NHTSA'S NCAP ROLLOVER RESISTANCE RATING SYSTEM

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ABSTRACT

Starting in the 2004 model year, the National Highway Traffic Safety Administration (NHTSA) improved the rollover resistance ratings in its New Car Assessment Program (NCAP) consumer information by adding a dynamic maneuver test. NHTSA had provided rollover resistance ratings in the 2001 – 2003 model years based solely on the Static Stability Factor (SSF) measurement of vehicles. The ratings express the risk of a vehicle rolling over in the event of a single vehicle crash, the type of crash in which most rollovers occur. The SSF, which is determined by a vehicle's center of gravity height and track width, had proved to be a powerful predictor of rollover risk based on a linear regression study of rollover rates of 100 vehicle models in 224,000 single vehicle crashes ($R^2 = 0.88$).

The TREAD Act required NHTSA to change its rollover resistance ratings to use a dynamic maneuver test, and the 2004 and later NCAP rollover resistance ratings use both SSF and a dynamic maneuver. This paper describes the development of the risk prediction model used for present rating system. Twenty-five vehicles were tested using two highly objective automated steering maneuvers (J-turn and Fishhook) at two levels of passenger loading. A logistic regression risk model was developed based on the rollover outcomes of 86,000 single-vehicle crashes involving the make/models that were tested. The vehicles were characterized by their SSF measurements and binary variables indicating whether or not they had tipped up during the maneuver tests. It was found that the Fishhook test in the heavy (5 passenger equivalent) load was the most useful maneuver test for predicting rollover risk. The relative predictive powers of the SSF measurement and the Fishhook test were established by a logistic regression model operating on the rollover outcomes of real-world crash data. This model was used to predict the rollover rates of vehicles in the 2004 and 2005 NCAP program based on their SSF measurements and Fishhook maneuver test performance. The information in this paper first appeared in NHTSA's Federal Register notice [1] that established the NCAP rollover resistance rating system for model year 2004.

INTRODUCTION

Prior NCAP Program and the TREAD Act

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 2001-2003 NCAP rollover resistance ratings were based on the Static Stability Factor (SSF) of a vehicle, which is the ratio of one half its track width to its center of gravity (C.G.) height. After an evaluation of some driving maneuver tests in 1997 and 1998, NHTSA chose to use SSF instead of any driving maneuvers to characterize rollover resistance. NHTSA chose SSF as the basis of NCAP ratings because it represents the first order factors that determine vehicle rollover resistance in the vast majority of rollovers which 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, but such crashes represent less than five percent of rollover crashes [2].

At the time, NHTSA believed it was necessary to choose between SSF and driving maneuver tests as the basis for rollover resistance ratings. SSF was chosen because it had a number of advantages: it 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. NHTSA also considered the fact that an improvement in SSF represents an increase in rollover resistance in both tripped and untripped circumstances while maneuver test performance can be improved by reduced tire traction and certain implementations of electronic stability control that it believes are much less likely than SSF improvements to increase resistance to tripped rollovers.

Congress directed the agency to enhance the NCAP rollover resistance rating program. 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 was to be carried out by November 1, 2002.

Research and Public Comment on Dynamic Rollover Tests

On July 3, 2001, NHTSA published a Request for Comments notice (66 FR 35179) regarding its research plans to assess a number of possible dynamic rollover tests. The notice discussed the possible advantages and disadvantages of various approaches that had been suggested by manufacturers, consumer groups, and NHTSA’s prior research. 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. The principal theme of the comments was a sharp division of opinion about whether the dynamic rollover test should be a closed loop maneuver test like the ISO 3888 double lane change that emphasizes the handling properties of vehicles or whether it should be an open loop maneuver like a J-Turn or Fishhook that are limit maneuvers in which vulnerable vehicles would actually tip up. Ford recommended a different type of closed loop lane change maneuver in which a path-following robot or a mathematical correction method would be used to evaluate all vehicles on the same set of paths at the same lateral acceleration. It used a measurement of partial wheel unloading without tip-up at 0.7g lateral acceleration as a performance criterion in contrast to the other closed loop maneuver tests that used maximum speed through the maneuver as the performance criterion. Another unique comment was a recommendation from Suzuki to use a sled test developed by Exponent Inc. to simulate tripped rollovers.

The subsequent test program [3] (using four SUVs in various load conditions and with and without electronic stability control enabled on two of the SUVs) showed that open-loop maneuver tests using an automated steering controller could be performed with better repeatability of results than the other maneuver tests. The J-Turn maneuver and the Fishhook maneuver (with steering reversal at maximum vehicle roll angle) were found to be the most objective tests of the susceptibility of vehicles to maneuver-induced on-road rollover. Except for the Ford test, the closed loop tests were found not to measure rollover resistance. Instead, the evaluation criterion of maximum maneuver entrance speed measured just prior to entering a double lane change assessed vehicle agility. None of the test vehicles tipped up during runs in which they maintained the prescribed path even when loaded with roof ballast to experimentally reduce their rollover resistance. The speed scores of the test vehicles in the closed loop maneuvers were found to be unrelated to their resistance to tip-up in the open-loop maneuvers that actually caused tip-up. The test vehicle that was clearly the poorest performer in the maneuvers that caused tip-ups achieved the best score (highest speed) in the ISO 3888 and CU short course double lane change, and one vehicle improved its score in the ISO 3888 test when roof ballast was added to reduce its rollover resistance.

