U.S. DEPARTMENT OF TRANSPORTATION

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

LABORATORY TEST PROCEDURE

FOR

ROLLOVER STABILITY MEASUREMENT FOR NEW CAR ASSESSMENT PROGRAM (NCAP)

STATIC STABILITY FACTOR (SSF) MEASUREMENT

MARCH 2013

U.S. Department of Transportation
National Highway Traffic Safety Administration
1200 New Jersey Avenue SE
Washington, DC 20590

LABORATORY TEST PROCEDURE
TABLE OF CONTENTS

1. PURPOSE AND APPLICATION

This Laboratory Test Procedure defines the procedure for making vehicle Static Stability Factor (SSF) measurements. The National Highway Traffic Safety Administration (NHTSA) uses measured SSF values to assign star ratings to vehicles as part of its New Car Assessment Program (NCAP).

NHTSA provides contractor laboratories with Laboratory Test Procedures as guidelines for obtaining test data. The purpose of the NHTSA Laboratory Test Procedures is to present a uniform testing and data recording format and provide suggestions for the use of specific equipment and procedures.

2. GENERAL REQUIREMENTS

SSF is defined by the following relationship:

$$SSF = \frac{T}{2H}$$

where T is the average track width of the vehicle and H is the center of gravity height of the vehicle. The SSF values used by NHTSA to make NCAP ratings are based on T and H measurements of vehicles loaded in a Driver Only configuration. Determining SSF requires making accurate measurements of T and H.

The factors T and H shall be measured for the Driver Only loading condition (for the SSF) and possibly, at NHTSA's discretion, for other vehicle loading conditions.

3 SECURITY

The contractor shall protect and segregate the data obtained during this testing. No information concerning the vehicle testing program shall be released to anyone except the Contracting Officer's Technical Representative (COTR), unless specifically authorized by the COTR or the COTR's Branch or Division Chief.

RULES FOR CONTRACTORS

A. All communications with vehicle manufacturers shall be referred to the NHTSA. The contractor shall not release measurement data without the permission of the NHTSA.

B. Occasional visits by the vehicle manufacturer's representative(s), for observing a vehicle measurement, shall be permitted with prior approval from the COTR. NHTSA and/or contractor personnel must escort the representative(s).

C. Photographs and videotapes of the test vehicle, associated test equipment and test event will be allowed under the supervision of the NHTSA or the contractor. However, test personnel shall not be included in any photographic coverage, and videotaping of vehicle preparation must be approved by NHTSA. The contractor's personnel shall not respond to any questions from the manufacturer's representatives regarding the NHTSA test. All questions shall be referred to the COTR, a NHTSA representative present at the test site, or to NHTSA.

D. The contractor shall permit public access to and inspection of the test vehicles during the times specified by the NHTSA COTR. NHTSA shall advise interested parties that such access and inspection shall be limited to a specified day, and specified hours and require prior approval from the NHTSA. The contractor shall refer all visit requests from vehicle manufacturer's representatives to the NHTSA. This service shall be included as an incidental part of the NCAP program and will not result in any additional cost to the NHTSA. The contractor shall make his own arrangements with interested parties for expenses incurred beyond providing access and inspection services.

4 TEST SCHEDULING AND VEHICLE PROCUREMENT

The contractor will schedule the tests, based on availability of vehicles from various sources. These sources may include dealerships and rental agencies. Test vehicles may also be provided by NHTSA. Vehicles may be obtained from private owners only after approval by the COTR. Such privately owned vehicles shall have been recently acquired as new vehicles.

5 FACILITIES AND EQUIPMENT

5.1 CENTER OF GRAVITY HEIGHT MEASUREMENT

The facility used for measuring the center of gravity height (H) shall be capable of making measurements on all production passenger cars and light trucks up to 10,000 lb including the weight of the simulated driver and other occupant and cargo loading.

