Vehicle Research
and Test Center

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

Discussed in this presentation

- **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

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

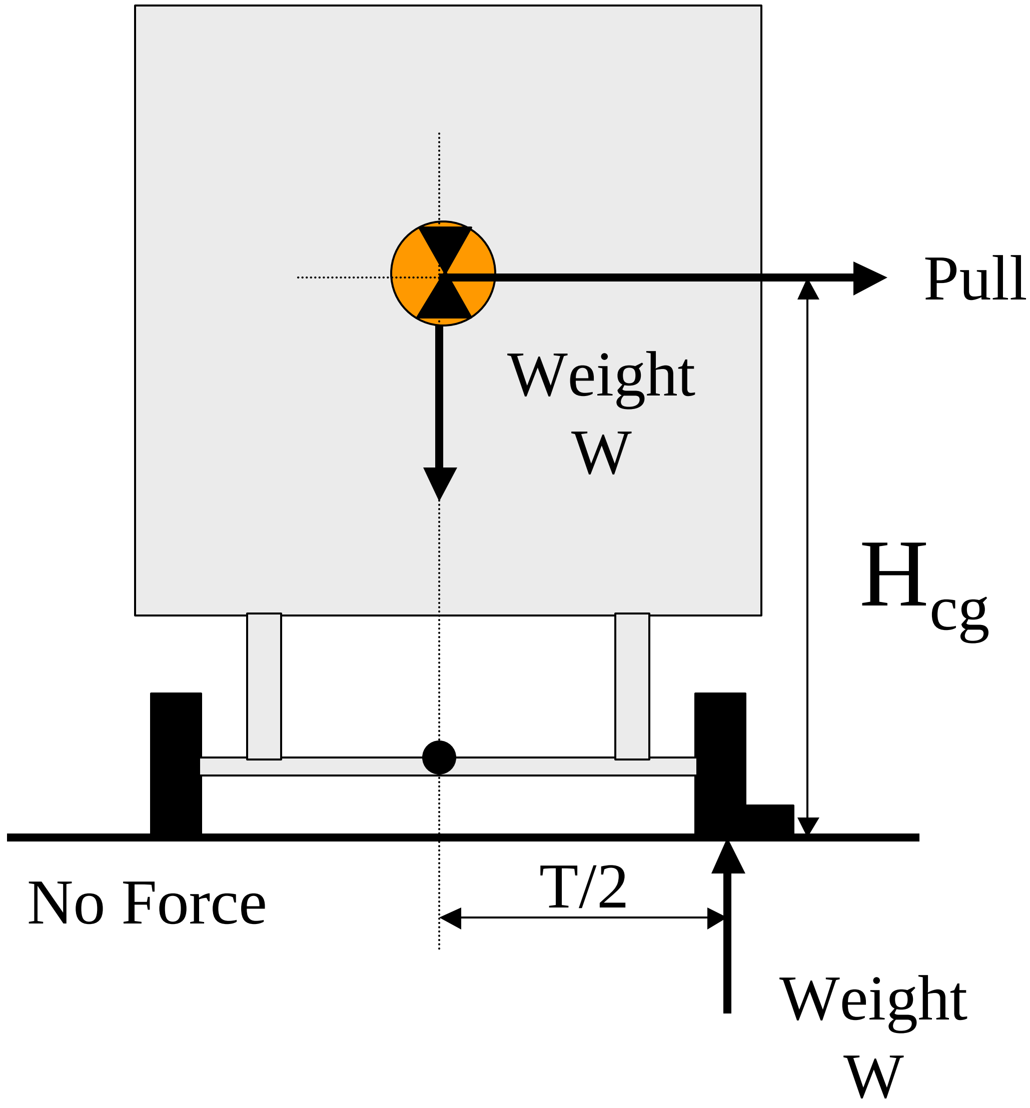
Additional Background

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

