SPECIFICATION FOR THE ATI
REVERSE-STEER ROLLOVER TEST PROTOCOL

(January 2010)

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INTRODUCTION

A rollover test protocol, to be useful, must satisfy the "Three R's" - Relatability, Repeatability, and Reproducibility. A rollover protocol must relate to a particular driving scenario, without discriminating in favor of one vehicle and against another. Performance variability during a test program must be minimized. And the tests must be reproducible by other testing organizations. ATI 's Reversed Steer rollover test protocol attempts to satisfy these requirements.

For relatability, the protocol is intended to form an idealized simulation, under closely controlled test conditions, of a hypothetical driving scenario. The Reversed Steer test procedure simulates an accident scenario in which a driver drifts off the right side of the road, overreacts to discovery of the error by turning left in an ergonomic rather than controlled manner, then makes a similarly excessive steer reaction to the right. This procedure can produce "on-road rollover" with path deviations not greater than a normal roadway width. The nominal test consists of test runs with steer increments of increasing magnitude at a speed of 50 mph.

A specific steer timing which might produce maximum roll response in one vehicle may produce minimum roll response in another. The ATI test protocol is designed to eliminate this problem by use of roll velocity feedback, from which steering reversals are made to occur at maximum dynamic roll angles for all vehicles, independent of a vehicle's rate of roll response.

For repeatability, the protocol eliminates the human driver. It uses programmed maneuvers, with throttle fully off during the test maneuver.

For reproducibility, the protocol offers precise detail, and pays careful attention to ambient conditions that may affect results.

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1 TEST PROGRAM

1.1 OBJECT

The object of this test is documentation of a vehicle's rollover threshold. The criteria to be measured are the speed, steer angle, and lateral acceleration at which tip-up occurs.

1: 2 SCOPE

The ATI Reverse Steer Rollover Test Protocols is applicable to passenger cars and light trucks, including vans and Sport-Utility vehicles. The maneuvers specified in the protocol is designed to form idealized simulations, under closely controlled test conditions, of a hypothetical driving scenario.

2 REFERENCES

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3 TEST PROCEDURE

3.1 DESCRIPTION OF THE TEST PROCEDURE

The basic test procedure simulates an accident scenario in which a driver drifts off the right side of the road, overreacts to the discovery of the error by turning left in an ergonomically-limited manner, then makes a similar overreaction to the right. In the initial left steer the driver is assumed to keep his hands on the steering wheel, but in the following right steer he may go "hand-over-hand". The accelerator pedal is released prior to the initial steer. Although in an accident scenario throttle release is most likely to be co-incident with the beginning of steer, in the interests of test simplicity at least two seconds of "settling time" is allowed between throttle release and steer. Test sequences are run without braking. Selected steering angles and rates are ergonomically reasonable (Appendix A1). Timing of steer reversals are chosen to eliminate the effect of different roll-mode response times, and timing of accelerator pedal release is chosen to suppress the effects of pitch-mode response times.

During the test, motion variables are recorded sufficient to detect incipient tip-up, measure lateral acceleration at tip-up, and plot vehicle trajectories.

A programmable steering machine is used in conducting the test, for precision and repeatability.

Protective outriggers must be used to limit tip-up and prevent complete rollover.

The test is performed only with "driver side down" to avoid driver injury, in view of the violence with which a vehicle "free-falls" from its tipped-up roll angle.

3.2 ITERATING STEER ANGLES AND SPEED

Tip-up requires the product of sideforce and time (Reference 5). Increased steer angles tends to increase sideforce, and increased test speeds tend to increase sideforce level and duration. Testing with a fixed initial speed of 60 mph or 100 km/h is consistent with most ISO and industry test protocols, but lower speeds are safer and speed iteration is often used in rollover testing. This test protocol therefore provides for either steer or speed schedules. A standard steer schedule is run at one speed, typically 50 mph, with optional partial schedules then run at lower or higher speeds. A speed schedule may be run with a customer-selected steer profile. Coarse set-point schedules (Section 12.2) are used together with a search routine to "zero-in" on the tip-up thresholds.

Test speeds may be limited for safety considerations, especially with vans or large SUVs. At request by the test customer, higher or lower steering rates may be used.

3.3 SPEED/STEER DATA FAMILIES

To increase information regarding the various factors involved in rollover, each increment of steer can be run in a speed sequence: 40, 45, 50, 55, 60 mph (or to tip-up). This allows plotting of “families of curves”: lateral acceleration, yaw velocity, sideslip, roll angle, etc. versus speed and steer angle. In any case, the “standard speed” for “Lateral Acceleration at Tip-up” shall be 50 mph.

4 INERTIAL REFERENCE SYSTEM

The origin of the inertial reference system for testing shall be fixed in the vehicle on the longitudinal plane of symmetry, as nearly as possible, at the height of the estimated whole-vehicle center of gravity. Depending on vehicle geometry, it may be fixed longitudinally at the midpoint of the wheelbase or at the estimated location of the as-tested whole-vehicle center of gravity. Sufficient data shall be recorded to transform inertial data to other origin points.