H shall be measured using the stable pendulum configuration. A representative commercial device that uses this configuration is the Vehicle Inertia Measurement Facility (VIMF) (1,2). Using this method, the vehicle is driven or loaded onto a stiff platform and restrained to the platform at its trim height. The trim height in this case is the normal ride height of the vehicle for the given test loading condition. The platform is connected to a pivot that is above the combined vehicle and platform center-of-gravity height. The platform and vehicle are then tilted in a stable manner by applying known weights at either end of the platform. Detailed error analyses have indicated that this method provides very good results for H measurements (1). The stable pendulum methodology utilized for VIMF testing is consistent with ISO 10392: Road Vehicles – Determination of Centre of Gravity (3).The platform used to make H measurements shall be rigid enough so that the platform deflection during any part of the test shall not exceed 0.1 inch. Platform deflection shall be either measured or calculated and the result shall be used to compensate the H calculation.

The subject vehicles shall be firmly restrained to the rigid platform so that the vehicle's H does not significantly change during the measurements. The restraint system shall allow less than 0.2 in. horizontal motion relative to the platform during the H measurement. The vehicle's horizontal motion relative to the platform shall be measured and accounted for when calculating H. Additionally, the weights and center-of-gravity locations of all components and mechanisms used to restrain the vehicle to the platform must be accounted for in the calculation of H.

The system shall be able to measure H to within a repeatability tolerance of 0.5%.

As part of the H measurement, an accurate vehicle and axle weight is needed. The tolerance for each axle shall be ± 2 lb.

5.2 TRACK WIDTH MEASUREMENT

The steering wheel and steered road wheels should be set straight ahead (zero steer angle) when measuring the track width. In practice, the road wheel steering angles will not be exactly zero, but should be set to near zero. The equipment used to measure the track width of a vehicle consists of two Tire Edge Determination Tools (Section 8.2) and a high-quality tape measure. The final Track Width measurement uses the average of multiple independent measurements in order to minimize errors associated with small steer angles.

6 INSTRUMENTATION AND CALIBRATION REQUIREMENTS

6.1 CENTER OF GRAVITY HEIGHT MEASUREMENT

The facility used to measure H shall be calibrated yearly using a calibration standard. This calibration standard shall have at least two configurations – simulating the weight, weight distribution and H of: (1) a typical passenger car and (2) a typical pickup truck. The facility shall be capable of measuring the H of the standard to within an accuracy tolerance of 0.5% of the theoretical H.

All individual transducers used in the H computation (e.g. platform tilt angle and vehicle relative motion transducers) shall be calibrated annually. The accuracy of the individual transducers used must be consistent with the requirement that the overall H measurement be reliable to 0.5 %. The results of the individual transducer and scale calibrations as well as the overall measurement verifications using the calibration standard shall be documented in a concise report as part of the annual calibration.

The scales used to measure the vehicle and axle weight shall be calibrated annually and shall be accurate to ± 1 lb per wheel or ± 2 lb per axle.

Reference (1) lists a number of data quality checks that are used to assure that the data being collected is reliable.

6.2 TRACK WIDTH MEASUREMENT

The measuring tool used for the track width measurement shall have a least count (division spacing in the case of a tape measure) of no greater than 0.1 inch, providing for measurements to be recorded with a resolution of 0.05 inches.

7 PHOTOGRAPHIC DOCUMENTATION

Two digital images shall be made of each vehicle tested: a driver's side view, and an oblique passenger's side/front view. When applicable, a digital image of a dealer's sticker should be made. These images shall each have a resolution of at least 300 pixels per inch. The images shall be delivered to the COTR using a standard method (e.g. CD, DVD or ftp) of the COTR's choosing.

8 TEST EXECUTION

8.1 VEHICLE PREPARATION

Test vehicles should be new or in as-new condition. Prior to testing, each test vehicle's fuel tank shall be filled with fuel (topped-off by continuing to fill after each of three automatic stops on the pump, the "Three-Click Method"), and its tires inflated to the vehicle manufacturer's recommended pressure. The tires shall be those specified for the vehicle by the manufacturer. Adjustable seats shall be set to the mid-point of the possible travel. If a height adjustment is available, the seat shall be at its lowest position. Vehicle information shall be recorded and reported to NHTSA. Table I contains a complete list of the items to be measured and recorded.

8.2 TRACK WIDTH MEASUREMENT

The track width measurements shall be made using the following procedure:

- Measure the track width with the vehicle in its Driver Only configuration.

- Make two Tire Edge Determination Tools as shown in Figure 1. These are modified 4-inch beams which, when placed on the floor and pushed against the tire, will define a longitudinal line on the inside or outside lower sidewall of the tire approximately 4 inches (100 mm) above the floor.