$W(T/2)=P(H_{cg})$

$Pull/W = (T/2)/ H_{cg}$

Pull/W=SSF

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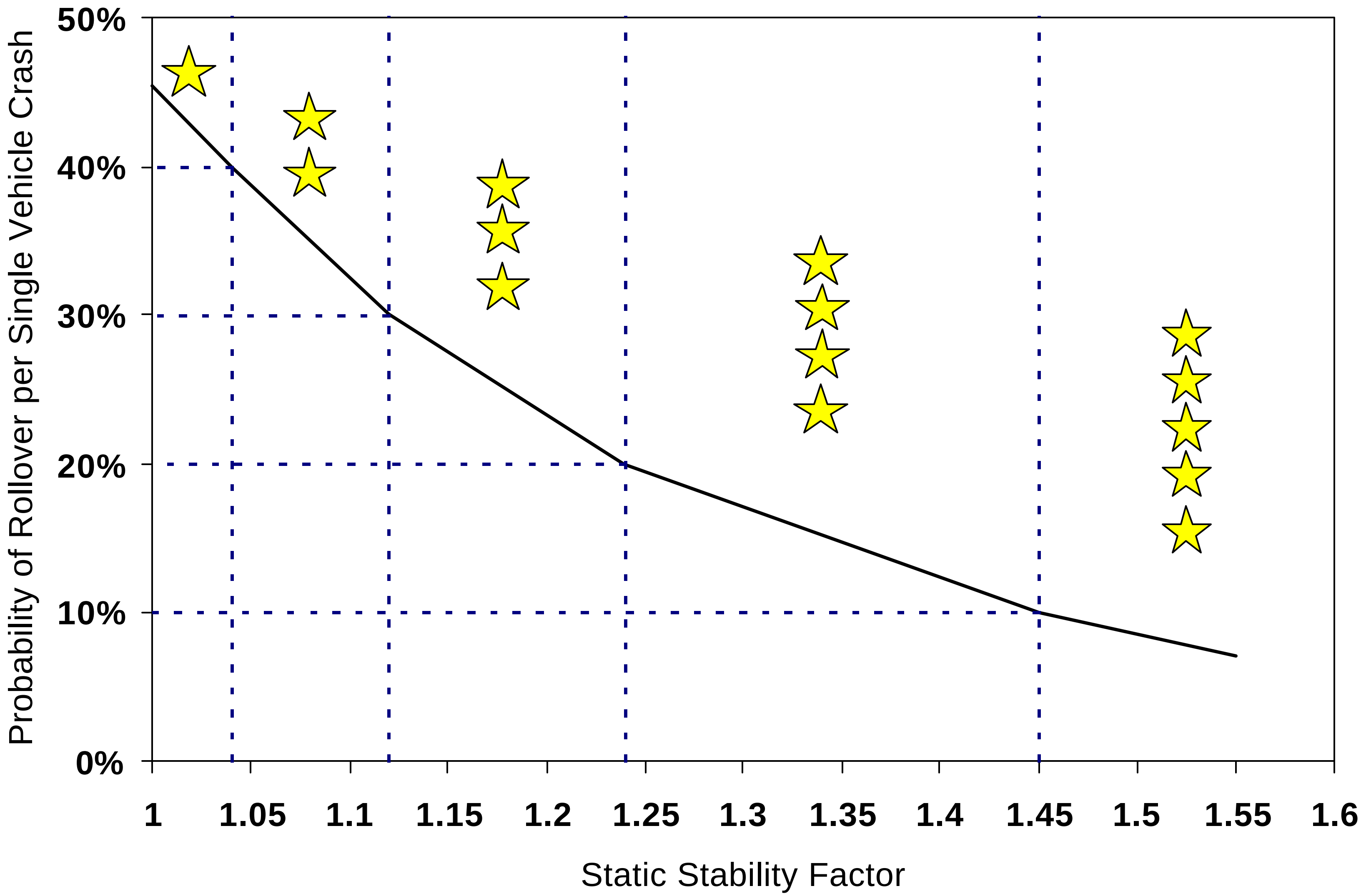

Maneuver Recommendations

- **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

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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

