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Forensic Engineering Resource: Dynamic Testing for Vehicle Rollover Threshold, Using a Programmable Steering Machine and "Zero Roll Rate Feedback"

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Abstract

A single vehicle accident of a sport utility vehicle is be used to describe a typical accident avoidance maneuver and subsequent on-road non trip rollover. An additional objective was to examine vehicle dynamic rollover stability.

Circumstances of the event will be reviewed including results of the reconstruction. Test methodology used to determine a dynamic vehicle rollover threshold on a paved road surface will be presented.

Introduction

On-road rollover accidents frequently occur when the driver permits the vehicle to drift off a paved surface roadway onto the adjacent shoulder area and in response initiates a steer input followed by a counter steer. Accident avoidance of an object within the roadway also produces an initial steer input followed by a counter steer. These maneuvers may result in large vehicle sideslip angles, lateral accelerations exceeding the vehicle dynamic rollover stability and a subsequent on-road non-trip rollover event.

Examination of a vehicle static geometric configuration (rigid vehicle), c.g. height and half tread distance (T/2H) value, usually has a static rollover stability factor in excess of the tire-road surface friction coefficient. However, during dynamic maneuvers, this initial (T/2H) value decreases due to tire and suspension lateral compliance and c.g. roll angle displacement. H, the c.g. height, may also increase due to suspension jacking.

Reconstruction of a Suzuki Sidekick on-road rollover event was conducted and rollover tests performed to determine the dynamic rollover stability factor expressed in lateral g's. A rollover test protocol, to be useful, must satisfy reliability, repeatability and reproducibility. The dynamic reverse steer test utilizes

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a programmable steering machine, providing repeatable steering amplitudes and rates within ergonomic limits and objectively quantifies a vehicle rollover threshold during predictable transient maneuvers.

Accident Background

This accident occurred on a north-south two lane paved roadway bordered by improved shoulders. The accident occurred during darkness on dry pavement, weather was cloudy and cool. The vehicle was a 1993 Suzuki Sidekick, four wheel drive (in two wheel drive mode), four door model with standard transmission. Occupants were a driver and right front passenger who were using their available lap-shoulder belts.

The investigating Police officer who dimensionally documented westbound vehicle path, described a left steer followed by a right steer. The right counter steer resulted in a clockwise yaw and a subsequent on-road, no-trip counterclockwise rollover. Measurements and witness marks defining various vehicle to ground contacts during the rollover sequence were recorded by the investigating police officer. The subject Suzuki Sidekick was available for damage examination and location of various witness score marks. A visit to the accident site did not reveal adverse roadway surface conditions.

A survey of the accident site was prepared and the police' documented witness marks located. A reconstruction of this rollover event was conducted. Vehicle to ground contacts during the roll sequence were identified matching the Sidekick damage and score marks. Speed and side slip angle at rollover initiation were determined.

Results of the reconstruction revealed a rollover initiation speed of approximately 53 mph, two complete rolls at an average 250 deg/sec. Side slip angle at roll initiation was approximately 35 degrees.

Rollover Stability Background

Figure 1 represents rollover stability analysis of a rigid vehicle neglecting suspension, tire lateral compliance, c.g. shift, roll inertia and roll acceleration. Sum of moments about the outside tire defines static lateral acceleration required to initiate rollover.

Rigid body analysis of an exemplar Suzuki Sidekick and Geo Tracker; neglecting roll inertia, roll acceleration, suspension, tire displacement and c.g. shift, reveals a static rollover stability factor of 1.14,[1]. Coefficient of friction for this roadway measured approximately 0.90. Based upon this Suzuki sidekick geometric rigid vehicle dimensions, theoretical rollover should not have occurred since the static rollover stability factor exceeded the roadway friction value.

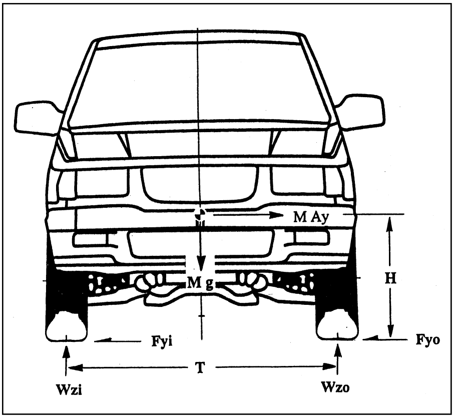

Figure 1
Rigid Body Vehicle-No Deflections

M = vehicle mass
H = C.G. height
T = average half tread distance
g = gravitational constant
Ay = lateral acceleration
SRSF = static rollover stability factor

M (Ay) H = M (g) T/2
SRSF = Ay = [T/2H] (g)

Transient Rollover Stability Analysis

During a typical transient accident avoidance maneuver, increased tire contact patch displacement and sprung mass lateral displacement of the c. g. due to roll velocity results in additional degradation of rollover stability, figure 2. Sprung mass roll damping is not considered.

During an initial left steer input, the sprung mass roll displacement compresses the right suspension springs and tires; storing roll energy. During a subsequent right counter steer, this stored energy is released, load transfer is experienced by the left tires and the sprung mass with additional roll velocity,

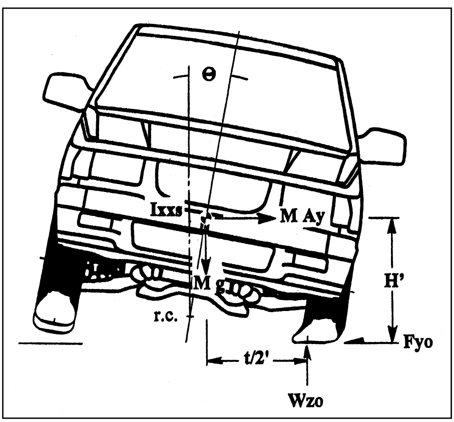

Figure 2
Transient Steer Maneuver; Sprung Mass roll velocity with Lateral C.G. and Tire Deflection

t/2' = dynamic half tread distance
H' = dynamic c.g. height
Ay' = dynamic lateral acceleration
DRSF' = dynamic rollover stability factor

DRSF' = Ay' = [(t/2')/(H')](g)

resulting in displacement of the c.g. movement beyond the steady state value. Figure 3 is a representation of step input roll response vehicle c.g. overshoot[2].

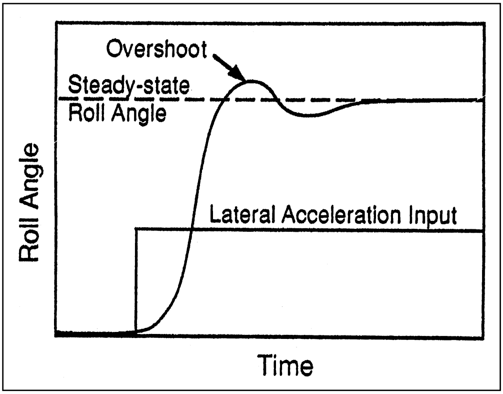

Figure 3
Roll Response to a Step Input

Examination of a steady state vs transient maneuver reveals a significant difference in vehicle side slip angles which is the angle between the traces of the X-Y plane of the vehicle x-axis and the vehicle velocity vector at the c.g.. During a steady state, constant radius maneuver, figure 4, the front tires of an understeering vehicle develop high slip angles which achieve maximum cornering force at the limit of directional control. However, the rear tires closely resemble the low vehicle side slip angle and do not experience a similar maximum value. During a reverse steer transient maneuver, figure 5, a vehicle experiences a high side slip angle during the counter steer, maximizing both front and rear tire friction values.

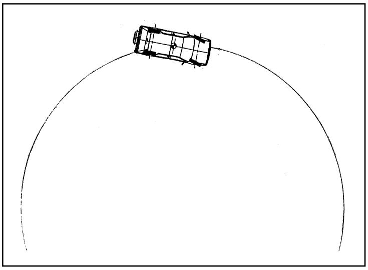

Figure 4

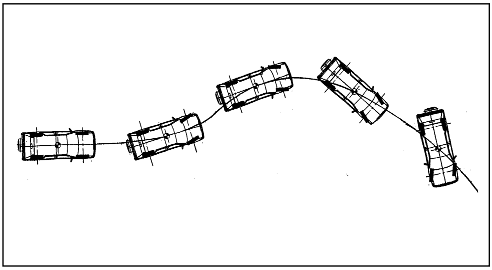

Figure 5

Dynamic Reverse Steer Test For Vehicle Rollover Stability

This reverse steer test is designed to address a typical accident avoidance maneuver or driver encroachment onto an adjacent road shoulder with an initial left steer back onto the roadway followed by a right counter steer. All steer inputs of amplitude and rate should be within ergonomic limits.

The "Open Loop" reverse steer test is designed to be objective by eliminating potential driver influence by using a programmable steering machine for all steer inputs. Since each vehicle has a unique spring-mass and roll response, a common characteristic, "zero roll rate feedback", is used to initiate the counter steer maneuver. Initiating the counter steer at this point in time, the roll response of one vehicle is not favored over another. The steering reversal is made at the maximum dynamic roll angle and is not dependent upon a vehicle roll response rate. Tests are conducted at 50 mph, throttle off, a constant steer rate and selected amplitudes.

Test Protocol

The purpose of a reverse steer test is to objectively define and quantify a particular vehicle rollover tip-up threshold for a given set of steer angles, steer rates, lateral acceleration and test entry speed. These tests are conducted under controlled conditions and environment representing a typical paved hard surface roadway.

Environment

A smooth, level, paved surface representative of roadway composition should be used. The surface must be clean, dry and free of local irregularities which may affect the test results. Ambient air and surface temperature and humidity must be measured. Surface temperature must be higher than ambient air and surface humidity must be lower than air humidity so that the friction surface is not affected by moisture content. Post winter testing on an asphalt surface should consider (water-ice) moisture in aggregate pores which may cause asphalt oils to rise to the surface affecting the friction coefficient.