- Place the beams on the right sides of both front tires and measure the separation of the beams below the front and rear edges of the tires. Repeat this with the beams on the left sides of the front tires. This will result in a total of four measurements, the average of which is the front track width. An identical procedure is used for measuring the rear track width. Thus, a total of eight measurements are taken, the average of which is reported as the average vehicle track width (Average Track or T).

- The measurements shall be recorded with a resolution of no greater than 0.05 inches. The four front measurements shall be averaged and reported as "Track Front." Similarly, the four rear measurements shall be averaged to

compute the “Track Rear” listed. The “Average Track” is the average of Track Front and Track Rear. Since no rounding takes place in the calculations of Track Front and Track Rear, the value computed for Average Track is the same as if all eight individual measurements were averaged. The individual measurements shall be listed on the results sheets using two decimal places. The Track Front, Track Rear, and Average Track calculations shall be listed using one decimal place. The SSF shall be calculated using un-rounded numbers for the Average Track and H. Rounding shall occur only in the presentation of the SSF values.

8.3 CENTER-OF-GRAVITY HEIGHT MEASUREMENT

For both the “Driver Only” and “Loaded” vehicle conditions, the vehicle’s H shall be measured with the device described in Section 5.1. H shall be recorded using multiple measurements for each loading condition.

8.3.1 “Driver Only” Load Condition

Each test vehicle shall be loaded with an anthropomorphic test dummy or something which is representative in size, overall weight, and weight distribution of a 50th percentile human male in the driver seating position of the vehicle. An example of an appropriate anthropomorphic test dummy is a Hybrid II dummy as specified in the Code of Federal Regulations, Title 49, Part 572, Subpart B (without instrumentation). The COTR must approve of the method used to simulate the driver’s weight.

8.3.2 “Loaded” Load Condition

In addition to the “Driver Only” Load Condition, NHTSA may require that measurements be made in other vehicle loading conditions. Examples of potential loading conditions include: a fixed number of occupants, Occupant-in-every-seat loading, and loading to gross vehicle weight rating (GVWR). “Loaded” conditions, which are left to NHTSA’s discretion, will typically include appropriate anthropomorphic test dummies as described in Section 8.3.1, water dummies, and possibly other simulated cargo ballast and simulated or actual vehicle outriggers.

Table I
Vehicle Information Contained in Spreadsheets

Seq. No.
Testing sequence number for current contract

MY
Model Yea

Make, Model and Body Style
Three columns with Manufacturer's information about the test vehicle

VIN
17 Digit Vehicle Identification Number

Engine Size/Type
Vehicle engine size and type

Trans. Type
Vehicle transmission type

Drive
FWD – Front Wheel Drive
RWD – Rear Wheel Drive
4WD or 4X4 – Four Wheel Drive
4X4 – All Wheel Drive
4X2 – Two Wheel Drive

Doors
Number of doors

Significant Options
Optional equipment that may significantly affect the CG Height.
Shorthand notes: RR = Roof Rack, RB = Running Boards, SR = Sun Roof, MR = Moon Roof.

Front Tire Make/Type – Front Tire Size - Front Pressure
Rear Tire Make/Type – Rear Tire Size - Rear Pressure
These six columns contain information on the tires on the test vehicles. The tire size and type are specified, and the tire pressures are the vehicle manufacturers' specified tire pressures that were used during the tests.

Front Track - Rear Track - Average Track (T)
Front, rear and average track widths measured on test vehicles (Section 8.2)

Table I (continued)
Vehicle Information Contained in Spreadsheets

Wheelbase
Average of measured left side wheelbase and right side wheelbase (tolerance ±0.1 in.)

GVWR, GAWR Front, GAWR Rear
Gross vehicle and axle weight ratings for the test vehicle

Load
Driver (only) or Loaded. Loading conditions for "Loaded" vehicle tests are specified by NHTSA.

Test Date
Test date for the VIMF test

VIMF Test No.
VIMF test number

Roof Height
Measured height of test vehicle after loading – does not include roof rack (tolerance ±0.1 in.)

