shear effects to SSF, tether release modes which add roll inertial forces somewhat analogous to J-turn and fishhook maneuvers, and a curb trip mode with a sliding table. They also suggested that a driving maneuver handling test for yaw stability be performed in addition to the centrifuge test. As noted above, a quasi-static centrifuge test for tripped rollover was part of Honda's recommendation. CU also suggested a centrifuge (or SSF as an alternative) as part of recommended suite of tests also including a dynamic maneuver test with steering reversal (like the fishhook) and handling tests for maximum lateral acceleration and yaw stability. Advocates commented that driving maneuver tests by themselves are not sufficient for rollover resistance tests because they only define untripped rollover resistance, and Advocates recommend that UMTRI's centrifuge tests should be investigated because they can be applied to both tripped and untripped rollover resistance.

GM recommended that the centrifuge test be substituted for Side Pull Ratio or SSF in the Stability Margin concept it had recommended to NHTSA in comments to previous notices on rollover resistance ratings. It also supplied information addressing NHTSA's concern that the centrifuge test could reward undesirable changes in suspension roll stiffness distribution. The issue first arose in comments from Ford on a 1994 NHTSA proposal for rollover consumer information based on Tilt Table Ratio. Ford stated that a vehicle's score in a tilt table test is greatest if both the front and rear tires lift simultaneously when the table is inclined at the minimum angle for two wheel lift, and that the manufacturer could achieve the optimum score by stiffening the rear suspension relative to the front. If the manufacturer did so, the result would be a vehicle with less understeer as the trade-off for a better Tilt Table Ratio. The same optimization principal would apply to centrifuge tests. GM's comment included curves showing the point of optimization of Side Pull Ratio (theoretically the same as the centrifuge measurement) and its sensitivity to the proportion of total roll stiffness provided by the front suspension for a typical SUV and a typical car. GM compared the curves to the suspension characteristics of these production vehicles and found that (a) the suspension roll stiffnesses of the production vehicles were close to the optimized condition as designed with a very small sensitivity to further suspension changes and (b) the suspension changes to obtain the negligible improvement in rollover test score involved a relative stiffening at the front that would increase rather than decrease the understeer. GM concluded that manufacturers would have little to gain by suspension tuning for centrifuge test scores and that the tuning would be at least as likely to increase understeer as to decrease it. We believe that Ford's comment was correct in 1994, but NHTSA has recently reviewed data showing a trend toward less understeer in SUVs of more recent design. GM's dismissal of the issue may reflect more accurately the design of today's new vehicles.

Toyota and GM were the only commenters to suggest how the results of their rollover and handling tests could be expressed in ratings. GM suggested that the following conditions be used to define ''good rollover resistance for light-duty vehicles'': (a) quasi-static centrifuge test tip-up threshold of at least 0.9g; (b) maximum lateral acceleration in a circular driving maneuver of at least 0.6g; and (c) a stability margin (a–b) at least 0.2g or 1.5/wheelbase [in meters] squared. GM estimated that a centrifuge measurement of 0.9g would correspond to a SSF of 1.06. However, we would estimate that centrifuge measurement as corresponding closer to a SSF of 1.00, based on comparisons with tilt table tests with an allowance for the vertical load error inherent with the tilt table.

Based on its stability margin concept of good rollover resistance, GM suggested the following ''star rating'' system. A vehicle passing all three conditions for good rollover resistance would be rated with two stars. Failing any one of the conditions would reduce its rating to one star. Bonus stars above the two star level would be awarded for a centrifuge test measurement 1.0g or better, a maximum lateral acceleration measurement of 0.7g or better, or a stability margin 0.1 or more above the minimum (0.2g or 1.5/wheelbase [in meters] squared). A vehicle satisfying all of these higher conditions would receive a five star rating. GM also suggested that NHTSA consider a symbol other than a star for rollover resistance ratings to differentiate them from frontal and side crashworthiness ratings. As previously mentioned, Toyota offered a hypothetical star rating breakdown for LAR in a Fishhook as a rollover rating.

Previously, Ford had suggested a proprietary test method (Path Corrected Limit Lane Change (PCLLC)) involving a series of double lane change maneuvers controlled by a human driver and a mathematical technique for correcting the measurements of vehicle acceleration and wheel force to those expected if the vehicle perfectly adheres to a desired common path for vehicle comparisons. NHTSA agreed to evaluate this method but keep the details of the analytical technique confidential. Appendix I of this notice discusses the results of PCLLC testing using the same vehicles tested in other maneuver tests.

In its comment to the July notice, Ford announced that the same test measurements could be made using a newly developed advanced path following steering controller to replace the human driver and the proprietary mathematical correction technique. Ford expected both implementations of the protocol to produce the same measurements. But it changed its recommendation to the path following steering controller because the face validity (realistic appearance) of the test would be enhanced by having the advanced steering controller actually drive the vehicles through nominally identical paths rather than rely on corrections to the unavoidably variable paths taken by skilled human test drivers. Ford's comment was made after

NHTSA had run the PCLLC maneuvers in a cooperative effort with Ford to evaluate that test method. However, we believe that the results of the tests of our vehicles using the PCLLC mathematical corrections would be representative of same maneuver tests accomplished with a path following steering controller.

Ford's path following steering controller is not the same as the automated steering controller NHTSA used to obtain repeatable steering inputs for open-loop maneuvers. Ford's steering controller is designed to drive different vehicles in the same repeatable path although the steering inputs to guide the various vehicles along the same path may be quite different. It uses a real-time computer simulation of the vehicle steering responses and a differential GPS position signal as feedback signals for closed-loop control.

Unlike the other maneuver tests in NHTSA's evaluation, Ford's maneuvers are not intended to produce wheel lift or loss of control or invoke ESC operation. Ford suggests four lane change maneuvers (like those shown in Figure 9) varying in offset and length, each producing a maximum lateral acceleration of 0.7g at a single test speed of 45 mph, but varying in fundamental lateral acceleration frequency from 0.29 Hz to 0.40 Hz. The scoring metric is the maximum dynamic weight transfer measured as a 400 ms moving average. It refers to the percent reduction in vertical load for the two wheels on the side of the vehicle approaching tip-up. At tip-up, the dynamic weight transfer is 100 percent, but dynamic weight transfer in the range of 50 to 80 percent would be typical in the Ford maneuver. A lower percent weight transfer score indicates a vehicle with higher rollover resistance. The tests are performed with the vehicle loaded to the gross vehicle weight rating and the rear axle load at the rear axle weight rating.

Intrinsic advantages of this test method are its insensitivity to changes in pavement and tire friction because the tests are performed at lateral force levels below the friction limit and its continuous (as opposed to binary, tip-up or no tip-up) performance metric with a comparative score for all vehicles. Intrinsic disadvantages are its compression of vehicle differences as a result of tests restricted to a smaller range of lateral acceleration, the need for very accurate and repeatable vertical wheel force measurements to discriminate the compressed vehicle differences, and the question of whether non-limit dynamic tests can predict the comparative dynamic behavior of vehicles in limit maneuvers. Ford believes that non-limit results can be projected up to the limit, but it is certainly possible that anomalies in suspension behavior may occur only at the limit.

Suzuki commented that driving maneuver tests should not be used as NHTSA's dynamic rollover test because they measure only resistance to untripped rollover, are unrealistic driving maneuvers and have many practical problems. Suzuki argued that a dynamic tripped rollover test should be used instead. In November 2001, Suzuki and its contractor Exponent made a suggestion how a ''dynamic tripped rollover test'' could be conducted. The test would use a braked sled with the vehicle placed transversely on the sled adjacent to tripping curb. From a constant speed of 25 mph, the sled would be braked at a relatively constant deceleration which produces a steady lateral acceleration on the test vehicle. Repeated runs of the sled at incrementally higher levels of deceleration would be made until the vehicle lifts and rolls at least 20 degrees to a position restrained by safety straps. Such a test imposes a step increase of lateral acceleration on the vehicle and measures the result of weight transfer due to the static rigid body (SSF) properties of the vehicle, to the c.g. movement due to quasi-static body roll, and to the dynamic effects of roll inertia and suspension damping. This test is very similar to the ''straight tethered'' centrifuge test suggested by UMTRI in which the steady lateral acceleration imposed on the vehicle by the centrifuge is resisted by a tether until the tether is released and the vehicle experiences a step increase of lateral acceleration. Both are also analogous to a J-turn test with an extremely high level of tire adhesion.

Question 2: How should NHTSA address the problem of long term and short term variations in pavement friction in conducting comparative driving maneuver tests of vehicle rollover resistance for a continuing program of consumer information?

Comments: Toyota, D–C, and Ford addressed the question explicitly. Toyota had suggested a fishhook maneuver using the scoring metric LAR (lateral acceleration at roll). It believes that LAR is not very sensitive to changes in pavement friction, but if the pavement friction is too low it will become impossible for the vehicle to achieve sufficient lateral acceleration in the maneuver to reach LAR. Toyota also suggested a double lane change handling maneuver in which entry speed and peak to peak yaw rate were scoring metrics that it considers sensitive to pavement friction. It suggests strict limits on the course parameters to qualify the handling tests as valid, giving as an example the surface temperature limits (35C ± 10C) used by the Japanese government NCAP protocol for braking tests.

D–C suggested that a standard pavement friction monitoring trailer using a standard ASTM tire be used to define the nominal surface friction of a test track, and that at least five braking tests be conducted using the same anti-lock equipped vehicle with standard tires to qualify the surface before a test session. Limits for braking test measurements, temperature and wind velocity would be established to qualify the surface. VW made a similar recommendation of defined limits on temperature, humidity, wind speed and surface friction (presumably using a pavement friction monitoring trailer with a standard ASTM tire).

Ford explained that its test protocol for the double lane change maneuvers performed either by a path-following robot or by mathematical path-correction of driver-controlled tests calls for comparing the side to side load transfer at a standard 0.7g lateral acceleration. Since almost all vehicles can achieve this level of lateral acceleration on ordinary dry pavement despite expected fluctuations in surface friction, the test method is not sensitive to ordinary pavement friction fluctuations.

Likewise, fluctuations in pavement friction are not an issue for the centrifuge test suggested by UMTRI and the sled test suggested by Exponent/ Suzuki because both tests use a curb-like structure rather than pavement friction to initiate an overturning moment.

Question 3: Some ESC systems presently have two functions. One is yaw stability which uses one or more brakes to keep the vehicle headed in the right direction in a limit maneuver, and the other is simple brake intervention in excess of the braking required for yaw stability. It is expected that the presence of a brake intervention function in ESC will have a large effect on the rating of vehicles because the average speed through a given test maneuver for vehicles having this function will be much less than for vehicles without it (even if equipped with ESC for yaw stability) under the usual test protocols of coasting through maneuvers and using the entry speed as the test speed. Is the value given to the brake intervention function of ESC as opposed to the yaw stability function by potential rollover rating tests commensurate with its safety value to consumers? Please provide all the data and reasoning that support your view. Should NHTSA measure the vehicle speed at the completion of the maneuver as well as vehicle speed at entry?

Comments: Toyota commented that automatic braking in excess of what is required for yaw stability control to further lower the speed is a good strategy to mitigate harm in an emergency, but it recognizes NHTSA's concern that dynamic rollover tests could give the same credit to less sophisticated systems as to yaw control. Toyota believes that its suggestion of a separate handling test to accompany the dynamic rollover test would reward controllability and show the advantage of yaw control systems.

D–C commented that ESC should operate during rollover maneuver tests with entry speed being the only criterion for the stringency of the maneuver. The exit speed should not be considered.[3] Continental-Teves also commented that only the entry speed is an appropriate measure because it best defines the obstacle avoidance situation facing the driver.

TRW commented that ESC should be rewarded if it enhances roll dynamic behavior, and it also stated that ''Differential Braking Roll Prevention'' should be rewarded by the agency's rollover maneuver tests. It did not define the term ''Differential Braking Roll Prevention'', but we understand it to mean an automatic braking system in which selected brakes are applied for the purpose of reducing the lateral force generating capability of the selected tires rather than to augment yaw stability or to simply slow down.

Ford also opposed using the average speed through a given test as a criterion and pointed out that its recommended test does not use speed as a comparative metric at all. It also stated that its test is unlikely to invoke ESC but would measure the effect of active stabilizer bars and electronically controlled shocks.

Several other manufacturers share Ford's view that the operation of ESC is not essential to rollover resistance tests. GM suggested laboratory tests of rollover resistance using a centrifuge in which ESC would not operate. It stated that ''the rollover resistance of the underlying vehicle structure and suspension is a more important parameter than the possible use of ESC to mask poor rollover resistance of the foundation vehicle.'' Similarly, the recommendations from Suzuki and Exponent for a tripped rollover test do not involve the use of ESC. Honda suggested that if a vehicle is equipped with an on/off switch for ESC, it should be tested with the switch in the off position.

One of the agency's reasons for posing this question was that ESC systems with a component of ordinary four wheel braking above the differential braking for yaw control are performing a braking action that the driver is also likely to do in an emergency. However, the usual test protocol for the maneuver tests being evaluated requires the driver to coast rather than brake. Therefore, there was a question whether the potential advantage of vehicles with automatic braking tied to ESC would be unrealistically amplified by a test protocol that would prevent driver braking in circumstances where actual drivers would be likely to brake. Our concern over this theoretical problem has been reduced by our observations during the recent maneuver test research that vehicles tip up early in rollovers maneuvers minimizing the effect of automatic braking.

Question 4: If open-loop (defined steering input) maneuvers are used to determine whether a vehicle is susceptible to two wheel lift as a result of severe steering actions, superficial changes that reduce tire traction or otherwise reduce vehicle handling (but prevent wheel lift) would be rewarded the same as more fundamental or costly improvements. The same is true of closed loop (path following) maneuvers that use wheel lift as the sole criterion. Should measures of vehicle handling be reported so that consumers can be aware of possible trade-offs. What indicators of vehicles handling would be appropriate to measure, and how should this consumer information be reported?

Comments: Many commenters recommended handling tests either in addition to rollover resistance maneuver tests or instead of rollover resistance maneuver tests. Nissan had earlier recommended a fishhook maneuver test for rollover resistance and had proposed a method of timing the steering reversal to achieve maximum severity for each test vehicle. However, in its comments to the July notice, Nissan recommended that NHTSA measure handling rather than rollover resistance on the basis that the fishhook test may be too severe for the purposes of consumer information and that Nissan had no data regarding the correlation of fishhook test performance to real-world crashes. It suggested a steady state lateral acceleration test and a lateral transient response test. D–C addressed the question directly by stating that its recommended ISO 3388 PART 2 test does not give incentives for negative trade-offs but rather encourages optimized cornering capability and ''limit condition performance'' by giving lower ratings for ''bad handling''. In its recommendation of the ISO 3388 PART 2 test, Continental-Teves actually described it as a handling test.

The combination of a rollover test and a separate handling test was recommended by many commenters. Toyota suggested that a closed loop stability and controllability test should be combined with an open loop rollover resistance test to deal with the trade-off issue for rollover tests. It suggested using the ISO 3388 PART 2 test as a handling test with both entry speed and peak-to-peak yaw rate as performance criteria. The peak-to-peak yaw rate would reflect on the yaw stability of the vehicle. UMTRI suggested the centrifuge test for a rollover resistance but recommended adding a driving maneuver test to characterize yaw controllability. GM also recommended the centrifuge test, but suggested combining its results with a driving test of steady state maximum lateral acceleration to create a stability margin and set a lower limit for handling. In addition to static and dynamic rollover resistance tests, CU recommended a steady state lateral acceleration test on a skip pad and ''track-type tests to assess the vehicle's controllability, response and grip.'' VW also suggested static and dynamic rollover resistance tests , but called for a handling test that ''would give positive credit to ESP [ESC in generic parlance], since experience in Germany appears to substantiate the real world benefits of ESP. It did suggest a specific test, but tests of yaw stability would be expected to measure an aspect of handling benefited by ESC operation.

Question 5: What criteria should NHTSA use to select the best vehicle maneuver test for rollover resistance? Should the maneuver that has the greatest chance of producing two wheel lift in susceptible vehicles be chosen regardless of its resemblance to driving situations? Is it more important that the maneuver resemble an emergency maneuver that consumers can visualize? How important is objectivity and repeatability?

Comments: One issue is the potential conflict between the ability of a dynamic rollover test to produce tip-up in vulnerable vehicles (severity) and its resemblance to a driving maneuver consumers can imagine doing (face validity). Toyota commented that it

[3] NHTSA notes that if the stringency of a rollover maneuver test was determined by averaging the entry and exit speeds, a test in which the vehicle performed automatic braking would be considered less stringent than one in which the vehicle entered at the same speed and coasted through at a higher speed.

views severity as the more important property for a rollover resistance test and face validity as the more important property for a handling test. Ford and D–C took the opposite position. Ford stated that extreme maneuvers that cause two wheel lift of some vehicles on a paved road surface are unrelated to the vast majority of crashes. D–C said that resemblance to emergency maneuvers is more important than determining ''artificial conditions'' under which a particular vehicle is likely to roll over.

There were other comments about the general issue of criteria for selecting a rollover test. Continental-Teves stated that ''a dynamic test for vehicle rollover rating should assess whether the vehicle system (driver and vehicle) is capable of keeping the vehicle on the road'' which is consistent with the view that the ISO 3388 PART 2 test is more of a handling test than a rollover test. Advocates disagreed with NHTSA's conclusion that the TREAD Act called for a driving maneuver test as a rollover test, and suggested that UMTRI's ideas for a centrifuge test should be investigated. IIHS stated that ''although some of the test maneuvers may have considerably greater consumer face validity, the ultimate decision as to which maneuvers to use should rest on which provide the best correlation with real-world crash risk.''

Commenter's Recommended Approaches

D–C, Mitsubishi, VW, BMW and Continental-Teves recommended the ISO 3388 PART 2 closed-loop tight double lane change test as the best dynamic rollover test, but also described it as a handling test.

Toyota, Honda, CU, and TRW recommended Fishhook tests optimized in various ways to present the worst-case timing to each vehicle as the best dynamic rollover test. Nissan had recommended the Fishhook earlier but decided that the Fishhook test may be too severe for consumer information, and recommended handling tests instead of a rollover test.

UMTRI, GM, Advocates, CU and Honda recommended a centrifuge test as at least part of the rollover rating despite NHTSA's elimination of it from the research plan announced in July 2001.

Honda, CU, and VW suggested the combination of a rollover maneuver test and the centrifuge test or SSF for rollover ratings.

Toyota, UMTRI, Nissan, VW and Ford recommend a separate handling test distinct from the rollover rating with particular emphasis on yaw stability and ESC.

Suzuki and Ford recommended tests other than those discussed in the July 2001 Notice. Suzuki recommended a dynamic tripped rollover test such as the sled test described by Exponent. Ford recommended using a new path following steering controller instead of the PCLLC mathematical path correction technique it previously recommended, but it continued to recommend the maneuvers and performance metric used in the PCLLC.

NHTSA notes that although the Alliance criticized SSF for not measuring the effect of ESC, the tests recommended by Ford and GM do not measure the effect of ESC. Also, Honda recommended testing with ESC turned off if an on/off switch is provided.

V. National Academy of Sciences Study

In the conference report dated October 23, 2000 of the FY 2001 DOT Appropriation Act, Congress directed the agency to fund a National Academy of Sciences study on vehicle rollover ratings. The study topics were ''whether the static stability factor is a scientifically valid measurement that presents practical, useful information to the public including a comparison of the static stability factor test versus a test with rollover metrics based on dynamic driving conditions that may induce rollover events.'' The National Academy's report was completed and made publicly available on February 21, 2002.

The National Academy of Sciences made a number of findings and recommendations concerning NHTSA's present ratings of rollover resistance that we view as guidance for our efforts under the TREAD Act to improve the rating system.

Finding 1: Through a rigid-body model, SSF relates a vehicle's track width, T, and center of gravity height, H, to a clearly defined level of the sustained lateral acceleration that will result in the vehicle's rolling over. The rigid-body model is based on the laws of physics and captures important vehicle characteristics related to rollover.

Finding 2: Analysis of crash data reveals that, for higher-risk scenarios, SSF correlates significantly with a vehicle's involvement in single-vehicle rollovers, although driver behavior and driving environment also contribute. For these scenarios, the statistical trends in crash data and the underlying physics of rollover provide consistent insight: an increase in SSF reduces the likelihood of rollover.

Finding 3: Metrics derived from dynamic testing are needed to complement static measures, such as SSF, by providing information about vehicle handling characteristics that are important in determining whether a driver can avoid conditions leading to rollover.

The first three findings help resolve some very important questions facing NHTSA regarding the implementation of the TREAD Act to improve the rollover rating system. Namely, is SSF a scientifically valid measure of rollover resistance and should a dynamic rollover test replace SSF? The National Academy confirmed that SSF is a scientifically valid measure of rollover resistance for which the underlying physics and real-world crash data are consistent in the conclusion that an increase in SSF reduces the likelihood of rollover. It also found that dynamic tests should complement static measures, such as SSF, rather than replace them in consumer information on rollover resistance.

The National Academy's report describes a rollover crash as an event having three phases: A phase in which the driver is in control of the vehicle, a transition phase in which loss of control develops, and a phase in which the vehicle is out of control. The report gives SSF (along with the terrain) as the dominant determinants of rollover in the final, out of control phase, of a crash leading to rollover. It is in the previous transition phase of the crash that other vehicle properties reflected in the ideal dynamic test can potentially influence whether the crash enters the final phase in which only the geometric properties of the vehicle matter.

In its presentation to NHTSA of the findings and recommendations, the NAS study committee clarified that it envisions dynamic tests as limit maneuvers where loss of control and actual on-road vehicle tip-up can be expected for vulnerable vehicles. The NAS study panel also expressed a preference for combining static and dynamic vehicle information in a single rollover resistance rating, but it did not offer explicit suggestions for accomplishing the combination or conveying the rating to the consumer.

The next series of findings involve the statistical relationship between SSF and rollover rate that NHTSA uses to interpret the rollover resistance ratings.

Finding 4: NHTSA's implementation of an exponential statistical model lacks the confidence levels needed to permit discrimination among vehicles within a vehicle class with regard to differences in rollover risk.

Finding 5: The relationship between rollover risk and SSF can be estimated accurately with available crash data and software using a logit model. For the analysis of rollover crash data, this model is more appropriate than an exponential model.

Finding 6: The approximation of the rollover curve with five discrete levels—corresponding to the five rating categories—is coarse and does not adequately convey the information provided by the available crash data, particularly at lower SSF values where the rollover curve is relatively steep.

NHTSA calculated what it believed was an accurate trend line between the rollover rate in single vehicle crashes and SSF using data from over 221,000 single vehicle crashes of 100 vehicle make/model/generations representing the range of SSFs and vehicle classes (cars, vans, pickup trucks and SUVs). It determined the average rollover rate for each of the 100 vehicles, corrected the rates for differences in demographic and road use variables (driver age, gender, alcohol use, road and weather conditions, etc) and performed a linear regression between SSF and the logarithm of the corrected average rollover rate of each vehicle. The NAS report refers to this approach as the exponential model because it creates an exponential regression line between SSF and rollover rate. NHTSA chose this approach because the exponential form of the regression line fits the rollover rate data well, and linear regression computes the R^2 goodness of fit statistic that is familiar to many scientific readers who are not professional statisticians. However, the standard statistical technique for determining the confidence limits of the regression line (which estimate how well the line would be replicated with another sample of crash data for the same vehicles) only considers a data set of 518 points. The 518 data points are the rollover rates in each of six states for those vehicles in the 100 make/model population for which more than 25 single vehicle crashes were reported. Consequently, the 95th percentile confidence limits computed for the exponential line are much larger than what would be expected for a data set of 221,000 points. This is the basis for Finding Number 4. Since each of the 518 data points on average represents 486 crashes, it stands to reason that the actual reproducibility of the line is much better than that computed on the basis of only 518 points. As the NAS study notes, the standard method of computing confidence limits for linear regression is the wrong method for our regression line, but it offered no other method of computing the confidence limits of our present model.

In Finding Number 5, the National Academy offered an alternative solution to the confidence limits issue. It recommended that the logit model be used in place of the exponential model (linear regression on the logarithm of rollover rate). The logit model operates on the 221,000 crash data samples individually rather than as 518 averages. Consequently, the confidence limits are extremely narrow as would be expected for a regression line representing a huge database. However, the change to logit model produces another problem. Each model incorporates an implicit assumption about the form of the regression line. We chose the exponential form because it appeared to follow the locus of data points. The form of the line produced by logit model in our application is closer to a straight line than to an exponential line. Consequently, it does not follow the locus of the raw data points as well. It appears to underestimate the rollover rate of vehicles at the low end of the SSF range by a substantial margin (36% versus about 45% @ SSF=1.00). The NAS study acknowledged this shortcoming and gives the example of a nonparametric-based rollover curve it calculated on a subset of NHTSA data that represents the low end of the SSF range much better than the logit curve. We are investigating non-parametric models and logit models using various transformations of SSF to develop a model combining the demonstrated tight confidence limits of the logit model with the more accurate estimate of rollover risk of our exponential model.

For the interpretation of vehicle measurements for consumer information on rollover risk, NAS concentrated exclusively on using statistical models relating measurements, such as SSF, to rollover risk in a single vehicle crash. Finding 5 concerns the choice of model within this methodology. Finding 6 suggests that a five interval system loses some of the power of the data to discriminate rollover risk between vehicles. The committee goes on to recommend that the agency look at a greater number of intervals or even a continuous risk scale.

Finding 7: A gap exists between recommended practices for the development of safety information and NHTSA's current process for identifying and meeting consumer needs for such information. In particular:

- The focus group studies used to develop the star rating system were limited in scope.
- The agency has not undertaken empirical studies to evaluate consumers' use of the rollover resistance rating system in making vehicle safety judgments or purchase decisions.

Focus group testing is the most appropriate tool we can use within our budget and time constraints. As mentioned in the response to Recommendation 3, below, we plan to use interviewing in conjunction with focus group testing to design second-tier information to be used by consumers who want more information than the star ratings. The agency has not undertaken empirical studies to evaluate consumer's use of the rollover rating system because the program was just initiated for the 2001 model year. Such a study would provide useful feedback for the development of additional consumer rollover information. However some history of use by the public needs to be acquired before the current system can be evaluated.

Recommendation 1: NHTSA should vigorously pursue its ongoing research on driving maneuver tests for rollover resistance, mandated under the TREAD Act, with the objective of developing one or more dynamic tests that can be used to assess transient vehicle behavior leading to rollover.

This notice describes the results of test program that is part of NHTSA's pursuit of the requirements of the TREAD Act to develop dynamic tests for rollover. We believe that the limit maneuver tests we are developing will provide the evaluation of the transient vehicle behavior that the NAS committee has recommended as a complement to the information from static measures. We also trying to develop tests of vehicle controllability to give consumers some information on the relative difficulty of keeping the vehicle on the road away from tripping mechanisms in the event of an emergency maneuver.

Recommendation 2: In the longer term, NHTSA should develop revised consumer information on rollover that incorporates the results of one or more dynamic tests on transient vehicle behavior to complement the information from static measures, such as SSF.

NHTSA will evaluate possible changes in its present consumer information on rollover resistance, based on SSF, as we develop the protocol for dynamic testing for rollover required by the TREAD Act. Part of our research planned for March to November 2002 will be to investigate the best way to present both static and dynamic information to consumers.

Recommendation 3: NHTSA should investigate alternative options for communicating information to the public on SSF and its relationship to rollover. In developing revised consumer information, NHTSA should:

- Use a logit model as a starting point for analysis of the relationship between rollover risk and SSF.
- Consider a higher-resolution representation of the relationship between rollover risk and SSF than is provided by the current five-star rating system.
- Continue to investigate presentation metrics other than stars.
- Provide consumers with more information placing rollover risk in the broader context of motor vehicle safety.

NHTSA is considering changing to a new model in conjunction with the incorporation of dynamic test results into the rollover resistance rating program. While the NAS prefers the logit model because it has tighter confidence bounds than the linear model we used, the logit model underestimates the risk of rollover for low-SSF vehicles. To attempt to overcome the drawbacks of both our original method and the logit model, while keeping tight confidence bounds, we will investigate the use of other statistical models to better estimate rollover risk in future model years at the same time that we improve our model to include dynamic test results.

The NAS committee stated that it believed that NHTSA had documented the relationship between SSF and rollover risk in single-vehicle crashes so well that we were short-changing the public by reducing this information to five star-rating levels.[4] The NAS committee recommended that we provide the public with additional rating levels in order to allow the public to better differentiate rollover risk between vehicles. The focus groups we conducted before implementing the current program indicated that consumers would prefer the five-star rating system. This star rating method is also consistent with the other parts of NCAP (frontal and side crash ratings). However, we will explore the use of greater differentiation of the data as well as alternative presentation formats in future consumer research. We will change our presentation of the second-level detailed information as soon as possible. We already provide the actual SSF number for each vehicle in NCAP in addition to the star rating, for those consumers who want more detailed information on the vehicles. This hierarchical approach was recommended in the 1996 NAS study, ''Shopping for Safety.'' We are considering refining this level of information by placing that SSF number in the context of all the other vehicles tested. We can also provide the public with the point estimate for the rollover risk associated with each value of the SSF using the logit curve. We will conduct interviews and focus groups this spring to determine the most effective way to communicate primary and secondary level information to consumers. Different communication methods may be developed for print and web site implementation.

We agree that providing more information about rollover risk in the context of overall motor vehicle risk would be useful information to consumers. The agency presently includes an explanation of rollover resistance ratings, how they were derived, and safe driving tips on its web site.

We intend to develop further consumer information on rollovers. In the short term, we are looking into providing consumers a better context for rollover risk by better describing the size of the rollover crash problem and its risk relative to other crash modes. In the long term, the agency is trying to develop a method of combining available information on the safety performance of each new vehicle model. The approach we are exploring uses the front, side, and rollover measures from NCAP combined with the safety benefits of rollover resistance and vehicle weight estimated from real-world crash data. We would like to combine the individual measures (for front, side, and rollover crashes) to reflect their relative frequency in the real world. However, a complete description of the safety of a new vehicle model should include the effect of that vehicle on other road users (including occupants of other vehicles on the road, pedestrians, and bicyclists). We are still performing research that will help us better understand the factors critical to vehicle aggressiveness and compatibility, and that will provide a basis for a comprehensive combined safety rating.

VI. Choice of Maneuvers for Rollover Resistance Tests

Appendix I describes the candidate vehicle maneuver tests evaluated as possible tests for dynamic rollover resistance and presents the results of our evaluation program. The research to evaluate potential maneuver tests for rollover is fully documented in the NHTSA technical report ''Another Experimental Examination of Selected Maneuvers That May Induce On-Road Untripped, Light Vehicle Rollover—Phase IV of NHTSA's Light Vehicle Rollover Research Program''.