If possible, peak and sliding pavement friction using the ASTM-1336 Standard Reference Test Tire (SRTT) and subject vehicle exemplar tire used in the test series should be measured,[3]. The test surface should be of sufficient length and width to achieve desired speed and accommodate anticipated steer angles with sufficient run out distance.

Test Vehicle Preparation

The exemplar vehicle must be serviced to represent original manufacture's specifications. A typical check list follows:

- Suspension and steering alignment-front and rear
- Steering system linkage tightness
- Front suspension ball joints
- OEM springs
- OEM shock absorbers
- OEM trim height
- OEM or specified tires

- Outrigger selection and contact pad height above ground.
- Strut air cylinder pressurized.
- Representative occupant and cargo loading, measure all four corners for wheel loads and trim heights.
- Determine test condition c.g. height.
- Full fuel load
- Correct cold tire inflation pressure

Instrumentation

- Steer angle and rate: Heitz "Sprint 1", with "Sprint 2" upgrades, programmable steering machine,4.
- X, Y, Z accelerations, pitch, yaw, roll velocities using Humphrey Inertial Measurement Unit. Acceleration calibration by rotation 90 degrees; rate gyro calibration on 36 degrees/second rate table. Instrumentation package located as close to vehicle c.g. as possible.
- Data acquisition system: All data are conditioned in instrumentation amplifiers and anti-alias-filtered in Butterworth active filters. Data is displayed and recorded on an interior video camera screen during a test, appendix 1.
- Speed and distance: Fifth wheel calibrated for accuracy
- Throttle position: LVDT or RVDT attached to throttle linkage
- Brake pedal force transducer
- Pavement temperature and humidity measured using a Extech Hydro-Thermometer Model B445701. Wind speed and ambient air temperature are measured using a hand held Extech
- Digital Thermometer/Anemometer Model 407112.
- Tire pressure measurement gage
- Interior and exterior video cameras to record data, vehicle motion and driver remarks
- Still documentation photographs
- Additional instrumentation may be used to measure suspension deflections and other components

Vehicle Pre Test Preparation

Typically the passenger front seat is removed to accommodate the instrumentation package which is mounted on a plywood platform. A fifth wheel velocity measuring system is mounted to the rear bumper. Rollover outrigger assembly is installed. Total vehicle test weight at each wheel is recorded. All instrumentation, driver weight and locations within the test vehicle are recorded. Total test configuration c.g. is measured or calculated.

Documentation of the instrumentation weights and locations for the Suzuki Sidekick are listed in appendix 2.

New O.E.M. tires and recommended cold inflation pressures should be used unless otherwise specified. Each tire serial number should be recorded and initial location identified by engraving a reference number or letter on the inner and outer sidewall. A sinusoidal steer tire scuff program should be used to remove surface sheen and mold release tips prior to any testing. Initial pre test tire temperatures should be recorded at the conclusion of this scuff program. Each tire should be photographed to document pre test appearance.

If a right and left understeer gradient test is to be included, it may be conducted at the conclusion of this tire scuff program, appendix 3.

Test Protocol

A rollover test protocol, to be useful must satisfy Reliability, Repeatability and Reproducibility. A rollover protocol must relate to a particular driving scenario, without discriminating in favor of one vehicle and against another. Performance variability during a test program must be minimized. The tests must be reproducible by other testing organizations.

Use of a programmable steering machine for pre selected steer input amplitudes and rate eliminates the potential driver influence. All tests are conducted with the throttle off. Ambient conditions are closely monitored to insure reproducibility.

A specific steer timing which might produce maximum rollover response in one vehicle may not produce rollover response in another. The test protocol is designed to eliminate this problem by use of “zero roll rate feedback” from which steering reversals are made to occur at maximum dynamic roll angles for all vehicles, independent of a vehicle’s rate of roll response.

Reverse steer tests are conducted at pre selected input steer angles, rate and entry speed. 50 mph is selected as a standard test entry speed with programmed left-right steer inputs at 500 or 600 degrees per second.

The following are some of the left-right steer inputs in degrees which are considered ergonomically reasonable;

90L/90R	90L/120R	90L/150R
120L/120R	120L/150R	135L/135R
150L/150R	165L/165R	180L/180R

Left followed by a right steer maneuver is selected to minimize potential driver injury due to elevation and subsequent drop during tip-up.

Selected steer inputs and standard test initiation speed (50 mph) are programmed into the computer. The vehicle is brought to a speed in excess of the test initiation speed, (top gear), in a straight line. The program switch located on the steering wheel is depressed and throttle released. When the vehicle slows to 50 mph, the steer program automatically begins. At the predetermined steer rate, a left steer is initiated and is held until the vehicle achieves maximum clockwise roll angle, (zero roll rate). The counter right steer angle is introduced at this point, at the same degrees per second and is maintained until the driver releases the program switch and regains hands on steering wheel control. The reverse or second steer timing is designed to occur during a common event to all vehicles, at the initial steer maximum roll angle, which is the "zero roll rate feedback" point. Vehicles will have different dynamic roll response times. However, all will experience a "zero roll rate feedback" dependent upon their individual characteristics. Initiating the reverse steer at this common point in time does not discriminate one vehicle against another.

If tip-up is experienced, the test is repeated with the same steer values at a lower speed until no tip-up occurs. At this point additional runs may be conducted on either side of the threshold speed for verification.

During the test session, tire replacement may be required due to tread wear. The left front tire will wear the most and the right rear the least. The right front tire does not experience equal wear compared to the left front due to differences in loading. Left rear wear becomes significant when the vehicle spins or is subjected to large side slip angles for extended time. When required, the left front is replaced by the right rear and other tires as required.

At the conclusion of the test series a comparison run is conducted to verify the rollover outrigger does not influence the results. A speed and steer input identical to a previous run is selected below the rollover threshold and rerun with outrigger assembly removed. Overlaid comparison of the output data confirms absence of outrigger influence.

Rollover Test Data Analysis

The following data may be printed with a time base; zero indicating first steer input.

- Test vehicle longitudinal speed, mph
- Steering wheel angle, degrees
- Roll rate, deg/sec
- Yaw rate, deg/sec
- Roll angle, degrees
- Lateral acceleration, g's after 0.5 sec running average filter
- Roll acceleration, deg/sec-sec
- Outrigger force, lbs.
- Ax, g's
- Ay, g's
- Sideslip rate, degrees/sec
- Sideslip angle, degrees
- Throttle, x
- Brake force, lbs.

Appendix 4a,b is a partial list of Suzuki Sidekick test runs with corresponding data. Appendix 5a,b,c,d are corresponding test data plots. Analysis of the rollover threshold data reveals rollover occurs at the non-reversible roll angle curve inflection point and subsequent outrigger ground contact. Appendix 5b and 5d identify this location with a corresponding lateral acceleration value.

A rollover threshold is determined by averaging the lowest tip-up and highest non-tip-up lateral accelerations. The threshold may also be defined as the test entry speed for a specific reverse steer maneuver or lateral acceleration above which tip-up will always or almost always occur and below which tip-up will seldom occur. Appendix 6a,b,c are comparison runs with and without outriggers.

The following test values are used to determine the Suzuki Sidekick rollover threshold.

50 mph "Standard Speed"

Low tip	0.822 @ 6-21:44
High non-tip	0.832 @ 5-54:03 and 6-04:06
Average	0.83 g

For all speeds

Low tip	0.822 g @ 6-21:44
High non-tip	0.856 g @ 7-25:16 at 65 mph
Average	0.84 g

Appendix 7 is a table of reverse steer inputs at test entry speeds either side of the tip-up threshold. The results indicate that tip-up threshold can be determined with a tolerance of +/- one mph. Appendix 8 is a plot of the 120L/150R reverse steer data and reveals a 56-mph (entry speed) tip-up threshold.

Analysis of the test data will permit the reviewer to evaluate the effects of c.g. height, half tread distance, roll damping, tire characteristics and other vehicle parameters contributing to rollover instability.

A plot of right turn roll rate vs. right turn roll angle and lateral acceleration appears in appendix 9 and 10. It is apparent, vehicle roll rate, which is a momentum quantity, may affect tip-up at the threshold

Appendix 11 is reverse steer test data from modifications to the Suzuki Sidekick. The front and rear track width was increased 2 1/4 inches and the c.g. lowered 1/2 inch by replacing the standard 205/75R-15 tire with a 195/70R-15 tire. Appendix 12a,b,c,d are time history data plots for test 4-20:38. Tip-up was not experienced with these bolt on modifications.

Conclusion

The rollover test protocol described within this paper satisfies the requirement of reliability, repeatability and reproducibility without discriminating in favor of one vehicle against another. Analysis of the test data provides an objective scientific basis upon which to make vehicle changes to prevent non trip on-road rollover. The test protocol, presentation and analysis of test data discussed in this paper is an on-going work in progress and will receive additional analysis and refinement.

Acknowledgment

The rollover research, test methodology and contents of this paper would not be possible without the contributions of Edward J. Heitzman and Edward F. Heitzman of Automotive Testing, Inc.. They are the designers, developers and manufactures of the Heitz, programmable steering machine which has provided an open loop, method to test, evaluate and objectively quantify a rollover threshold.

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2. Fundamentals of Vehicle Dynamics, Thomas Gillespie, 1992, Published by The Society of Automotive Engineers

3. American Society for Testing Materials, ASTM E 1337-90: Determining Longitudinal Peak Braking Coefficient of Paved Surfaces Using a Standard reference Tire.

