UM-HSRI-78-12-3

Appendices

IMPROVED PASSENGER CAR BRAKING PERFORMANCE

R.D. Ervin
J.D. Campbell
M. Sayers
H. Bunch

Contract Number DOT-HS-6-01368
Contract Amount: $193,655

March, 1978

Highway Safety Research Institute
The University of Michigan

Prepared for:

National Highway Traffic Safety Administration
U. S. Department of Transportation

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UM-HSRI-78-12-3		

4. Title and Subtitle	5. Report Date
IMPROVED PASSENGER CAR BRAKING PERFORMANCE Appendices	March 1978
	6. Performing Organization Code
7. Author(s) Ervin, R.D., Campbell, J.D. Sayers, M., and Bunch, H.	8. Performing Organization Report No. UM-HSRI-78-12-3
9. Performing Organization Name and Address Highway Safety Research Institute The University of Michigan Huron Parkway & Baxter Road Ann Arbor, Michigan 48109	10. Work Unit No. 11. Contract or Grant No. DOT-HS-6-01368
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration U. S. Department of Transportation Washington, D.C. 20590	13. Type of Report and Period Covered Final 6/76-2/78 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Test conditions were studied as candidates for extending the scope of the stopping distance requirements of FMVSS 105-75, "Hydraulic Brake Systems." Conditions of interest included low and split friction surfaces as well as straight-line braking and braking-in-a-turn maneuvers. Two large test programs were conducted and various analytical efforts were applied to the examination of the candidate test conditions and methods. Throughout all of the study activities, only stopping distance performance was taken as the measure for evaluating the utility of the candidate conditions and methods.

It was concluded that only the low friction, straight-line braking condition constitutes a viable extension of the stopping requirements of 105-75. It was also found that stopping distances in a turn do not differ significantly from stopping distances measured in straight-line braking. Further, stopping distances on split friction surfaces do not appear generally useful as characterizations of vehicle safety quality.

17. Key Words	18. Distribution Statement
friction, braking, split friction, vehicles, stopping distance, standards	UNLIMITED

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
NONE	NONE		

Prepared for the Department of Transportation,
National Highway Traffic Safety Administration
under Contract No. DOT-HS-01368. The opinions,
findings, and conclusions expressed in this
publication are those of the authors and not
necessarily those of the National Highway
Traffic Safety Administration.

TABLE OF CONTENTS

APPENDIX A

DATA FROM TWELVE CAR SURVEY TEST PROGRAM
VEHICLE DISCRIPTIONS AND DATA SUMMERIES.

VEHICLE INFORMATION SHEET

Vehicle:

Make: CHEVETTE — NHTSA No. —

Model: 2 DR. SEDAN — GVWR: 2790

Model Year: 1976 — Manufacture Date: 03/76

V.I.N.: 1B08E6Y223124 — Wheelbase: 94.3 IN

Engine Type: 4 CLY — Displacement: 98 in³ — Hp: 60

Engine Idle Speed: — — Engine Timing: —

Transmission: Type: AUTO — Speeds: 3

No. of Axles: 2 — Ratio(s) —

GAWR: Front: 1297 — Rear: 1493

Tires:

Size: P155/80D13 — Mfr: GOODYEAR

Type: 2 PLY POLYESTER MINI CUSTOM G8

Recommended Pressure at GVWR: 24 psi front

24 psi rear

Brakes:

Front: ( ) Drum (✓) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Rear: (✓) Drum ( ) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Variable Proportioning System: Yes ______ No ✓

Brake Power Assist Unit: Yes ______ No ✓

Brake Power Unit w/Accumulator: Yes ______ No ______

Power Assist or Power Unit w/Backup: Yes ______ No ______

Antiskid Device: Yes ______ No ✓

Parking Mechanism: (see definition) — Mfr — ; Yes ______ No ______

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated ( )

Nonservice Brake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ______________________

Wheel Cylinder Diameter: ______________________

Describe Hydraulic Circuit Split: ______________________

____

____

____

Will adjusters be locked out for this test series?

Yes ________ No ✓________

VEHICLE INFORMATION SHEET

Vehicle:

Make: PINTO — NHTSA No. —

Model: STN. WAG. — GVWR: 3923

Model Year: 1976 — Manufacture Date: 2/76

V.I.N.: 6X12Y208175 — Wheelbase: 94.8 IN.

Engine Type: 4 CYL. Displacement: 140 IN.^{3} Hp: 92

Engine Idle Speed: — Engine Timing: —

Transmission: Type: AUTO Speeds: 3

No. of Axles: 2 Ratio(s) —

GAWR: Front: 1833 Rear: 2140

Tires:

Size: B-78-13 Mfr: GOODYEAR

Type: POWER CUSTOM POLYESTER

Recommended Pressure at GVWR: 24 psi front

28 psi rear

Brakes:

Front: ( ) Drum (✓) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Rear: (✓) Drum ( ) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Variable Proportioning System: Yes ✓ No ______

Brake Power Assist Unit: Yes ______ No ✓

Brake Power Unit w/Accumulator: Yes ______ No ✓

Power Assist or Power Unit w/Backup: Yes ______ No ✓

Antiskid Device: Yes ______ No ✓

Parking Mechanism: (see definition) Mfr —

Yes ______ No ______

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated (✓)

Foot Operated ( )

Nonservice Brake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ____________

Wheel Cylinder Diameter: ____________

Describe Hydraulic Circuit Split: ____________

FRONT/REAR

Will adjusters be locked out for this test series?

Yes ______ No ✓

VEHICLE INFORMATION SHEET

Vehicle:

Make: AMC GREMLIN NHTSA No. —

Model: 2 DR. SEDAN GVWR: 3911

Model Year: 1976 Manufacture Date: 5/76

V.I.N.: A6A465C742485 Wheelbase: 96.0 IN

Engine Type: 6 CYL. Displacement: 258 IN^3 Hp: 95

Engine Idle Speed: — Engine Timing: —

Transmission: Type: AUTO Speeds: 3

No. of Axles: 2 Ratio(s) —

GAWR: Front: 2076 Rear: 1836

Tires:

Size: 6.95-14 Mfr: FIRESTONE

Type: DELUXE CHAMPION POLYESTER

Recommended Pressure at GVWR: 24 psi front

24 psi rear

Brakes:

Front: ( ) Drum (✓) Disc Diam: ____

( ) Bonded ( ) Riveted

Friction Surface Width: ____ Length: ____

Rear: (✓) Drum ( ) Disc Diam: ____

( ) Bonded ( ) Riveted

Friction Surface Width: ____ Length: ____

Variable Proportioning System: Yes ____ No ✓

Brake Power Assist Unit: Yes ____ No ✓

Brake Power Unit w/Accumulator: Yes ____ No ✓

Power Assist or Power Unit w/Backup: Yes ____ No ✓

Antiskid Device: Yes ____ No ✓

Parking Mechanism: (see definition) Mfr —

Yes ____ No ____

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated ( )

Nonservice Brake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ____________________

Wheel Cylinder Diameter: ____________________

Describe Hydraulic Circuit Split: ____________________

FRONT/REAR ____________________

____

____

Will adjusters be locked out for this test series?

Yes ________ No ✓

VEHICLE INFORMATION SHEET

Vehicle: Make: NOVA NHTSA No. —

Model: 2 DR. SEDAN GVWR: 4604

Model Year: 1976 Manufacture Date: 3/76

V.I.N.: 1X27D6W185015 Wheelbase: 111.0 IN

Engine Type: 6 CYL Displacement: 250 IN^3 Hp: 105

Engine Idle Speed: — Engine Timing: —

Transmission: Type: AUTO Speeds: 3

No. of Axles: 2 Ratio(s) —

GAWR: Front: 2132 Rear: 2472

Tires: Size: FR-78-14 Mfr: UNIROYAL

Type: STEEL BELTED RADIAL

Recommended Pressure at GVWR: 24 psi front

24 psi rear

Brakes: Front: ( ) Drum (✓) Disc Diam: ____

( ) Bonded ( ) Riveted

Friction Surface Width: ____ Length: ____

Rear: (✓) Drum ( ) Disc Diam: ____

( ) Bonded ( ) Riveted

Friction Surface Width: ____ Length: ____

Variable Proportioning System: Yes ✓ No ____

Brake Power Assist Unit: Yes ____ No ✓

Brake Power Unit w/Accumulator: Yes ____ No ✓

Power Assist or Power Unit w/Backup: Yes ____ No ✓

Antiskid Device: Yes ____ No ✓

Parking Mechanism: (see definition) Mfr —
Yes ____ No ____

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated (✓)

Nonservice Brake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ____________________

Wheel Cylinder Diameter: ____________________

Describe Hydraulic Circuit Split: ____________________

FRONT/REAR

Will adjusters be locked out for this test series?

Yes ________ No ✓

VEHICLE INFORMATION SHEET

Vehicle:
- Make: AMC PACER — NHTSA No. —
- Model: 2 DR. SEDAN — GVWR: 4378
- Model Year: 1976 — Manufacture Date: 1/76
- V.I.N.: A6A667C271877 — Wheelbase: 100.0 IN.
- Engine Type: 6 CYL. Displacement: $258 IN^3$ Hp: 98
- Engine Idle Speed: — Engine Timing: —
- Transmission: Type: AUTO Speeds: 3
- No. of Axles: 2 Ratio(s) —
- GAWR: Front: 2166 Rear: 2214

Tires:
- Size: 6.95-14 Mfr: GOODYEAR
- Type: POWER CUSHION POLYESTER
- Recommended Pressure at GVWR: 26 psi front
- 24 psi rear

Brakes:
- Front: ( ) Drum (✓) Disc Diam: ____
  - ( ) Bonded ( ) Riveted
  - Friction Surface Width: ____ Length: ____
- Rear: (✓) Drum ( ) Disc Diam: ____
  - ( ) Bonded ( ) Riveted
  - Friction Surface Width: ____ Length: ____
- Variable Proportioning System: Yes ____ No ✓
- Brake Power Assist Unit: Yes ____ No ✓
- Brake Power Unit W/Accumulator: Yes ____ No ✓
- Power Assist or Power Unit W/Backup: Yes ____ No ✓
- Antiskid Device: Yes ____ No ✓
- Parking Mechanism: (see definition) Mfr — Yes ____ No ____

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated ( )

Nonservice Drake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ____________________

Wheel Cylinder Diameter: ____________________

Describe Hydraulic Circuit Split: ____________________

FRONT/REAR

____

____

Will adjusters be locked out for this test series?

Yes ________ No ✓

VEHICLE INFORMATION SHEET

Vehicle: Make: VOLVO 244DL NHTSA No. —

Model: 4 DR. SEDAN GVWR: 4030

Model Year: 1976 Manufacture Date: 9-75

V.I.N.: VC2445E2092348 Wheelbase: ______

Engine Type: 4 CYL. Displacement: ______ Hp: ______

Engine Idle Speed: — Engine Timing: —

Transmission: Type: AUTO Speeds: 3 ?

No. of Axles: 2 Ratio(s) —

GAWR: Front: 1885 Rear: 2180

Tires: Size: 175-14 Mfr: MICHELIN

Type: RADIAL

Recommended Pressure at GVWR: 26 psi front

28 psi rear

Brakes: Front: ( ) Drum (✓) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Rear: ( ) Drum (✓) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Variable Proportioning System: Yes ✓ No ______

Brake Power Assist Unit: Yes ✓ No ______

Brake Power Unit w/Accumulator: Yes ______ No ✓

Power Assist or Power Unit W/Backup: Yes ______ No ✓

Antiskid Device: Yes ______ No ✓

Parking Mechanism: (see definition) Mfr —

Yes ______ No ______

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated ( )

Nonservice Drake Type Parking Brake: Hand Operated (✓)

Foot Operated ( )

Master Cylinder Diameter: ____________________

Wheel Cylinder Diameter: ____________________

Describe Hydraulic Circuit Split: ____________________

TRIANGLE SPLIT

Will adjusters be locked out for this test series?

Yes ________ No ✓

VEHICLE INFORMATION SHEET

Vehicle:

Make: MONTE CARLO — NHTSA No. —

Model: 2 DR. SPORT COUPE — GVWR: 5587

Model Year: 1976 — Manufacture Date: 7/76

V.I.N.: 1H57U6150529S — Wheelbase: 116 IN.

Engine Type: V-8 — Displacement: 400 IN.^{3} — Hp: 175

Engine Idle Speed: — — Engine Timing: —

Transmission: Type: AUTO — Speeds: 3

No. of Axles: 2 — Ratio(s) —

GAWR: Front: 2749 — Rear: 2838

Tires:

Size: GR70-15 — Mfr: UNIROYAL

Type: STEEL BELTED RADIAL

Recommended Pressure at GVWR: 28 psi front

28 psi rear

Brakes:

Front: ( ) Drum (✓) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Rear: (✓) Drum ( ) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Variable Proportioning System: Yes ✓ No ______

Brake Power Assist Unit: Yes ✓ No ______

Brake Power Unit w/Accumulator: Yes ______ No ✓

Power Assist or Power Unit w/Backup: Yes ______ No ✓

Antiskid Device: Yes ______ No ✓

Parking Mechanism: (see definition) Mfr —

Yes ______ No ______

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated (✓)

Nonservice Drake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ____________________

Wheel Cylinder Diameter: ____________________

Describe Hydraulic Circuit Split: ____________________

FRONT/REAR

____

____

Will adjusters be locked out for this test series?

Yes ________ No ✓

VEHICLE INFORMATION SHEET

Vehicle:

Make: PLYMOUTH FURY — NHTSA No. —

Model: 4 DR. SEDAN — GVWR: 5750

Model Year: 1977 — Manufacture Date: 9/76

V.I.N.: R14IN7A119804 — Wheelbase: 117.4

Engine Type: V-8 — Displacement: 360 IN^3 — Hp: 155

Engine Idle Speed: — — Engine Timing: —

Transmission: Type: AUTO — Speeds: 3

No. of Axles: 2 — Ratio(s) —

GAWR: Front: 2855 — Rear: 2945

Tires:

Size: GR70-15 — Mfr: GOODYEAR

Type: CUSTOM STEELGARD

Recommended Pressure at GVWR: 26 psi front

26 psi rear

Brakes:

Front: ( ) Drum (✓) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Rear: (✓) Drum ( ) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Variable Proportioning System: Yes ✓ No ______

Brake Power Assist Unit: Yes ✓ No ______

Brake Power Unit w/Accumulator: Yes ______ No ✓

Power Assist or Power Unit W/Backup: Yes ______ No ✓

Antiskid Device: Yes ______ No ✓

Parking Mechanism: (see definition) Mfr ______ Yes ______ No ______

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated (✓)

Nonservice Brake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ______________________

Wheel Cylinder Diameter: ______________________

Describe Hydraulic Circuit Split: ______________________

FRONT/REAR

____

____

Will adjusters be locked out for this test series?

Yes ________ No ✓

VEHICLE INFORMATION SHEET

Vehicle: Make: FORD TORINO NHTSA No. —

Model: 4 DR. SEDAN GVWR: 5957

Model Year: 1976 Manufacture Date: 3/76

V.I.N.: 6H25H167254 Wheelbase: 118.0 IN

Engine Type: V-8 Displacement: 351 IN³ Hp: 154

Engine Idle Speed: — Engine Timing: —

Transmission: Type: AUTO Speeds: 3

No. of Axles: 2 Ratio(s) —

GAWR: Front: 3016 Rear: 2991

Tires: Size: HR-78-14 Mfr: UNIROYAL

Type: STEEL BELTED RADIAL

Recommended Pressure at GVWR: 24 psi front

24 psi rear

Brakes: Front: ( ) Drum (✓) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Rear: (✓) Drum ( ) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Variable Proportioning System: Yes ✓ No ______

Brake Power Assist Unit: Yes ✓ No ______

Brake Power Unit w/Accumulator: Yes ______ No ✓

Power Assist or Power Unit w/Backup: Yes ______ No ✓

Antiskid Device: Yes ______ No ✓

Parking Mechanism: (see definition) Mfr —

Yes ______ No ______

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated ( )

Nonservice Brake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ______________

Wheel Cylinder Diameter: ______________

Describe Hydraulic Circuit Split: ______________

FRONT/REAR

Will adjusters be locked out for this test series?

Yes ______ No ✓

VEHICLE INFORMATION SHEET

Vehicle: Make: BUICK LESABRE NHTSA No. —

Model: 2 DR SEDAN GVWR: 6140

Model Year: 1976 Manufacture Date: 3/76

V.I.N.: 4P69J6H519155 Wheelbase: 124 IN.

