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Experimental Examination of Test Maneuvers That May Induce On-Road, Untripped Light Vehicle Rollover

SAE Papers 2003-01-1008 and 2003-01-1009

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Outline of Presentation

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- Background Information
- Research Performed
  - Testing
  - Summary of results
- Maneuver Assessments
  - Objectivity and Repeatability
  - Performability
  - Discriminatory Capability
  - Appearance of Reality

Overview of NHTSA's Rollover Research Phases

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- **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**
  - Summer 2002
  - Evaluation of 26 vehicles using Phase IV recommendations

Phase IV Background

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TREAD Act Requirement:

Develop dynamic rollover propensity tests to facilitate a consumer information program

National Academy of Sciences:

"NHTSA should vigorously pursue the development of dynamic testing to supplement the information provided by SSF."

Phase IV Objectives

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- Test many maneuvers with a limited number of vehicles
- Select maneuvers appropriate for use in a Government rollover resistance rating system

Maneuver Recommendations

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- Recommendations received from Government and industry
- NHTSA
  - VRTC
  - Safety Performance Standards
- Alliance of Automobile Manufacturers
- Consumers Union
- Ford Motor Company
- Heitz Automotive, Inc.
- ISO 3888 Part 2 Consortium
  - VW
  - BMW
  - DiamlerChysler
  - Porsche
  - Mitsubishi
- MTS Systems Corporation
- Nissan Motors
- Toyota Motor Company
- UMTRI

Test Conditions

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- Test vehicles
  - 2001 Chevrolet Blazer
  - 2001 Ford Escape
  - 2001 Toyota 4Runner
  - 1999 Mercedes ML320
- Fully fuelled
- Front and rear mounted aluminum outriggers
- Performed with and without stability control, if applicable
- All tests performed on a dry, high-mu asphalt surface
  - TRC VDA
  - Peak mu: 0.94 to 0.98
  - Slide mu: 0.81 to 0.88
- Multiple configurations
  - Nominal vehicle
  - Reduced rollover resistance

Reduced Rollover Resistance (RRR)

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- Roof-mounted ballast
- Designed to reduce SSF by 0.05
  - SSF-based rollover rating reduction of 1-star for 3 of 4 Phase IV vehicles
- Increased roll inertia from Nominal condition
  - Escape = 8.0 %
  - Blazer = 11.5%
- Longitudinal C.G. preserved
- Useful as a maneuver sensitivity check

Up to 180 lbs

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 Maneuvers

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- **Characterization**
  - Constant Speed, Slowly Increasing Steer (SAE J266)
- **Rollover Resistance Assessment**
  - NHTSA J-Turn
  - Fishhooks
    - Fixed Timing Fishhook (Fixed Dwell Time)*
    - Roll Rate Feedback Fishhook (Variable Dwell Time)*
    - Nissan Fishhook
  - Double Lane Changes
    - Ford Path-Corrected Limit Lane Change (PCL LC)
    - Consumers Union Short Course*
    - ISO 3888 Part 2*
    - Open-loop Pseudo Double Lane Change

Use of Slowly Increasing Steer Data

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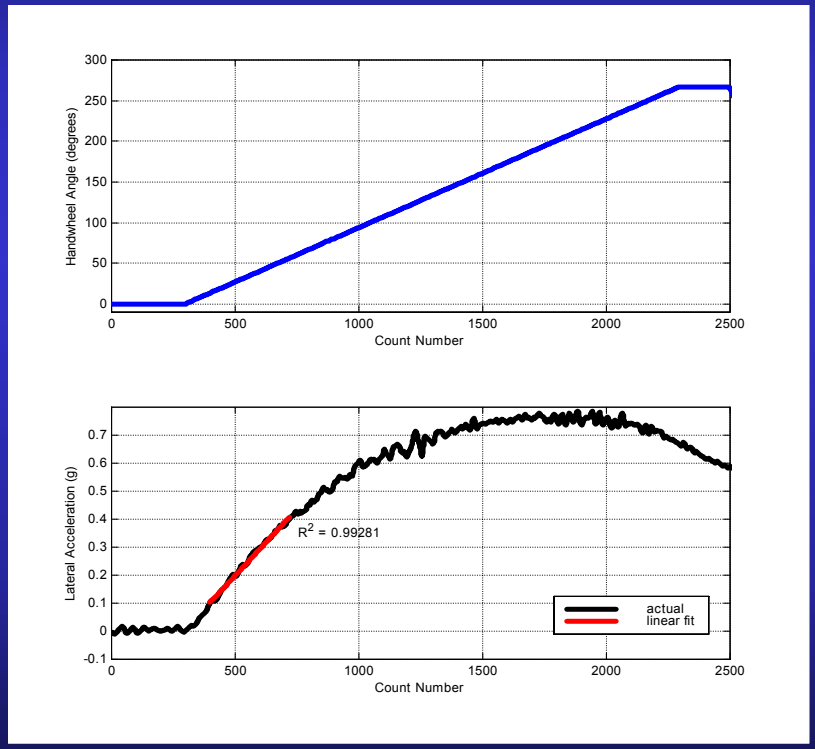
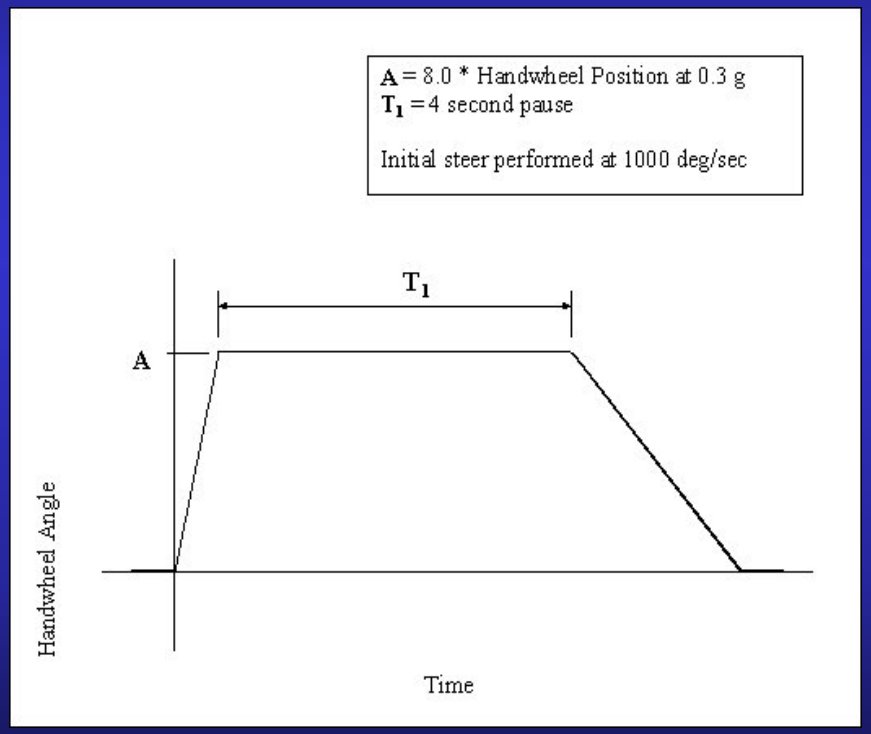
- **Steering magnitude based on vehicle response**
  1. Determine the handwheel angle at 0.3 g from Slowly Increasing Steer results
  2. Multiply by a scalar (derived with Phase II data)
     - J-Turn = 8.0
     - Fishhook = 6.5
- **Steering rate based on successful Phase II testing**
  - J-Turn = 1000 deg/sec
  - Fishhook = 720 deg/sec