5 VARIABLES DIRECTLY RECORDED OR COMPUTED

1. Vehicle speed
2. Steering wheel angle and rate
3. Throttle position
4. Brake pedal force
5. Yaw rate
6. Roll rate
7. Lateral acceleration perpendicular to gravity vertical
8. Longitudinal acceleration perpendicular to gravity vertical
9. Accelerometer platform roll angle
10. Suspension travel or wheel speed or other option
11. Sideslip angle (computed)
12. Vehicle trajectory (computed).
13. Roll angle computed by integration of roll rate.
14. Roll acceleration computed by differentiation of roll rate.

6 MEASURING AND RECORDING EQUIPMENT

6.1 TRANSDUCERS

- Vehicle speed, distance and Heading Angle: GPS system.
- Steering wheel angle: Programmable Steering Machine.
- Throttle: encoder in throttle linkage or electronic pickoff from vehicle electronics.
- Brake force: pedal effort load cell.
- Yaw, roll, & pitch rates: three-axis rate sensor assembly.
- X, Y, Z accelerations: stable platform or strapdown triad.
- Roll & pitch angles: stable platform or integration of angular rates.

6.2 VIDEO

A video camera shall be mounted immediately behind and to the right of the driver, to provide a "driver's eye" view of the road ahead. The picture shall have the instrument data inserted as described in Section 6.3, and shall be recorded in a digital VTR as the basic record of the test. The inserted data shall be decoded and displayed as a column of numerics for monitoring by the driver during the test. Optionally, the composite picture may also be transmitted to a base station for monitoring by observers or for "on-line" data processing.

6.3 DATA ACQUISITION

Recording equipment shall consist of data acquisition system and video camera, recorder, and monitor. Transducer data is conditioned, digitized to 12 bits, and recorded on one video line at the top of the "driver's view" video picture. Before digitizing, analog transducer data shall be anti-alias filtered in precision (0.1 percent components) 10-pole Butterworth filters flat to one LSB at 10 Hz and attenuated to one LSB at one-half the 60 Hz sampling frequency. Phase shifts in the anti-aliasing filters produce a time delay of 0.067 seconds. In a test, this means that the zero-crossing of the roll rate feedback signal to the steering machine is delayed by that amount. In processing test data this time delay can be removed from the data set, as described in Section 14.1.

6.4 INERTIAL MEASUREMENT PACKAGES

Either of two inertial measurement packages: the "Humphrey Stabilized Accelerometer System" (38 pounds) or the "Strapdown System" (5 pounds) may be used. Whichever package is selected shall be secured as near as possible to the origin of the inertial reference system, and shimmed level to within 0.15 degree of gravity perpendicular, with the driver aboard and the vehicle in test configuration. The location shall be recorded, for transformation of recorded data to the Vehicle CG or other location.

6.5 ADDITIONAL VEHICLE INSTRUMENTATION

Additional instrumentation may be used as required: for example, suspension deflections and bumpstop compression.

6.6 TEST CONDITIONS INSTRUMENTATION

Ambient conditions which can have a significant effect on test results are the temperature and dampness of the test surface, ambient air temperature, tire temperature, and wind. Reference 9 recommends measuring the relative humidity of the test surface; and the temperature of the test surface, the ambient air (at a height of 1.5 meters above ground) and the tire. The pavement temperature and humidity is measured using an EXTECH Hygro-Thermometer Model B445701. The wind speed and ambient air temperature are measured using a hand-held EXTECH Digital Thermometer / Anemometer Model 407112.

6.7 VEHICLE TRANSDUCER SPECIFICATIONS

Speed and distance: VBOX GPS system. Distance output has 45 pulses per foot.. Distance output is set to 10 or 1 pulse/ft by a BCD rate multiplier, calibrated to ±1 ft. over a taped 1877 ft distance.

Individual wheel speed: Heavy-duty encoders with 180 pulses/rev fasten to lugnut extensions on as many wheels as required by test. Vertical torque arms fasten to car body with riv-nuts or suction cups. Signal conditioners convert pulse rates to analog voltages.

Suspension deflection: String encoders incorporated into wheelspeed torque arms. 32 inch range, resolution 0.01 inch at 4X, accuracy 0.05 inch.

Throttle position: throttle shaft nut replacements with built-in shaft encoders, or string encoder attached to accelerator linkage, or tap into the vehicle's throttle position sensor.

Brake effort: LEBOW 3363-300 brake pedal load cell. 300 pounds full-scale; linearity 0.1 percent. Cal by precision 100 lb TROEMER 9082 NBS Class F weight. Used alone or incorporated into brakeforce actuator.