Engine Type: V-8 Displacement: 350 $IN.^3$ Hp: 155

Engine Idle Speed: — Engine Timing: —

Transmission: Type: AUTO Speeds: 3

No. of Axles: 2 Ratio(s) —

GAWR: Front: 2984 Rear: 3156

Tires: Size: HR-78-15 Mfr: UNIROYAL

Type: STEEL BELTED RADIAL

Recommended Pressure at GVWR: 24 psi front

24 psi rear

Brakes: Front: ( ) Drum (✓) Disc Diam: ____

( ) Bonded ( ) Riveted

Friction Surface Width: ____ Length: ____

Rear: (✓) Drum ( ) Disc Diam: ____

( ) Bonded ( ) Riveted

Friction Surface Width: ____ Length: ____

Variable Proportioning System: Yes ✓ No ____

Brake Power Assist Unit: Yes ✓ No ____

Brake Power Unit w/Accumulator: Yes ____ No ✓

Power Assist or Power Unit W/Backup: Yes ____ No ✓

Antiskid Device: Yes ____ No ✓

Parking Mechanism: (see definition) Mfr — Yes ____ No ____

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated (✓)

Nonservice Brake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ____________________

Wheel Cylinder Diameter: ____________________

Describe Hydraulic Circuit Split: ____________________

FRONT / REAR

Will adjusters be locked out for this test series?

Yes ________ No ✓

VEHICLE INFORMATION SHEET

Vehicle:

- Make: FORD LTD
- NHTSA No. —
- Model: 4 DR SEDAN
- GVWR: 6384
- Model Year: 1976
- Manufacture Date: 3/76
- V.I.N.: 6B63H194520
- Wheelbase: 121.0 IN.
- Engine Type: V-8
- Displacement: 351 IN.^{3}
- Hp: 152
- Engine Idle Speed: —
- Engine Timing: —
- Transmission: Type: AUTO
- Speeds: 3
- No. of Axles: 2
- Ratio(s): —
- GAWR: Front: 3177
- Rear: 3266

Tires:

- Size: HR-78-15
- Mfr: UNIROYAL
- Type: STEEL BELTED RADIAL
- Recommended Pressure at GVWR: 26 psi front; 28 psi rear

Brakes:

- Front: ( ) Drum (✓) Disc Diam: ______
- ( ) Bonded ( ) Riveted
- Friction Surface Width: ______ Length: ______
- Rear: (✓) Drum ( ) Disc Diam: ______
- ( ) Bonded ( ) Riveted
- Friction Surface Width: ______ Length: ______
- Variable Proportioning System: Yes ✓ No ______
- Brake Power Assist Unit: Yes ✓ No ______
- Brake Power Unit w/Accumulator: Yes ______ No ✓
- Power Assist or Power Unit w/Backup: Yes ______ No ✓
- Antiskid Device: Yes ______ No ✓
- Parking Mechanism: (see definition) Mfr —; Yes ______ No ______

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated (✓)

Nonservice Brake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ______________________

Wheel Cylinder Diameter: ______________________

Describe Hydraulic Circuit Split: ______________________

FRONT/REAR

____

____

Will adjusters be locked out for this test series?

Yes ________ No ✓

VEHICLE INFORMATION SHEET

Vehicle:

Make: DODGE MONACO — NHTSA No. —

Model: 4 DR SEDAN — GVWR: 6265

Model Year: 1977 — Manufacture Date: 6-76

V.I.N.: DH41K6D213815 — Wheelbase: 117.4 IN

Engine Type: V-8 — Displacement: 360 IN^3 — Hp: 155

Engine Idle Speed: — — Engine Timing: —

Transmission: Type: AUTO — Speeds: 3

No. of Axles: 2 — Ratio(s) —

GAWR: Front: 3055 — Rear: 3260

Tires:

Size: HR-78-15 — Mfr: MICHELIN

Type: STEEL BELTED RADIAL

Recommended Pressure at GVWR: 30 psi front

30 psi rear

Brakes:

Front: ( ) Drum (✓) Disc Diam: ____

( ) Bonded ( ) Riveted

Friction Surface Width: ____ Length: ____

Rear: (✓) Drum ( ) Disc Diam: ____

( ) Bonded ( ) Riveted

Friction Surface Width: ____ Length: ____

Variable Proportioning System: Yes ✓ No ____

Brake Power Assist Unit: Yes ✓ No ____

Brake Power Unit w/Accumulator: Yes ____ No ✓

Power Assist or Power Unit w/Backup: Yes ____ No ✓

Antiskid Device: Yes ____ No ✓

Parking Mechanism: (see definition) Mfr —
Yes ____ No ____

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated (✓)

Nonservice Brake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ______________________

Wheel Cylinder Diameter: ______________________

Describe Hydraulic Circuit Split: ______________________

FRONT/REAR

Will adjusters be locked out for this test series?

Yes ________ No ✓

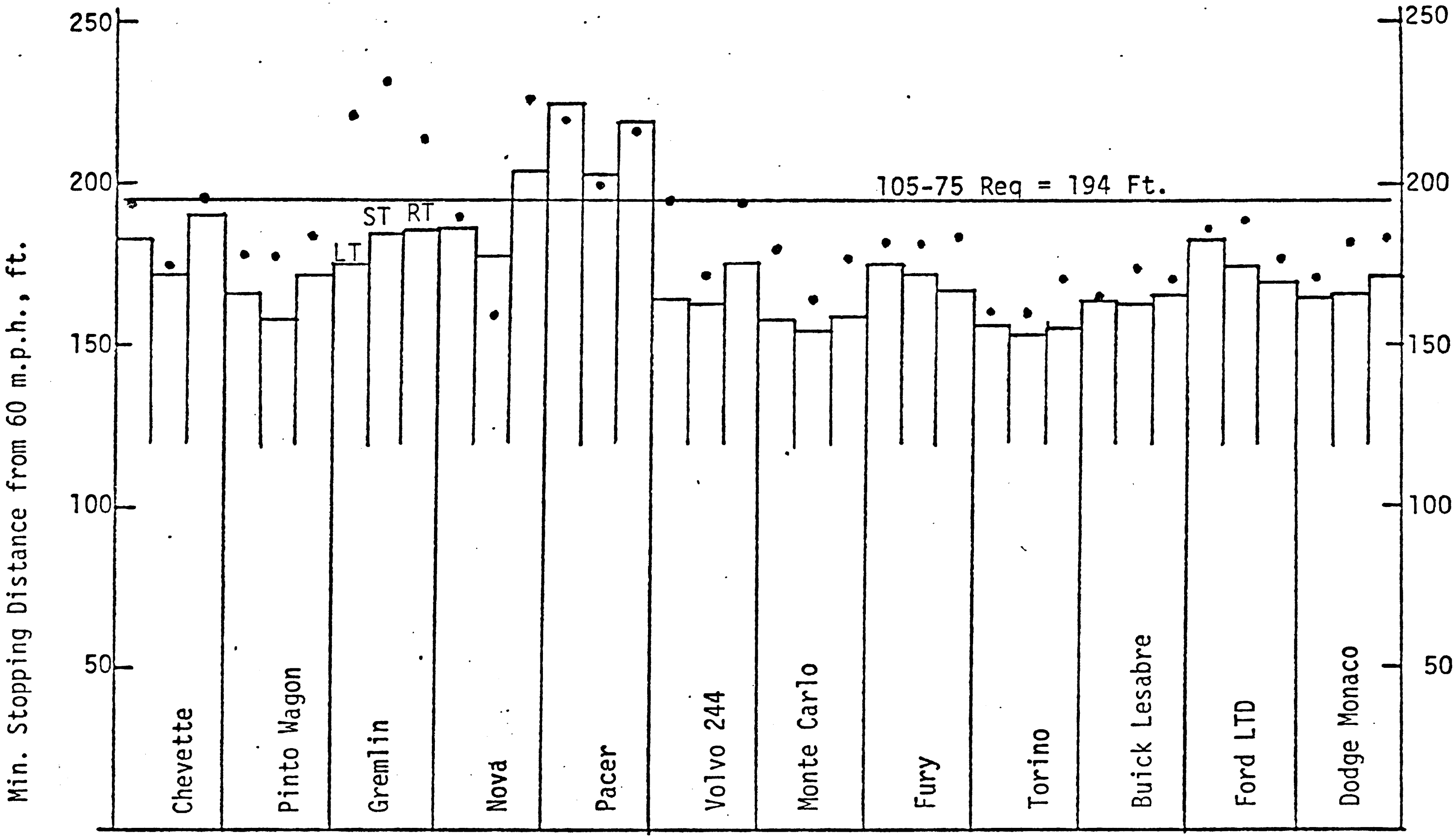


FIGURE A.1. Minimum stopping distances with brake force machine control (bar chart) and for driver best effort (dots). Straight and left and right turning stops from 60 m.p.h. on dry brushed concrete. Initial lateral acceleration 0.3g. Turn radius 801 feet.

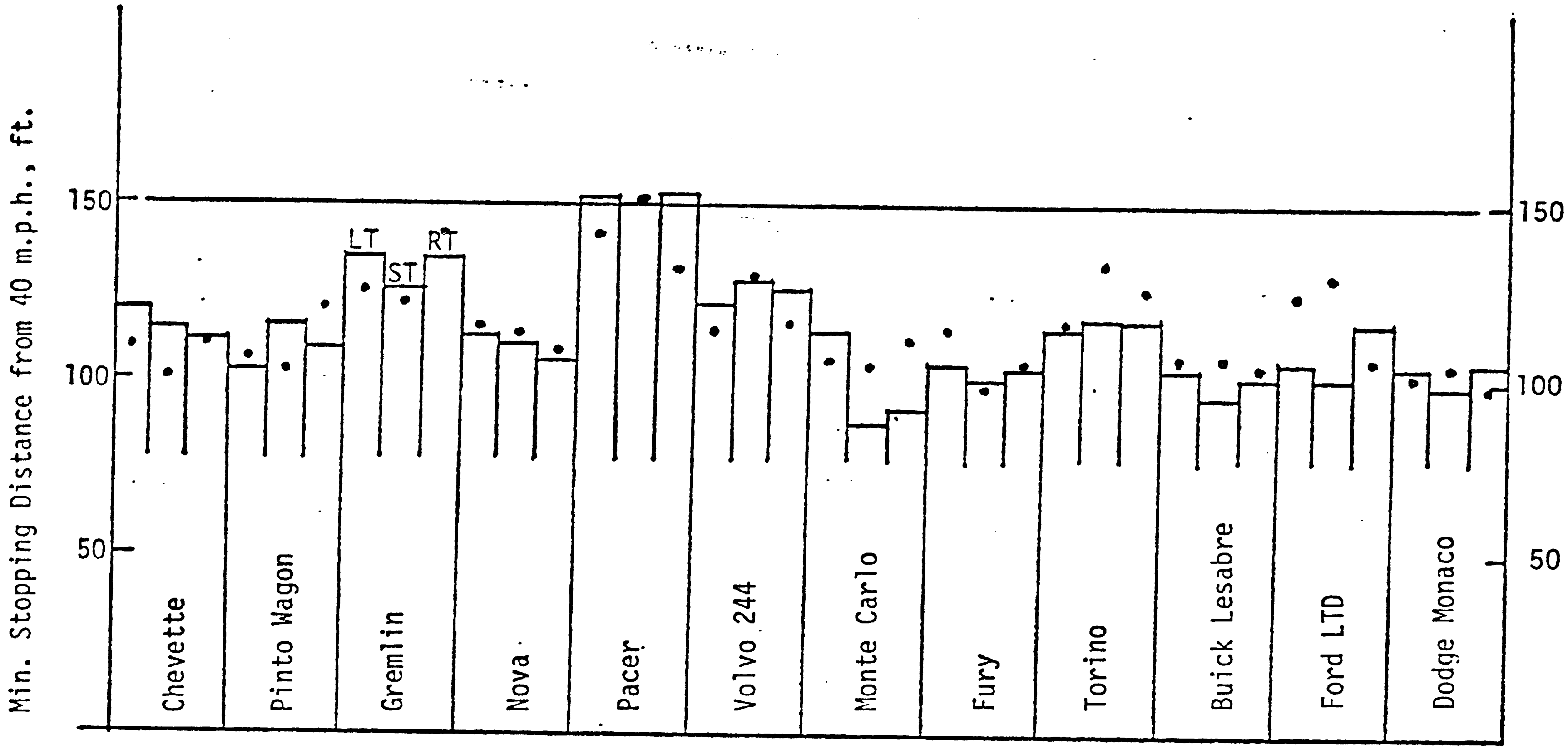


FIGURE A.2. Minimum stopping distance with brake force machine control (bar chart) and for driver best effort (dots). Straight and left and right turing stops from 40 m.p.h. on wet jennite. Initial lateral acceleration, 0.2g. Turn radius 801 feet.

An Experimental Measure of Stopping Distance vs. Brake Pressure Build Up Time.

A brief experiment was conducted with the 1977 Dodge Monaco to observe the change in stopping distance from 40 m.p.h. on wet jennite vs. brake line pressure build up time. Figure A.3. shows the result. Stopping distance is seen to increase linearly with increasing pressure build up time with a slope of about 42 feet/second.

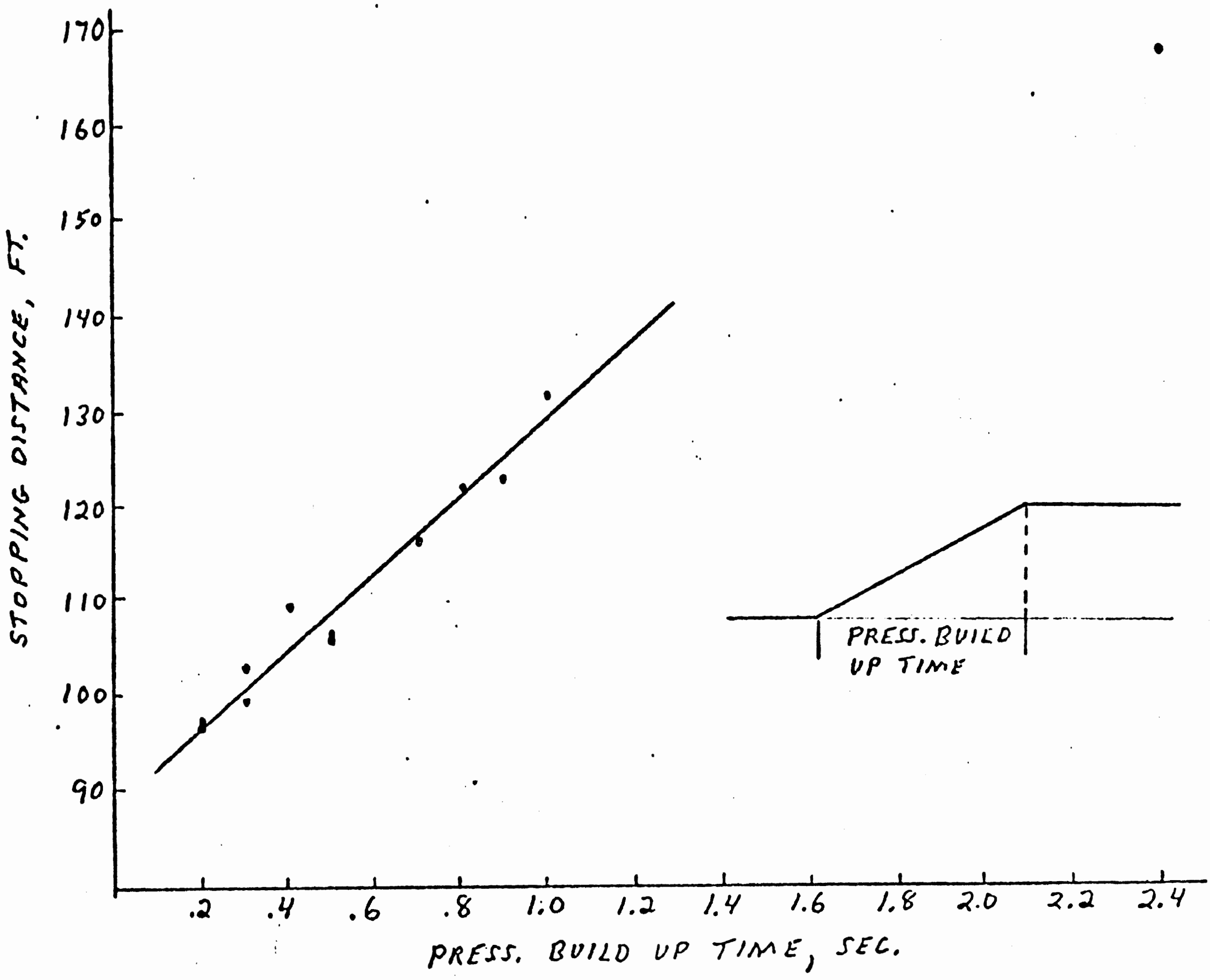


Figure A.3. Stopping Distance vs. Master Cylinder Pressure Build up Ramp Time. 1976 Dodge Monaco. Initial Velocity = 40 m.p.h. Wet Jennite Surface.

Table A.1. Minimum Stopping Distances on Dry Concrete, Straight Line and In-A-Turn. Initial Velocity = 60 m.p.h. Turn Radius = 801 feet. Initial Lateral Acceleration = 0.3g. Surface Skid No. SN_{40} = 80. Nominal Peak Friction = 0.95.

