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EUROPEAN NEW CAR ASSESSMENT PROGRAMME
(Euro NCAP)

THE DYNAMIC TEST OF CAR
ELECTRONIC STABILITY CONTROL (ESC)
SYSTEMS PROTOCOL

Version 1.2
June 2011

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CONTENTS

1.   INTRODUCTION

This test specifies performance and equipment requirements for Electronic Stability Control (ESC) systems. The purpose of this test is to reduce the number of deaths and injuries that result from crashes in which the driver loses directional control of the vehicle, including those resulting in vehicle rollover.

2.   DEFINITIONS

For the purpose of this procedure, the following definitions shall apply:

2.1.   **Ackerman Steer Angle** means the angle whose tangent is the wheelbase divided by the radius of the turn at a very low speed.

2.2.   **Electronic Stability Control System or ESC System** means a system that has all of the following attributes:

(a)   That improves vehicle directional stability by at least having the ability to automatically control individually the braking torques of the left and right wheels on each axle or an axle of each axle group[1] to induce a correcting yaw moment based on the evaluation of actual vehicle behaviour in comparison with a determination of vehicle behaviour demanded by the driver;

(b)   That is computer-controlled with the computer using a closed-loop algorithm to limit vehicle oversteer and to limit vehicle understeer based on the evaluation of actual vehicle behaviour in comparison with a determination of vehicle behaviour demanded by the driver;

(c)   That has a means to determine directly the value of vehicle's yaw rate and to estimate its side slip or side slip derivative with respect to time;

(d)   That has a means to monitor driver steering inputs; and

(e)   That has an algorithm to determine the need, and a means to modify propulsion torque, as necessary, to assist the driver in maintaining control of the vehicle.

2.3.   **Lateral Acceleration** means the component of the vector acceleration of a point in the vehicle perpendicular to the vehicle x axis (longitudinal) and parallel to the road plane.

2.4.   **Oversteer** means a condition in which the vehicle's yaw rate is greater than the yaw rate that would occur at the vehicle's speed as result of the Ackerman Steer Angle.

2.5.   **Sideslip or side slip angle** means the arctangent of the ratio of the lateral velocity to the longitudinal velocity of the centre of gravity of the vehicle.

2.6.   **Understeer** means a condition in which the vehicle's yaw rate is less than the yaw rate that would occur at the vehicle's speed as result of the Ackerman Steer Angle.

2.7.   **Yaw rate** means the rate of change of the vehicle's heading angle measured in degrees/second of rotation about a vertical axis through the vehicle's centre of gravity.

2.8.   **Peak braking coefficient (PBC)**: means the measure of tyre to road surface friction based on the max deceleration of a rolling tyre.

2.9.   **Centre of Gravity (CoG)**: means the mean location of all the mass in the vehicle at kerb weight and with a full fuel load. . In case the CoG height is not available or supplied by the OEM, it will be approximated as 38% of maximum roof height.

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[1] An axle group shall be treated as a single axle and dual wheels shall be treated as a single wheel.

2.10. **Static Stability Factor (SSF)** means one-half the track width of a vehicle divided by the height of its Centre of gravity:

SSF = T/2H

T = track width average of front and rear axle

H = height of the Centre of Gravity (CoG) of the vehicle at kerb weight and with a full fuel load. By default it will be approximated as 38% of maximum roof height. Where CoG height is measured and/or supplied by the OEM, these values must be reported for monitoring purpose.

3.   REFERENCE SYSTEM

The coordinate system used must be an ordinary Cartesian co-ordinate system with 90°
between the axes and the sign convention detailed in Table 1 and Figure 1:

Table 1: Coordinate system

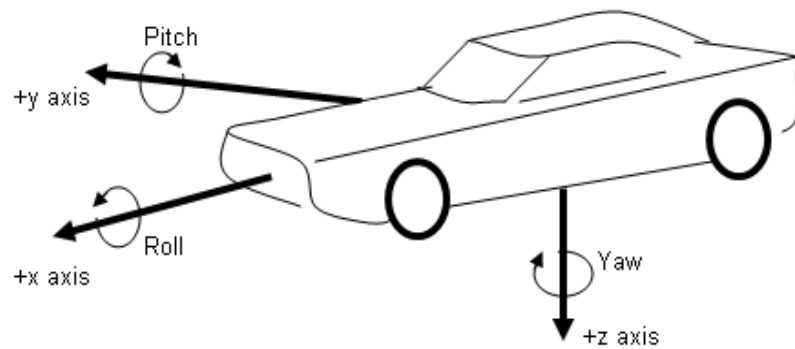| Measure	Reference
Positive X	Horizontally forward, in the longitudinal symmetry plane
Positive Y	To the driver's right-hand side
Positive Z	Vertically downward

Figure 1: Coordinate system
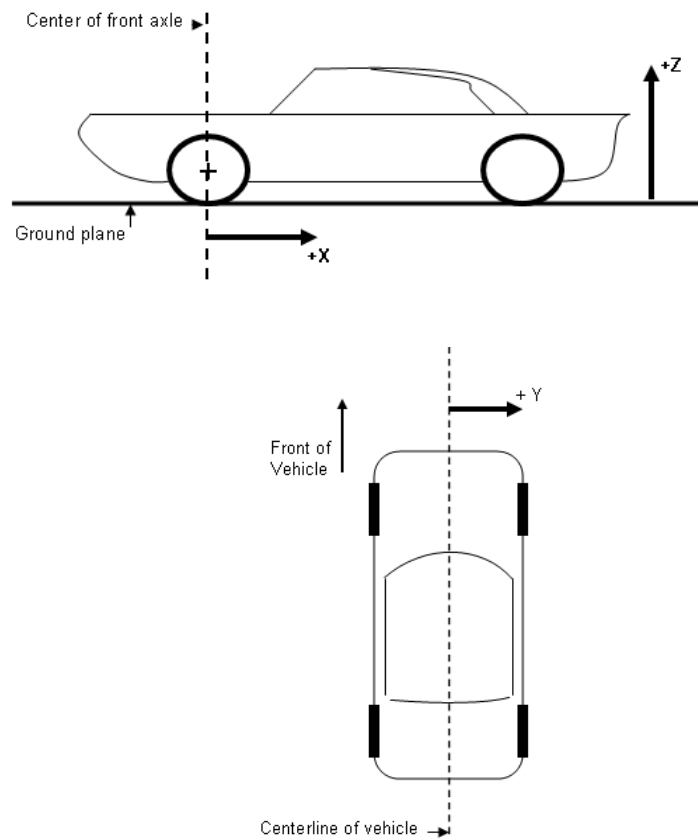
Figure 2: Centre of Gravity and inertial sensor reference

4.   VARIABLES

The following variables shall be determined:

1) Steering wheel angle
2) Longitudinal acceleration
3) Lateral acceleration
4) Vertical acceleration
5) Yaw velocity
6) Pitch velocity
7) Roll velocity
8) Longitudinal velocity
9) Roll angle
10) Pitch angle
11) Steering wheel rate (by measurement or calculation)
12) Lateral velocity

The following variables may be determined (optional – monitoring purpose only):

13) Wheel lift
14) Brake pressures
15) Sideslip angle
16) Vehicle trajectory (GPS)
17) Steering wheel torque

5. MEASURING EQUIPMENT

The variables to be determined in accordance with Chapter 4 shall be measured by means of appropriate transducers. Their time histories shall be recorded on a multi-channel recording system having a time base. The typical operating ranges and recommended specifications are given in the table below:

Variables to be measured	Range	Resolution and accuracy
Steering wheel angle	-360º to 360º	Resolution 0.25º Accuracy ± 0.25º
Longitudinal acceleration Lateral acceleration Vertical acceleration	-20 m/s^2 to 20 m/s^2	Resolution $< 100 \mu m/s^2$ Accuracy < 0.05% of full range
Roll rate Pitch rate Yaw rate	-100º/s to 100 º/s	Resolution < 0.004 deg/s Accuracy + 0.05% of full range
Longitudinal velocity	-	Accuracy 0.2 kph RMS
Roll angle Pitch angle	-15º to 15º	Accuracy ± 1% of full range