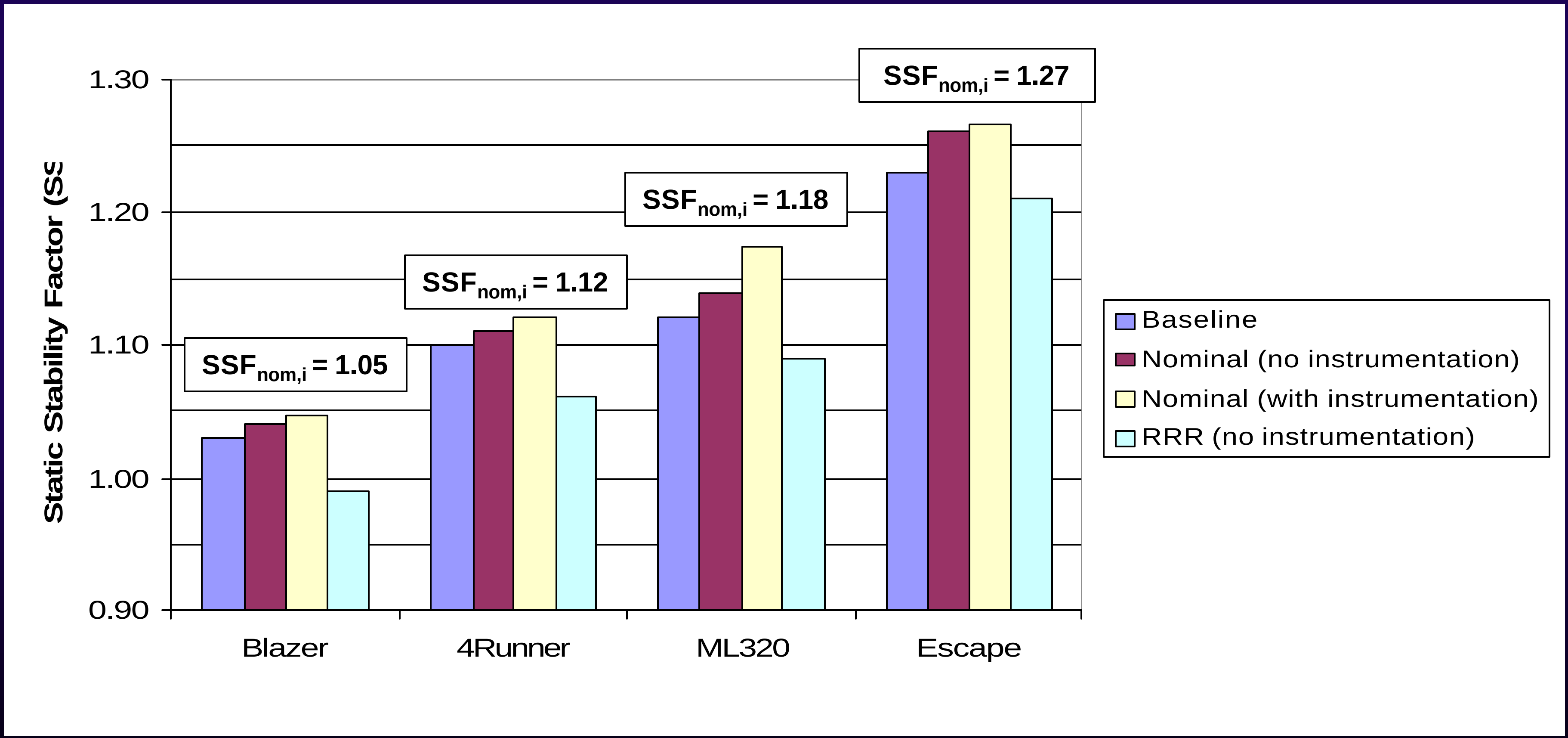
Reduced Rollover Resistance

(measurements taken without instrumentation)

- **4Runner**
  - **180 lbs ballast**
  - **C.G. raised 1.3”**
  - **$SSF_{NOMINAL}$ = 1.11 (★★)**
  - **SSF_{RRR} = 1.06 (★★)**
- **Blazer**
  - **180 lbs ballast**
  - **C.G. raised 1.3”**
  - **$SSF_{NOMINAL}$ = 1.04 (★★)**
  - **SSF_{RRR} = 0.99 (★)**
- **Escape**
  - **120 lbs ballast**
  - **C.G. raised 1.0”**
  - **$SSF_{NOMINAL}$ = 1.26 (★★ ★★)**
  - **SSF_{RRR} = 1.21 (★★★)**
- **ML320**
  - **180 lbs ballast**
  - **C.G. raised 1.2”**
  - **$SSF_{NOMINAL}$ = 1.14 (★★★)**
  - **SSF_{RRR} = 1.09 (★★)**

Note: Nominal SSF differ from those measured without outriggers.