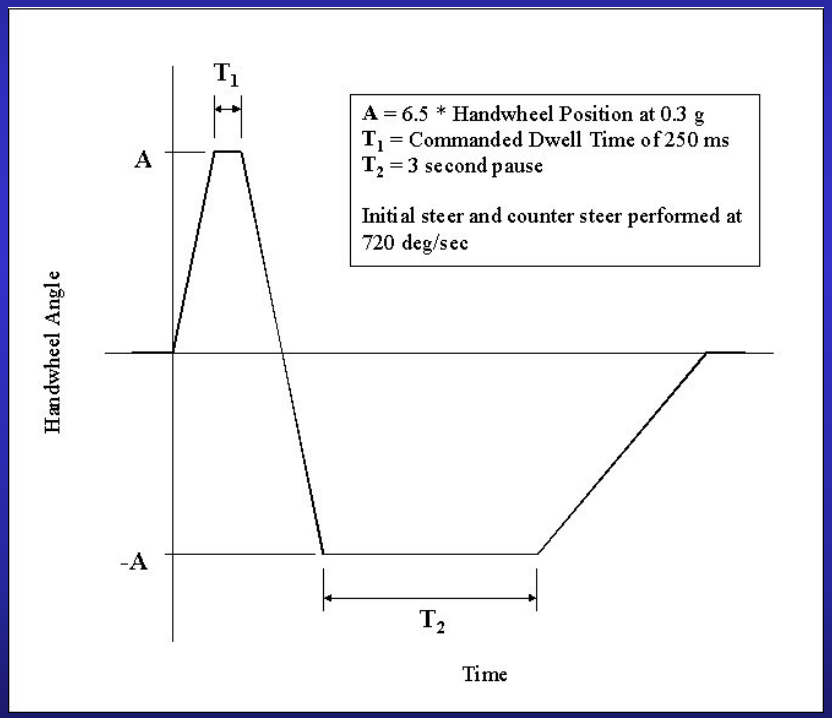


J-Turn



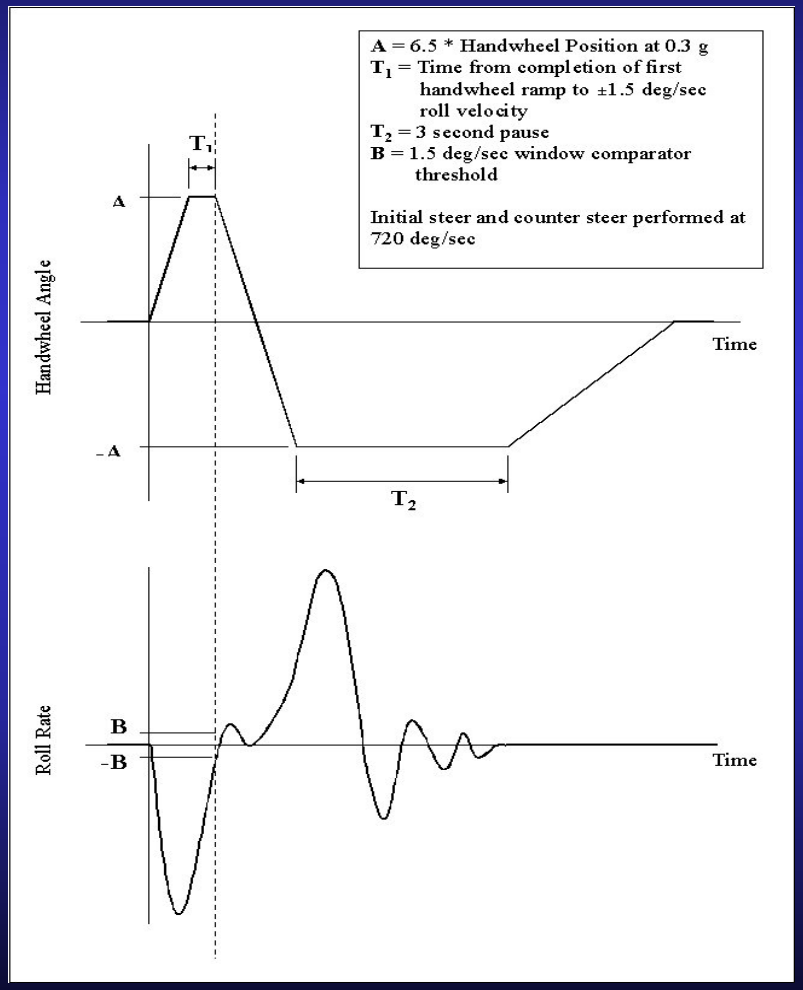
Vehicle	Handwheel Input (degrees)
Blazer	401
4Runner	354
ML320	310
Escape	287

Fixed Timing Fishhook
(Symmetric)



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

Roll Rate Feedback Fishhook
(Symmetric)



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

Closed-loop, Path-Following Double Lane Changes

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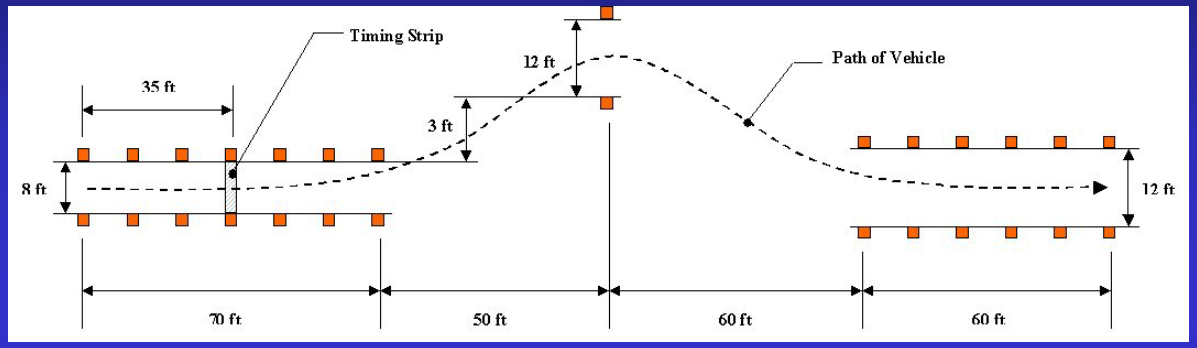
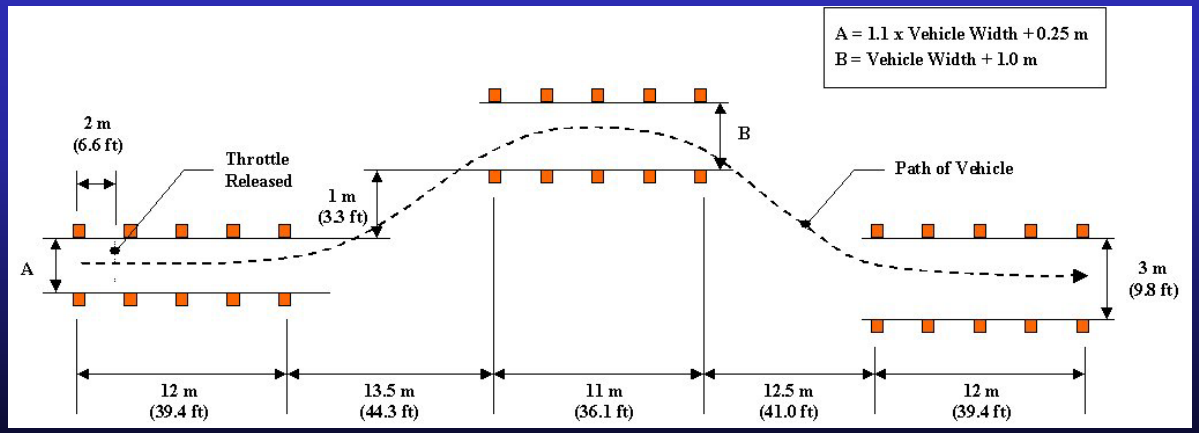
Consumers Union Short Course



ISO 3888 Part 2



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Questions?

