



*Vehicle Research
and Test Center*

Automated Steering Reversals and Pulse Braking Performed at Maximum Roll Angle

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Background

- **Evaluation of rollover propensity requires accurate and repeatable inputs**
 - Steering
 - Braking
- **Steering machine purchased from Heitz Automotive, Inc. in the Fall of 1997.**
- **Fixed handwheel inputs were successfully executed with the steering machine during Phases I-B and II research**
- **Excellent repeatability and accuracy**

Maneuver History

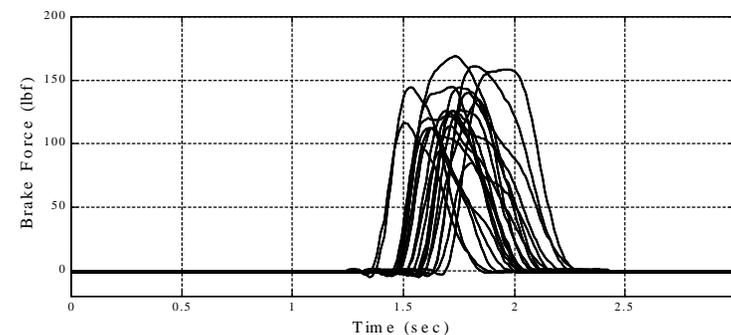
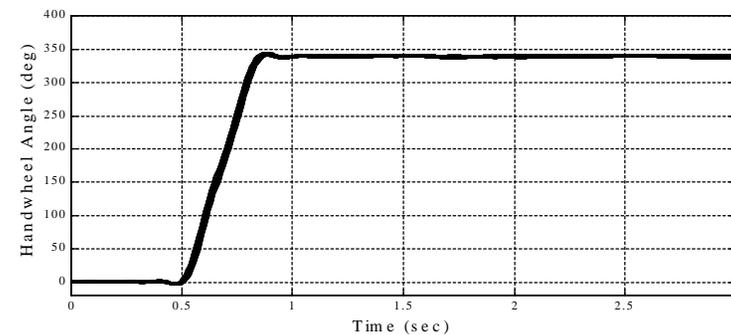
- **Previous maneuvers comprised of fixed handwheel inputs**
 - Fishhook
 - J-Turn
 - Resonant Steer
- **J-Turn with Pulse Braking**
 - Automated steering
 - Manual brake force application

Fishhook Maneuver Deficiencies

- **Fishhook #1**
 - Attempts to steer the vehicle at its roll angle resonant frequency
 - Vehicle response often found to be flat, preventing accurate frequency determination
 - 0.5 Hz assumed roll angle resonance may affect some vehicles more than others
- **Dwell time influences maneuver severity**
- **Remains consistent over all test speeds**

J-Turn with Pulse Braking Deficiencies

- Physically challenging
- Imposes nearly impossible demands on the test driver
 - Specified force and duration
 - Brake and steer phasing
- Example: Phase II 1998 Tracker data



New Steering Machine Features

- **Developed by Heitz Automotive, Inc.**
- **Designed to address maneuver deficiencies**
- **Relate steering reversals and pulse braking to the vehicle's actual roll response**



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Study Objectives

Automated Steering Reversals

- **Assess repeatability**
- **Investigate the effects on vehicle response**
- **Compare vehicle response severity to that induced by Phase II Fishhooks #1 and #2**

Automated Pulse Braking

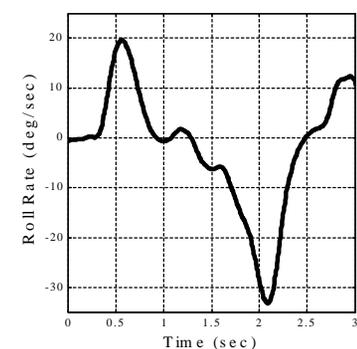
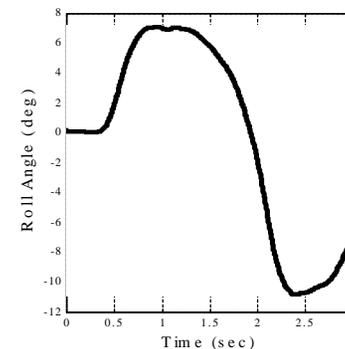
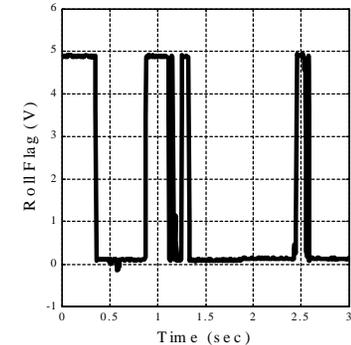
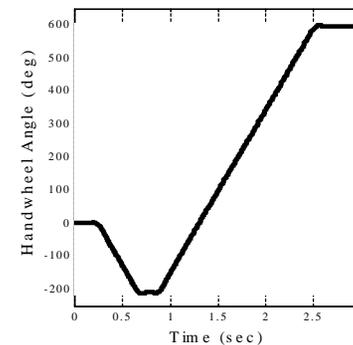
- **Assess repeatability**
- **Investigate the effects of pulse braking on vehicle response**
 - Force magnitude
 - Pulse duration