Roll, pitch, yaw velocities: NORTHRUP Nortronics 3-axis DC-DC rate gyro package, P/N 77025. 90 deg/sec FS; linearity 0.5 percent; hysteresis 0.1 deg/sec; threshold 0.01 deg/sec. Calibration on 36 degrees/sec rate table. S/N 17 is installed in Humphrey Package, S/N 18 is spare.

Stabilized Inertial Reference System: Pitch & roll Angles, X,Y,Z accelerations, pitch, roll, yaw velocities: HUMPHREY Stabilized Accelerometer System, Model SA07-0304-1. Vertical/free gyro can be used with servo erection (at 2 deg/min) or as low-drift free gyro caged until beginning of maneuver. Angles are calibrated against accelerometers by forced drift. Level-stabilized accelerometers are SUNDSTRAND Linear Servo Accelerometer Model 303. Full scale 1 g, linearity 0.05 percent. Calibration ±1 g by tilting. Package is modified by installing NORTRONICS rate gyro package (S/N 17) inside and incorporating power supplies in box lid.

Strap-down Inertial Reference Unit: X,Y,Z accelerations, Roll, Pitch, Yaw Rates. Assembly consists of three orthogonally mounted SUNDSTRAND Model 303 linear servo accelerometers, together with a SYSTRON/DONNER three-axis rate sensor package. Other inertial variables are computed in software from these basic measurements.

Steering Machine: Heitz "Sprint 1" with "Sprint 2" upgrades. Fully described in Part 6 of ATI/Heitz website.

6.8 LOCATION AND WEIGHTS OF BASIC INSTRUMENTATION

Instrumentation shall be installed in locations which will produce a CG height as close as possible to a vehicle with a driver and one passenger. The *Sprint 1* (26 pounds) or *Sprint 3* (28 pounds) steering machine shall be fitted to the steering wheel with its mechanical grounding plate attached with struts and suction cups to the vehicle windshield. The steering machine battery/electronics Box (30 pounds), GPS unit (2 pounds), data acquisition system (14 pounds), video recorder (1 pound), flat-screen video monitor (1 pound), video PIP system (2 pounds), 12-volt junction box (1 pound) shall be secured in convenient locations. A brake pedal force transducer (12 ounces) shall be fitted. A throttle position transducer (vehicle system pickoff or separate transducer) shall be installed in the engine compartment. A video camera (3 pounds with mounting post assembly) shall be mounted immediately behind the front seats.

7 TEST VEHICLE

7.1 DOCUMENTATION

The vehicle VIN; engine, transmission and driveline types; tire make/model/construction, size and DOT serial number; rim width and contour; and all accessories shall be recorded. Vehicle ride height under curb-weight shall be measured under specified and reproducible conditions: for example, from ground to fender cut-out at the wheel centers, ground to rocker bottom front/rear, or other methods as described in publications such as Reference 8. All doorjamb Placard information shall be recorded.

7.2 OPERATING COMPONENTS

All operating components likely to influence the results of this test (for example springs, shock absorbers, bump/rebound stops, wheel rims, lug nuts, and other suspension components) shall be inspected, and any worn or damaged components replaced, prior to the test. Suspension geometry shall be set to specification. The results of these inspections shall be recorded, and any deviations from manufacturer's specification shall be noted in the test report. Inspections should be repeated at intervals during the test, and any damaged components shall be replaced and noted. For the standard test condition all components shall be OEM or equivalent, new or in good condition, and set to manufacturer's specification. The fuel tank shall be full, for CG location and to prevent slosh effects on dynamic loading.

7.3 TIRES

7.3.1 TIRE SELECTION

For standard test condition OEM tires in new condition shall be used.
Any tires used should be broken-in and warmed up as described in Section 11.
For standard test conditions cold inflation shall be that of the test vehicle's placard recommendation at the ambient temperature of the test site. Tire inflation pressure should be checked and recorded after warm-up, and for operator safety should be checked at intervals during the test.

7.3.2 TIRE REPLACEMENT

In ATI Reversed Steer testing the left front tire experiences by far the most rapid wear. The right front has significantly less because of cornering weight transfer. The left rear wears only if the vehicle tends to spin, and the unloaded right rear wears not at all. For this reason, in an "ATI tire change" the left front tire is replaced by the right rear, and a new tire, not necessarily broken-in, replaces the right rear.
Test tires shall be replaced when specified in the individual Test Sequences, Section 12. All tires are inspected, and if only the left front appears excessively worn an ATI Tire change is made. If other tires (for example, the left rear) are excessively worn they are also replaced.

8 OUTRIGGERS

Outriggers shall be mounted as close to the longitudinal CG as practical. The complete outrigger systems should weigh no more than 3 percent of the vehicle test. Outriggers should be set to touch down at about 15 degrees of total roll angle and shall be rigidly down at 20 degrees. (Ref.5). A "tell-tale" o-ring installed on the shaft of the outrigger air cylinder "cushion" shall be used to indicate the degree of outrigger loading. Alternatively, a load cell may be used to record outrigger loading.