Evaluation Technique

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- **Each maneuver evaluated in 4 categories**
  - Objectivity and Repeatability
  - Performability
  - Discriminatory Capability
  - Appearance of Reality
- **Ratings assigned as follows**
  - Excellent
  - Good
  - Satisfactory
  - Bad
  - Very Bad

Objectivity and Repeatability

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Criteria	J-Turn	FT Fishhook	RRF Fishhook	ISO 3888-2	CU Short Course
Drivers Required	*One*	*One*	*One*	*Multiple*	*Multiple*
Steering Input	*Controller*	*Controller*	*Controller*	*Driver*	*Driver*
Steering Repeatability	*High*	*High*	*High*	*Driver-Dependent*	*Driver-Dependent*
Precise Reproducibility	*High*	*High*	*High*	*Low*	*Low*
Rating	*Excellent*	*Excellent*	*Excellent*	*Bad*	*Bad*

Objectivity and Repeatability
(Example: Steering Inputs)

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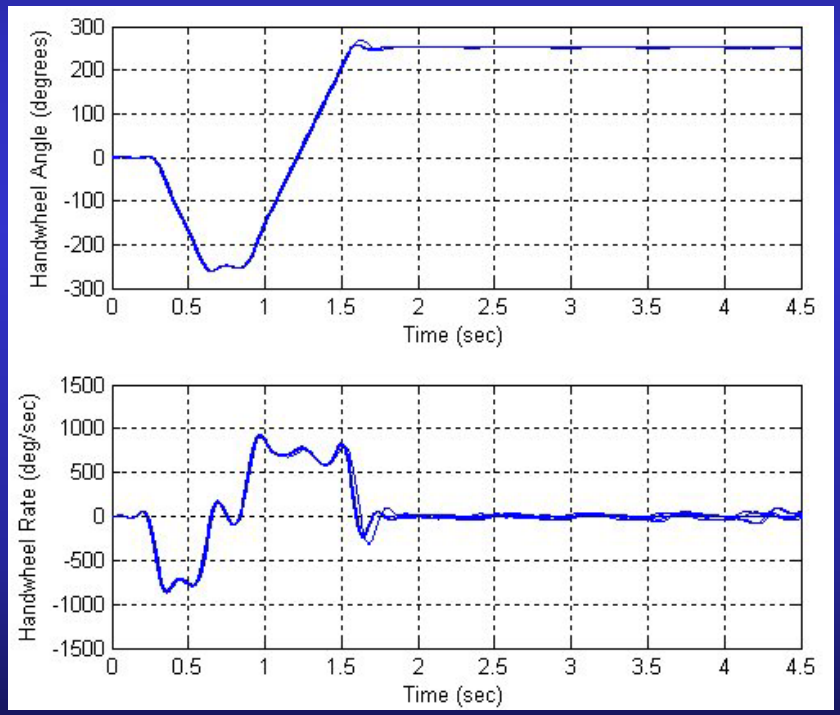
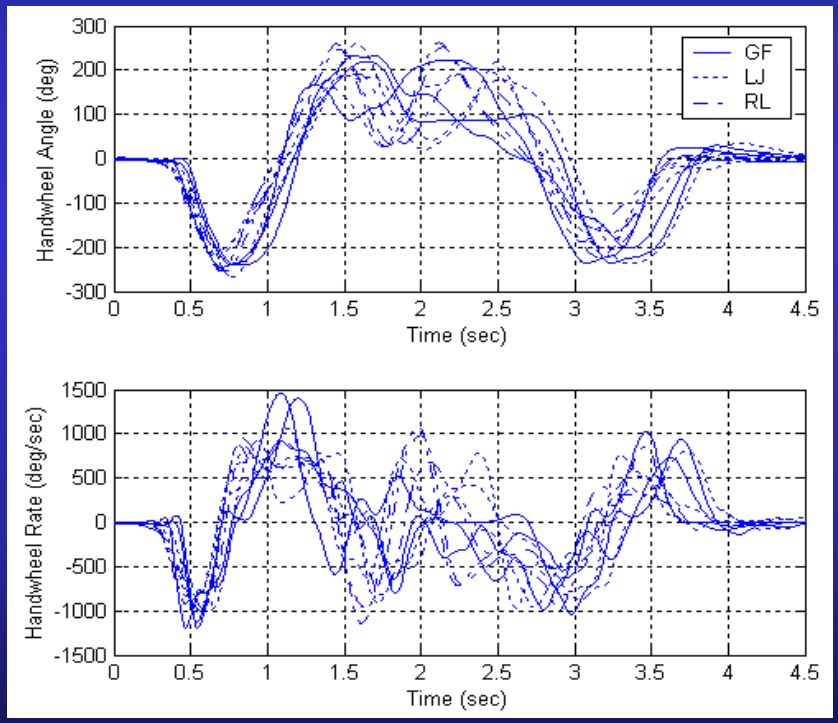
Steering Machine-Based Fixed Timing Fishhook



Six tests are presented

Driver-Based ISO 3888 Part 2 Double Lane Change



Nine tests are presented

Objectivity and Repeatability
(Example: Steering Inputs)

