Light Vehicle Dynamic Rollover Propensity Phases IV, V, and VI

Research Activities

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Overview of NHTSA Rollover Research Phases

Phase I-A
• Spring 1997
• Exploratory in nature
• Emphasized maneuver selection and procedure development

Phase I-B
• Fall 1997
• Evaluation of test driver variability
• Introduction of the programmable steering machine

Phase II
• Spring 1998
• Evaluation of 12 vehicles using maneuvers researched in Phase I

Phase III-A
• Spring 2000
• Introduction of “Roll Rate Feedback”

Phase III-B
• Summer 2000
• Pulse brake automation

Phase IV
• Spring 2001
• Response to TREAD Act
• Consideration of many maneuvers

Phase V
• Spring 2002
• Research factors that may affect dynamic rollover propensity tests
• Rollover and handling rating development

Phase VI
• Evaluation of 26 vehicles using Phase IV recommendations

Discussed in this presentation
Phase IV Background

TREAD Act / Congressional Requirements:
• Develop dynamic rollover propensity tests to facilitate a consumer information program
• Consumer Information methodology released by November 2002
• National Academy of Sciences Report
Additional Background

In their assessment of NHTSA’s existing rollover resistance rating system (January, 2002) the National Academy of Sciences recently recommended:

“NHTSA should vigorously pursue the development of dynamic testing to supplement the information provided by SSF.”
Additional Background

• NHTSA is presently providing Rollover Resistance Rating
• Based on vehicle measurements and real world crash data
• Vehicle measurement is Static Stability Factor
• 5 Star ratings are similar to NCAP Crash Ratings
Impending Rollover
\[ W(T/2) = P(H_{cg}) \]
\[ \frac{\text{Pull}}{W} = \frac{T/2}{H_{cg}} \]
\[ \frac{\text{Pull}}{W} = \text{SSF} \]
Probability of Rollover per Single Vehicle Crash

Static Stability Factor

- 50%
- 40%
- 30%
- 20%
- 10%
- 0%

- 1.05
- 1.1
- 1.15
- 1.2
- 1.25
- 1.3
- 1.35
- 1.4
- 1.45
- 1.5
- 1.55
- 1.6

Graph showing the relationship between probability of rollover and static stability factor.
Maneuver Recommendations

- Alliance of Automobile Manufacturers
- Consumers Union
- Ford Motor Company
- Heitz Automotive, Inc.
- ISO 3888 Part 2 Consortium
  - VW, BMW, Daimler Chrysler
  - Porsche, Mitsubishi
- MTS Systems Corporation
- Nissan Motors
- Toyota Motor Company
- UMTRI
Phase IV Test Conditions
Test Vehicles

2001 Chevrolet Blazer 4x2
- One star static rollover rating
- High sales volume

1999 Mercedes ML320 4x4
- “Less aggressive” stability control intervention
- Two star static rollover rating
- First SUV with available stability control (ESP)

2001 Ford Escape 4x4
- Three star static rollover rating
- Smaller, car-like SUV

2001 Toyota 4Runner 4x4
- “Aggressive” stability control intervention
- Two star static rollover rating
- Relatively high sales volume
Vehicle Configurations

- Instrumented
- Fully fueled
- Front and rear mounted aluminum outriggers
- Performed with and without stability control
- Multiple configurations
  - Nominal vehicle
  - Reduced rollover resistance
Reduced Rollover Resistance

• Roof-mounted ballast
• Designed to reduce SSF by 0.05
• Increased roll inertia from Nominal condition
  ➢ Escape = 8.0 %
  ➢ Blazer = 11.5%
• Longitudinal C.G. preserved
• Maneuver sensitivity check
Reduced Rollover Resistance
(measurements taken without instrumentation)

<table>
<thead>
<tr>
<th>Car</th>
<th>Ballast</th>
<th>C.G. raised</th>
<th>SSF&lt;sub&gt;NOMINAL&lt;/sub&gt;</th>
<th>SSF&lt;sub&gt;RRR&lt;/sub&gt;</th>
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<tbody>
<tr>
<td>4Runner</td>
<td>180 lbs</td>
<td>1.3”</td>
<td>1.11 (★★)</td>
<td>1.06 (★★)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blazer</td>
<td>180 lbs</td>
<td>1.3”</td>
<td>1.04 (★★)</td>
<td>0.99 (★)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Escape</td>
<td>120 lbs</td>
<td>1.0”</td>
<td>1.26 (★★★★)</td>
<td>1.21 (★★★)</td>
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<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>ML320</td>
<td>180 lbs</td>
<td>1.2”</td>
<td>1.14 (★★★★)</td>
<td>1.09 (★★)</td>
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</tbody>
</table>