Test Vehicle SSF Summary



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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 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**

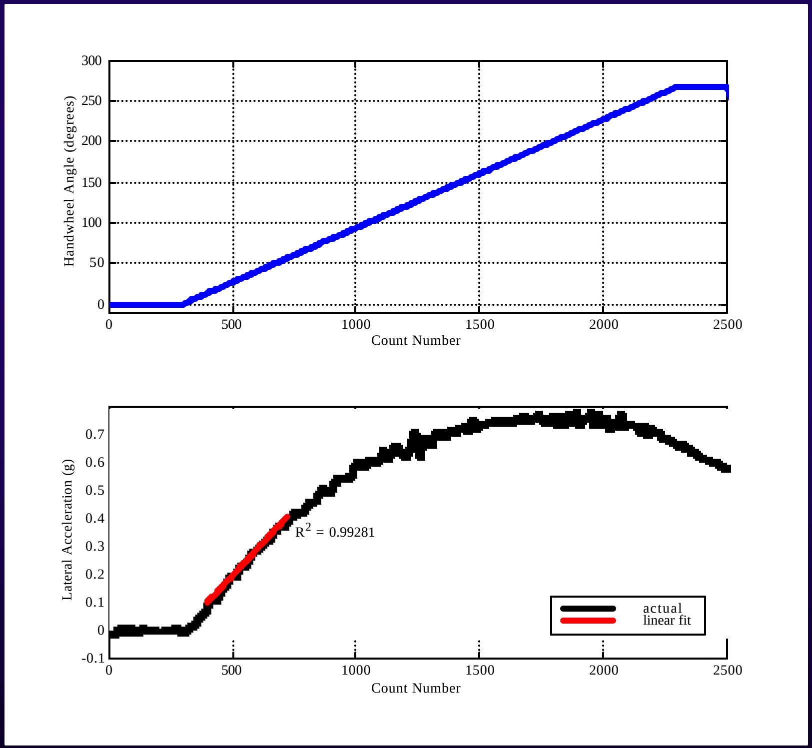
- **Automated Steering**
  - J-Turns
  - Fixed Timing Fishhook
  - Roll Rate Feedback Fishhook
  - Nissan Fishhook
  - Open-Loop Pseudo-Double Lane Change

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

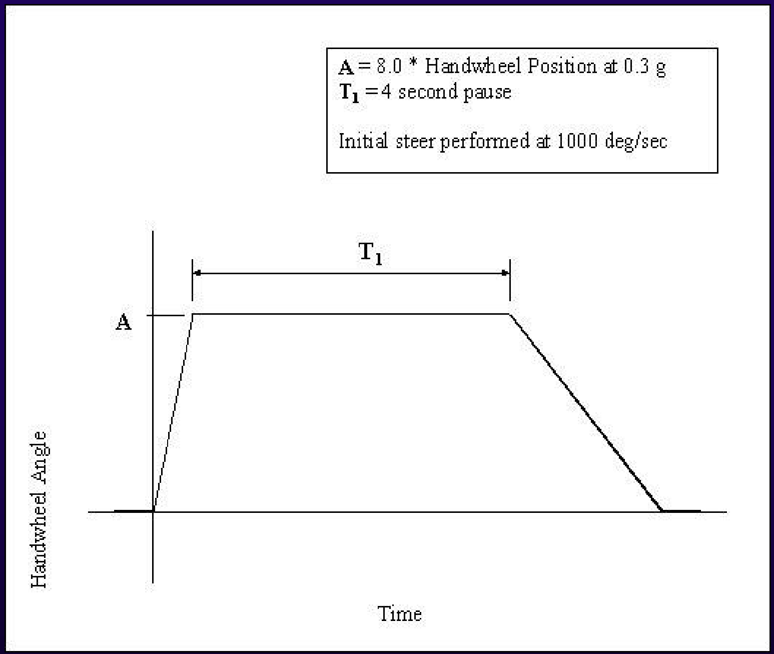
- **Driver-based Steering, Computer Corrected**
  - Ford PCL LC