VEHICLE	STRAIGHT	LEFT TURN	RIGHT TURN	TURN AVERAGE
Chevette	171 ft.	183 ft.	190 ft.	186 ft.
Pinto Wagon	157	166	171	169
Gremlin	184	174	185	179
Nova	177	186	203	194
Pacer	202	225	219	222
Volvo 244	162	164	174	169
Monte Carlo	154	158	159	158
Fury	171	175	167	171
Torino	152	156	154	155
Buick Lesabre	162	163	166	164
Ford LTD	173	182	169	175
Dodge Monaco	165	164	171	167

Table A.2. Minimum Stopping Distances on Wet Jennite, Straight Line and In-A-Turn. Initial Velocity = 40 m.p.h. Turn Radius = 535 feet. Initial Lateral Acceleration = 0.2g. Surfact Skid No. SN = 30. Nominal Peak Friction = 0.70.

VEHICLE	STRAIGHT	LEFT TURN	RIGHT TURN	TURN AVERAGE
Chevette	114 ft.	120 ft.	111 ft.	115 ft.
Pinto Wagon	116	102	109	105
Gremlin	125	134	134	134
Nova	110	112	106	109
Pacer	150	151	152	151
Volvo 244	129	122	126	124
Monte Carlo	87	114	91	102
Fury	100	105	103	104
Torino	117	114	117	115
Buick Lesabre	95	102	100	101
Ford LTD	100	105	116	110
Dodge Monaco	98	103	105	104

Table A.3. Differences Between Left and Right Turning Stopping Distances on High Coefficient (Dry Concrete) and Low Coefficient (Wet Jennite) Surfaces.

VEHICLE	HIGH COEFFICIENT DIFFERENCE FEET (%)		LOW COEFFICIENT DIFFERENCE FEET (%)	
Chevette	7	(3.8)	9*	(8.1)
Pinto Wagon	5	(3.0)	7	(6.9)
Gremlin	11	(6.3)	0	(0.0)
Nova	17	(9.1)	6*	(5.7)
Pacer	6*	(2.7)	1	(0.6)
Volvo 244	10	(6.1)	4	(3.3)
Small Car Average	9.3 ft.	(5.2)	4.5 ft.	(4.1)
Monte Carlo	1	(0.6)	23*	(25.)
Fury	8*	(4.8)	2*	(1.9)
Torino	2*	(1.2)	3	(2.6)
Buick Lesabre	3	(1.8)	2*	(2.0)
Ford LTD	13*	(7.7)	11	(10.)
Dodge Monaco	7	(4.3)	2	(1.9)
Large Car Average	5.6 ft.	(3.4)	7.1 ft.	(7.3)
Overall Average	7.5 ft	(4.3)	5.8 ft.	(5.7)

* Right Turning Stopping Distance Shorter Than Left Turning Stopping Distance.

Table A.4. Differences Between Straight Line and Braking-In-A-Turn Stopping Distances on High Coefficient (Dry Concrete) and Low coefficient (Wet Jennite) Surfaces.

VEHICLE	HIGH COEFFICIENT DIFFERENCE FEET	(%)	LOW COEFFICIENT DIFFERENCE FEET	(%)
Chevette	15	(8.8)	1	(0.9)
Pinto Wagon	12	(7.6)	11*	(9.4)
Gremlin	5*	(2.7)	9	(7.2)
Nova	17	(9.6)	1*	(0.9)
Pacer	20	(9.9)	1	(0.7)
Volvo 244	7	(4.3)	5*	(3.9)
Small Car Average	12.7 ft.	(7.2)	4.7 ft.	(3.8)
Monte Carlo	4	(2.6)	15	(17.2)
Fury	0	(0.0)	4	(4.0)
Torino	3	(2.0)	2*	(1.7)
Buick Lesabre	2	(1.2)	6	(6.3)
Ford LTD	2	(1.2)	10	(10.0)
Dodge Monaco	2	(1.2)	6	(6.1)
Large Car Average	2.2 ft.	(1.4)	7.2 ft.	(7.6)
Overall Average	7.4 ft.	(4.3)	5.9 ft.	(5.7)

* In-A-Turn Stopping Distance Shorter Than Straight Line Stopping Distance.

Table A.5. Repeatability of Experimental Stopping Distance Measurements Expressed as the Percentage Difference Over Three Stops Made at the Same Pedal Force.

VEHICLE	HIGH COEFFICIENT			LOW COEFFICIENT		
	ST	LT	RT	ST	LT	RT
Chevette	2.4	3.8	5.8	2.6	5.0	5.4
Pinto Wagon	4.5	6.0	2.9	6.0	15.7	9.2
Gremlin	2.2	7.5	7.6	6.4	4.5	2.2
Nova	7.3	1.6	4.4	6.4	4.5	12.3
Pacer	1.5	4.9	4.1	5.3	10.0	5.9
Volvo 244	1.9	6.1	3.4	6.2	4.9	7.1
Small Car Average	3.3%	5.0%	4.7%	5.5%	7.4%	7.0%
Monte Carlo	4.5	3.8	8.8	1.1	4.4	12.0
Fury	1.2	3.4	0.6	5.0	2.9	3.9
Torino	2.0	1.3	6.5	5.1	2.6	11.1
Buick Lesabre	5.6	7.4	4.2	4.2	8.8	12.0
Ford LTD	3.5	1.6	4.7	12.0	4.8	2.6
Dodge Monaco	3.0	1.8	4.7	2.0	1.9	1.9
Large Car Average	3.3%	3.2%	4.9%	4.9%	4.2%	7.2%
Overall Average	3.3%	4.1%	4.8%	5.2%	5.8%	7.1%

Average High Coefficient	Average Low Coefficient
4.1%	6.0%

Surface Friction Dynamometer Calibration Check

The load cell in the Surface Friction Dynamometer provides for measurement of the vertical tire load, F_z, and the longitudinal force, F_x, exerted at the tire/road interface. Calibration of the SFD load cell was checked by applying input forces through a calibrated reference load cell and recording both the reference cell output and the SFD load cell output. The results are tabulated in Tables A.6 through A.8.

Table A.6. SFD Loan Cell Calibration Check October 12, 1976. F_z Calibration, F_x Offset (Cross Talk) Due to F_z at F_x = 0.

REFERENCE LOAD CELL OUTPUT, F_z	SFD LOAD CELL OUTPUT F_z	F_x
0 lbs.	0 lbs.	0 lbs.
341	340	6
478	481	7
510	512	8
560	562	10
700	703	14
852	856	17
1,000	1,003	20
1,200	1,204	24
1,402	1,404	30
1,603	1,604	35
1,810	1,809	39
1,995	1,991	42
1,807	1,805	39
1,600	1,600	35
1,394	1,395	30
1,198	1,203	26
1,000	1,004	22
795	799	17
602	605	13
549	550	13
499	502	11
450	451	10
397	398	9
0	0	0

Table A.7. SFD Load Cell Calibration Check October 12, 1976. F_X Calibration, F_Z Offset (cross Talk) Due to F_X at $F_Z = 0$. F_X Applied Through Center Line of the Load Cell.

REFERENCE LOAD CELL OUTPUT, F_X	SFD LOAD CELL OUTPUT F_X	SFD LOAD CELL OUTPUT F_Z
0 lbs.	0 lbs.	0 lbs.
180	180	7
316	314	11
512	506	16
783	777	23
1,074	1,065	32
1,356	1,346	40
1,600	1,589	48
1,810	1,800	56
1,530	1,520	45
1,220	1,214	38
952	938	29
812	810	24
460	462	15
227	229	9
1	1	3

Table A.8. SFD Loan Cell Calibration Check October 12, 1976. F_X Calibration, F_Z Offset (Cross Talk) Due to F_X at F_Z = 0. F_X Applied at Approximately 12 Inches from Cell Center Line.

REFERENCE LOAD CELL OUTPUT, F_X	SFD LOAD CELL OUTPUT F_X	F_Z
0 lbs.	0 lbs.	0 lbs.
90	86	0
289	283	1
646	637	3
966	957	1
1,110	1,106	2

APPENDIX B

CALCULATED RESULTS OF A QUASI-STATIC ANALYSIS

The purpose of this appendix is to document the quasi-static analysis of straight- and curved-path braking which was conducted for this study. The intent of the analysis was to observe the behavior of an automobile with conventional brakes (no antilock systems) while braking under a broad range of conditions. These conditions include loaded and unloaded vehicles, surfaces having high and low friction characteristics, as well as different friction levels on the right- and left-hand sides of the vehicle (that is, the split friction condition), and finally, the lateral acceleration condition which is present at the initiation of a braking-in-a-turn maneuver.

Since only the first-order effects were desired, the number of parameters needed to describe the maneuvers was kept as small as possible. The parameters which were required are all listed and defined in Table B.1.

The maximum braking force which can be applied before a wheel locks is constrained by the peak traction coefficient, designated μ_p. If lockup occurs, the braking force is limited to the product of the normal force and the sliding traction coefficient, μ_s. On split coefficient surfaces, of course, the values of μ_p and μ_s will differ between the right- and left-hand sides of the car.

This simple model of the tire traction constraints, together with a purely kinematic representation of the vehicle itself utilizing the remaining parameters in Table B.1, allows a first-order look into the sensitivity of braking performance to the described condition variables.

Table B.1. Vehicle Parameter Definitions

μ_{p1}	Peak traction coefficient on left side of car
μ_{s1}	Sliding traction coefficient on left side of car
μ_{p2}	Peak traction coefficient on right side of car
μ_{s2}	Sliding traction coefficient on right side of car
A/L	Fraction of wheelbase in front of vehicle mass center
H/L	Ratio of mass center height to wheelbase
H/W	Ratio of mass center height to track width
P	Fraction of total braking torque which acts on front axle
C_ϕ	Fraction of lateral load transfer that occurs on the front axle
A_y	Constant lateral acceleration

B.1 Describing Equations

The different wheels are identified by the subscripts RF, LF, LR, and RR, which represent right front, left front, left rear, and right rear, respectively. Since none of the parameters depend upon absolute force levels, it is convenient to normalize all forces to the weight of the automobile.

Upon initiating the calculation sequence, a braking force, proportional to brake torque, is assumed for the RF wheel. The actual braking forces are calculated according to the relations

$$\left.\begin{aligned} F_{BLF} &= F_{BRF} = F'_F \\ F_{BRR} &= F_{BLR} = F'_R = F'_F\left(\frac{1}{p} - 1\right) \end{aligned}\right\} F'_j \leq \mu_p F_{zi} \qquad \text{(B.1)}$$

$$F_{Bi} = \mu_s F_{zi} \qquad \Big\} F'_j > \mu_p F_{zi} \qquad \text{(B.2)}$$

$$i = RF \ldots RR$$
$$j = F, R$$

where F_{zi} refers to the loading at wheel i. The deceleration in g's is then:

$$A_x = \Sigma F_{Bi} \qquad i = RF \ldots RR \qquad \text{(B.3)}$$

The normal loads, used in Equations (B.1) and (B.2), are calculated by summing the pertinent component of static weight distribution, the load transfer due to longitudinal deceleration, and the load transfer due to lateral acceleration. The static, longitudinally-transferred and laterally-transferred load quantities are are given by Equations (B.4), (B.5), and (B.6).

$$C_1 = A_x \cdot H/L + 1 - A/L \tag{B.4}$$

$$C_F = A_y \cdot C_\phi \cdot H/W \tag{B.5}$$

$$C_R = A_y \cdot (1-C_\phi) \cdot H/W \tag{B.6}$$

Individual wheel loads then are expressed by:

$$F_{zRF} = C_F + \frac{1}{2} C_1 \tag{B.7}$$

$$F_{zLF} = -C_F + \frac{1}{2} C_1 \tag{B.8}$$

$$F_{zLR} = -C_R + \frac{1}{2} (1-C_1) \tag{B.9}$$

$$F_{zRR} = C_R + \frac{1}{2} (1-C_1). \tag{B.10}$$

(Note: C_1 must be between 0 and 1. If Equation (B.4) gives a value greater than 1, the value 1 is used. Also, none of the normal forces can be negative. If any of Equations (B.7)-(B.10) do give a negative value, 0 is used instead and the normal load on the other axle is adjusted to C_1 for the front axle or $(1-C_1)$ for the rear.)

The vehicle deceleration can be computed by combining Equations (B.1)-(B.10) for any selected F_F' (front braking force proportional to torque). Stopping distance may also be calculated, as

$$x = \frac{V^2}{2A_x \cdot g} \tag{B.11}$$

where V is the initial velocity and g is a gravitational constant.

B.2 Computational Procedure

The braking deceleration, defined by Equations (B.1)-(B.10), involves eight unknowns (the four normal and four braking forces) which can be calculated by the numerical method summarized as follows:

1) Select F_F' value small enough that no lockup will occur.

2) Calculate trial braking forces on each tire, based on F_F'.

3) Calculate the four normal forces.

4) Check the ratio of braking force to normal force for each wheel, for comparison with frictional limits. Change the braking forces to the sliding limit if peak traction has been exceeded.

5) If any changes were made in (4), go back to (3) and repeat. Otherwise, check for axle lockup. If there is no axle lockup, increment F_F' and go to (2). If an axle has locked up, output best performance, defined by maximum deceleration.

This procedure was followed with the aid of a digital computer.

Braking performance results are represented in this study by braking efficiency (BE) which is calculated according to the relationship

$$BE = \frac{A_x}{A_{xmax}} \times 100 \qquad (B.12)$$

where A_{xmax} is the maximum deceleration of which a vehicle is capable in straight-line braking, with "optimal" proportioning for the surface being considered. One hundred percent efficiency is realized under a single coefficient surface condition when the front/rear proportioning is set so that the front and rear axles are both on the verge of lockup. The deceleration then is simply

$$A_{xmax} = \mu_p \tag{B.13}$$

The 100% efficiency condition is not so easily calculated on a split coefficient surface, where optimal braking may involve the locking of one, two (not on the same axle), or no wheels. A_{xmax} is therefore found by incrementally varying p from 0 to 1 and noting the largest value of A_x encountered. This value is then used as the normalizing deceleration, A_{xmax}.

B.3 Study of Braking Efficiency Sensitivities

Due to the lack of a loading sensitivity in the assumed tire/road friction properties, the vehicle weight and wheelbase are not needed, and therefore all of the parameters listed in Table B.1 are dimensionless. Two distinct sets of baseline parameter values were chosen to be representative of basic car geometries, and are given in Table B.2. Car Number 1 is typical of most compact and subcompacts where the engine is the most significant component determining center-of-gravity location. Due to shorter wheelbase and narrower width, the vehicle exhibits high values of the load transfer gains, H/L and H/W. The opposite tendencies are apparent in the values selected for Car Number 2: the center of gravity is located slightly behind the center of the wheelbase, and the reaction to external accelerations is not so pronounced.

Differences between loaded and unloaded conditions are not directly evidenced in the parameter values shown. However, when limited by the assumptions made in this analysis, the only change between a driver-only and GVW condition involves the value of A/L.

In the calculations to be reported here, the interest was in examining the significance, over many braking conditions, of a fixed selection of brake proportioning. Clearly, this is the problem which has traditionally confronted the brake engineer. This examination was implemented, however, through a numerical calculation scheme

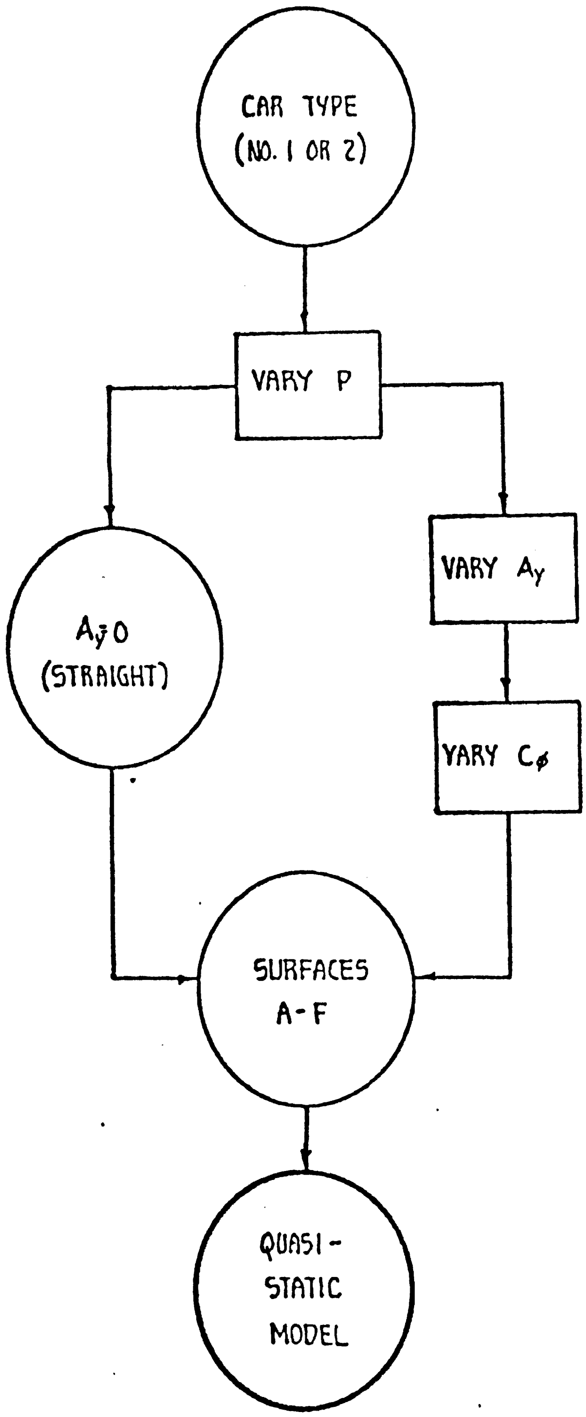

CAR TYPE
(NO. 1 OR 2)
VARY P
$A_y = 0$
(STRAIGHT)
VARY A_y
VARY C_ϕ
SURFACES
A-F
QUASI-
STATIC
MODEL

Figure B.1

Table B.2. Baseline Car Type and Surface Characteristics.