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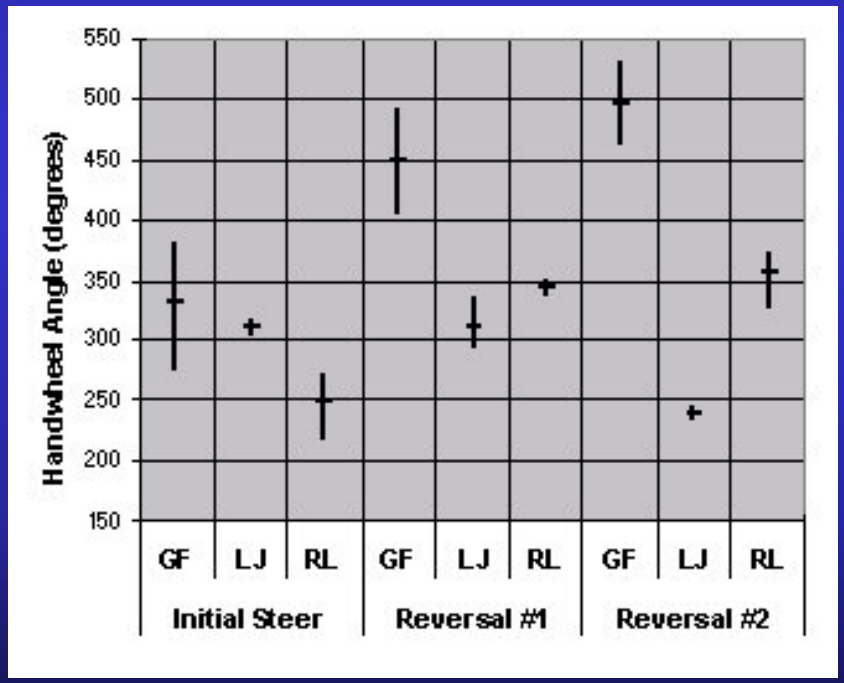
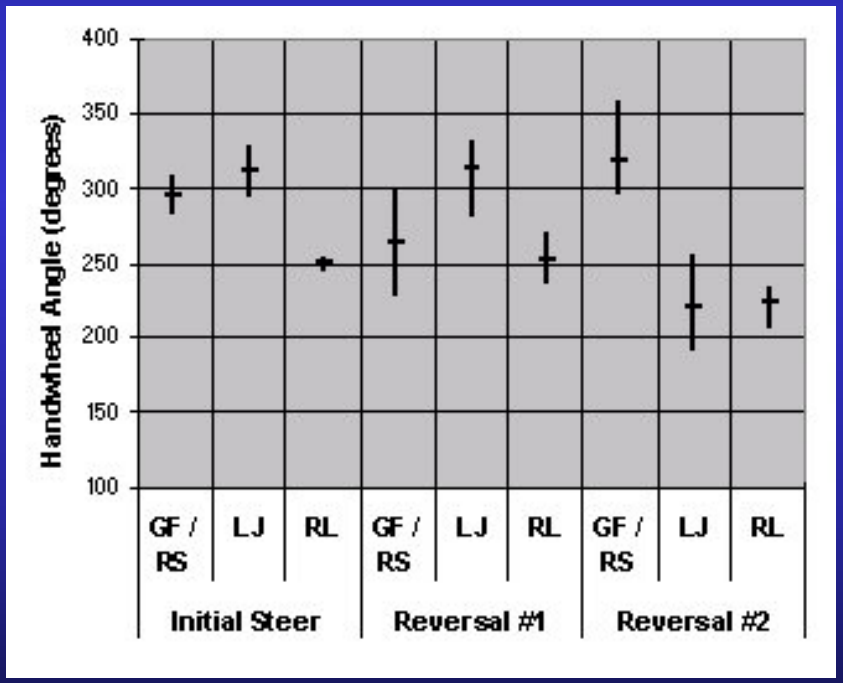
CU Short Course
Double Lane Change



ISO 3888 Part 2
Double Lane Change



Objectivity and Repeatability
(Example: DLC Output Repeatability)

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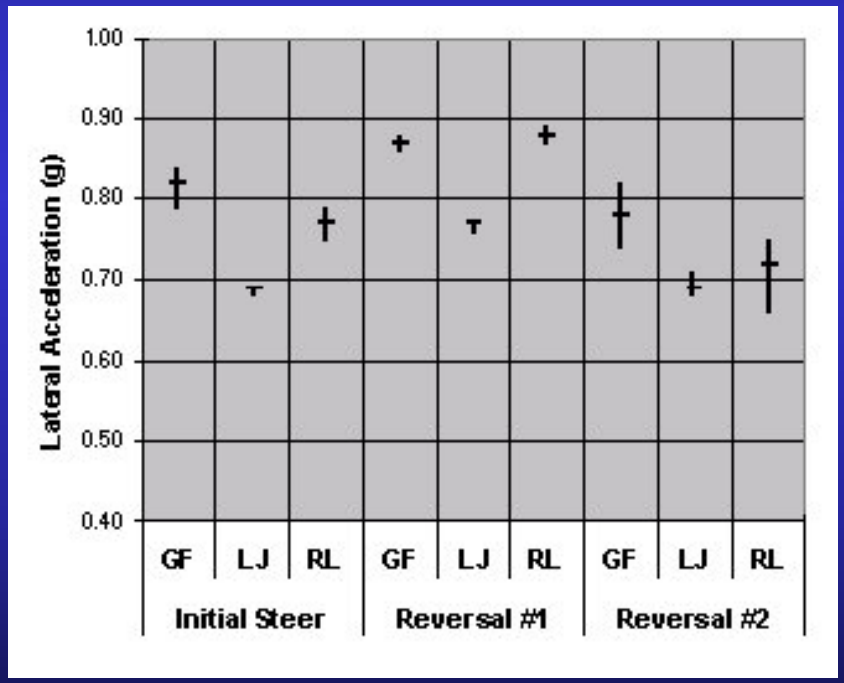
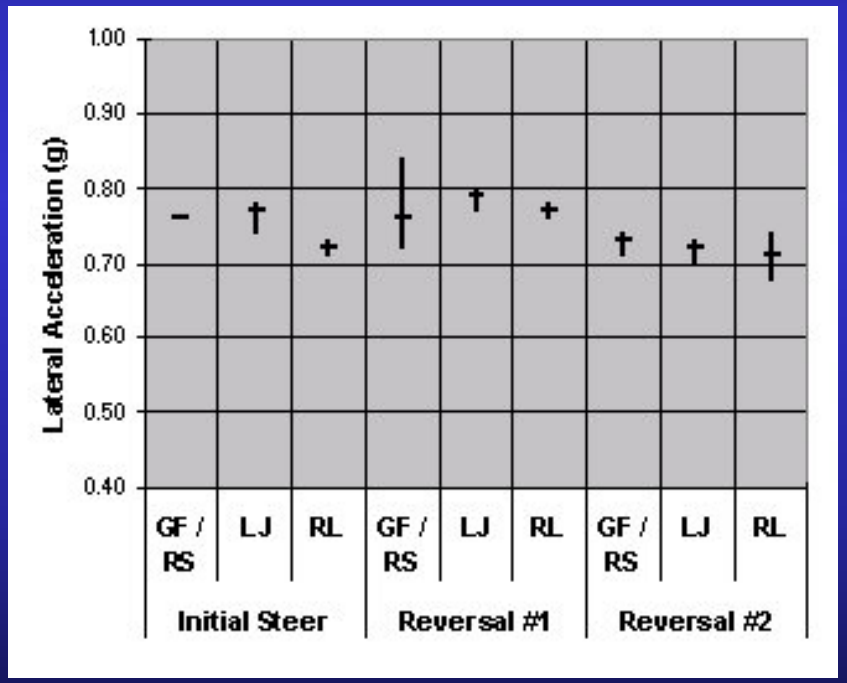
CU Short Course
Double Lane Change



ISO 3888 Part 2
Double Lane Change



Objectivity and Repeatability
(Example: Fishhook Output Repeatability)

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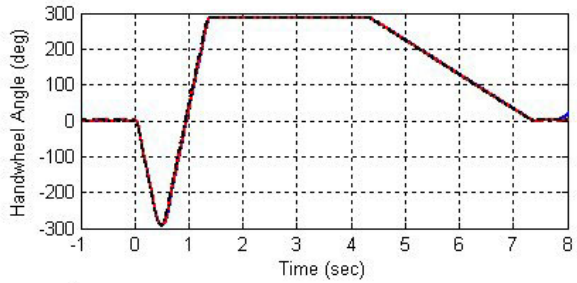