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**



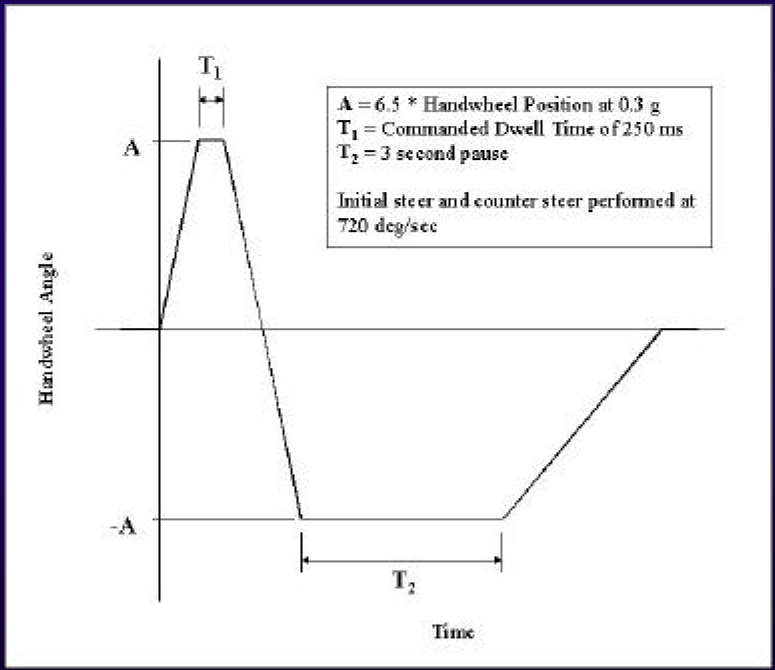
NHTSA J-Turn



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

NHTSA Fixed Timing Fishhook

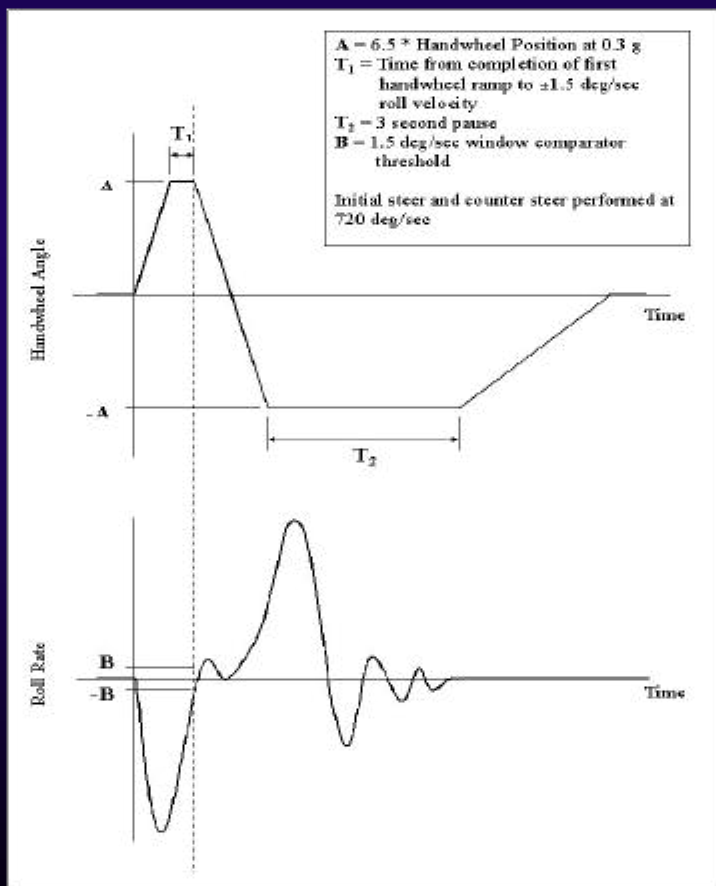
(Symmetric)