Table 1 summarizes the observations in Appendix I about each of the nine Rollover Resistance maneuvers in the areas of Objectivity and Repeatability, Performability, Discriminatory Capability, and Realistic Appearance.

TABLE 1.—SUMMARY OF ROLLOVER RESISTANCE MANEUVER OBSERVATIONS

	NHTSA J-Turn	J-Turn with pulse braking	Fixed timing fishhook	Roll rate feedback fishhook	Nissan fishhook	Ford path corrected limit lane change	ISO 3888 part 2 double lane change	Consumers union short course double lane change	Open-loop pseudo -double lane change
Objectivity and Repeatability.	Advantage	Advantage	Advantage	Advantage	Advantage	Disadvantage	Disadvantage	Disadvantage	Advantage
Performability	Advantage	Disadvantage	Advantage	Advantage	Disadvantage	Disadvantage	Advantage	Advantage	Disadvantage
Discriminatory Capability.	Advantage*	Unacceptable	Advantage	Advantage	Advantage	Advantage	Unacceptable	Unacceptable	Unacceptable
Realistic Appearance.	Disadvantage	Disadvantage	Disadvantage	Disadvantage	Disadvantage	Advantage	Advantage	Advantage	Advantage

*When limited to vehicles with low rollover resistance and/or disadvantageous load condition.

A. Closed-Loop Driver Controlled Rollover Resistance Maneuvers

We continue to have substantial concerns about the use of maneuvers with driver generated steering inputs to develop NCAP rollover resistance ratings. Although fairly good driver-to-driver repeatability was seen during the Phase IV testing, this partially reflects the approximately equal skill levels of the test drivers. (This also partially reflects the small range of the rating metric, maneuver entrance speeds, that was seen.) A professional race driver

[4] Finding 3–5, ''The current practice of approximating the rollover curve with five discrete levels does not convey the richness of the information provided by available crash data.'' ''An Assessment of the National Highway Traffic Safety Administration's Rating System for Rollover Resistance,'' TRB NRC, prepublication copy February 21, 2002, page 3–27.

could probably drive cleanly through these maneuvers with higher entrance speeds. Conversely, an inexperienced driver who has never done any test driving could probably only manage lower speeds. We remain concerned that ratings generated with a driver-closed steering loop maneuver might not be fair or helpful to consumers if this year's test driver were not as good as last year's or the test driver was having an off day when a particular make-model was tested.

A further problem for maneuvers with driver generated steering inputs is that of ''clean'' (none of the cones delimiting the maneuver's course were bypassed or struck) versus ''not clean'' runs. Only for a ''clean'' run do we know that the driver actually drove the prescribed maneuver. If the vehicle during a run bypasses or hits one or more of the delimiting cones, then there is no way to ensure that the driver was actually trying to steer the prescribed course. To give two extreme examples, a test driver could drive through the ISO 3888 Part 2 Double Lane Change at a very high speed without a chance of two-wheel lift occurring by going straight. Or, at the same speed, he could achieve two-wheel lift by performing a fishhook maneuver. For either case, a ''not clean'' run would be recorded.

It is extremely difficult to generate two-wheel lift while having a ''clean'' run. While Consumers Union has stated that on a rare occasion it managed to achieve two-wheel lift in a ''clean'' run, in general, two-wheel lift will result in the vehicle not following the prescribed course. Therefore, we must use maximum maneuver entrance speed for a ''clean'' run as the rating metric instead of the more directly rollover related metric of when two-wheel lift first occurs. The relationship between maximum maneuver entrance speed and rollover resistance is not known.

Although all Rollover Resistance maneuvers are influenced by both a vehicle's handling characteristics and its resistance to tip-up, it appears that handling dominates the Double Lane Change maneuvers but is less important for the J-Turn and Fishhook maneuvers. The Double Lane Change maneuvers are better for studying emergency vehicle handling than rollover resistance. Clean runs of the CU and ISO 3388 tests are not limit maneuvers in the sense of the J-Turn and Fishhook because they cannot measure tip-up after the vehicle's direction control is lost.

One way to characterize maneuvers is by the number of major steering movements they involve. The J-Turn has just one major steering movement, the initial steer. A Fishhook has two major steering movements, the initial steer and the countersteer. As shown by Figures 11 and 14, a Double Lane Change has four major steering movements, the initial lane change steer, the second lane change steer, the recovery steer, and the stabilization steer, plus some minor steering movements. We believe that these additional major steering movements increase the influence of handling for Double Lane Change results compared to J-Turn and Fishhook maneuvers.

During the Phase IV Rollover Research there were a number of ''not clean'' runs of the CU Double Lane Change maneuver that resulted in two-wheel lift. These two-wheel lifts always occurred just after the completion of the second major steering movement, well before the third. In other words, the two-wheel lifts occurred while the Double Lane Change and Fishhook steering inputs were still similar and not after they had diverged. No two-wheel lifts in Double Lane Change maneuvers were seen after the third major steering movement. We believe that by the time of the third major steering movement, the severity of the steering has caused sufficient speed to be scrubbed-off to make two-wheel lifts at this point in the maneuver very unlikely.

Double lane change maneuvers scored on the basis of highest ''clean'' run speed had no value as dynamic tests of rollover resistance. For our sample of test vehicles, there was actually an inverse relationship between double lane change speed scores and the incidence of tip-up in more severe maneuvers that induced tip-up. The test vehicle that tipped-up the most often in other maneuvers and at a consistently lower tip-up speed than other test vehicles would be rated the best vehicle for rollover resistance by the CU Short Course or ISO 3888 Part 2 double lane change on the basis of maximum clean run speed. These tests measure a type of handling performance but do not measure rollover resistance.

B. Sub-Limit Maneuvers Measuring Dynamic Weight Transfer

Ford suggested two methods of implementing the same idea. It first suggested the Path Corrected Limit Lane Change method in which vertical wheel force measurements made in driver controlled runs over a number of nominal double lane change paths are corrected mathematically for variations due to the vehicle's departure from the ideal path. Appendix I reported the results of a demonstration of this method in which Ford assisted NHTSA in performing the test runs, and Ford performed the mathematical corrections and calculated the Dynamic Weight Transfer Metric (DWTM) for each of our test vehicles. In its subsequent comments to the docket, Ford announced that it had developed an advanced path following robot that could drive each test vehicle repeatably through the ideal path directly, eliminating the need for mathematical path correction. Ford expected both implementations to produce the same DWTM for a given vehicle, and the following remarks address both implementations.

Four double lane change courses are run at 45 mph. They are each designed to produce a maximum lateral acceleration of 0.7g, but at a different frequency of motion due to their different combinations of length and offset. The performance metric for each test vehicle is highest dynamic weight transfer produced by any of the four double lane change courses.

Ford's use of the double lane change is much more relevant to rollover resistance than the ISO 3888 or Consumers Union double lane change tests described above. Dynamic weight transfer is the mechanism that leads to tip-up. However, the Ford test is not a limit maneuver. It will not cause vehicles to tip-up, lose control, or even invoke ESC in most instances. From a theoretical point of view, this is the source of its greatest advantage and greatest limitation. Running the tests at sub-limit 0.7g lateral acceleration is a great advantage because any reasonable concrete or asphalt pavement should supply sufficient traction. It should eliminate concern about pavement traction variation at a designated test location, and even permit comparable tests at different locations. It should also eliminate the possibility of tire debeading during test conditions. However, sub-limit tests require that the comparison of dynamic performance between vehicles be extrapolated from a test condition that does not cause control problems to the extreme conditions that may actually produce rollover. Suspension effects that may be important at tip-up would not necessarily appear at the sub-limit test condition. While the swing-axle suspension design is not in current use, it offers a clear example of the theoretical problem of sub-limit tests. If a rear swing-axle vehicle enjoys a DWTM advantage over a vehicle with a beam rear axle at a sub-limit condition, it is easy to see how that advantage may not extrapolate to a limit condition where weight jacking and severe positive camber angles associated with swing-axle suspension manifest themselves.

Sub-limit maneuver testing also may not predict vehicle rollover resistance at limit conditions. It is unclear how great a practical limitation on rollover resistance testing is presented by the inability of sub-limit tests to measure anomalies in suspension behavior that may occur only in limit conditions. However, in the case of the Ford test, the evaluation of the results for our test vehicles shows other practical limitations that are certainly important. We included the 2WD Chevrolet Blazer and the 4WD Ford Escape among our test vehicles because they represented a large difference in static stability factor (0.21) within the SUV class. In every test maneuver that produced tip-up and in all load conditions, the Blazer had the worst performance and the Escape had the best. Under the PCLLC method, the Mercedes ML320 with ESC enabled performed worse than the Blazer and significantly worse than the performance of the same ML320 with the ESC disabled. Since no other test showed a loss of rollover resistance due to the operation of ESC, we conclude that there was an error in the PCLLC method for this vehicle. Aside from the ML320 with ESC, the Blazer and Escape set the performance range among our test vehicles in the Ford test as well. However, the standard deviation of DTWM measurement is so large in comparison to the range of differences in DTWM between vehicles, that the large difference in rollover resistance between the 2WD Blazer and the 4WD Escape barely attains statistical significance. Aside from the erroneous result for the ML320s with ESC, none of the other differences in DTWM between test vehicles were statistically distinguishable from random measurement variation. The measurement repeatability of the present form of the Ford test makes it not suitable for comparisons of vehicles within a class. The measurement variation of DWTM relative to the range of values across vehicle population is at least 20 times that of SSF measurements.

A surprising limitation of the Ford test was that there was no discernable dynamic weight transfer component in the measured Dynamic Weight Transfer Metric. Except for the measurement of the ML320 with ESC that we consider erroneous, the ''dynamic'' weight transfer measurements were not different from the quasi-static weight transfer calculated from c.g height, track width, and an allowance for steady state body roll. This suggests that the same weight transfer would be measured if the vehicle were simply driven in a circle at 0.7g lateral acceleration.

The centrifuge is a theoretically ideal way to make the same measurement. The weight transfer measurement could be made by placing the vehicle on stationary scales on the centrifuge platform. Stationary scales are a much more accurate way of measuring vertical load than the method used in the Ford test. Both the PCLLC method and the path-following robot method of Ford's test rely on measurements of axle height and camber relative to the road to deduce vertical loads from separate studies of tire deflection versus vertical and lateral loads and camber angle. The centrifuge test could directly measure quasi-static weight transfer at 0.7g, but it could also measure the lateral acceleration at tip-up for each vehicle which would increase the measurement range across the population of vehicles. We expect that the repeatability of centrifuge measurements would approach that of SSF measurements, and Section VIII describes our plans to investigate the potential of centrifuge testing. The ''straight tether release'' method of centrifuge testing suggested by UMTRI also provides for a dynamic component of load transfer that can be measured under laboratory conditions. It is identical in concept to the sled tests for tripped rollover suggested by Exponent.

Although Ford's PCLLC test produces results that are more quasi-static than dynamic, rollover resistance ratings based on quasi-static load transfer are useful if measured precisely, and they are likely to correlate very well with real-world crash statistics. However, only true limit maneuver tests measure the effects of ESC and potential anomalies in suspension behavior on rollover resistance. Unfortunately, limit maneuver tests are affected by pavement friction to a much greater degree than Ford's test or centrifuge tests that do not involve pavement friction. We do not expect pavement effects to be an insurmountable obstacle to practical limit maneuver tests, but should that occur, we believe that the centrifuge test has a great advantage in precision, simplicity, and cost of operation over the PCLLC method while sharing its advantage of pavement insensitivity.

C. Choice of the Fishhook Test With Roll Rate Feedback and the J–Turn as an Effective Pair of Dynamic Rollover Resistance Test Maneuvers

The fishhook and J-turn maneuvers turned out to be the only true limit maneuvers in the test program. Unlike the other maneuvers they were capable of causing tip-up in vehicles susceptible to on-road untripped rollover. They were able to detect an increase in resistance to on-road untripped rollover as a result of ESC operation, and they place the vehicle in a circumstance where anomalies in suspension behavior will manifest themselves. They were very objective and repeatable because they were performed using a steering controller. We estimate that the speed at tip-up is repeatable within 2 mph on the same surface. A test performance criterion of tip-up or no tip-up would be absolutely repeatable except for vehicles with a tip-up speed within 2 mph of the maneuver cut-off speed set by safety concern for test drivers. We are examining the repeatability of limit maneuver tests on different pavements and in different seasonal conditions on the same pavement.

Our reasons for not choosing a Double Lane Change maneuver are summarized in Table 1, discussed in Appendix I of this notice and further clarified in subsections A and B above. However, to briefly repeat, our primary concerns with the Double Lane Change maneuvers are: (a) The Ford version appears to be a very complex and expensive way of measuring quasi-static load transfer with poor measurement precision; also it does not measure ESC effects or anomalies in suspension behavior at the limit; and (b) the ISO 3388 and CU Short Course simply do not measure rollover resistance under the performance criteria of maximum entry speed of a clean run, nor are they limit tests.

Table 1 summarizes the observations that point to the Fishhook maneuver as the best choice for a dynamic rollover resistance test maneuver. We prefer the Roll Rate Feedback Fishhook to the Fixed Timing Fishhook because roll rate feedback feature adapts the timing of steering to characteristics of the vehicle being tested. This feature resolves long-standing criticism of double lane change maneuvers for rollover testing that the inherent timing of the course could favor the frequency response of some vehicles over others. (The Ford test used a variety of double lane change courses to address the same issue.) The Nissan Fishhook also contains a procedure to adjust the steering timing to the vehicle characteristic, but it is a more difficult test to perform than is the automated Roll Rate Feedback Fishhook maneuver.

One of the problems with using the Roll Rate Feedback Fishhook (or any other Fishhook) maneuver for consumer information is that Fishhook does not give people an understanding as to how this maneuver occurs during driving. To help people understand this test, we have decided to rename Fishhook maneuvers (all variants) as Road Edge Recovery Maneuvers. The Roll Rate Feedback Fishhook will be renamed the NHTSA Road Edge Recovery Maneuver.

NHTSA analyses of crash databases have found that the most common scenario leading to untripped rollover is road edge recovery. This scenario begins with the vehicle dropping two wheels off the right edge of the paved roadway onto an unpaved shoulder. The reasons for this occurring include, among others, driver inattention, distraction and fatigue. The driver attempts to regain the paved roadway by steering to the left. Due to the lip between the pavement and the shoulder, a substantial steer angle is required to start the vehicle moving to the left. However, once the vehicle overcomes the lip and starts moving, it quickly threatens to depart from the left side of the road. Therefore, the driver rapidly countersteers to the right. This pattern of steering during a road edge recovery was discovered during research done by the Texas Transportation Institute.[5]

The similarity between the characteristic pattern of steering used by drivers during a road edge recovery and a fishhook maneuver is apparent. We note that fishhook maneuvers do not simulate the lip between the pavement and the shoulder. However, we do not believe that this matters since the effects of this lip occur at the very beginning of the maneuver, well before the vehicle is likely to have two-wheel lift.

The NHTSA J-Turn maneuver (without pulse braking) was the easiest limit maneuver to perform repeatably and objectively. However, it was not chosen as a stand-alone dynamic rollover resistance test because it is not severe enough. While our research has shown that the J-Turn can discriminate between vehicles that have a low rollover resistance, J-Turns generally do not induce tip-up for modern production vehicles loaded only with a driver and instrumentation. Fishhook maneuvers induce two-wheel lifts for more production vehicles.

The discriminatory power of the dynamic rollover test program will be maximized by having test maneuvers with different levels of stringency rather than just a single maneuver with tip-up speed as the only metric. The NHTSA J-Turn is our choice for a lower severity dynamic rollover resistance test maneuver. We have selected it because it has excellent objectivity and repeatability, is easy to perform, and has a well worked out test procedure. Having only a single major steering movement, it is a logical step down from the Fishhook. This maneuver has a long history of industry use. During NHTSA's discussions with the automotive industry, every manufacturer stated that they routinely perform J-Turn testing during vehicle development.

Another way to increase the range of test severity is by testing vehicles in different load conditions. Ford suggested using the PCLLC tests with vehicles loaded to their Gross Vehicle Weight Rating with the rear axle carrying its maximum rated load. The tests described in this notice used a roof load as a second load configuration. The rating system alternatives described in the next section presume that the vehicles will be tested in two load conditions. We have tentatively decided that the light load condition will be just the driver and instruments and that the heavy load condition will be the equivalent of fiftieth percentile male dummies in all seating positions. Thus, we will test in four levels of stringency: J-turn with light and heavy loads; and Roll Rate Feedback Fishhook with light and heavy loads. The J-turn with light load is the least stringent, and the Fishhook with heavy load is the most stringent. The rating example in the next section assumes only four binary dynamic performance variables, namely did it tip-up or not in each of the four maneuver/load combinations. The speed at tip-up will be available as another level of stringency, but it is not clear whether it will be needed. A greater number of dynamic variables may not further improve the fit of the statistical model.

VII. Proposed Rollover Resistance Rating Alternatives

While many commenters suggested or supported specific dynamic rollover tests, only two of them made suggestions about how to use the results of dynamic rollover tests in ratings of rollover resistance. GM defined minimum levels of performance for the centrifuge tip-up test, the constant radius driving maneuver test of maximum lateral acceleration, and the stability margin which is the difference between centrifuge test result and the constant radius maneuver test result. A vehicle meeting all three minimum levels of performance would be rated 2 stars. It also defined a single higher ''bonus star'' level for each of the three performance criteria, making it possible to rate up to 3 bonus stars for total rating of 5 stars. Toyota presented an example of a range of Lateral Acceleration for Rollover (LAR) in a fishhook maneuver (with pulse braking if necessary) for a number of hypothetical vehicles divided into 5 star levels of increasing LAR, noting that the actual star levels should be determined ''through NHTSA testing/ data analysis.'' GM's suggestion is based on the idea of being directionally correct—a vehicle with better rollover stability attributes should earn a higher rating. Toyota's example is based on directional correctness as a minimum; it is unclear whether its reference to NHTSA data analysis refers to the analysis of test data to determine the likely extremes of LAR or to the analysis of rollover statistics for vehicles of known LAR.

NHTSA's present rollover resistance ratings based on SSF are interpreted in terms of a predicted rollover rate for the vehicle if it is involved in a single vehicle crash. This goes far beyond the GM-suggested minimum quality of directional correctness for a rating system. The NAS study strongly supported the use of SSF to predict rollover rate as long as the model relating SSF and rollover risk could be demonstrated to be repeatable across data sets (shown by a tight confidence limits about the regression line). While the logit model underestimates the rollover risk of vehicles with very low SSF, its tight confidence limits can be calculated by standard statistical software, and NAS concluded that the repeatability of the model would support the discrimination of more than 5 levels of rollover resistance for light vehicles.

Should Rollover Resistance Be Rated Using Dynamic Maneuver Tests Alone?

The requirements of the TREAD Act refer only to a ''dynamic test on rollovers'' and are silent about rollover resistance information derived from static measures. However, the NAS study of the present rollover rating system recommended that ''NHTSA should vigorously pursue the development of dynamic testing to *supplement* the information provided by SSF'' [emphasis added]. NAS did not suggest that any combination of dynamic tests alone was sufficient for consumer information on rollover resistance, and its report explained that in the final out-of-control phase of a rollover crash ''SSF and the terrain over which the vehicle is moving are the dominant determinants of whether rollover will occur.''

NHTSA agrees that the dynamic tests should supplement rather than replace the static measures for the reasons given by NAS, but also because ratings

[5] Ivey, D.L., Sicking, D.L., ''Influence of Pavement Edge and Shoulder Characteristics on Vehicle Handling and Stability,'' Transportation Research Record 1084.

derived only from dynamic driving maneuver tests would severely limit the scope of the consumer information. The terrain over which dynamic driving maneuver tests for rollover take place is smooth dry pavement, but the vast majority of rollovers take place on terrain that includes soft soil, curbs and other objects that can place higher tripping forces on the vehicle than can tire/pavement friction. There are a number of vehicle design strategies for preventing tip-up in maneuver tests. Those that involve lowering the center of gravity of the vehicle, increasing its track width or reducing body sway would be expected to increase the vehicle's general rollover resistance both on-road and in the event of contact with a curb, soft soil or other tripping mechanism.

There are also a number of vehicle design strategies to prevent tip-up in maneuver tests that involve reducing the lateral tire/pavement friction. These strategies range from simply using low traction tires to sophisticated ''rollover prevention'' systems that can apply one or more brakes in response to sensing a potential rollover situation. When a tire is subjected to heavy braking, its capacity for lateral traction is greatly reduced. This principle can be used to cause the vehicle to skid rather than tip-up under control of a ''rollover prevention'' system (that uses the brake intervention capability of ESC under control of a tip-up sensing rather than yaw sensing computer program). Design strategies that depend on the active or passive management of tire traction can be effective in reducing the risk of a vehicle rolling over on the road where tire traction matters. However, the on-road untripped rollover is a special and limited case of rollover crash; most rollovers are initiated by a tripping mechanism other than tire traction. NAS found that dynamic maneuver tests for rollover are important because they are sensitive to vehicle properties that are not reflected in static measures of rollover resistance. But, a dynamic maneuver test *alone* can only assure the measured level of rollover resistance in the case of on-road untripped rollover because tip-up in the dynamic test can be prevented by tire traction management strategies that have no effect when a tripping mechanism (other than tire traction) initiates the rollover. Using dynamic maneuver tests to supplement the information on rollover resistance obtained from static measurements represents a potential improvement in consumer information, but the use of dynamic maneuver tests alone would result in rollover resistance ratings that may not apply to the most common type of real-world rollover crash in which the vehicle strikes a tripping mechanism. That would significantly reduce the correlation of rollover resistance ratings to real-world rollover crashes.

Rollover Resistance Ratings Based on Both Static Measures and Dynamic Maneuver Tests

Alternative 1—Combine Static and Dynamic Vehicle Measurement in a Statistical Model of Rollover Risk

The ideal rollover resistance rating system would give consumers information on the risk of rollover in a single vehicle crash taking into account both the static properties of a vehicle and its performance in dynamic maneuver tests. The risk based system is better than a system that is merely directionally correct. In addition to answering the question ''is the rollover risk lower for vehicle A or vehicle B?'', it can answer also the questions, ''how much lower?'' and ''what is the absolute risk?''.

The present rollover resistance ratings are based on a statistical model that considers about 221,000 single vehicle crashes of 100 popular make/model vehicles for which we have SSF measurements. In addition, each state accident report provides a number of driver demographic variables (sex, age, sobriety), road characteristic variables (speed limit, hill, curve, slippery surface), and weather variables (storm, darkness). A statistical model can use the real-world crash data to determine the effect of any variable on the proportion of single vehicle crashes that result in rollover (rollover risk) in the presence of other variables that may also exert an influence. In the present case, the only vehicle variable is SSF, and the model predicts the risk of rollover as a function of SSF in the presence of the many combinations of confounding variables in the data sample of 221,000 crashes. The predicted rollover risk of a vehicle in a single vehicle crash, based on its SSF, becomes its rollover resistance rating which is expressed in five discrete levels (less than 10%, 10% to 20%, 20% to 30%, 30% to 40%, more than 40%) designated by one to five stars.

As mentioned previously, the NAS recommended that we use a logistic regression model instead of the linear regression model in order to establish tight confidence limits on the repeatability of the model, and it found that the differences of rollover risk between vehicles predicted by the statistical model were significant enough to support more than five discrete levels. Also, the NAS study recommended that NHTSA develop a risk model that combines the SSF measurement with the results of one or more dynamic maneuver tests for a more robust consumer information rating on rollover resistance.

The NAS study was not concerned with the distinction between tripped and untripped rollovers because it is the magnitude and duration of the forces that cause rollover in all circumstances. NHTSA has considered the distinction between tripped and untripped rollovers important in making a choice between a road maneuver test or a general rollover resistance indicator metric like SSF for consumer information because tripped rollovers are much more common occurrences. However, the NAS recommendation of including both SSF and road maneuver test results in a risk model makes the distinction between tripped and untripped rollovers unnecessary. The recommendation does not require a choice between the two types of rollover resistance measures because both are included. Also, the risk model will be calculated using all available rollover data including tripped and untripped rollovers from several states for a number of vehicles that we will test using J-Turn and Fishhook maneuvers and measure for SSF. The predictive power of both SSF and road maneuver tests determined by real-world data will be reflected in the risk model.

We plan to conduct dynamic rollover tests of various levels of stringency. The J-turn maneuver with a driver and instruments (light load configuration) is the least stringent. It would be rare for this maneuver to cause tip-up of a modern vehicle. The same J-turn test performed with a passenger load in every seating position (heavy load configuration) is a more stringent test that is likely to cause tip-up for a few vehicles. The Fishhook test with roll rate feedback is more stringent than the J-turn test because it includes a steering reversal designed to occur at the least favorable instant for each vehicle. It would also be performed in both light and heavy vehicle load configurations for a total of four levels of test stringency. Each maneuver is repeated in a series of increasing speeds until it tips-up or reaches the maximum test speed. The speed at tip-up offers a discriminator within each stringency level if needed.

We believe that this suite of dynamic rollover tests will identify vehicles vulnerable to rolling over without the presence of a tripping mechanism, and identify a relative rank order of vehicles regarding this vulnerability. However, the vehicle's rank order alone does not predict the rollover risk associated with its level of vulnerability to tip-up in dynamic rollover tests. Also, the dynamic test program is not expected to distinguish between vehicles having an SSF of about 1.2 or greater because they are unlikely to tip-up in any dynamic maneuver test for rollover. This expectation is based upon NHTSA's rollover maneuver research from 1997 to present.

Combining the dynamic rollover test results with SSF in a risk model should overcome the limitations discussed above. Consider two vehicles with a similar SSF. If one vehicle tips up during dynamic rollover tests but the second does not, we would expect this advantage to manifest itself in the rollover crash statistics of real vehicles. Likewise, a vehicle that tips-up only in high severity maneuvers should have better real-world performance than a vehicle of similar SSF that tips up in lower severity maneuvers as well. Even if the real-world reduction in rollover risk associated with better dynamic maneuver test performance proves to not be large, it is certainly reasonable to expect it to affect the statistical risk model when it is entered along with SSF as one or more additional vehicle variables.

The logistic regression model recommended by NAS (referred to as the logit model) gives an example of how the dynamic and static information could be combined in a risk model. As presented in the NAS report, the model operated on three driver description variables, four road description variables, two weather variables, but only one vehicle variable. There is no obvious reason why the same model could not operate on additional vehicle variables. While we are particularly interested in differences in rollover risk between vehicles with different dynamic test performance but similar SSF, we recognize that dynamic test results and SSF are not independent variables. But some of the variables describing the driver, road and weather also were not independent. The hypothetical exercise described below seems to confirm that logistic regression can use interrelated variables without difficulty.

The data base we have used to construct linear and logistic regression models for the existing rating program and to assist NAS in its study of rollover ratings contains the state crash data for 100 vehicle make/models and their SSF measurements, but we do not have dynamic maneuver test results for these vehicles. In order to evaluate the logistic regression process when dynamic test results as well as SSF are used as vehicle variables, we selected 25 vehicles from our 100 vehicle data base and tried to estimate their probable dynamic maneuver test results based on previous dynamic tests of similar make/models. In the absence of real test results these hypothetical maneuver test results allowed us to use the logistic regression software with vehicle multiple variables. The hypothetical dynamic maneuver test results were in the form of 4 binary (yes/no) variables representing whether the vehicle would tip-up in the four maneuver tests of differing stringency (J-turn/light load, J-turn/heavy load, Fishhook/light load, Fishhook/heavy load). The possible sub-levels of performance defined by test speed at tip-up were not used. The data base included about 88,000 single vehicle crashes of the 25 vehicle make/models with the real driver, road, weather and SSF data, but only our estimates for dynamic ''data'.

First, logistic regression was performed with SSF as the only vehicle variable. The result is presented by the dashed line in Figure 1. It is essentially identical to the result of the ''logit model'' recommended by NAS that was constructed using a 221,000 crash data base of which the 88,000 crashes are a subset. The similarity of the results is consistent with the finding of very tight confidence limits for the model.

Next, the logistic regression was repeated using the hypothetical dynamic maneuver test results in addition to SSF as vehicle variables. The points on the graph are the predicted rollover rates for each of the 25 vehicles considering both its static and dynamic measurements under the mean distribution of the driver, road and weather variables. The locus of points generally follows the line predicted by SSF alone but shows differences in predicted rollover rates as a result of hypothetical dynamic test performance, especially at the low end of the SSF range. We estimated in the hypothetical dynamic maneuver test results that, with one exception, none of the vehicles with an SSF greater than 1.17 would tip up in even our most severe dynamic maneuver test. However, even if a vehicle does not tip-up in our maneuver tests, its risk of rollover is not zero, and it is strongly related to SSF as shown in the model. The model also allows for the possibility that vehicles with the same SSF may have significant differences in dynamic test results that influence the real rollover risk. These are the characteristics we expect in a reasonable risk model. While this preliminary investigation of logistic regression as a means to combine static and dynamic measurements is encouraging, NHTSA will continue to examine the theoretical soundness and confidence limits of the model in keeping with the recommendations of NAS.[6]

The relative value of static versus dynamic measurements for determining the rollover resistance of vehicles is a significant question. Certainly, the use of both types of information to determine rollover resistance should lead to the most accurate information, but one must determine the relative weighting of the static and dynamic measurements. The combination of the static and dynamic information in a statistical model of rollover risk is an objective way to let real-world crash data determine the weighting that best represents the outcomes of crashes. Besides providing the best rollover risk estimates, the statistical model also has the advantage of not requiring judgments about appropriate data weighting from NHTSA or any of the interested parties. Regardless of the rating method, the NCAP program will make available the test results for SSF and for each of the dynamic maneuver

[6] We noted that the predicted rollover risk of vehicles at the low end of the SSF range in Figure 1 was considerably larger for the model including dynamic maneuver results than for the logistic model using SSF only. This is due in part to an apparent limitation in the form of the risk prediction curve with a single independent variable inherent to the basic logistic regression procedure that prevents the line from having sufficient curvature to follow the trend in rollover risk versus SSF in the data set presented to the model. The exponential risk curve upon which our current SSF rollover resistance ratings are based agrees more closely with the logistic model operating on both the SSF and the hypothetical dynamic maneuver tests. Our current rating system also agrees more closely with the actual rollover rates of vehicles than does the basic logistic regression procedure operating on SSF alone. We expect to overcome the limitation in the form of the risk prediction curve of the logistic regression model operating on SSF alone by using transformations of SSF (log(SSF) for example) as the vehicle variable. Once we have achieved a model with the goodness of fit of our current exponential model and the narrow confidence limits of the logistic model recommended by NAS, we can add the dynamic maneuver test results with the certainty that we are refining the risk prediction rather than compensating for the deficiencies of the base model. In the example of Figure 1, we would not expect much change in the points representing the risk predictions of the 25 vehicle with both SSF and dynamic maneuver test results. The use of multiple variables tends to free the model of the restrictions in form that are otherwise manifested in a single variable model by the need to represent an exponential risk relationship by single continuous line with a large change in curvature in our data range. However, we would expect the line representing an improved logistic model with SSF only to conform more closely to the actual vehicle rollover rates, and we would expect the spread between the SSF line and the vehicle points to represent only the effect of the dynamic performance of the vehicle.

tests, so that consumers can see the basis of our rating and exercise their own judgments about their particular concerns.