9 VEHICLE LOADING

9.1 DRIVER & EQUIPMENT

The D&E test condition should approximate curb weight plus driver and one passenger.

9.2 ADDITIONAL LOADING

Each specified passenger shall be represented by a "Water-man" water-filled dummy filled to 175 pounds, or sandbag equivalent, positioned at the estimated passenger CG height and securely fastened by the appropriate seat belt. For the fully loaded condition additional ballast shall be added with its CG height centered in the load space to bring the vehicle to a test condition in which total weight equals the specified gross vehicle weight (GVW) and the rear axle weight equals the specified maximum rear axle weight.

10 TEST CONDITIONS

10.1 TEST TRACK

All tests shall be carried out on a level, clean, dry, uniform, and smooth hard road surface. The local gradient shall not exceed 1 percent in any direction, in the area of the vehicle trajectory. The gradient along and perpendicular to the test direction shall be included in the test report along with the method of measurement. The macrostructure of the test surface shall be measured according to Reference 13, and the result recorded in the test report. At the time of test the temperature and humidity of the test surface and the relative humidity of the ambient air shall be measured and recorded in the test report.

10.3 WIND VELOCITY

The general wind velocity shall not exceed 10 mph at a height of 4 feet as measured with a hand-held anemometer, and the wind speed and direction shall be recorded in the test report along with the ambient temperature at the time of the test.

11 TIRE BREAK-IN & WARMUP

11.1 INITIAL CYCLING

For initial tire break-in the vehicle shall be driven at 35 mph for 60 seconds with a 1.0 Hz sinusoidal steering input, with sufficient amplitude for a ±0.4-0.5 g lateral acceleration, to remove mold lubricant and mold sheen from the tread surface and exercise the tire carcass (See Reference 4). Subsequently, a tire placed in the right rear position for several test runs will satisfy this requirement.

11.2 TIRE WARMUP/STEADY-STATE TEST (Optional)
With the steering wheel locked at 150 or 180 degrees, the vehicle shall be accelerated at approximately 1 mph/second (Reference 3, Section 7.2.2.2) to the point of its plow or incipient spin limit, to determine the variation in understeer behavior and its steady-state maximum lateral acceleration. The test shall be conducted once in each direction, immediately before testing to warm the tires and further exercise the tire carcass.

11.3 TIRE STRESS EXERCISE
The vehicle shall be driven at 35 mph with ten cycles of sinusoidal steer input at a frequency of 1.0 Hz and an amplitude twice that used in 11.1.

12 TEST PROCEDURE
12.1 The vehicle shall be brought to a steady speed of at least 3 miles per hour above the selected test speed, while traveling in a straight line with the ENERGIZE switch depressed. The straight-line travel shall be maintained for at least 3 seconds. Then the accelerator pedal shall be released and the START PROGRAM switch depressed. When the vehicle speed equals the selected test speed the steer program shall automatically start. The steer angle shall ramp in a left steer at a constant 600 degrees per second until the programmed left-steer set-point is reached, and shall be held at that angle until a "zero-crossing" of the roll velocity signal (i.e., at the maximum roll angle). At that point the steer angle shall begin to traverse in the opposite direction at a constant 600 degrees per second until the right-steer set point is reached. Steer shall be held at that angle for at least 3 seconds, at which time the steer angle may ramp back to zero. The program shall end at approximately 3 seconds after the return to zero steer is accomplished.
The driver shall be able to abort the test and restore manual control at any time by releasing either or both of the START PROGRAM or ENERGIZE switches.
After each run the vehicle shall be stopped in a level location (preferably always the same location and direction) to record post-run instrument zeroes.

12.2 SET-POINT SCHEDULES

Test Run	Program	Left Steer	Right Steer
1	1	90	90
2	2	120	120
3	4	150	150
4	6	180	180
5	8	180	210
6	A	180	240
7	C	180	270

12.3 SCHEDULES AVAILABLE IN STANDARD TEST EPROM

EPROM #5, REVSTR @ 600 deg/sec.

Program	Left steer: angle/seconds	Right steer: angle/seconds
0	Tire break-in sinusoid at 1 Hz	
1	90/.150s	90/.300s
2	120/.200s	120/.400s
3	135/.225s	135/.450s
4	150/.250s	150/.500s
5	165/.275s	165/.550s
6	180/.300s	180/.600s
7	180/.300s	195/.625s
8	180/.300s	210/.650s
9	180/.300s	225/.675s
A	180/.300s	240/.700s
B	180/.300s	255/.725s
C	180/.300s	270/.750s
D	180/.300s	300/.800s
E	180/.300s	330/.850s
F	180/.300s	360/.900s

12.4 ROLLOVER CRITERION

During the test, a run shall be considered a rollover (for purposes of run repetition or tire replacement) when the driver observes that the outrigger air cushion is fully-stroked, as shown by the tell-tale o-ring on the air cylinder shaft. In data processing, a run shall normally be declared a rollover when a roll angle inflection point is clearly present. (See Appendix A6).

