

wheel rim at the completion of the mounting procedure.

2.3.2 Frequency of Tire Changes

To minimize the effects of tire wear on vehicle response and rollover propensity, rollover research requires frequent tire changes. For each loading condition, the following guidelines must be followed:

- One set of tires is to be used for each Slowly Increasing Steer test series. Each series is comprised of left and right steer tests.
- Up to two tire sets are to be used for the Fishhook maneuver test series. The actual number of tire sets used is dependent on the response of each vehicle. The tire change protocol is presented in the Fishhook maneuver test procedure (Section 3.2). **Note:** A tire change between the completion of the Slowly Increasing Steer maneuver and initiation of Fishhook testing is not required provided the abbreviated Slowly Increasing Steer procedure described in Section 3.1.2 is used. If the abbreviated procedure is not used (*i.e.*, the maneuver is performed such that maximum lateral acceleration is achieved), a

tire change between the completion of the Slowly Increasing Steer maneuver and initiation of Fishhook testing is required, as tire wear associated with these tests may potentially confound Fishhook test outcome.

2.3.3 Use of Inner Tubes

Fishhook maneuvers have been shown to produce debanding of the outside front and rear tires. The occurrence of debands can result in significant damage to the test surface. NHTSA research has concluded the easiest, most cost effective way to minimize debanding is the use of inner tubes designed for radial tires. Inner tubes must be installed prior to any Fishhook test "one inner tube for each of the vehicle's tires. Inner tubes should be appropriately sized for the test vehicle's tires.

Installation of inner tubes is not required prior to Slowly Increasing Steer tests, regardless of vehicle or load condition.

2.4 Data Collection

All data is to be sampled at 200 Hz. NHTSA's signal conditioning consists of amplification, anti-alias filtering, and digitizing. Amplifier gains are selected to

maximize the signal-to-noise ratio of the digitized data. Filtering is performed with two-pole low-pass Butterworth filters with nominal cutoff frequencies selected to prevent aliasing. The nominal cutoff frequency is 15 Hz (calculated breakpoint frequencies are 18 and 19 Hz for the first and second poles respectively).

Data collection is initiated manually by the test driver immediately before the start of the maneuver or automatically by "Handwheel Command Flag" signal from the steering machine (refer to Section 3.2.4.2.2, Handwheel Command Flag).

2.5 Instrumentation

Each test vehicle is to be equipped with sensors, a data acquisition system, and a programmable steering machine. Equipment location and weight specifications are presented in Table I.1 and Figure I.1.

2.5.1 Sensors and Sensor Locations

Table I.2 lists the sensors required by NHTSA's dynamic rollover propensity test procedure. A brief description of these sensors is provided in this section.

TABLE I.2.—RECOMMENDED SENSOR SPECIFICATIONS

Type	Output	Range	Resolution	Accuracy
Multi-Axis Inertial Sensing System	Longitudinal, Lateral, and Vertical Acceleration.	Accelerometers: ± 2 g	Accelerometers: ≤ 10 ug.	Accelerometers: $\leq 0.05\%$ of full range.
Angle Encoder	Roll, Yaw, and Pitch Rate.	Angular Rate Sensors: ± 100 deg/s.	Angular Rate Sensors: ≤ 0.004 deg/s.	Angular Rate Sensors: 0.05% of full range.
Handwheel Angle	Handwheel Angle	± 800 deg	0.25 deg	± 0.25 deg.
Ultrasonic Distance Measuring System	Left and Right Side Vehicle Height.	5–24 inches	0.01 inches	$\pm 0.25\%$ of maximum distance.
Load Cell	Brake Pedal Force	0–300 lbf	N/A	N/A.
Radar Speed Sensor	Vehicle Speed	0.1–125 mph	0.009 mph	$\pm 0.25\%$ of full scale.
Infrared Distance Measuring System	Wheel Lift	13.75–33.5 inches	0.10 in., short range ... 0.3 in., long range	$\pm 1\%$ of full scale
Data Flag (Handwheel Command Flag)	Pauses in commanded steering inputs.	0–10 V	N/A	Flag should respond within 10 ms.
Data Flag (Roll Rate Flag)	Indication of ± 1.5 deg/s roll rate.	0–10 V	N/A	Flag should respond within 10 ms.

2.5.1.1 Handwheel Angle

Handwheel position is measured via an angle encoder integral with the programmable steering machines.

2.5.1.2 Vehicle Speed

Vehicle speed is measured with a non-contact speed sensor placed at the center rear of each vehicle.

NHTSA has had good experiences with the use of Doppler radar based sensors. Sensor outputs are to be transmitted not only to the

data acquisition system, but also to a dashboard display unit. This allows the driver to accurately monitor vehicle speed.

2.5.1.3 Chassis Dynamics

A 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 C.G. of the vehicle in the Nominal Load and Multi-Passenger Configurations. These data are required to translate the motion of the

vehicle at the measured location to that which occurred at the actual C.G. to remove roll, pitch, and yaw effects. NHTSA uses an independent laboratory to measure the C.G. of its test vehicles.

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. The coordinate transformations are:

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

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

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