Car Type

Car No. 1:	A/L = .34	
	H/L = .227	
	H/W = .45	
Car No. 2:	A/L = .54	
	H/L = .185	
	H/W = .36	

Surface Type, Given as $\mu = \mu_p/\mu_s$

Surface A	μ = .95/.90	
Surface B	μ = .60/.40	
Surface C	μ = .45/.30	
Surface D	μ_1 = .70/.45	μ_2 = .50/.35
Surface E	μ_1 = .75/.50	μ_2 = .45/.30
Surface F	μ_1 = .80/.55	μ_2 = .60/.40

which varied proportioning in a stepwise fashion over the entire range, for the cited vehicles. Results are displayed, then, showing braking performance levels as a function of proportioning for the various surface friction conditions of interest.

Accordingly, along with two car types, the six surfaces described in Table B.2 were used throughout the simulations. Surfaces A, B, and C represent the range of "single coefficient" surfaces, while surfaces D, E, and F are used to simulate "split coefficient" surfaces in which the right and left sides of the vehicle contact pavements with different frictional properties. It should be noted that the average values of surfaces D and E are identical, although they clearly represent different split conditions.

Qualitatively, the overall sensitivity matrix is given in Figure B.1, where the nonvaried, baseline parameters are in circles and parameters to be varied are in rectangles.

B.3.1 Straight-Line Braking Study. Braking performance in a straight line was examined by taking the twelve combinations of the two car types and six surfaces from Table B.2 and, for each combination, varying the front-rear proportioning, p, continuously over the range of possible design values. Figure B.2 illustrates the relationship between proportioning and the limit deceleration capabilities of Car No. 1. In all cases, the curve shows the limit braking performance achievable without accruing lockup of both wheels on an axle. The curves for the homogeneous surfaces A, B, and C are shown as solid lines, indicating that no lockup has occurred, since symmetry requires that no single wheel could lock alone, in straight braking on a uniform friction condition. Each curve has a "peak" at which the proportioning is optimal for that combination of car type and surface. At the peak, the deceleration (in g's) is equal to the coefficient of peak friction, μ_p. At proportioning values less than the optimal, performance is limited by a tendency of the rear wheels to lock prematurely, negating the opportunity

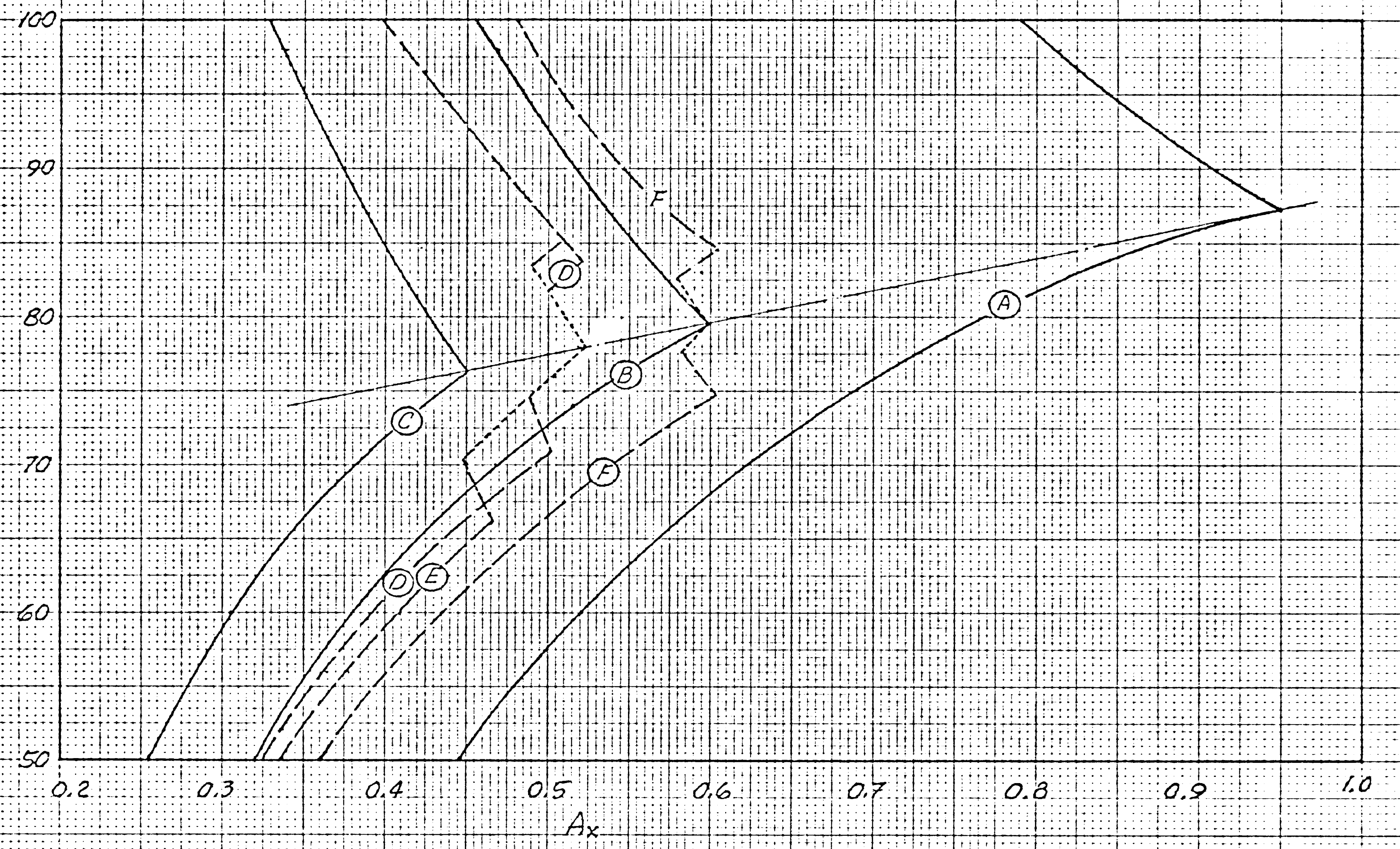


Figure B.2. Relation between deceleration and proportioning on six surfaces. Curves for car number 1.

for more utilization of front tire traction potential. (While pedal force is not actually calculated, it is often referred to in this appendix, as a common reference. When increasing the pedal force is mentioned, the implied meaning is that the braking forces of the unlocked wheels are increased by a common ratio. In the computerized version of the analysis, the variable F_F' serves as the reference force.)

At proportioning values greater than the optimal, performance is limited because the front wheels are on the verge of lockup. Since the load transfer to the front axle increases linearly with the longitudinal deceleration, A_x, the optimal proportioning varies with A_x along the line shown.

An examination of the plots of the vehicle performance on the split coefficient surfaces D, E, and F clearly indicates a greater complexity. The limit braking usually involves one or two locked wheels, as greater retardation is typically achieved by increasing the brake forces on the unlocked wheels, even at the expense of the reduced braking capabilities of the locked wheel(s).

The curves from Figure B.2 are shown mainly to indicate the method of determining the maximum possible deceleration in straight-line braking. Once found, this value is used to normalize the performance in terms of braking efficiency (BE). The curves from Figure B.2 are re-plotted in terms of BE in Figures B.3 and B.4.

The nature of the performance curves shown in these and subsequent figures may be clarified somewhat by "walking" through one curve and carefully examining the mechanisms responsible for the behavior. For example, the curve representing surface E in Figure B.4 shows that limit performance involves one locked wheel at very low proportionings. The rear wheel on the low coefficient side is locked, and the other rear wheel limits performance by being on the threshold of lockup. As the proportioning increases, more braking force can be applied at the front axle (by increasing pedal force)

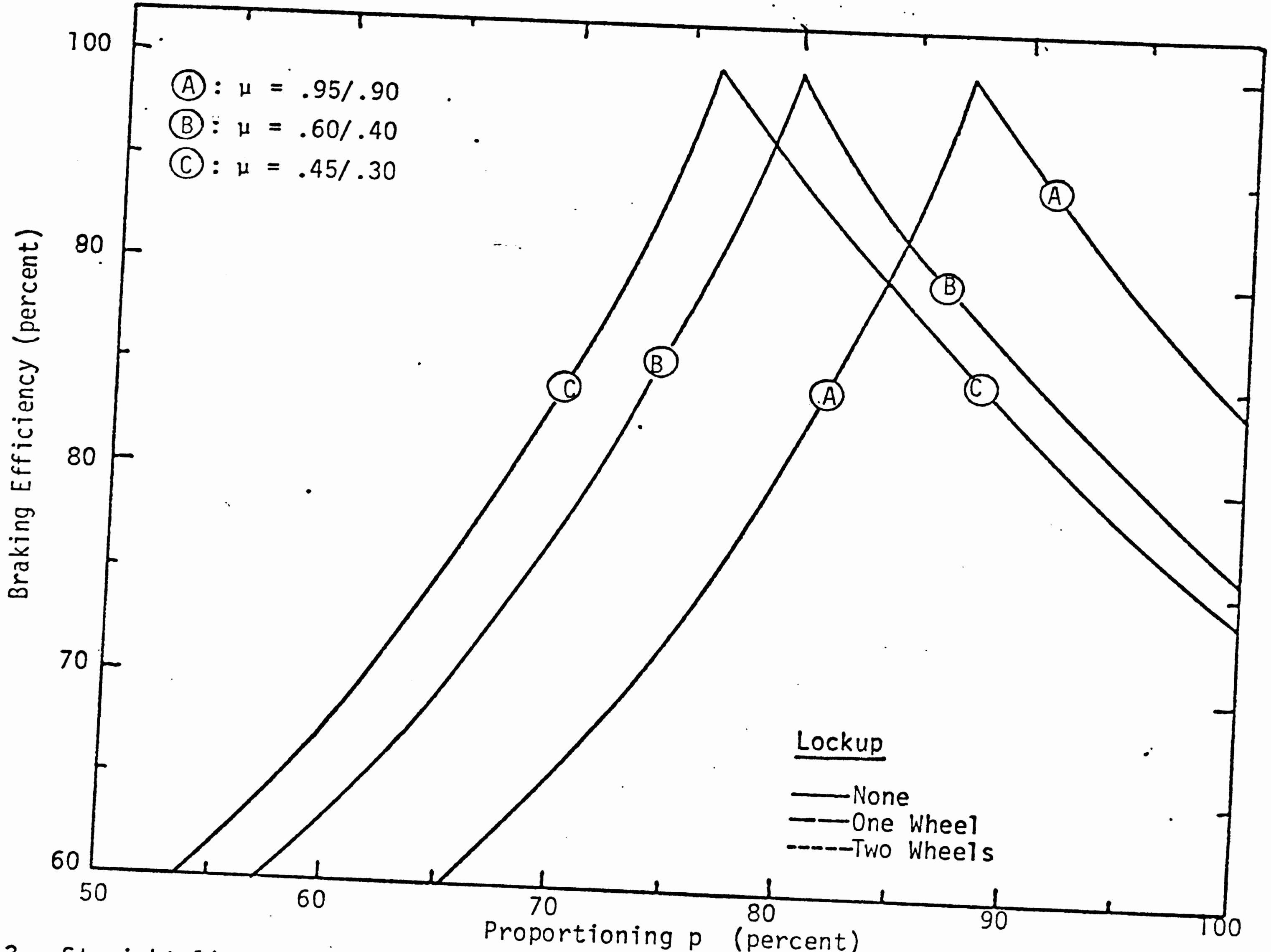


Figure B.3. Straight-line efficiency as a function of proportioning for Car No. 1 on uniform friction surfaces.

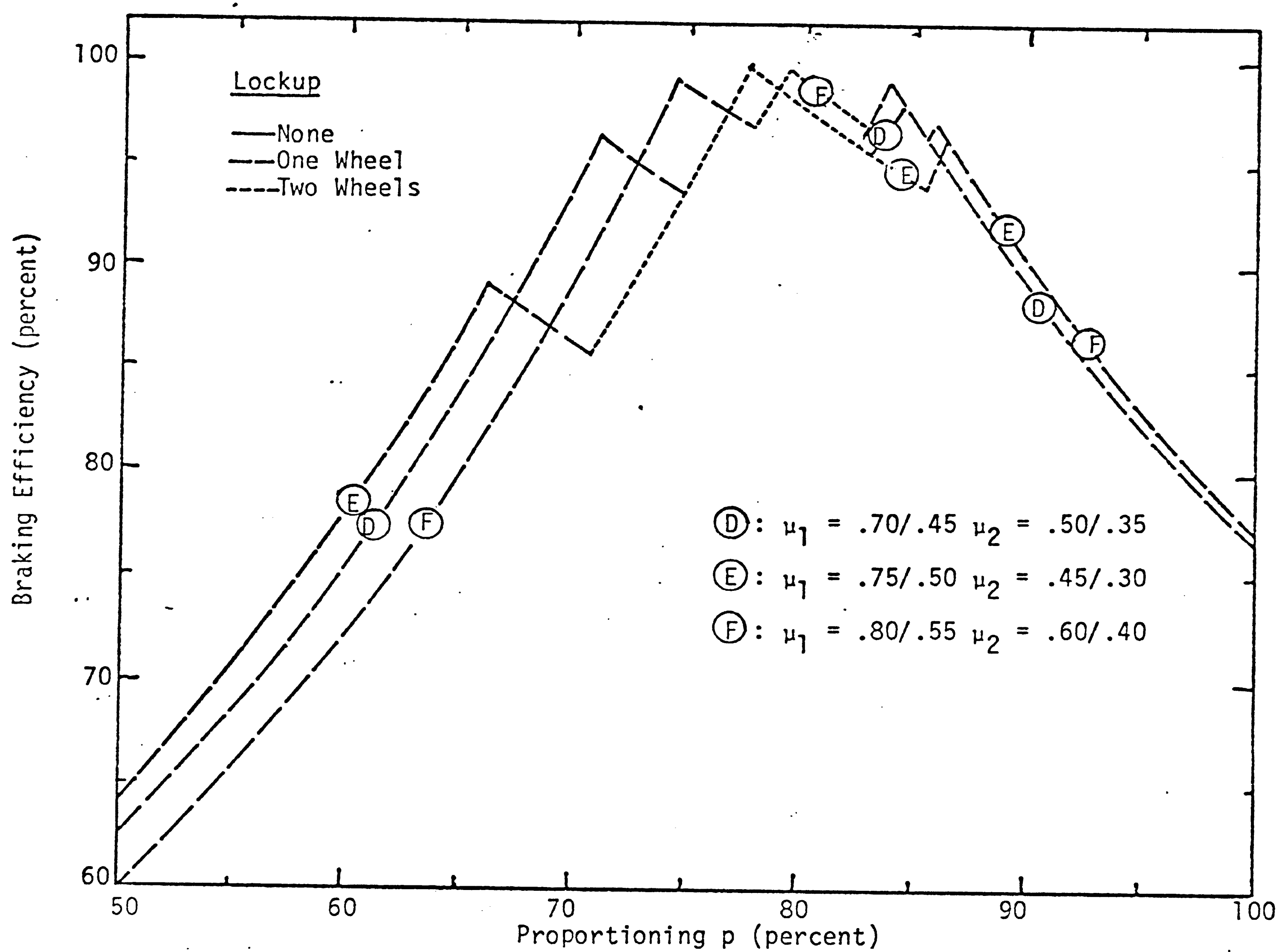


Figure B.4. Straight-line efficiency as a function of proportioning for Car No. 1 on split coefficient surfaces.

to increase efficiency, until the first local maximum is reached at p = 66%. At this point, both rear wheels and the front wheel on the low coefficient surface are producing braking forces at their respective peak frictional limits. As p is further increased, BE is limited by the front wheel on the low coefficient side. Increasing the pedal force in this domain, to the level at which the other rear wheel is again near lockup, would reduce the BE because of the lost braking force at the front wheel on the low coefficient side. Thus the pedal force must be reduced, and the smaller braking force of the unlocked rear wheel results in a lower efficiency. At the point where p = 71%, the same efficiency is attainable with two different pedal force levels, each with a different lockup combination. Along with the condition considered in the region $.66 < p < .71$, there is the condition in which the pedal force is increased, locking both wheels on the low coefficient side, and putting the other rear wheel at its peak braking limit. As p increases from this point, the latter condition is more efficient. One hundred percent BE is realized at p = 77%, when both wheels on the high coefficient side are on the verge of lockup. As p increases further, the pedal force must be reduced, otherwise the second front wheel would lock. Then, at p = 85%, the same BE can be obtained in two ways; one of these is the condition just described, and the other results when the pedal force is reduced until the rear wheel on the low coefficient side is unlocked and providing more braking force. This condition provides higher BE in the small range of $85\% < p < 86\%$. At 86% proportioning, both the rear wheel on the low coefficient side and the front wheel on the high coefficient side are near lockup. As p increases to 100%, BE is limited by the front wheel on the high coefficient side which is braking at its frictional limit.