12.5 STEER SEQUENCE

The run sequence shall be in the order enumerated in 12.2. If tip-up occurs in a given run, that run shall be repeated If repetition does not produce tip-up, the steer sequence shall be continued in fine program steps until repeatable tip-ups are obtained. Then a Section 7.3.2 tire change shall be made and a new, fine-step EPROM sequence shall begin at the last non-tip run and shall progress from that point until repeatable tip-ups are obtained.

Any test run what results in an “almost tip-up” as evidenced by outrigger scraping shall be repeated, and if the same response is repeated a fine steer sequence shall be taken from that point.

12.6 THRESHOLD SEARCH

The run sequence shall be in the order enumerated in section 12.2. If tip-up occurs in a given run, a run shall be made with one EPROM program step backward. If tip-up occurs at this steer, the test speed shall be reduced in one mph increments until repeatable tip-ups are no longer obtained. Then a Section 7.3.2 tire change shall be made, and a one mph increasing sequence shall begin at that steer angle until repeatable tip-ups are obtained. This shall be declared the speed/steer threshold. For definitive results the speed/steer threshold value must be repeatable with unworn tires.

12.7 SPEED SEQUENCE

Any speed sequence shall be run in 5 mph increments. If tip-up occurs in a given run, that run shall be repeated at least twice. If repetitions do not produce consistent tip-up, the speed sequence shall be continued, at 1 mph increments, until repeatable tip-ups are obtained. Then a Section 7.3.2 tire change shall be made and a new, 1 mph increment sequence shall begin at the last no-tip run and shall progress from that point until repeatable tip-ups are obtained.

Any test run that results in an “almost tip-up” as evidenced by light outrigger scraping shall be repeated, and if the same condition is repeated a one mph sequence shall begin at that point.

13 END-OF-TEST MEASUREMENTS

13.1 OUTRIGGER EFFECT

After determining a set-point combination sufficiently removed from tip-up for safety, one or more runs should be repeated with and without outriggers, for evaluation of outrigger effect on vehicle responses.

14 DATA ANALYSIS

14.1 PRELIMINARY

A test record shall begin 3 seconds before depression of the PROGRAM switch and end at the end of the program or 5 seconds after tip-up.

The lateral acceleration trace shall be processed with a .5 second running-average filter, for determination of maximum lateral acceleration (Section 14.4) or Lateral Acceleration at Tip-up (Section 14.5)

14.2 DATA PLOTTING

Vehicle accelerations shall be referred to the axis system selected by the test customer.

Computed data except vehicle trajectory shall be plotted against time. Trajectory shall be an X-Y plot with the X-axis horizontal and the Y-axis vertical.

Each data plot shall be labeled with identification of the time in hours, minutes and seconds where it can be found on the original test videotapes.

Only selected plots may be made, for budgetary considerations, by request of the test customer. Trajectory plots are not made unless requested, as they can add significantly to the required time. All test data shall be available for later processing and plotting, by ATI or by the test customer.

14.3 DETERMINATION OF TIP-UP POINT

The tip-up point shall be determined from the characteristic form of the roll angle and roll rate data traces. Typically, roll angle increases to a quasi-steady state maximum at a decreasing rate, then turns up as the point of instability is passed. The inflection point, which is determined from the roll angle and roll rate plots, is considered to be the tip-up point.

14.4 DETERMINATION OF MAXIMUM LATERAL ACCELERATION WITHOUT TIP-UP

Maximum lateral acceleration without tip-up shall be defined as the average of the lateral acceleration over a 0.5 second interval in the vicinity of the maximum roll angle for that test run. The peak value of a trace processed thru a 0.5 second running-average filter may be used in this determination.

14.5 DETERMINATION OF LATERAL ACCELERATION AT TIP-UP

Lateral acceleration at tip-up shall be determined as the acceleration in the vicinity of the tip=up point, averaged over a .5 second period (considered as a conservative force/time pulse required for tip-up - see Reference 5). The peak value over this period of a trace processed thru a 0.5 second running-average filter shall be used. Generally, this value will coincide with the maximum lateral acceleration determined in Section 14.4.

14.7 STEADY-STATE UNDERSTEER AND MAX LAT (Optional)

The understeer gradient shall be determined by the "Constant Steer Angle" protocol of SAE J266, from the steer angle, speed, and yaw rate data measured in 10.4.2. Maximum lateral acceleration shall be obtained from the maximum value averaged over 3 seconds of the centripetal acceleration (forward speed times yaw velocity) trace, ignoring any lift-throttle transient at the end of the run. The path radius at max lat shall be computed and noted in the test report.