Automated Steering Reversal in the Fishhook Maneuver



Fishhook Description

- Dwell time no longer fixed
- Steering reversals based on roll response
- Roll rate sensor data passed through a window comparator
- When roll rate = 0, roll angle is at its maximum
- Method allows vehicle to seek out its own roll angle natural frequency



Part I - Repeatability

- **1998 Chevrolet Tracker**
- **Test Speed = 45 mph***
- **Three initial steer magnitudes**
 - 159 degrees
 - 212 degrees
 - 270 degrees
- **600 degree reversals**
- **Two handwheel rates**
 - 500 deg/sec
 - 720 deg/sec
- **Both Directions of Steer**
- **Most conditions repeated four times**
 - Twice per tire set
 - Randomized

***Two test performed at 43 mph due to moderate two-wheel lift at 45 mph**

159 Degree Initial Steer

Steering Rate (deg/sec)	DOS	Dwell Time (ms)		Roll Rate at Reversal (deg/sec)		Max Two- Wheel Lift
		Ave	Std Dev	Ave	Std Dev	
500	R-L	234	8	-2.1	0.11	--
	L-R	224	11	1.5	0.06	moderate
720	R-L	256	6	-2.0	0.22	--
	L-R	251	10	1.3	0.12	moderate

212 Degree Initial Steer

Steering Rate (deg/sec)	DOS	Dwell Time (ms)		Roll Rate at Reversal (deg/sec)		Max Two- Wheel Lift
		Ave	Std Dev	Ave	Std Dev	
500	R-L	176	12	-1.9	0.20	moderate
	L-R	206	39*	1.4	0.17	moderate
720	R-L	225	7	-2.1	0.31	moderate
	L-R	210	11	1.6	0.07	moderate

*Dwell time of 155 ms recorded during one test

270 Degree Initial Steer

Steering Rate (deg/sec)	DOS	Dwell Time (ms)		Roll Rate at Reversal (deg/sec)		Max Two- Wheel Lift
		Ave	Std Dev	Ave	Std Dev	
500	R-L	104	17	-2.0	0.12	Minor
	L-R	200	28	1.2	0.00	Moderate
	L-R*	108	11	1.5	0.07	Moderate
720	R-L	153	10	-1.9	0.06	Minor
	L-R	--	--	--	--	--

*Tests performed at 43 mph

Maneuver Reduction

- **Criteria**
 - Did the maneuver produce two-wheel lift?
 - To what extent did the maneuver maximize response AY, roll, and yaw severity?
- **For each initial steer condition, the “best” rate was selected**
- **Result: Fishhooks #3, #4, #5**

Fishhook Maneuver Description

Fishhook #	Steering Information		
	Magnitude (degrees)		Rate (deg/sec)
	Initial	Reversal	
3	159	600	500
4	212	600	720
5	270	600	500

Part II - Performance Assessment

- **Vehicle speed iteratively increased from 34 mph**
 - Driver safety
 - Maneuver severity metric
 - Termination speed = 50 mph
- **One tire set per Fishhook series**
- **Fishhooks #4 and #5 series each repeated to increase sample size**
- **Phase II Fishhooks #1 and #2 included for comparison**



Two-Wheel Lift Summary

Fishhook #	Minimum Two-Wheel Lift Speed (mph)			
	R-L		L-R	
	Series 1	Series 2	Series 1	Series 2
1	None	--	36.5	--
1 (1998)	42.3	--	37.6	--
2	46.8	--	43.2	--
2 (1998)	47.0	--	44.0	--
3	48.2	--	45.6	--
4	47.1	47.1	41.1	39.4
5	None*	41.1	39.4	38.4