The following table summarises the main specifications of the test equipment required for the test:

Equipment	Specifications
Data acquisition system	Sampling rate: real 100 Hz Signal conditioning: amplification, anti-alias filtering, digitising. Amplifier gains: selected to maximise the signal-to-noise ratio of the digitised data. Filtering: two-pole low-pass Butterworth filters with nominal cut-off frequencies selected to prevent aliasing.
Automated steering machine	Fitted with steering angle encoder for controlling steering wheel angle input and output. Torque: minimum of 60 Nm when operating with steering wheel velocities up to 1200 deg/sec. The steering machine must be able to move the vehicle's steering system through its full range. Accept vehicle speed sensor feedback input to initiate steering programs at a preset road speeds. Possible to change the steering program during test sessions.

Additionally, the following variables may be determined:

Variables to be measured	Range	Resolution and accuracy
Steering wheel torque	-125 Nm to 125 Nm	Accuracy ± 0.3 Nm
Steering wheel rate	-1500º/s to 1500 º/s	(SWA differentiation)
Height sensor (wheel lift)	300 ± 200 mm	Resolution 0.2 mm Linearity ≤ 0.4%
Lateral velocity	-	Accuracy 0.2 kph RMS
Sideslip angle	- 90º to 90º	Accuracy ± 0.3º
Brake pressure	0 to 200 bar	Accuracy ± 1 bar
Trajectory (posX, posY)	-	Accuracy ≤ 0.02 m (DGPS)

6.   TEST CONDITIONS

Limits and specifications for the ambient wind and vehicle test conditions are established in this chapter and shall be maintained throughout each test. Any deviations shall be shown in the test report.

6.1.   Test track

6.1.1. The tests shall be conducted on a smooth, clean, dry, uniform, solid-paved surface. Surfaces with irregularities and undulations, such as dips and large cracks, are unsuitable.

6.1.2. The test surface shall have has a consistent slope between level and 1%.

6.1.3. The road test surface shall have a minimal peak braking coefficient (PBC) of 0.9, when measured using the method specified in (ASTM) E1136-93 (1993) standard reference test tyre, in accordance with ASTM Method E 1337-90 (reapproved 1996).

6.2.   Weather conditions

6.2.1. During the measurements, the ambient temperature shall be between 7° C and 35° C and there shall be dry weather conditions.

6.2.2. During the measurements, ambient wind velocity shall not exceed 10 m/s for vehicles with SSF > 1.25 and 5 m/s for vehicles with SSF ≤ 1.25 regardless of wind direction.

6.2.3. For each test procedure, weather conditions shall be recorded in the test report.

6.3.   Test vehicle

6.3.1.   ESC system

6.3.1.1. The ESC system is enabled for all testing.

6.3.1.2. If possible to change, the vehicle will be tested with the default (normal) ESC mode. When the vehicle is equipped with a hardware (manual) switch or a memory key that stores ESC settings, the most challenging mode will be tested.

6.3.2.   Tyres

6.3.2.1. The test shall be performed with the tyres fitted on the test vehicle (according to the manufacturer's specifications). It is allowed to change to tyres which are acquired at an official car dealer, if those tyres are identical make, model, size, speed and load rating to original.

6.3.2.2. The tyres shall be inflated to the vehicle manufacturer's recommended cold tyre inflation pressure(s) e.g. as specified on the vehicle's placard or the tyre inflation pressure label. Inflation pressures should be those corresponding to least loading condition. Tubes may be installed to prevent tyre de-beading.

6.3.2.3. The tyres shall be run in according to the paragraph 7.2 tyre conditioning. After running in, the tyres shall be maintained at the same position on the vehicle throughout the tests.

6.3.3.   Vehicle loading conditions

6.3.3.1.   Outriggers. Outriggers may be used for testing if deemed necessary for test drivers' safety. As a guideline, the following applies. The test laboratory will choose the most appropriate outrigger based on their experience.
For vehicles with a Static Stability Factor (SSF) ≤ 1.25;
(a) Vehicles with a mass in running order under 1,800 kg shall be equipped with "standard" outriggers. Standard outriggers shall be designed with a maximum mass of 35 kg and a maximum roll moment of inertia of 35 kg·m^2

(b) Vehicles with a mass in running order equal to or greater than 1,800 kg shall be equipped with "heavy" outriggers. Heavy outriggers shall be designed with a maximum mass of 40 kg and a maximum roll moment of inertia of 40 kg·m^2.

