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

Research Activities

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NHTSA / VRTC
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 25 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:
\[ W\left(\frac{T}{2}\right) = P(H_{cg}) \]
\[ \frac{\text{Pull}}{W} = \frac{(T/2)}{H_{cg}} \]
\[ \frac{\text{Pull}}{W} = \text{SSF} \]
The graph illustrates the probability of rollover per single vehicle crash as a function of the static stability factor. The probability decreases as the static stability factor increases. The data points are scattered around the trend line, indicating variability in real-world conditions. The x-axis represents the static stability factor, while the y-axis shows the probability of rollover.
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

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

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

- **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

Up to 180 lbs
Reduced Rollover Resistance
(measurements taken without instrumentation)

- **4Runner**
  - 180 lbs ballast
  - C.G. raised 1.3”
  - $\text{SSF}_{\text{NOMINAL}} = 1.11$ (★★)
  - $\text{SSF}_{\text{RRR}} = 1.06$ (★★)

- **Blazer**
  - 180 lbs ballast
  - C.G. raised 1.3”
  - $\text{SSF}_{\text{NOMINAL}} = 1.04$ (★★)
  - $\text{SSF}_{\text{RRR}} = 0.99$ (★)

- **Escape**
  - 120 lbs ballast
  - C.G. raised 1.0”
  - $\text{SSF}_{\text{NOMINAL}} = 1.26$ (★★★★)
  - $\text{SSF}_{\text{RRR}} = 1.21$ (★★★★)

- **ML320**
  - 180 lbs ballast
  - C.G. raised 1.2”
  - $\text{SSF}_{\text{NOMINAL}} = 1.14$ (★★★★)
  - $\text{SSF}_{\text{RRR}} = 1.09$ (★★★)

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

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Static Stability Factor (SSF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blazer</td>
<td>SSF_{nom,i} = 1.05</td>
</tr>
<tr>
<td>4Runner</td>
<td>SSF_{nom,i} = 1.12</td>
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<tr>
<td>ML320</td>
<td>SSF_{nom,i} = 1.18</td>
</tr>
<tr>
<td>Escape</td>
<td>SSF_{nom,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 damage due to debeading
Test Surface

- All tests performed on TRC’s VDA (a dry, high-mu asphalt surface)
- Tests performed 05/01 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
Characterization 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
- **Automated Steering**
  - J-Turns
  - 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

A = 8.0 * Handwheel Position at 0.3 g
$T_1 = 4$ second pause
Initial steer performed at 1000 degree/second

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<td>4Runner</td>
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<td>ML320</td>
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<tr>
<td>Escape</td>
<td>287</td>
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NHTSA Fixed Timing Fishhook (Symmetric)

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<td>4Runner</td>
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<tr>
<td>ML320</td>
<td>252</td>
</tr>
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<td>Escape</td>
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NHTSA Roll Rate Feedback Fishhook (Symmetric)

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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
Consumers Union Short Course

ISO 3888 Part 2
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
Comments Based on 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 instrumentation needed to run
- 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
- 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 VTRC 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

- Intended to research the effects of different test surfaces on dynamic rollover propensity
- Testing presently underway in Arizona
  - DaimlerChrysler Arizona Proving Grounds (APG)
  - GM Desert Proving Grounds
  - Performed with the Blazer and 4Runner
- Results from Arizona will be compared with those produced at TRC
Phase VI
Phase VI Overview

- Maneuvers based on Phase IV findings
- Two load conditions are anticipated
- Titanium outriggers
- 25 Vehicles
- Will include a wide range of make/models for which state rollover rate data is available