4. E. J. Heitzman and E. F. Heitzman, A Programmable Steering machine for Vehicle Handling Tests, SAE Paper 971057

5. Thomas J. Wielenga, Tire Properties Affecting Vehicle Rollover, SAE Paper 1999-01-0126

REVERSE STEER RECORDED DATA SCALE

Data Channel	Item	Display: one count equals:
1	Speed	0.1 mph
2	Steering Wheel Angle	1 degree
3	Throttle	0.1 percent full throttle
4	Brake Effort	1.0 pound
5	Yaw velocity	0.1 degrees/second
6	Roll Velocity	0.1 degrees/second
7	Lateral Acceleration	0.001 g.
8	Fore Acceleration	0.001 g.
9	Humphrey Roll Angle	0.02 degrees
10	Pitch Angle	0.01 degrees
11	Outrigger Load Cell	1 pound
12	Distance	1 foot

Notes:
1. Resolution into computer is twice that of display
2. Roll angle is plotted from integrated roll velocity when gyro's 15 degree limit is exceeded.

Appendix 1

1993 SUZUKI SIDEKICK
INSTRUMENTATION WEIGHTS AND LOCATION

INSTRUMENT LOCATION

Item	Weight Pounds	Height inches	Moment inch-pounds
Original seat	-30	27.3	-819
Front-seat panel	18	26.3	473
Humphrey	38	30.3	1151
Data System	14	31.3	438
Electronics box	11	31.3	344
Steering machine	22	39.0	858
Video tape recorder	1	35.8	36
Video camera and monopod	3	45.0	135
Junction box	1	27.3	27
Fifth wheel	14	12.0	166
Fifth wheel bumper bracket	2	18.0	36
Rear seat panel	18	31.3	563
Battery box	32	33.8	1082
Totals	144	31.2	4492
Driver	265	36.0	

OUTRIGGER WEIGHTS:

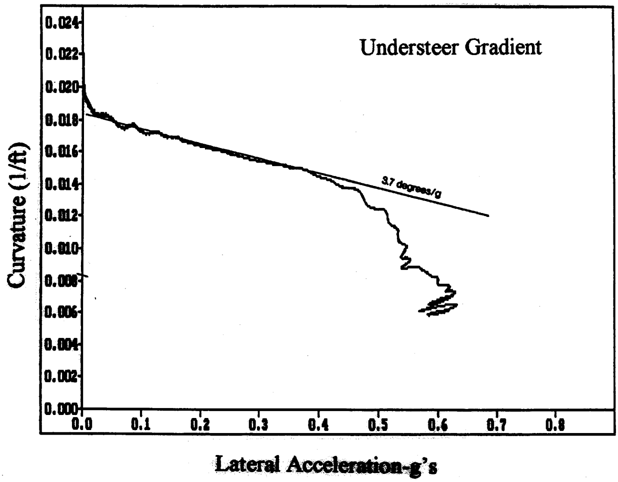
Item	Weight Pounds	Height inches	Moment inch-pounds
Roof rail brackets	2x7	65	910
Roof cross tube	7	69	483
Lower cross arms	2x13.5	12	324
Slider assemblies	2x4	13	104
Strut, driver side	10	41	410
Strut, passenger side	8	40	320
Unibody structure	16	10.5	168
Totals	90	30.2	2719

Appendix 2

1993 Suzuki Sidekick Circle Test 5-13:32

Curvature (1/ft) vs ur (g)

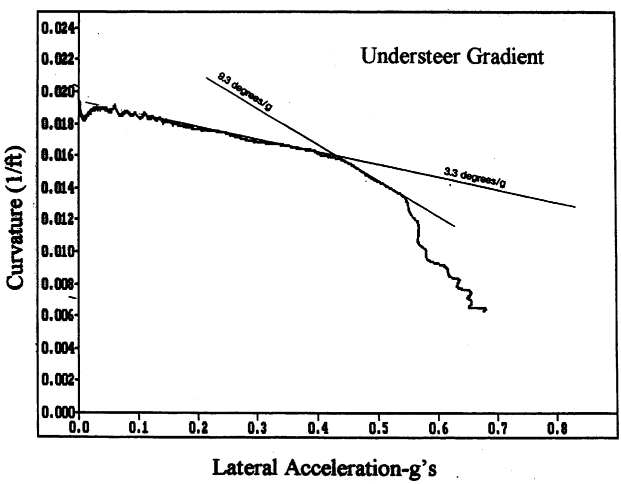
OEM wheels & tires; handwheel angle 178° right
Fourier filter flat to 0.5 hz; zero past 0.7 hz



1993 Suzuki Sidekick Circle Test 5-11:35

Curvature (1/ft) vs ur (g)

OEM wheels & tires; handwheel angle 180° left
Fourier filter flat to 0.5 hz; zero past 0.7 hz



Appendix 3

1993 SUZUKI SIDEKICK ROLLOVER TEST DATA

TAPE TIME	SPEED mph	STEER Degrees	Ay g's	ROLL ANGLE Degrees	OUTRIGGER Pounds
5-44:57	50	165/165	.814	12.65	150
5-47:16	50	165/165	.823	8.90	n.c.*
5-54:03	50	165/165	.832	8.50	n.c.
6-04:06	50	165/165	.832	8.90	n.c.
6-09:53	50	165/165	.820	13.25	100
6-49:06	51	165/165	.839	17.4	375
5-51:16	51	165/165	.827	18.35	475
6-05:52	52	165/165	.848	20.75	650
6-08:04	52	165/165	.834	21.05	650
6-01:57	55	165/165	.869	20.35	650
6-15:62	45	180/180	.796	9.40	n.c.
6-17:54	47	180/180	.800	8.35	n.c.
6-19:40	48	180/180	.826	8.50	n.c.
6-29:20	48	180/180	.820	18.70	425
6-31:15	48	180/180	.841	9.20	n.c.
6-33:04	48	180/180	.833	17.50	450
6-34:07	48	180/180	.832	18.9	425
6-37:06	48	180/180	.828	19.35	450
6-23:53	49	180/180	.811	18.70	400
6-25:39	49	180/180	.817	20.90	575
5-34:08	50	180/180	.831	19.15	575
5-40:39	50	180/180	.855	18.55	525
6-21:44	50	180/180	.822	20.50	475

*no ground contact

Appendix 4a

1993 SUZUKI SIDEKICK ROLLOVER TEST DATA

TAPE TIME	SPEED mph	STEER Degrees	Ay g's	ROLL ANGLE Degrees	OUTRIGGER Pounds
7-48:14	40	120/150	.653	6.60	n.c.*
7-50:02	45	120/150	.730	7.40	n.c.
7-51:53	50	120/150	.792	8.25	n.c.
7-53:41	55	120/150	.841	20.5	475
7-55:47	53	120/150	.808	8.75	n.c.
7-57:36	54	120/150	.829	9.70	n.c.
7-59:06	55	120/150	.816	9.55	n.c.
8-03:00	60	120/150	.873	23.45	750
8-05:21	55	120/150	.842	10.25	n.c.
8-07:18	57	120/150	.839	22.40	650
8-09:56	56	120/150	.840	22.05	625
8-11:30	56	120/150	.831	8.75	n.c.
8-13:26	56	120/150	.847	21.50	525
8-15:25	56	120/150	.857	21.50	550
Outrigger/No Outrigger Comparison runs					
6A-01:32	50	120/120	.714	4.55	n.c.
6A-03:11	50	120/120	.699	4.95	n.c.