Due to the non-limit test conditions and the averaging necessary for stable wheel force measurements, the wheel unloading measured in the Ford test appeared to be more quasi-static (as in driving in a circle at a steady speed or placing the vehicle on a centrifuge) than dynamic. Sled tests were not evaluated because NHTSA believed that SSF already provided a good indicator of resistance to tripped rollover.

National Academy of Sciences Study

During the time NHTSA was evaluating dynamic maneuver tests in response the TREAD Act, the National Academy of Sciences (NAS) was conducting a study of the SSF-based rollover resistance ratings and was directed to make recommendations regarding driving maneuver tests. NHTSA expected the NAS recommendations to have a strong influence on TREAD-mandated changes to NCAP rollover resistance ratings.

When NHTSA proposed the prior (SSF only) rollover resistance ratings in June 2000, vehicle manufacturers generally opposed it because they believed that SSF as a measure of rollover resistance is too simple since it does not include the effects of suspension deflections, tire traction and electronic stability control (ESC). In addition, the vehicle manufacturers argued that the influence of vehicle factors on rollover risk is too slight to warrant consumer information ratings for rollover resistance. In the conference report of the FY2001 DOT Appropriations Act, Congress permitted NHTSA to move forward with its rollover rating program, but directed the agency to fund a National Academy of Sciences (NAS) 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 available at the end of February 2002 [4].

The NAS study found that SSF is a scientifically valid measure of rollover resistance for which the underlying physics and real-world crash data are consistent with 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 dynamic tests the NAS recommended would be driving maneuvers used to assess "transient vehicle behavior leading to rollover."

The NAS study also made recommendations concerning the statistical analysis of rollover risk and the representation of ratings. It recommended that NHTSA use logistic regression rather than linear regression for analysis of the relationship between rollover risk and SSF, and it recommended that NHTSA consider a higher-resolution representation of the relationship between rollover risk and SSF than is provided by a five-star rating system.

NHTSA published a Federal Register notice on October 7, 2002 (67 FR 62528) that proposed to modify the NCAP rollover resistance ratings to satisfy the requirements of the TREAD Act and to align it with the recommendation of the NAS report. NHTSA chose the J-Turn and Fishhook maneuver (with roll rate feedback) as the dynamic maneuver tests because they were the type of limit maneuver tests that could directly lead to rollover as recommended by the NAS. NHTSA also proposed to use a logistic regression analysis to determine the relationship between vehicle properties and rollover risk, as recommended by the NAS.

DYNAMIC MANEUVER TESTS OF 25 VEHICLES

The original NCAP rollover resistance ratings predicted the rate of rollovers per single vehicle crash based on the SSF of vehicles. Stars were used to express rollover risk in rate increments of 10% (i.e., 2 stars for a predicted rollover rate between 30 and 40%, 3 stars for a predicted rollover rate between 20 and 30%, etc.). The relationship between rollover rate and SSF was determined using a linear regression between the logarithm of SSF and the actual rollover rates of 100 vehicle make/models [5]. The rollover rates were determined from 224,000 state crash reports and were corrected for differences between vehicles in demographic and road condition variables reported by the states.

The idea for improving the prediction of rollover rate (the risk model) using dynamic maneuver tests was to describe the vehicle by its SSF plus a number of variables resulting from the vehicle's behavior in the dynamic maneuvers. In that way, the risk model would consider more than just the geometric properties of the vehicle. Four binary variables were anticipated. They would describe whether the vehicle tipped up or did not in the J-turn and in the Fishhook maneuver, each performed with the vehicle in two passenger load configurations. The risk model for predicting rollover rate on the basis of SSF plus dynamic test results would be determined using logistic regression between the rollover outcomes of state crash reports of single vehicle crashes of a number of vehicles and the new set of vehicle attributes (SSF plus dynamic test variables). The expression of rollover risk by stars would continue with the same relationship between the number of stars and the predicted rollover rate.

The linear regression, SSF only, risk model used crash data on 100 vehicles, but it was impractical to perform maneuver tests on that many vehicles to develop the present risk model. This section presents an overview of the test maneuvers and the results for the subset of 25 vehicles selected for developing the logistic regression risk model. A more extensive account of the test program is contained in the Phase VI and VII rollover research report [6]. The NHTSA J-Turn and Fishhook (with roll rate feedback) maneuver tests were performed for 25 vehicles representing four vehicle types including passenger cars, vans, pickup trucks and SUVs. NHTSA chose mainly high production vehicles that spanned a wide range of SSF values, using vehicles NHTSA already owned where possible. Except for four 2001 model year vehicles NHTSA purchased new, the vehicle suspensions were rebuilt with new springs and shock absorbers, and other parts as required for all the other vehicles included in the test program.