6.3.3.2. The vehicle is loaded with the fuel tank filled to at least 90 per cent of capacity, and a total interior load of 168 kg comprised of the test driver and test equipment (automated steering machine, data acquisition system and the power supply for the steering machine), and ballast as required to make up for any shortfall in the weight of test drivers and test equipment.

6.3.3.3. Unladen Kerb Mass

6.3.3.3.1. Fill up the tank with fuel to 100% of the tank's capacity of fuel.

6.3.3.3.2. Check the oil level and top up to its maximum level if necessary. Similarly, top up the levels of all other fluids to their maximum levels if necessary.

6.3.3.3.3. Ensure that the vehicle has its spare wheel on board, if fitted, along with any tools supplied with the vehicle. Nothing else should be in the car.

6.3.3.3.4. Ensure that all tyres are inflated according to the manufacturer's instructions for the appropriate loading condition.

6.3.3.3.5. Measure the front and rear axle masses and determine the total mass of the vehicle. The total mass is the 'unladen kerb mass' of the vehicle. Record this mass in the test details.

6.3.3.3.6. If outriggers are required by the SSF, mount the outriggers to the vehicle and repeat paragraph 6.3.3.3.5.

6.3.3.3.7. Calculate the required ballast mass, by subtracting the mass of the test driver and test equipment from the required 168 kg interior load.

6.3.4. Wheel alignment measurement

6.3.4.1. The vehicle should be subject to a vehicle (in-line) geometry check to record the wheel alignment set by the OEM. This should be done with the vehicle in test weight, meaning kerb weight and full fuel load.

6.3.5. Vehicle Preparation

6.3.5.1. Fit the on-board test equipment and instrumentation in the vehicle. Also fit any associated cables, cabling boxes and power sources.

6.3.5.2. Place weights with a mass of the ballast mass. Any items added should be securely attached to the car.

6.3.5.3. With the driver in the vehicle, weigh the front and rear axle loads of the vehicle. Compare these loads with those determined in paragraph 6.3.3.3.5.

6.3.5.4. The total vehicle mass shall be the unladen kerb plus full fuel load mass, plus 168kg +/- 1%. The front/rear axle load distribution needs to be within 5% of the front/rear axle load distribution of the original unladen kerb mass plus full fuel load. If the vehicle differs from the requirements given in this paragraph, items may be removed or added to the vehicle which has no influence on its performance. Any items added to increase the vehicle mass should be securely attached to the car.

6.3.5.5. Repeat paragraphs 6.3.5.3 and 6.3.5.4 until the front and rear axle loads and the total vehicle mass are within the limits set in paragraph 6.3.5.4. Care needs to be taken when adding or removing weight in order to approximate the original vehicle inertial properties as close as possible. Record the final axle loads in the test details.

7. TEST PROCEDURE

7.1. **Brake Conditioning**. Condition the vehicle brakes using the method described:

7.1.1. Ten stops are performed from a speed of approximately 56 km/h, with an average deceleration of approximately 0.5g.

7.1.2. Immediately following the series of approximately 56 km/h stops, three additional stops are performed from 72 km/h at higher deceleration.

7.1.3. When executing these 3 stops, sufficient force is applied to the brake pedal to activate the vehicle's antilock brake system (ABS) for a majority of each braking event.

7.1.4. Following completion of the final stop in paragraph 7.1.2, the vehicle is driven at a speed of approximately 72 km/h for five minutes to cool the brakes.

7.2. **Tyre Conditioning**. Condition the tyres to wear away mould sheen and achieve operating temperature. Condition the tyres immediately before beginning the test runs of paragraphs 7.3 and 7.4 using the method described:

7.2.1. The test vehicle is driven around a circle 30 metres in diameter at a speed that produces a lateral acceleration of approximately 0.5g to 0.6g for three clockwise laps followed by three counter clockwise laps.