Effect of Vehicle Speed on Dwell Time

- **Previously established as an important consideration when designing fishhooks**
- **In this study, dwell time is a function of vehicle roll response**
- **Iterative increase in speed allows a dwell time vs. vehicle speed comparison**

Fishhook #1

- **Baseline condition**
- **Dwell time specified to be 250 ms (fixed)**
- **Actual dwell times**
 - Right-Left : 265 - 280 ms
 - Left-Right: 260 - 270 ms
- **Fishhook #2 results are similar**

Fishhook #3

- **Right-Left Steering**

- 190 to 225 ms
- Entire range differed by
£ 35 ms
- 46% within the 190-210 ms
range established by two
47 mph tests

- **Left-Right Steering**

- 195 to 245 ms
- Entire range differed by
£ 50 ms
- 80% within the 215-245 ms
range established by two
42 mph tests

Fishhook #4

- **Right-Left Steering**

- 195 to 235 ms
- Entire range differed by £ 45 ms
- 89% within the 200-225 ms range established by two 47 mph tests

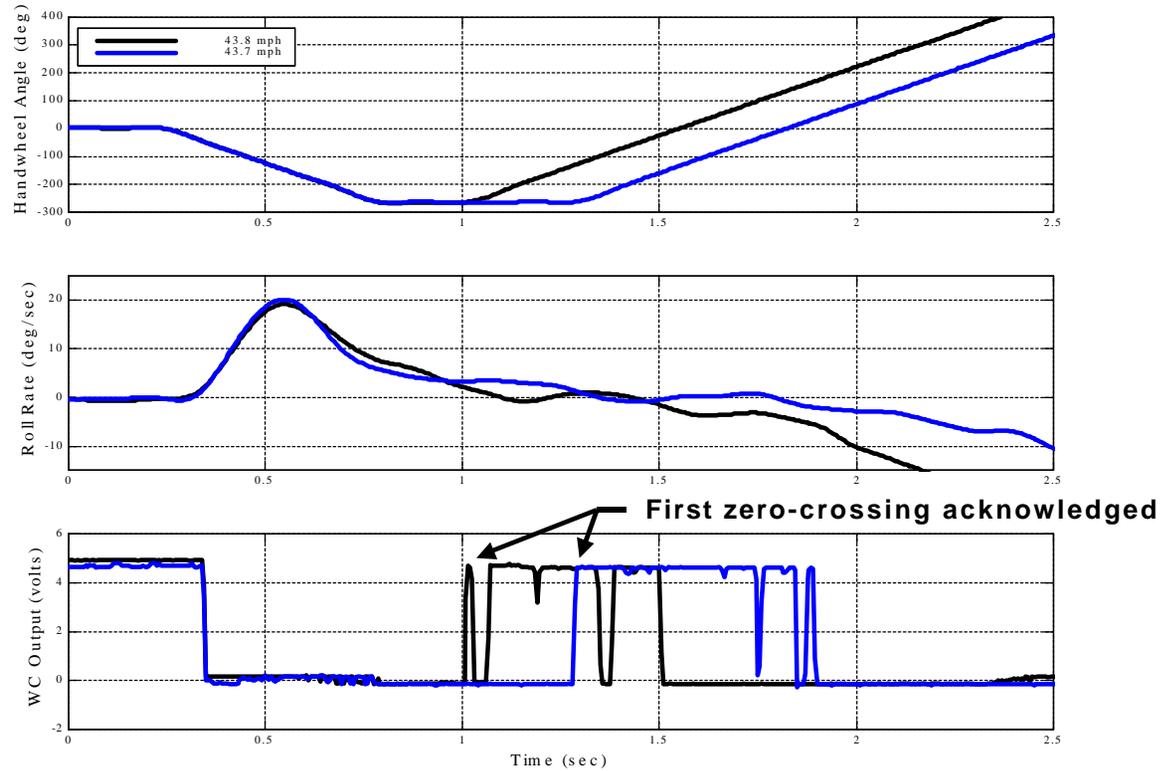
- **Left-Right Steering**

- 200 to 220 ms
- Entire range differed by £ 20 ms
- 100% within the range established by two 42 mph tests