14.8 OUTRIGGER EFFECT

The time histories for all measured variables for runs with and without outriggers shall be plotted as overlays and included in the test report.

15 RECORD OF THE TEST

The record of the test shall consist of:

- A copy of the test protocol in effect on the test date;
- Unedited videotapes with and without "tape time" in hours, minutes and seconds overlaid;
- All noted data specified thruout this specification;
- A written report containing all plotted data and noted information;

- Still photographs to document location of measuring equipment and ballast;
- Still photographs to document tire wear;
- All processed data on floppy disk or alternative digital format.
- The following video tapes shall be generated from the original test tapes as requested by the test customer:
- Videotapes edited to show each test record as defined in section 10.1;
- Tapes showing the view from the internal camera with real-time, raw instrumentation readings
- superimposed as a column of numerics.

16 MATERIAL RETENTION

16.1 In accordance with the ATI/Heitz "Statement of Terms and Conditions of Agreement" (Website Section 2.7) which is part of any contract, all data and related materials are the property of the test customer, and shall be retained by ATI/HEITZ only according to agreement with the customer.

16.2 Unless otherwise agreed, the original test videotapes shall be archived by ATI/Heitz, solely for the benefit of the customer. All other material related to the test program shall be discarded twelve months after the test date.

16.3 At customer request all tires used in the test will be sectioned, with the 90 degree segment centered on the DOT Number retained as part of the test documentation. Alternatively, the test tires may remain on the test vehicle; or they may be discarded or sent whole to the test customer.

17 MISCELLANEOUS

All other aspects of the test program shall be carried out according to the "Statement of Terms and Conditions of Agreement" in Section 2.7 of the ATI/Heitz Internet Website, at www.atiheitz.com.

A 1 RELATABILITY

A1.1 STEER ANGLES & RATES

The open literature contains little data on steering angles and rates in severe maneuvers. Most publications give only maximum angle and rate averaged for a driver sample, along with standard deviations. These are no help in choosing ramp steer angles and rates. However, Reference 7 does give time histories of steer inputs in a "surprise test" in which a hidden obstacle is suddenly moved in front of the driver's vehicle. Figure A1 is reproduced from Reference. It shows that drivers were able to turn at 820 degrees/second over a range of ±180 degrees. On this basis, ramp rates of 600 degrees/second for ±180 degrees are not unreasonable.

A 2 REPEATABILITY

A2.1 TIRE WEAR

Testing in 1971 with squared-shoulder bias-ply tires concluded that shoulder wear caused extreme changes in tire performance, so that the testing process altered the vehicle system. Repeatability could be attained only when the tires were no longer relatable to highway use.

In 1998 testing at NHTSA and ATI, using the Heitz Programmable Steering Machine for perfectly repeatable steering inputs and modern radial tires having rounded shoulders, the resulting time traces of yaw rate, lateral acceleration, roll rate and roll angle were shown to be extremely repeatable.

A2.2 THE HUMP PROBLEM

In the initial steer, as the vehicle approaches maximum roll angle the roll rate must go to and pass through zero. Test data shows a "hump" in the roll rate response which may occur slightly before, at, or slightly after the zero point. If it is sufficiently before, the zero-crossing may be delayed, causing a significantly longer pause before steer reversal. The reversal still occurs at max roll angle, but sideslip may be larger at the reversal point. The hump can be removed by a suitable filter in the roll rate signal, which can be switched in or out by the driver. The filter restores the steer reversal time; but now the roll angle at steer reversal is no longer maximum. When the test driver senses a long delay, he can switch in the filter, for a comparison run with the hump effect removed. For details, see Reference 8.

A3 REPRODUCIBILITY

A3.1 THE TIRE-PAVEMENT PROBLEM

Repeatable rollover tests run with the same protocol at different facilities should produce comparable results - provided that the pavement friction is either high enough or precisely comparable at both facilities. Generally, rollover requires friction coefficients in the range 0.8 to 1.0. A given vehicle might roll on a 0.90 pavement, but not on a 0.80 pavement.

A3.2 PAVEMENT MONITORING

Pavement friction may vary considerably from day to day and month to month at the same facility. For this reason it is very important to monitor the pavement friction at the time of the test. The best way of doing this is to measure the surface friction with a consistent methodology. For reproducibility between facilities the friction measuring device should use a standard system such as ISO 8349 (Reference 9). In that Standard Section 5 suggests that measurement should preferably be made "before and after each vehicle test and at least before and after each test day."

The coarseness of the pavement macrostructure appears to affect friction measurements. Using the volumetric methodology of Reference, ATI's Raceway Park test site has a mean texture depth of 0.95 mm.

When a friction test is not made the pavement characteristics: materials; macrostructure; and temperature and surface moisture content should be included in the test report.