However, this method of rollover resistance rating has some drawbacks. Dynamic maneuver test results for vehicles with large samples of single vehicle crash data are needed to compute a robust risk model. In order to use dynamic test results in risk-based ratings, NHTSA must first test a number of older vehicles to correlate the combined vehicle information of dynamic test performance and SSF to rollover rate using a large crash database. Eventually the NCAP test results will supply the risk model with vehicle information, but sufficient corresponding crash data will trail the vehicle measurements by at least four years. State accident records are reported to NHTSA yearly, but they lag by about two model years. Even a high production vehicle requires about two years of exposure to accumulate sufficient single vehicle crash data in the few states with reliable reporting of both vehicle identification and rollover crashes. Consequently, it will be a number of years before the effects on rollover rate of traction management strategies and other technologies that improve dynamic maneuver test results are represented directly in the risk model. In the mean time, vehicle characteristics that improve rollover resistance only in the special case of on-road untripped rollover may be overvalued in the risk model in comparison to vehicle characteristics that improve resistance to both untripped and tripped rollover.

Critics of the SSF-based rating system may view the combination of dynamic and static measurements in a risk model as an attempt by NHTSA to devalue the dynamic tests. That is not the case.[7] It is true that SSF is a strong predictor of the risk of rollover especially in a tripping situation and that most rollovers are tripped. Consequently, we expect SSF to have a strong effect in a risk model even when dynamic test variables are also included. However, the strong effect of SSF is not likely to diminish the differences in rollover rate predicted for difference in dynamic performance. We note that the example of Figure 1 is based only on estimates of dynamic test performance. We will not know until we have actual dynamic test results for some of the 100 vehicles in our 221,000 crash database whether the effect of dynamic test performance on the rollover risk model is as great as expected.

Alternative 2: Separate Ratings for Dynamic Rollover Test Results and Static Vehicle Measurements

An alternative rating system is proposed to address concerns that combining the dynamic and static information in a risk model could give the dynamic tests less influence than concerned parties would prefer. It is based on the idea that the dynamic rollover maneuver tests are a direct representation of an on-road untripped rollover. Therefore, the dynamic test results may be reported separately as ratings of resistance to untripped rollover. Likewise, the SSF measurements would be presented separately as ratings of resistance to tripped rollover.

We believe that the vast majority of the rollovers in our 221,000 single vehicle crash database are tripped rollovers. However, it is impossible to identify those that may be untripped because state accident reports are not concerned with that level of detail. About 95 percent of the small number of rollover crashes investigated directly by NHTSA in great detail (the NASS–CDS program) were tripped. Assuming a similar distribution of tripped and untripped rollovers, our large database is a suitable basis for a risk model of tripped rollover using SSF. The tripped rollover risk predictions would be the same as the present risk predictions except for the changes in statistical methodology recommended by NAS.

Unfortunately, the NASS–CDS database receives reports of only about 10 untripped rollovers (and about 200 tripped rollovers) a year, precluding any possibility of risk prediction on a make/model basis for untripped rollover. Ratings of resistance to untripped rollover would have to be based simply on the principal of directional correctness. For instance, a vehicle that did not tip-up in any maneuver at any load condition would be rated ''A''; a vehicle that would tip-up in a maneuver test only when loaded at every seating position would be rated ''B''; and a vehicle that would tip-up in a maneuver test even in the lightly loaded condition would be rated ''C''.

This rating system also has some disadvantages. The use of two sets of ratings about the same general type of crash would be difficult to communicate effectively to consumers. It will also be hard to explain to consumers why the SSF rating may be expressed in terms of risk but not the dynamic rating. Since the only risk information in the rating system would be associated with the static measures, those most interested in the dynamic tests may find that more dismissive of the dynamic tests than the combination of both types of information in a single risk model. Since an unknown portion of our crash database does contain untripped rollovers, the risk model based on that data without the use of untripped rollover test data at hand may also be perceived as not the best use of all data available to NHTSA.

Some of the parties most interested in dynamic tests have commented repeatedly that SSF should not be used in the rollover resistance rating of vehicles. However, consumer information based only on dynamic maneuver tests greatly reduces the assessment of the physical forces that cause real world rollovers. That would make the consumer information less useful to the public.

SSF measures the steady, rigid body load transfer common to all rollovers. The quasi-static centrifuge test adds a measurement of the load transfer due to body roll which should also be common to all rollovers. The Exponent sled test and the straight tethered centrifuge test add roll momentum effects typical of tripped rollovers and possibly J-turn tests. The dynamic maneuver tests add to these only a measurement of the effect of ESC and other electronic ''rollover prevention'' systems and a measurement of dynamic suspension behavior that may detect unusual problems at limit conditions. However, the test conditions of dynamic maneuver tests are limited by on-road tire traction and represent only the special case of on-road untripped rollover. Hence, we believe the dynamic maneuver tests should be used to supplement in some way one of the other three types of tests with relevance to tripped rollovers because tripped rollovers represent the vast majority of real world rollovers.

Consumers Preferences for Presentation of Rollover Ratings

In response to the NAS recommendations and in order to better refine approaches to developing and delivering consumer information on rollover, NHTSA recently initiated additional consumer research on rollover. This research was to further explore the perceptions, opinions, beliefs and attitudes of drivers about vehicle rollover, and to gather reactions

[7] The example of Figure 1 shows substantial differences in risk prediction by standard logistic regression when hypothetical dynamic test results are added to a model using only SSF to describe the vehicle. This example demonstrates the potential value of adding dynamic test results to the logit model because the predictions that include the hypothetical dynamic test results more closely match the actual rollover rates.

to different presentations of ratings and other rollover information.

The consumer research conducted was iterative in that it utilized individual in-depth interviews as a first phase, and focus group testing as a second phase. The in-depth interviews were conducted with 22 persons in Baltimore, MD in March, 2002. A total of 12 focus groups of 106 persons were conducted in Chicago, Dallas, and Richmond in April, 2002. Participants for both the interviews and focus groups had to have purchased or planned to purchase a vehicle within the year. They also had to rate safety as somewhat or very important in their vehicle purchase decisions. One-third of the participants also had to rate rollover as somewhat or very important in their purchase decisions.

The in-depth interviews were conducted with the intention of exploring consumer beliefs and perceptions in a probing more detailed way than is possible in focus groups. The interviews also served to provide insights as to how the focus groups could be most effectively conducted to acquire the desired findings. The interview results provided the basis for modifying approaches and sample materials presented at the focus groups. This iterative process did not, however, render opposing or contradictory results. The findings of the interviews and focus groups were remarkably and consistently similar. The key findings are as follows:

Understanding of and Preference for Dynamic and/or Static Rating for Rollover

• Virtually all participants were able to identify the difference between the tests for the Static Stability Factor (SSF) Rollover Rating and the Dynamic Test rollover rating, *i.e.*, that the first is a vehicle measurement and that the latter involves maneuver tests.

• Most participants preferred a combined rating, especially once they understood that 95% of real-world rollovers are accounted for by SSF. Those who said they should be presented separately thought they would provide consumers with more information; but they also thought that the different (5 pt vs.3 pt) rating scales presented would confuse people. Many thought that a dynamic test was more realistic.

• Some participants had trouble understanding ''track width'' and ''center of gravity height'' in the description of SSF.

• Even though most participants did not explain rollover in the same way it was described to them, most stated that the description of rollover they read (from NHTSA web-site information on rollover) was understandable.

• Some of the rollover terminology; ''rollover resistance rating,'' ''tripped by'' and especially ''tripped by a *ditch,*'' were confusing or did not make sense to many of the participants.

Preferences for Presentation of Rollover Ratings and Information

• Participants were presented with stars, numbers, letters and descriptive language as alternatives for presenting rollover ratings. Stars were overwhelmingly preferred by both interview and focus group participants. They clearly disliked number ratings, and were ambivalent about letters and descriptors. Graphics presented to participants are shown in Figure 2 and in the report ''Findings of 21 In-Depth Interviews and 12 Focus Group Discussions Regarding Vehicle Rollover,'' which is available in the docket for this notice.

• Participants accurately interpreted the star ratings, with and without the key that explained what each star meant and which was better. However, many did not fully grasp that the ratings were vehicle ratings and were therefore confused by or did not find credible the actual data sets that showed percentages from over 40% to under 10% for rollover risk.

• When presented with a bar graph that showed an individual vehicle among all vehicles, most interview participants found the bar graph complicated and too vague. Some said it might be useful to decide between different vehicle classes. The bar graph was refined visually and presented as a way of checking an individual vehicle through the web-site for the focus groups. When shown this graph depicting where a certain vehicle ranked in relationship to other vehicles in it's class, and against all classes as well as where it fell in the star rating range, most participants understood it and thought it useful.

Preferences for Rating Levels for Rollover Ratings

• Nearly all of the participants preferred five rating levels. Alternatives of three and ten ratings were presented through the use of numbers, letters, half-stars and narrative descriptors. Most said they did not like the half stars, but when probed said it might make a difference in whether or not they would consider a vehicle. Interestingly, many assigned different values to half-star ratings; *e.g.* 3½ stars was considered more important than 4½ stars.

• Most participants felt three rating levels were too few. Very few felt that 10 rating levels were appropriate. Most thought it was too much information and unnecessary.

The findings of this research will help NHTSA to develop appropriate and useful rollover ratings and consumer information in the future. NAS has recommended that the agency provide the public with additional rating levels in order to allow better differentiation of rollover risk between vehicles. While clearly there are improvements to be made in how rollover resistance and ratings are explained and made useful to the consumer, there does not seem to be any basis in our research to date for deviating from stars or from the five rating levels presently being used. However, for consumers who desire more information than just star-ratings, we will provide detailed information on each vehicle on the web-site. Consumers will also be able to differentiate between vehicles through use of the internet based bar-graph data that tested positively, and through other as yet undeveloped presentations.

VIII. Intent To Evaluate Centrifuge Test

The test device for the centrifuge test is similar in concept to a merry-go-round. A person seated at the edge of the merry-go-round feels a lateral force pushing him or her away from the spinning surface that increases with the rotational speed of the merry-go-round. The centrifuge device test shown in Figure 3 consists of an arm attached to a powered vertical shaft. At the end of the arm is a horizontal platform upon which the test vehicle is parked. As the vertical shaft rotates, the parked vehicle is subjected to a lateral acceleration that can be precisely controlled and measured. The basic quasi-static measurement is the lateral acceleration at which the parked vehicle experiences two-wheel lift. The outside tires are restrained by a low curb so the measurement is independent of surface friction, and the vehicle is tethered for safety to prevent excessive wheel lift. This test method was suggested by the University of Michigan Transportation Research Institute (UMTRI) both in comments to our notice about the present rollover resistance ratings and more recently in the context of the TREAD Act. As discussed in Section III, the quasi-static centrifuge test was also recommended by GM, Honda, CU and Advocates as a possible improvement on SSF to measure general rollover resistance. The test method is directed primarily at tripped rollover, which UMTRI noted accounts for all but a small percentage of rollovers.

The centrifuge test has many advantages. Like SSF, it is a measurement that that can be performed accurately, repeatably and economically (at least in labor costs). It is arguably more accurate than SSF in evaluating tripped rollover resistance because it includes the effect of the outward c.g. movement as a result of suspension and tire deflections. Its correlation to SSF would be high, and it would be expected to correlate well with the actual rollover rates of vehicles, because those statistics are largely driven by tripped rollovers. The quasi-static centrifuge measurement of a vehicle's lateral acceleration at two-wheel lift is expected to be roughly 10 percent less than the vehicle's SSF with about a +/−5 percent range to cover extremes in roll stiffness.

Despite these advantages, we did not include the centrifuge test in the test evaluation plan that was the subject of our July 2001 notice. We stated the following reasons:

> Improvements in centrifuge test performance can be made by suspension changes that degrade handling. The best performance in the centrifuge test (and in the closely related but less accurate tilt table test) occurs when the front and rear inside tires lift from the platform at the same time. The tuning of the relative front/rear suspension roll stiffness to accomplish this will cause the vehicle to oversteer more than most manufacturers would otherwise desire. We do not want to tempt manufacturers to make this kind of trade-off. Further, we understood the intention behind TREAD to be that NHTSA should give the American public information on performance in a driving maneuver that would evaluate the performance of new technologies like ESC. The centrifuge test would not do so.

As discussed in Section III of this notice, GM provided some data disputing our concern that improvements in centrifuge test scores could be obtained at the expense of changing the understeer/oversteer suspension tuning of vehicle from what the manufacturer would otherwise choose as optimum for handling and consumer satisfaction. We request that other manufacturers and vehicle designers review GM's information (comment 6 to docket NHTSA–2001–9663 notice 1) and comment on the validity of NHTSA's concern.

In view of the interest expressed by several commenters in centrifuge testing and the potential importance GM's information, NHTSA intends to evaluate the practicability of centrifuge testing. To our knowledge, centrifuge tests for rollover resistance of vehicles have never been performed. The interest of commenters is based on theoretical advantages over SSF. NHTSA will develop a test fixture and test a number of vehicles in the quasi-static mode using a very large centrifuge at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

IX. Handling Tests

A. The Need for Handling Testing and a Handling Rating

NHTSA expects that implementation of a rollover rating system using dynamic tests will, over time, influence vehicle designs. Therefore, it is of the utmost importance that we do not encourage designers to maximize vehicle performance in rollover resistance tests by degrading other safety relevant areas of vehicle performance.

Several possible ways to maximize vehicle performance in rollover resistance tests would degrade vehicle handling. For example, better performance in rollover resistance tests could be achieved by one or more of:

- Making the vehicle have less turning capability. Unfortunately, this would make it harder, in difficult situations, for drivers to keep the vehicle on the road or to avoid colliding with other vehicles, pedestrians, animals, and other objects.
- Equalizing the roll stiffnesses of the front and rear suspensions. Unfortunately, this may make the vehicle spin-out in limit maneuvers.
- Making the vehicle respond slowly to steering inputs. Again, this would make it harder, in some situations, for drivers to keep the vehicle on the road or to avoid colliding with other vehicles or pedestrians.

To discourage vehicle designers from maximizing rollover resistance at the expense of handling, NHTSA believes that if our rollover ratings are directly influenced by dynamic tests then we must also have a handling rating based on handling tests.

In addition to discouraging vehicle designers from maximizing rollover resistance at the expense of handling, having a handling rating based on handling tests should also encourage the adoption of yaw stability control. While the crash prevention benefits of yaw stability control have not yet been proven, we anticipate that it may help prevent crashes. Based on NHTSA's Phase IV Rollover Research, we will see some improvement in a vehicle's rollover resistance rating due to yaw stability control. However, a handling rating provides another opportunity for showing the beneficial effects of yaw stability control.

B. Guiding Principles for NHTSA Handling Testing and Handling Rating

What is handling? In this document, what we mean by handling is the lateral response of the vehicle to a driver's control inputs. Clearly steering inputs are the most important control inputs for handling, however, brake and throttle pedal inputs can also have an effect.

Traditionally, handling assessments have been made subjectively. Several test drivers drive a vehicle for a period of time through a broad variety of maneuvers. The maneuvers range in severity from mild to severe to limit. After driving the vehicle, each driver independently assigns a numerical handling rating to the vehicle. Ratings from all of the test drivers are averaged to obtain an overall handling rating.

We do not believe that a subjective handling rating is suitable for inclusion in the New Car Assessment Program. Government generated handling ratings must be objectively and repeatably determined.

There are two perspectives for handling ratings. One perspective is how safe the vehicle is to drive. The other is how well the vehicle gives an enthusiast driver a pleasurable sense of control. Given its mission, a NHTSA generated handling rating can only assess how safe a vehicle is to drive, not how pleasurable it is to drive.

What aspects of handling affect safety? NHTSA has identified the following four:

1. Amount of turning capability. A vehicle that can turn more sharply should be easier for drivers to keep on the road and to avoid colliding with other vehicles, pedestrians, animals, and other objects.

2. Graceful degradation at/near limits. When a driver approaches or tries to exceed the maximum turning capability of a vehicle the vehicle should plow-out (saturate traction on the front wheels first) instead of spin-out (saturate traction on the rear wheels first).

3. Predictability. When the driver steers, brakes, or changes the throttle level, the vehicle should do what the driver expects the vehicle to do. Since all vehicles have delays between steering, braking, or throttle application and the response of the vehicle, drivers must predict the response of the vehicle to a control input. If the vehicle does not perform as expected, there may not be time for the driver to react to the unexpected motion before a crash occurs.

4. Responsiveness. When the driver steers, brakes, or changes the throttle level, the vehicle should respond

quickly to the driver's inputs. A slowly responding vehicle would be harder for drivers to keep on the road or to avoid colliding with other vehicles, pedestrians, animals, and other objects.

We have discussed the aspects of handling that affect safety with Consumers Union. In addition to the four aspects listed above, Consumers Union uses a fifth, appropriate feedback to the steering handwheel, in developing ratings for their magazine. While we do not dispute the importance of appropriate feedback to the steering handwheel, this seems to us to be such an inherently subjective assessment that we have not included it in the above list.

We welcome comments as to the correctness of the above list of handling aspects that affect safety. Are the aspects that are listed appropriate? Have we left anything out?

C. Handling Tests Being Considered by NHTSA

NHTSA is considering developing a handling rating based upon results from the three handling maneuvers. The handling maneuvers are:

1. Slowly Increasing Steer maneuver. Using a programmable steering controller, the steering handwheel is turned slowly (13.5 degrees per second) from zero to well beyond the point at which the maximum lateral acceleration occurs (a handwheel steering angle of 270 degrees). The driver applies the throttle to keep the vehicle's speed as constant at 50 mph as possible during the turn.

The Slowly Increasing Steer maneuver provides data to assess the amount of turning capability of a vehicle (the Maximum Attainable Lateral Acceleration) and whether the vehicle's handling degrades gracefully at the limit (did the vehicle plow or spin when the maximum achievable turn was attained). We performed this maneuver for every vehicle tested during Phases II, III, and IV of NHTSA Rollover Research. Based on our experience we believe that this maneuver can be performed with excellent objectivity and repeatability. There is a well worked out and widely accepted procedure for the Slowly Increasing Steering maneuver that is contained in the Society of Automotive Engineers Standard J266.

2. Dropped Throttle in a Turn maneuver. Using a programmable steering controller, the steering handwheel is turned quickly, and then held at, the angle required to attain 90 percent of the vehicle's maximum achievable lateral acceleration. The driver initially applies the throttle to keep the vehicle's speed as constant as possible during the turn. The throttle is then suddenly released and the resulting vehicle motion measured.

The Dropped Throttle in a Turn maneuver provides data to assess the predictability of the vehicle. Desirable behavior is for the vehicle to either maintain the same radius of curvature or to ''tuck-in'' a bit (slightly decrease the radius of curvature). While we have not performed this maneuver in the past, we expect that this maneuver can be performed with excellent objectivity and repeatability. There is a well worked out and widely accepted procedure for the Dropped Throttle in a Turn maneuver that is contained in the International Standards Organization's Standard 9816.

Multiple measures of vehicle performance are determined from this test. One is the Dropped Throttle Yaw Rate Ratio, defined as the maximum yaw rate attained at any time during the three seconds after the throttle was released divided by the initial yaw rate. The second is the Dropped Throttle Path Deviation, defined as the lateral displacement of the vehicle's center of gravity two seconds after the throttle has been released from the anticipated path if the throttle had not been released.

3. The Step Steer maneuver. This maneuver is performed in the same manner as the NHTSA J-Turn except that the handwheel steering angle used is less. Instead of turning the steering handwheel to 8.0 times the angle needed to achieve 0.3 g lateral acceleration in the Slowly Increasing Steer maneuver (the angle used for the NHTSA J-Turn), for this maneuver the steering wheel is only turned to the angle needed to achieve 4.0 meters per second squared lateral acceleration. A handwheel steering rate of 1,000 degrees per second is used. The maneuver entrance speed is 50 mph (80 kph) and the throttle is held constant through the test.

Multiple measures of vehicle performance are determined from this test. One is the Yaw Rate Response Time, defined as the time from when the steering handwheel reaches 50 percent of its final value to the time when the yaw rate reaches 90 percent of its steady-state value. The second is the Peak Yaw Rate Response Time, defined as the time from when the steering handwheel reaches 50 percent of its final value to the time when the yaw rate reaches it peak value. The third is Percent Overshoot, defined as the difference between the peak and steady state yaw rates divided by the steady state yaw rate.

The Step Steer maneuver provides data to assess the predictability (from the Percent Overshoot measure) and the responsiveness (from the Yaw Rate Response Time and the Peak Yaw Rate Response Time measures) of the vehicle. We performed this maneuver for every vehicle tested during Phase IV of NHTSA Rollover Research; based on our experience we believe that this maneuver can be performed with excellent objectivity and repeatability. There is a well worked out and widely accepted procedure for the Step Steer maneuver that is contained in the International Standards Organization's Standard 7401.

Each Handling Maneuver would be performed at two loading conditions, Nominal Load and Rear Load. The Nominal Load consists of the curb weight vehicle plus the driver plus NHTSA's instrumentation package plus NHTSA's titanium outriggers. The Rear Load adds to the Nominal Load ballast positioned such that the vehicles rear Gross Axle Weight Rating (GAWR) and Gross Vehicle Weight Rating (GVWR) are achieved simultaneously. The ballast is comprised of bags of lead shot, positioned as flat as possible across the rear cargo area of the test vehicle. The ballast will be secured in a manner that insures it does not shift during testing. We will use a '' inch enclosed plywood box to contain the ballast used in the Rear Load condition. Due to the wide range of shapes and sizes of light vehicle cargo areas, such boxes will need to be constructed on a per-vehicle basis.

We welcome comments as to the appropriateness of the above list of handling maneuvers. What have we left out?

NHTSA is seeking tests of handling and controllability both as way of dealing with potential trade-offs between handling properties and rollover tests and as a way of giving credit to technologies that improve controllability. We request comment on the value of such tests to resolve the concern for design compromises that could improve centrifuge test scores.

One of our concerns is that yaw stability control is supposed to increase a vehicle's predictability; however, our Dropped Throttle in a Turn Maneuver test is may not be adequate for measuring the effects of yaw stability control. What other objective and repeatable tests exist for measuring vehicle predictability?

D. Combining Handling Test Results to Generate a Handling Rating

As is the case for rollover resistance ratings, an ideal handling rating system would use data obtained from the above mentioned handling tests to predict the risk, for a vehicle make/model assuming an ‘‘average’’ driver, of a single vehicle crash. The risk based ratings are better than ratings that are merely directionally correct because in addition to answering the question ‘‘Is the single vehicle crash risk lower for Vehicle A or Vehicle B?’’, it can also answer the questions, ‘‘How much lower?’’, and ‘‘What is the absolute risk?’’.

The influence of drivers on whether or not a single vehicle crash occurs is very high. The driver demographic variables that are available in the crash data bases are believed not to be sufficient to quantify this influence (*i.e.*, there is no variable quantifying a driver’s aggressivity). Therefore, we believe that, unlike rollover resistance ratings, handling ratings will not be able to predict single vehicle crash risk. They can, at best, be directionally correct.

We envision a three level handling rating system, tentatively, from best to worst, A, B, and C. A star rating system would not be used for handling ratings because they are not risk based but only directionally correct.

The handling rating calculation method proposed below contains many constants whose values NHTSA will specify at a later date (*e.g.*, a_{YMinN} and $a_{YRangeN}$). Our intention is to determine values for these constants based on data collected during the Phase VI testing. During Phase VI 25 vehicles for which we have state crash data on rollover will be tested using both rollover maneuver tests and handling tests concluding in Fall 2002. We have tried to choose the Phase VI test vehicles so as to cover the full range of handling that is seen in the current fleet, from excellent to average. (We do not believe that any current production vehicle has handling we would characterize as bad.) Once we have the Phase VI data, we will select values for the constants so that approximately one-third of the vehicles earn A ratings, one-third earn B ratings, and one-third earn C ratings.

The handling rating would be determined from the measurements results of the handling tests as follows:

1. Calculate a Handling Score, HS, from the formula:

$HS = W_1 * H_1 + W_2 * H_2 + W_3 * H_3 + W_4 * H_4$
$+ W_5 * H_5 + W_6 * H_6 + W_7 * H_7 + W_8 * H_8$
$+ W_9 * H_9 + W_{10} * H_{10} + W_{11} * H_{11} + W_{12} * H_{12}$

where W_1 through W_{12} are weights that NHTSA will select values for at a later date, H_1 is the Maximum Attainable Lateral Acceleration at Nominal Load sub-score, H_2 is the Dropped Throttle Yaw Rate Ratio at Nominal Load sub-score, H_3 is the Dropped Throttle Path Deviation at Nominal Load sub-score, H_4 is the Yaw Rate Response Time at Nominal Load sub-score, H_5 is the Peak Yaw Rate Response Time at Nominal Load sub-score, and H_6 is the Percent Overshoot at Nominal Load sub-score, H_7 is the Maximum Attainable Lateral Acceleration at Rear Load sub-score, H_8 is the Dropped Throttle Taw Rate Ratio at Rear Load sub-score, H_9 is the Dropped Throttle Path Deviation at Rear Load sub-score, H_{10} is the Yaw Rate Response Time at Rear Load sub-score, H_{11} is the Peak Yaw Rate Response Time at Rear Load sub-score, and H_{12} is the Percent Overshoot at Rear Load sub-score.

2. Calculate the Maximum Attainable Lateral Acceleration at Nominal Load sub-score, H_1, from the formulas:

If $a_{YMaxN} < a_{YMinN}$ then $H_1 = 0$
If $a_{YMaxN} > (a_{YMinN} + a_{YRangeN})$ then $H_1 = 1$

Otherwise

$a_{BarN} = (a_{YMaxN} - a_{YMinN}) / a_{YRangeN}$
$H_1 = a_{BarN} * (2 — a_{BarN})$

where a_{YMaxN} is the measured Maximum Attainable Lateral Acceleration at Nominal Load, and a_{YMinN} and $a_{YRangeN}$ are constants that NHTSA will select values for at a later date.

3. Calculate the Dropped Throttle Yaw Rate Ratio at Nominal Load sub-score, H_2, from the formula:

If $R_{MaxN} > R_{RangeN}$ then $H_2 = 0$

Otherwise

$H_2 = 1 - ((R_{MaxN} — 1) / R_{RangeN})^2$

where R_{MaxN} is the measured Dropped Throttle Yaw Rate Ratio at Nominal Load, and R_{RangeN} is a constant that NHTSA will select a value for at a later date. Note that R_{MaxN} can never be less than one.

4. Calculate the Dropped Throttle Path Deviation at Nominal Load sub-score, H_3, from the formula:

If $Y_{DevN} < Y_{MinN}$ then $H_3 = 0$
If Y_{DevN} Y_{MinN} and $Y_{DevN} < 0$ then
$H_3 = 1 — (Y_{DevN}/Y_{MinN})^2$
If Y_{DevN} 0 and $Y_{DevN} < Y_{OkN}$ then $H_3 = 1$
If Y_{DevN} Y_{OkN} and $Y_{DevN} < Y_{MaxN}$ then
$Y_{BarN} = (Y_{DevN} — Y_{OkN})/(Y_{MaxN} — Y_{OkN})$
$H_3 = Y_{BarN} * (2 — Y_{BarN})$
If $Y_{DevN} > Y_{MaxN}$ then $H_3 = 0$

where Y_{DevN} is the measured Dropped Throttle Path Deviation at Nominal Load, and Y_{MaxN}, Y_{MinN}, and Y_{OkN} are constants that NHTSA will select values for at a later date.

5. Calculate the Yaw Rate Response Time at Nominal Load sub-score, H4, from the formula:

If $t_{rN} < t_{rMinN}$ then $H_4 = 1$
If $t_{rN} > (t_{rMinN} + t_{rRangeN})$ then $H_4 = 0$

Otherwise

$H_4 = ((t_{rMinN} + t_{rRangeN}) - t_{rN}) / t_{rRangeN}$

where t_{rN} is the measured Yaw Rate Response Time at Nominal Load, and t_{rMinN} and $t_{rRangeN}$ are constants that NHTSA will select values for at a later date.

6. Calculate the Peak Yaw Rate Response Time at Nominal Load sub-score, H_5, from the formula:

If $t_{pN} < t_{pMinN}$ then $H_5 = 1$
If $t_{pN} > (t_{pMinN} + t_{pRangeN})$ then $H_5 = 0$

Otherwise

$H_5 = ((t_{pMinN} + t_{pRangeN}) - t_{pN}) / t_{pRangeN}$

where t_{pN} is the measured Yaw Rate Response Time at Nominal Load, and t_{pMinN} and $t_{pRangeN}$ are constants that NHTSA will select values for at a later date.

7. Calculate the Percent Overshoot at Nominal Load sub-score, H_6, from the formula:

If $O_{r\%N} < 0$ then $H_6 = 1$

Otherwise

$H_6 = 1 - (O_{r\%N} / O_{rRangeN})^2$

where $O_{r\%N}$ is the measured Percent Overshoot at Nominal Load, and $O_{rRangeN}$ is a constant that NHTSA will select a value for at a later date. Note that $O_{r\%N}$ can never be less than zero.

8. Calculate the Maximum Attainable Lateral Acceleration at Rear Load sub-score, H_7, from the formulas:

If $a_{YMaxR} < a_{YMinR}$ then $H_7 = 0$
If $a_{YMaxR} > (a_{YMinR} + a_{YRangeR})$ then $H_7 = 1$

Otherwise

$a_{BarR} = (a_{YMaxR} - a_{YMinR}) / a_{YRangeR}$
$H_7 = a_{BarR} * (2 - a_{BarR})$

where a_{YMaxR} is the measured Maximum Attainable Lateral Acceleration at Rear Load, and a_{YMinR} and $a_{YRangeR}$ are constants that NHTSA will select values for at a later date.

9. Calculate the Dropped Throttle Yaw Rate Ratio at Rear Load sub-score, H_8, from the formula:

If $R_{MaxR} > R_{RangeN}$ then $H_8 = 0$

Otherwise

$H_8 = 1 - ((R_{MaxR} - 1) / R_{RangeR})^2$

where R_{MaxR} is the measured Dropped Throttle Yaw Rate Ratio at Rear Load, and R_{RangeR} is a constant that NHTSA will select a value for at a later date. Note that R_{MaxR} can never be less than one.