J-Turn Maneuver

The NHTSA J-Turn maneuver represents an

avoidance maneuver in which a vehicle is steered away from an obstacle using a single input. The maneuver is similar to the J-Turn used during NHTSA's 1997-98 rollover research program and is a common maneuver in test programs conducted by vehicle manufacturers and others. Often the J-Turn is conducted with a fixed steering input (handwheel angle) for all test vehicles. In its 1997-98 testing, NHTSA used a fixed handwheel angle of 330 degrees. During the development of the present tests, NHTSA developed an objective method of specifying equivalent handwheel angles for J-Turn tests of various vehicles, taking into account their differences in steering ratio, wheelbase and linear range understeer properties [3]. Under this method, one first measures the handwheel angle that would produce a steady-state lateral acceleration of 0.3 g at 50 mph on a level paved surface for a particular vehicle. In brief, the 0.3 g value was chosen because the steering angle variability associated with this lateral acceleration is quite low and there is no possibility that stability control intervention could confound the test results. Since the magnitude of the handwheel position at 0.3 g is small, it must be multiplied by a scalar to have a high maneuver severity. In the case of the J-Turn, the handwheel angle at 0.3 g was multiplied by eight. When this scalar is multiplied by handwheel angles commonly observed at 0.3 g, the result is approximately 330 degrees. Figure 1 illustrates the J-Turn maneuver in terms of the automated steering inputs commanded by the programmable steering machine. The rate of the handwheel turning is 1000 degrees per second.

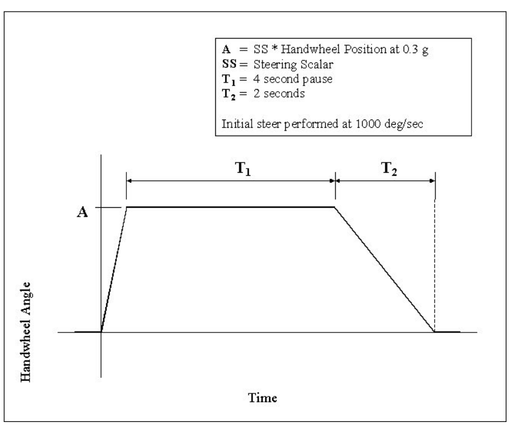

Figure 1. NHTSA J-turn maneuver description.

To begin the maneuver, the vehicle was driven in a straight line at a speed slightly greater than the desired entrance speed. The driver released the throttle, coasted to the target speed, and then triggered the commanded handwheel input. The nominal maneuver entrance speeds used in the J-Turn maneuver ranged from 35 to 60 mph, increased in 5 mph increments until a termination condition was achieved. Termination conditions were simultaneous two inch or greater lift of a vehicle's inside tires (two-wheel lift) or completion of a test performed at the maximum maneuver entrance speed without two-wheel lift. If two-wheel lift was observed, a downward iteration of vehicle speed was used in 1 mph increments until such lift was no longer detected. Once the lowest speed for which two-wheel lift could be detected was isolated, two additional tests were performed at that speed to monitor two-wheel lift repeatability.

Fishhook Maneuver

The Fishhook maneuver uses steering inputs that approximate the steering a driver acting in panic might use in an effort to regain lane position after dropping two wheels off the roadway onto the shoulder. NHTSA has often described it as a road edge recovery maneuver. As pointed out by some commenters, it is performed on a smooth pavement rather than at a road edge drop-off, but its rapid steering input followed by an over-correction is representative of a general loss of control situation. The original version of this test was developed by Toyota, and variations of it were suggested by Nissan and Honda. NHTSA has experimented with several versions since 1997, and the present test includes roll rate feedback in order to time the counter-steer to coincide with the maximum roll angle of each vehicle in response to the first steer.

Figure 2 describes the Fishhook maneuver in terms of the automated steering inputs commanded by the programmable steering machine and illustrates the roll rate feedback. The initial steering magnitude and countersteer magnitudes are symmetric, and are calculated by multiplying the handwheel angle that would produce a steady state lateral acceleration of 0.3 g at 50 mph on level pavement by 6.5. When this scalar is multiplied by handwheel angles commonly observed at 0.3 g, the result is approximately 270 degrees. This is equivalent to the 270 degree handwheel angle used in earlier forms of the maneuver but, as in the case of the J-Turn, the procedure above is an objective way of compensating for differences in steering gear ratio, wheelbase and understeer properties between vehicles. The fishhook maneuver dwell times (the time between completion of the initial steering ramp and the initiation of the countersteer) are defined by the roll motion of the vehicle being evaluated, and can vary on a test-to-test basis. This is made possible by having the steering machine monitor roll rate (roll velocity). If an initial steer is to the left, the steering reversal following completion of the first handwheel ramp occurs when the roll rate of the vehicle first equals or goes below 1.5 degrees per second. If an initial steer is to the right, the steering reversal following completion of the first handwheel ramp occurs when the roll rate of the vehicle first equals or exceeds -1.5 degrees per second. The handwheel rates of the initial steer and countersteer ramps are 720 degrees per second.