Vehicle	Handwheel Input (degrees)
Blazer	326
4Runner	287
ML320	252
Escape	233

NHTSA Roll Rate Feedback Fishhook

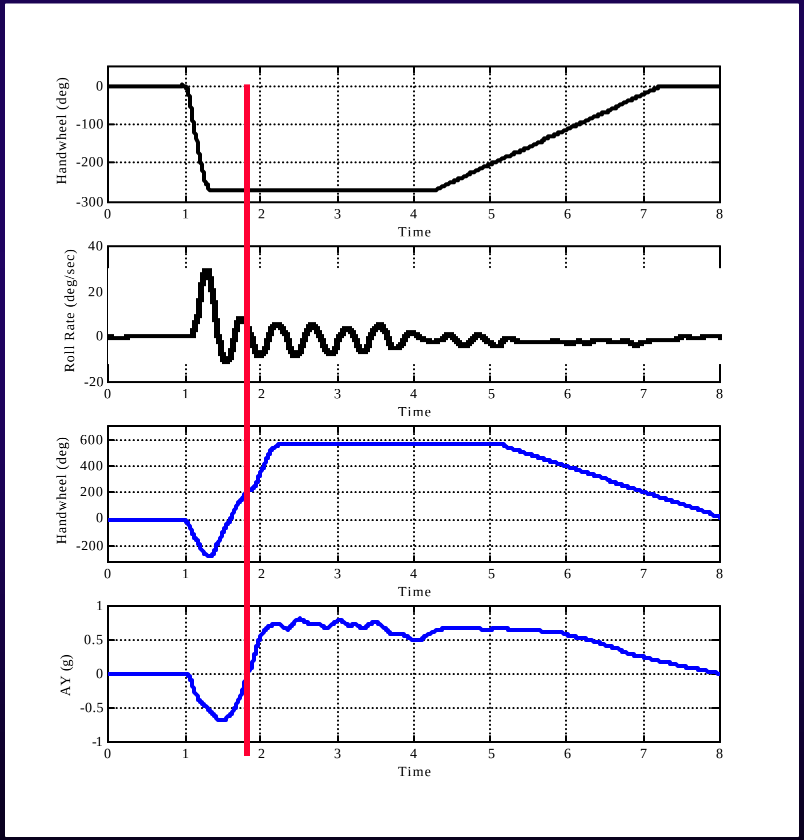
(Symmetric)



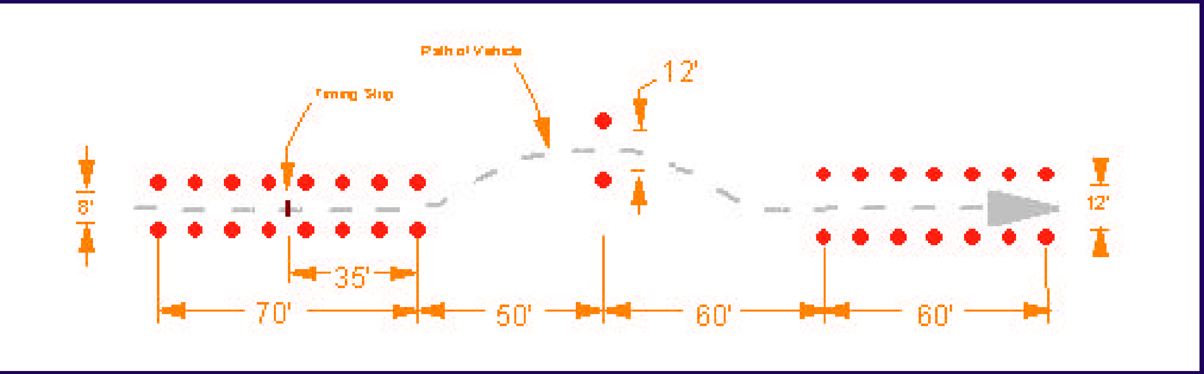
Vehicle	Handwheel Input (degrees)
Blazer	326
4Runner	287
ML320	252
Escape	233