10. Calculate the Dropped Throttle Path Deviation at Rear Load sub-score, H_9, from the formula:

If $Y_{DevR} < Y_{MinR}$ then $H_9 = 0$
If Y_{DevR} Y_{MinR} and $Y_{DevR} < 0$ then
$H_9 = 1 - (Y_{DevR}/Y_{MinR})^2$
If Y_{DevR} 0 and $Y_{DevR} < Y_{OkR}$ then $H_9 = 1$
If Y_{DevR} Y_{OkR} and $Y_{DevR} < Y_{MaxR}$ then
$Y_{BarR} = (Y_{DevR} - Y_{OkR})/(Y_{MaxR} -$

Y_{OkR})

$H_9 = Y_{BarR} * (2 - Y_{BarR})$

If $Y_{DevR} > Y_{MaxR}$ then $H_9 = 0$

where Y_{DevR} is the measured Dropped Throttle Path Deviation at Nominal Load, and Y_{MaxR}, Y_{MinR}, and Y_{OkR} are constants that NHTSA will select values for at a later date.

11. Calculate the Yaw Rate Response Time at Rear Load sub-score, H_{10}, from the formula:

If $t_{rR} < t_{rMinR}$ then $H_{10} = 1$

If $t_{rR} > (t_{rMinR} + t_{rRangeR})$ then $H_{10} = 0$

Otherwise

$H_{10} = ((t_{rMinR} + t_{rRangeR}) - t_{rR})/t_{rRangeR}$

where t_{rR} is the measured Yaw Rate Response Time at Rear Load, and t_{rMinR} and $t_{rRangeR}$ are constants that NHTSA will select values for at a later date.

12. Calculate the Peak Yaw Rate Response Time at Rear Load sub-score, H_{11}, from the formula:

If $t_{pR} < t_{pMinR}$ then $H_{11} = 1$

If $t_{pR} > (t_{pMinR} + t_{pRangeR})$ then $H_{11} = 0$

Otherwise

$H_{11} = ((t_{pMinR} + t_{pRangeR}) - t_{pR})/t_{pRangeR}$

where t_{pR} is the measured Yaw Rate Response Time at Rear Load, and t_{pMinR} and $t_{pRangeR}$ are constants that NHTSA will select values for at a later date.

13. Calculate the Percent Overshoot at Rear Load sub-score, H_{12}, from the formula:

If $O_{r\%R} < 0$ then $H_{12} = 1$

Otherwise

$H_{12} = 1 - (O_{r\%R}/O_{rRangeR})^2$

where $O_{r\%R}$ is the measured Percent Overshoot at Rear Load, and $O_{rRangeR}$ is a constant that NHTSA will select a value for at a later date. Note that $O_{r\%R}$ can never be less than zero.

14. Calculate the provisional Handling Rating from the Handling Score, HS, as follows:

If $HS > HS_A$ then the provisional Handling Rating is an A

If $HS < HS_C$ then the provisional Handling Rating is a C

Otherwise the provisional Handling Rating is a B

where HS_A and HS_C are constants that NHTSA will select values for at a later date.

15. If the vehicle spins when determining the Maximum Attainable Lateral Acceleration at Nominal Load, then reduce the provisional Handling Rating by one letter (but never below a C).

16. If the vehicle spins when determining the Maximum Attainable Lateral Acceleration at Rear Load, then reduce the provisional Handling Rating by one letter (but never below a C).

17. The provisional Handling Rating now becomes the final Handling Rating.

We welcome comments as to the appropriateness of the above technique for determining handling ratings. How can it be improved? One possibility would be to have two handling ratings, one for Nominal Load and one for Rear Load. Would this be better? Or should we consider the ratings for the different loadings to be an additional level of detail available to interested persons who want more than just the one rating?

X. Assessment of Costs and Benefits

The costs are Federal Government costs for developing the test protocol and rating system, conducting the tests, and disseminating the information. The benefits are information to consumers. Consumers want additional information. It is impossible for us to quantify the effect on consumer behavior or on manufacturer behavior.

XI. Rulemaking Analyses and Notices

A. Executive Order 12866

Executive Order 12866, ''Regulatory Planning and Review'' (58 FR 51735, October 4, 1993), provides for making determinations whether a regulatory action is ''significant'' and therefore subject to Office of Management and Budget (OMB) review and to the requirements of the Executive Order. The Order defines a ''significant regulatory action'' as one that is likely to result in a rule that may:

(1) Have an annual effect on the economy of $100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local, or Tribal governments or communities;

(2) Create a serious inconsistency or otherwise interfere with an action taken or planned by another agency;

(3) Materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights and obligations of recipients thereof; or

(4) Raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in the Executive Order.

NHTSA has considered the impact of this action under Executive Order 12866 and the Department of Transportation's regulatory policies and procedures. This action has been determined to be economically not significant. However, because it is a subject of Congressional interest, this rulemaking document was reviewed by the Office of Management and Budget under Executive Order 12866, ''Regulatory Planning and Review.''

B. Regulatory Flexibility Act

The Regulatory Flexibility Act of 1980 (5 U.S.C. § 601 *et seq.*) requires agencies to evaluate the potential effects of their proposed and final rules on small business, small organizations and small governmental jurisdictions. I hereby certify that the proposed amendment would not have a significant economic impact on a substantial number of small entities. The proposed action does not impose regulatory requirements on any manufacturer or other party.

C. National Environmental Policy Act

NHTSA has analyzed this proposal for the purposes of the National Environmental Policy Act. The agency has determined that implementation of this action would not have any significant impact on the quality of the human environment.

D. Executive Order 13132 (Federalism)

The agency has analyzed this rulemaking in accordance with the principles and criteria contained in Executive Order 13132 and has determined that it does not have sufficient federal implications to warrant consultation with State and local officials or the preparation of a federalism summary impact statement. The proposal would not have any substantial impact on the States, or on the current Federal-State relationship, or on the current distribution of power and responsibilities among the various local officials.

E. Unfunded Mandates Act

The Unfunded Mandates Reform Act of 1995 requires agencies to prepare a written assessment of the costs, benefits and other effects of proposed or final rules that include a Federal mandate likely to result in the expenditure by State, local or tribal governments, in the aggregate, or by the private sector, of more than $100 million annually (adjusted annually for inflation with base year of 1995). Adjusting this amount by the implicit gross domestic product price deflator for the year 2000 results in $109 million (106.99/98.11 = 1.09). The assessment may be included in conjunction with other assessments, as it is here.

The proposed action does not impose regulatory requirements on any manufacturer or other party.

F. Civil Justice Reform

This proposal would not have any retroactive effect. Under 49 U.S.C. 21403, whenever a Federal motor vehicle safety standard is in effect, a State may not adopt or maintain a safety standard applicable to the same aspect of performance which is not identical to the Federal standard, except to the extent that the state requirement imposes a higher level of performance and applies only to vehicles procured for the State's use. 49 U.S.C. 21461 sets forth a procedure for judicial review of final rules establishing, amending or revoking Federal motor vehicle safety standards. That section does not require submission of a petition for reconsideration or other administrative proceedings before parties may file suit in court.

G. Paperwork Reduction Act

This proposal does not contain ''collections of information,'' as that term is defined in 5 CFR Part 1320 Controlling Paperwork Burdens on the Public.

H. Plain Language

Executive Order 12866 and the President's memorandum of June 1, 1998, require each agency to write all rules in plain language. This action will not result in regulatory language.

XII. Submission of Comments

How Can I Influence NHTSA's Thinking on This Proposed Rule?

In developing this proposal, we tried to address the concerns of all our stakeholders. Your comments will help us improve this rule. We invite you to provide views on options we propose, to suggest new approaches we have not considered, provide new data, indicate how this proposed rule may affect you, or provide other relevant information. We welcome your views on all aspects of this proposed rule, but request comments on specific issues throughout this document. We grouped these specific requests near the end of the sections in which we discuss the relevant issues. Your comments will be most effective if you follow the suggestions below:

- Explain your views and reasoning as clearly as possible.
- Provide solid technical and cost data to support your views.
- If you estimate potential costs, explain how you arrived at the estimate.
- Tell us which parts of the proposal you support, as well as those with which you disagree.
- Provide specific examples to illustrate your concerns.
- Offer specific alternatives.
- Refer your comments to specific sections of the proposal, such as the units or page numbers of the preamble, or the regulatory sections.
- Be sure to include the name, date, and docket number with your comments.

How Do I Prepare and Submit Comments?

Your comments must be written and in English. To ensure that your comments are correctly filed in the Docket, please include the docket number of this document in your comments.

Your comments must not be more than 15 pages long. (49 CFR 553.21). We established this limit to encourage you to write your primary comments in a concise fashion. However, you may attach necessary additional documents to your comments. There is no limit on the length of the attachments.

Please submit two copies of your comments, including the attachments, to Docket Management at the address given above under ADDRESSES.

Comments may also be submitted to the docket electronically by logging onto the Dockets Management System Web site at *http://dms.dot.gov.* Click on ''Help & Information'' or ''Help/Info'' to obtain instructions for filing the document electronically.

How Can I Be Sure That My Comments Were Received?

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If you wish to submit any information under a claim of confidentiality, you should submit three copies of your complete submission, including the information you claim to be confidential business information, to the Chief Counsel, NHTSA, 400 Seventh Street, SW., Washington, DC 20590. In addition, you should submit two copies, from which you have deleted the claimed confidential business information, to Docket Management at the address given above under ADDRESSES. When you send a comment containing information claimed to be confidential business information, you should include a cover letter setting forth the information specified in our confidential business information regulation. (49 CFR part 512.)

Will the Agency Consider Late Comments?

We will consider all comments that Docket Management receives before the close of business on the comment closing date indicated above under DATES. To the extent possible, we will also consider comments that Docket Management receives after that date. If Docket Management receives a comment too late for us to consider it in developing a final rule (assuming that one is issued), we will consider that comment as an informal suggestion for future rulemaking action.

How Can I Read the Comments Submitted by Other People?

You may read the comments received by Docket Management at the address given above under ADDRESSES. The hours of the Docket are indicated above in the same location.

You may also see the comments on the Internet. To read the comments on the Internet, take the following steps:

(1) Go to the Docket Management System (DMS) Web page of the Department of Transportation (*http://dms.dot.gov/*).

(2) On that page, click on ''search.''

(3) On the next page (*http://dms.dot.gov/search/*), type in the four-digit docket number shown at the beginning of this document. Example: If the docket number were ''NHTSA–1998–1234,'' you would type ''1234.'' After typing the docket number, click on ''search.''

(4) On the next page, which contains docket summary information for the docket you selected, click on the desired comments. You may download the comments. However, since the comments are imaged documents, instead of word processing documents, the downloaded comments are not word searchable.

Please note that even after the comment closing date, we will continue to file relevant information in the Docket as it becomes available. Further, some people may submit late comments. Accordingly, we recommend that you periodically check the Docket for new material.

Issued on: September 27, 2002.

Stephen R. Kratzke,

Associate Administrator for Safety Performance Standards.

BILLING CODE 4910–59–P

Figure 1. Rollover Risk from Two Logistic Models, with and without Hypothetical Dynamic Maneuver Test Results

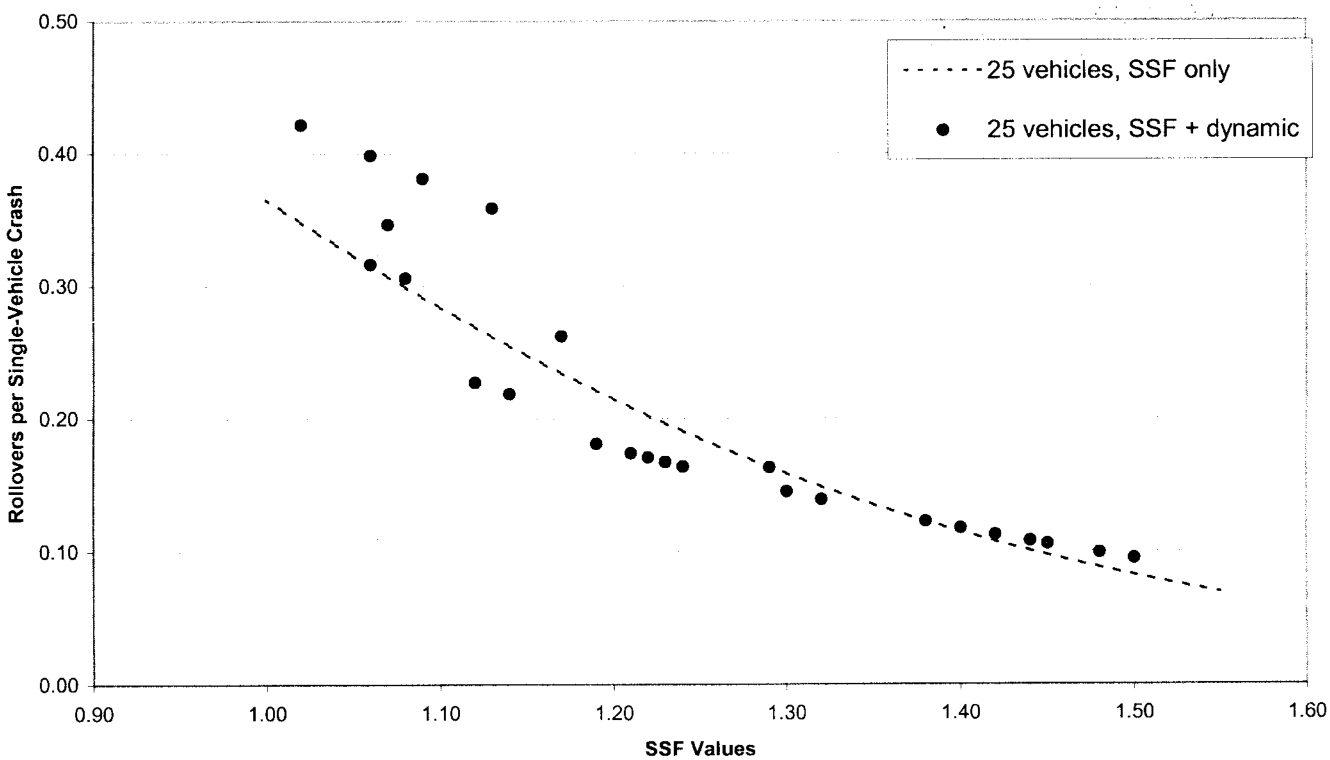


Figure 2a. Graphics presented to focus groups – 4 out of 5 stars, without key

Figure 2b. Graphics presented to focus groups – 4 out of 5 stars, with key

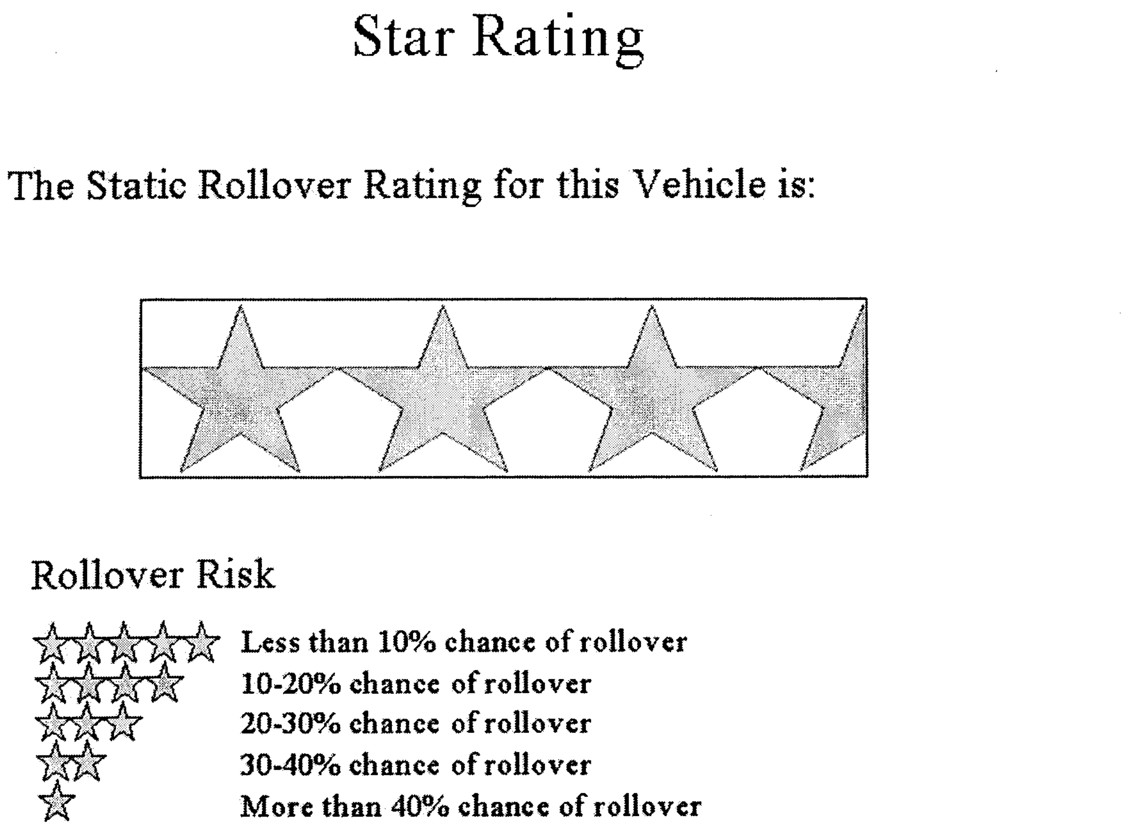


Figure 2c. Graphics presented to focus groups – 5 star system with half stars used

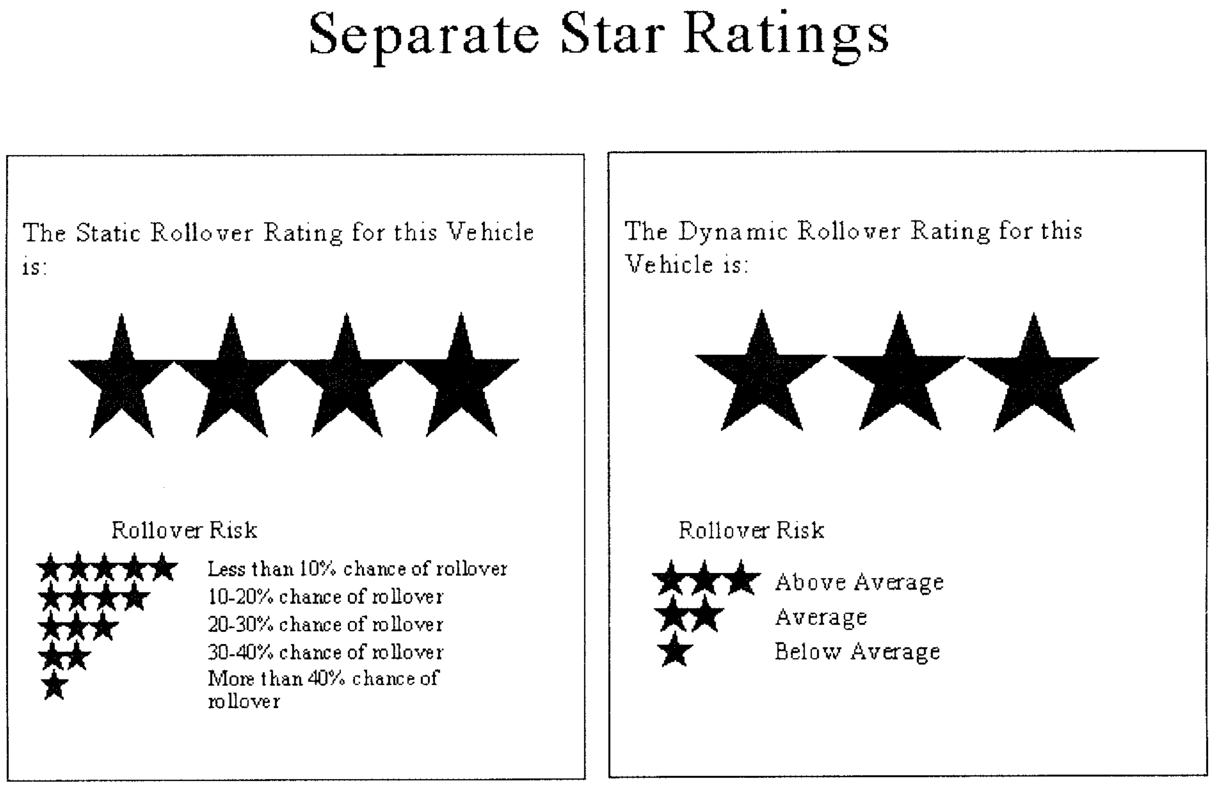


Figure 2d. Graphics presented to focus groups – separate presentation of static and dynamic ratings

Number Rating

The Static Rollover Rating for this Vehicle is:

4

Rollover Risk

1 Less than 10% chance of rollover
2 10-20% chance of rollover
3 20-30% chance of rollover
4 30-40% chance of rollover
5 More than 40% chance of rollover

Figure 2e. Graphics presented to focus groups – 5 level system expressed with numbers rather than stars

Number Rating

The Static Rollover Rating for this Vehicle is:

7

Rollover Risk

1 Less than 10% chance of rollover
2 11-14 % chance of rollover
3 15-18% chance of rollover
4 19-22% chance of rollover
5 23-26% chance of rollover
6 27-30% chance of rollover
7 31-34% chance of rollover
8 35-38% chance of rollover
9 39-42% chance of rollover
10 More than 42% chance of rollover

Figure 2f. Graphics presented to focus groups – 10 level system expressed with numbers rather than half-stars

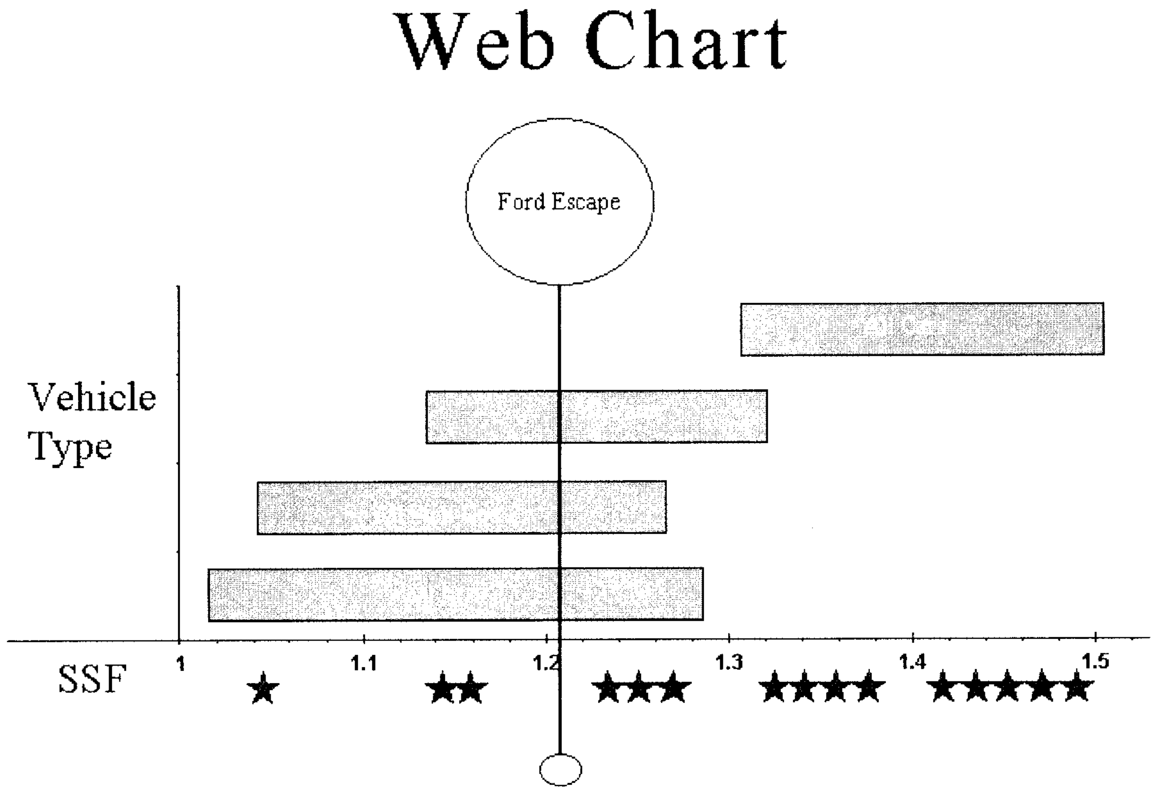


Figure 2g. Graphics presented to focus groups – rating of the vehicle of interest shown graphically in context of all other rated vehicles

Emergency Handling Letter Rating

The Vehicle Control Rating for this Vehicle is:

B

Key

A Above Average

B Average

C Below Average

Figure 2h. Graphics presented to focus groups – 3 level system expressed with letters

Emergency Handling Narrative Rating

The Vehicle Control Rating for this Vehicle is:

Average

Key

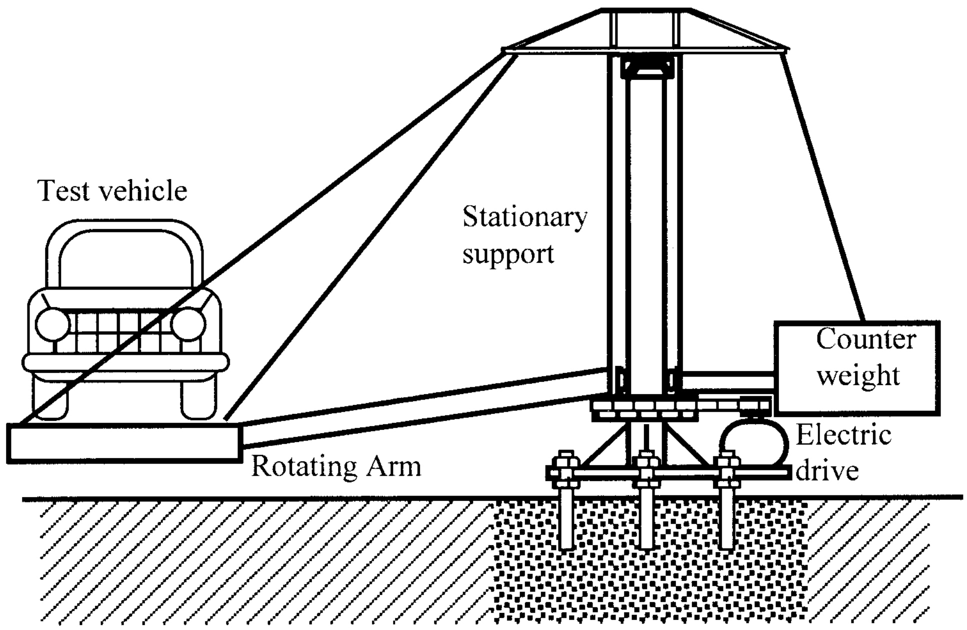
Below Average

Average

Above Average

Figure 2i. Graphics presented to focus groups – 3 level system expressed with words

Figure 3. Centrifuge Test



BILLING CODE 4910–59–C

Appendix I.—Summary of Maneuver Evaluation Test Results

Prior to the initiation of this research, NHTSA met with the Alliance of Automobile Manufacturers, Daimler-Chrysler, BMW, Volkswagen, Mitsubishi, Ford, Nissan, Toyota, Consumers Union of the United States, MTS Systems Corporation, Heitz Automotive Inc., and other interested parties to gather information on possible approaches for dynamic rollover tests. NHTSA also corresponded with the University of Michigan Transportation Research Institute. These parties made specific suggestions about approaches to dynamic testing of vehicle rollover resistance. Based on these suggestions plus NHTSA's experience in this area, a set of nine rollover resistance maneuvers were selected for evaluation. These nine maneuvers were listed in the July 2001 notice.

The research to evaluate potential maneuver tests for rollover is fully documented in the NHTSA technical report ''Another Experimental Examination of Selected Maneuvers That May Induce On-Road Untripped, Light Vehicle Rollover—Phase IV of NHTSA's Light Vehicle Rollover Research Program''. A number of test results and principal observations about the maneuvers are discussed here under the following four general headings:

1. Objectivity and Repeatability, *i.e.*, whether a maneuver could be performed objectively with repeatable results for the same vehicle.

2. Discriminatory Capability, *i.e.*, whether a maneuver demonstrated poorer performance for vehicles that have less resistance to rollover. Although of obvious importance, a maneuver's ability to discriminate between different levels of vehicle handling was not considered.

3. Performability *i.e.*, how difficult each maneuver is to objectively perform while obtaining repeatable results, how well developed are the test procedures for each maneuver, and whether the test procedure includes adequate means for adapting to differing vehicle characteristics.

4. Realistic Appearance, *i.e.*, whether a test maneuver looks like a maneuver consumers might imagine performing in an emergency.

The headings are useful for organizing the information, but they are not mutually exclusive. For example, the discussion of whether the performance of a vehicle in a particular maneuver is influenced more by handling properties than by rollover resistance would be under the heading of Discriminatory Capability. But the repeatability of the performance measurement discussed under Objectivity and Repeatability also influences the discriminatory capability of the maneuver. Similarly, Performability is a catch-all category that includes discussions of topics outside of the more specific headings.

Realistic Appearance helps consumers visualize the test maneuvers, but it is less important than the other three categories of test attributes because we are interested in anything that the vehicle is capable of doing. What we desire are ''worst case'' maneuvers, not necessarily ones that drivers try to perform. For example, drivers would not try to drive in a fishhook pattern, but the steering movements are similar to what occurs in an unsuccessful road edge recovery attempt. The maneuver only looks like a fishhook path if the vehicle does not tip-up. If the vehicle tips-up, it occurs shortly after the counter-steer when a driver in a road edge recovery attempt would still be on the pavement.

The specific reasons for the choice of maneuvers we are proposing for rollover resistance ratings are discussed in Section VI. The reasons are a consequence of the observations made in this section plus other practical considerations such as the desirability of multiple maneuvers to create a range of test severity were taken into account.

Four sport utility vehicles were tested during the summer of 2001 to obtain the data needed to perform this maneuver evaluation (the Phase IV Rollover Research). Two of the vehicles tested during the Phase IV research (the 1999 Mercedes ML320 and the 2001 Toyota 4Runner) came with yaw stability control systems as original equipment. Both of these vehicles were treated, for the purposes of maneuver evaluation, as two vehicles, one with yaw stability control and one without.

Therefore, the six test vehicles were:

1. 2001 Chevrolet Blazer without yaw stability control
2. 2001 Ford Escape without yaw stability control.

Note: The Automotive News Truck Market classifications classify this vehicle as a Sport Wagon instead of a Sport Utility Vehicle.