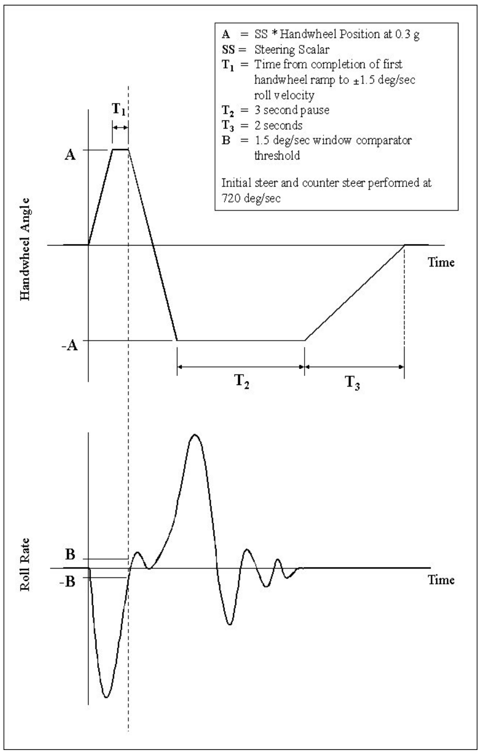

Figure 2. NHTSA Fishhook maneuver description.

To begin the maneuver, the vehicle was driven in a straight line at a speed slightly greater than the desired entrance speed. The driver released the throttle, coasted to the target speed, and then triggered the commanded handwheel input described in Figure 2. The nominal maneuver entrance speeds used in the fishhook maneuver ranged from 35 to 50 mph, increased in 5 mph increments until a termination condition was achieved. Termination conditions included simultaneous two inch or greater lift of a vehicle's inside tires (two-wheel lift) or completion of a test performed at the maximum maneuver entrance speed without two-wheel lift. If two-wheel lift was observed, a downward iteration of vehicle speed was used in 1 mph increments until such lift was no longer detected. Once the lowest speed for which two-wheel lift could be detected was isolated, two additional tests were performed at that speed to check two-wheel lift repeatability.

NHTSA observed that during the Fishhook tests, excessive steering caused some vehicles to reach their maximum roll angle response to the initial steering input before it had been fully completed (this is essentially equivalent to a "negative" T_1 in Figure 2). Since dwell time duration can have a significant effect on how the Fishhook maneuver's ability to produce two-wheel lift, excessive steering may stifle the most severe timing of the counter steer for some vehicles. In an attempt to better insure high maneuver severity, a number of vehicles that did not produce two-wheel lift with steering inputs calculated with the 6.5 multiplier were also tested with lesser steering angles by reducing the multiplier to 5.5. This change increased the dwell times observed during the respective maneuvers. Some vehicles tipped up in Fishhook maneuvers conducted at the lower steering angle (5.5 multiplier) but not at the higher steering angle (6.5 multiplier). NHTSA adopted the practice of performing Fishhook maneuvers at both steering angles for NCAP.

Loading Conditions

The vehicles were tested in each maneuver in two load conditions in order to create four levels of stringency in the suite of maneuver tests. The light load was the test driver plus instrumentation in the front passenger seat, which represented two occupants. A heavier load was used to create a higher level of stringency for each test. In our NPRM, NHTSA announced that the heavy load would include 175 lb anthropomorphic forms (water dummies) in all rear seat positions. During the test of the 25 vehicles, it became obvious that heavy load tests were being run at very unequal load conditions especially between vans and other vehicles (two water dummies in some vehicles but six water dummies in others). While very heavy passenger loads can certainly reduce rollover resistance and potentially cause special problems, crashes at those loads are too few to greatly influence the overall rollover rate of vehicles. Over 94% of van rollovers in our 293,000 crash database occurred with five or fewer occupants, and over 99% of rollovers of other vehicles occurred with five or fewer occupants. The average passenger load of vehicles in our crash database was less than two: 1.81 for vans; 1.54 for SUVs; 1.48 for cars; and 1.35 for pickup trucks. In order to use the maneuver tests to predict real-world rollover rates, it seemed inappropriate to test the vehicles under widely differing loads that did not correspond to the real-world crash statistics. Therefore, the tests used to develop a statistical model of rollover risk were changed to a uniform heavy load condition of three water dummies (representing a 5-occupant loading) for all vehicles capable of carrying at least five occupants. Some vehicles were loaded with only two water dummies because they were designed for four occupants. For pickup trucks, water dummies were loaded in the bed at approximately the same height as a passenger in the front seat.