* no ground contact

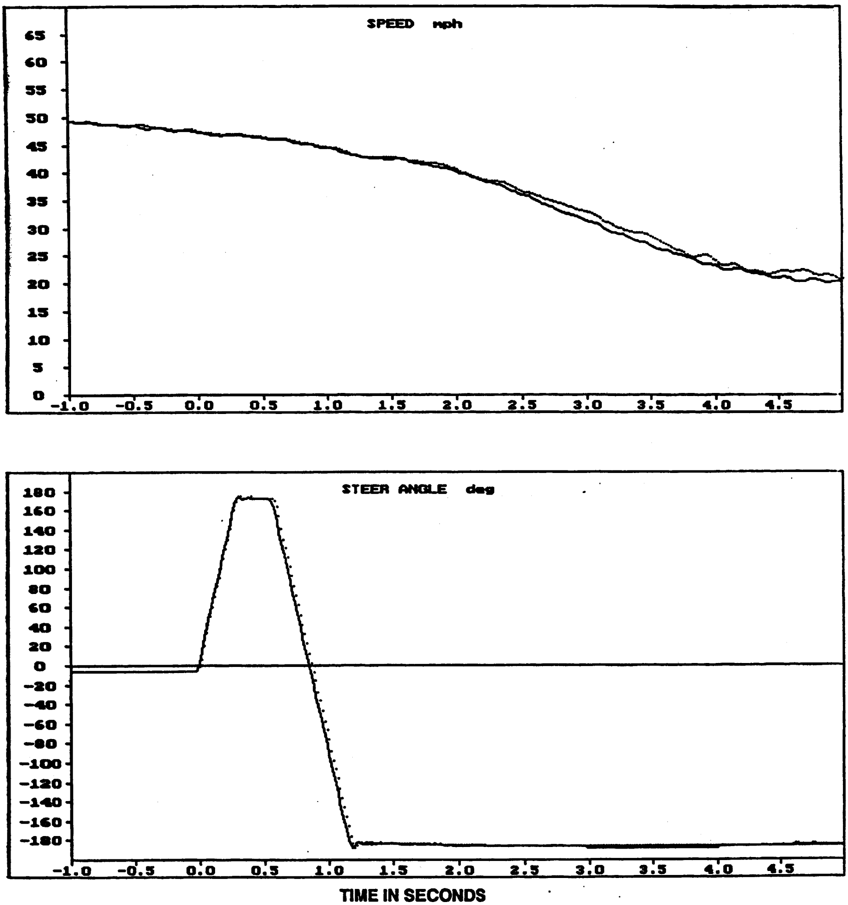
Removed Outriggers

6A-04:59	50	120/120	.727	5.20
6A-06:45	50	120/120	.710	4.95

Appendix 4b

1993 SUZUKI SIDEKICK REVERSE STEER TEST DATA

180/180 48 MPH THRESHOLD COMPARISON

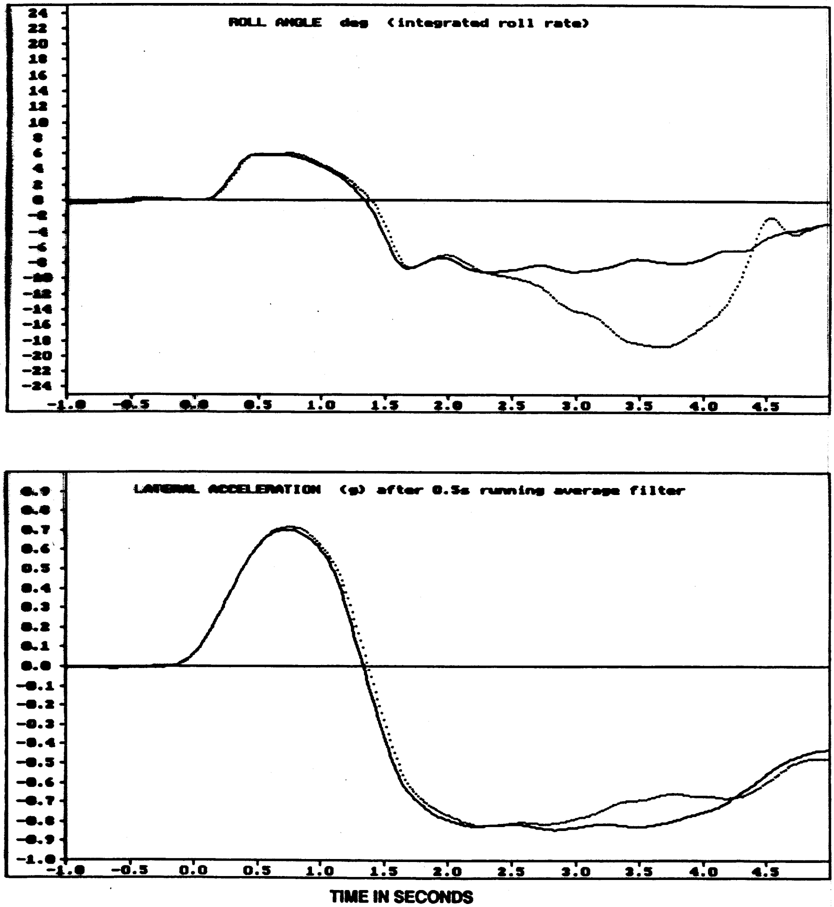


Data runs 6-31:15 and 6-29:20 (dotted)

Appendix 5a

1993 SUZUKI SIDEKICK REVERSE STEER TEST DATA

180/180 48 MPH THRESHOLD COMPARISON

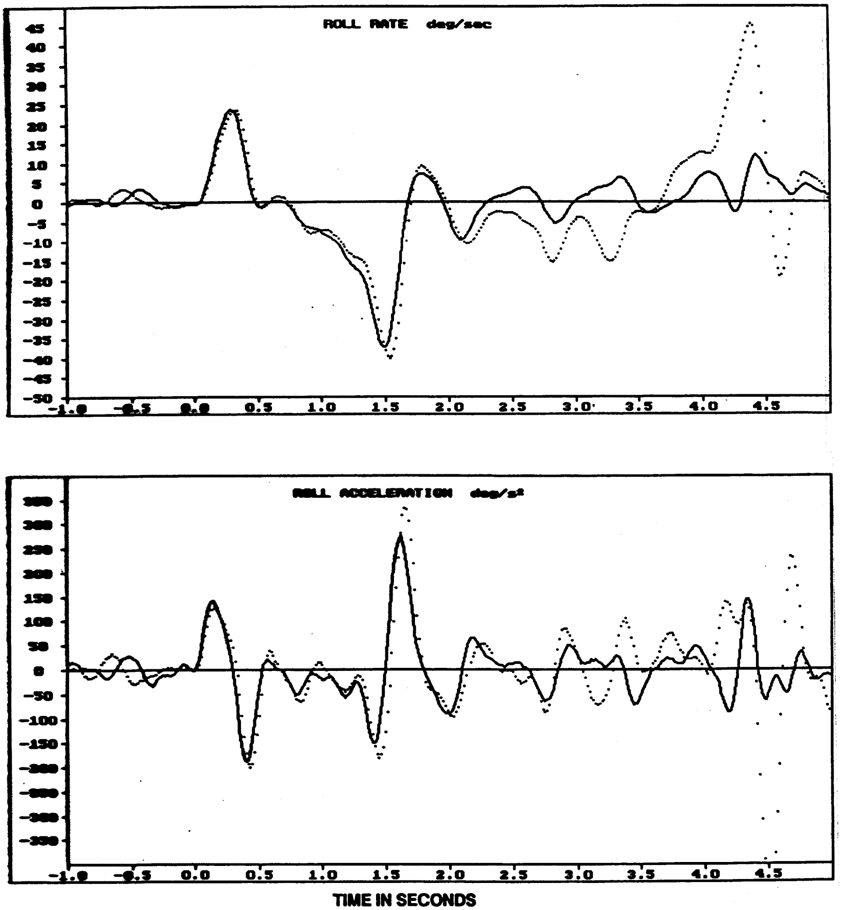


Data runs 6-31:15 and 6-29:20 (dotted)

Appendix 5b

1993 SUZUKI SIDEKICK REVERSE STEER TEST DATA

180/180 48 MPH THRESHOLD COMPARISON

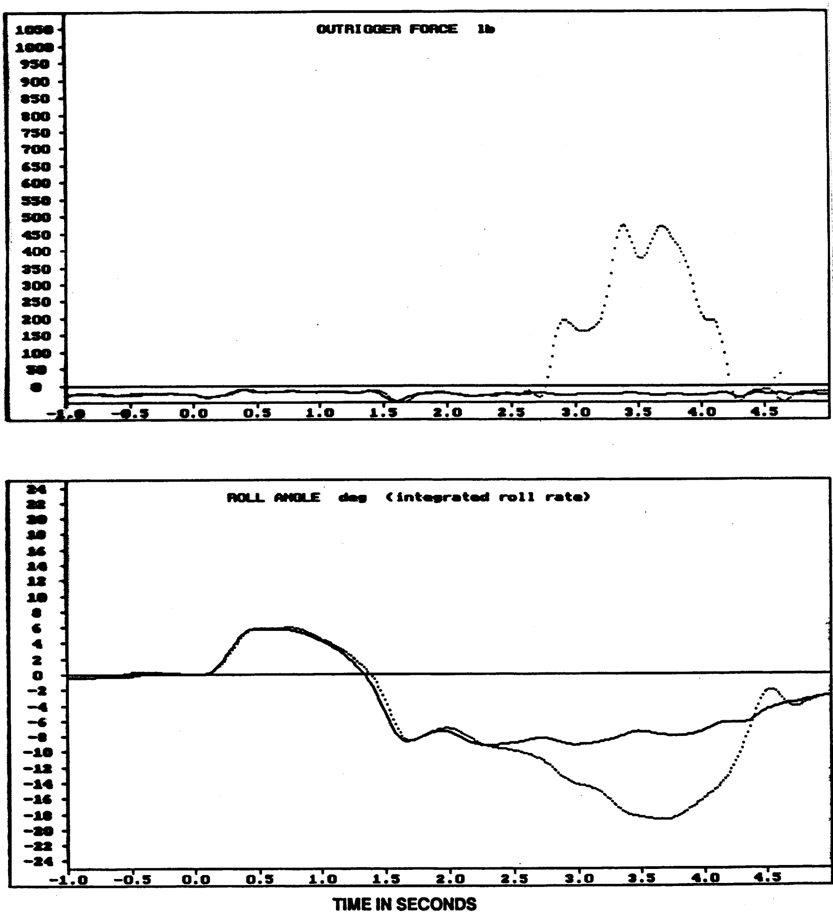


Data runs 6-31:15 and 6-29:20 (dotted)

Appendix 5c

1993 SUZUKI SIDEKICK REVERSE STEER TEST DATA

180/180 48 MPH THRESHOLD COMPARISON

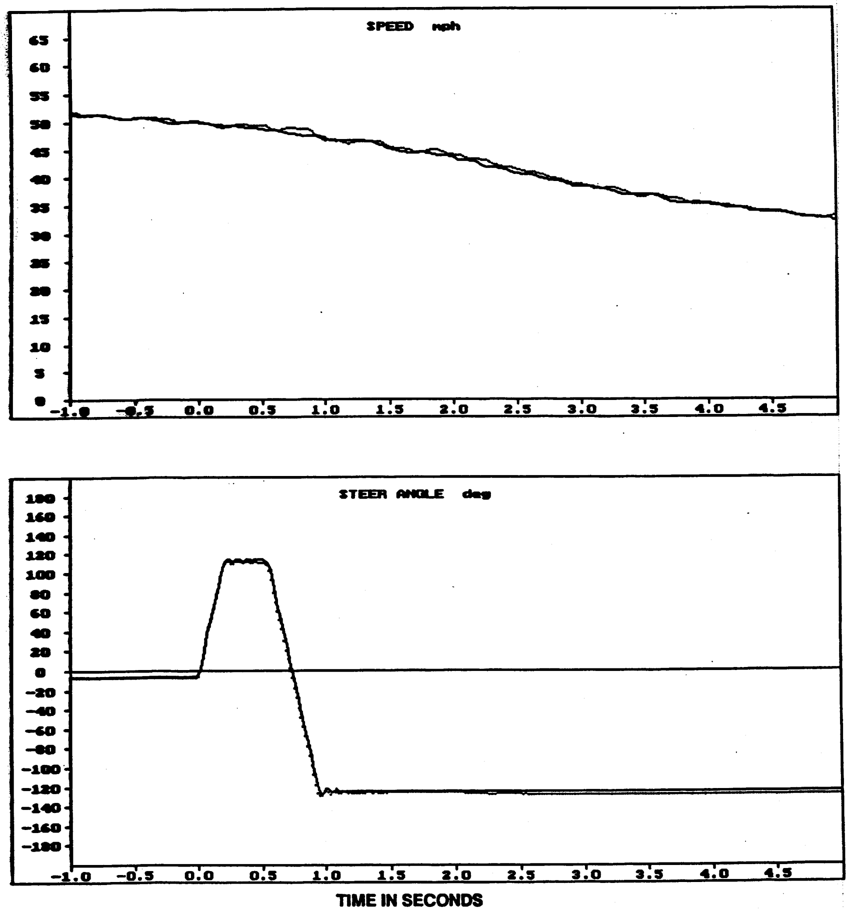


Data runs 6-31:15 and 6-29:20 (dotted)