A3.3 HUMIDITY AT TEST SURFACE

The rate of evaporation of water from the pavement surface depends on the temperature difference between the surface and the dew point: at the dew point the surface will absorb moisture from the air. According to Annex C of Reference 9 (Relative Humidity of the Air in Contact With the Track Surface) "Water, even in very small amounts, influences the tire/road friction significantly on some types of road surfaces. When dry friction measurements are to be made on such surfaces, it is therefore important that the relative humidity of the air in contact with the test surface is well below 100 percent (i.e., the temperature must be well above the dew point). The measurement is recommended to be made with a thin-film sensor in contact with or not more than 10 mm from the surface. If the test surface is warmer than the ambient air and the relative humidity of that air is below 70 percent, no special humidity measurements are required near the surface."

The comment in Reference 9 applies to a surface in equilibrium with the ambient air, but not necessarily to a drying surface. A sun-warmed *dry* surface should be warmer than the ambient air and so have equal or lower relative humidity, but for a *drying* surface the pavement moisture is higher. The surface can be considered dry only when the surface humidity measured by a hygrometer in contact with the surface but isolated from the ambient air (to read the vapor pressure of the surface), reads the same as for the ambient air. Overcast-day measurements by ATI on a wetted blacktop with ambient air at 32% relative humidity and 70 deg F showed the following: when the blacktop was wet the isolated relative humidity was 83 percent at 68 degrees F; when it was visibly discolored by dampness the relative humidity was 75 percent and 72 deg F; when it appeared dry the relative humidity was 48% and 74 deg F; and a separate dry location had readings of 32% at 75 deg F. On a sunny day following an all-night rain, the sun-warmed pavement showed 80 percent relative humidity as long as it was even slightly discolored, and the same 30 percent relative humidity as the ambient air when it appeared dry.

A4 FIGURES OF MERIT

Lateral acceleration at tip-up is the preferred criteria because it is the only one insensitive to pavement friction. Every vehicle has a lateral acceleration at tip-up: however, a vehicle can tip up only if the combination of its tires and the road friction will produce that level of lateral acceleration. Failure to tip up means only that the required lateral acceleration was not reached, or if reached it was not sustained for a long enough time.

8A4.1 SPEED AT TIP-UP

Speed at tip-up is an improper criterion, because of the roll bouncing behavior noted in Section A5 below. Tip-ups have been observed as low as 10 mph when steer input began at 50 mph. The proper speed criterion is the point at which steer is input.

A5 ROLL OSCILLATIONS

SUVs equipped with large, soft tires tend to show severe roll oscillations in rollover maneuvers. Part of these oscillations involve rolling on the suspension, but a major effect comes from tire deflection. Suspension roll frequency is determined by suspension roll stiffness and sprung mass moment of inertia in roll, and tire roll frequency is determined by tire stiffness and total vehicle moment of inertia about the tire fulcrum. Since the "tire spring" has little damping it may predominate. The tire spring is stiffer than the suspension springs, but the vehicle moment of inertia about the tire fulcrum is generally about three times that of the rolling sprung mass, so the resonant frequencies can be very close. When the two resonances coincide their combination is synergistic. The characteristic vehicle behavior is a roll oscillation in which amplitude increases, until tip-up occurs on the third, fourth, or fifth cycle. In this case starting steer input at higher speeds, which increase the time in which the vehicle's resonant roll angle can build up, can result in tip-up at relatively small steer inputs.

A 6 DEFINITION OF ROLLOVER

In a quasi-static sidepull test the slightest two-wheel liftoff represents the rollover point, since continuation of the force causing the lift will cause complete rollover. For this reason many test organizations define two-wheel lift as the rollover point. In a dynamic situation, however, this may not be the case. At the point of two-wheel lift the vehicle state variables – speed, lateral acceleration, etc., are changing, and may not be "strong enough & long enough" for complete rollover.

Reference 5 studies the rollover forces and concludes that:

1. “Sufficient sideforce" must be present for 0.5 seconds;
2. Outrigger loads increase very rapidly as rollover velocity is allowed to increase.

From the first conclusion, the maximum value of the lateral acceleration trace run through a 0.5 second running-average filter is the "Lateral Acceleration for Rollover". (Note: Ford and NHTSA both use 0.4 seconds based on their own unpublished analyses).

During rollover the vehicle rolls rapidly on its suspension, slowing as the suspension limits are reached; then it "takes off" as it begins to roll about the outside tires as the new fulcrum. The inflection point in the roll angle trace is the rollover point: usually it coincides with two-wheel lift.

If the outrigger strikes down before or too close to the inflection point it may prevent development of any significant outrigger force.