The trend in all of the curves of Figures B.3 and B.4 is for BE to increase with p when a rear wheel is at the lockup point, and for BE to decrease when a front wheel is at the limit. The added complexity of the curves for split coefficient surfaces clearly stems from the varied possibilities of lockup. Curve Ⓔ has three lockup combinations, each of which is optimal over a certain region of p.

We can see that, in general, the split surfaces show the same type of behavior over small variations in p as seen for the single coefficient surfaces. However, the overall sensitivity is less for the split, because of the multitude of lockup possibilities, each of which is best over a definite region.

The straight-line BE of Car No. 2, on the same six surfaces, is also plotted as a function of proportioning in Figures B.5 and B.6.

B.3.2 Braking in a Turn. As complex as the BE versus p presentation becomes for straight-line, we find another dimension of complication for the cases of braking in a turn. As in the example of Figure B.7, the explanation of discontinuity points in the curves for braking efficiency in a turn require the tracking of right/left differences in tire load, as distributed according to the roll stiffness coefficient, C_ϕ, as well as accounting for all previously mentioned factors. As seen in this example, BE levels for in-a-turn stopping on a split friction surface offer the possibility of exceeding 100%. This occurs due to the straight-line reference condition for computing braking efficiency in a turn and also due to the improved utilization of adhesion levels when the more heavily loaded tires in a turn run on the higher friction surface.

The quasi-static simulation study proceeded from this format of examination to evaluate certain selected sensitivities using only a few representative values of proportioning.

Proportioning values were chosen to offer contrast in vehicle performance levels, and still be realistic. The values picked are the optimum proportioning figures for the high coefficient and mid-coefficient surfaces. For Car No. 1, these values are p = 80% and p = 87%. The case where p = 80% gives high values of performance for

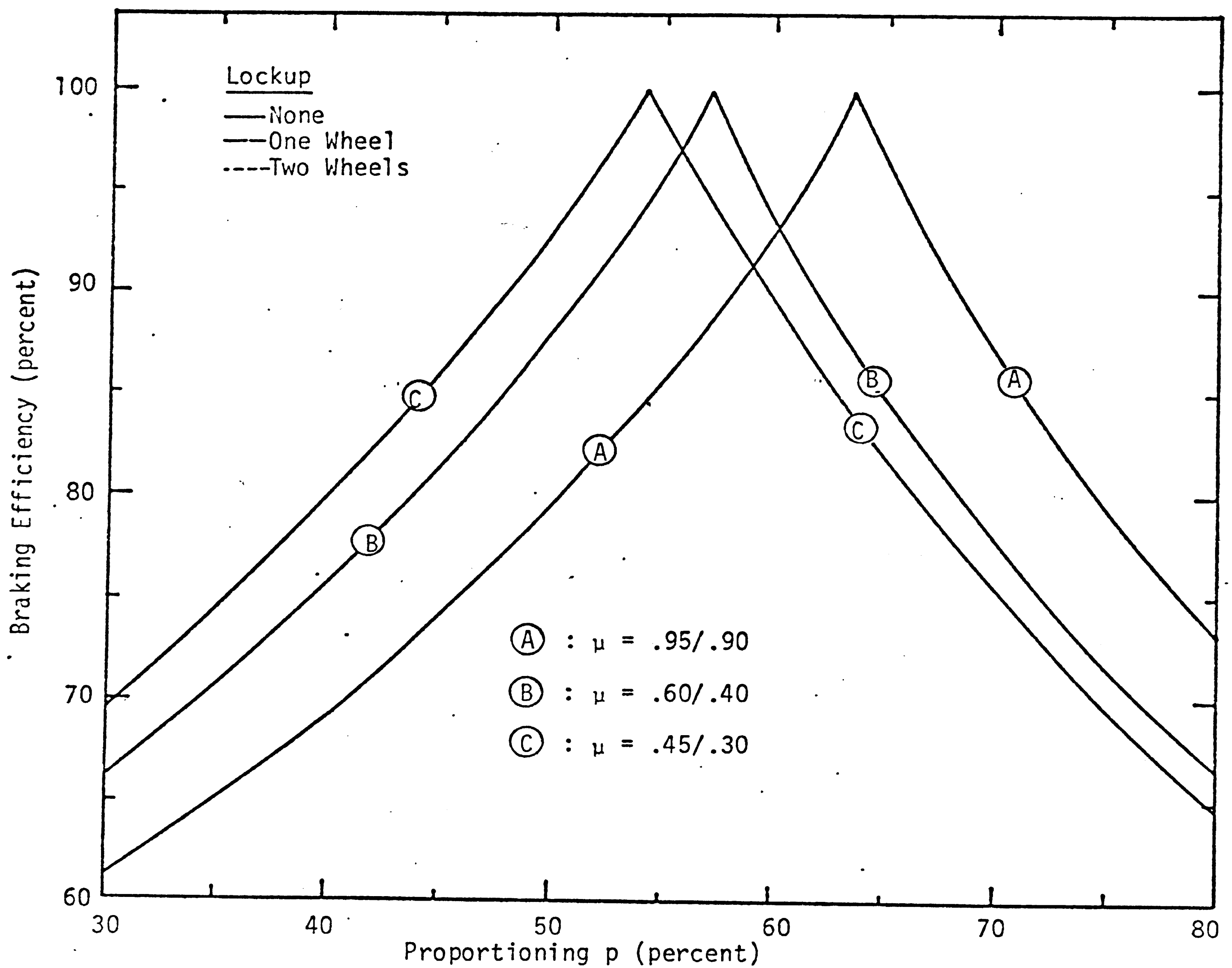


Figure B.5. Straight-line efficiency as a function of proportioning for Car No. 2 on uniform surfaces.

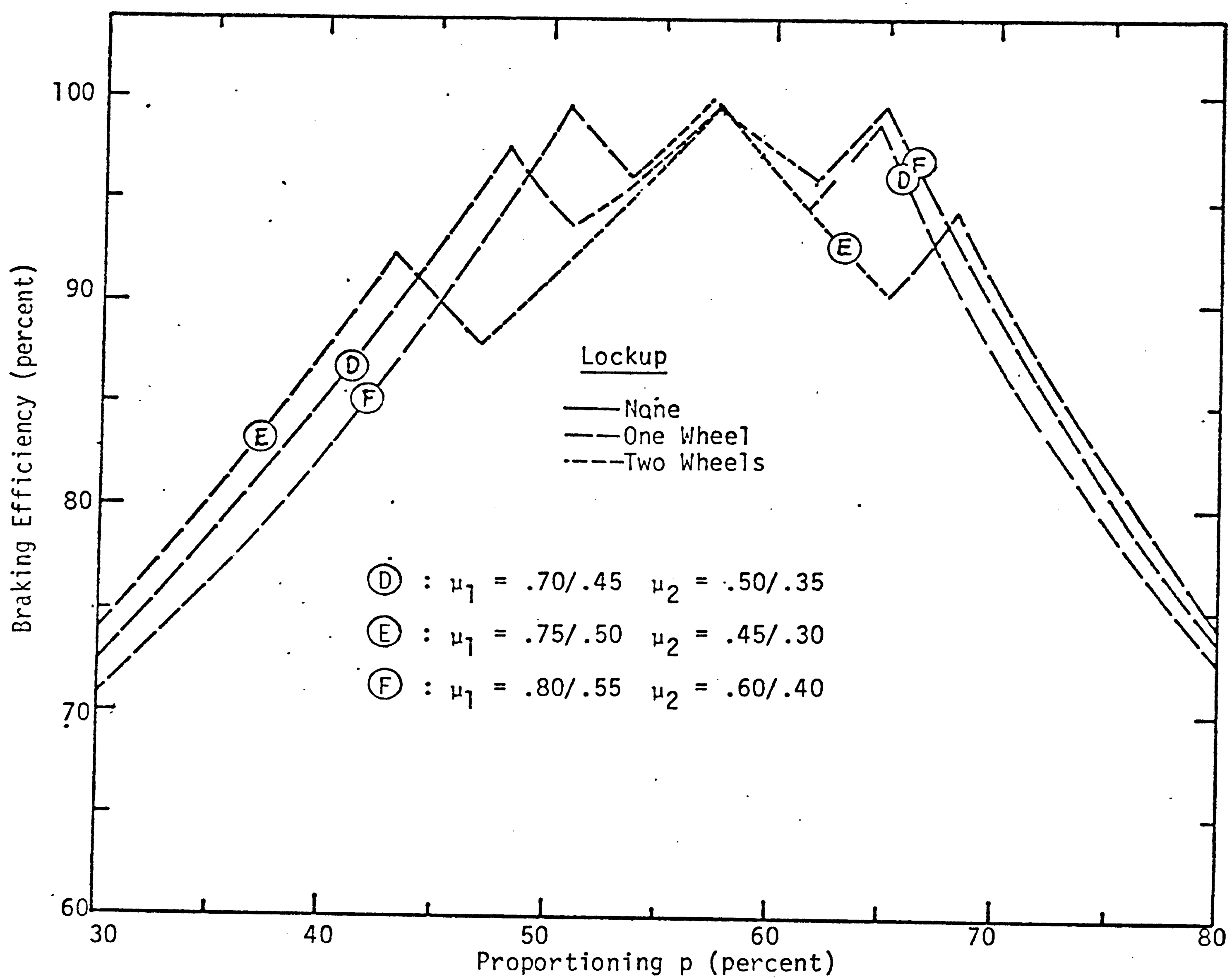


Figure B.6. Straight-line efficiency as a function of proportioning for Car No. 2 on split coefficient surfaces.

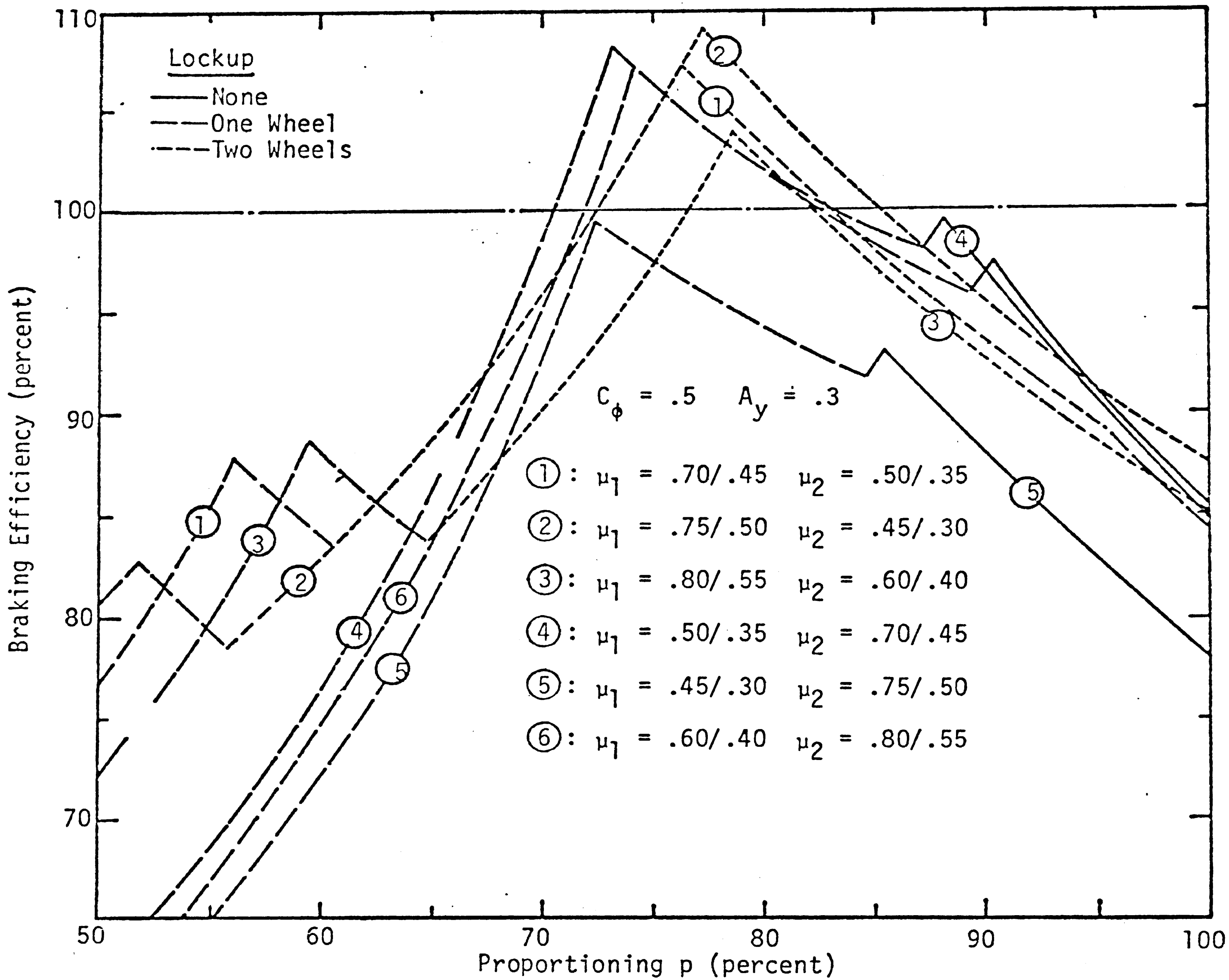


Figure B.7. Efficiency as a function of proportioning for Car No. 1 while braking in a turn on split coefficient surfaces.

mid-coefficient surfaces, rear axle limited performance on higher coefficient surfaces, and front axle limited performance on lower coefficient surfaces. A value of p = 87% could represent conditions such as

1) optimized performance for high coefficient surfaces such as is required by FMVSS 105,

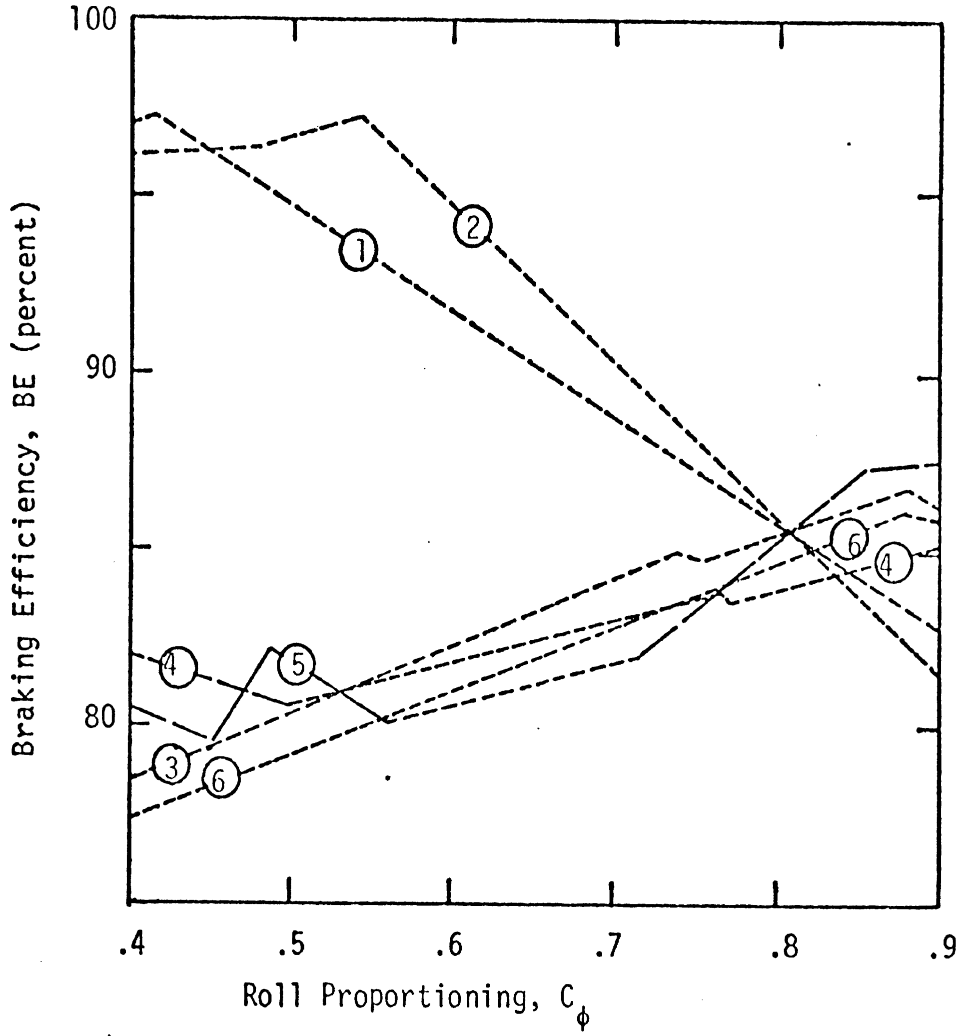
2) intentionally front-biased proportioning to assure that rear axle lockup will not occur on normal surfaces (as is a common design philosophy in Europe).