Appendix 5d

1993 SUZUKI SIDEKICK REVERSE STEER TEST DATA

OUTRIGGER / NO OUTRIGGER COMPARISON

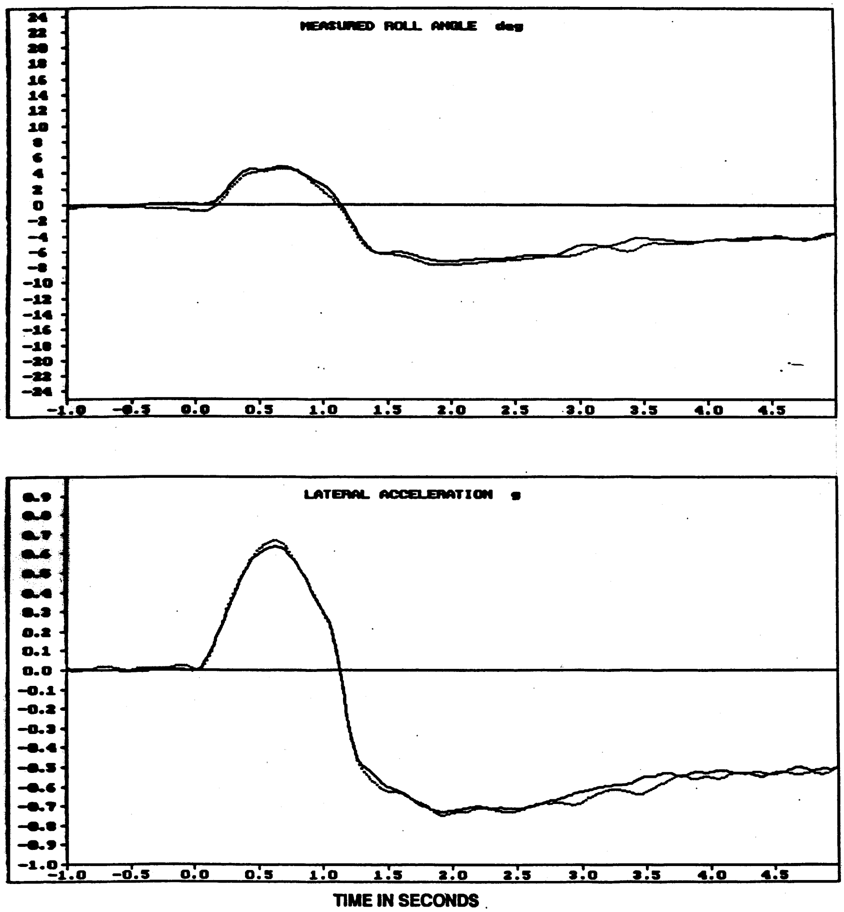


Data runs 6A-01:32 and 6A-04:59 (dotted)

Appendix 6a

1993 SUZUKI SIDEKICK REVERSE STEER TEST DATA

OUTRIGGER / NO OUTRIGGER COMPARISON

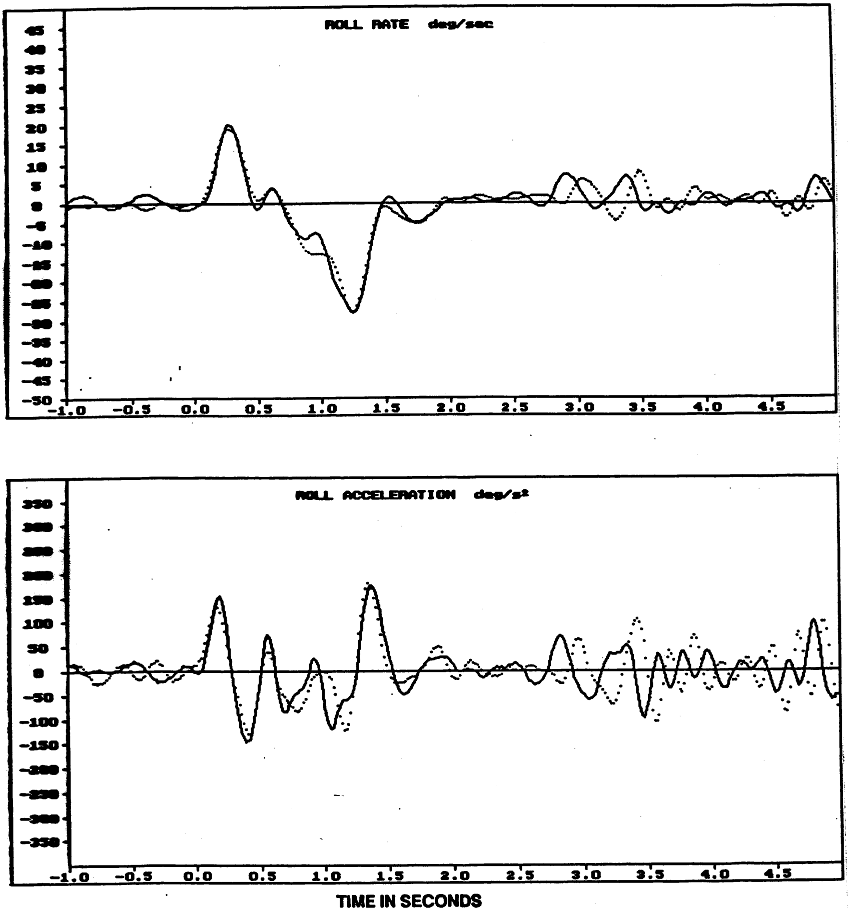


Data runs 6A-01:32 and 6A-04:59 (dotted)

Appendix 6b

1993 SUZUKI SIDEKICK REVERSE STEER TEST DATA

OUTRIGGER / NO OUTRIGGER COMPARISON



Data runs 6A-01:32 and 6A-04:59 (dotted)

Appendix 6c

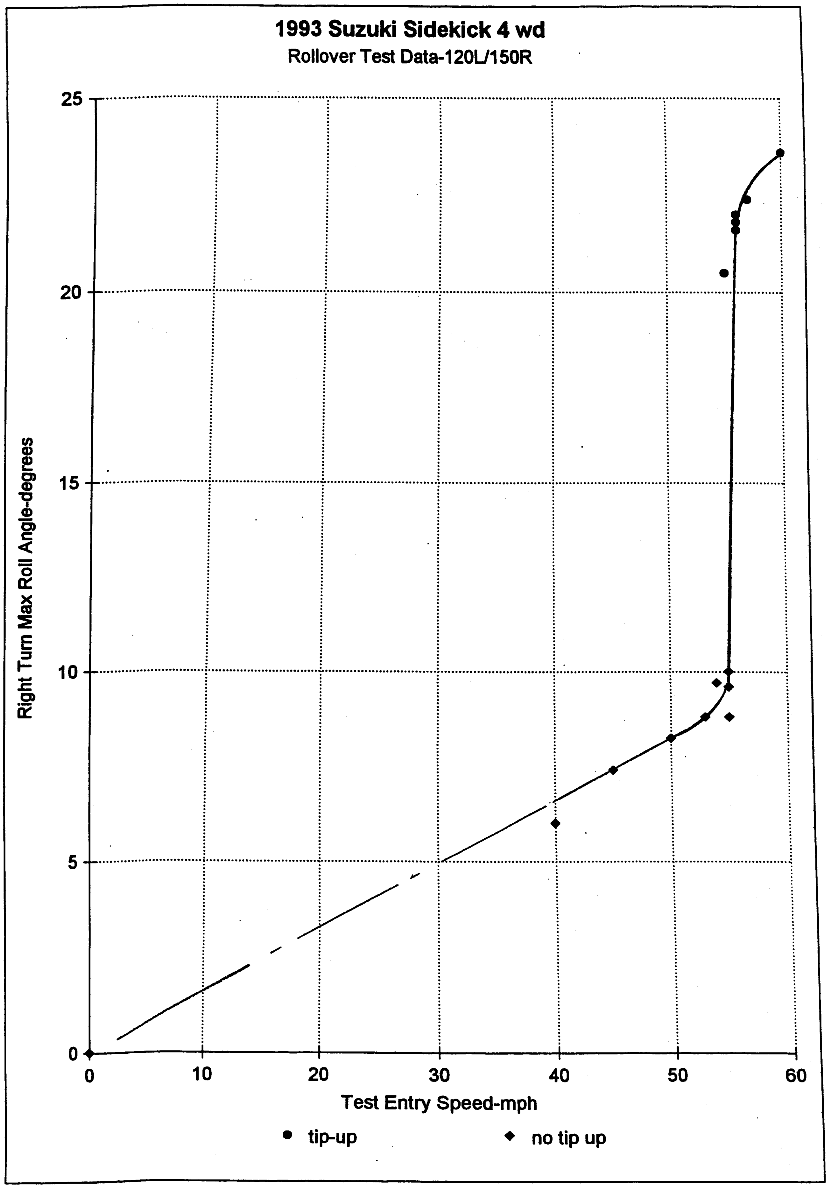
SUZUKI SIDEKICK
ATI Report No. 080201

180/180 DEGREES STEER AT 600 DEGREES/SECOND			
Speed (mph)	Number of Tip-ups	Total number of Runs	Comment
<48	none		
48	5	7	Threshold
49	2	2	
50	3	3	