Test Weight
Measured weight of test vehicles

CG Long.
Longitudinal distance from front wheel axis (axis through the centers of the front wheels) to vehicle center of gravity location

CG Lateral
Lateral distance from vehicle centerline to vehicle center of gravity location (negative to driver's side of vehicle)

CG Height (H)
Measured height of vehicle center of gravity

T/2H (SSF for Driver Only Loading Condition)
(Average Track Width) / (2 x CG Height)

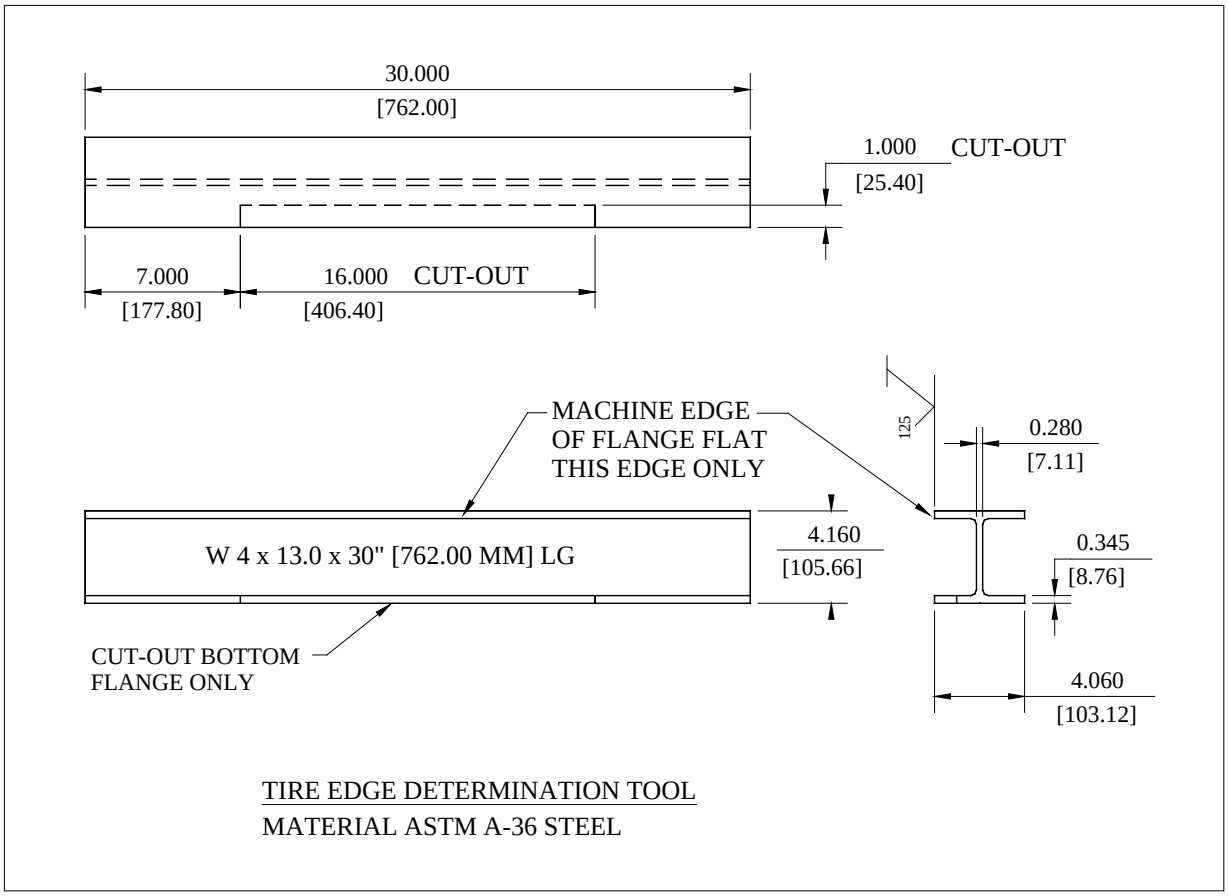

Figure 1: Tire Edge Determination Tool Used for Track Width Measurements
Dimensions in inches and [mm]

9 PRESENTATION OF RESULTS

All information will be presented in a format that has been approved by the COTR. Typically, this will involve a commercial word processing and spreadsheet format for data, and jpeg format for photographs.

The contractor shall provide the following items:

A. Periodic summary results with vehicle description, date tested, measured track widths, measured H values, and calculated SSF.

