Effects of Stability Control on the Rollover Propensity of Two Sport Utility Vehicles

A Preliminary Investigation

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Stability Control Background

- Affects vehicle response
  - Throttle (engine) intervention
  - Selective brake application
- First available on high-end luxury passenger cars
- Nineteen automakers now offer stability control
- Presently available on some SUVs
  - BMW X5
  - Mercedes M-Class
  - Toyota/Lexus
    - RX300
    - 4Runner
    - Sequoia
    - Land Cruiser/LX470
NHTSA Research
Desired Test Matrix

- Must be extensive
- Severe Maneuvers
  - Rollover propensity
    - J-Turn
    - Fishhook
    - Resonant Steer
  - Handling
    - Double Lane Change
    - Elk Test
- Roadway Orientation
  - Straight
  - Corners
- Surfaces
  - High-mu
  - Lo-mu
  - Transitions
- Driver Inputs
  - Throttle
    - With / without
  - Brake Application
    - With / without
Abbreviated Test Matrix

- Brief testing opportunity before and during equipment procurement phase of TREAD Act preparation
- Allowed 3 Phase II maneuvers to be performed with 2 vehicles
- No handling or braking maneuvers
Test Vehicles

- 1999 Mercedes ML320
  - First production SUV equipped with standard stability control
  - Continental Teves ESP
  - Push-button deactivation

- 2000 Lexus LX470
  - Large SUV (6000 lbs with outriggers)
  - Aisen VSC
  - Driver cannot disable
Objective: Investigate how stability control can affect rollover propensity
Test Matrix

- Phase II Maneuvers
  - J-Turn (no pulse braking)
  - Fishhook #1
  - Fishhook #2

- Closed-loop double lane change
J-Turn

- Identical handwheel inputs for each vehicle
- 330 degree magnitude
- 1000 deg/sec rate
Fishhook #1

- 270 → 600 degree magnitudes
- ML320
  - 0.8 Hz roll natural frequency peak produced with pulse steer
  - 1440 and 750 deg/sec rates
- LX470
  - Response flat in pulse steer
  - Roll natural frequency assumed to be 0.5 Hz
  - 720 and 750 deg/sec rates
Fishhook #2

- **Initial steer magnitude based on steering ratio**
  - **ML320**
    - Steering ratio = 19.4
    - Initial steer = 146 degrees
  - **LX470**
    - Steering ratio = 21.5
    - Initial steer = 161 degrees
- **Reversal** = 600 degrees
- **All rates** = 500 deg/sec
Closed-Loop Double Lane Change

- New maneuver
- Uses roll rate feedback
- **Progressively Increasing Steer Maneuver (PRISM)**
  - Designed to simulate a driver who over-corrects steering
  - Yaw magnitude increases with each successive handwheel input
- Performed with the LX470
Closed-Loop Double Lane Change

- Handwheel magnitudes based on Steering Gain #1 test
- Sample Steering Magnitudes
  - LX470
  - 36.8 mph
  - Initial steer = $\theta_{Ay_{\text{max}}}$ (191 deg)
  - 2$^{\text{nd}}$ steer = 1.5*$\theta_{Ay_{\text{max}}}$ (287 deg)
  - 3$^{\text{rd}}$ steer = 2.0*$\theta_{Ay_{\text{max}}}$ (382 deg)
Miscellaneous Test Conditions

- Vehicle speed incrementally increased
- Performed with and without stability control
- Front and rear mounted outriggers
- Lightly laden
- Dry, high-mu asphalt surface
- Used the steering machine
- Performed with steering in both directions
Preliminary Results (J-Turn)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Right Steer</th>
<th>Left Steer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Early Termination Condition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stability Control</td>
<td>Disabled Stability Control</td>
</tr>
<tr>
<td>ML320</td>
<td>--</td>
<td>N/A*</td>
</tr>
<tr>
<td>LX470</td>
<td>--</td>
<td>Plow-out (55.0 mph)</td>
</tr>
</tbody>
</table>

*Test not required. No ESP intervention was detected during active-ESP, right-steer J-Turn testing.
J-Turn Results – ML320

Handwheel Angle (deg)

Vehicle Speed (mph)

Lateral Acceleration (g)

Yaw Rate (deg/sec)

Roll Angle (degrees)

Time (sec.)

Roll Rate (deg/sec)

Handwheel Angle (deg)

Vehicle Speed (mph)

Lateral Acceleration (g)

Yaw Rate (deg/sec)

Roll Angle (degrees)

Time (sec.)

Roll Rate (deg/sec)

Handwheel Angle (deg)

Vehicle Speed (mph)

Lateral Acceleration (g)

Yaw Rate (deg/sec)

Roll Angle (degrees)

Time (sec.)

Roll Rate (deg/sec)
J-Turn Results – LX470

Vehicle Speed (mph)

Lateral Acceleration (g)

Roll Angle (degrees)

Roll Rate (deg/sec)

Time (sec.)

Longitudinal Acceleration (g)

LF Brake Line Pressure (psi)

RF Brake Line Pressure (psi)

LR Brake Line Pressure (psi)

RR Brake Line Pressure (psi)

VSC Flag (volts)

Vehicle Speed (mph)

Lateral Acceleration (g)

Roll Angle (degrees)

Roll Rate (deg/sec)

Time (sec.)