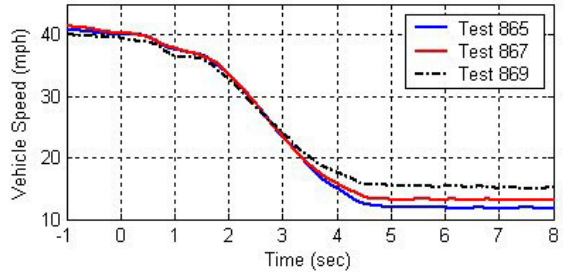

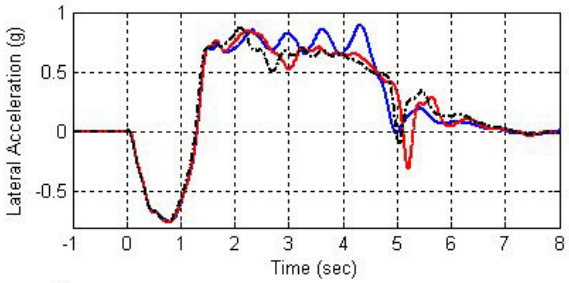

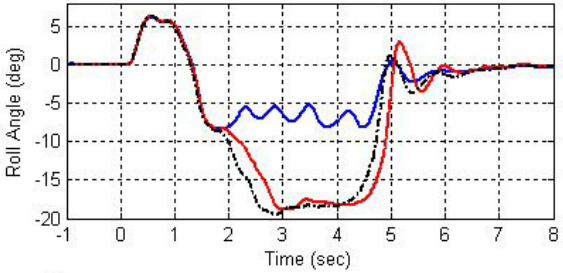

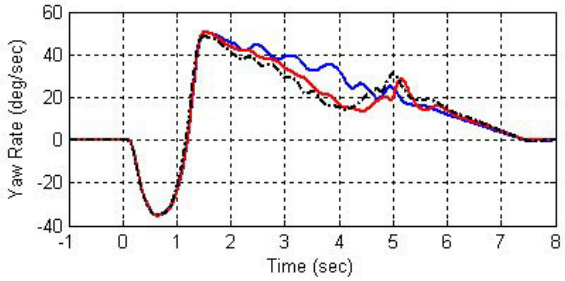

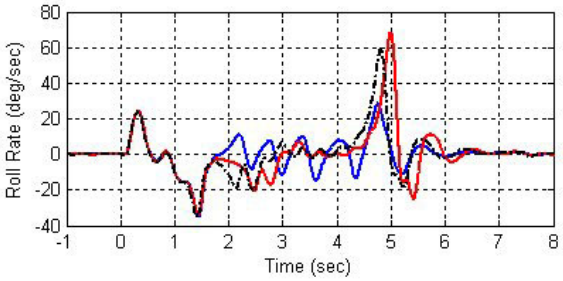

Objectivity and Repeatability (Summary)

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- One of the largest disadvantages of the ISO and CU Double Lane Changes
  - Driver input variability unavoidable
- Use of a steering machine insures accurate, repeatable, reproducible inputs
- Operating vehicles at two-wheel lift threshold is a concern for all maneuver that endeavor to measure dynamic rollover resistance

Performability

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Criteria	J-Turn	FT Fishhook	RRF Fishhook	ISO 3888-2	CU Short Course
Instrumentation Required	*Vehicle Speed, Handwheel Position, Accelerations, Rates, Wheel Lift Sensors*	*Vehicle Speed, Handwheel Position, Accelerations, Rates, Wheel Lift Sensors*	*Vehicle Speed, Handwheel Position, Accelerations, Rates, Wheel Lift Sensors*	*Vehicle Speed*	*Vehicle Speed*
Ease of Use	*Straight-forward*	*Straight-forward*	*Straight-forward*	*Very Easy*	*Very Easy*
Means of Adaptation	*Handwheel Angle*	*Handwheel Angle*	*Handwheel Angle, Roll Rate Feedback Control Loop*	*Course Layout*	*No Provision*
Procedure Development	*Well developed*	*Well developed*	*Well developed*	*Well developed*	*Well developed*
Rating	*Excellent*	*Good*	*Excellent*	*Good*	*Satisfactory*

Performability
(Example: Means of Adaptation)

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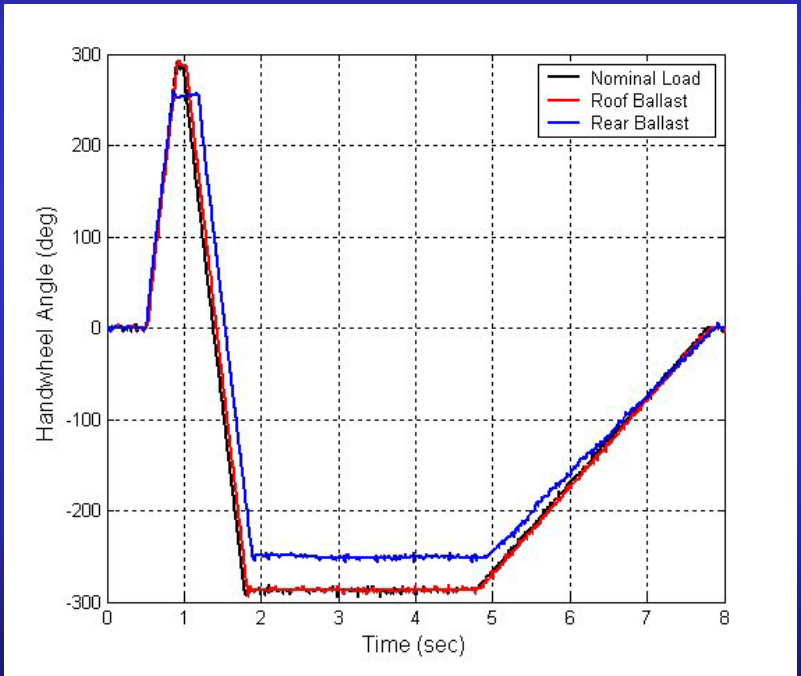
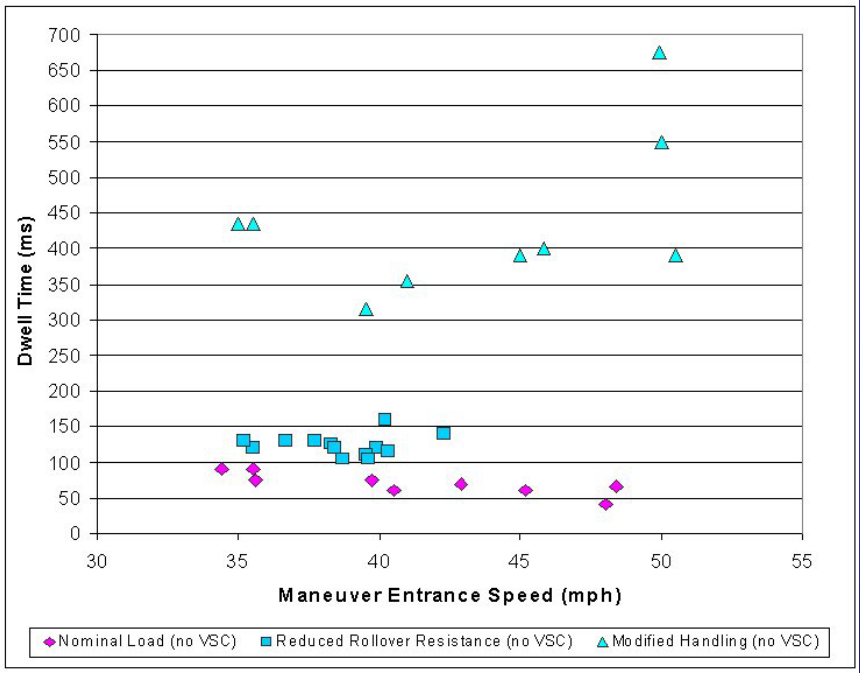
Handwheel Angle Comparison