7.2.2. Using a sinusoidal steering pattern at a frequency of 1 Hz, a peak steering wheel angle amplitude corresponding to a peak lateral acceleration of 0.5g to 0.6g, and a vehicle speed of approximately 56 km/h, the vehicle is driven through four passes performing 10 cycles of sinusoidal steering during each pass.

7.2.3. The steering wheel angle amplitude of the final cycle of the final pass is twice that of the other cycles. The maximum time permitted between each lap or pass is five minutes.

7.3. **Slowly Increasing Steer Procedure**.

7.3.1. The vehicle is subjected to two series of runs of the Slowly Increasing Steer Test using a constant vehicle speed of 80 ±2 km/h and a steering pattern that increases by 13.5 degrees per second until a lateral acceleration of approximately 0.5g is obtained. Three repetitions are performed for each test series. One series uses counter clockwise steering, and the other series uses clockwise steering. The maximum time permitted between each pass is five minutes.

7.3.2. From the Slowly Increasing Steer tests, the quantity "A" is determined. "A" is the steering wheel angle in degrees that produces a steady state lateral acceleration (corrected using the methods specified in paragraph 8.3) of 0.3g for the test vehicle. Utilising linear regression, "A" is calculated, to the nearest 0.1 degrees, from each of the six Slowly Increasing Steer tests. The absolute value of the six A's calculated is averaged and rounded to the nearest 0.1 degrees to produce the final quantity, A, used below.

7.3.3. After the quantity "A" has been determined, without replacing the tyres, the tyre conditioning procedure described in paragraph 7.2 is performed immediately prior to conducting the Sine with Dwell Test of paragraph 7.4.

7.3.4. Initiation of the first Sine with Dwell test series shall begin within two hours after completion of the Brake Conditioning in paragraph 7.1.

7.3.5. Check that the ESC system is enabled by ensuring that the ESC malfunction and "ESC Off" (if provided) tell-tales are not illuminated.

7.4. **Sine with Dwell Test of Oversteer Intervention and Responsiveness**.

7.4.1. The vehicle is subjected to two series of test runs using a steering pattern of a sine wave at 0.7 Hz frequency with a 500 ms delay beginning at the second peak amplitude as shown in Figure 3 (the Sine with Dwell tests).
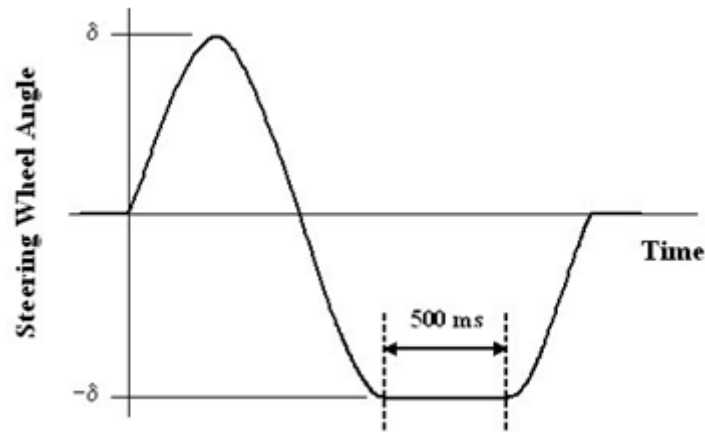
Figure 3: Sine with Dwell steering profile.

7.4.2. One series uses both counter clockwise steering for the first half cycle, and the other series uses clockwise steering for the first half cycle.

7.4.3. The vehicle is allowed to cool-down between each test run of 90 seconds to five minutes, with the vehicle stationary.

7.4.4. The steering motion is initiated with the vehicle coasting, no throttle input, in the highest possible gear with a minimum engine speed of 2000 rpm at 80 ± 2 km/h. For vehicles with automatic transmission, the gear shall be placed in the drive position D.

7.4.5. The steering amplitude for the initial run of each series is 1.5A, where "A" is the steering wheel angle determined in paragraph 7.3.2.