Test Results

The test results in Table 1 (presented on the next page) reflect the performance as described for a heavy load condition representing five occupants except for the Ford Explorer 2DR, the Chevrolet Tracker and Metro that were designed for only four occupants, and the Honda CRV, Honda Civic and Chevrolet Cavalier that could not be loaded to the 5-occupant level without exceeding a gross axle weight rating because of the additional weight of the outriggers.

Each test vehicle in Table 1 represented a generation of vehicles whose model year range is given. Twenty-four of the vehicles were taken from 100 vehicle groups whose 1994-98 crash statistics in six states were the basis of the present SSF based rollover resistance ratings. The nominal SSFs used to describe the vehicle groups in the prior statistical studies are given. While there were some variations between the SSFs of the individual test vehicles and the nominal vehicle group SSF values, the nominal SSFs were retained for the present statistical analyses because they represent vehicles produced over a wide range of years in many cases and provide a simple comparison between the risk model presented in this notice and that discussed in the previous notices.

The X's under the various test maneuver names indicate which vehicles tipped up during the tests. Eleven of the twenty-five vehicles tipped up in the Fishhook maneuver conducted in the heavy condition. The heavy condition represented a five-occupant load for all vehicles except the six mentioned above that were limited to a four-occupant load by the vehicle seating positions and GVWR. All eleven were among the sixteen test vehicles with SSFs less than 1.20. None of the vehicles with higher SSFs tipped up in any test maneuver. The Fishhook test under the heavy load clearly had the greatest potential to cause tip-up. The groups of vehicles that tipped up in other tests were subsets of the larger group of eleven that tipped up in the Fishhook Heavy test. There were seven vehicles in the group that tipped up in the J-Turn Heavy test, six of which also tipped up in the Fishhook Light test. The J-Turn Light test had the least potential to tip up vehicles. Only three vehicles tipped up, all of which had tipped up in every other test.

ROLLOVER RISK MODEL

In its study of NHTSA's rating system for rollover resistance [4], the National Academy of Sciences (NAS) recommended that NHTSA use logistic regression rather than linear regression for analysis of the relationship between rollover risk and SSF. Logistic regression has the advantage that it operates on every crash data point directly rather than requiring that the crash data be aggregated by vehicle and state into a smaller number of data points. For example, NHTSA now has state data reports of about 293,000 single-vehicle crashes of the hundred vehicle make/models (together with their corporate cousins) whose single-vehicle crashes NHTSA have been tracking in six states. The logistic regression analysis of this data would have a sample size of 293,000, producing a narrow confidence interval on the repeatability of the relationship between SSF and rollover rate. In contrast, the linear regression analysis operates on the rollover *rate* of the hundred vehicle make/models in each of the six states. It produces a maximum sample size of only 600 (100 vehicles times six states) minus the number of samples for which fewer than 25 crashes were available for determining the rollover rate (a data quality control practice). Confidence limits computed for a data sample size of 600 will be much greater than those based on a sample size of 293,000. On average, each sample in the linear regression analysis was computed from over 400 crash report samples. However, ordinary techniques to compute the confidence intervals of linear regression results do not take into account the actual sample size represented by aggregated data. The statistical model created to combine SSF and dynamic test information in the prediction of rollover risk was computed by means of logistic regression as recommended by the NAS. Logistic regression is well suited to the correlation with crash data of vehicle properties that include both continuous variables like SSF and binary variables like tip-up or no tip-up in maneuver tests.

NHTSA had previously considered logistic regression during the development of the SSF based rating system [4], but found that it consistently under-predicted the actual rollover rate at the low end of the

Table 1. Dynamic Maneuver Test Results (the X indicates tip-up observed).