Each test performed at 40 mph

Dwell Time Comparison



Performability
(Summary)

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- Each procedure was well developed
- ISO and CU Double Lane Changes
  - Simplest to perform
  - Require little instrumentation
- CU Short Course does not adapt course layout to vehicle
- RRF Fishhook offers better adaptability than does the FT Fishhook

Discriminatory Capability

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Criteria	J-Turn	FT Fishhook	RRF Fishhook	ISO 3888-2	CU Short Course
Metric	*Two-wheel Lift*	*Two-wheel Lift*	*Two-wheel Lift*	*Max Entrance Speed*	*Max Entrance Speed*
Able to Produce Two-Wheel Lift?	*Yes* (may require additional load)	*Yes*	*Yes*	*No*	*No*
Sensitivity to Vehicle Changes	*High**	*High**	*High**	*Low*	*Low*
Potentially Confounded by Driver Effects?	*No*	*No*	*No*	*Yes*	*Yes*
Rating	*Excellent*	*Excellent*	*Excellent*	*Very Bad*	*Very Bad*

**Especially when stability control is disabled*

Discriminatory Capability
(Metric Comparison)

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Roll Rate Feedback Fishhook

Vehicle	Configuration			
	Nominal Load		Reduced Rollover Resistance	
	Left-Right (mph)	Right-Left (mph)	Left-Right (mph)	Right-Left (mph)
Toyota 4Runner (VSC on)	--	--	--	49.6
Toyota 4Runner (VSC disabled)	--	--	39.5	37.7
Chevrolet Blazer	40.3	40.1	36.8	36.2
Ford Escape	--	--	46.0	--
Mercedes ML320 (ESP on)	49.9	--	Tests not performed	
Mercedes ML320 (ESP disabled)	46.4	50.6		

Minimum two-wheel lift entrance speeds

ISO 3888 Part 2 Double Lane Change

Vehicle	Configuration		
	Nominal Load	Reduced Rollover Resistance	Difference
Toyota 4Runner (VSC on)	37.6	39.3	-1.7
Toyota 4Runner (VSC disabled)	37.0	38.0	-1.0
Chevrolet Blazer	41.0	39.0	2.0
Ford Escape	38.0	37.3	0.7
Mercedes ML320 (ESP on)	38.0	37.4	0.6
Mercedes ML320 (ESP disabled)	38.9	37.1	1.8

Maximum "clean" run entrance speeds

Discriminatory Capability
(Two-Wheel Lift Summary, Nominal Load)

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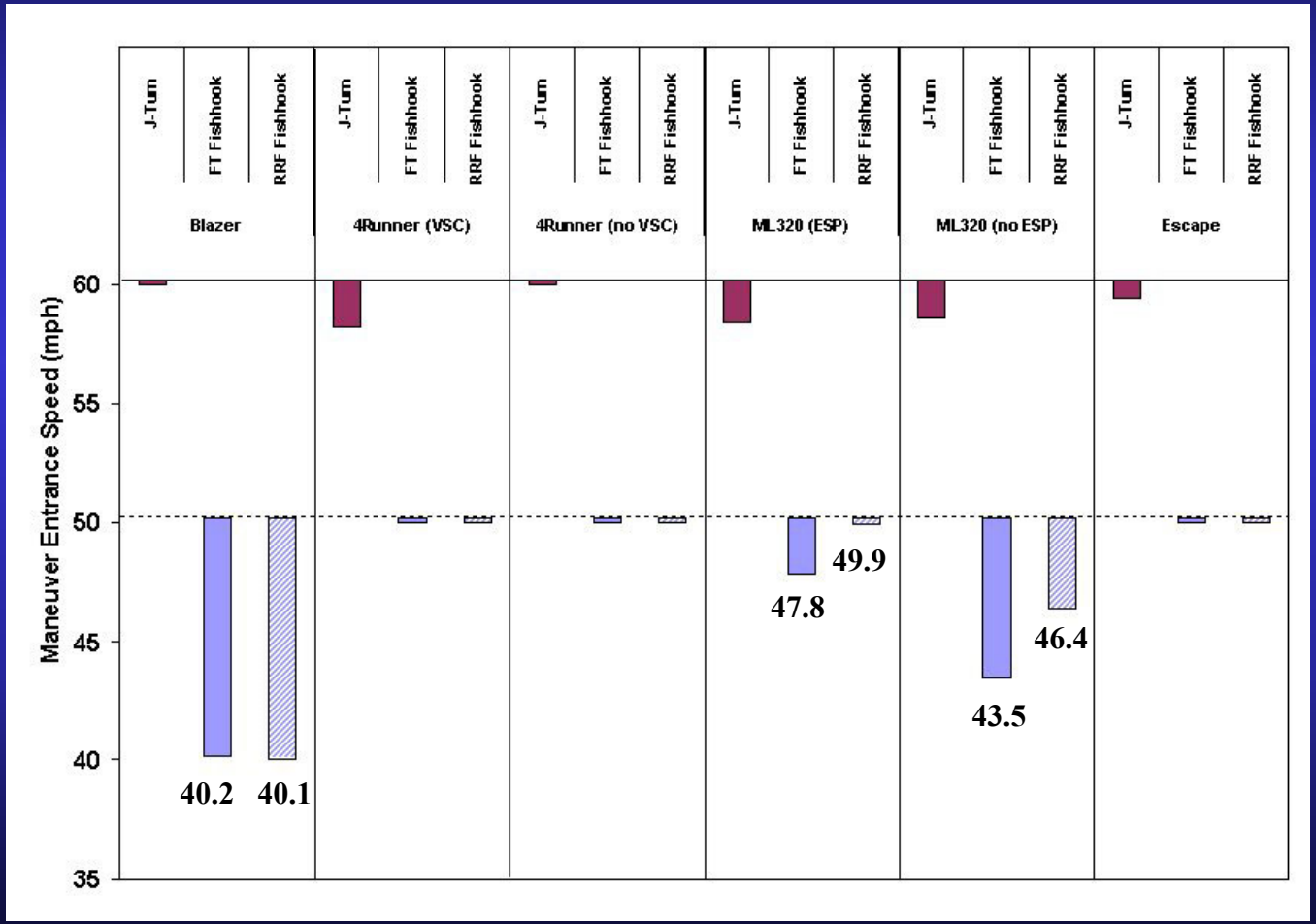

Discriminatory Capability
(Two-Wheel Lift Summary, RRR)