7.4.6. In each series of test runs, the steering amplitude is increased from run to run, by 0.5A, provided that no such run will result in a steering amplitude greater than that of the final run specified in paragraph 7.4.7.

7.4.7. The steering amplitude of the final run in each series is the greater of 6.5A or 270 degrees, provided the calculated magnitude of 6.5A is less than or equal to 300 degrees. If any 0.5A increment, up to 6.5A, is greater than 300 degrees, the steering amplitude of the final run shall be 300 degrees.

7.4.8. Upon completion of the two series of test runs, post processing of yaw rate and lateral acceleration data is done as specified.

8. POST DATA PROCESSING: CALCULATIONS FOR PERFORMANCE METRICS

Yaw rate and lateral displacement measurements and calculations shall be processed utilising the techniques specified in paragraphs 8.1. to 8.9.

8.1. Raw steering wheel angle data is filtered with a 12-pole phase-less Butterworth filter and a cut-off frequency of 10 Hz. The filtered data is then zeroed to remove sensor offset utilising static pre-test data.

8.2. Raw yaw rate data is filtered with a 12-pole phase-less Butterworth filter and a cut-off frequency of 6 Hz. The filtered data is then zeroed to remove sensor offset utilising static pre-test data.

8.3. Raw lateral acceleration data is filtered with a 12-pole phase-less Butterworth filter and a cut-off frequency of 6 Hz. The filtered data is then zeroed to remove sensor offset utilising static pre-test data. The lateral acceleration data at the vehicle centre of gravity is determined by removing the effects caused by vehicle body roll and by correcting for sensor placement via use of coordinate transformation. For data collection, the lateral accelerometer shall be located as close as possible to the position of the vehicle's longitudinal and lateral centres of gravity.

8.4. Steering wheel velocity is determined by differentiating the filtered steering wheel angle data. The steering wheel velocity data is then filtered with a moving 0.1 second running average filter.

8.5. Lateral acceleration, yaw rate and steering wheel angle data channels are zeroed utilising a defined "zeroing range". The methods used to establish the zeroing range are defined in paragraphs 8.5.1 and 8.5.2.

8.5.1. Using the steering wheel rate data calculated using the methods described in paragraph 8.4, the first instant steering wheel rate exceeding 75 deg/sec is identified. From this point, steering wheel rate shall remain greater than 75 deg/sec for at least 200 ms. If the second condition is not met, the next instant steering wheel rate exceeding 75 deg/sec is identified and the 200 ms validity check applied. This iterative process continues until both conditions are ultimately satisfied.

8.5.2. The "zeroing range" is defined as the 1.0 second time period prior to the instant the steering wheel rate exceeds 75 deg/sec (i.e. the instant the steering wheel velocity exceeds 75 deg/sec defines the end of the "zeroing range").

8.6. The Beginning of Steer (BOS) is defined as the first instance filtered and zeroed steering wheel angle data reaches - 5 degrees (when the initial steering input is counter clockwise) or +5 degrees (when the initial steering input is clockwise) after time defining the end of the "zeroing range". The value for time at the BOS is interpolated.

8.7. The Completion of Steer (COS) is defined as the time the steering wheel angle returns to zero at the completion of the Sine with Dwell steering manoeuvre. The value for time at the zero degree steering wheel angle is interpolated.

8.8. The second peak yaw rate is defined as the first local yaw rate peak produced by the reversal of the steering wheel. The yaw rates at 1.000 and 1.750 seconds after COS are determined by interpolation.

8.9. Determine lateral velocity by integrating corrected, filtered and zeroed lateral acceleration data. Zero lateral velocity at BOS event. Determine lateral displacement by integrating zeroed lateral velocity. Zero lateral displacement at BOS event. Lateral displacement at 1.07 seconds from BOS event is determined by interpolation. Lateral displacement may also be determined using GPS data.

9. PHOTOGRAPHIC AND VIDEO REQUIREMENTS

9.1. Vehicle Markings

9.1.1. Euro NCAP markings will be attached to the exterior of the vehicle in the following locations; upper half of driver's door, upper half of front passenger's door, left and right side.