Model Range, Make / Model	Nominal Static Stability Factor	Fishhook Light (FL) (2 occ.)	Fishhook Heavy (FH) (5 occ.)	J-Turn Light (JL) (2 occ.)	J-Turn Heavy (JH) (5 occ.)
’92 – ‘00 Mitsubishi Montero 4WD	0.95	**X**	**X**	--	**X**
’95 – ’03 Chevrolet Blazer 2WD	1.02	**X**	**X**	--	**X**
’95 – ’01 Ford Explorer 2dr 2WD	1.06	--	--	--	--
’95 – ’01 Ford Explorer 4dr 4WD	1.06	--	**X**	--	--
’96 – ’00 Toyota 4Runner 4WD	1.06	--	**X**	--	--
’93 – ’97 Ford Ranger p/u 4WD	1.07	**X**	**X**	**X**	**X**
’88 – ’97 Jeep Cherokee 4WD	1.08	--	--	--	--
’95 – ’02 Acura SLX / Isuzu Trooper 4WD	1.09	**X**	**X**	**X**	**X**
’88 – ’98 Ford Aerostar 2WD	1.10	**X**	**X**	**X**	**X**
’88 – ’02 Chevrolet Astro 2WD	1.12	--	**X**	--	--
’89 – ’98 Chevrolet/Geo Tracker 4WD	1.13	--	**X**	--	--
’88 – ’98 Chevrolet K1500 p/u 4WD	1.14	--	--	--	--
’93 – ’97 Ford Ranger p/u 2WD	1.17	--	**X**	--	**X**
’97 – ’02 Ford F-150 p/u 2WD	1.18	--	--	--	--
’97 – ’01 Honda CR-V 4WD	1.19	**X**	**X**	--	**X**
’88 – ’96 Ford F-150 p/u 2WD	1.19	--	--	--	--
’88 – ’95 Dodge Caravan / Plymouth Voyager 2WD	1.21	--	--	--	--
’88 – ’98 Chevrolet C1500 p/u 2WD	1.22	--	--	--	--
’96 – ’00 Dodge Caravan / Plymouth Voyager 2WD	1.23	--	--	--	--
’95 – ’98 Ford Windstar 2WD	1.24	--	--	--	--
’95 – ’01 Chevrolet / Geo Metro	1.29	--	--	--	--
’88 – ’94 Chevrolet Cavalier	1.32	--	--	--	--
’91 – ’96 Chevrolet Caprice	1.40	--	--	--	--
’88 – ’95 Ford Taurus	1.45	--	--	--	--
’92 – ’95 Honda Civic	1.48	--	--	--	--
Total Tip-ups		**6**	**11**	**3**	**7**

SSF range where the rollover rates are high. The NAS study acknowledged this situation and gave the example of another analysis technique (non-parametric) that made higher rollover rate predictions at the low end of the SSF scale. NHTSA decided to first examine ways to improve the fit of the logistic regression model to the actual rollover rates in the simpler model with SSF as the only vehicle attribute before expanding the logistic regression model to predict rollover rates using maneuver test results and SSF as vehicle attributes. In this way, the addition of maneuver test results is more likely to have an effect that reflects the additional information it represents on rollover causation.

Appendix II of reference [1] discusses the details of seeking a mathematical transformation of SSF to improve the accuracy of logistic regression models. NHTSA found that logistic regression on the transformation "Log(SSF – 0.9)" rather than on SSF directly computed a risk model whose predictions of rollovers per single-vehicle crash more closely matched the relationship between vehicle SSF and actual rollover rates observed in state crash data. NHTSA sought to optimize the accuracy of the predictions in the SSF range between 1.0 and 1.25 that includes the vehicles with the highest rollover rates, even at the expense of accuracy in predicting the low rollover rates at high end of the SSF scale.

The risk model that resulted from this exercise is equivalent to the SSF-based rating system used for 2001-2003 NCAP rollover resistance ratings except that it was computed using logistic regression rather than linear regression as the statistical technique. Figure 3 compares the logistic regression model and linear regression model formerly used for NCAP ratings. The linear regression model is not in the form of a straight line because it also operated on a transformation of SSF (Log(SSF) in this case). The logistic regression model is the more accurate at lower end of the SSF range, and the linear regression model is the more accurate at the upper end of the SSF range. But, the two curves are quite similar.

A good logistic regression risk model using SSF only was the starting point for models using dynamic variables together with SSF. The dynamic maneuver test results (tip-up or no tip-up in each maneuver/load combination in Table 1) were used as four binary dynamic variables in the logistic regression analysis. The dynamic variables were entered in addition to SSF to describe the vehicle. The same driver and road variables from state crash reports discussed above were used. The state crash report data for twenty four of the vehicles used in the logistic regression analysis with dynamic maneuver test variables was a subset of the database of 293,000 single-vehicle crashes described above. One extra vehicle was added for the maneuver tests that was not among the 100 vehicle groups NHTSA had studied previously, but state crash report data from the same years and states was obtained for it. However, the database with SSF and dynamic maneuver test results was much smaller than the 293,000 sample size available for the logistic regression model with SSF only. Its sample size was 96,000 single-vehicle crashes of 25 vehicles including 20,000 rollovers.