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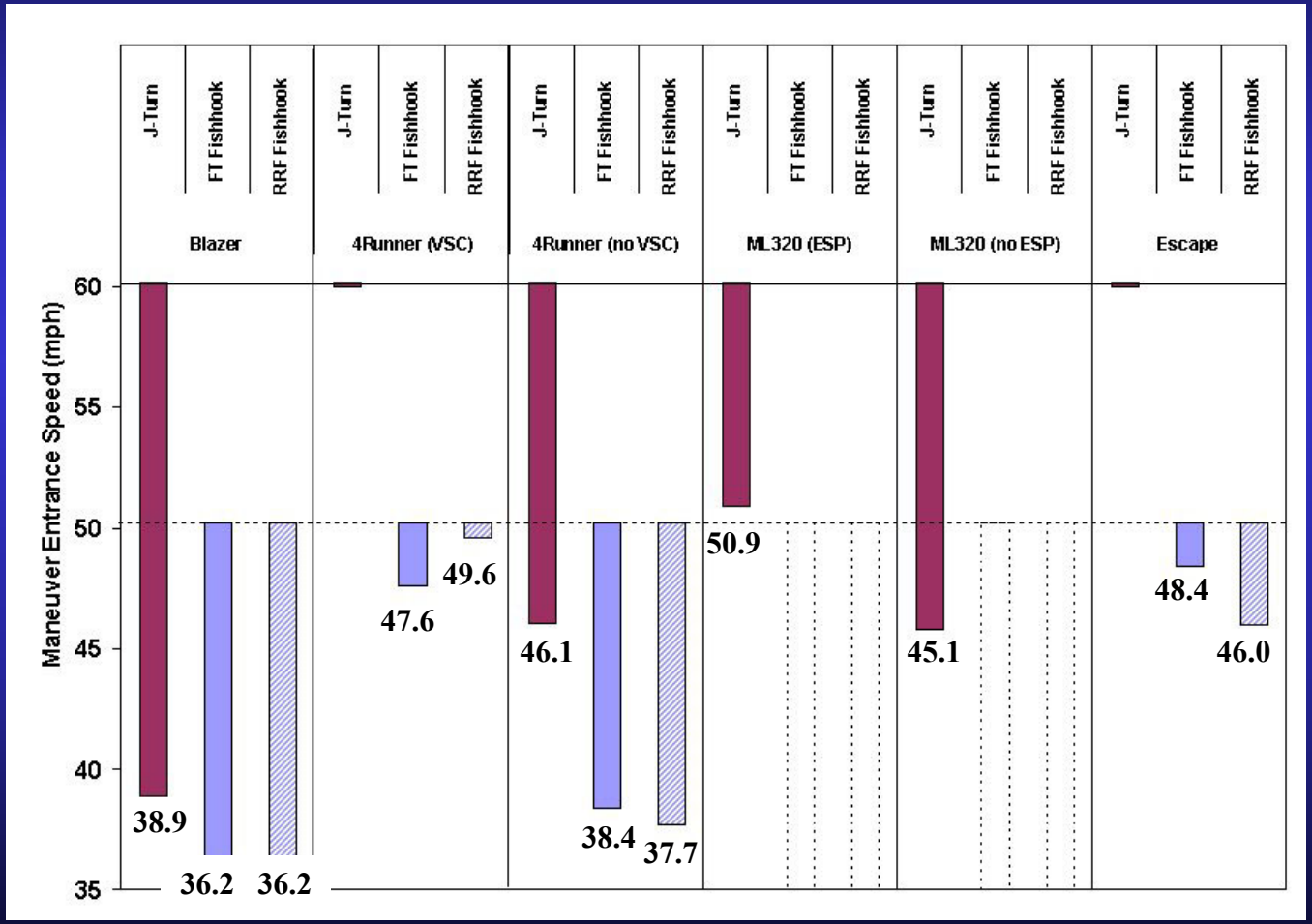

Discriminatory Capability
(Video Comparison)

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Discriminatory Capability (Summary)

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- **Lack of discriminatory capability is the largest disadvantage of using ISO or CU Double Lane Changes**
  - Entire range of max entrance speeds no more than 5.7 mph
  - Driver variability accounts for up to 70% of this range
- **ISO and CU Double Lane Changes were not capable of producing two-wheel lift during "clean" runs**

Discriminatory Capability (Summary)

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- J-Turn required reduce rollover resistance loading to produce two-wheel lift in Phase IV
- J-Turn and Fishhooks sensitive to changes that reduce rollover resistance
- RRF Fishhook very close to “worst case” scenario

Appearance of Reality

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Criteria	J-Turn	FT Fishhook	RRF Fishhook	ISO 3888-2	CU Short Course
Real World Relevance	*High-Speed Turn with Excessive Steering*	*Road Edge Recovery*	*Road Edge Recovery*	*Emergency Obstacle Avoidance*	*Emergency Obstacle Avoidance*
Are Steering Inputs Humanly Possible?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Use of Braking	*None*	*None*	*None*	*None*	*None*
Rating	*Good*	*Excellent*	*Excellent*	*Excellent*	*Excellent*

Appearance of Reality
(Summary)

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- Each rollover resistance maneuver related to a real driving scenario
- ISO and CU Double Lane Changes emulate emergency crash avoidance maneuvers
- Fishhooks emulate road edge recovery maneuvers
  - Also very similar to first two steering inputs of the double lane changes
- J-Turn steering least likely to actually be used, but possible

Question:

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Are the steering angles and steering rates used for the NHTSA J-Turn and Fishhook maneuvers beyond driver capabilities?