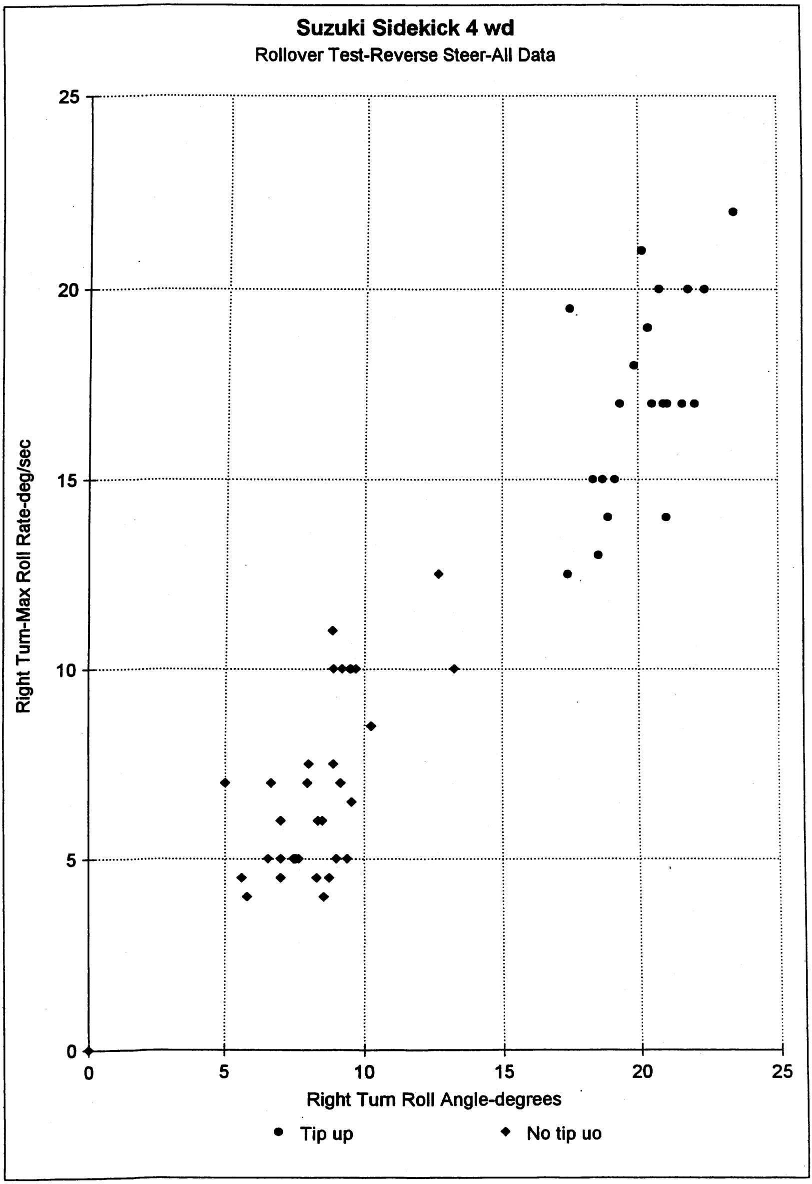
165/165 DEGREES STEER AT 600 DEGREES/SECOND			
Speed (mph)	Number of Tip-ups	Total number of Runs	Comment
50	0	5	
51	2	2	Threshold
52	2	2	

120/150 DEGREES STEER AT 600 DEGREES/SECOND			
Speed (mph)	Number of Tip-ups	Total number of Runs	Comment
<55	none		
55	1	4	
56	3	3	Threshold
57	1	1	
60	1	1	

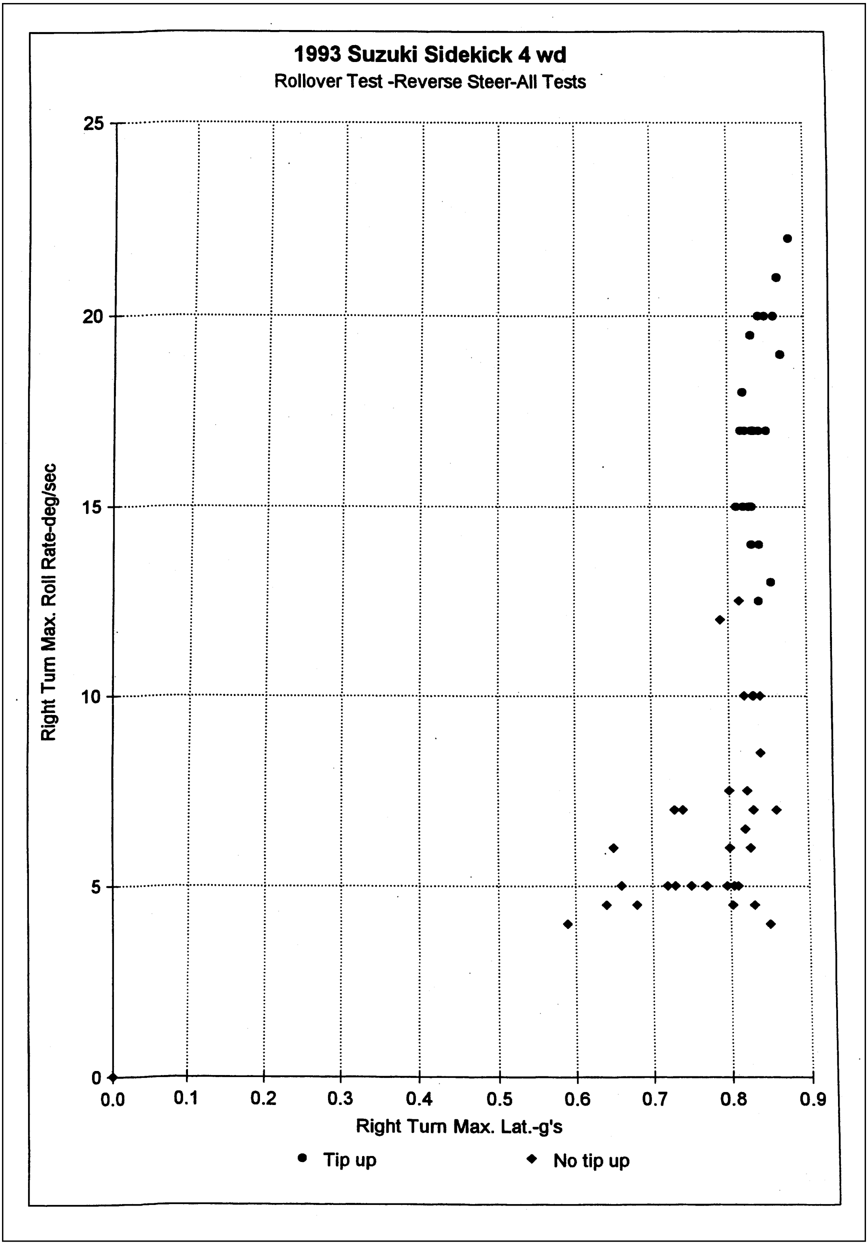
Appendix 7


1993 Suzuki Sidekick 4 wd
Rollover Test Data-120L/150R
Right Turn Max Roll Angle-degrees
0
5
10
15
20
25
0
10
20
30
40
50
60
Test Entry Speed-mph
tip-up
no tip up

Appendix 8


Suzuki Sidekick 4 wd
Rollover Test-Reverse Steer-All Data
Right Turn-Max Roll Rate-deg/sec
0
5
10
15
20
25
0
5
10
15
20
25
Right Turn Roll Angle-degrees
Tip up
No tip uo

Appendix 9


1993 Suzuki Sidekick 4 wd
Rollover Test -Reverse Steer-All Tests
Right Turn Max. Roll Rate-deg/sec
25
20
15
10
5
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Right Turn Max. Lat.-g's
Tip up
No tip up

Appendix 10

MODIFIED 1993 SUZUKI SIDEKICK REVERSE STEER TEST DATA:

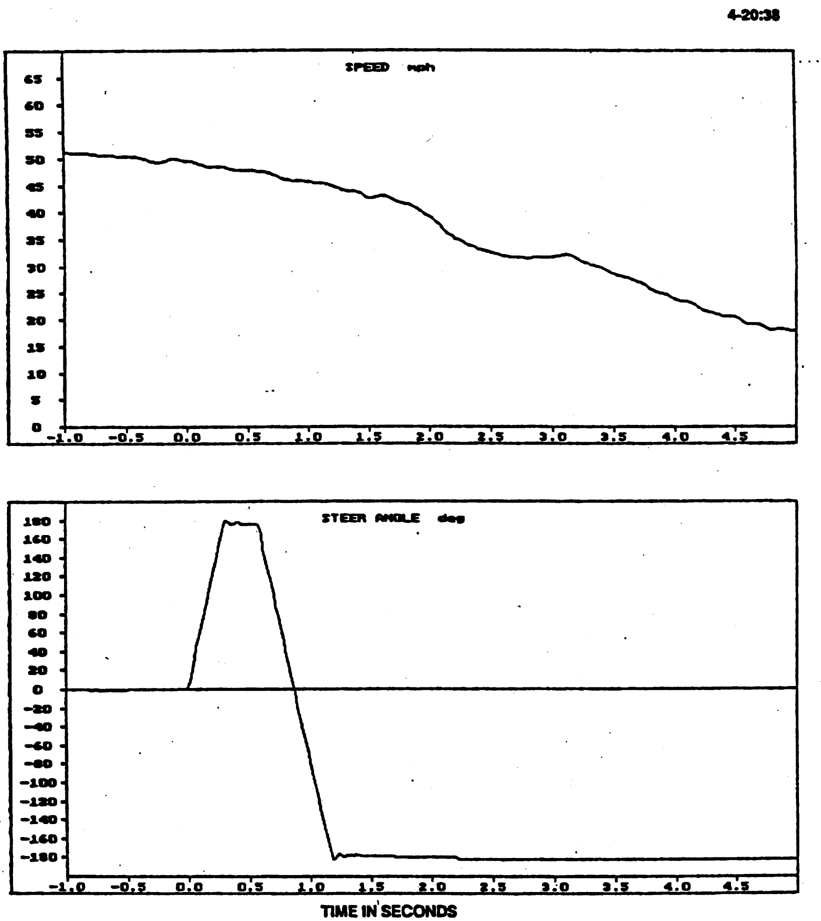
TRACK WIDTH INCREASED 2 1/4 INCHES AND C.G. LOWERED ½ IN.