3. 1999 Mercedes ML320 with yaw stability control disabled
4. 1999 Mercedes ML320 with yaw stability control enabled
5. 2001 Toyota 4Runner with yaw stability control disabled
6. 2001 Toyota 4Runner with yaw stability control enabled

Each of the above test vehicles was tested in three configurations. Only two of these configurations will be discussed in this notice; test data from the Modified Handling configuration were not used for the maneuver evaluations discussed in this notice. The test configurations of interest were:

Nominal Vehicle. The vehicle load consisted of one occupant (the driver), instrumentation, and outriggers in/on the vehicle.

Reduced Rollover Resistance Vehicle. In addition to the Nominal Vehicle load, sufficient weight was placed on the roof to reduce the vehicle's SSF by 0.05. The weight on the roof was positioned so that the longitudinal/lateral position of the center of gravity did not change.

The Reduced Rollover Resistance Vehicle was used as a check on the sensitivity of the test maneuvers. A 0.05 reduction in SSF equates, for sport utility vehicles, to approximately a one star reduction in the vehicle's rollover resistance rating. (A larger reduction in SSF is necessary to achieve a one star rating reduction for vehicles, such as passenger cars, that have higher SSFs.) NHTSA believes that a one star reduction in the rollover resistance rating should make a vehicle substantially easier to rollover. Maneuvers with good discriminatory capability should measure substantially worse performance for this vehicle configuration than for the Nominal Vehicle configuration.

Data collected during the Phase IV Rollover Research was used to evaluate eight of the rollover resistance maneuvers (all except the J-Turn with Pulse Braking). For each of these eight maneuvers, vehicles were tested in the Nominal Vehicle configuration. For maneuvers which we deemed appropriate, testing was also performed using the Reduced Rollover Resistance configuration. For the J-Turn with Pulse Braking, we decided that we had sufficient data from prior testing (Phases II and III of the Rollover Research program) to evaluate this maneuver.

The results of the evaluation for each rollover resistance maneuver follows. For each maneuver, a brief description of the maneuver is given followed by its scores in each of the four evaluation factors. Each evaluation factor score is followed by a discussion as to how that particular score was decided upon.

A. NHTSA J-Turn

Maneuver Description

To perform this maneuver, the programmable steering controller input the handwheel commands described by Figure 1.

The NHTSA J-Turn handwheel angle is eight times the handwheel angle that produces a quasi-static 0.3 g lateral acceleration at 50 mph for each particular test vehicle. The handwheel rate of the handwheel ramp was 1000 degrees per second.

J-Turn tests were performed with two directions of steer, to the left and to the right. Vehicle speed was increased in 5 mph increments from 35 to 60 mph, unless at least two inches of simultaneous two-wheel lift was observed. If such wheel lift was detected, entrance speeds were iteratively reduced by 1 mph until it was no longer apparent.

Objectivity and Repeatability

The NHTSA J-Turn is the most objective and repeatable of all of the rollover resistance maneuvers. Figure 2 shows the Handwheel Angle, Vehicle Speed, Lateral Acceleration, and Roll Angle as functions of time for three tests of the Toyota 4Runner with yaw stability control enabled that were run at approximately the same speed (59.4, 58.1, and 58.6 mph). The Handwheel Angle graph shows that, by using the programmable steering controller, the steering control input can be precisely replicated from run-to-run (there are three traces in this graph). Test drivers can repeatably achieve input speeds within ±2 mph of the target speed. The vehicle speed, lateral acceleration and roll angle traces clearly show the very high repeatability of this maneuver.

Data from these runs is typical of our experience with the maneuver, with one exception. For runs that are either result in two-wheel lift or are very near to the point at which it first occurs, the roll angle repeatability becomes much worse. This is the case for all rollover resistance maneuvers that induce tip up because the vehicle either falls over or it does not. As a result, small fluctuations in test performance can lead to large changes in roll angle in this situation. This results in a variability of approximately ±2 mph in determining the lowest speed at which two-wheel lift occurs. As such, roll angle variability at the tip-up threshold did not lower the Objectivity and Repeatability rating for this maneuver.

Performability

The NHTSA J-Turn is the easiest of all of the rollover resistance maneuvers to perform. Objective and repeatable NHTSA J-Turn maneuvers can easily be performed using a programmable steering controller. Having only one major steering movement maximizes maneuver repeatability. The test procedure is well developed. Procedures have been developed to adapt the NHTSA J-Turn maneuver to the characteristics of the vehicle being tested.

Discriminatory Capability

None of the vehicles tested had two-wheel lift during NHTSA J-Turn tests in their Nominal Vehicle configuration. However, all of the vehicles except the Ford Escape and the Toyota 4Runner with its yaw stability control enabled did have two-wheel lift when tested in their Reduced Rollover Resistance configuration. The NHTSA J-Turn is not a severe enough maneuver to discriminate between typical, current generation, sport utility vehicles loaded with a driver and passenger only. However, it was very sensitive to the decrease in rollover resistance attributable to a decrease in SSF of 0.05. Also the speed at tip-up could discriminate between our individual test vehicles when the entire group was loaded to produce a decrease in SSF of 0.05. We used a roof load of about 200 lb to reduce the SSF by 0.05, but the addition of 5 to 6 passengers causes a similar reduction in SSF for typical current generation SUVs, vans and pickup trucks.

Realistic Appearance

Drivers perform NHTSA J-Turns during actual driving on cloverleaf entrance/exit ramps and other, essentially constant radius, curves that are driven at substantial speeds. This maneuver is not given an excellent rating in this category, however, because for light vehicles, actual drivers are very unlikely to use the large steering magnitudes needed to induce two-wheel lift without also applying sustained braking.

During NHTSA's discussions with the automotive industry, every manufacturer stated that they routinely perform J-Turn testing during vehicle development. This maneuver has a long history of industry use.

B. J-Turn With Pulse Braking

Maneuver Description

To perform this maneuver, the programmable steering and braking controller input the handwheel steering and braking commands as shown in Figure 3. Figure 3 also shows a typical vehicle roll rate response resulting from the steering input so as to explain the timing of the brake pulse. Pulse braking was initiated at the first zero crossing (determined by the roll rate being between +1.5 degrees per second and −1.5 degrees per second) of the roll rate after the initiation of steering (*i.e.*, at the time when the maximum roll angle occurs).

The handwheel magnitudes used for the J-Turn with Pulse Braking maneuver were always 330 degrees. The handwheel rate of the handwheel ramp was 1000 degrees per second.

The maximum brake pedal force used for the J-Turn with Pulse Braking maneuver was 200 pounds. The brake pulse durations ranged from 0.25 to 0.55 seconds.

J-Turn with Pulse Braking tests were performed with two directions of steer, to the left and to the right. Vehicle speed was increased in 2 mph increments from 36 to 60 mph, unless simultaneous two-wheel lift was observed.

Objectivity and Repeatability

The J-Turn with Pulse Braking is not as objective and repeatable as the J-Turn due to the pulse braking. Research has shown that the results of this test depend upon the precise timing and magnitude of the brake pulse. Therefore, to perform this maneuver with reasonable objectivity and repeatability, both tightly controlled steering and braking are required. The programmable steering controller needed for the J-Turn has now become a programmable steering and braking controller with a corresponding increase in testing complexity, difficulty, and cost.

Figure 4 shows the Handwheel Angle, Brake Pedal Force, Lateral Acceleration, Longitudinal Acceleration, Roll Angle, and Vehicle Speed, as functions of time for two tests of a 1998 Chevrolet Tracker (this vehicle did not have either antilock brakes or yaw stability control) that were run at approximately the same speed (31.1 and 31.3 mph). Unlike the rest of the data presented in this section, the J-Turn with Pulse Braking data was collected during the summer of 2000 as part of the Phase III–B Rollover research.

Like the NHTSA J-Turn, due to the use of the programmable steering controller, the steering control input was precisely replicated from run-to-run. The apparent non-repeatability in the steering input (and lateral acceleration and roll angle) is actually after the test is over and the driver has retaken control of the vehicle.

Similarly, the Brake Pedal Force graph shows that, by using the programmable braking controller, the braking control input can be precisely replicated from run-to-run. The precisely overlaid lateral acceleration, longitudinal acceleration, roll angle, and vehicle speed traces clearly show the very high repeatability achieved for these two runs.

We caution, however, that data from these two runs is not typical of our experience with maneuver. In general, we saw somewhat more variability in the brake pedal force than is shown in Figure 4. Also, as was discussed above for the NHTSA J-Turn, for runs that are near the point at which two-wheel lift first occurs, roll angle repeatability becomes much worse.

Performability

The addition of pulse braking substantially reduces the performability of this maneuver relative to the NHTSA J-Turn. The addition of a programmable braking controller, which is necessary to achieve the precise pulse brake timing required for repeatable performance, makes this test significantly harder and more costly to run. Issues remain as to the brake pulse timing needed to achieve worst case rollover performance.

Through the use of roll rate feedback, the timing of the brake pulse can be adapted to the characteristics of the vehicle being tested. The magnitude of the steering input can also be adapted from vehicle-to-vehicle (although this was not done during the Phase III research).

Discriminatory Capability

The J-Turn with Pulse Braking is a very bad maneuver for measuring the rollover resistance of different vehicles. For vehicles equipped with antilock braking systems (ABS), it does not appear to give any additional information beyond that obtained from the NHTSA J-Turn maneuver (unless the ABS is disabled; not a realistic situation). For vehicles without ABS, it can be a very severe test vehicle provided the timing of the brake pulse is just right. If this test were used for NCAP, it would discriminate more on the basis of ABS equipment than rollover resistance.

Realistic Appearance

Drivers could perform J-Turns with Pulse Braking during actual driving on cloverleaf entrance/exit ramps and other, essentially constant radius, curves that are driven at substantial speeds. However, we think that the occurrence of this maneuver is unlikely. With the large steering magnitudes needed to induce two-wheel lift, we believe it to be far more probable that drivers will apply sustained braking (which discourages rather than encourages two-wheel lift) instead of pulse braking.

C. Fixed Timing Fishhook

Maneuver Description

To perform this maneuver, the programmable steering controller input the handwheel commands described by Figure 5.

Fixed Timing Fishhook handwheel angle is 6.5 times the handwheel angle that produces a quasi-static 0.3 g lateral acceleration at 50 mph for each particular test vehicle. The commanded dwell (amount of time after the first steer for which handwheel position was maintained) for the Fixed Timing Fishhook was 0.25 seconds. The handwheel rates of the initial steer and countersteer ramps were 720 degrees per second.

Fixed Timing Fishhook tests were performed with both initial directions of steer, to the left and to the right. Vehicle speed was increased in 5 mph increments from 35 to 50 mph, unless at least two inches of simultaneous two-wheel lift was observed. If such wheel lift was detected, entrance speeds were iteratively reduced by 1 mph until it was no longer apparent.

Objectivity and Repeatability

The Fixed Timing Fishhook can be performed with excellent objectivity and repeatability. Figure 6 shows the Handwheel Angle, Vehicle Speed, Lateral Acceleration, and Roll Angle as functions of time for three tests of the Chevrolet Blazer that were run at approximately the same speed (37.8, 37.8, and 37.3 mph). Data from these runs is typical of our experience with this maneuver.

The vehicle speed and lateral acceleration traces clearly show the very high repeatability of this maneuver. The roll angle traces show the non-repeatability in roll angle that occurs around the point of two wheel lift. All three of these runs had two wheel lift approximately three seconds into the test. The amount of two-wheel lift was substantially less for one run than for the other two. Near the initiation of two-wheel lift, the roll angle becomes mathematically unstable because the vehicle either falls over or it does not. As was discussed above for the NHTSA J-Turn, this roll angle non-repeatability occurs for all maneuvers that generate two-wheel lift.

Performability

Objective and repeatable Fixed Timing Fishhook maneuvers can easily be performed using a programmable steering controller. The test procedure is well developed. Procedures have been developed to adapt the steering magnitude used for the Fixed Timing Fishhook maneuver for the characteristics of the vehicle being tested.

Discriminatory Capability

The Fixed Timing Fishhook is excellent maneuver for measuring the rollover resistance of different vehicles. The Chevrolet Blazer and the Mercedes ML320 (with the stability control both enabled and disabled) had two-wheel lift when tested in their Nominal Vehicle configuration. All vehicles (with the stability control, if present, both enabled and disabled) had two-wheel lift when tested in their Reduced Rollover Resistance configuration. (The Mercedes ML320 was not tested in its Reduced Rollover Resistance configuration. However, we are certain that it would have had two-wheel lift in this configuration because it had two-wheel lift in its Nominal Vehicle configuration and raising its center of gravity height is going to encourage, not prevent, two-wheel lifts.) The maneuver initial speed (a severity measure for the Fixed Timing Fishhook) at which two-wheel lifts first occurred varied about as expected.

While the Fixed Timing Fishhook does an excellent job of discriminating between vehicles for typical, current generation, sport utility vehicles, it will not do as good a job for the entire vehicle fleet. It is doubtful that any two-wheel lifts will occur during testing of vehicles that have a Static Stability Factors of 1.2 or greater (*e.g.*, most vehicles that earn three or more stars under NHTSA's current rollover rating program). That said, no driving maneuver known to NHTSA is expected to cause two-wheel lifts for vehicles in the 1.20 SSF range. However, as the name of this maneuver implies, the timing of this maneuver does not change from vehicle-to-vehicle. This will result in some vehicles not being tested with the timing needed to achieve worst case rollover performance.

Realistic Appearance

The Fishhook maneuver's steering input, no matter whether it's the Fixed Timing, Roll Rate Feedback, or Nissan variant, approximates the steering that a driver might perform in an effort to resume traveling in the correct lane of a two lane road after dropping two-wheels off of the road. None of the Fishhooks simulate the effects of the road-edge drop-off.

D. Roll Rate Feedback Fishhook

Maneuver Description

This maneuver is performed similarly to the Fixed Timing Fishhook except for the timing of the steering reversal. Figure 7 shows the handwheel steering input, as a function of time, used for this maneuver. Note that the magnitude of the steering is identical to that of the Fixed Timing Fishhook. However, the steering dwell time (amount of time after the first steer for which handwheel position was maintained) is no longer kept at 0.25 seconds. Instead, this dwell time is varied so as to maximize the severity of the maneuver.

Figure 7 also shows a typical vehicle roll rate response resulting from the steering input so as to explain the timing of the steering reversal. The steering reversal was initiated at the first zero crossing (determined by the roll rate being between +1.5 degrees per second and −1.5 degrees per second) of the roll rate after the initiation of steering (*i.e.*, at the time when the maximum roll angle occurs).

Objectivity and Repeatability

The Roll Rate Feedback Fishhook can be performed with excellent objectivity and repeatability. 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, and it is obvious to the test driver when this delay causes the need to repeat the test run. Therefore, from a practical point of view, the objectivity and repeatability of this maneuver was not different from that of the Fixed Timing Fishhook.

Figure 8 shows the Handwheel Angle, Vehicle Speed, Lateral Acceleration, and Roll Angle as functions of time for three tests of the Toyota 4Runner with stability control disabled that were run at approximately the same speed (39.9, 40.3, and 39.5 mph). Data from these runs is typical of our experience with this maneuver.

The vehicle speed and lateral acceleration traces show the high repeatability of this maneuver. The roll angle traces show the non-repeatability in roll angle that occurs around the point of two wheel lift. As the traces show two of these runs had two wheel lift approximately three seconds into the test while one did not. Near the initiation of two-wheel lift, the roll angle becomes mathematically unstable because the vehicle either falls over or it does not. As was discussed above for the NHTSA J-Turn, this roll angle non-repeatability occurs for all maneuvers that generate two-wheel lift.

Performability

Objective and repeatable Roll Rate Feedback Fishhook maneuvers can easily be performed using a programmable steering controller equipped to handle roll rate feedback. The test procedure is well developed. Procedures have been developed to adapt both the steering magnitude and the steering reversal timing used for the Roll Rate Feedback Fishhook maneuver for the characteristics of the vehicle being tested.

Discriminatory Capability

The Roll Rate Feedback Fishhook is excellent maneuver for measuring the rollover resistance of different vehicles. The Chevrolet Blazer and the Mercedes ML320 (with the stability control both enabled and disabled) had two-wheel lift when tested in their Nominal Vehicle configuration. All vehicles (with the stability control, if present, both enabled and disabled) had two-wheel lift when tested in their Reduced Rollover Resistance configuration. (The Mercedes ML320 was not tested in its Reduced Rollover Resistance configuration. However, we are certain that it would have had two-wheel lift in this configuration because it had two-wheel lift in its Nominal Vehicle configuration and raising its center of gravity height is going to encourage, not prevent, two-wheel lifts.) The maneuver initial speed (a severity measure for the Roll Rate Feedback Fishhook) at which two-wheel lifts first occurred varied about as expected.

While the Roll Rate Feedback Fishhook does an excellent job of discriminating between vehicles for typical, current generation, sport utility vehicles, as explained above for the Fixed Timing Fishhook, it will not do as good a job for the entire vehicle fleet.

Realistic Appearance

See the Fixed Timing Fishhook maneuver Realistic Appearance discussion.

E. Nissan Fishhook

Maneuver Description

The Nissan Fishhook adds to the Fixed Timing Fishhook a procedure for adjusting the steering reversal timings to the vehicle being tested. This adjustment process has the same goal as the adjustment process used for the Roll Rate Feedback Fishhook, *i.e.*, to test each vehicle with the steering reversal timing required for the vehicle to have its worst case rollover performance. While the Roll Rate Feedback Fishhook maneuver accomplishes this by using roll rate feedback resulting in only one test run per initial maneuver speed, the Nissan Fishhook uses an iterative procedure to determine the timing.

First, a J-Turn is performed followed by a series of Fixed Timing Fishhooks (with different timings). Typically, two to four runs will be made for each initial maneuver speed. The procedure used to determine the final timing is too complex to give here but is fully described in the NHTSA technical report ''Another Experimental Examination of Selected Maneuvers That May Induce On-Road Untripped, Light Vehicle Rollover—Phase IV of NHTSA's Light Vehicle Rollover Research Program.'' However, the final dwell times (the length of the pause between completion of the first steer and the initiation of the countersteer, shown as time, T_1, in Figures 5 and 7) generated were close to those of the Roll Rate Feedback Fishhook.

Objectivity and Repeatability

The Nissan Fishhook was performed with good objectivity and repeatability. By using the programmable steering machine, handwheel inputs were precisely executed, and able to be replicated from run-to-run. Test drivers were able to achieve maneuver entrance speeds an average of ± 0.9 mph from the desired target speed.

Note that the Objectivity and Repeatability rating of the Nissan Fishhook maneuver was reduced from that assigned to the Fixed Timing Fishhook. This was due to roll rate zero-crossing variability observed in response to the step steer used in determining the timing of the maneuver. The Nissan Fishhook requires accurate determination of the third roll rate zero-crossing following input of the step steer. This is because zero crossing variability directly affects what dwell time duration will ultimately satisfy Nissan's requirements. If the third roll rate zero crossing is delayed (*e.g.*, due to an anomalous response produced during the step steer) an inappropriate dwell time extension will result.

Generally speaking the vehicle speed, lateral acceleration, and roll angle data observed during Nissan Fishhook tests were highly repeatable. However, as was discussed above for the NHTSA J-Turn, for runs that are near the point at which two-wheel lift first occurs, roll angle repeatability becomes much worse.

Performability

The Nissan Fishhook has a well worked out test procedure. It does not have a procedure to adapt the steering magnitude for the characteristics of the vehicle being tested although this could probably be added to the current test procedure without difficulty. The steering reversal timings used for the Nissan Fishhook maneuver are adjusted for the vehicle being tested.

The primary advantage of the Nissan Fishhook over the Roll Rate Feedback Fishhook is that by not using roll rate feedback you avoid the occasional need for repetitions caused by anomalies in the roll rate measurement and the extra expense of a programmable steering controller that can handle roll rate feedback.

The primary disadvantage of the Nissan Fishhook over the Roll Rate Feedback Fishhook is that the Nissan procedure requires three to four times as many test runs than does the Roll Rate Feedback Fishhook. As a result, greater tire wear occurs which has been shown to affect the results of Fishhook testing. It also increases testing time and costs.

The Nissan Fishhook, as proposed by Nissan, uses a very high steering wheel angle rate (1,080 degrees per second). Our programmable steering controller has some difficulty with such a high rate. Changing to the lower steering wheel angle rate (720 degrees per second) used for the Fixed Timing and Roll Rate Feedback Fishhooks would probably only minimally affect maneuver results. Reduction of the magnitude of the countersteer to the amount used for the Fixed Timing and Roll Rate Feedback Fishhooks should slightly increase maneuver severity. Our experience has been that the large countersteer used by the Nissan Fishhook slows the vehicle down more rapidly, decreasing maneuver severity.

Discriminatory Capability

The Nissan Fishhook was an excellent maneuver for measuring the rollover resistance of different vehicles. The dynamic rollover propensity of only the Chevrolet Blazer and Ford Escape was assessed using the Nissan Fishhook, and all tests were performed in the Nominal Load condition. Two-wheel lift was produced during tests performed with the Chevrolet Blazer.

The results obtained with Nissan's methodology were in good agreement with those produced during Fixed Timing and Roll Rate Feedback Fishhook testing. That said, the entrance speed of the Nissan Fishhook test for which two-wheel lift occurred was approximately 6 mph higher than that of either of the other Fishhooks.

While the Nissan Fishhook does an excellent job of discriminating between vehicles for typical, current generation, sport utility vehicles, as explained above for the Fixed Timing Fishhook, it will not do as good a job for the entire vehicle fleet.

Realistic Appearance

See the Fixed Timing Fishhook maneuver Realistic Appearance discussion.

F. Ford Path Corrected Limit Lane Change

Maneuver Description

Ford's procedure is a path specific method composed of an array of double lane change courses and a data-normalizing technique used to address driver variability. It results in a metric based on dynamic weight transfer.

Ford believes that a path specific method, wherein test vehicles navigate a standard set of paths, is preferable to maneuvers that employ open loop steering. Ford states that a specific path provides a basis for comparison of the resulting metrics. By ensuring that all vehicles experience the same magnitude of lateral acceleration, the effects of surface variability on test results are negated. Ford suggests that 0.7g is an appropriate target for lateral acceleration. Its suite of specific paths exercises vehicles through a range of frequencies and amplitudes at the proposed target lateral acceleration.

Three markers (short traffic cones) placed on the pavement delimit the path's lane change apertures with the middle marker representing an avoidance obstacle. Varying the position of the obstacle laterally and longitudinally (with corresponding longitudinal repositioning of the exit marker) produces an array of steering input amplitudes and frequencies. A test vehicle approaches the course at 45 mph. The driver releases the throttle at the course entrance and coasts while steering through the course. Figure 9 portrays the suite of double lane change paths to the left used for this maneuver. A similar suite of double lane change paths to the right is also tested.

Ford addresses driver and test surface variability with the Path Corrected Limit Lane Change (PCLLC) normalizing technique. The mathematical procedure is executed during post-processing of test data and is used ''to normalize the varying results of physical tests to a uniformly based metric.'' [8] The results indicate how the various vehicles would perform had they followed the exact same path.

Ford states, ''Post-test computer aided normalizing techniques have been sufficiently developed that we have high confidence in their applicability to this issue. The PCLLC technique uses physical test data to define a vehicle-specific transfer function. These functions are then used to normalize metric values, such as dynamic weight transfer, to a specific vehicle path common to all vehicles evaluated. The data suggests that use of these normalizing techniques eliminates concerns that may arise because of test driver variability and by subjecting the vehicles to the same path, help to eliminate track surface variability, thus providing the only dynamic test method and metric unaffected by these sources of variability. We [Ford] believe this is a technically sound method to achieve reliable, repeatable and objectively stated results that will improve upon SSF based star ratings.'' [9]

Ford reports that an analysis of the results of the normalizing technique shows that, despite varying styles of driving indicated by measurement of peak steering wheel angles and rates, the differences in the mean values of Dynamic Weight Transfer Metric (DWTM) among four test drivers driving the same vehicle are not statistically significant.

Ford has allowed NHTSA to evaluate the PCLLC technique under a confidentiality agreement. Thus, details of the procedure are not available for this notice. NHTSA expects that Ford would make the details of the procedure public if it proposed that Ford's test protocol as the dynamic rollover test mandated by the TREAD Act.

Ford proposes a rollover resistance metric based on dynamic lateral weight transfer. Ford defines dynamic weight transfer as the ''percentage of weight that is removed from a vehicle's two inside tires during a severe lane change.'' [10] The Dynamic Weight Transfer Metric (DWTM) is the maximum percent of dynamic weight transfer averaged over a minimum specific time. Ford recommends a minimum specific time of 400 milliseconds.

Objectivity and Repeatability

The Path Corrected Limit Lane Change maneuver consists of a series of closed-loop

[8] Copied from Page 4 of Ford Motor Company's submission of August 16, 2001 in response to NHTSA notice Consumer Information Regulations; Rollover Resistance, Docket No. NHTSA–2001–9663 (66 Fed. Reg. 35179–35193, July 3, 2001). Referred to subsequently as Ford's 2001 Rollover Comments.

[9] Copied from Page 5 of Ford's 2001 Rollover Comments.

[10] Copied from Page 1 of a Ford Motor Company memorandum titled ''Dynamic Weight Transfer Results from Path-Corrected Limit Lane Change Joint Testing with NHTSA.'' Referred to subsequently as Ford's PCLLC Report.

(test driver generated steering inputs) double lane changes. Data collected during these double lane changes is then processed ''to assure that all vehicles follow the same path and are subject to the same acceleration demands.'' [11] For reasons that are discussed below in the Discriminatory Capability subsection for this maneuver, Ford Motor Company (Ford) recommends the calculation of a Dynamic Weight Transfer Metric (DWTM) at 0.7 g lateral acceleration for this maneuver. ''Because different vehicle designs will react differently to forces of varying magnitude and time duration, a suite of various paths should be analyzed in determining an overall dynamic weight transfer metric (DWTM), based on values of maximum weight transfer.'' [12] Note that higher values of DWTM are worse than lower values.

Ford has performed a substantial amount of Path Corrected Limit Lane Change maneuver testing. While we do not have access to this data, Ford has summarized this data as follows: ''Ford's overall standard deviation for the DWT metric is 4.4 from multiple tests made on a variety of vehicles with a variety of drivers, over a time span of several months and using a new set of tires fitted for each test.'' [13] To understand the meaning of this standard deviation, we need to know the expected range of the dynamic weight transfer metric.

The most basic way to estimate this range is to approximate the vehicle as a rigid block in a steady state curve at 0.7g lateral acceleration. Using this approximation, the expected range of DWTM values is from 46.7 percent (corresponding to a vehicle with a static stability factor of 1.50) to 70.0 percent (corresponding to a static stability factor of 1.00).

Real vehicles, of course, are not rigid bodies. They have compliant suspensions and tires. This increases the DWTM values from those of rigid vehicles. Based on NHTSA's Tilt Table data and assumptions about the difference between tilt table and flat track testing, we estimate an addition of about 4% to 8% DWTM to the rigid body calculations as a result of quasi-static body roll at 0.7 g. Applying the average addition of 6% DWTM makes the expected range of DWTM approximately 53 percent to 76 percent. Therefore, Ford's standard deviation of 4.4 for DWTM is 19 percent of the entire expected range of DWTM values.

Another way to understand the meaning of this standard deviation is to analyze the values of DWTM that were measured by Ford and NHTSA during joint testing of the Phase IV rollover test vehicles. Table 1 lists these values, along with the number of observations that these values are based on, the calculated dynamic weight transfer at 0.7 g lateral acceleration based on a rigid body model, and the difference between these two dynamic weight transfer values.

Consider the Chevrolet Blazer and the Ford Escape. The Blazer receives one star; the lowest rating a for sport utility vehicle from NHTSA's current rollover rating system (which is based on Static Stability Factor). The Ford Escape has an SSF at the high end of the three star range; one of the higher ratings for sport utility vehicles. Most sport utility vehicles have Static Stability Factors between these two vehicles.

TABLE 1.—MEASURED AND CALCULATED DYNAMIC WEIGHT TRANSFERS [14]

	2001 Chevrolet Blazer	2001 Ford Escape	1999 Mercedes ML320 with ESC on	1999 Mercedes ML320 with ESC off	2001 Toyota 4Runner with ESC on	2001 Toyota 4Runner with ESC off
PCLLC Measured DWTM (in percent)	70.3	62.9	74.8	68.2	66.2	66.6
Number of Observations	4	4	4	10	4	4
Steady State Rigid Body WT Calculated from SSF (in percent)	67.3	55.6	60.9	60.9	63.1	63.1
Difference (in percent)	3.0	7.3	13.9	7.3	3.1	3.5

Now compare the DWTM values of these vehicles as measured using the Path Corrected Limit Lane Change and shown in Table 1. For the Chevrolet Blazer the measured DWTM value is 70.3. However, based on Ford's standard deviation and the number of samples, we have 95 percent confidence that the DWTM for this vehicle is between 66.0 and 74.6. Similarly, for the Ford Escape we have 95 percent confidence that the DWTM is between 58.6 and 67.2. Note that these ranges overlap. However, the difference between these two vehicles DWTM values is statistically significant (although just barely having a t-value of 2.38 versus the critical t-value of 2.37).

A measurement standard deviation for which the difference between a sport utility vehicle with high rollover resistance and one with low rollover resistance is only marginally statistically significant is too large for generating vehicle ratings.

Table 1 shows another problem with the measured DWTM values. When we estimated the expected range of DWTM as 53 percent to 76 over the entire range of vehicles from SUVs to sport sedans, we considered only the quasi-static load transfer due to the vehicle's rigid body geometry (SSF) and to its steady state body roll. We neglected the dynamic weight transfer that occurs as a result of body roll acceleration in an abrupt maneuver. However, when the calculated steady state, rigid body weight transfer in Table 1 is subtracted from the measured DWTM, the difference is no more than that expected for the steady state body roll in all but one case. It would appear that the Dynamic Weight Transfer Metric produced by PCLLC generally measures quasi-static rather than dynamic weight transfer. Quasi-static weight transfer is what occurs when a vehicle is driven in a circle at a constant speed without abrupt changes in speed or direction.

The exception is the DWTM measurement for the Mercedes ML320 with yaw stability control enabled. While the DTWM for this vehicle with yaw stability control disabled is no more than the expected quasi-static load transfer, the DTWM increases by 6.6 percent when the yaw stability control is enabled. The difference between these two values is statistically significant and would seem to represent a dynamic weight transfer component missing in the other PCLLC results in Table 1. However, it is hard to understand why stability control should lower the rollover resistance of this vehicle. Fishhook testing indicates just the opposite; that yaw stability control increases the rollover resistance of this vehicle. Therefore, we believe that the measured DWTM value for the Mercedes ML320 with yaw stability control enabled is incorrect.

In conclusion, the objectivity and repeatability of the Path Corrected Limit Lane Change has not yet attained an acceptable level for rating the rollover resistance of vehicles. Future improvements to the objectivity and repeatability of this maneuver can probably be made, but there are other tests with more potential for making highly objective and repeatable measurements of quasi-static weight transfer.