Similarly, values of p = 57% and p = 64% were chosen for Car No. 2.

Car braking performance in a turn depends on all of the vehicle/road parameters involved in the case of straight-line braking, along with the additional parameters, C_ϕ, H/W, and A_y. Reasonable choices for representative values of these variables were made more easily after observing the BE sensitivity involved with each of them. The methodology is similar to that in the last section, where BE is plotted as a continuous function of one variable, and discrete values for it are chosen on the basis of the curves.

Roll Stiffness Proportioning Sensitivity.

The sensitivity of BE to roll stiffness proportioning, C_ϕ, is shown in Figure B.8 for the case of Car No. 1 with p = 80% front/rear proportioning, and subject to lateral accelerations of .2 and .3 g's on the three uniform friction surfaces. The curves for the medium and low coefficient surfaces (curves ③ - ⑥) are all similar, showing an increase of about 6% braking efficiency when the roll proportioning is varied from .4 to .9. In the straight-line case, BE is limited by impending front axle lockup on the low friction surface, and by all wheels on the medium friction surface. When BE is less than 100%, the front/rear load transfer is not as large, thus BE is limited by impending front axle lockup on the medium



Key

Curve	μ	A_y
①	.95/.90	.2
②	.95/.90	.3
③	.60/.40	.3
④	.60/.40	.2
⑤	.45/.30	.2
⑥	.45/.30	.3

Car No. 1

p = 80%

Lockup

——None

— —One Wheel

----Two Wheels

Figure B.8. Braking efficiency as a function of roll distribution.

friction surface also. When more loading goes to one of the front wheels (due to A_y), higher brake forces can be applied. Since C_ϕ gives the proportion of the lateral transfer of vertical load which is exchanged between tires on the front axle, normal loading on the one front wheel increases with C_ϕ, and BE increases. Although different lockup possibilities cause the curves to change slope over the range of C_ϕ, the general behavior of curves ③ - ⑥, representing front-limited braking, are the same.

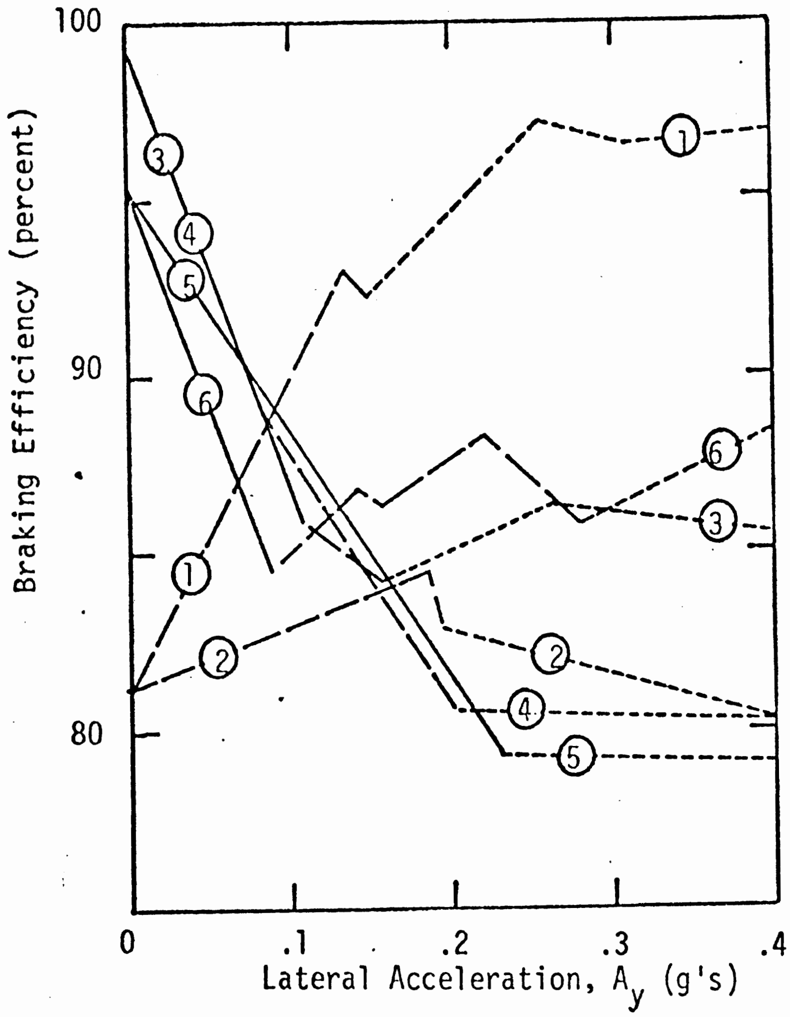
Rear-limited braking, a condition represented by curves ① and ② , causes BE to decrease as C_ϕ is increased. Again, there are no unusual breakpoints in curves ① and ② .

Roll proportioning values of C_ϕ = .5 and C_ϕ = .9 are used for following sensitivity curves and for a complete BE matrix. These two magnitudes cover the range of values likely to be encountered in practice, and, due to the well-behaved nature of the curves in Figure B.8, should not provide any singular types of BE.

Lateral Acceleration Sensitivity - Single Coefficient Surfaces

Regarding sensitivity of BE to lateral acceleration level during braking in a turn, it should first be pointed out that the lateral acceleration, A_y, and the mechanical "gain," H/W, of the vehicle in response to A_y can be considered together since the vehicle is affected by the product $A_y \cdot H/W$. While combining these two non-dimensional parameters may tend to obscure the physical understanding of each parameter's role in determining performance, the interdependence of A_y and H/W is pointed out to allow interpretation of the calculated changes in A_y as changes in H/W if desired. (For example, the BE calculated for increasing A_y by 50% may also be used for the case of A_y held constant and H/W increased by 50%.)

The effects of lateral acceleration on the single coefficient surfaces are presented in Figure B.9 for the case of Vehicle No. 1 with 80% proportioning, and C_ϕ values as shown. Here we see that the effects of A_y on efficiency also depend strongly on the type of surface involved.



Curve	μ	C_ϕ
①	.95/.90	.5
②		.9
③	.60/.40	
④		.5
⑤	.45/.30	
⑥		.9

Car No. 1

p = 80%

Lockup

——— None
— — — One Wheel
- - - - Two Wheels

Figure B.9. Braking efficiency as a function of lateral acceleration in the case of uniform friction surfaces.

The BE behavior is complicated when made a function of A_y, so we will again "walk through" a representative curve to understand this behavior. For the sake of this discussion, we assume that the car is making a left-hand turn, thus the effect of the A_y is to load the right-hand side.

Curves ① and ② both represent performance on the high coefficient surface, and initially show improved efficiency when a lateral acceleration is involved. Because the 80% proportioning is not optimal for this surface, the performance limitation at $A_y = 0$ (straight-line braking) is the rear axle, which is about to lock up.

By following curve No. ① , we see the effect of adding the lateral acceleration, which increases the normal load on the right-hand side of the vehicle. This allows more pedal force to be applied before the friction limit of RR (the right-rear wheel) is reached. The braking force at the front axle has also increased due to the extra pedal force, such that even though LR now slides and loses some braking force, the loss is more than made by the other three wheels and the performance improves with A_y. Until the peak at $A_y = .13$ g's, the limit on efficiency is impending lockup at RR. After the peak is reached, BE is limited by impending lockup at LF, and when $A_y = .15$ g's, efficiency is better with LF locked, and performance is again limited by RR. The efficiency climbs as more of the load is transferred to the right side, as greater pedal forces may be applied before RR will lock. The next peak, at $A_y = .26$ g's, when both right wheels are about to lock, occurs because of the relation between C_ϕ and p; that is, the rear axle receives 50% of the lateral load transfer, but only 20% of the incremental (total) braking torque. The front catches up, and performance decreases slightly with increasing A_y because not enough extra loading is applied at RF for the brake force to increase enough to offset losses from the left wheels. At $A_y = .3$ g's, the left-rear wheel has no normal loading at all, due to the combined longitudinal and lateral accelerations. Therefore, changes in C_ϕ have no effect on the rear axle, as the entire rear load is on RR. BE increases slightly over the rest of the curve, as the increase in braking force from RF (μ_p = .95) is more than the decrease from LF (μ_s = .90).

The general character of curve ① can be described by the following observations:

1) With small side forces, efficiency increases because one of the rear wheels will remain unlocked when pedal force is increased.

2) A change of the limiting axle from front to rear occurs because of the relation p has to C_ϕ.

3) When pedal force is limited by the possibility of rear axle lockup, performance increases with A_y since the torque threshold needed for lockup of the loaded rear wheel increases.

4) Eventually, one wheel goes to zero load, and BE hits a "plateau."

A different roll proportioning changes the overall shape of the plot, as evidenced by curve ② , where C_ϕ = .9. The same type of behavior occurs with small lateral accelerations, although the performance improvements are not as great as before because only 10% of the load transfer occurs at the rear axle. An opposite trend from curve ① is observed when two wheels are locked, however, because extra load on RR, which limits the pedal force, increases slowly while the load on LF decreases quickly. The trend in this case is for performance to suffer as the lateral acceleration increases.

When the front torque proportioning is near optimal for the surfaces, lateral acceleration can only deteriorate performance, as seen in curves ③ - ⑥. As A_y increases, pedal force must be decreased to prevent lockup and a loss of traction. When a certain amount of lateral acceleration is reached, it becomes better to increase pedal force, even though braking force is reduced in the locked wheel(s). After this point, the curves are qualitatively similar to those two discussed, in that the braking behavior includes lockup, and slopes and plateaus are determined by one wheel which is on the verge of lockup. When the location of the limiting wheel changes, the observed discontinuities in slope occur.

Discrete A_y values are selected for the comprehensive sensitivity matrix for performance on the single coefficient surfaces. The lateral acceleration sensitivity on these surfaces shows reduced change in efficiency after $A_y = .2$ g. For meaningful comparisons, a "low" acceleration of $A_y = .1$ g and a "high" acceleration of $A_y = .3$ g are selected for all single coefficient surface combinations (along with $A_y = 0$ - straight-line).

Lateral Acceleration Sensitivity - Split Coefficient Surfaces

Braking performance sensitivity to lateral acceleration was also calculated for the split coefficient surfaces, and shown in Figure B.10.

Here we see that when the side force tends to load the high coefficient side ($A_y<0$), performance increases to over 100% efficiency, with both wheels locked on the low coefficient side. Again, the detailed shape of the curves depends on which unlocked wheel is about to lock.

When the loading due to A_y occurs on the low coefficient side ($A_y>0$), behavior gets a bit complicated. An overall trend, however, is that performance doesn't suffer greatly; the lowest efficiency anywhere is 90%. There are so many possible pedal force levels and lockup combinations that one of them is usually suited to a particular A_y level. In fact, curve ⑥ shows better performance for loading the low coefficient side, for all levels up to $A_y = .2$ g. Applying a small side force makes the condition of a lower pedal force and four unlocked wheels more efficient (but puts the wheels which are on the high coefficient surface below their maximum braking force). Increasing A_y allows increasing braking force on the low coefficient surface and total braking increases.

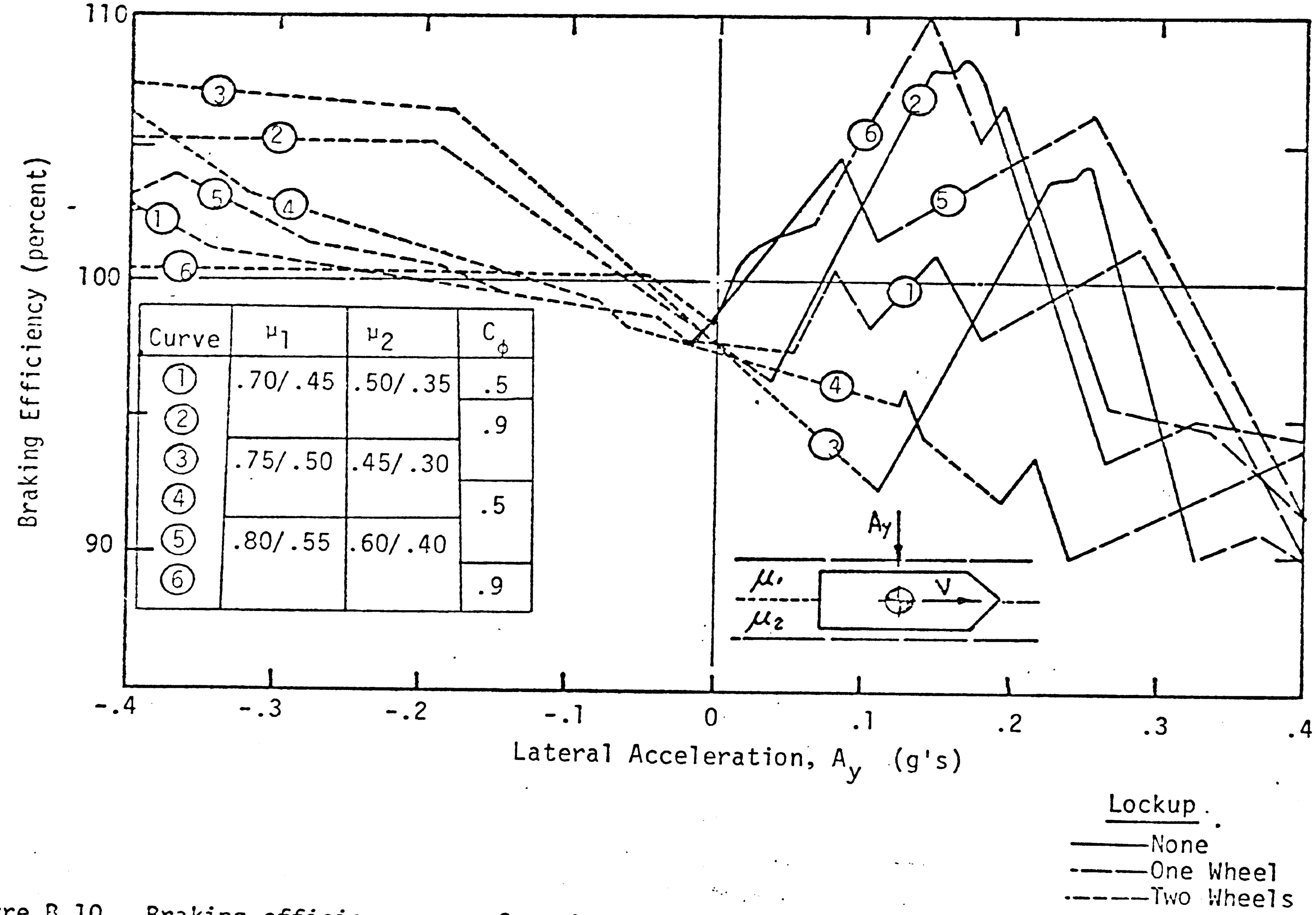
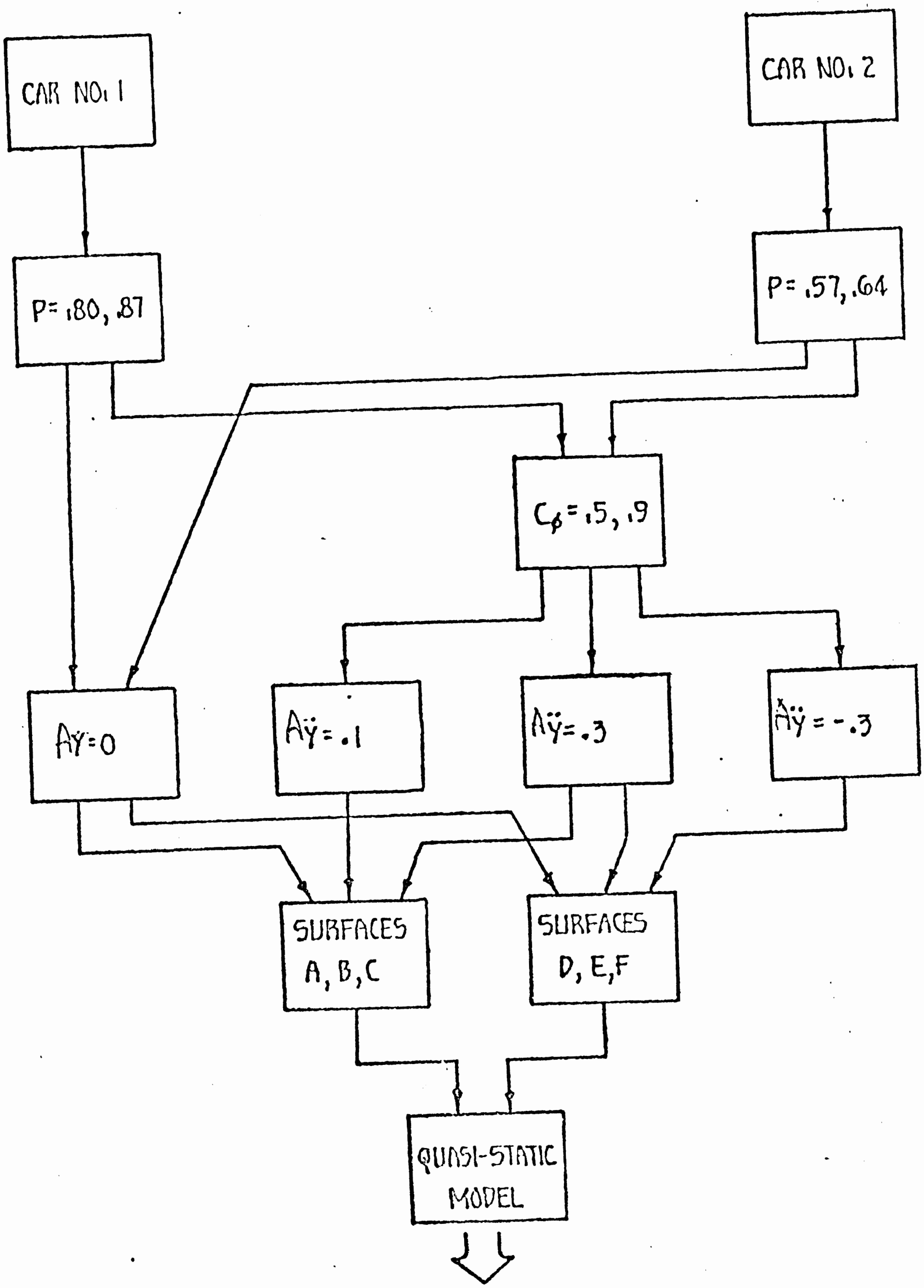


Figure B.10. Braking efficiency as a function of lateral acceleration, in the case of split coefficient surfaces.