Fishhook #5

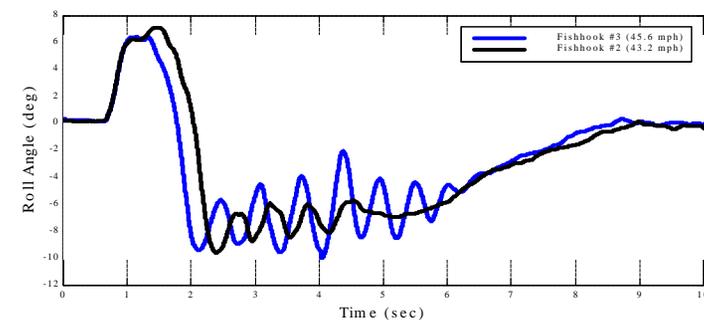
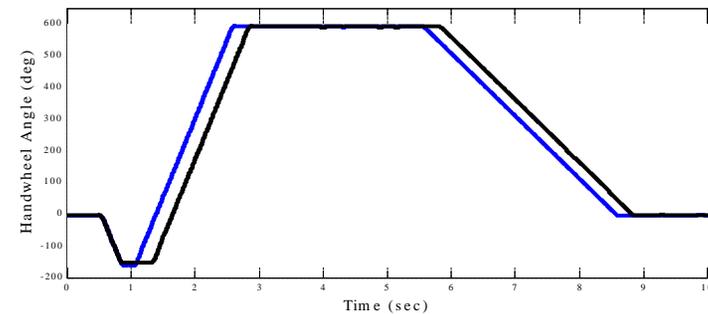
- **Right-Left Steering**
 - 20 to 175 ms
 - 100% within the range established by two 40 mph tests
- **Left-Right Steering**
 - 60 to 585 ms
 - 66% within the 140-585 ms range established by two 42 mph tests
- **Widest range of dwell times**
- **Not due to faulty steering machine operation**
- **Highlights importance of comparator window size**

Fishhook #5



Roll Feedback Induced Oscillations

- Roll oscillations more apparent than with fixed dwell times
- Higher order two-wheel lift produced during Fishhooks #3, #4, #5 but not during Fishhooks #1 and #2
- Example:
 - Fishhook #2
 - Fishhook #3



Conclusions

- **Results are encouraging**
- **Allowing a vehicle to seek its own roll natural frequency is desirable**
- **Determining roll angle natural frequency no longer required for Fishhook development**
- **Preserves the ability to produce two-wheel lift**
- **Initial steer - , minimum two-wheel lift speed -**
 - May be somewhat confounded with handwheel rate
 - Trend may differ as a function of vehicle

Conclusions

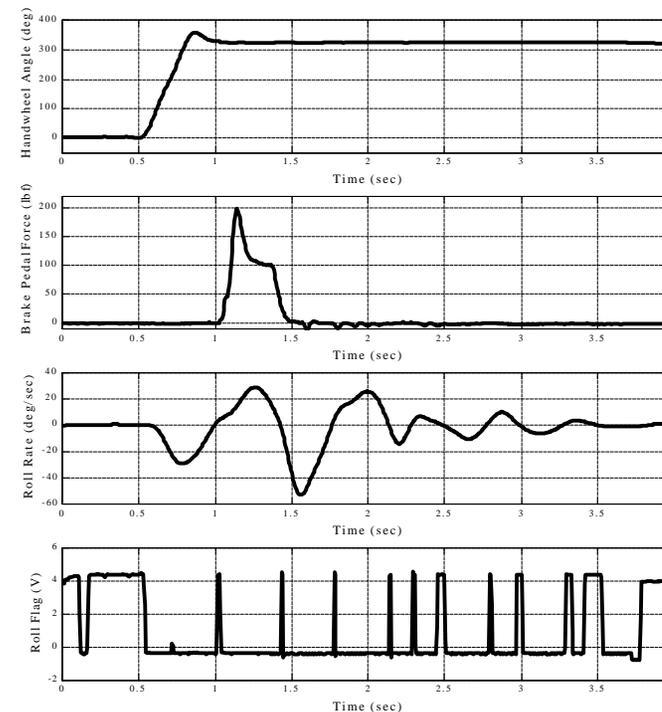
- **Not without compromise**
- **Comparator window size issues must be resolved**
 - While a maneuver may still be severe...
...its repeatability will likely be compromised
- **Feature requires a clean, drift-free roll rate signal**