Note: Nominal SSF differ from those measured without outriggers
Test Vehicle SSF Summary

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>SSFnom,i = 0.90</th>
<th>SSFnom,i = 1.00</th>
<th>SSFnom,i = 1.10</th>
<th>SSFnom,i = 1.20</th>
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<tbody>
<tr>
<td>Blazer</td>
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</tr>
<tr>
<td>4Runner</td>
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<td>SSFnom,i = 1.12</td>
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<tr>
<td>ML320</td>
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<td></td>
<td>SSFnom,i = 1.18</td>
<td></td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td>SSFnom,i = 1.27</td>
</tr>
</tbody>
</table>

- **Baseline**
- **Nominal (no instrumentation)**
- **Nominal (with instrumentation)**
- **RRR (no instrumentation)**
Tires

• OEM specification (as installed on vehicle when delivered)
  - Make
  - Model
  - DOT Code
  - Inflation pressure
• Frequent tire changes
• Innertubes used during some maneuvers to prevent debeading
• Maneuver speed iterations selected to minimize tire wear within a given test series
Test Surface

• All tests performed on TRC’s VDA (a dry, high-mu asphalt surface)
• Tests performed 04/01 to 11/01, 02/02
• Stable friction coefficients
  ➢ Peak $\mu$: 0.94 to 0.98
  ➢ Slide $\mu$: 0.81 to 0.88
Phase IV Maneuver Review
Charcterization Maneuvers

• Used to define NHTSA’s dynamic rollover propensity maneuvers
  ➢ Constant Speed, Slowly Increasing Steer

• Used to characterize transient response
  ➢ Pulse Steer
  ➢ Sinusoidal Sweep
  ➢ J-Turn Response Time Tests
Dynamic Rollover Propensity Maneuvers

**Automated Steering**
- NHTSA J-Turn
- Fixed Timing Fishhook
- Roll Rate Feedback Fishhook
- Nissan Fishhook
- Open-Loop Pseudo-Double Lane Change

**Driver-based Steering**
- ISO 3888 Part 2
- CU Short Course

**Driver-based Steering, Computer Corrected**
- Ford PCL LC
NHTSA J-Turn and Fishhooks

- Steering magnitude based on vehicle response
  1. Determine the handwheel angle at 0.3 g from Slowly Increasing Steer results
  2. Multiply by a scalar (derived with Phase II data)
- Steering rate based on successful Phase II testing
  - J-Turn = 1000 deg/sec
  - Fishhook = 720 deg/sec
NHTSA J-Turn

Vehicle | Handwheel Input (degrees)
---|---
Blazer | 401
4Runner | 354
ML320 | 310
Escape | 287

\[ A = 5.0 \times \text{Handwheel Position at 0.3 g} \]

\[ T_f = 4 \text{ seconds per sec} \]

Initial steer performed at 1000 deg/sec
NHTSA Fixed Timing Fishhook (Symmetric)

Vehicle | Handwheel Input (degrees)
---|---
Blazer | 326
4Runner | 287
ML320 | 252
Escape | 233
NHTSA Roll Rate Feedback Fishhook (Symmetric)

Vehicle Input (degrees)

<table>
<thead>
<tr>
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<td>233</td>
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</table>
Nissan Fishhook

- Adjusts timing to maximize roll motion
- 270 degree initial steer
- Vehicle-dependent reversal magnitude (for fishhooks)
  - Blazer = 570 degrees
  - Escape = 505 degrees
- All rates = 1080 deg/sec
- Response-dependent dwell times
  - Iterative determination
Closed-loop, Path-Following Lane Changes

Consumers Union Short Course

ISO 3888. Part 2 Course
Ford PCL LC

• Comprised of a suite of closed-loop paths (double lane changes)
• Data is processed to remove driver effects and facilitate comparison at a constant severity
  ➢ All vehicles taken to follow the same path
  ➢ All vehicles subject to the same lateral acceleration demands
• Test output is an overall dynamic weight transfer metric
Ford PCL LC

Full Lane

Half Lane

Lane and a Half

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Comments Based on the Phase IV Rollover Resistance Maneuvers
NHTSA J-Turn

• Lowest speed of two-wheel lift is metric
• Uses Programmable Steering Controller
• Simple step-steer (one cycle)
• Handwheel magnitude dependent on vehicle response
J-Turn with Pulse Braking

• Lowest speed of two-wheel lift is metric
• Uses Programmable Braking and Steering Controller
• Addition of Braking Controller makes maneuver substantially harder to perform
• Timing of brake pulse dependent on vehicle response (Roll Rate Feedback)
• Results significantly influenced by whether vehicle has working ABS
Fixed Timing Fishhook