A 7 COMPUTATION PROCEDURE FOR CONSTANT STEER ANGLE TEST

1. Plot steer angle and throttle vs time. Inspect for steer variations or sudden large throttle input.
2. Plot speed and yaw rate versus time and inspect.
3. Plot yaw rate versus speed, from zero. Fit fifth-order polynomial, beginning with 5 mph (7.5 ft/sec.). This will eliminate division-by-zero problems, effects of steering geometry which dominate in absence of lateral acceleration, and effect of too many data points present at near-zero speed. Plot fitted curve over raw data.
4. Compute and plot curvature vs (ur) from r vs u equation.
5. Compute and plot understeer gradient vs (ur).

A 8 TIRE SELECTION

For standard test condition OEM tires in new condition should be used. If possible, tires should not be more than one year past the manufacture date. Old tires must be used with caution, even if unused. The tire manufacture date must be noted in the test report.

If OEM tires are not available, every effort must be made to find the nearest equivalent: in size, construction, load and speed rating, and tread design. Differences between the OEM tire and the tire selected must be explained in the test report.

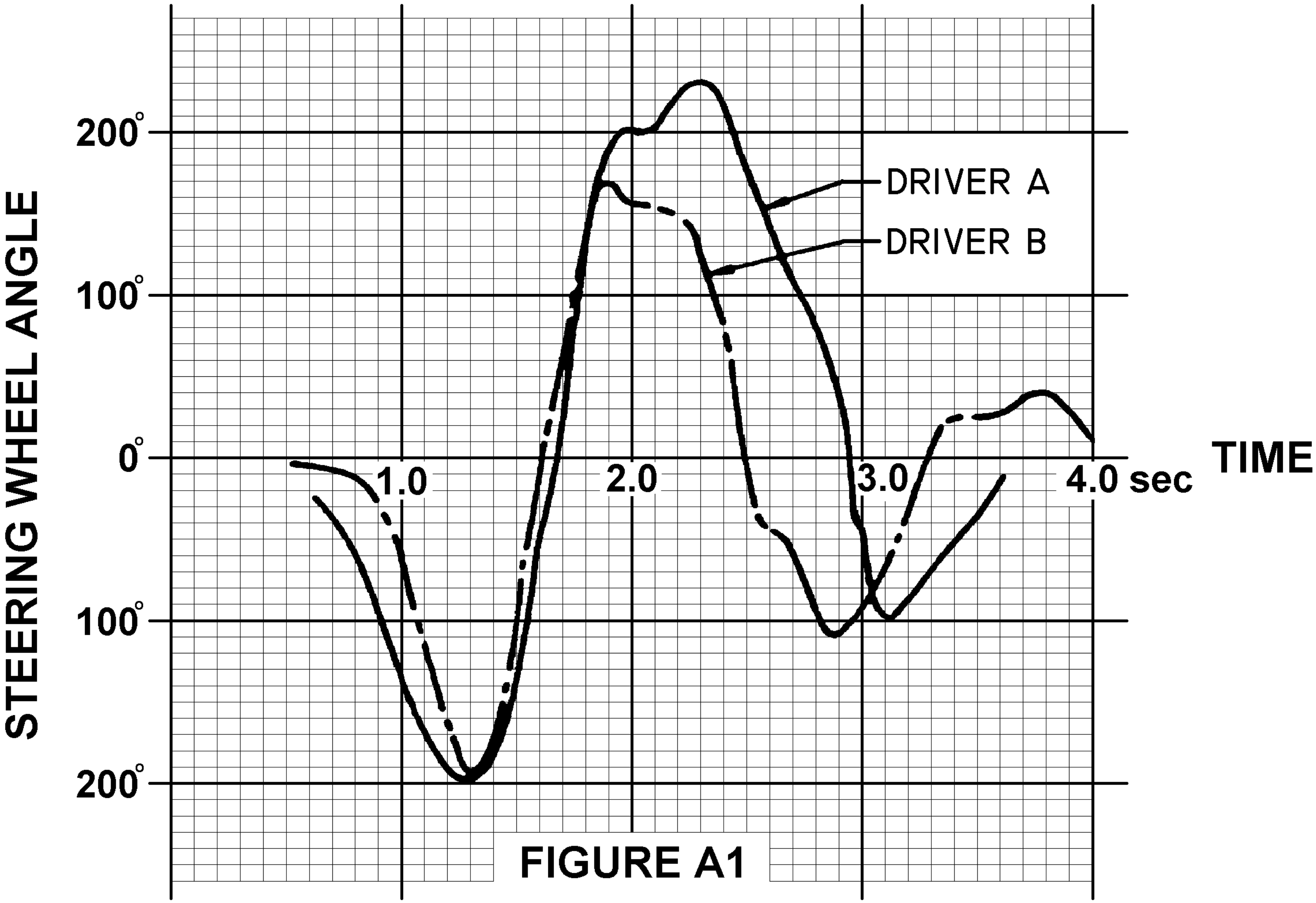
STEERING WHEEL ANGLE
200°
100°
0°
100°
200°
1.0
2.0
3.0
4.0 sec
TIME
DRIVER A
DRIVER B

FIGURE A1