Automated Pulse Braking in the J-Turn Maneuver



Maneuver Description

- **Steering**
 - 330 degree steer
 - 1000 deg/sec rate
- **Braking**
 - Occurs at maximum roll angle
 - Duration programmed
 - Magnitude selected via hand-held “command module”

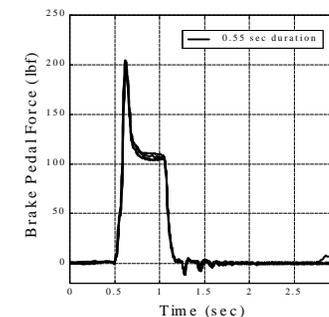
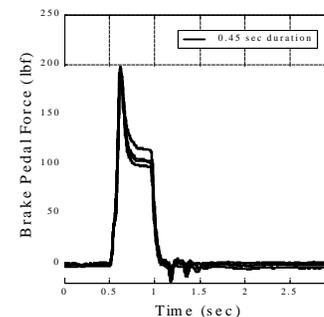
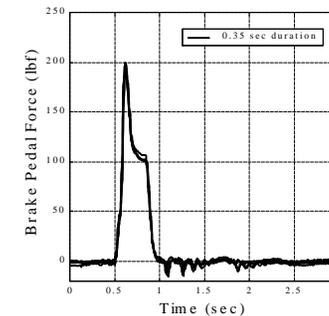
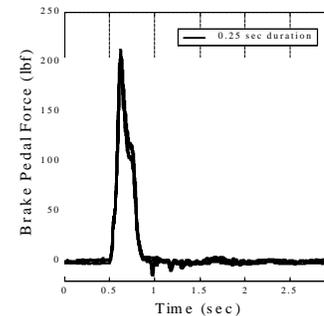


Test Matrix

- **1998 Chevrolet Tracker**
- **Test Speed = 32 mph**
- **Steering Magnitudes**
 - 330 degrees
 - 1000 deg/sec
- **Direction of Steer**
 - CW
 - CCW
- **Pulse Brake Duration**
 - 0.25 seconds
 - 0.35 seconds
 - 0.45 seconds
 - 0.55 seconds
- **Command Module Settings**
 - 001 (140 lbf)
 - 500 (200 lbf)
 - 999 (190 lbf)

Force Magnitude Repeatability

- Pulse brake magnitude and duration variability significantly reduced
- Example: pulse brake data observed during 200 lbf condition
 - Average force: 200.4 lbf
 - Standard Deviation: 6.1 lbf
 - Range: 190.7 - 212.6 lbf
 - Time to max force: 130 ms



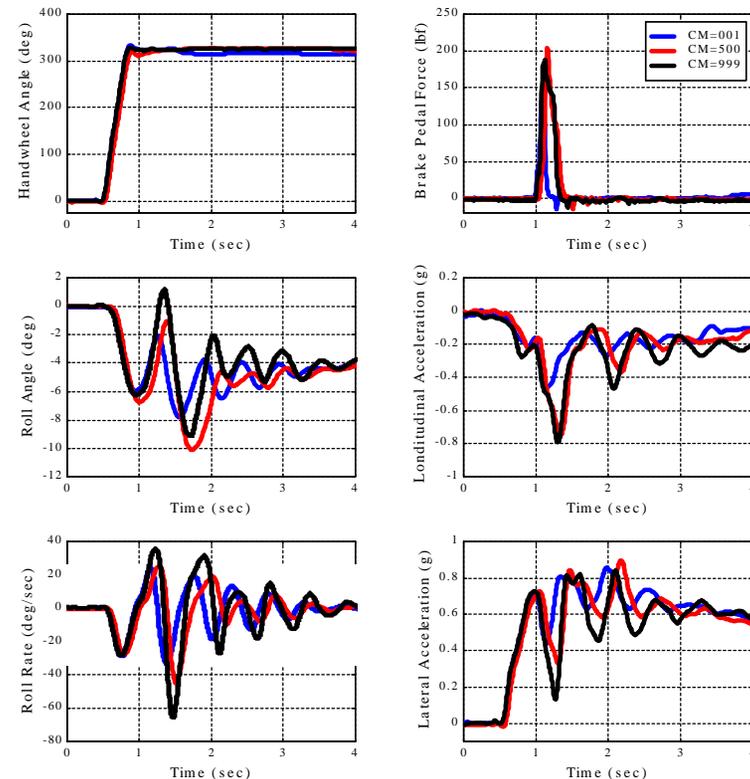
Force Duration Repeatability

Specified Pulse Duration (seconds)	Duration (seconds)			Time to Max Force (seconds)
	Range	Average	Standard Deviation	
0.25	0.37 to 0.38	0.38	0.00	0.13
0.35	None	0.48	0.00	0.13
0.45	0.57 to 0.58	0.58	0.01	0.13
0.55	None	0.69	0.00	0.13