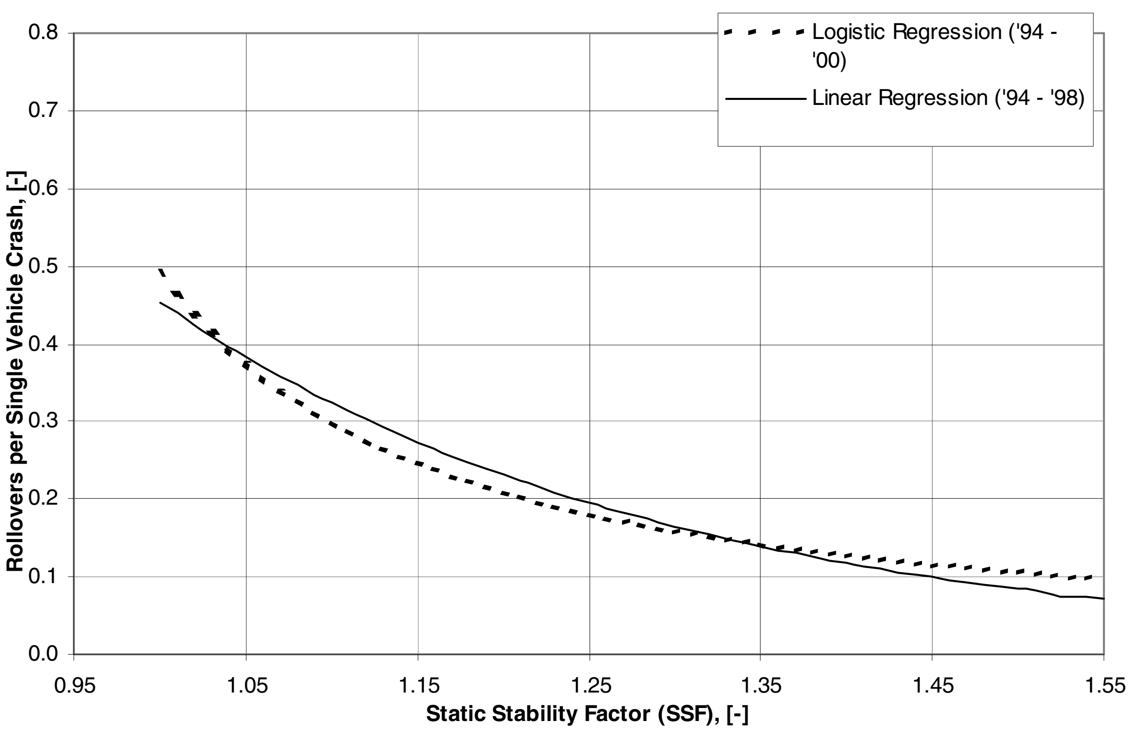

Figure 3. Logistic regression risk model using SSF only and linear regression risk model for 2001-2003 NCAP Rollover Resistance.

First, NHTSA tried each dynamic variable separately in conjunction with SSF. The models using variables for performance in the Fishhook Heavy and J-Turn Heavy maneuvers predicted a greater rollover risk for those vehicles that tipped up in the maneuver test. However, the models using variables for performance in the Fishhook Light and J-Turn Light maneuvers predicted a greater rollover risk for vehicles that did not tip up.

NHTSA does not believe vehicles that tip up in the least severe maneuvers are actually safer than those that do not tip up. A more rational interpretation is that the numbers of vehicle tipping up in these maneuvers were too few to establish a definitive correlation. Only three vehicles tipped up in the J-Turn Light maneuver, and six vehicles tipped up in the Fishhook Light maneuver. Only one more vehicle tipped up in the J-Turn Heavy maneuver than in the Fishhook Light, and the prediction of the model with J-Turn Heavy was consistent with expectations that tip-up in the test predicts greater rollover risk. However, the extra vehicle in the J-Turn Heavy tip-up group was the Ford Ranger 2WD with a very large sample size of over 8,000 single-vehicle crashes (nearly 10 percent of the entire data base).

Next NHTSA computed a logistic regression model combining SSF with the dynamic variables for both maneuvers, Fishhook Heavy and J-Turn Heavy, that were observed to have a directionally correct result when entered into the model individually. The variable for J-Turn Heavy was rejected by the logistic regression program as not statistically significant in the presence of the Fishhook Heavy variable. In other words, the predictions based on tip-up in the Fishhook Heavy maneuver do not change whether or not the vehicle also tips up in the J-Turn Heavy maneuver.

Figure 4 shows the final model that uses Fishhook Heavy as the only necessary dynamic variable. This model has a risk prediction for vehicles that tip up in the dynamic maneuver tests based on the greatest number of vehicles possible in our 25 vehicle data base. All 11 vehicles that tipped up in any maneuver are represented on the tip-up curve, and the 14 vehicles without tip-up are represented on the other curve. The risk curve in Figure 4 representing vehicles that tipped up in the Fishhook Heavy maneuver is very similar to the logistic regression model based on SSF only in Figure 3 (that was based on the rollover rates of 100 vehicles). This result is