Performability

The procedure for performing this test is straight-forward. However, substantial additional instrumentation, over and above that required to perform a Fishhook maneuver, are required. The costs and additional testing time associated with this equipment is expected to exceed the costs and additional testing time saved by not having to use a programmable steering controller. An additional test, on a tire testing machine, is also required.

Ford has ideas for reducing the additional instrumentation required for the Path Corrected Limit Lane Change procedure. However, this is a future enhancement and cannot be evaluated at this time.

[11] Copied from Page 3 of Ford's 2001 Rollover Comments.

[12] Copied from Page 1 of Appendix III of Ford's 2001 Rollover Comments.

[13] Copied from Page 2 of Ford's PCLLC Report.

[14] Values taken from Page 2 of Ford's PCLLC Report.

Since Ford processed the data collected during our testing, we are unable to say how difficult the data processing is to perform. However, with experience and the correct software it is expected to approximately equal the effort required to process data from a Fishhook or J-Turn test. There may be issues in making Ford's data processing software publicly available.

Due to the use of a suite of paths for calculating DWTM values, the Path Corrected Limit Lane Change procedure should adequately adapt to differing vehicle characteristics.

We also have concerns about determining dynamic weight transfer as an average value over a 400 millisecond window. The use of this broad a window may filter out dynamic effects that may be important in actual vehicle rollovers.

Discriminatory Capability

No two-wheel lifts occurred during Path Corrected Limit Lane Change testing for any of the test vehicles. However, unlike the J-Turn and Fishhook maneuvers, the occurrence/non-occurrence of two-wheel lift is not used as a measure of vehicle performance for this maneuver. The DWTM measured in PCLLC testing produces a continuous measure of rollover resistance that, like SSF, that allows discrimination even among vehicles that are not susceptible to on-road untripped rollover.

Ford recommends the calculation of a Dynamic Weight Transfer Metric (DWTM) at 0.7 g lateral acceleration as a measure of vehicle performance for this maneuver. Data collected during testing is processed to remove driver effects by having all vehicles always follow the same specified paths and be subject to the same acceleration demands. ''Because different vehicle designs will react differently to forces of varying magnitude and time duration, a suite of various paths should be analyzed in determining an overall dynamic weight transfer metric (DWTM), based on values of maximum weight transfer.'' [15] Ford's reasons for making this recommendation are as follows:

''For a given velocity change, various vehicle related factors determine the magnitude of dynamic weight transfer for events that can lead to both tripped or un-tripped rollover. Obviously, the higher the center-of-gravity, the greater the transfer for a given travel velocity change. Similarly, the smaller the track width, the greater the transfer. As is well known, many factors other than these two affect dynamic weight transfer and it is because of this that SSF is a narrow and inadequate concept. For example, if deflections occur in suspensions, tires, or other parts that control overall body movements such as active stabilizer bars or electronically controlled shock absorbers, when dynamic forces are applied, the magnitude of the dynamic weight transfer will also change. Inertial values, yaw plane motions, vertical motions and pitch plane motions that arise because of a vehicle's design details or features can affect force and moment balances and can change vehicle configurations to affect the magnitude of the dynamic weight transfer. It is a directionally correct proposition that the greater the magnitude of the dynamic weight transfer in a given high severity event, the less margin, reserve, or resistance remains to a rollover occurring. Based on these principles, Ford believes that dynamic weight transfer is a metric of value in a dynamic test.'' ''Our preliminary work has confirmed that this metric will discriminate among specific vehicles within a class and between classes of vehicles. We submit that DWTM is a more reliable metric than SSF alone.'' [16]

DWTM has the theoretical advantage over SSF of including load transfer due to quasi-static body roll and true dynamic load transfer due to body roll accelerations, but its measurement by the PCLLC method seems to be lacking the dynamic load transfer component. The PCLLC test also is not able to test for the effect of yaw stability control. In its comment to the docket of the last notice, Ford suggested that the same 0.7g lane change maneuvers and DTWM could be implemented directly with an advanced path following robot rather than with the PCLLC method, but it cautioned that the test would not evaluate the effect of yaw stability control. In light of this comment, it is not surprising that the PCLLC test measured no effect of yaw stability control of Toyota 4Runner, but it remains troubling that it measured a significant loss of rollover resistance for yaw stability control of the Mercedes ML320 contrary to its effect measured in other rollover maneuver tests.

As discussed above, we do not believe that dynamic weight transfer values determined using this maneuver have, so far, attained an acceptable level of repeatability. We are also concerned about not exercising vehicles to the limits of their performance. By not taking vehicles to their limits, some important limit performance problems could be overlooked.

Realistic Appearance

In general, double lane change maneuvers have an excellent appearance of reality. These are the emergency obstacle avoidance maneuvers that people think of first when they consider untripped rollover. While the Path Corrected Limit Lane Change trajectories are idealized, rather than actual, this distinction would likely not be noticed by consumers.

G. ISO 3888 Part 2 Double Lane Change

Maneuver Description

To perform ISO 3888 Part 2 Double Lane Change testing, the vehicle was driven through the course shown in Figure 10. The driver released the throttle 6.6 ft (2.0 m) from the entrance of the first lane. No throttle input or brake application occurred during the remainder of maneuver.

Drivers iteratively increased maneuver entrance speed from approximately 35 mph in 1 mph increments. The iteration continued until valid tests could no longer be performed (lane position could not be maintained without striking cones). Each driver was required to perform three valid runs at their maximum speed. This was to assess input and output variability for tests performed by the same driver with the same entrance speed.

The manner in which the 1 mph iterations were implemented was somewhat driver-dependent. Some drivers preferred to increase speed until they could no longer achieve a valid test. Once this threshold was reached, the driver would reduce speed slightly and perform three valid tests. Other drivers would perform three valid tests at one speed before proceeding to the next iteration. Both methods produced similar results.

So as to examine driver-to-driver differences, during the Phase IV research, this maneuver was performed for each vehicle by three drivers. To reduce any confounding effect tire wear may have on ISO 3888 Part 2 Double Lane Change test results, a new tire set was installed on each vehicle, for each driver.

Objectivity and Repeatability

Since steering inputs for the ISO 3888 Part 2 Double Lane Change maneuver are generated by the test driver, vehicle performance in this maneuver depends upon the skill of the test driver, the steering strategy used by the test driver, plus random run-to-run fluctuations.

The ISO 3888 Part 2 Double Lane Change maneuver attempts to minimize this variability through the use of an in-between lane of substantial length and very tight entry, exit, and in-between lanes, thereby minimizing a driver's steering options for getting through the course without striking delineating cones.

Figure 11 shows the range of handwheel steering angles used by three different test drivers while performing this maneuver multiple times while Figure 12 shows the range of handwheel steering angles used by these drivers at selected times during this maneuver. As these figures show, there are both substantial driver-to-driver differences and substantial within driver run-to-run differences in the steering inputs. These differences tend to increase as the maneuver progresses.

Arguably, the differences in steering inputs shown in Figure 11 and 12 do not really matter for the purposes of determining Rollover Resistance Ratings. What really matters are driver-to-driver differences in vehicle outputs, specifically the vehicle rating metrics.

The rating metric suggested by the Daimler-Chrysler Corporation is the maximum entry speed into the test course at which a driver successfully achieved a ''clean'' run. (A ''clean'' run is one during which none of the cones delineating the course were struck.)

Table 2 shows the maximum achievable ''clean'' run speeds for three test drivers for the Nominal Vehicle configuration for each of the Phase IV rollover test vehicles. (While each vehicle was tested by three drivers, four drivers actually participated in this testing.) Note that higher values of this metric indicate a better performing vehicle.

[15] Copied from Page 1 of Appendix III of Ford's 2001 Rollover Comments.

[16] Copied from Pages 5 and 6 of Ford's 2001 Rollover Comments.

TABLE 2.—MAXIMUM ACHIEVABLE ''CLEAN'' RUN SPEEDS FOR THE ISO 3888 PART 2 DOUBLE LANE CHANGE MANEUVER—NOMINAL VEHICLE CONFIGURATION

Test driver	2001 Chevrolet Blazer (mph)	2001 Ford Escape (mph)	1999 Mercedes ML320 with ESC on (mph)	1999 Mercedes ML320 with ESC off (mph)	2001 Toyota 4Runner with ESC on (mph)	2001 Toyota 4Runner with ESC off (mph)
GF/RS	39.0	36.9	38.0	37.2	37.6	35.9
LJ	40.0	36.6	37.0	36.7	36.7	35.3
RL	41.0	38.0	36.8	37.8	35.8	37.0
Range	2.0	1.4	1.2	1.1	1.8	1.7

Table 3 shows a rank ordering of the Phase IV rollover test vehicles based on the maximum ''clean'' run speeds achieved by the test drivers. Note that 1 is the best rank and 6 the worst.

TABLE 3.—VEHICLE RANKINGS BASED ON MAXIMUM ACHIEVABLE ''CLEAN'' RUN SPEEDS FOR THE ISO 3888 PART 2 DOUBLE LANE CHANGE MANEUVER—NOMINAL VEHICLE CONFIGURATION

Test driver	2001 Chevrolet Blazer	2001 Ford Escape	1999 Mercedes ML320 with ESC on	1999 Mercedes ML320 with ESC off	2001 Toyota 4Runner with ESC on	2001 Toyota 4Runner with ESC off
GF/RS	1	5	2	4	3	6
LJ	1	5	2	3	3	6
RL	1	2	5	3	6	4

As Table 2 shows, for the drivers used, the range of maximum achievable ''clean'' run entry speeds varied from 1.2 mph for the 1999 Mercedes ML320 with yaw stability control enabled to 2.0 mph for the 2001 Chevrolet Blazer. The average range was 1.5 mph. While these may seem like small ranges, the entire best-to-worst range in Table 2 is only 5.7 mph. Since we tested a fairly broad range of sport utility vehicles during the Phase IV research, the maximum achievable ''clean'' run speeds for most sport utility vehicles are expected to be in this 5.7 mph range. Therefore, driver-to driver variability averages 27 percent of the range of the rating metric and can be as much as 35 percent.

The problem caused by driver-to-driver variability combined with the small range of metric values is clearly shown by Table 3. While the Chevrolet Blazer attained the best ranking from all three test drivers, the ranking for the Mercedes ML320 with yaw stability control enabled varied from second best to second worst.

Driver skills and abilities vary with time. Although we did not do such testing, if we retested the Phase IV rollover test vehicles with the same test drivers performing the ISO 3888 Part 2 Double Lane Change maneuver we anticipate that our results would not exactly match those shown in Tables 2 and 3. Since we have such a small range for the rating metric day-to-day (or even hour-to-hour) changes in test driver performance would probably change the maximum achievable ''clean'' run entry speeds by a substantial percentage of the overall range.

Due to the problems associated with driver-to-driver variability and run-to-run for the same driver variability, the objectivity and repeatability of this maneuver is poor.

Performability

The procedure for performing this test is straight-forward. However, as discussed above, this maneuver has objectivity and repeatability issues. Resolving these issues adds difficulty and complexity to performing these tests.

For example, one possibility for improving objectivity and repeatability is to use multiple drivers to perform the testing (three drivers were used during the Phase IV testing). While this should help, there are still potential problems. One exceptionally skilled test driver could generate very good performance metrics for a mediocre vehicle. If this exceptionally skilled driver did not test some other vehicle, that vehicle's performance metrics might, incorrectly, be lower than they should be. Therefore, in addition to using multiple drivers, procedures would need to be developed to ensure that every vehicle is tested by drivers of approximately equal skill.

The ISO 3888 Part 2 Double Lane Change test procedure includes adjustments to lane width and lane change gate length for differing vehicle sizes. These should adequately adapt this maneuver for differing vehicle characteristics.

Discriminatory Capability

No two-wheel lifts occurred during any ''clean'' run of ISO 3888 Part 2 Double Lane Change testing for any of the test vehicles. (A ''clean'' run is one during which none of the cones delineating the course were struck.) While some two-wheel lifts did occur during runs that were not ''clean'', these should not be considered for the determination of our rollover resistance ratings. The reason is that when a run is not ''clean'', there is no way to determine whether the vehicle comes close to following the test course. For example, a driver could perform a fishhook maneuver or simply drive straight through. Either case would simply be recorded as not a ''clean'' run.

Unlike the J-Turn and Fishhook maneuvers, the occurrence/non-occurrence of two-wheel lift cannot be used as a measure of vehicle performance for this maneuver because two-wheel lifts during a clean run appear very unlikely for any NCAP vehicle. The rating metric suggested by the Daimler-Chrysler Corporation (Daimler) is the maximum entry speed into the test course at which a driver successfully achieved a ''clean'' run.

Table 4 shows the maximum achievable ''clean'' run speeds attained by any of the test drivers for both the Nominal Vehicle and Reduced Rollover Resistance configuration for each of the Phase IV rollover test vehicles. Note that higher values of this metric indicate a better performing vehicle.

The Reduced Rollover Resistance configuration vehicles have had weights placed on the roof so as to raise the center of gravity height. Their Static Stability Factors have been reduced by 0.05. A 0.05 reduction in SSF equates, for sport utility vehicles, to approximately a one star reduction in the vehicle's rollover resistance rating. As was previously stated, NHTSA believes that a one star reduction in the rollover resistance rating should make a vehicle substantially easier to rollover. Maneuvers with good discriminatory capability should measure substantially worse performance for Reduced Rollover Resistance the configuration than for the Nominal Vehicle configuration.

TABLE 4.—MAXIMUM ACHIEVABLE ''CLEAN'' RUN SPEEDS BY ANY DRIVER FOR THE ISO 3888 PART 2 DOUBLE LANE CHANGE MANEUVER—NOMINAL VEHICLE AND REDUCED ROLLOVER RESISTANCE CONFIGURATIONS

Test driver	2001 Chevrolet Blazer (mph)	2001 Ford Escape (mph)	1999 Mercedes ML320 with ESC on (mph)	1999 Mercedes ML320 with ESC off (mph)	2001 Toyota 4Runner with ESC on (mph)	2001 Toyota 4Runner with ESC off (mph)
Nominal Vehicle Configuration	41.0	38.0	38.0	38.9	37.6	37.0
Reduced Rollover Resistance Configuration	39.0	37.3	37.4	37.1	39.3	38.0
Difference	2.0	0.7	0.6	1.8	−1.7	−1.0

This expected substantial change in rollover resistance ratings is not seen for the ISO3888 Part 2 Double Lane Change maneuver. For three of the vehicles the maximum achievable ''clean'' run speeds attained by any of the test drivers in the Reduced Rollover Resistance configuration vehicles did decrease slightly compared to the Nominal Configuration vehicles while for the 2001 Toyota 4Runner they increased slightly. The average change was only 0.4 mph, far less than the average driver-to-driver variability of 1.5 mph.

The expected substantial change in rollover resistance measurement was not observed for the ISO3888 Part 2 Double Lane Change maneuver apparently because the sensitivity of the test to handling properties is predominant compared to its sensitivity to rollover resistance. Placing weight on a vehicle's roof raises its center of gravity height which reduces its rollover resistance. However, doing this also increases a vehicle's mass and roll moment of inertia, resulting in changes to a vehicle's handling that are not well understood. Since handling and rollover resistance are inextricably intertwined in the rating produced by this maneuver, the rating generated can improve even though the rollover resistance of a vehicle is getting worse.

Results from both J-Turn and Fishhook testing are, of course, also influenced by the handling characteristics of the vehicle. However, handling has less of a chance to dominate these maneuvers because they involve fewer major steering movements (one for a J-Turn, two for a Fishhook, and three for a Double Lane Change).

The above reasoning also explains an apparent anomaly in Table 3. In this table, the Chevrolet Blazer has the best ranking of any of the vehicles. However, based on its one star rating and performance in the NHTSA J-Turn and Fishhooks, we believe it to have the lowest rollover resistance of any of the Phase IV rollover test vehicles. The apparent contradiction is resolved once we realize that the ISO3888 Part 2 Double Lane Change maneuver measures mostly the handling rather than rollover resistance of vehicles.

Realistic Appearance

In general, double lane change maneuvers have an excellent appearance of reality. These are the emergency obstacle avoidance maneuvers that people think of first when they consider untripped rollover.

H. Consumers Union Short Course Double Lane Change

Maneuver Description

To perform Consumers Union Short Course Double Lane Change testing, the vehicle was driven through the course shown in Figure 13. As the vehicle approached the course entrance, the driver released the throttle so as to achieve a desired target speed as the vehicle passed over a timing strip 35 feet from the entrance of the first lane. Otherwise, the procedure for this maneuver was identical to that used for the ISO 3888 Part 2 Double Lane Change testing.

Objectivity and Repeatability

Since steering inputs for the Consumers Union Short Course Double Lane Change maneuver are generated by the test driver, vehicle performance in this maneuver depends upon the skill of the test driver, the steering strategy used by the test driver, plus random run-to-run fluctuations.

Figure 14 shows the range of handwheel steering angles used by three different test drivers while performing this maneuver multiple times while Figure 15 shows the range of handwheel steering angles used by these drivers at selected times during this maneuver. As these figures show, there are both substantial driver-to-driver differences and substantial within driver run-to-run differences in the steering inputs. These differences tend to increase as the maneuver progresses.

Arguably, the differences in steering inputs shown in Figures 14 and 15 do not really matter for the purposes of determining Rollover Resistance Ratings. What really matters are driver-to-driver differences in vehicle outputs, specifically the vehicle rating metrics.

The rating metric used by NHTSA is the maximum entry speed into the test course at which a driver successfully achieved a ''clean'' run. (A ''clean'' run is one during which none of the cones delineating the course were struck.) Note that this is not the rating metric used by Consumers Union for this maneuver; Consumers Union performs subjective rating of the emergency handling capability of vehicles with vehicles that have large amounts of two-wheel lift in this maneuver receiving an ''unacceptable'' safety rating.

Table 5 shows the maximum achievable ''clean'' run speeds for three test drivers for the Nominal Vehicle configuration for the Phase IV rollover test vehicles. Note that higher values of this metric indicate a better performing vehicle.

TABLE 5.—MAXIMUM ACHIEVABLE ''CLEAN'' RUN SPEEDS FOR THE CONSUMERS UNION SHORT COURSE DOUBLE LANE CHANGE MANEUVER—NOMINAL VEHICLE CONFIGURATION

Test driver	2001 Chevrolet Blazer (mph)	2001 Ford Escape (mph)	1999 Mercedes ML320 with ESC on (mph)	1999 Mercedes ML320 with ESC off (mph)	2001 Toyota 4Runner with ESC on (mph)	2001 Toyota 4Runner with ESC off (mph)
GF	39.3	37.0	38.8	36.7	36.5	37.7
LJ	38.1	37.1	37.1	36.6	37.4	35.7
RL	40.7	40.5	39.2	38.3	37.8	37.8
Range	2.6	3.5	1.7	1.7	1.3	2.1

Table 6 shows a rank ordering of the Phase IV rollover test vehicles based on the maximum ''clean'' run speeds achieved by the three test drivers. Note that 1 is the best rank and 6 the worst.

TABLE 6.—VEHICLE RANKINGS BASED ON MAXIMUM ACHIEVABLE ''CLEAN'' RUN SPEEDS FOR THE CONSUMERS UNION SHORT COURSE DOUBLE LANE CHANGE MANEUVER—NOMINAL VEHICLE CONFIGURATION

Test driver	2001 Chevrolet Blazer	2001 Ford Escape	1999 Mercedes ML320 with ESC on	1999 Mercedes ML320 with ESC off	2001 Toyota 4 Runner with ESC on	2001 Toyota 4 Runner with ESC off
GF	1	4	2	5	6	3
LJ	1	3	3	5	2	6
RL	1	2	3	4	5	5

As Table 5 shows, for three test drivers used, the range of maximum achievable ''clean'' run entry speeds varied from 1.3 mph for the 2001 Toyota 4Runner with yaw stability control enabled to 3.5 mph for the 2001 Ford Escape. The average range was 2.2 mph. While these may seem like small ranges, the entire best-to-worst range in Table 5 is only 5.0 mph. Since we tested a fairly broad range of sport utility vehicles during the Phase IV research, the maximum achievable ''clean'' run speeds for most sport utility vehicles are expected to be in this 5.0 mph range. Therefore, driver-to driver variability averages 44 percent of the range of the rating metric and can be as much as 70 percent.

The problem caused by driver-to-driver variability combined with the small range of metric values is clearly shown by Table 6. While the Chevrolet Blazer attained the best ranking from all three test drivers, the ranking for the Toyota 4Runner with yaw stability control enabled varied from second best to worst.

Driver skills and abilities vary with time. Although we did not do such testing, if we retested the Phase IV rollover test vehicles with the same test drivers performing the Consumers Union Short Course Double Lane Change maneuver we anticipate that our results would not exactly match those shown in Tables 4 and 5. Since we have such a small range for the rating metric day-to-day (or even hour-to-hour) changes in test driver performance would probably change the maximum achievable ''clean'' run entry speeds by a substantial percentage of the overall range.

Due to the problems associated with driver-to-driver variability and run-to-run for the same driver variability, the objectivity and repeatability of this maneuver are poor. However, it is important to recognize that NHTSA's objective for this maneuver, the determination of rollover resistance ratings, is not the same as Consumers Union's objective, the evaluation of a vehicle's emergency handling capabilities. Handling evaluation has always been a subjective process. This appears to be a better maneuver for what Consumers Union wants to accomplish than for what the NHTSA wants to accomplish.

Performability

The procedure for performing this test is straight-forward. However, as discussed above, this maneuver has objectivity and repeatability issues. Resolving these issues adds difficulty and complexity to performing these tests.

For example, one possibility for improving objectivity and repeatability is to use multiple drivers to perform the testing (three drivers were used during the NHTSA testing). While this should help, there are still potential problems. One exceptionally skilled test driver could generate very good performance metrics for a mediocre vehicle. If this exceptionally skilled driver did not test some other vehicle that vehicle's performance metrics might, incorrectly, be lower than they should be. Therefore, in addition to using multiple drivers, procedures would need to be developed to ensure that every vehicle is tested by drivers of approximately equal skill.

The Consumers Union Short Course Double Lane Change test procedure does not change from vehicle-to-vehicle. This reflects Consumers Union's reason for developing this maneuver; as a test of emergency handling. On an actual road, if an obstacle suddenly intrudes into a vehicle's lane requiring emergency maneuvering to avoid, the parameters of the intrusion (distance ahead of oncoming vehicle at which the intrusion begins, amount of intrusion) do not depend on the characteristics of the oncoming vehicle. In other words, if a child runs out in front of you, they do not run out sooner because your vehicle is bigger or wider.

However, NHTSA has a different purpose. We are trying to rate a vehicle resistance to rollover. As such, we would like to test with worst case lane geometry. This may well change with vehicle size or other characteristics. Therefore, for NHTSA's purpose, we believe that a test maneuver should adapt for differing vehicle characteristics.

Discriminatory Capability

No two-wheel lifts occurred during any ''clean'' run of Consumers Union Short Course Double Lane Change testing for any of the test vehicles. (A ''clean'' run is one during which none of the cones delineating the course were struck.) While some two-wheel lifts did occur during runs that were not ''clean'', these should not be considered for the determination of our rollover resistance ratings. The reason is that when a run is not ''clean'', there is no way to determine whether the vehicle comes close to following the test course. For example, a driver could perform a fishhook maneuver or simply drive straight through. Either case would simply be recorded as not a ''clean'' run.

Unlike the J-Turn and Fishhook maneuvers, the occurrence/non-occurrence of two-wheel lift cannot be used as a measure of vehicle performance for this maneuver because two-wheel lifts during clean run appear unlikely for NCAP vehicles. The rating metric use by NHTSA is the maximum entry speed into the test course at which a driver successfully achieved a ''clean'' run.

We did not perform testing of the Reduced Rollover Resistance configurations of the Phase IV test vehicles with this maneuver; so, we cannot make the comparisons shown in Table 4 for this maneuver. However, the discussion following Table 4 likely applies to this maneuver as well as to the ISO 3888 Part 2 Double Lane Change. Again, this maneuver tests both the handling and rollover resistance of vehicles. In fact, since Consumers Union developed this maneuver to examine the emergency handling of vehicles, and because this maneuver is not as tightly constrained as is the ISO 3888 Part 2 Double Lane Change, we believe that this maneuver focuses more on handling than does the ISO maneuver. Since handling and rollover resistance are inextricably intertwined in the rating produced by this maneuver with handling dominating, the rating generated can easily improve even though the rollover resistance of a vehicle is getting worse.

The above reasoning explains the apparent anomaly in Table 6. In this table, the Chevrolet Blazer has the best ranking of any of the vehicles. However, based on its one star rating and performance in the NHTSA J-Turn and Fishhooks, we believe it to have the lowest rollover resistance of any of the Phase IV rollover test vehicles. The apparent contradiction is resolved once we realize that the Consumers Union Double Lane Change maneuver measures both the handling and rollover resistance of vehicles with handling dominating.

Due to the fact that this maneuver is not focused solely on a vehicle's rollover resistance but instead measures some combination of their handling and rollover resistance properties, its discriminatory capability for rollover resistance (not emergency handling) is poor.

Realistic Appearance

See the ISO 3888 Part 2 Double Lane Change maneuver Realistic Appearance discussion.

I. Open-Loop Pseudo-Double Lane Change

Maneuver Description

Driver-based, path-following double lane changes have historically been associated with considerable handwheel variability. This was in evidence during the ISO 3888 Part 2 and Consumers Union Short Course testing performed during the Phase IV research. Although the ISO 3888 Part 2 Double Lane Change course layout attempts to minimize this variability by relating lane width to vehicle width, handwheel variability observed during this maneuver continues to exceed that typically observed during steering machine-based maneuvers.

Aside from the handwheel variability issues, double lane changes have a certain appeal. It is foreseeable that the inputs of either double lane change used in Phase IV could emulate a driver's reaction to a variety of crash avoidance scenarios. Furthermore, examination of what effects the third steering input (second reversal) has on dynamic rollover propensity is of interest. To facilitate examination of third steer effects without the confounding effect of handwheel variability, open-loop handwheel inputs executed with the steering machine that approximated a double lane change were performed.

Two open-loop pseudo-double lane changes were performed during the Phase IV research: ISO 3888 Part 2 and Consumers Union Short Course simulations. For each maneuver, handwheel inputs were chosen to approximate those observed during closed-loop, path-following tests performed at VRTC by three test drivers. Specifically, steering recorded during the three tests begun with the highest, yet most similar, entrance speeds was considered for each driver, per maneuver. Using these data, handwheel input composites were developed. Open-loop double lane changes were performed in the Nominal load condition, with the Toyota 4Runner and Chevrolet Blazer only. The Ford Escape and Mercedes ML320 were not evaluated with these maneuvers.

Upon completion of the path-following double lane changes, the three highest, most consistent valid maneuver entrance speeds attained by each driver were determined. A valid test was one in which no vehicle-to-cone contact was detected. This produced a total of nine valid runs for each vehicle (recall the 4Runner with enabled stability control was considered to be separate vehicle from the 4Runner with disabled stability control).

Double lane change simulation began by plotting of the handwheel angles for all drivers of a particular vehicle. The plots were overlaid and centered about the middle peak of the maneuver in the time domain. After each of the nine tests was centered, the data were averaged to form a preliminary composite.

Once the preliminary composite was created, averages for each of the three primary handwheel peaks were calculated. These averages were based on peak value data (independent of time) from each of the nine driver-based tests. Each average was then divided by the appropriate preliminary composite value to produce a ratio. The three ratios were averaged to produce a final, overall ratio. This final ratio was multiplied by preliminary composite data to yield a final handwheel input composite.[17]

Piecewise approximation was used to construct ramp-based handwheel profiles representative of the final handwheel composites. The approximation was programmed into the steering machine, and the maneuver performed.

Figure 16 presents the suite of piecewise approximations used to define the Consumers Union Short Course simulations for the Toyota 4Runner (enabled and disabled stability control) and Chevrolet Blazer.

Generally speaking, closed-loop Consumers Union Short Course tests performed with the 4Runner (disabled stability control) and Blazer contained four significant steering inputs (*i.e.*, third reversals). The drivers used the fourth steering inputs to preserve lateral stability and insure exit lane position. These inputs were included in Consumers Union Short Course approximations for the 4Runner with disabled stability control and for the Blazer, but were not required for approximation of 4Runner steering observed during tests performed with enabled stability control.

Due to the length of the second lane in the ISO 3888 Part 2 course, each driver made steering adjustments after the second handwheel peak to maintain lane position. As a result, each ISO 3888 Part 2 simulation contained five significant handwheel peaks. Figure 17 presents the open-loop steering inputs used to simulate the ISO 3888 Part 2 Double Lane Change maneuver for each vehicle.

During testing, runs of the Open-Loop Pseudo-Double Lane Change were performed beginning with a maneuver entry speed of 35 mph. Vehicle speed was iteratively increased in 5 mph increments to 50 mph or until two-wheel lift occurred. Additionally, tests were performed at the average maximum entrance speed attained by test drivers at VRTC during closed-loop tests without the steering machine. No downward speed iterations were used to isolate the lowest entrance speed capable of producing two-wheel lift.

Objectivity and Repeatability

The Open-Loop Pseudo-Double Lane Change can be performed with excellent objectivity and repeatability. Figure 18 shows the Handwheel Angle, Vehicle Speed, Lateral Acceleration, and Roll Angle as functions of time for two tests of the Chevrolet Blazer that were run at approximately the same speed (40.3 and 40.7 mph). Data from these runs is typical of our experience with this maneuver.

Since this maneuver uses the programmable steering controller, the steering control input is once again precisely replicated from run-to-run. However, the lateral acceleration becomes slightly less repeatable when the vehicle is in the recovery portion (*i.e.*, while trying to straighten out after performing the return lane change).

As was discussed above for the NHTSA J-Turn, for runs near the point at which two-wheel lift first occurs, roll angle repeatability becomes much worse.

Performability

Objective and repeatable Open-Loop Pseudo-Double Lane Change maneuvers can easily be performed using a programmable steering controller.

While running this maneuver is straight-forward, we have substantial concerns about the maneuver itself. Unfortunately, due to lack of development time, we doubt that the steering inputs used during the Phase IV Rollover Research correspond to worst case conditions. Work is needed as to how to adapt this maneuver for different vehicles sizes or characteristics. Probably at least one year of effort would be required to develop and refine this maneuver.

Discriminatory Capability

Testing for the Open-Loop Pseudo-Double Lane Change maneuver was only performed using two vehicles, the 2001 Chevrolet Blazer and the 2001 Toyota 4Runner (both with the yaw stability control enabled and disabled). Two different steering inputs were used for this Open-Loop Pseudo-Double Lane Change testing, one that simulated the ISO 3888 Part 2 Double Lane Change and one that simulated the Consumers Union Short Course Double Lane Change.

