

where,

$x''_{corrected}$ ,  $y''_{corrected}$ , and  $z''_{corrected}$  =

longitudinal, lateral, and vertical accelerations, respectively, at the vehicle's center 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 center of gravity with respect to the accelerometer location

$\phi'$  and  $\phi''$  = roll rate and roll acceleration, respectively

$\theta'$  and  $\theta''$  = pitch rate and pitch acceleration, respectively

$\psi'$  and  $\psi''$  = yaw rate and yaw acceleration, respectively

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. This is discussed in Section 4.12.

#### 2.5.1.4 Roll Angle

An ultrasonic distance measurement system is 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 center of gravity. With these data, roll angle is calculated during post-processing using trigonometry.

#### 2.5.1.5 Wheel Lift

Wheel lift is measured individually with two height sensors attached to spindles installed at the wheel. Using trigonometry, the output of the two sensors can be used to resolve the camber angle of the wheel, and remove its influence from the uncorrected height sensor output. Information on NHTSA's wheel lift measurement system is documented in [4].

#### 2.5.1.6 Brake Application

Brake pedal force is measured with a load cell transducer attached to the face of the brake pedal. While brake pedal force is not explicitly required by this test procedure, it is important to monitor the driver's braking activity during testing. No test included in this procedure requires brake application. If the driver applies force to the brake pedal before completion of a test, that test is not valid, and should not be considered in further analyses.

### 2.5.2 Additional Mnemonics

#### 2.5.2.1 Handwheel Command Flag

Refer to Section 3.2.4.2.2, Handwheel Command Flag.

#### 2.5.2.2 Roll Rate Flag

Refer to Section 3.2.4.2.3, Roll Rate Flag.

### 2.6 Steering Machine

A programmable steering machine is used to generate handwheel steering inputs for all test maneuvers. The machine must provide at least 35 lb-ft of torque at a handwheel rate of 720 deg/sec, be able to move each vehicle's steering system through its full range, and accept angular rate sensor feedback input for

roll rate-induced steering reversals (refer to section 3.2.4). It is recommended that the steering machine be capable of initiating steering programs at a preset road speed, and have the convenience of changing the steering program during test sessions.

### 3.0 Test Maneuvers

#### 3.1 Slowly Increasing Steer

The Slowly Increasing Steer maneuver is used to characterize the lateral dynamics of each vehicle, and is based on the "Constant Speed, Variable Steer" test defined in SAE J266 [5]. The maneuver is used to determine the steering that produces a lateral acceleration of 0.3 g. This handwheel angle is used to define the magnitude of steering to be used for the NHTSA Fishhook maneuver.

##### 3.1.1 Maneuver Description (Option #1)

To begin this maneuver, the vehicle is driven in a straight line at 50 mph. The driver must attempt to maintain this speed during and briefly after the steering is input using smooth throttle modulation. At time zero, handwheel position is linearly increased from zero to 270 degrees at a rate of 13.5 degrees per second. Handwheel position is held constant at 270 degrees for two seconds, after which the maneuver is concluded. The handwheel is then returned to zero as a convenience to the driver. The maneuver is performed three times to the left and three times to the right for each load configuration. Figure I.6 presents a description of the handwheel angles to be used during Slowly Increasing Steer, Option #1 tests.

##### 3.1.2 Maneuver Description (Option #2, Preferred)

Historically, NHTSA has used Slowly Increasing Steer tests to measure linear range and maximum quasi steady state lateral acceleration. While maximum lateral acceleration data is interesting, it is not a required metric when determining a vehicle's NCAP rollover resistance rating. For this reason, NHTSA recommends use of an "abbreviated" Slowly Increasing Steer maneuver. The handwheel angles used in this abbreviated procedure only steer the vehicle enough to assess its linear range lateral acceleration performance.

To determine the most appropriate Slowly Increasing Steer handwheel angle for a given vehicle, a preliminary left steer test is performed. The test speed during this test was held constant at 50 mph via throttle modulation, and the steering input ranged from 0 to 30 degrees, applied at 13.5 degrees per second. The magnitude of this input was selected because it was believed to be capable of producing a steady state lateral acceleration within the linear range for any light vehicle. Using the ratio of steady state handwheel position and lateral acceleration established by this test, the maximum steering input for the abbreviated Slowly Increasing Steer test was derived using the below equation:

$$\text{Equation 3.1} \quad \frac{30 \text{ degrees}}{a_{y, 30 \text{ degrees}}} = \frac{\partial_{SIS}}{0.55 \text{ g}}$$

where,

$a_{y,30 \text{ degrees}}$  was the raw lateral acceleration produced with a constant handwheel angle of 30 degrees during a test performed at 50 mph

$\partial_{SIS}$  was the steering input that, if the relationship of handwheel angle and lateral acceleration was linear, would produce a lateral acceleration of 0.55 g during a test performed at 50 mph

**Note:**  $a_{y,30 \text{ degrees}}$  is "raw" data, not corrected for the effects of roll, pitch, and yaw. NHTSA acknowledges the relationship of handwheel angle and corrected lateral acceleration data is often not linear at 0.55 g. However, previously collected data indicates the magnitude of raw 0.55 g acceleration data is typically reduced by approximately 9.6 percent to 0.497 g, when corrected for roll, pitch, and yaw, just outside of the linear range for most vehicles. Removing the effect of accelerometer offset (error due to the accelerometer not being positioned at the vehicle's actual center of gravity) typically reduces the magnitude of these data by an additional 0.07 percent. The importance of Equation 3.1 is that it simply provides experimenters with a direct, "in-the-field" way of determining an appropriate steering input for which to proceed with further tests for a given vehicle.

Figure I.7 presents a description of the handwheel angles to be used during the abbreviated Slowly Increasing Steer, Option #2 tests.

##### 3.1.3 Measured Parameters

Analyses of Slowly Increasing Steer tests output overall average handwheel position at a specified lateral acceleration

When lateral acceleration data collected during Slowly Increasing Steer tests is plotted with respect to time, a first order polynomial best-fit line accurately describes the data from 0.1 to 0.375 g. NHTSA defines this as the linear range of the lateral acceleration response. A simple linear regression is used to determine the best-fit line, as shown in Figures I.8 and I.9.

Using the slope of the best-fit line, the average of handwheel position at 0.3 g is calculated using data from each of the six Slowly Increasing Steer tests performed for each vehicle. This average handwheel position is used to calculate NHTSA Fishhook maneuver steering inputs, as described in Section 3.2.

### 3.2 NHTSA Fishhook Maneuver

#### 3.2.1 Maneuver Overview

To begin the maneuver, the vehicle is driven in a straight line at a speed slightly greater than the desired entrance speed. The driver releases the throttle, and when at the target speed, initiates the handwheel commands described in Figure I.10 using a programmable steering machine. Following completion of the countersteer, handwheel position is maintained for three seconds. As a convenience to the test driver, the handwheel is then returned to zero.

Each Fishhook maneuver test series contains two sequences (with exceptions noted in the following sections): Tests performed with left-right steering (first sequence), and tests performed with right-left