All data for the 200 lbf pulse condition

Effects of Pulse Magnitude

- Pulse Duration set to 0.25 seconds
- 140, 190, 200 lbf brake applications
- Dip magnitudes increased as a function of applied force to 190 lbf
- AY and Roll Angle dip magnitudes decreased slightly with 200 lbf applications

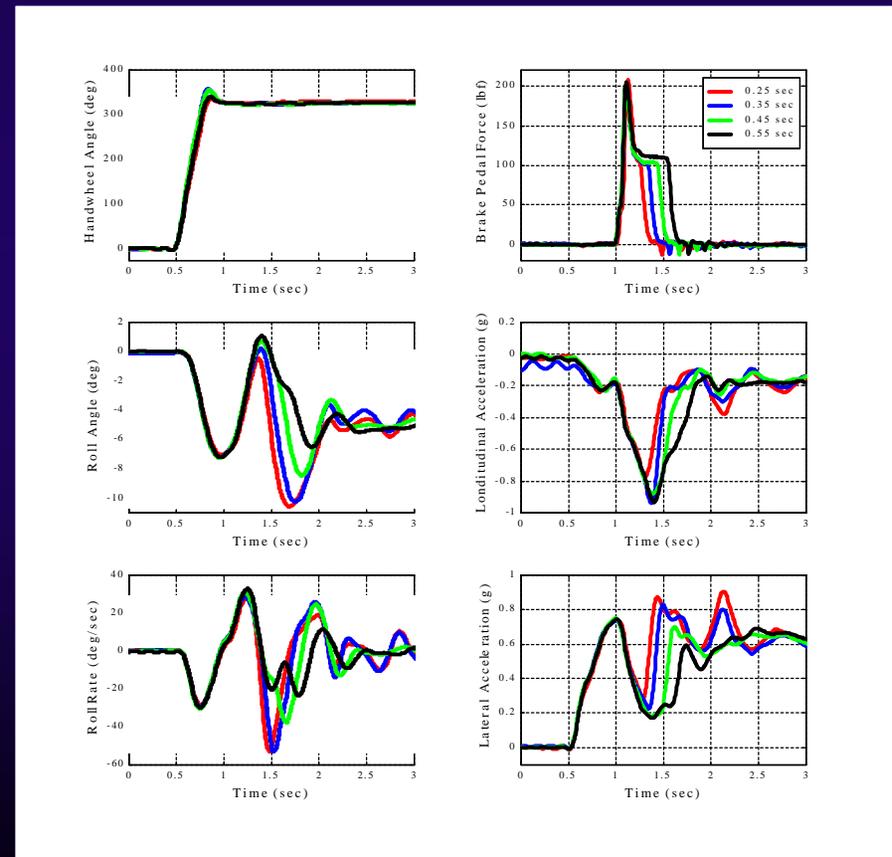


Effects of Pulse Magnitude

Description	Max Post-Pulse Response			Post-Pulse Response Increase (%)		
	140 lbf	190 lbf	200 lbf	140 lbf	190 lbf	200 lbf
AY (g)	0.83	0.84	0.90	13.7	14.4	19.9
Roll Angle (deg)	7.6	9.2	10.6	23.8	48.2	50.4
Roll Rate (deg/sec)	29.9	63.5	53.7	2.7	122.8	85.7

Effects of Pulse Duration

- Force magnitude set to 200 lbf
- Four pulse durations
 - 0.25 sec
 - 0.35 sec
 - 0.45 sec
 - 0.55 sec
- Dip magnitudes a function of pulse duration



Effects of Pulse Duration

Specified Pulse Duration (sec)	Max Post-Pulse Response			Post-Pulse Response Increase (%)		
	AY (g)	Roll Angle (deg)	Roll Rate (deg/sec)	AY	Roll Angle	Roll Rate
0.25	0.90	10.6	53.7	19.9	50.4	85.6
0.35	0.86	10.6	56.7	16.3	48.6	92.3
0.45	0.74	9.0	39.1	-0.7	26.3	32.6
0.55	0.64	6.7	23.3	-14.6	-4.7	-20.1