For the simulated ISO 3888 Part 2 Double Lane Change, the Chevrolet Blazer had two-wheel lift while the Toyota 4Runner with yaw stability control enabled and disabled did not. However, the maneuver entry speed at which the Chevrolet Blazer had two-wheel lift was substantially (5 mph) higher than the maximum speed at which Toyota 4Runner testing was stopped. When yaw stability control was disabled, the speed at which Toyota 4Runner testing was stopped was determined by when spin-out occurred. When yaw stability control was enabled, the speed at which Toyota 4Runner testing was stopped was determined by test driver concerns about possible loss of control. So two-wheel lift was seen for the Chevrolet Blazer but not the Toyota 4Runner because the Blazer was able to perform this maneuver at higher speeds than was the 4Runner. As was the case for the actual ISO 3888 Part 2 Double Lane Change, handling and rollover resistance appear to be inextricably intertwined in the ratings produced by this maneuver.

For the simulated Consumers Union Short Course Double Lane Change, the Chevrolet Blazer and the Toyota 4Runner with yaw stability control disabled had two-wheel lift while the Toyota 4Runner with yaw stability control enabled did not. The maneuver entry speed at which the Chevrolet Blazer had two-wheel lift was higher than the maximum speed at which Toyota 4Runner two-wheel lift occurred. However, based on its one star rating and performance in the NHTSA J-Turn and Fishhooks, we believe the Chevrolet Blazer to have the lowest rollover resistance of any of the Phase IV rollover test vehicles. The explanation for this apparent anomaly is that, as was the case for the actual Consumers Union Short Course Double Lane Change, handling and rollover resistance appear to be inextricably intertwined in the ratings produced by this maneuver.

Because this maneuver is not focused solely on a vehicle's rollover resistance but

[17] Determination of the final composite was necessary because the peak handwheel input of a particular test did not necessarily occur at the same time as the others. The preliminary composite was used to establish trends (*e.g.*, timing, rates, *etc.*) in the handwheel position data. The final composite increased handwheel magnitudes, so as to insure maneuver severity was preserved.

instead measures some combination of handling and rollover resistance properties, its discriminatory capability for rollover resistance is poor.

Realistic Appearance

The Realistic Appearance discussion from the Ford Path Corrected Limit Lane Change again applies.

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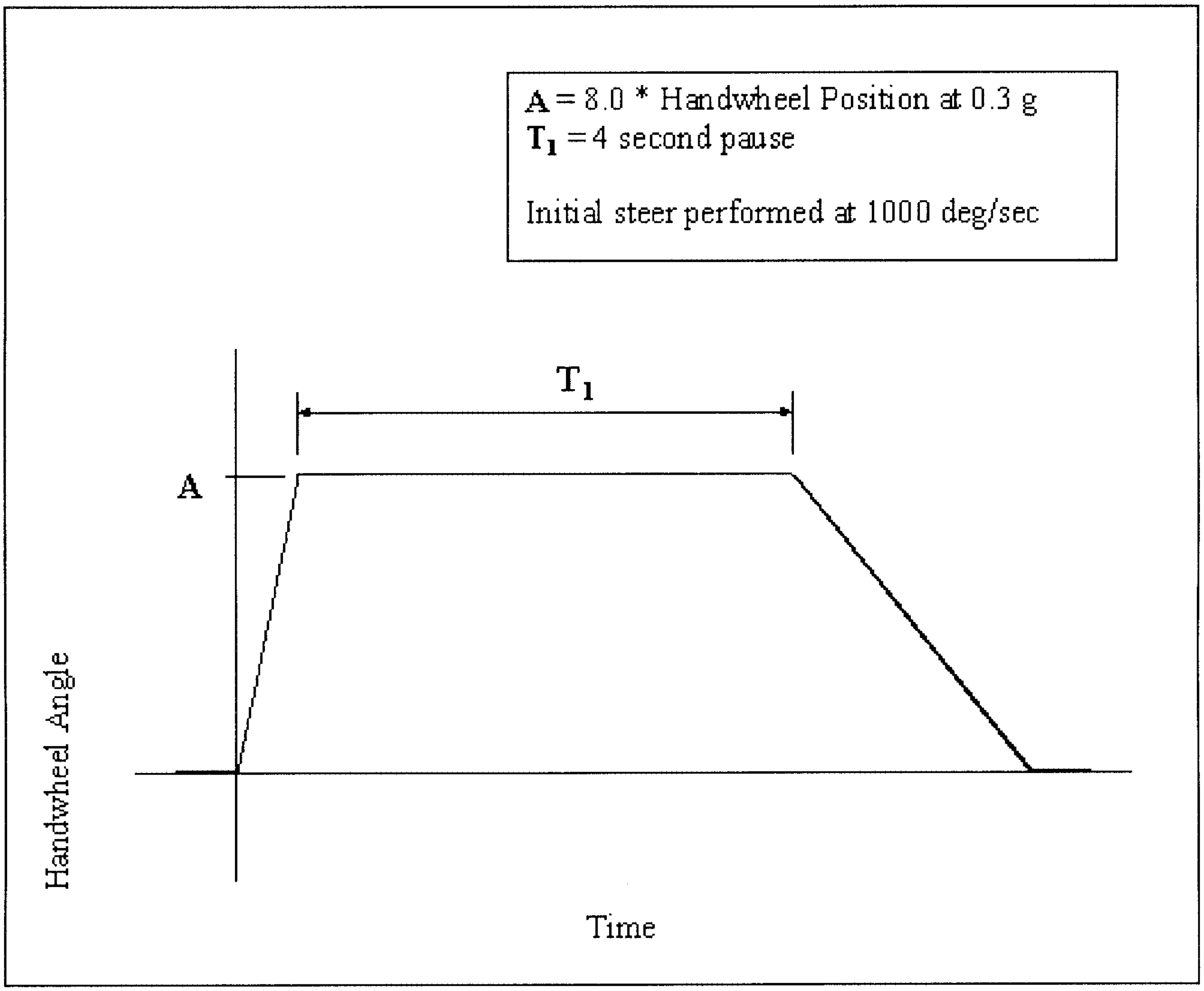

Figure 1: J-Turn maneuver description.

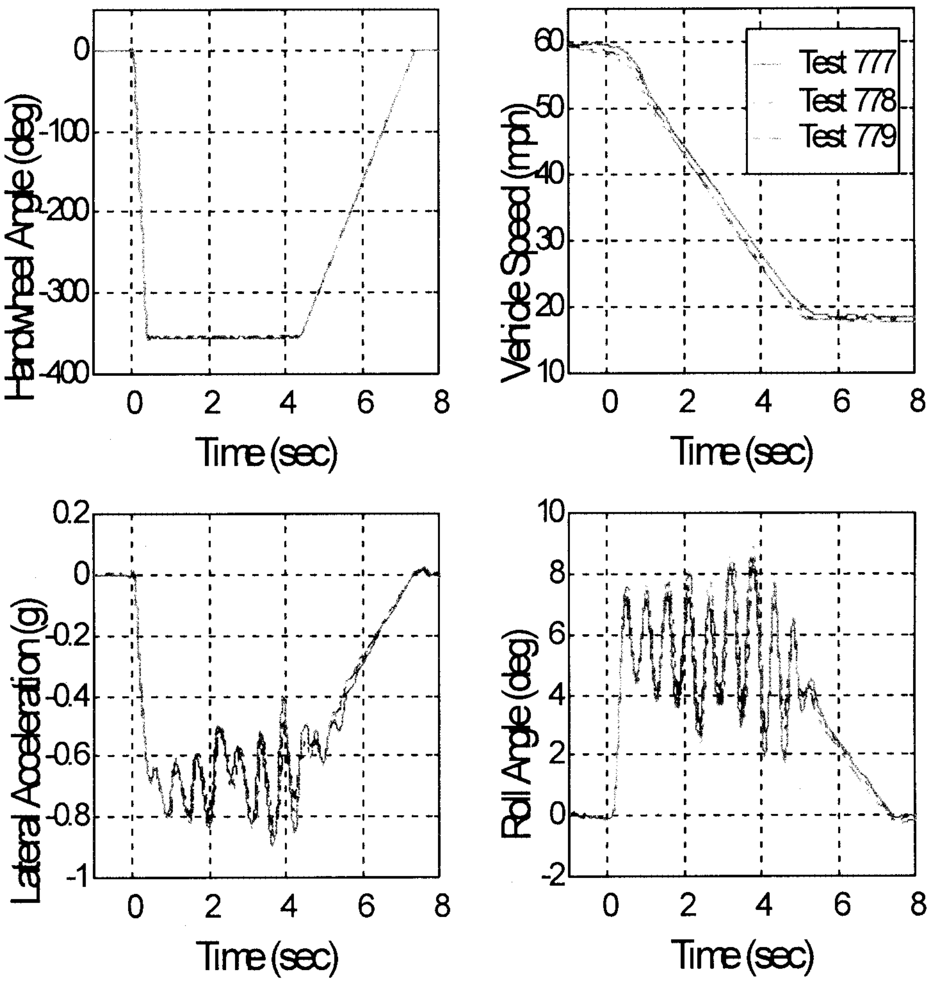

Figure 2: NHTSA J-Turn test inputs and outputs for three tests performed with the Toyota 4Runner with yaw stability control disabled

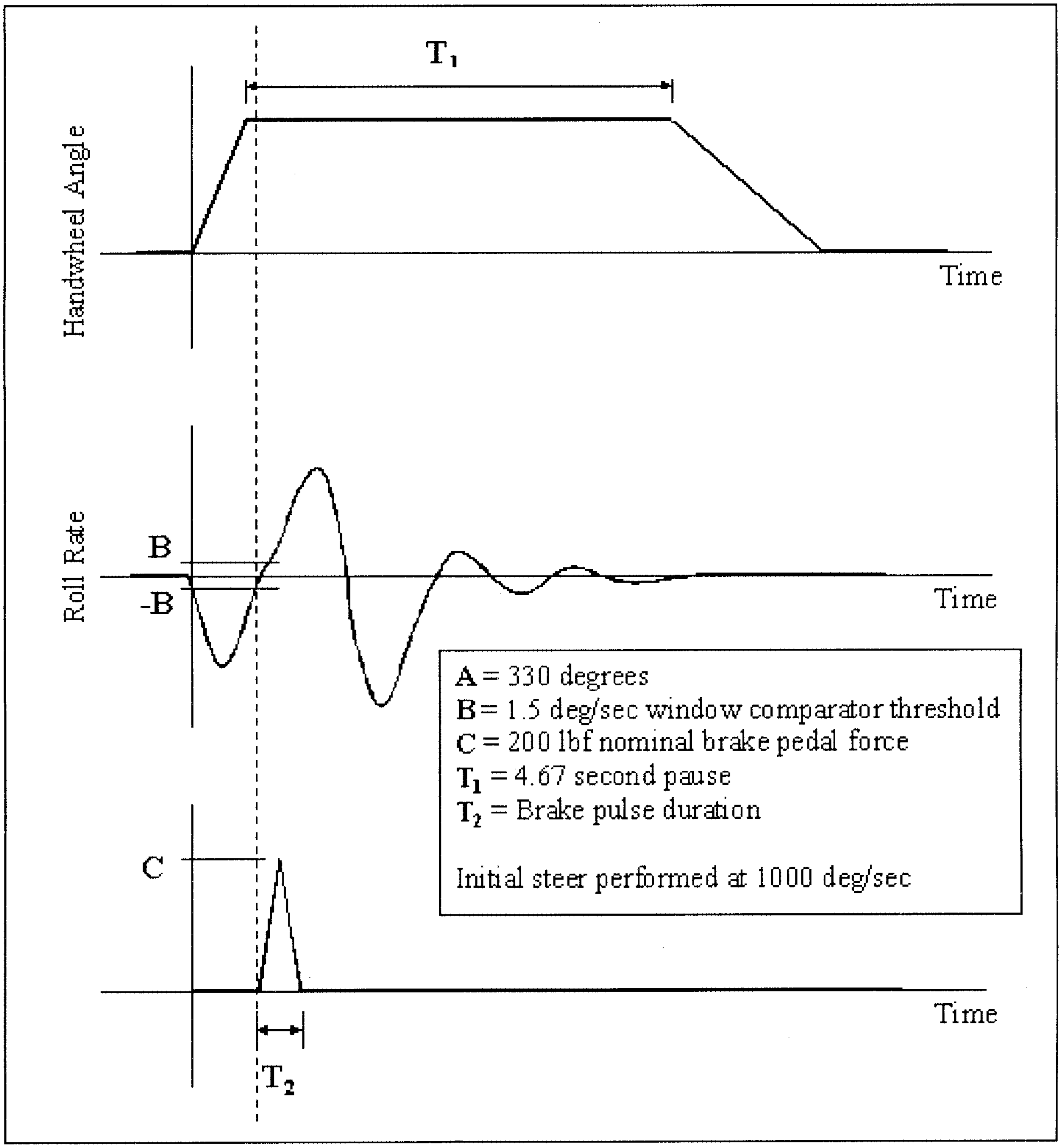

Figure 3: J-Turn with Pulse Braking Handwheel Steering Angle and Brake Pedal Force

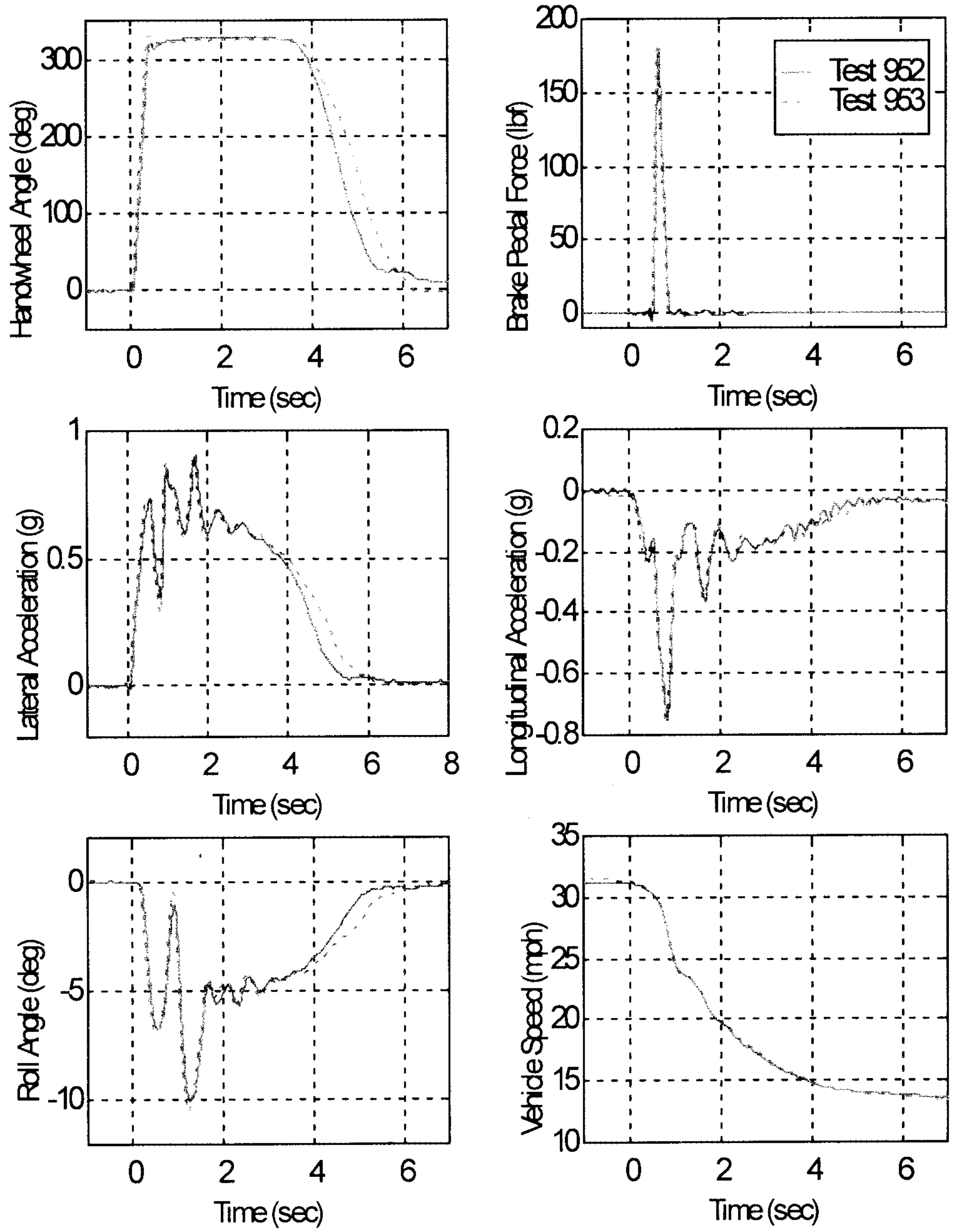

Figure 4: J-Turn with Pulse Braking test inputs and outputs for two tests performed with the Chevrolet Tracker during Phase III-B of Rollover Research

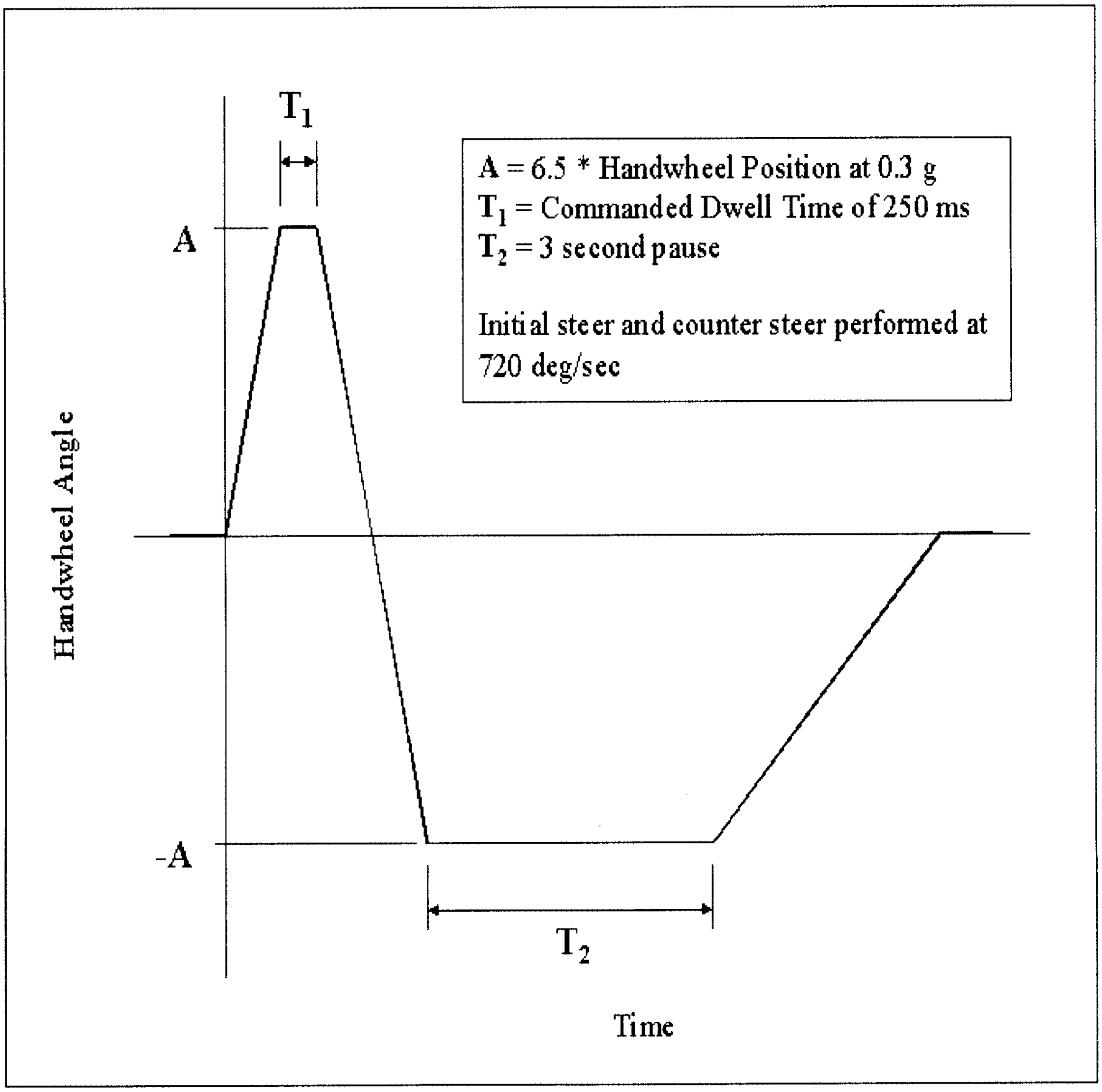

Figure 5: Fixed Timing Fishhook maneuver description

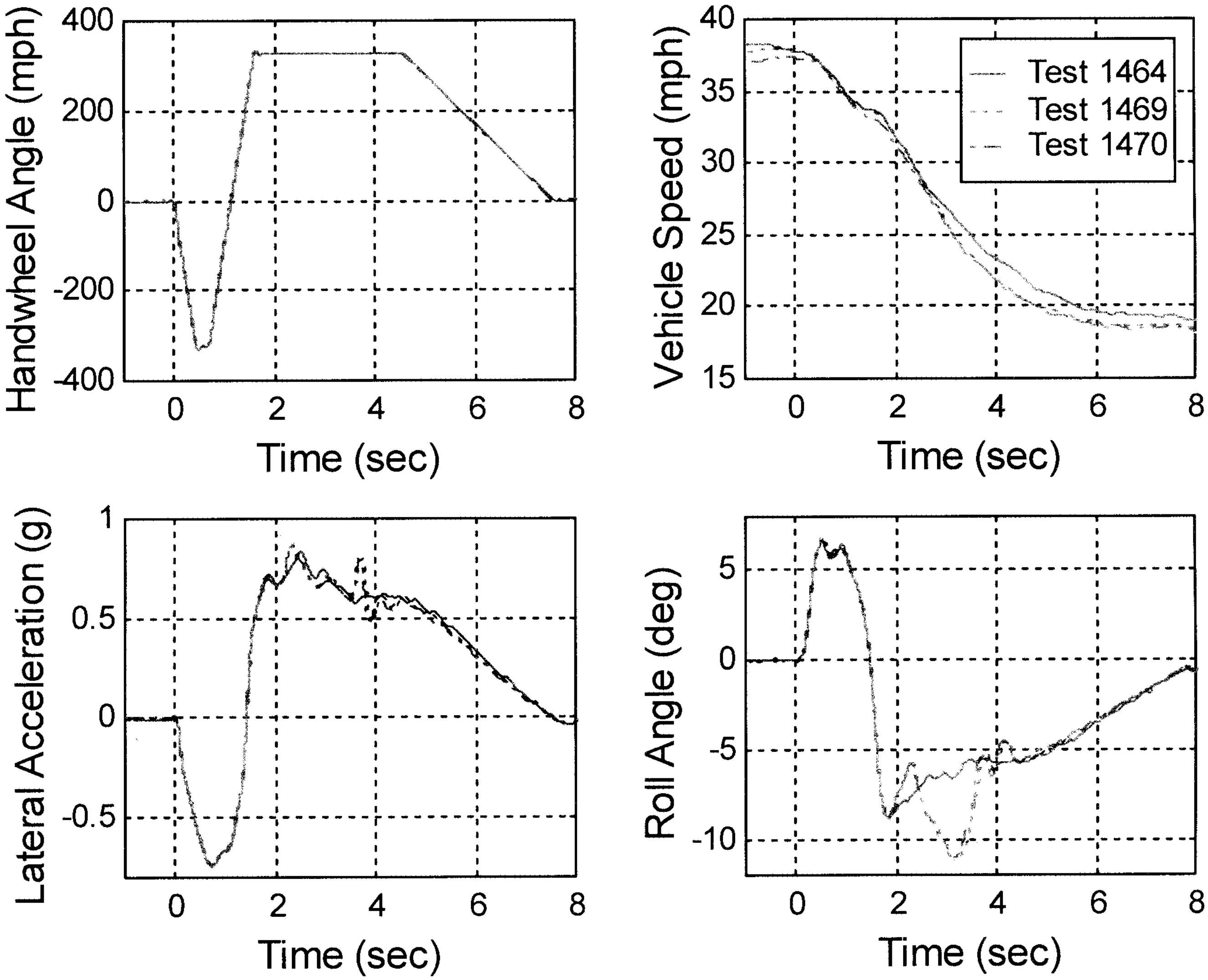

Figure 6: Fixed Timing Fishhook test inputs and outputs for three tests performed with the Chevrolet Blazer

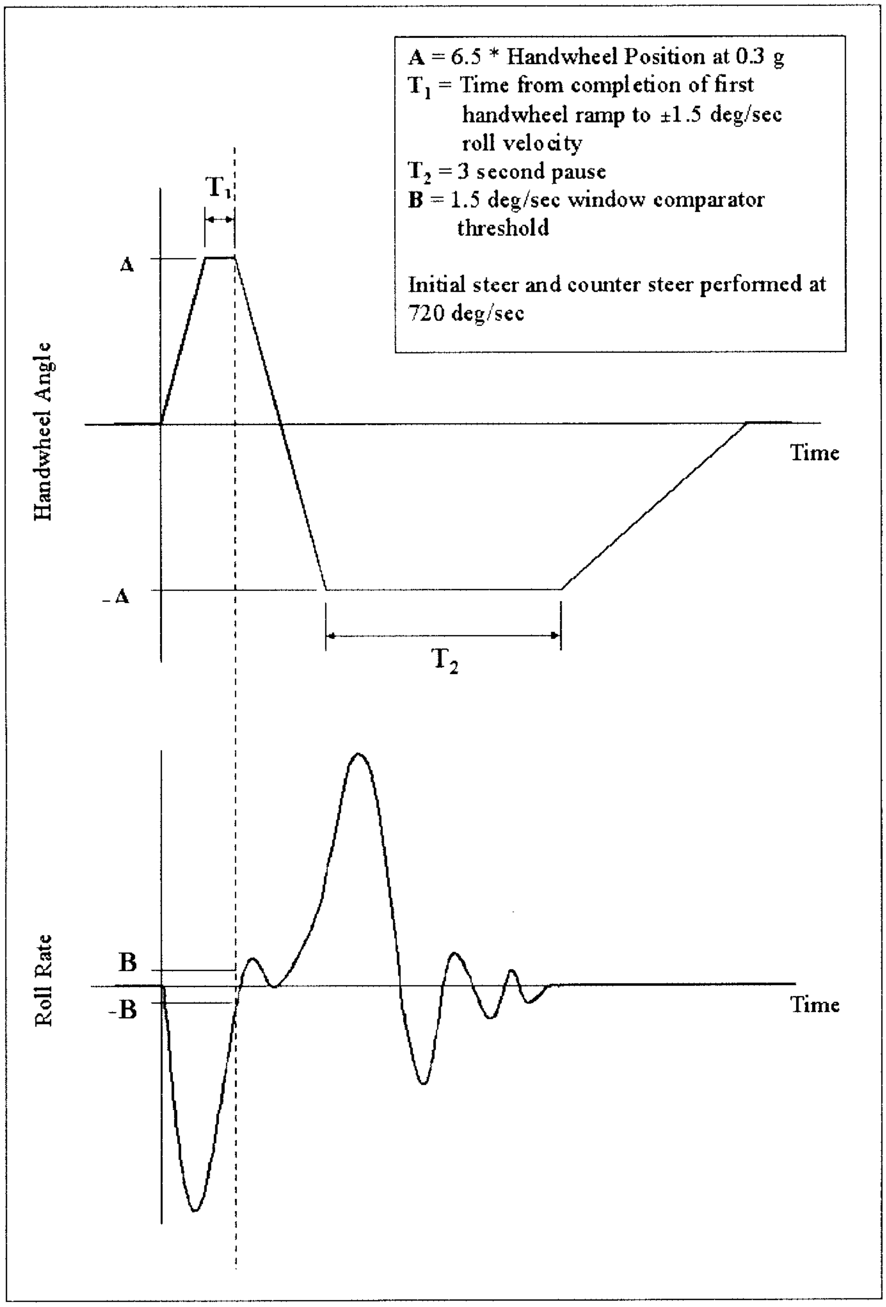

Figure 7: Roll Rate Fishhook maneuver description

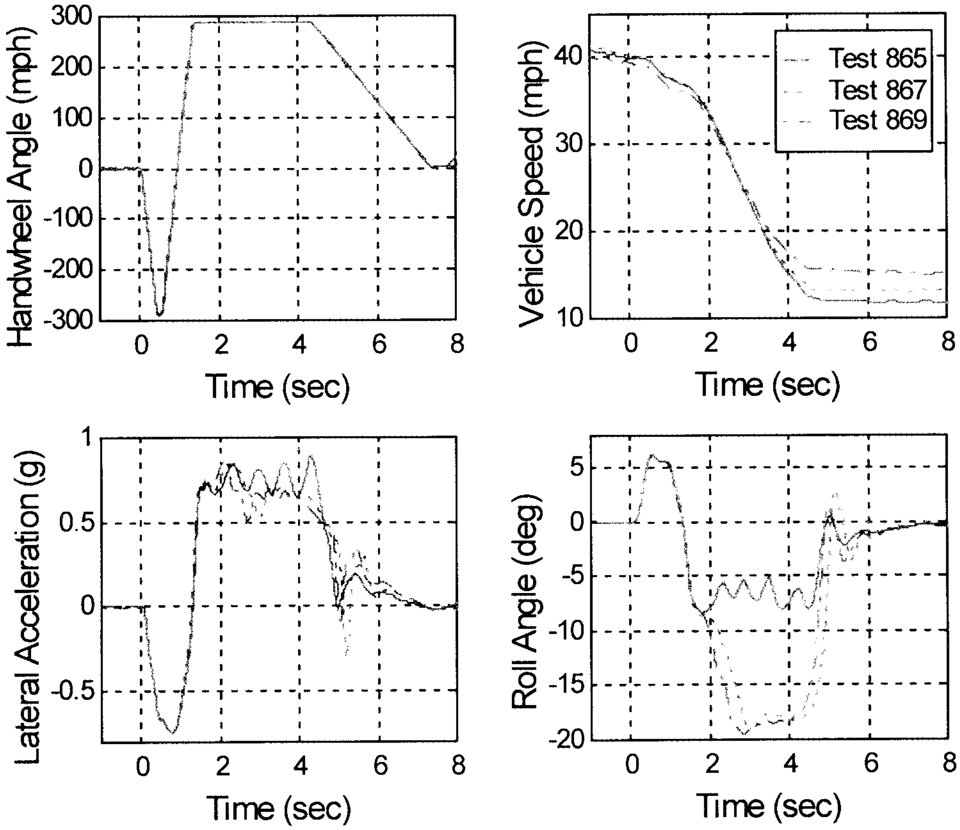

Figure 8: Roll Rate Feedback Fishhook test inputs and outputs for three tests performed with the Toyota 4Runner with yaw stability control disabled