B. Final Table with vehicle information as well as T and H results. Table I contains a list of the required items that shall be provided in tabular hardcopy form and in a spreadsheet table.

C. Photographs as described in Section 7.

D. Detailed Final Report containing a list of vehicles tested, the date tested, and the contractor's test numbers for the tests (See Figure 2 for example). The Final Report shall also contain description of the test procedures used, description of the test equipment used, and the data provided by the test equipment for each test. Figure 3 contains an example of the individual Test Results Page provided for each test.

The T and H measurements shall contain more decimal places than would be warranted for these measurements if they were to stand alone. Rounding shall occur only after the SSF values have been calculated. The following represents an appropriate method for calculating the SSF:

The critical calculations listed on the Test Results Pages are Average Track (same as T used heretofore), Average C.G. Height (same as H used heretofore), and SSF. As mentioned, the Average Track is calculated from eight individual track width measurements, four for the front track and four for the rear track. Each of the eight measurements is made using a tape measure divided into tenths of an inch. The measurements are recorded to the nearest half division, which is 0.05 inches. The four front measurements are averaged using Microsoft (MS) Excel to compute the Track Front listed on the results sheets. Similarly, the four rear measurements are averaged to compute the Track Rear listed. The Average Track is the average of Track Front and Track Rear. Since no rounding takes place in the calculations of Track Front and Track Rear, the value computed for Average Track is the same as if all eight individual measurements were averaged. The individual measurements are listed on the results sheets using two decimal places. This is because the measurements are made to the nearest 0.05 inches. The Track Front, Track Rear, and Average Track calculations are listed using one decimal place. However, decimal places beyond the first are retained in MS Excel and used in the calculations for SSF. The Track Front, Track Rear, and Average Track width measurements are thought to be accurate to the nearest 0.1 inches. Based on a 60 inch Average

Track and 0.1 inches measurement accuracy, the Average Track value listed is good to an accuracy of 0.17 %. The resolution in the recorded value is 0.05 inches, which is one-half of the listed accuracy.

The Average C.G. Height listed is based on the average value calculation for the four individual C.G. Height tests (Runs #2-5 listed on the results pages). The VIMF software/database uses more than two decimal places in this calculation, and rounding to two decimal places is done for reporting purposes. The values listed on the sheets for Average C.G. Height are to the nearest 0.01 inches, with a resolution of 0.005 inches. Based on theoretical error analysis, on doing numerous repeat testing of the same vehicles, and on numerous tests done using calibration fixtures; the accuracy of the VIMF is thought to be 0.5 % or better. This means that for a 20 inch C.G. Height, the measured value is accurate to 0.1 inches, or better. Based on this fact and the significance of the VIMF measurement values that go into calculating C.G. Height, recording the Average C.G. Height using two decimal places is warranted.

The SSF values are listed on the data sheets using three decimal places. The calculations for SSF are done in MS Excel, and no rounding of the Average Track or Average C.G. Height is done prior to making these calculations. Because of this, there may be differences in the listed SSF values and the values one would obtain using the listed, rounded values for Average Track and Average C.G. Height. Doing the calculation retaining more decimals than the values listed provides the best value for SSF. The computed SSF is unaffected by the resolution issues of recording the Average Track and Average C.G. Height to the listed number of decimal places.

Since three significant figures are used to list the Average Track, the SSF should be listed to no more than three significant figures (two decimal places). NHTSA, at their discretion, may use two decimal places in reporting SSF values, which is sound practice based on the measurements and calculations made.

Seq No.	Vehicle	Date	VIMF Test No.
1	Hyundai Sonata	5/10/2010	4188
2	Toyota Sienna FWD	5/28/2010	4205
3	Toyota Sienna AWD	5/28/2010	4206
4	Infiniti M37X AWD	7/1/2010	4211
5	Kia Sorento FWD	7/14/2010	4221
6	Kia Sorento AWD	7/14/2010	4222
7	Jeep Grand Cherokee 4x4	7/23/2010	4229
8	BMW 550i	7/28/2010	4233
9	Ford Fiesta	8/9/2010	4234
10	Jeep Grand Cherokee 4x2	8/30/2010	4238
11	Honda CR-Z	9/23/2010	4258