Steering Angles and Rates

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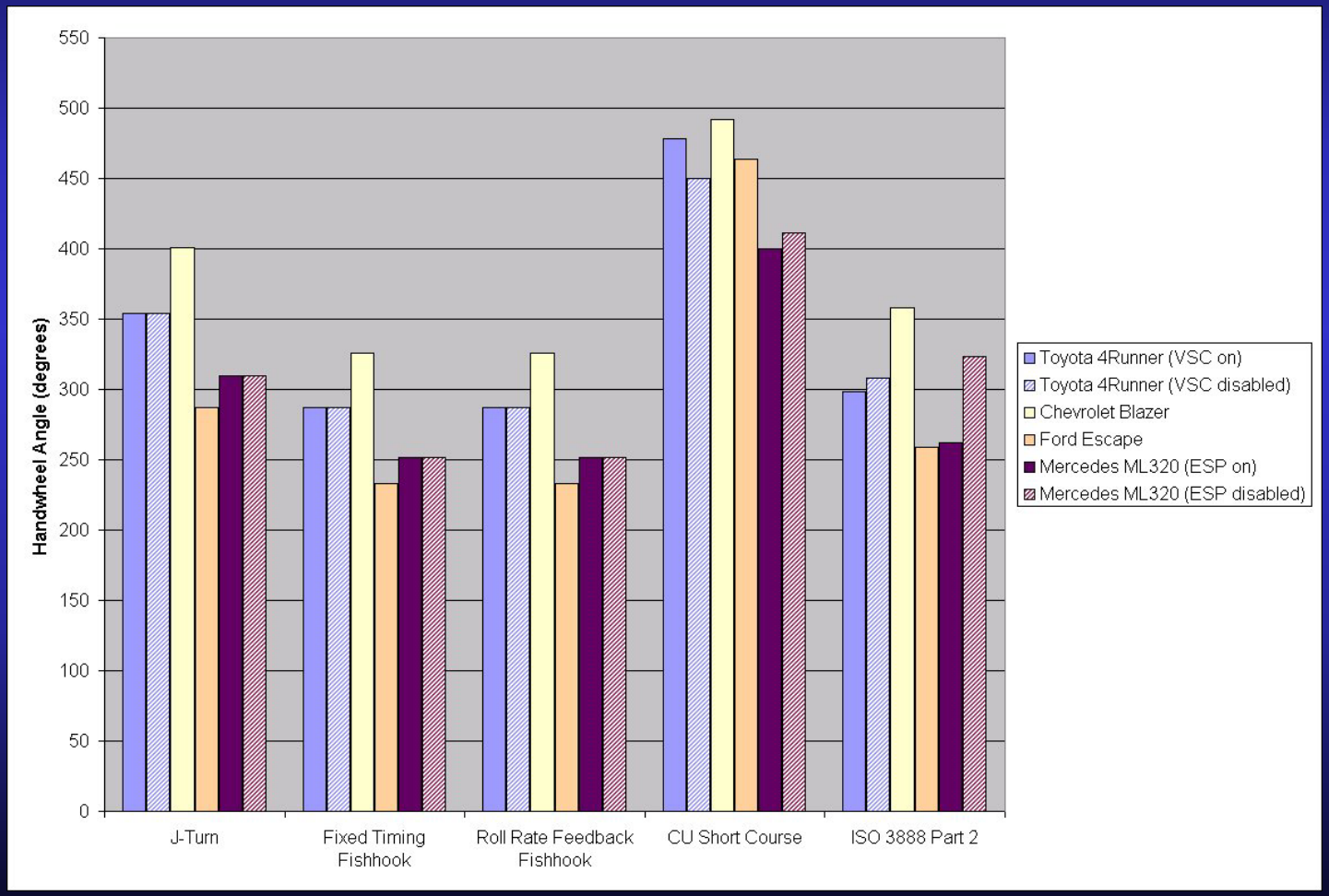
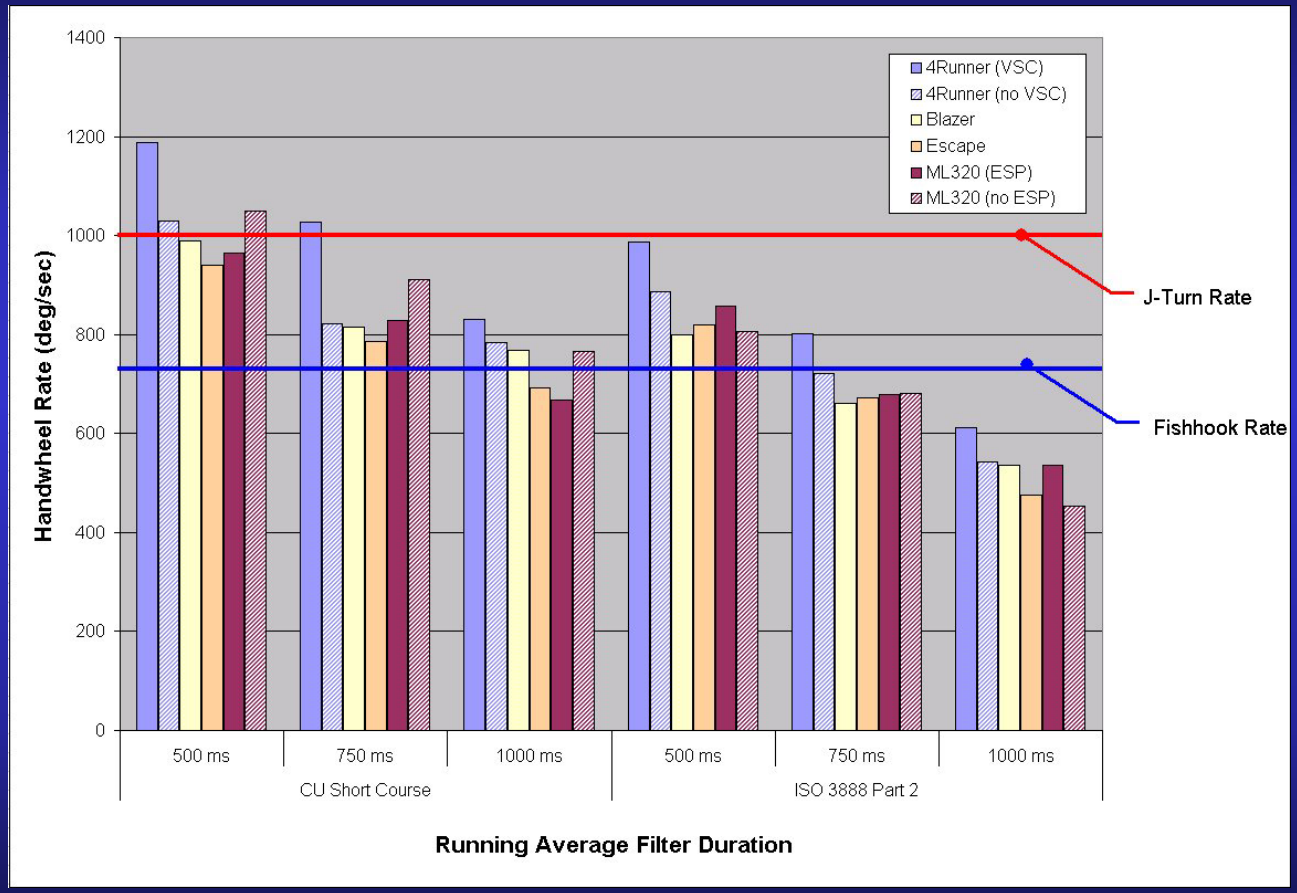
- Handwheel inputs of J-Turn and Fishhooks compared to those recorded during ISO and CU Double Lane Changes
  - Angles
  - Rates
- ISO and CU Double Lane Change data filtered with various “Running Average” filters
  - 500 ms
  - 750 ms
  - 1000 ms
- Running average data used to quantify the steering ability of the human driver

Peak Steering Angles



Peak Steering Rates



J-Turn Steering Durations: 287 – 401 ms

Fishhook Steering Durations: 647 – 906 ms

Overall Assessment

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- Roll Rate Feedback Fishhook deemed the best overall maneuver (see below)
- J-Turn the most basic maneuver, can be a useful compliment to the Roll Rate Feedback Fishhook
- Both maneuvers selected for use in Phases V and VI

Criteria	J-Turn	FT Fishhook	RRF Fishhook	ISO 3888-2	CU Short Course
Objectivity and Repeatability	*Excellent*	*Excellent*	*Excellent*	*Bad*	*Bad*
Performability	*Excellent*	*Good*	*Excellent*	*Good*	*Satisfactory*
Discriminatory Capability	*Excellent**	*Excellent*	*Excellent*	*Very Bad*	*Very Bad*
Face Validity	*Good*	*Excellent*	*Excellent*	*Excellent*	*Excellent*

**When limited to vehicles with low rollover resistance and/or disadvantageous load configurations*

Concluding Remarks

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- "Fishhook" gives the impression that the maneuver not performed during actual driving
  - Approximates steering performed by a driver after dropping two-wheels off edge of road
  - Handwheel inputs within ranges established during ISO and CU double lane change testing
- For the sake of clarity, the Roll Rate Feedback Fishhook has been renamed
- Now known as the "NHTSA Road Edge Recovery"

Additional Information

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- Phase IV Technical Report (DOT HS 809 513)
- SAE Papers
  - 2003-01-1008
  - 2003-01-1009
- http://www-nrd.nhtsa.dot.gov/vrtc/ca/rollover.htm