Nissan Fishhook

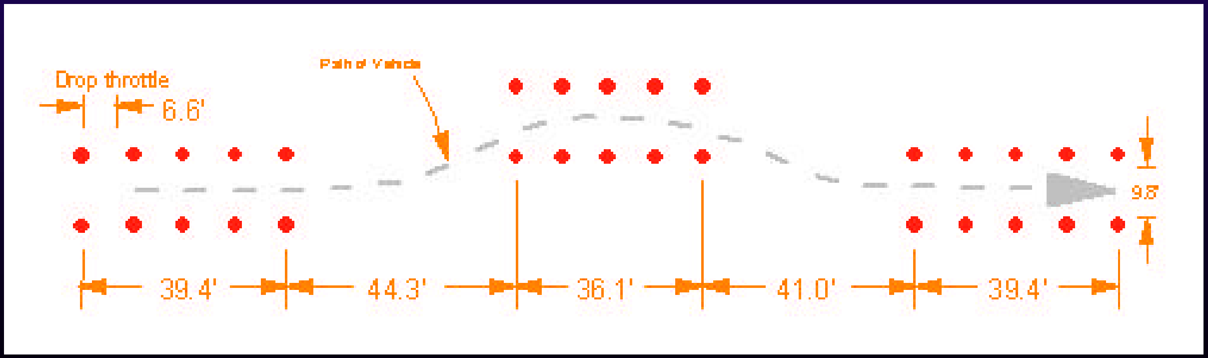
- **Adjusts timing to maximize roll motion**
- **270 degree initial steer**
- **Vehicle-dependent reversal magnitude (for fishhooks)**
  - **Blazer = 570 degrees**
  - **Escape = 505 degrees**
- **All rates = 1080 deg/sec**
- **Response-dependent dwell times**
  - **Iterative determination**