Seq No.	Vehicle	Date	VIMF Test No.
12	Volvo XC60 AWD	10/13/2010	4269
13	Volvo XC60 FWD	10/25/2010	4273
14	Volkswagen Jetta	10/27/2010	4274
15	Honda Odyssey	10/28/2010	4276
16	Chevrolet Cruze	11/5/2010	4280
17	KIA Optima LX	1/14/2011	4300
18	Toyota Corolla	2/7/2011	4307
19	Scion tC	3/31/2011	4347
20	Chevrolet Volt	5/4/2011	4364
21	Nissan Leaf SL	6/7/2011	4402
22	Kia Sorento AWD	8/18/2011	4435

Figure 2. Example of Vehicle List

Hyundai Sonata Driver

YEAR:	2011	**DATE TESTED:**	5/10/2010
MAKE:	Hyundai	**VIMF TEST NO.:**	4188
MODEL:	Sonata		
VIN:	5NPEB4AC8BH01####	**Mfg Date:**	2/10

BODY STYLE AND TRIM:	Sedan, GLS
LOAD:	Driver
ENGINE SIZE AND TYPE:	2.4L I4
TRANSMISSION TYPE:	Auto
DRIVE:	FWD
DOORS:	4
FUEL:	Full
OPTIONAL EQUIPMENT:	

FRONT TIRE TYPE:	Kumho Solus KH24 M+S
FRONT TIRE SIZE:	P205/65R16 94H
FRONT TIRE PRESSURE:	33
REAR TIRE TYPE:	Kumho Solus KH24 M+S
REAR TIRE SIZE:	P205/65R16 94H
REAR TIRE PRESSURE:	33

TRACK FRONT:	62.8	**inches**
TRACK REAR:	62.8	**inches**
AVERAGE TRACK:	**62.8**	**inches**
WHEELBASE:	110.1	**inches**
ROOF HEIGHT:	57.5	**inches**
GVWR	4299	**lb**
FRONT GAWR	2425	**lb**
REAR GAWR	2116	**lb**
LEFT FRONT WEIGHT	1057.4	**lb**
RIGHT FRONT WEIGHT	996.6	**lb**
LEFT REAR WEIGHT	703.1	**lb**
RIGHT REAR WEIGHT	643.3	**lb**
TOTAL WEIGHT	3400.4	**lb**

Track Width Measurements

Front A	62.80	**inches**
B	62.85	**inches**
C	62.85	**inches**
D	62.85	**inches**
Rear E	62.85	**inches**
F	62.90	**inches**
G	62.70	**inches**
H	62.85	**inches**

Wheelbase Measurements

Left Side	110.00	**inches**
Right Side	110.10	**inches**

C.G. LONGITUDINAL	43.57	**inches** (From Front Axle)
C.G. LATERAL	-1.11	**inches** (Negative Towards Driver's Side)

VIMF C.G. HEIGHT MEASUREMENT RESULTS

	Applied Weight (lb)	Platform Angle (deg)	Relative Motion (inches)	C.G. Height (inches)
Run #1	0.0	0.000	0.000	0.00
Run #2	40.2	3.088	-0.018	21.49
Run #3	50.3	3.859	-0.024	21.53
Run #4	40.2	-3.049	0.016	21.31
Run #5	50.3	-3.803	0.021	21.31
			AVERAGE C.G. HEIGHT	**21.41**

T/(2 x H) = AVERAGE TRACK/(2 x AVERAGE C.G. HEIGHT)

T/2h **1.4673**

SEA,Ltd. Vehicle Dynamics Division

Figure 3: Example of Individual Test Results Page

10 REFERENCES

1) *The Design of a Vehicle Inertia Measurement Facility*, Heydinger, G.J., Durisek, N.J., Coovert, D.A., Guenther, D.A., and Novak, S.J., SAE Paper No. 950309, February, 1995. Also presented and reprinted by invitation at the 1995 Society of Allied Weight Engineers (SAWE) International Conference, May, 1995.

2) *An Overview of a Vehicle Inertia Measurement Facility*, Heydinger, G.J., Durisek, N.J., Coovert, D.A., Lawrence, R.D., Nowjack, J.A., and Guenther, D.A., 27th International Symposium on Automotive Technology and Automation, ISATA Paper 94SF034, October, 1994.

3) *Road Vehicles – Determination of Centre of Gravity*, International Standard ISO 10392, Second Edition, March, 2011.