VSC Flag (volts)

Longitudinal Acceleration (g)

LF Brake Line Pressure (psi)

RF Brake Line Pressure (psi)

LR Brake Line Pressure (psi)

RR Brake Line Pressure (psi)
J-Turn Video

- LX470
- w/o VSC at 55.0 mph (plow-out)
- w/VSC
  - At 55.5 mph
  - At 60.0 mph
## Preliminary Results (Fishhooks)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Fishhook Maneuver</th>
<th>Early Termination Condition</th>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Right-Left</td>
<td>Left-Right</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Stability Control</td>
<td>Disabled Stability Control</td>
<td>Stability Control</td>
<td>Disabled Stability Control</td>
<td></td>
</tr>
<tr>
<td>ML320</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>Minor TWL (38.8 mph)</td>
<td>Minor TWL (35.2 mph)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Minor TWL (45.5 mph)</td>
<td>Minor TWL (47.0 mph)</td>
<td>Minor TWL (46.4 mph)</td>
<td>Minor TWL (44.0 mph)</td>
<td></td>
</tr>
<tr>
<td>LX470</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>Minor TWL (40.3 mph)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>Minor TWL (47.3 mph)</td>
<td></td>
</tr>
</tbody>
</table>
Fishhook #2 Results – ML320

Graphs showing various performance metrics over time for ML320: Handwheel Angle (deg), Vehicle Speed (mph), Lateral Acceleration (g), Yaw Rate (deg/sec), Roll Angle (degrees), Roll Rate (deg/sec), Longitudinal Acceleration (g), LF Brake Line Pressure (psi), RF Brake Line Pressure (psi), LR Brake Line Pressure (psi), RR Brake Line Pressure (psi).
Fishhook #2 Results – LX470

- Vehicle Speed (mph)
- VSC Flag (volts)
- Lateral Acceleration (g)
- Yaw Rate (deg/sec)
- Roll Angle (degrees)
- Roll Rate (deg/sec)
- Longitudinal Acceleration (g)

- LF Brake Line Pressure (psi)
- RF Brake Line Pressure (psi)
- LR Brake Line Pressure (psi)
- RR Brake Line Pressure (psi)

Comparison of results with and without VSC.
Fishhook #2 Video

- ML320

- Minor TWL w/o ESP
  - 45.6 mph
  - Increasing roll oscillations

- Minor TWL w/ESP
  - 46.4 mph
  - Increasing roll oscillations
## Preliminary Results (PRISM)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Early Termination Condition*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right-Left-Right</td>
</tr>
<tr>
<td></td>
<td>Stability Control</td>
</tr>
<tr>
<td></td>
<td>Disabled Stability Control</td>
</tr>
<tr>
<td>LX470</td>
<td>Only 1 test (45.5 mph)</td>
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<td></td>
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</tbody>
</table>

*Termination conditions not defined prior to PRISM testing. Spin-outs were observed during each non-VSC test performed above 40 mph.

**Two-wheel lift observed earlier at 38.1 mph
PRISM Results – LX470

Vehicle Speed (mph)

VSC Flag (volts)

Lateral Acceleration (g)

Roll Angle (degrees)

Time (sec.)

Roll Rate (deg/sec)

Longitudinal Acceleration (g)

LF Brake Line Pressure (psi)

RF Brake Line Pressure (psi)

LR Brake Line Pressure (psi)

RR Brake Line Pressure (psi)

rold218 (no VSC)

rold219 (VSC)

rold218 (no VSC)

rold219 (VSC)
PRISM Results – LX470

- Handwheel Angle (degrees) vs. Time (sec.)
- Vehicle Speed (mph) vs. Time (sec.)
- Lateral Acceleration (g) vs. Time (sec.)
- Yaw Rate (deg/sec) vs. Time (sec.)
- Roll Angle (degrees) vs. Time (sec.)
- Roll Rate (deg/sec) vs. Time (sec.)
- VSC Flag (volts) vs. Time (sec.)
- Longitudinal Acceleration (g) vs. Time (sec.)
- LF Brake Line Pressure (psi) vs. Time (sec.)
- RF Brake Line Pressure (psi) vs. Time (sec.)
- LR Brake Line Pressure (psi) vs. Time (sec.)
- RR Brake Line Pressure (psi) vs. Time (sec.)

rold213 (no VSC; 32.3 mph)
rold219 (VSC; 45.5 mph)
PRISM Video

- **LX470**
- **w/o VSC**
  - 38.1 mph
  - Two instances of minor TWL at 38.1 mph
  - Spin-out, no TWL at 46.7 mph
- **w/VSC**
  - 45.5 mph
  - Similar speed to max used w/VSC
Future Testing

- 2 / 4 Vehicles purchased for TREAD Act maneuver development are equipped with stability control
  - 2001 Toyota 4Runner
  - 1999 Mercedes ML320
- TREAD-related maneuver development test matrices promise to be extensive
  - Optimized Fishhooks and J-Turns
  - Handling maneuvers (e.g., Elk Test, etc.)
  - Vehicle modifications
- Performed with and without stability control
Conclusions

- NHTSA has begun to research stability control
- TREAD Act related testing will allow NHTSA to gain significant experience with stability control and how it relates to dynamic rollover propensity
- Potentially promising technology
- Vehicle response with stability control can be very different than that with it disabled
- Warning indicator lights should be taken seriously!