The overall trend with the split coefficients is that BE sensitivity, even with all the jagged peaks and depressions, does not respond as much to lateral acceleration as with the single coefficient surface conditions. At levels of A_y = .3 g and greater, the curves are more stable than at lower levels. The values A_y ±.3 g were thus chosen for use in the overall sensitivity study of braking performance on split coefficient surfaces.

The entire braking efficiency sensitivity calculation matrix is shown schematically in Figure B.11 with all of the parameter values chosen from the previous sections. Tables B.3 through B.6 summarize the computation results, and besides giving BE, also include the stopping distances which would occur with the quasi-static model, at initial speeds of 20, 40, and 60 mph.



120 Calculations

Figure B.11. Schematic of complete calculation matrix.

Table B.3. Sensitivities of Car No. 1 on Uniform Friction Surfaces.

P	C_ϕ	$\ddot{Y}$ (g)	Surface μ_p/μ_s (Left Side / Right Side)	Lockup	$\ddot{X}$ (ft/s^2)	Stopping Distance (ft) 20 mph	40 mph	60 mph	% EFF
.87	X	0	.95/.90	NONE	30.7	14	56	126	100
.80					25.0	17	69	155	81
			.60/.40		19.4	22	89	199	100
.87					17.4	25	99	223	89
			.45/.30		12.4	34	138	311	86
.80					13.7	31	126	283	95
	.5	.1			12.8	34	135	304	88
		.3		LF LR	12.8	34	135	304	88
			.60/.40		15.6	28	110	248	81
		.1		LR	17.0	25	101	227	88
			.95/.90		27.6	16	62	140	90
	.9	.3		LF LR	29.7	14	58	130	97
					25.1	17	69	154	82
		.1		LR	25.5	17	68	152	83
			.60/.40	NONE	16.8	26	102	230	87
		.3		LF LR	16.7	26	103	232	86
			.45/.30	LF	12.3	35	140	315	85
		.1		LF LR	12.4	35	138	311	86
.87				LF	10.9	39	157	354	76
		.3			11.8	36	145	327	82
			.60/.40		16.5	26	104	235	85
		.1		NONE	15.2	28	113	254	78
			.95/.90	LF LR	29.6	15	58	131	96
	.5	.3			29.4	15	59	132	96
					28.0	15	61	138	91
		.1			29.1	15	59	133	95
			.60/.40	NONE	16.2	27	106	239	83
		.3		LF LR	14.7	29	117	264	76
			.45/.30	LF	10.9	39	157	354	76
		.1		NONE	11.6	37	148	334	80

Table B.4. Sensitivities of Car No. 1 on Split Coefficient Surfaces.

P	C_ϕ	$\ddot{Y}$ (g)	Surface μ_P/μ_S Left Side	Surface μ_P/μ_S Right Side	Lockup	X (ft/s²)	Stopping Distance (ft) 20 mph	Stopping Distance (ft) 40 mph	Stopping Distance (ft) 60 mph	% EFF
.87		0	.70/.45	.50/.35	RF	16.5	26	104	235	98
.80					RF RR	16.1	27	107	240	96
			.75/.50	.45/.30		16.4	26	105	236	98
.87					RF	15.9	27	108	244	94
			.80/.55	.60/.40		18.5	23	93	209	95
.80					NONE	19.4	22	89	199	100
	.5	-.3			RF RR	19.8	22	87	196	102
		.3			LR	19.7	22	87	197	102
			.75/.50	.45/.30		15.4	28	111	251	92
		-.3			RF RR	17.4	25	99	223	103
			.70/.45	.50/.35		17.0	25	101	228	101
		.3			LR	16.9	26	102	230	100
	.9				LF	15.9	27	108	243	94
		-.3			RF RR	17.7	24	97	218	105
			.75/.50	.45/.30		18.0	24	96	215	107
		.3			NONE	16.0	27	108	242	95
			.80/.55	.60/.40	LF	18.4	23	93	210	95
		-.3			RF RR	19.5	22	88	199	100
.87						20.1	21	86	193	103
		.3			LF	18.0	24	96	215	93
			.75/.50	.45/.30	NONE	14.4	30	120	269	85
		-.3			RF RR	17.8	24	97	218	106
			.70/.45	.50/.35		17.4	25	99	223	103
		.3			LF	14.5	30	119	268	86
	.5				LR	16.1	27	107	241	95
		-.3			RF RR	15.8	27	109	244	94
			.75/.50	.45/.30		16.1	27	107	240	96
		.3			NONE	15.0	29	115	258	89
			.80/.55	.60/.40	LR	18.8	23	92	206	97
		-.3			RF RR	18.4	23	94	211	95

Table B.5. Sensitivities of Car No. 2 on Uniform Friction Surfaces.

P	C_ϕ	$\ddot{Y}$ (g)	SURFACE μ_p/μ_s LEFT SIDE / RIGHT SIDE	LOCKUP	$\ddot{X}$ (ft/s²)	STOPPING DISTANCE (ft) 20 mph	40 mph	60 mph	% EFF
.64		0	.95/.90	NONE	30.7	14	56	126	100
.57					27.2	16	63	142	89
			.60/.40		19.4	22	89	199	100
.64					16.8	26	102	231	87
			.45/.30		11.9	36	144	324	83
.51					13.7	31	126	283	95
	.5	.1			12.6	34	137	307	87
		.3		LF LR	11.9	36	145	327	82
			.60/.40		16.2	26	106	238	84
		.1		NONE	17.8	24	96	217	92
			.95/.90	LR	28.1	15	61	138	92
		.3		LF LR	28.5	15	60	136	93
	.9				26.0	17	66	149	85
		.1		LR	27.3	16	63	142	89
			.60/.40	LF	17.1	25	101	227	88
		.3			15.9	27	108	243	82
			.45/.30		12.4	35	139	313	86
		.1			13.1	33	132	296	91
.64					11.3	38	152	341	79
		.3			13.0	33	133	299	90
			.60/.40		17.5	25	98	221	90
		.1			15.9	27	109	244	82
			.95/.90	LF LR	29.5	15	58	131	96
		.3			28.3	15	61	125	92
	.5				28.9	15	60	134	94
		.1			29.3	15	59	132	95
			.60/.40	NONE	15.5	28	111	251	80
		.3		LF	15.3	28	112	253	79
			.45/.30		11.7	37	147	331	81
		.1		NONE	11.0	39	156	351	76

Table B.6. Sensitivities of Car No. 2 on Split Coefficient Surfaces.

p	C_ϕ	$\ddot{Y}$(g)	SURFACE μ_p/μ_s LEFT SIDE	RIGHT SIDE	LOCKUP	X (ft/s²)	STOPPING DISTANCE (ft) 20 mph	40 mph	60 mph	% EFF
.64		0	.70/.45	.50/.35	RF	16.2	26	106	238	96
.57					RF RR	16.5	26	104	235	98
			.75/.50	.45/.30		16.3	26	105	237	97
.64						15.1	28	114	256	90
			.80/.55	.60/.40	RF	19.0	23	91	204	98
.57					NONE	19.4	22	89	199	100
	.5	-.3			RF RR	20.2	21	85	192	104
		+.3			NONE	19.2	22	89	201	99
			.75/.50	.45/.30		16.9	25	102	229	100
		-.3			RF RR	17.7	24	97	219	105
			.70/.45	.50/.35		17.5	25	99	222	104
		+.3			NONE	17.4	25	99	223	103
	.9				LF RR	15.7	27	110	247	93
		-.3			RF RR	16.6	26	104	233	99
			.75/.50	.45/.30		16.8	26	102	230	100
		+.3			NONE	14.9	29	116	261	88
			.80/.55	.60/.40	LF RR	18.5	23	93	209	95
		-.3			RF RR	18.6	23	92	208	96
.64						20.3	21	85	191	105
		+.3			LF	19.2	22	90	202	99
			.75/.50	.45/.30		14.2	30	121	272	84
		-.3			RF RR	17.8	24	96	217	106
			.70/.45	.50/.35		17.5	25	80	221	104
		+.3			LF	15.4	28	112	251	91
	.5				NONE	15.5	28	111	250	92
		-.3			RF RR	16.0	27	108	242	95
			.75/.50	.45/.30		16.2	26	106	238	96
		+.3			NONE	14.8	29	117	262	88
			.80/.55	.60/.40		18.4	23	93	210	95
		-.3			RF RR	13.6	23	92	208	96

APPENDIX C

DATA FROM IN DEPTH TEST PROGRAM ON FIVE CARS.
VEHICLE DISCRIPTIONS AND DATA SUMMERIES.

VEHICLE INFORMATION SHEET

Vehicle: Make: MONTE CARLO NHTSA No. —

Model: 2DR. SPORT COUPE GVWR: 5587

Model Year: 1976 Manufacture Date: 7/76

V.I.N.: 1H57V6I505295 Wheelbase: 116

Engine Type: V8 Displacement: 400 in^3 Hp: 175

Engine Idle Speed: — Engine Timing: —

Transmission: Type: AUTO Speeds: 3

No. of Axles: 2 Ratio(s) —

GAWR: Front: 2749 Rear: 2838

Tires: Size: GR70X15B Mfr: UNIROYAL

Type: STEEL BELTED RADIAL

Recommended Pressure at GVWR: 28 psi front

28 psi rear

Brakes: Front: ( ) Drum (✓) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Rear: (✓) Drum ( ) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Variable Proportioning System: Yes ✓ No ______

Brake Power Assist Unit: Yes ✓ No ______

Brake Power Unit w/Accumulator: Yes ______ No ✓

Power Assist or Power Unit w/Backup: Yes ______ No ✓

Antiskid Device: Yes ______ No ✓

Parking Mechanism: (see definition) Mfr —

Yes ______ No ______

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated (✓)

Nonservice Brake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ____________

Wheel Cylinder Diameter: ____________

Describe Hydraulic Circuit Split: ____________

FRONT/REAR

Will adjusters be locked out for this test series?

Yes ________ No ✓

VEHICLE INFORMATION SHEET

Vehicle:

Make: Ford LTD — NHTSA No. ____

Model: 4 Dr. Sedan — GVWR: 6384

Model Year: 1976 — Manufacture Date: 3/76

V.I.N.: 6B63H194520 — Wheelbase: 121 in

Engine Type: V8 — Displacement: 351 in^3 — Hp: —

Engine Idle Speed: — — Engine Timing: —

Transmission: Type: AUTO — Speeds: 3

No. of Axles: 2 — Ratio(s) —

GAWR: Front: 3177 — Rear: 3266

Tires:

Size: HR78x15 — Mfr: Goodyear

Type: Custom Polysteel Radial

Recommended Pressure at GVWR: 26 psi front

28 psi rear

Brakes:

Front: ( ) Drum (✓) Disc Diam: ____

( ) Bonded ( ) Riveted

Friction Surface Width: ____ Length: ____

Rear: (✓) Drum ( ) Disc Diam: ____

( ) Bonded ( ) Riveted

Friction Surface Width: ____ Length: ____

Variable Proportioning System: Yes ✓ No ____

Brake Power Assist Unit: Yes ✓ No ____

Brake Power Unit W/Accumulator: Yes ____ No ✓

Power Assist or Power Unit W/Backup: Yes ____ No ✓

Antiskid Device: Yes ____ No ✓

Parking Mechanism: (see definition) Mfr ____ Yes ____ No ____

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated (✓)

Nonservice Brake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ____________

Wheel Cylinder Diameter: ____________

Describe Hydraulic Circuit Split: ____________

FRONT / REAR

Will adjusters be locked out for this test series?

Yes ______ No ✓

VEHICLE INFORMATION SHEET

Vehicle: Make: MERCURY NHTSA No. ________

Model: BOBCAT ST. WAG. GVWR: 3842

Model Year: 1977 Manufacture Date: 04/77

V.I.N.: 7T22Y522082 Wheelbase: 94.5 in

Engine Type: 4CYL. Displacement: 140 in^3 Hp: 92

Engine Idle Speed: — Engine Timing: —

Transmission: Type: AUTO Speeds: 3

No. of Axles: 2 Ratio(s) —

GAWR: Front: 1813 Rear: 2069

Tires: Size: BR78-13 Mfr: FIRESTONE

Type: STEEL BELTED RADIAL

Recommended Pressure at GVWR: 24 psi front

30 psi rear

Brakes: Front: ( ) Drum (✓) Disc Diam: ________

( ) Bonded ( ) Riveted

Friction Surface Width: ________ Length: ________

Rear: (✓) Drum ( ) Disc Diam: ________

( ) Bonded ( ) Riveted

Friction Surface Width: ________ Length: ________

Variable Proportioning System: Yes ✓ No ________

Brake Power Assist Unit: Yes ________ No ✓

Brake Power Unit W/Accumulator: Yes ________ No ✓

Power Assist or Power Unit W/Backup: Yes ________ No ✓

Antiskid Device: Yes ________ No ✓

Parking Mechanism: (see definition) Mfr ________

Yes ________ No ________

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated (✓)

Foot Operated ( )

Nonservice Drake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ______________________

Wheel Cylinder Diameter: ______________________

Describe Hydraulic Circuit Split: ______________________

FRONT/REAR

Will adjusters be locked out for this test series?

Yes ________ No ✓

VEHICLE INFORMATION SHEET

Vehicle: Make: AMC PACER   MITSA No. ______

Model: 2DR. SEDAN   GVWR: 4326

Model Year: 1977   Manufacture Date: 3-77

V.I.N.: A7A667C213340   Wheelbase: 100 in

Engine Type: 6CYL   Displacement: 258 in³   Hp: 98

Engine Idle Speed: —   Engine Timing: —

Transmission: Type: AUTO   Speeds: 3

No. of Axles: 2   Ratio(s) —

GAWR: Front: 2145   Rear: 2201

Tires: Size: D78X14   Mfr: GOODYEAR

Type: CUSTOM POWER CUSHION POLYGLAS

Recommended Pressure at GVWR: 24 psi front

28 psi rear

Brakes: Front: ( ) Drum (✓) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Rear: (✓) Drum ( ) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Variable Proportioning System: Yes ______ No ✓

Brake Power Assist Unit: Yes ______ No ✓

Brake Power Unit w/Accumulator: Yes ______ No ✓

Power Assist or Power Unit w/Backup: Yes ______ No ✓

Antiskid Device: Yes ______ No ✓

Parking Mechanism: (see definition) Mfr ______ Yes ______ No ______

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated (✓)

Nonservice Drake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ____________________

Wheel Cylinder Diameter: ____________________

Describe Hydraulic Circuit Split: ____________________

FRONT/REAR

Will adjusters be locked out for this test series?

Yes ________ No ________

VEHICLE INFORMATION SHEET

Vehicle:

Make: CHEVY NOVA NHTSA No. ______

Model: 4 DR SEDAN GVWR: 4836

Model Year: 1976 Manufacture Date: 11/75

V.I.N.: 1X69L6W141117 Wheelbase: 111 in

Engine Type: V8 Displacement: 350 in³ Hp: ______

Engine Idle Speed: — Engine Timing: —

Transmission: Type: AUTO Speeds: 3

No. of Axles: 2 Ratio(s) —

GAWR: Front: 2311 Rear: 2525

Tires:

Size: FR70 x 14 Mfr: FIRESTONE

Type: SUPER 125 RADIAL

Recommended Pressure at GVWR: 24 psi front

28 psi rear

Brakes:

Front: ( ) Drum (✓) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Rear: (✓) Drum ( ) Disc Diam: ______

( ) Bonded ( ) Riveted

Friction Surface Width: ______ Length: ______

Variable Proportioning System: Yes ✓ No ______

Brake Power Assist Unit: Yes ✓ No ______

Brake Power Unit w/Accumulator: Yes ______ No ✓

Power Assist or Power Unit w/Backup: Yes ______ No ✓

Antiskid Device: Yes ✓ No ______

Parking Mechanism: (see definition) Mfr KELSEY HAYES Yes ______ No ______

VEHICLE INFORMATION SHEET

Brakes (contd): Friction-type Parking Brake: Hand Operated ( )

Foot Operated (✓)

Nonservice Brake Type Parking Brake: Hand Operated ( )

Foot Operated ( )

Master Cylinder Diameter: ______________

Wheel Cylinder Diameter: ______________

Describe Hydraulic Circuit Split: ______________

FRONT/REAR

4 Wheel Anti-lock, Axle Control

____

Will adjusters be locked out for this test series?