TAPE TIME	SPEED mph	STEER Degrees	Ay g's	ROLL ANGLE Degrees	OUTRIGGER Pounds
4-17:06	50	120/120	.789	4.65	n.c.*
4-18:51	50	150/150	.881	8.20	n.c.
4-20:38	50	180/180	.877	8.80	n.c.
4-22:29	50	180/240	.870	8.20	n.c.
4-25:38	50	180/300	.847	9.60	n.c.
8-27:45	50	180/360	.861	9.45	n.c.
4-29:46	60	180/300	.843	10.90	n.c.
4-34:31	50	135/135	.836	7.95	n.c.
Removed Outriggers					
4-36:08	50	135/135	.841	6.95	n.c.
4-37:55	50	135/135	.842	6.50	n.c.

* no ground contact

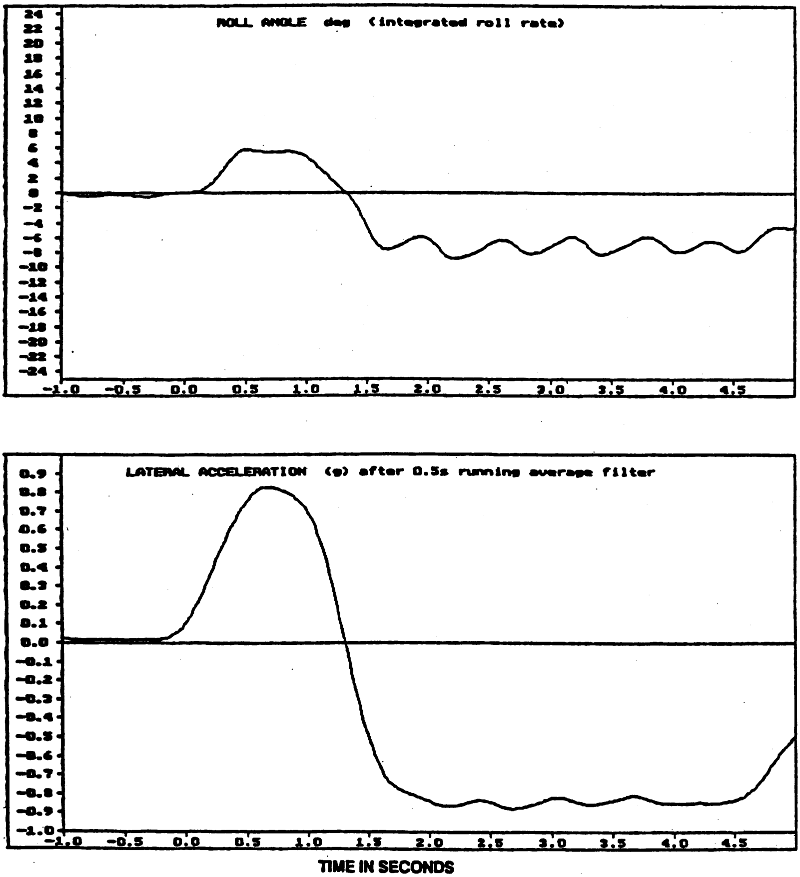
Appendix 11

MODIFIED 1993 SUZUKI SIDEKICK REVERSE STEER TESTS;
TRACK WIDTH INCREASED 2 1/4 IN. AND C.G. LOWERED ½ IN.



Appendix 12a

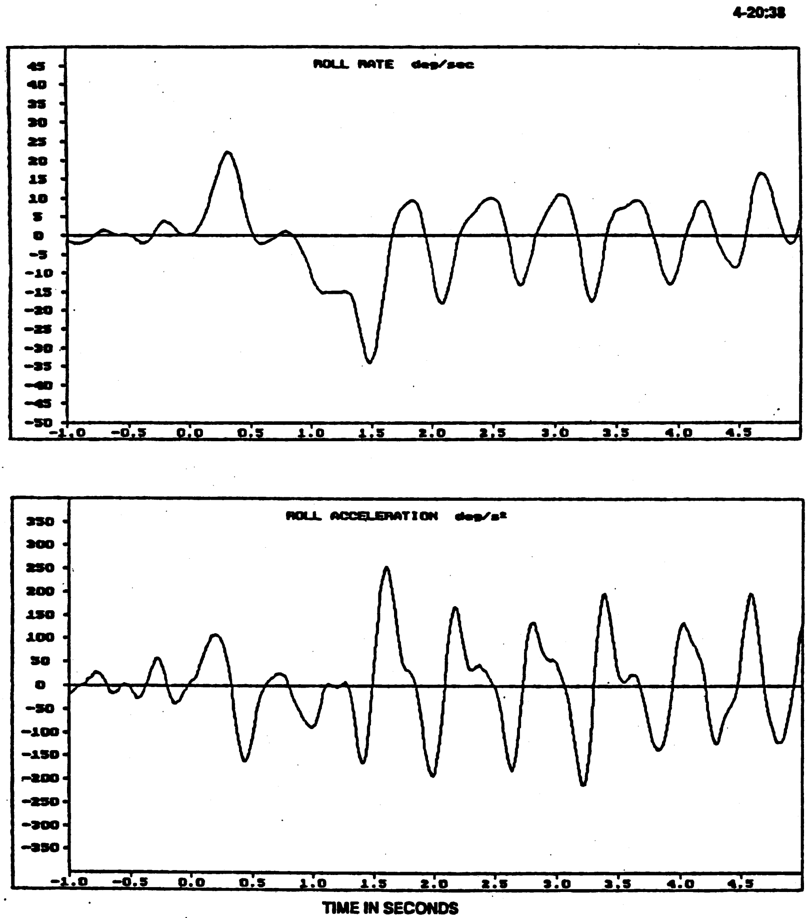
MODIFIED 1993 SUZUKI SIDEKICK REVERSE STEER TESTS;
TRACK WIDTH INCREASED 2 1/4 IN. AND C.G. LOWERED ½ IN.



Ay peaks: -0.877 g at 2.683 sec; 0.828 g at 0.667 sec.
Roll angle peaks: -8.800 deg; 5.700 deg.

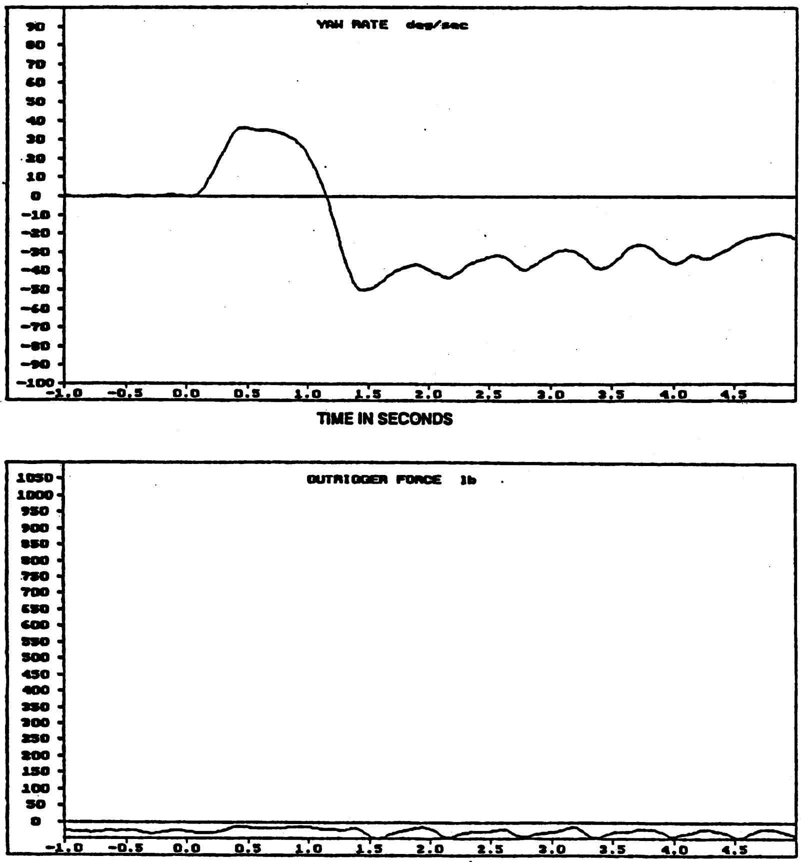
Appendix 12b

**MODIFIED 1993 SUZUKI SIDEKICK REVERSE STEER TESTS;
TRACK WIDTH INCREASED 2 1/4 IN. AND C.G. LOWERED ½ IN.**



Appendix 12c

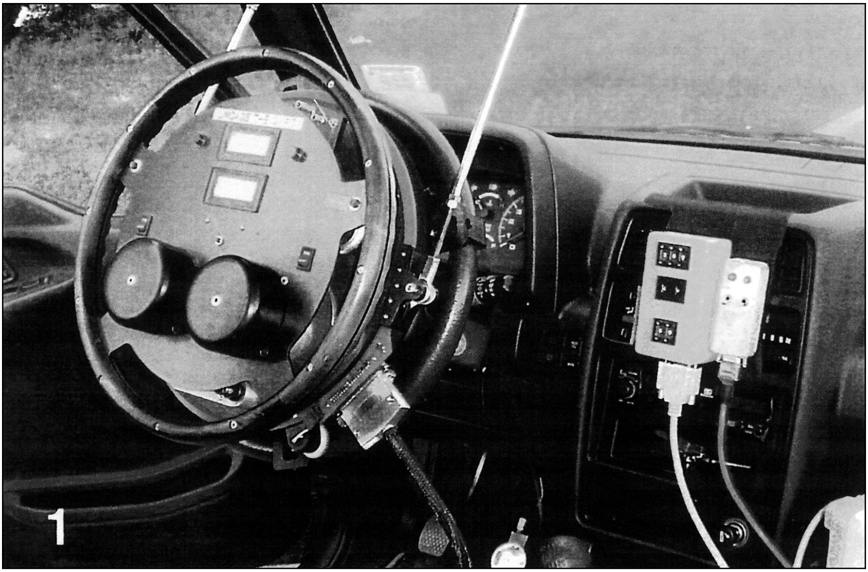
MODIFIED 1993 SUZUKI SIDEKICK REVERSE STEER TESTS;
TRACK WIDTH INCREASED 2 1/4 IN. AND C.G. LOWERED ½ IN.