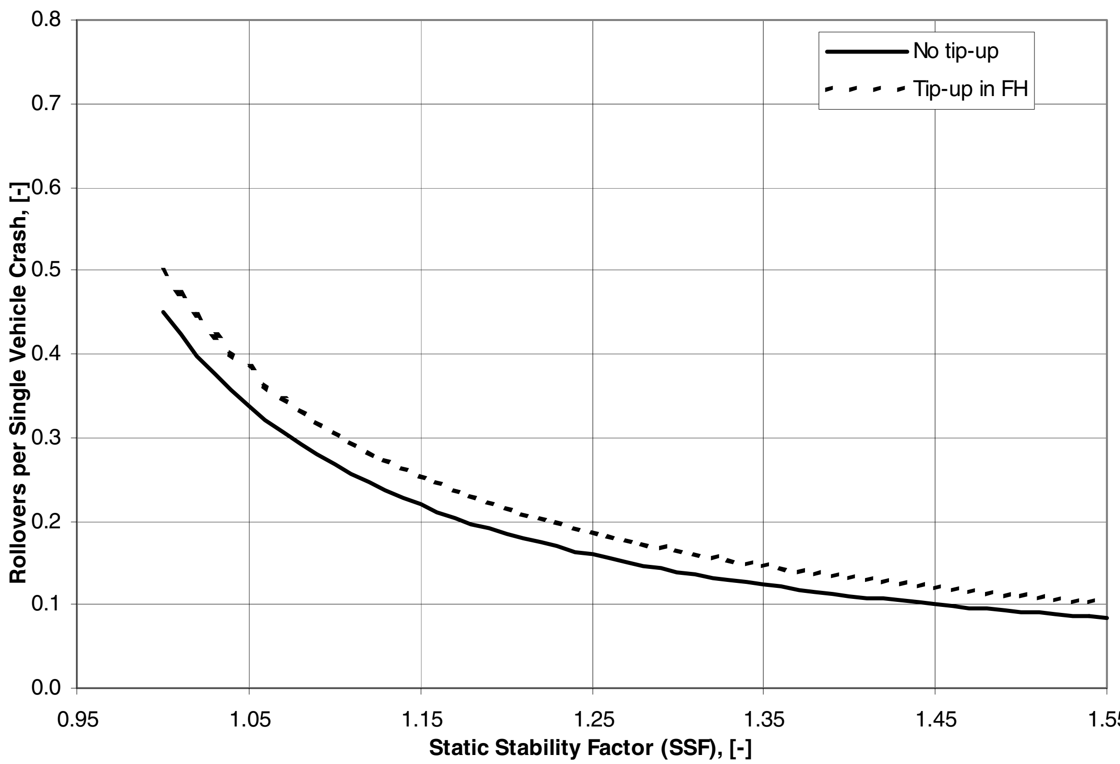

Figure 4. Final dynamic model using Fishhook maneuver with heavy load (FH) as the only necessary dynamic variable.

logical because the SSF only model was optimized for best fit in the 1.00 to 1.25 SSF range that included all vehicles tipping up in dynamic maneuver tests. Also, the fact that the risk curve of the logistic regression model in Figure 3 that was based on the SSF of 100 vehicles closely matches the risk curve in Figure 4 that was based on 11 vehicles that tipped up in the dynamic tests suggests that the curve in Figure 4 is robust. However, the small difference in Figure 4 between the risk curve for vehicles that tip up in the dynamic test and the risk curve for those that do not tip up suggests that the predictive power of tip-up in the dynamic test may not be great.

Our testing and logistic regression analysis was sufficient to assign a greater rollover risk to vehicles that tipped up in the most severe maneuver than to those that did not tip up at all. However, the extra risk was small, and NHTSA were not able to distinguish a rollover risk difference between vehicles that tipped up in the less severe Fishhook maneuver with a two occupant load from those that tipped up only with a five occupant load. In general, vehicles that tip up in the Fishhook maneuver with a two occupant load also tip up at a slower entry speed in the Fishhook maneuver with a five occupant load than those that do not. Therefore, our data does not allow us to distinguish rollover risk differences between vehicles on the basis of maneuver entry speed for tip-up. The objective of using different load conditions and different maneuvers instead of different speeds in a single maneuver to provide a range of test severity was to reduce the sensitivity of the result to differences in pavement friction and to extraneous factors such as tire wear.

It is noteworthy that the final rollover risk model required results from only the Fishhook maneuver. This is an advantage from the standpoint of minimizing the practical problems of the effects of tire wear during a test series and of deviations from uniformity of surface friction at a test facility. The Fishhook maneuver produces less wear on the test tires and requires only about 2 or 3 lane widths of uniform test surface versus 10 or more lane widths for the J-Turn maneuver. The commenters also considered it more representative of a real driving situation than the J-Turn.

CONCLUSIONS

The logistic regression risk model based on SSF only in Figure 3 is practically identical to the rollover rate prediction versus SSF in the final dynamic model of Figure 4 for vehicles that tip up in the Fishhook maneuver. Therefore, the only difference in NCAP rollover resistance ratings for those vehicles in the new “dynamic” rating system is attributable to the change in analysis technique from linear regression to logistic regression. For vehicles that do not tip up in the Fishhook maneuver, the predicted rollover rate is lower by a modest amount that would increase the “star rating” for the vehicle by somewhat less than “half a star.” This improvement would change the star rating only for those vehicles whose predicted rollover rate would otherwise fall near a “star boundary.” However, the NCAP web site presentation has been revised to show the predicted rollover rate of a vehicle and the range of predicted rollover rates for that class of vehicle as well as its star rating. In that way, the lower rollover risk of vehicles that do not tip up in the Fishhook maneuver is reported even if it did not change the star rating.

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