• Lowest speed of two-wheel lift is metric
• Dwell time independent of vehicle response
• Handwheel magnitudes dependent on vehicle response
• Handwheel inputs within ranges established during ISO and CU double lane change testing
• Timing may be better for one vehicle than another
Roll Rate Feedback Fishhook

- Lowest speed of two-wheel lift is metric
- Handwheel magnitudes dependent on vehicle response
- Handwheel inputs within ranges established during ISO and CU double lane change testing
- Dwell time also dependent on vehicle response
- Timing should no longer favor one vehicle over another
Nissan Fishhook

- Lowest speed of two-wheel lift is metric
- Iterative procedure requires additional testing time
- Large number of tests required many tire changes (to reduce tire wear concerns)
- Reversals are harsh; increases steering machine wear
Ford Path Corrected Limit Lane Change (PCL LC)
Ford PCL LC

- Metric Dynamic Weight Transfer at $0.7\,g$ based on one of four standard paths (DWTM)
- Method removes driver dependence by normalizing data
- Extra tire testing required (tire measurements)
- Concerns about 0.40 second window used for metric calculation (mitigates dynamic weight transfer observed)
- Metric now measured during tests performed with a driving robot
ISO 3888 Part 2
Double Lane Change

• Suggested rating metric is maximum achievable “clean” run speed
  ➢ “Clean” run → no cones struck/bypassed
• Test driver generated steering inputs
• Not as repeatable as programmable steering controller inputs
• Tests are straightforward to perform
• Course adapts to vehicle width
Consumers Union Short Course
Double Lane Change

- Suggested rating metric is maximum achievable “clean” run speed
  - “Clean” run → no cones struck/bypassed
- Test driver generated steering inputs
- Not as repeatable as programmable steering controller inputs
- Tests are straightforward to perform
- Course does not adapt to vehicle size
Open-Loop Pseudo-Double Lane Change

• Uses programmable steering controller
• Having three major steering moves slightly degrades repeatability
• Straight-forward to perform
• Uses programmable steering controller
• Additional development required
Reporting of Phase IV Findings

Draft of Phase IV NHTSA Technical Report has been written

- Reviews in progress
- Anticipated release late Spring ‘02
Phase V Research
Phase V Overview

- Investigate potential use of a centrifuge
- Improved test equipment
  - Alternative outrigger development
  - Quantification of two-wheel lift
- Resolution of existing matters
  - Cold and hot weather testing
  - Surface effects testing
- Finalize methodology for Phase VI
  - Loading
Centrifuge

- Metric could be lateral acceleration at wheel lift or weight transfer
- Quasi-static test
- May be demonstrated by NHTSA using a NASA Facility
Outrigger Development

• Reduce effects of outrigger installation without compromising driver safety
• Use wheel load transducers to evaluate dynamic load transfer and cornering forces

• Compare three designs
  ➢ Existing VRTC Design
    ✓ Aluminum
    ✓ 78 lbs per outrigger
  ➢ New VRTC Design
    ✓ Titanium
    ✓ 68 lbs per outrigger
  ➢ Carr Engineering
    ✓ Carbon fiber
    ✓ 58 lbs per outrigger

• Testing complete
Carbon Fiber

• Manufactured by Carr Engineering
• Light weight (58 lbs)
• Strong
• Expensive ($25k / set)
Titanium

- Designed at VRTC using finite element analysis
- Light weight (68 lbs)
- Less roll inertia than aluminum or carbon fiber
- Strong
- 1/3 cost of carbon fiber
- 6Al-4V a common Ti alloy
- Low-mu hemispherical skid pads replace heavier casters
Quantification of Two-Wheel Lift

• Objective methodology required
• Laser-based height sensors on each wheel
  ➢ Eliminates video data analysis subjectivity
Cold and Hot Weather Testing

• Will research the effects of temperature extremes on dynamic rollover propensity
• All testing to be performed at TRC
• Cold weather tests performed during January ‘02
• Hot weather tests to be performed Summer ‘02
Surface Effects Testing

• Determine effects of different test surfaces on dynamic rollover propensity

• Testing performed in Arizona
  - DaimlerChrysler Arizona Proving Grounds (APG)
  - GM Desert Proving Grounds
  - Performed with the Blazer and 4Runner

• Testing complete

• Results from Arizona will be compared with those produced at TRC
Phase VI
Phase VI Overview

• Maneuvers based on Phase IV findings
• Three load conditions
• Titanium outriggers
• 26 Vehicles
• Will include a wide range of make/models for which state rollover rate data is available