9.1.2. Test house logos may be added to the vehicle provided that they do not detract attention from the Euro NCAP markings. Suitable locations for such markings would be the lower half of the rear doors and on the bonnet at the base of the windscreen.
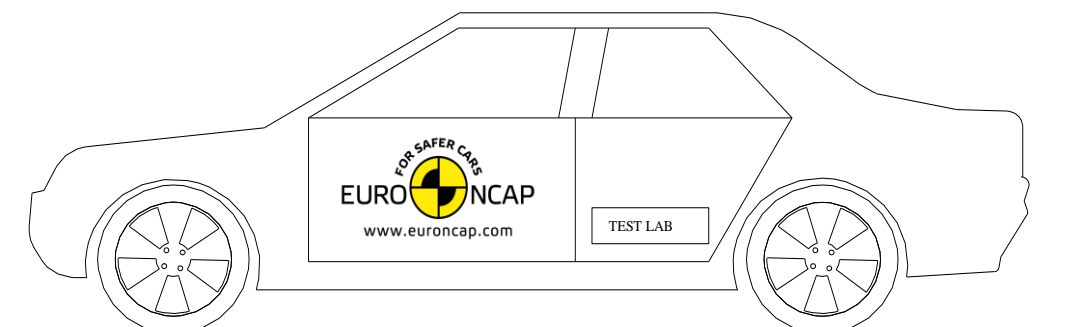
9.2. Event Recording

9.2.1. Each test vehicle shall be photographed in test condition prior to test: these photographs should effectively show positioning of the test equipment within the vehicle and good general reference photographs of all sides of the exterior of the vehicle. Where applicable a photographic record of the chassis plate including Vehicle Identification Number should also be made.

9.2.2. Each sine with dwell test run should be filmed from an external position to effectively record any behavioural characteristics of the vehicle for each run. This should be filmed in a way to best allow a clear and repeatable view of all test runs and camera location shall not alter once testing has commenced, although camera "panning" can be used. The camera should be positioned at normal height and not elevated; this will allow viewing of any wheel lift that may be apparent during testing. Camera positioning from behind the vehicle as it travels away from the camera is accepted as a practical solution, however any safe position that gives a good representation of both left hand and right hand test runs is acceptable.

9.2.3. On-board cameras shall be used to further record vehicle behaviour from inside the vehicle or mounted on the vehicle exterior as long as these do not exceed the vehicle mass as detailed in paragraph 6.3.5.4 or effect vehicle behaviour through positioning of mass or influencing vehicle movements.

APPENDIX I - VEHICLE SPECIFICATIONS

		Detail		
General				
Make				
Model				
Type				
Doors				
Driver				
Year				
VIN				
Dimensions				
Height				
Track	Front			
	Rear			
Length				
Width				
Wheelbase				
Engine				
Type				
Capacity				
Fuel type				
Transmission				
Drive axle				
Gearbox				
Steering				
Assistance				
Steering wheel Ø				
Transmission				
Drive mode		*FWD, RWD, 4WD…*		
Gearbox		*Manual, auto*		
Front suspension				
Type				
Rear suspension				
Type				
Wheels				
Rim dimension				
ET value (offset)				
Weight				
Max. axle capacity		*Front/rear*		
GVW				
Wheel alignment		*(vehicle in kerb condition)*		
			Left	Right
Front		Camber		
		Caster		
		Toe		
		KPI		
Rear		Camber		
		Toe		

APPENDIX II - TEST CONDITIONS

	Test Condition
Test	
Date	*Day/month/year*
Time	*Start time, end time*
Test track (laboratory)	*IDIADA, Thatcham, UTAC (2011)*
Test track condition	*Dry only (protocol)*
Test track surface	*Uniform, solid-paved surface (protocol)*
Test track temperature	*Start temperature, end temperature*
Mileage	*Initial, final*
Weather	
Condition	*Sunny, cloudy, rain*
Ambient temperature	*Start temperature, end temperature* *Between 7° C and 35° C (protocol)*
Relative Humidity	*%*
Wind speed	*10 m/s if SSF > 1.25, 5 m/s if SSF ≤ 1.25 (protocol)*
Tyres	
Make	
Model	
Specification	*Original or replacement from OEM dealer*
Size and diameter	
Load and speed codes	
Date of production	
Pressures (Front / Rear)	*Manufacturer specification*
Front axle wear	
Rear axle wear	
Outriggers	
SSF	*SSF=T/2H*
Fitted	*Yes/No; if SSF ≤ 1.25 (protocol)*
Type	*Standard, heavy (protocol)*
Active systems	
Systems enabled	*ABS, TCS, ESC, AFS...*
Mode	*Default, unless manual switch/memory key*
Weight condition	