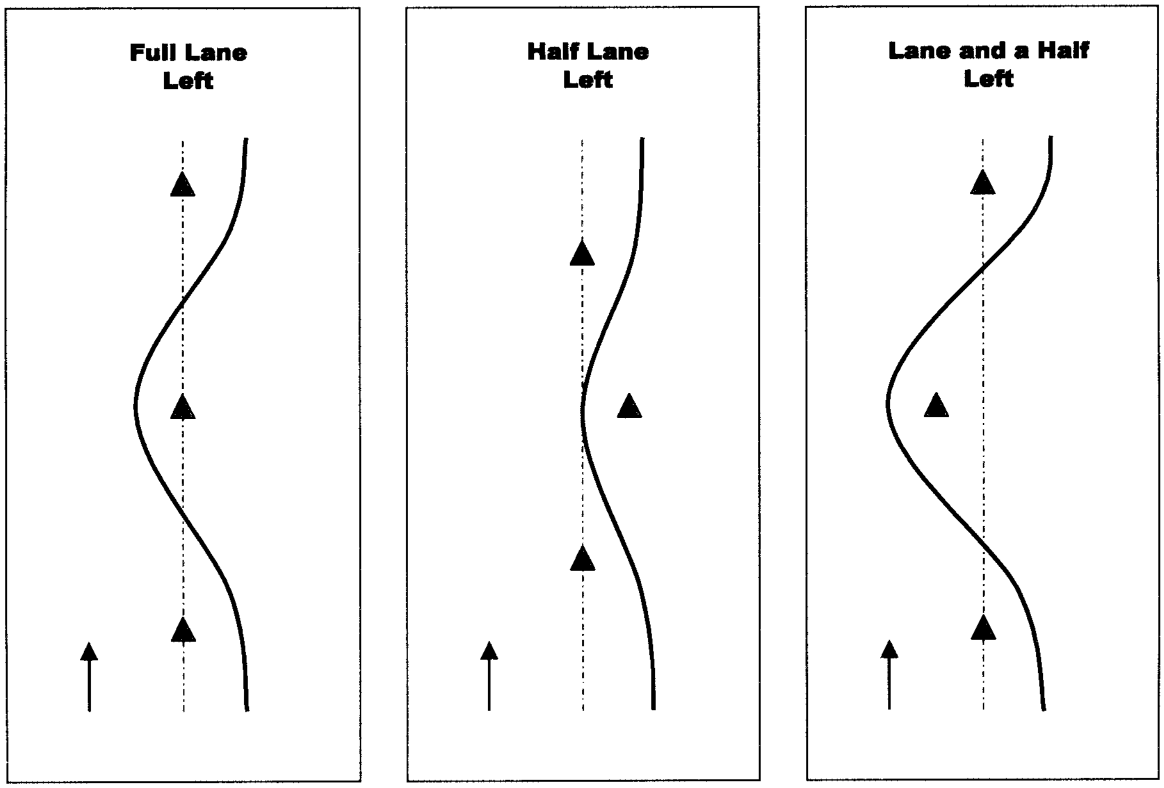

Figure 9: Ford Path Specific Double Lane Change Course

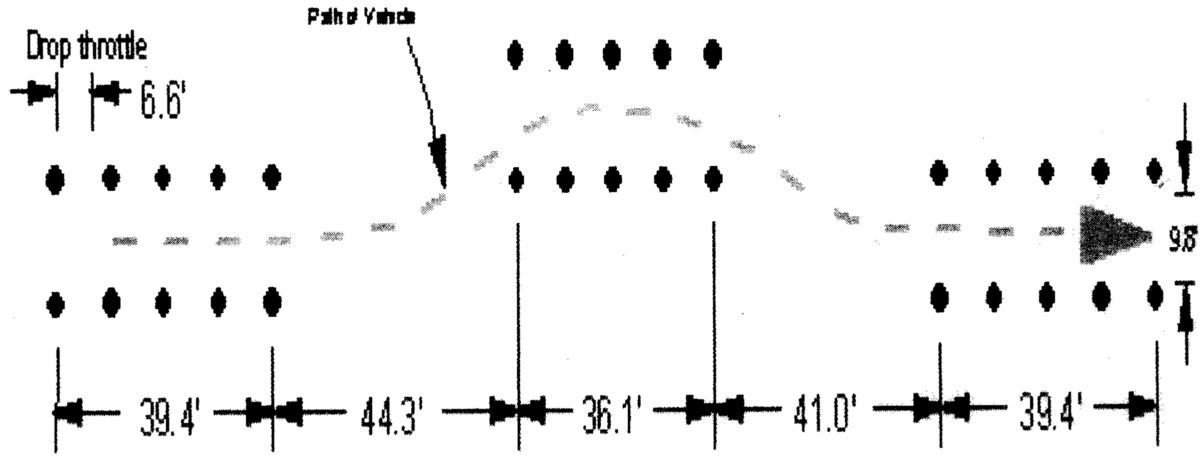

Figure 10: The ISO 3888 Part 2 Double Lane Change Course

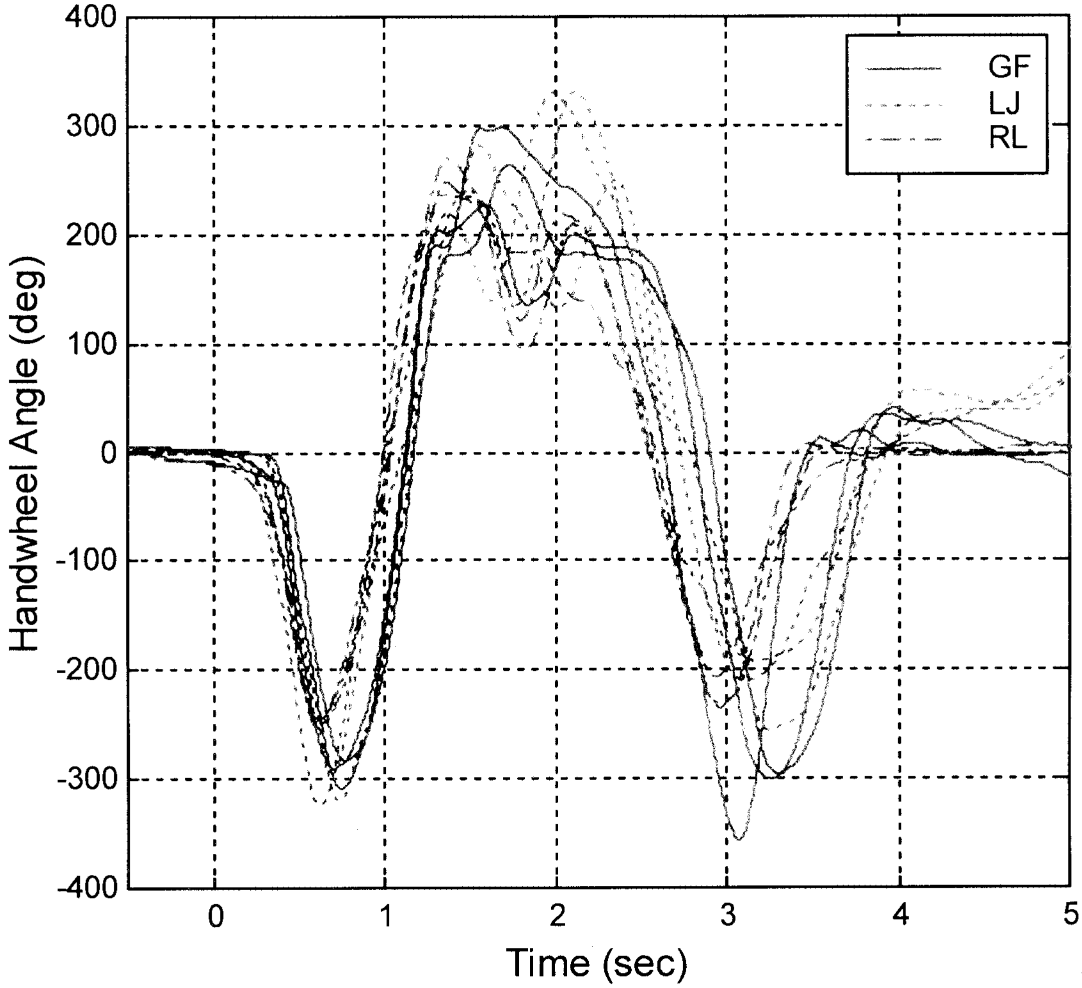

Figure 11: Handwheel input repeatability observed during ISO 3888 Part 2 Double Lane Change testing performed with the Chevrolet Blazer

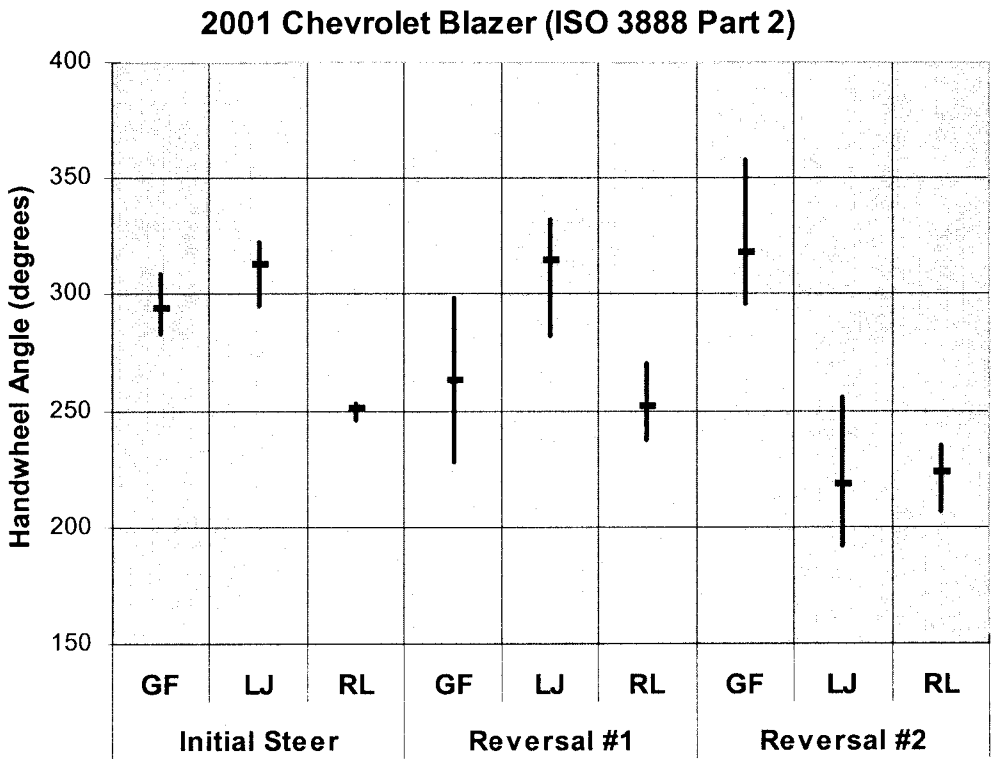

Figure 12: Handwheel input repeatability observed during ISO 3888 Part 2 Double Lane Change testing performed with the Chevrolet Blazer

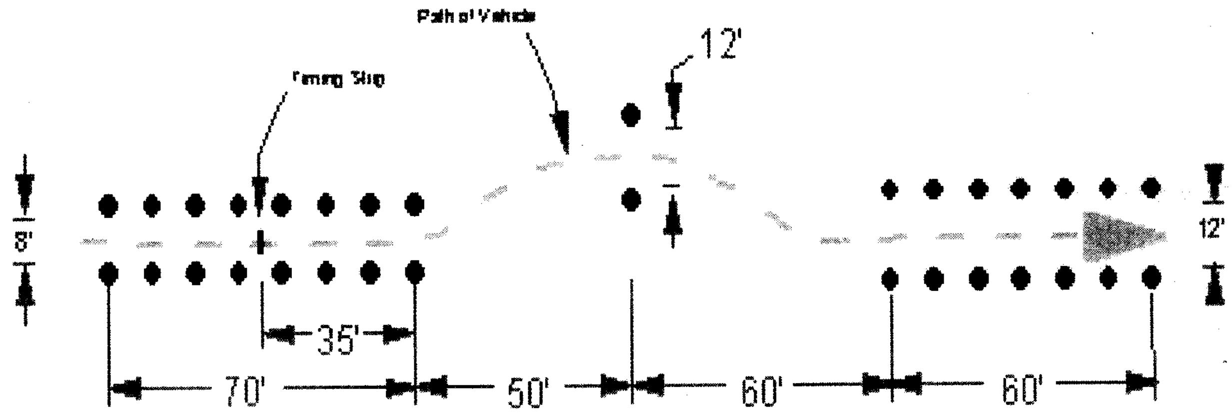

Figure 13: The Consumers Union Short Course Double Lane Change

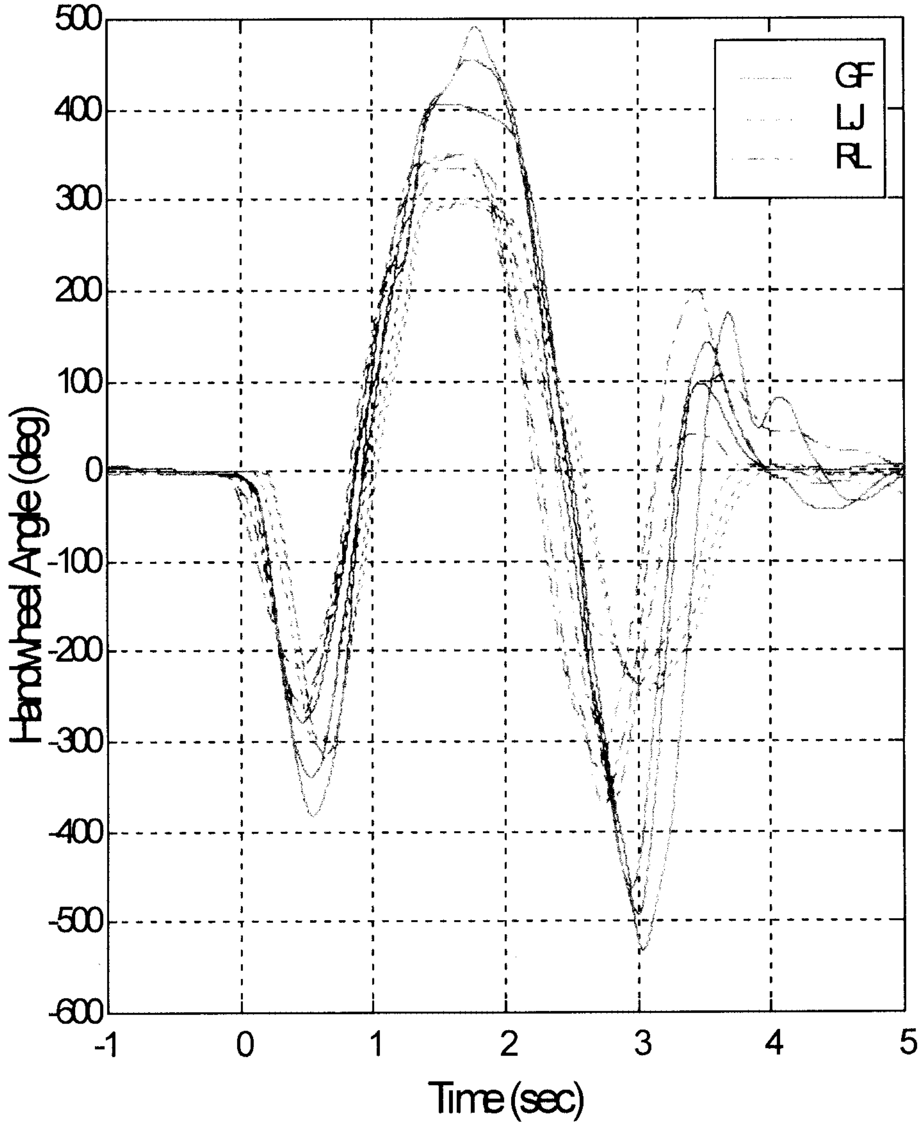

Figure 14: Handwheel input repeatability observed during Consumers Union Short Course testing performed with the Chevrolet Blazer.

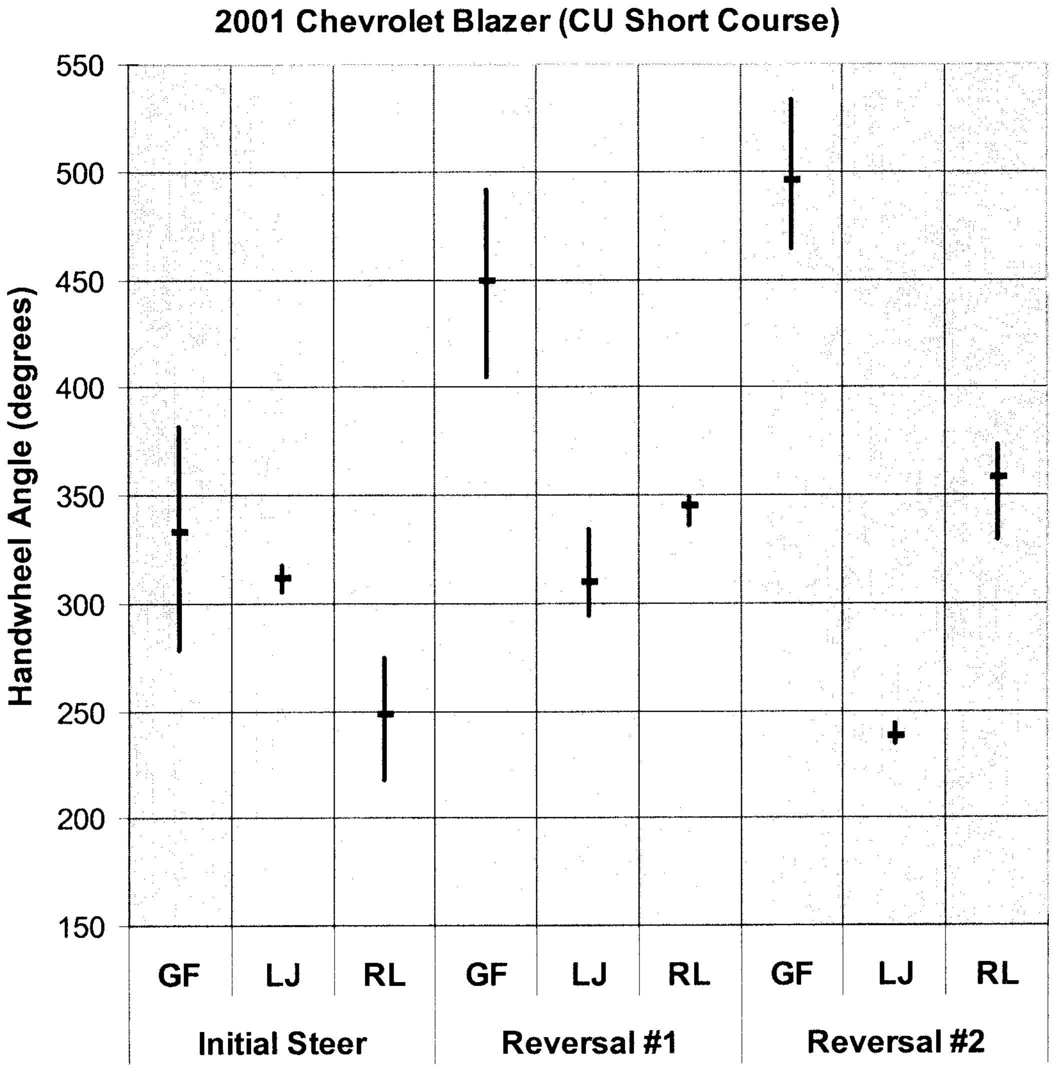

Figure 15: Handwheel input repeatability observed during Consumers Union Short Course Double Lane Change testing performed with the Chevrolet Blazer

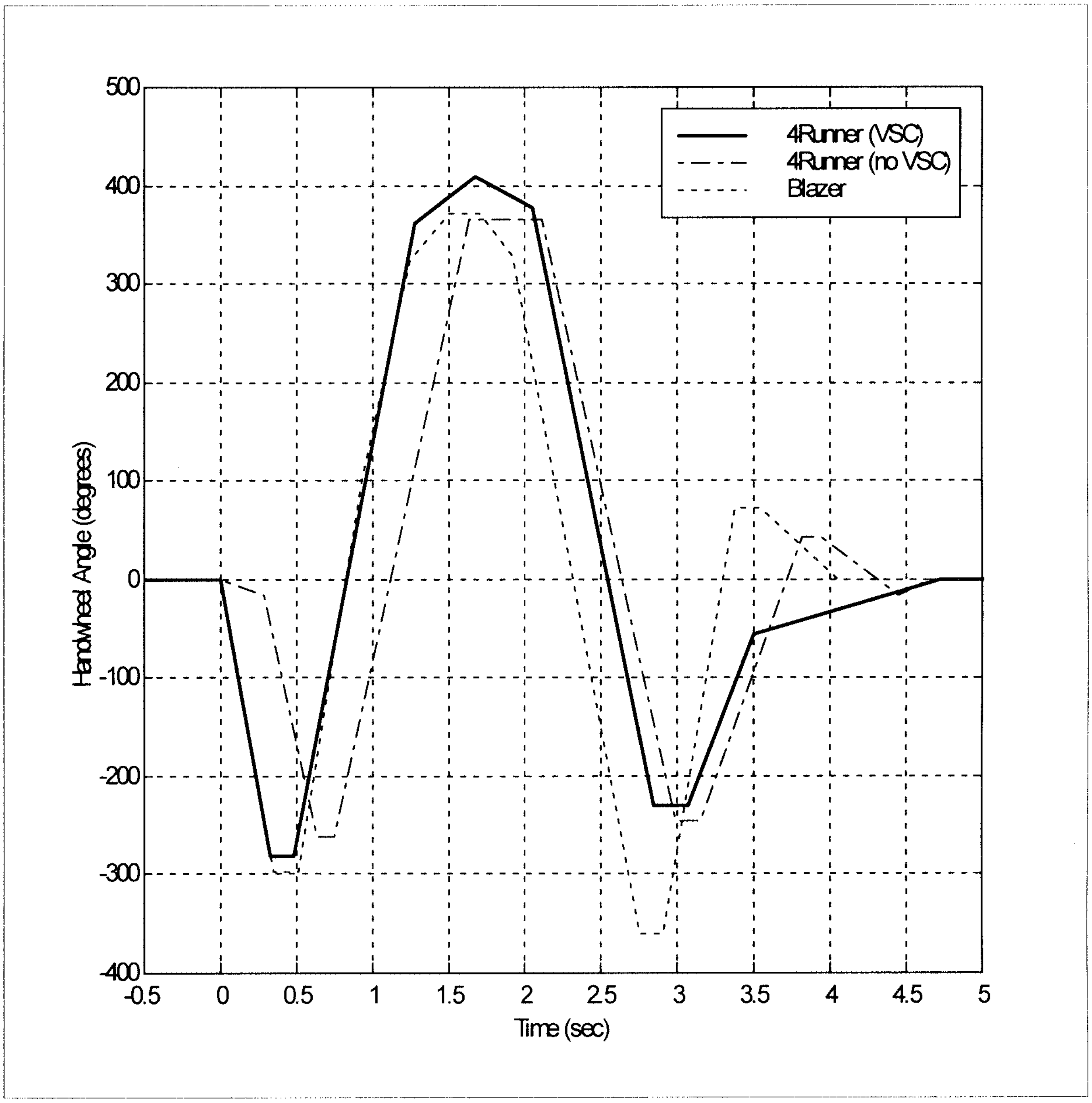

Figure 16: Consumers Union Short Course Pseudo-Double Lane Change Steering Inputs

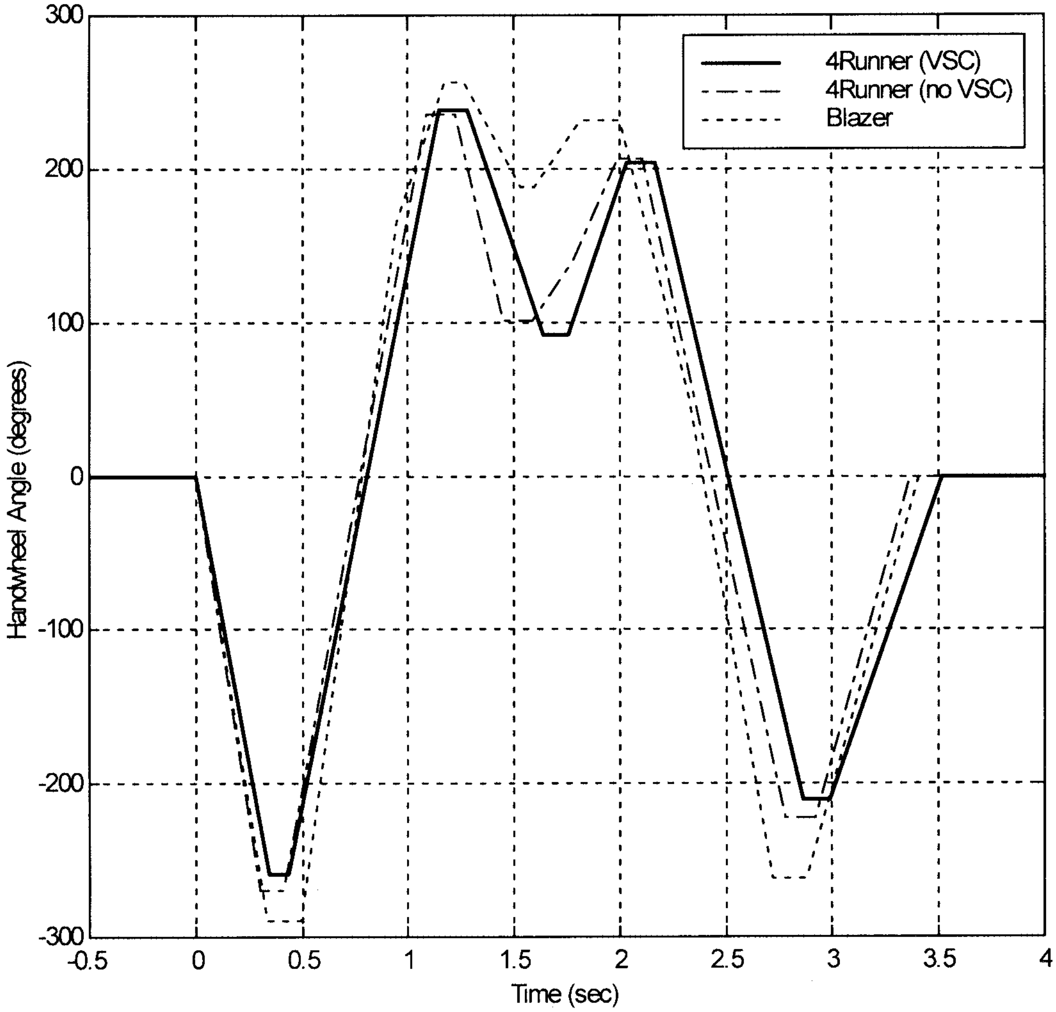

Figure 17: ISO 3888 Part 2 Pseudo-Double Lane Change Steering Inputs

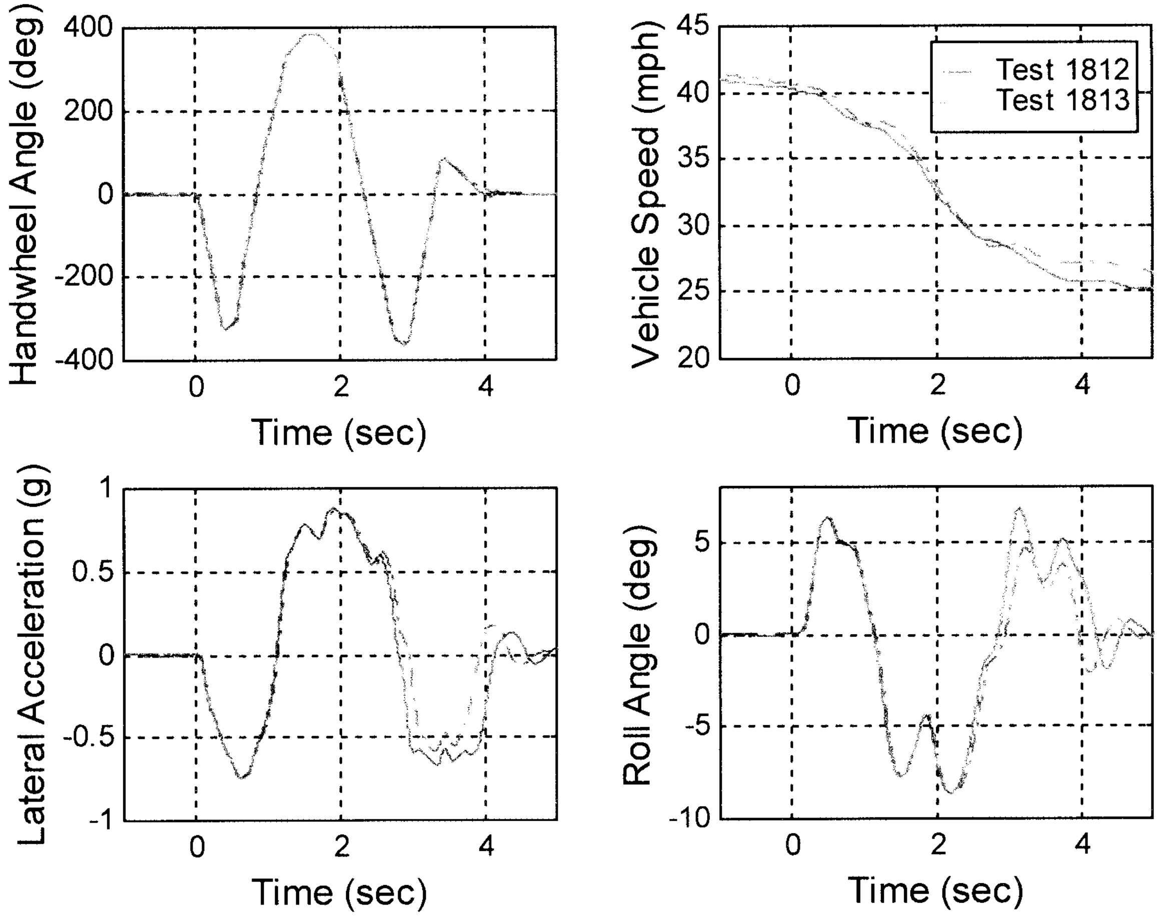

Figure 18: Open-Loop Pseudo-Double Lane Change test inputs and outputs for two tests performed with the Chevrolet Blazer

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