Consumers Union Short Course



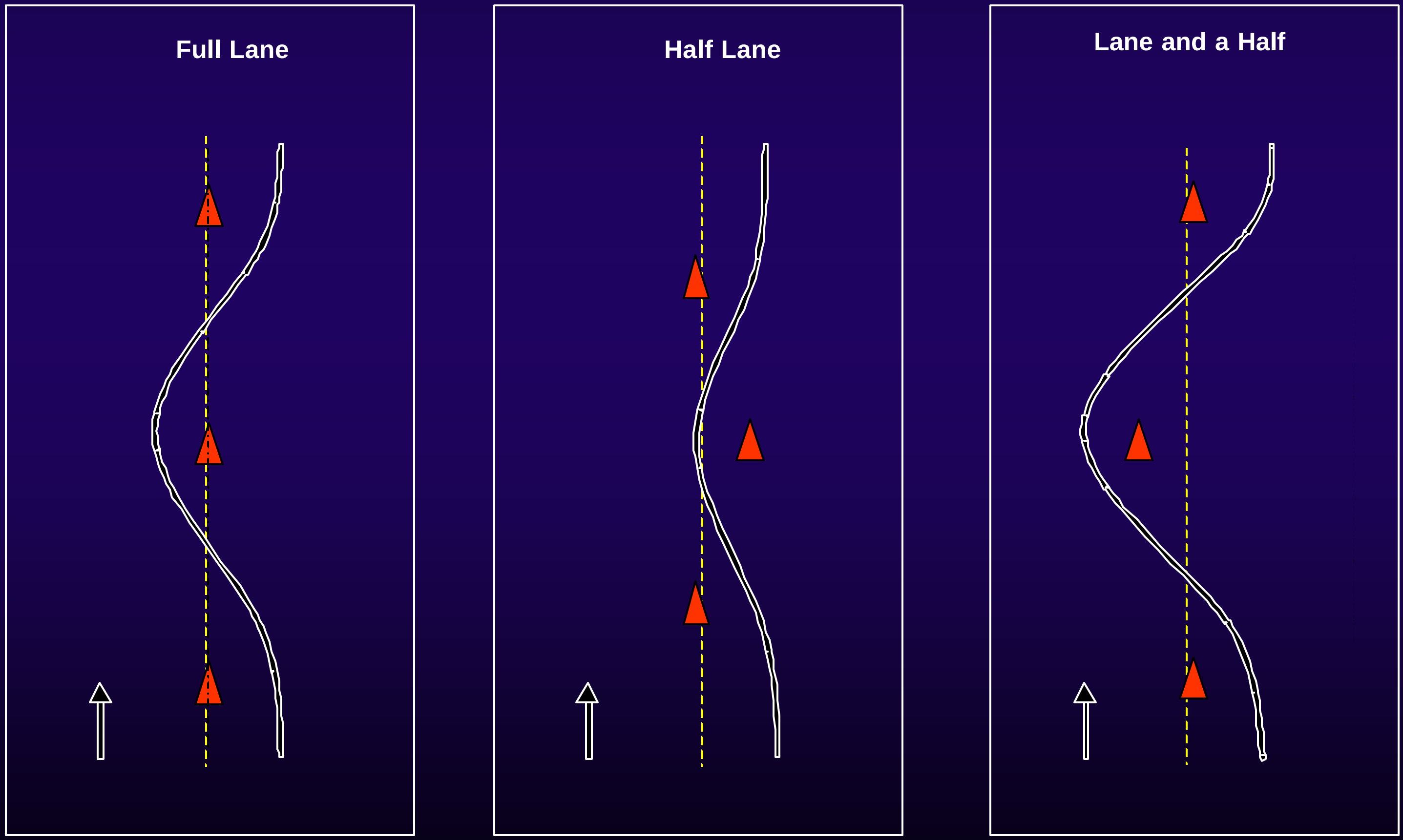
ISO 3888 Part 2



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

Ford PCL LC



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 <u>0.7 g</u> 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**

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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

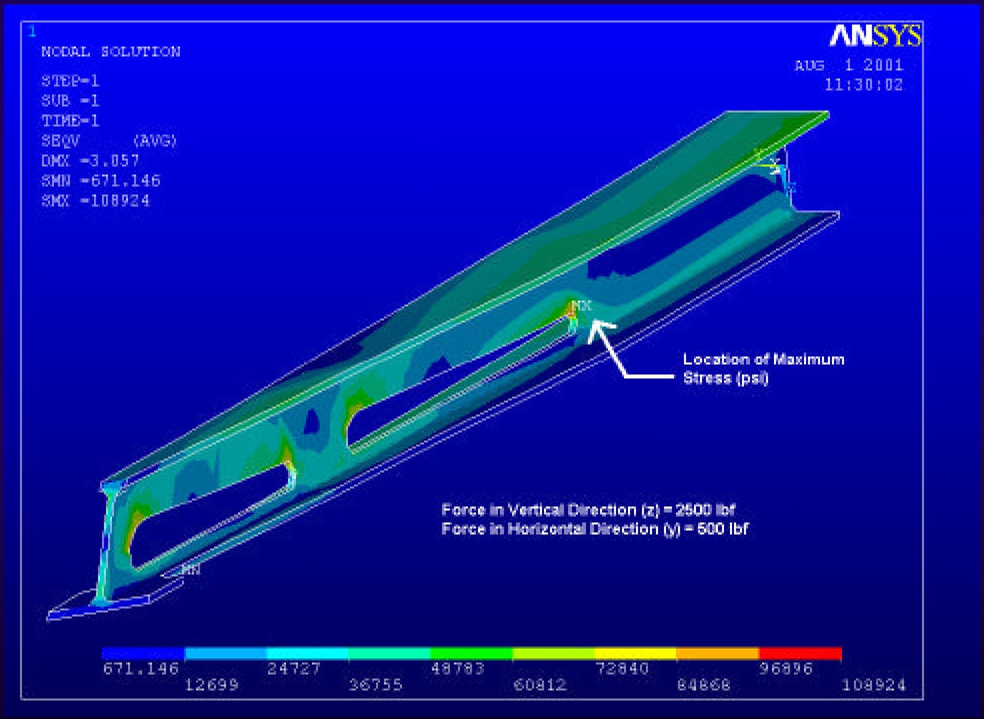
- Compare three designs
  - Existing VRTC Design
    - Aluminum
    - 78 lbs per outrigger
  - New VTRC Design
    - Titanium
    - 68 lbs per outrigger
  - Carr Engineering
    - Carbon fiber
    - 58 lbs per outrigger
- Testing complete

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**