	Left	Right	Total	%
Front axle				
Rear axle				

APPENDIX III - COORDINATE TRANSFORMATIONS

Determine the lateral acceleration at the vehicle Centre of gravity by correcting for sensor placement via use of coordinate transformation. The multi-axis inertial sensing system is used to measure linear accelerations and roll, pitch, and yaw angular rates. The position of the multi-axis inertial sensing system must be accurately measured relative to the CoG of the vehicle in its loaded configuration.

These data are required to translate the motion of the vehicle at the measured location to that which occurred at the actual CoG to remove roll, pitch, and yaw effects. The following equations are used to correct the accelerometer data in post-processing. They were derived from equations of general relative acceleration for a translating reference frame and use the SAE Convention for Vehicle Dynamics Coordinate Systems:

Equation 1: $x''_{corrected} = x''_{accel} - (\Theta'^2 + \Psi'^2)x_{disp} + (\Theta'\Phi' - \Psi'')y_{disp} + (\Psi'\Phi' - \Theta'')z_{disp}$

Equation 2: $y''_{corrected} = y''_{accel} + (\Theta'\Phi' + \Psi'')x_{disp} - (\Phi'^2 + \Psi'^2)y_{disp} + (\Psi'\Theta' - \Phi'')z_{disp}$

Equation 3: $z''_{corrected} = z''_{accel} + (\Psi'\Phi' - \Theta'')x_{disp} + (\Psi'\Theta' + \Phi'')y_{disp} - (\Phi'^2 + \Theta'^2)z_{disp}$

Where;

$x''_{corrected}$, $y''_{corrected}$, and $z''_{corrected}$ = longitudinal, lateral, and vertical accelerations, respectively, at the vehicle's centre of gravity.

x''_{accel}, y''_{accel}, and z''_{accel} = longitudinal, lateral, and vertical accelerations, respectively, at the accelerometer location.

x''_{disp}, y''_{disp}, and z''_{disp} = longitudinal, lateral, and vertical displacements, respectively, of the centre of gravity with respect to the accelerometer location.

Φ' and Φ'' = roll rate and roll acceleration, respectively

Θ' and Θ'' = pitch rate and pitch acceleration, respectively

Ψ' and Ψ'' = yaw rate and yaw acceleration, respectively

Data Correction

Correct lateral acceleration at the vehicle centre of gravity by removing the effects caused by vehicle body roll. NHTSA does not use inertially stabilized accelerometers for this test procedure. Therefore, lateral acceleration must be corrected for vehicle roll angle during data post processing. The ultrasonic distance measurement sensors are used to collect left and right side vertical displacements for the purpose of calculating vehicle roll angle. One ultrasonic ranging module is mounted on each side of a vehicle, and is positioned at the longitudinal CoG. With these data, roll angle is calculated during post processing using trigonometry.

$a_{yc} = a_{ym}\cos\phi - a_{zm}\sin\phi$

Where;

ayc is the corrected lateral acceleration (i.e., the vehicle's lateral acceleration in a plane horizontal to the test surface)
aym is the measured lateral acceleration in the vehicle reference frame
azm is the measured vertical acceleration in the vehicle reference frame
Φ is the vehicle's roll angle

Note: The z-axis sign convention is positive in the downward direction for both the vehicle and test surface reference frames.

APPENDIX IV – REFERENCES

1. Global Technical Regulation No.8 - Electronic Stability Control Systems, Established in the Global Registry on 26 June 2008

2. ECE Regulation No. 13-H - Uniform Provisions Concerning the Approval of Passenger Cars With Regard To Braking, Revision 2, including the amendments which entered into force on 16 October 1995.