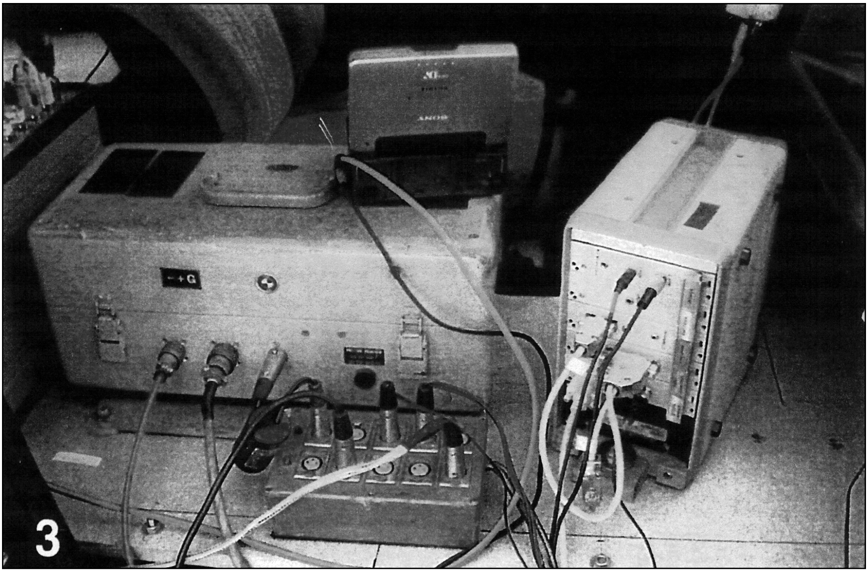
Appendix 12d

1993 Suzuki Sidekick – Left side Outrigger and 5th wheel

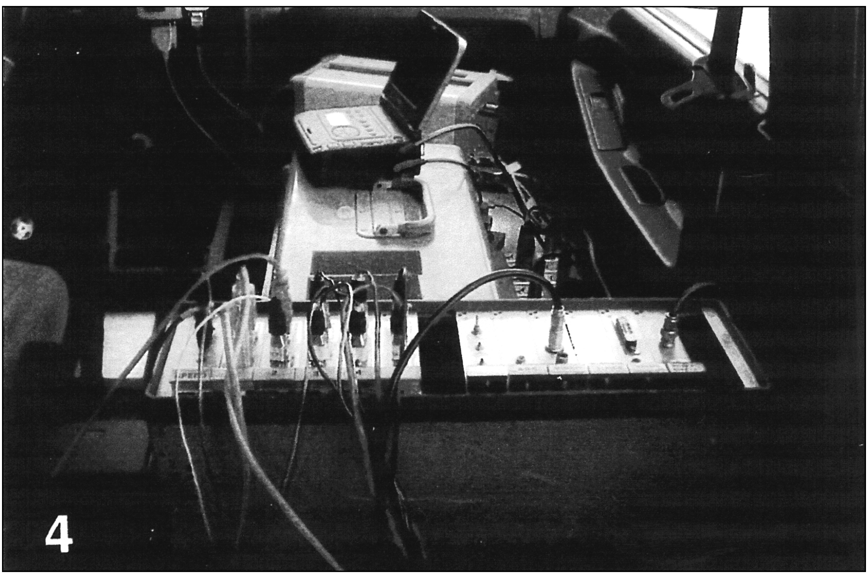
Front View

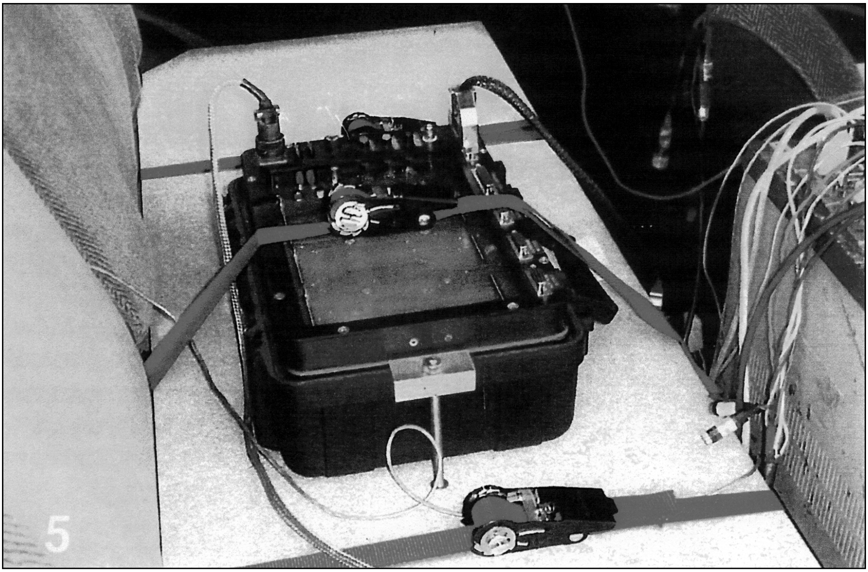


Heitz Sprint 1 programmable Steering Machine

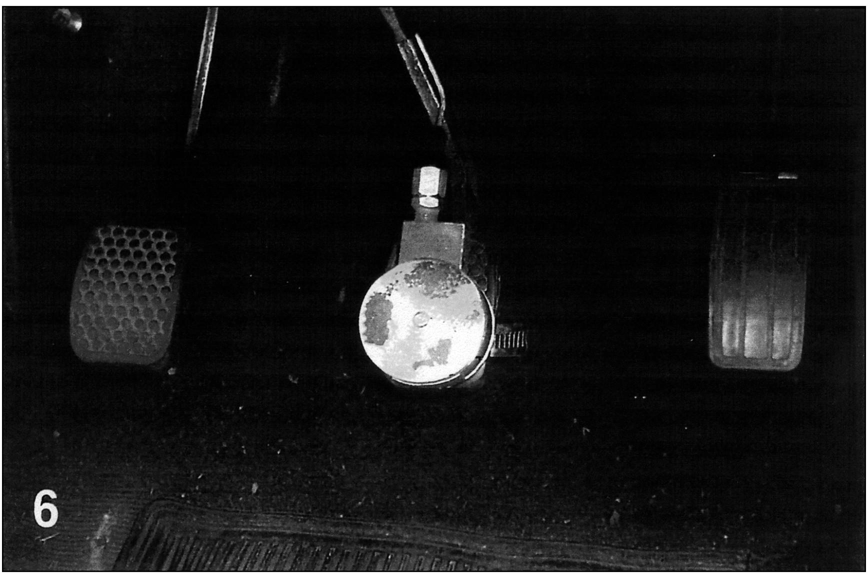


Instrumentation located at right front seat position



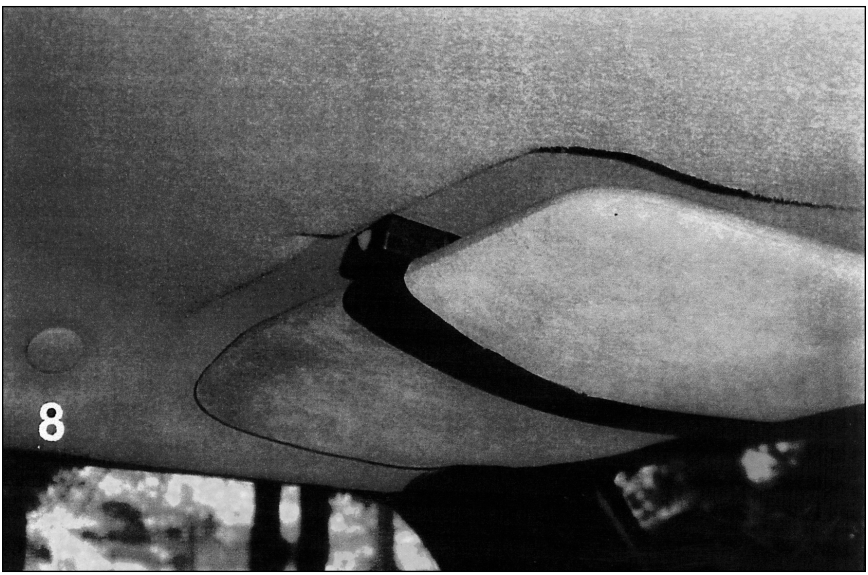


Instrumentation located in rear seat position



Foot brake transducer

Interior video camera



Sun visor mounted microphone