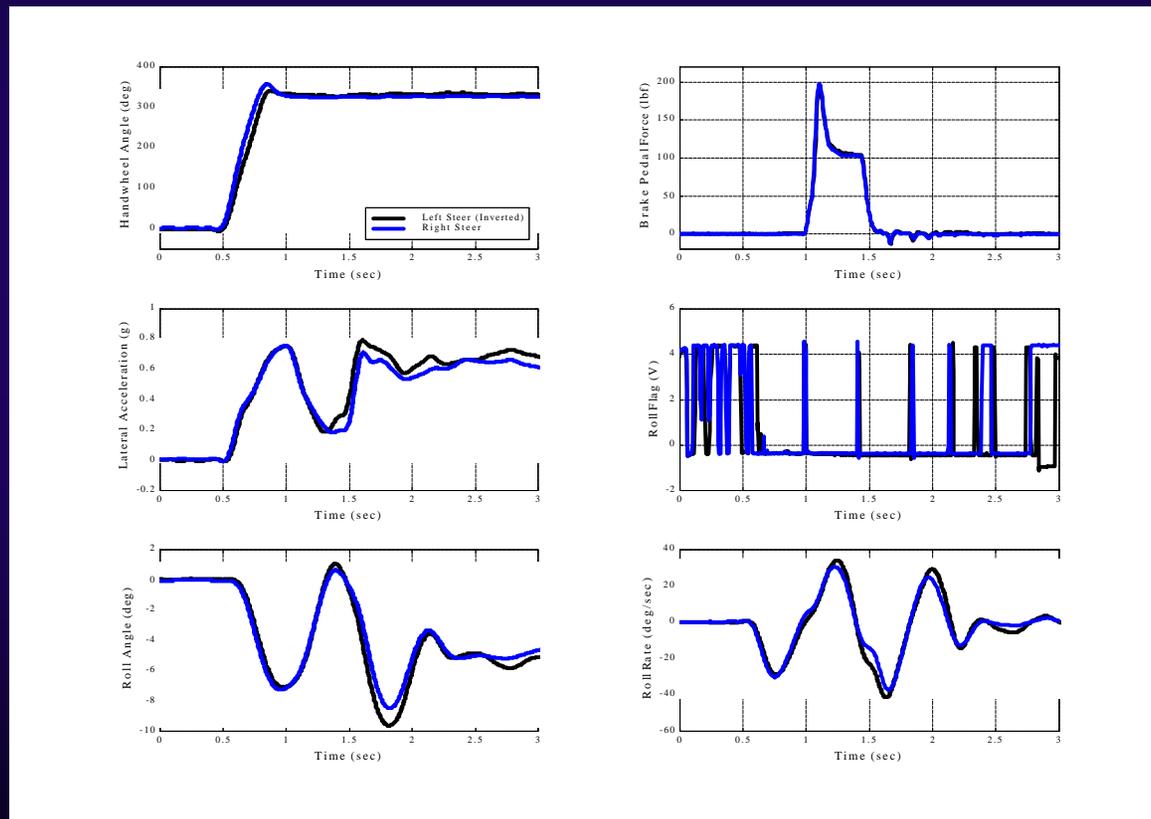
Maximum Rollback

- **Maximize rocking motion of the vehicle established by steering and braking**
- **Compensate for differences in roll natural frequency**
- **Functionality not tested directly**
- **0.45 second pulse (0.58 sec actual duration) used to reasonable assess conceptual viability**

Maximum Rollback

Specified Pulse Duration (seconds)	Overall Delay From Applicable Zero Crossing (seconds)	
	Apply	Retract
0.25	0.008	-0.135
0.35	0.006	-0.070
0.45	0.003	0.026
0.55	0.005	0.128

Maximum Rollback



Overall max post-pulse AY 0.7% less than pre-pulse

Conclusions

- **Automation of pulse braking provides a significant reduction in application magnitude and duration**
- **Maximum post-pulse responses more severe with greater force magnitudes**
- **200 lbf remains NHTSA recommended pulse magnitude**
- **Maximum rollback not the worst-case scenario**
- **Optimal pulse duration between 0.38 and 0.48 seconds**