Yes ________ No ✓

Minimum Stopping Distances and Wheel Lock Conditions

Tables C.1 through C.5 summerize the minimum stopping distances and the wheel lock conditions for the minimum distance stops for each of the five test vehicles in each of the 28 tests. Figures C.6 shrough C.10 give the peak to peak steering wheel displacement angle and the number of steering wheel reversals for each vehicle in each of the 28 tests. Abreviations used in the Tables discribing the test conditions are:

HI-CO. ST.	High Coefficient. Straight
LO-CO. ST.	Low Coefficient. Straight
HI-R. SP. ST.	Split Coefficient. Straight. HI-CO on Right.
HI-L. SP. ST.	Split Coefficient. Straight. HI-CO on Left.
HI-CO, T-R	High Coefficient, Turn Right.
HI-CO, T-L	High Coefficient, Turn Left.
LO-CO, T-R	Low Coefficient, Turn Right.
LO-CO, T-L	Low Coefficient, Turn Left.
HI-R, SP. T-R	Split Coefficient. Turn Right. HI-CO on Right.
HI-R, SP. T-L	Split Coefficient. Turn Left. HI-CO on Right.
HI-L, SP. T-R	Split Coefficient. Turn Right. HI-CO on Left.
HI-L, SP. T-L	Split Coefficient. Turn Left. HI-CO on Left.

Table C.1. 1976 Monte Carlo, Minimum Stopping Distances and Wheel Lock Conditions.

TEST CONDITION	STOPPING DISTANCE - FEET 1st. EFF.	2nd. EFF.	3rd. EFF.
60 m.p.h. HI CO. ST.	174.0 (LF)	179.0 (LF)	161.0 (RF)
40 m.p.h. LO CO. ST.	110.1 -	116.6 (LF)	95.7 -
40 m.p.h. HI-R,SP.ST.	96.4 (LF,LR)	109.1 (LF)	107.9 (LF,LR)
40 m.p.h. HI-L,SP.ST.	108.0 (RF)	113.1 (RF)	102.6 (RF,RR)
40 m.p.h. HI CO. T-R		72.9 -	69.7 (RR)
40 m.p.h. HI CO. T-L		72.2 -	67.1 (LR)
40 m.p.h. LO CO. T-R		132.8 -	109.4 -
40 m.p.h. LO CO. T-L		120.1 -	96.8 -
40 m.p.h. HI-R,SP. T-R		116.2 (LF)	110.1 -
40 m.p.h. HI-R,SP. T-L		108.5 (LF)	109.1 (LF,LR)
40 m.p.h. HI-L,SP. T-R		115.9 (RF)	112.5 (RF,RR)
40 m.p.h. HI-L,SP. T-L		109.3 (RF)	102.6 (RF)

Table C.2. 1976 Ford LTD, Minimum Stopping Distances and Wheel Lockup Conditions.

TEST CONDITION	STOPPING DISTANCE - FEET 1st. EFF.	2nd. EFF.	3rd. EFF.
60 m.p.h. HI CO. ST.	175.5 -	184.0 -	159.2 (LF)
40 m.p.h. LO CO. ST.	125.3 -	140.6 -	124.2 -
40 m.p.h. HI-R SP. ST.	124.1 (LF)	118.5 (LF)	122.4 (LF,LR)
40 m.p.h. HI-L SP. ST.	126.8 (RF)	129.6 (RF)	113.1 (RF,RR)
40 m.p.h. HI CO, T-R		82.4 -	66.8 (RR)
40 m.p.h. HI CO, T-L		81.5 (LF)	67.4 (LF)
40 m.p.h. LO CO, T-R		153.1 -	114.4 (RF,RR)
40 m.p.h. LO CO, T-L		147.4 (LF)	107.0 (LF)
40 m.p.h. HI-R, SP. T-R		135.2 (LF)	125.1(LF)
40 m.p.h. HI-R, SP. T-L		122.0 (LF)	105.2 (LF,LR)
40 m.p.h. HI-L, SP. T-R		133.4 (RF)	117.0 (RF,RR)
40 m.p.h. HI-L, SP. T-L		133.0 (RF)	120.5 (RF)

Table C.3. 1977 Mercury Bobcat Station Wagons, Minimum Stopping Distances and Wheel Lockup Conditions.

TEST CONDITION	STOPPING DISTANCE - FEET 1st. EFF.	2nd. EFF.	3rd. EFF.
60 m.p.h. HI CO. ST.	167.3 (RF,RR)	192.6 -	151.1 (LR)
40 m.p.h. LO CO. ST.	110.6 (LF)	119.3 -	102.8 -
40 m.p.h. HI-R SP. ST	117.5 (LF)	115.5 (LF)	110.2 (LF,LR)
40 m.p.h. HI-L SP. ST	114.2 (RF)	123.4 (RF)	103.3 (RF,RR)
40 m.p.h. HI-CO, T-R		85.4 (RF)	70.0 (RF)
40 m.p.h. HI-CO, T-L		79.0 (LF)	67.8 (LF,LR)
40 m.p.h. LO-CO, T-R		134.2 (RF)	115.0 (RF)
40 m.p.h. LO-CO, T-L		124.8 (LF)	107.8 -
40 m.p.h. HI-R, SP. T-R		121.3 (LF)	114.9 (LF)
40 m.p.h. HI-R, SP. T-L		106.6 (LF)	104.2 (LF,LR)
40 m.p.h. HI-L, SP. T-R		116.8 (RF)	108.0 (RF,RR)
40 m.p.h. HI-L, SP. T-L		118.1 (RF)	108.1 (RF)

Table C.4. 1977 AMC Pacer, Minimum Stopping Distances and Wheel Lockup Conditions.

TEST CONDITION	STOPPING DISTANCE - FEET 1st. EFF.	2nd. EFF.	3rd. EFF.
60 m.p.h. HI CO. ST.	175.8 -	165.8 (LR)	176.6 -
40 m.p.h. LO CO. ST.	141.8 (RF)	180.7 (RF)	143.7 -
40 m.p.h. HI-R, SP. ST.	111.0 (LF,LR)	121.6 (LF,LR)	127.5 (LF)
40 m.p.h. HI-L, SP. ST.	123.3 (RF,RR)	125.5 (RF)	112.4 (RF,RR)
40 m.p.h. HI-CO, T-R		75.8 (RF)	84.4 (RR)
40 m.p.h. HI-CO, T-L		71.2 (LF,LR)	73.8 (LR)
40 m.p.h. LO-CO, T-R		194.1 (RF)	136.0 (RF)
40 m.p.h. LO-CO, T-L		159.6 (LF)	144.1 -
40 m.p.h. HI-R, SP. T-R		169.0 (LF)	125.5 (LF,LR)
40 m.p.h. HI-R, SP. T-L		125.3 (LF,LR)	133.9 (LF,LR)
40 m.p.h. HI-L, SP. T-R		136.2 (RF)	133.9 (RF,RR)
40 m.p.h. HI-L, SP. T-L		139.8 (RF)	132.9 (RF)

Table C.5. 1976 Four Wheel Anti-Lock Equipped Nova, Minimum Stopping Distances and Anti-Lock Cycling Conditions.

TEST CONDITION	STOPPING DISTANCE - FEET 1st. EFF.	2nd. EFF.	3rd. EFF.
60 m.p.h. HI-CO. ST.	169.2 F&R	172.2 (F)	152.1 F&R
40 m.p.h. LO-CO. ST.	104.6 F&R	102.9 (F)	99.8 F&R
40 m.p.h. HI-R, SP. ST.	112.2 F&R	116.1 F&R	125.3 F&R
40 m.p.h. HI-L, SP. ST.	121.9 F&R	118.1 (F)	128.7 F&R
40 m.p.h. HI-CO, T-R		75.2 F&R	74.7 F&R
40 m.p.h. HI-CO, T-L		71.9 F&R	70.6 F&R
40 m.p.h. LO-CO, T-R		110.4 (F)	99.0 F&R
40 m.p.h. LO-CO, T-L		106.9 F&R	103.1 F&R
40 m.p.h. HI-R, SP. T-R		135.0 F&R	124.6 F&R
40 m.p.h. HI-R, SP. T-L		148.5 F&R	144.9 F&R
40 m.p.h. HI-L, SP. T-R		144.2 (F)	147.1 F&R
40 m.p.h. HI-L, SP. T-L		113.6 F&R	125.9 F&R

Table C.6. 1976 Monte Carol. Peak to Peak Steering Wheel Displacement Angle and Number of Reversals.

TEST	1st. EFF.		2nd. EFF.		3rd. EFF.	
	MAX. ANG. P-P	NO. OF REV.	MAX. ANG. P-P	NO. OF REV.	MAX. ANG. P-P	NO. OF REV.
HI-CO, ST.	30	2 (LF)	-	-	-	-
LO-CO, ST.	-	-	-	-	-	-
HI-R, SP. ST.	Failed Steering Wheel Angle Sensor.				110	4 (LF,LR)
HI-L, SP. ST.					130	4 (RF,RR)
HI-CO, T-R			-	-	-	-
HI-CO, T-L			-	-	-	-
LO-CO, T-R			-	-	60	4 -
LO-CO, T-L			-	-	40	2 -
HI-R, SP. T-R			-	-	55	4 -
HI-R, SP. T-L			-	-	200	3 (LF,LR)
HI-L, SP. T-R			-	-	80	1 (RF,RR)
HI-L, SP. T-L			-	-	150	3 (RF)

Table C.7. 1976 Ford LTD. Peak to Peak Steering Wheel Displacement Angle and Number of Reversals.

TEST	1st. EFF. MAX. ANG. P-P	1st. EFF. NO. OF REV.	2nd. EFF. MAX. ANG. P-P	2nd. EFF. NO. OF REV.	3rd. EFF. MAX. ANG. P-P	3rd. EFF. NO. OF REV.
HI-CO, ST.	Failed Steering Wheel Angle Sensor.				55	2 (LF)
LO-CO, ST.					100	3 -
HI-R, SP. ST.					200	3 (LF,LR)
HI-L, SP. ST.					140	3 (RF,RR)
HI-CO, T-R					80	6 (RR)
HI-CO, T-L					100	5 (LF)
LO-CO, T-R					180	5 (RF,RR)
LO-CO, T-L					180	4 (LF)
HI-R, SP. T-R					200	4 (LF)
HI-R, SP. T-L					230	4 (LF,LR)
HI-L, SP. T-R					220	4 (RF,RR)
HI-L, SP. T-L					230	4 (RF)

Table C.8. 1977 Mercury Bobcat Station Wagon. Peak to Peak Steering Wheel Displacement Angle and Number of Reversals.

TEST	1st. EFF. MAX. ANG. P-P	1st. EFF. NO. OF REV.	2nd. EFF. MAX. ANG. P-P	2nd. EFF. NO. OF REV.	3rd. EFF. MAX. ANG. P-P	3rd. EFF. NO. OF REV.
HI-CO, ST.	270	3 (RF,RR)	20	7 -	30	3 (LR)
LO-CO, ST.	150	5 (LF)	30	4 -	50	3 -
HI-R, SP. ST.	230	5 (LF)	80	4 (LF)	7,360	3 (LF,LR)
HI-L, SP. ST.	240	5 (RF)	180	3 (RF)	7,200	2 (RF,RR)
HI-CO, T-R			100	3 (RF)	80	2 (RF)
HI-CO, T-L			145	4 (LF)	120	2 (LF,LR)
LO-CO, T-R			80	5 (RF)	80	4 (RF)
LO-CO, T-L			140	3 (LF)	90	4 -
HI-R, SP. T-R			130	6 (LF)	180	5 (LF)
HI-R, SP. T-L			240	4 (LF)	230	2 (LF,LR)
HI-L, SP. T-R			220	2 (RF)	120	1 (RF,RR)
HI-L, SP. T-L			170	4 (RF)	160	5 (RF)

Table C.9. 1977 Pacer. Peak to Peak Steering Wheel Displacement Angle and Number of Reversals.

TEST	1st. EFF. MAX. ANG. P-P	1st. EFF. NO. OF REV.	2nd. EFF. MAX. ANG. P-P	2nd. EFF. NO. OF REV.	3rd. EFF. MAX. ANG. P-P	3rd. EFF. NO. OF REV.
HI-CO, ST.	72	7 -	160	3 (LR)	40	2 -
LO-CO, ST.	112	3 (RF)	112	5 (RF)	16	1 -
HI-R, SP. ST.	152	3 (LF,LR)	200	6 (LF,LR)	148	3 (LF)
HI-L, SP. ST.	240	3 (RF,RR)	240	6 (RF)	220	5 (RF,RR)
HI-CO, T-R			40	1 (RF)	190	2 (RR)
HI-CO, T-L			120	2 (LF,LR)	100	2 (LR)
LO-CO, T-R			40	3 (RF)	160	1 (RF)
LO-CO, T-L			152	2 (LF)	120	3 -
HI-R, SP. T-R			120	7 (LF)	340	2 (LF,LR)
HI-R, SP. T-L			240	5 (LF,LR)	280	2 (LF,LR)
HI-L, SP. T-R			240	1 (RF)	200	1 (RF,RR)
HI-L, SP. T-L			270	4 (RF)	200	5 (RF)

Table C.10. 1976 Nova Anti-Lock. Peak to Peak Steering Wheel Displacement and Number of Reversals.

TEST	1st. EFF. MAX. ANG. P-P	1st. EFF. NO. OF REV.	2nd. EFF. MAX. ANG. P-P	2nd. EFF. NO. OF REV.	3rd. EFF. MAX. ANG. P-P	3rd. EFF. NO. OF REV.
HI-CO, ST.	32	5	8	6	8	4
LO-CO, ST.	16	3	8	2	8	2
HI-R, SP. ST.	72	5	40	8	24	4
HI-L, SP. ST.	10	6	30	4	8	1
HI-CO, T-R			70	3	80	1
HI-CO, T-L			20	2	-	-
LO-CO, T-R			30	5	30	4
LO-CO, T-L			60	3	40	4
HI-R, SP. T-R			50	6	80	5
HI-R, SP. T-L			60	5	120	7
HI-L, SP. T-R			40	3	70	8
HI-L, SP. T-L			40	5	60	7

Table C.11. Repeatability of Experimental Stopping Distance Measurements Expressed as the Percentage Difference Between Two Shortest Stops.

TEST NO.	MONTE CARLO	FORD LTD	BOBCAT WAGON	PACER	NOVA ANTI-LOCK
1	1.4%	2.4%	1.6%	2.1%	3.0%
2	1.6	28.9	2.3	5.2	0.3
3	4.5	3.2	0.5	3.7	2.0
4	1.4	9.3	2.5	2.5	0.3
5	0.7	0.2	0.2	0.8	1.5
6	0.4	0.6	1.4	0.3	1.4
7	1.7	0.1	2.4	0.3	2.5
8	0.9	0.8	0.4	1.3	5.1
9	1.7	0.8	0.3	6.7	2.1
10	0.0	0.8	0.3	1.2	10.8
11	1.0	7.1	0.7	5.4	4.0
12	5.2	6.0	2.5	11.2	1.0
13	0.1	0.9	2.1	1.8	2.1
14	4.0	2.5	0.7	7.0	3.1
15	1.3	0.2	1.6	0.4	3.7
16	2.4	5.4	0.2	4.4	9.8
17	0.9	0.3	2.6	0.2	0.5
18	4.7	0.9	0.3	0.9	0.3
19	0.3	3.6	0.4	2.7	0.4
20	1.1	4.0	0.0	6.5	1.2
21	0.4	1.0	3.2	1.3	1.7
22	0.6	2.3	0.8	1.0	1.9
23	2.0	2.4	2.6	10.7	5.8
24	12.5	0.8	2.4	1.3	2.6
25	3.4	1.8	1.9	3.3	1.5
26	1.1	2.3	2.7	1.2	3.2
27	2.4	1.8	2.0	2.2	5.4
28	3.8	3.8	1.2	5.6	1.7
Average	2.2%	3.4%	1.4%	3.3%	2.8%

Table C.12. Average Stopping Distance Variability for Eight Surface and Braking Test Conditions. Average Values Derived From Chart in Table C.11.

HI - CO Straight	1.23%
LO - CO Straight	4.00%
HI - CO Turn	1.28%
LO - CO Turn	4.36%
SP - CO Straight	2.29%
SP - CO Turn (Heavily Load Tire on HI - CO)	2.44%
SP - CO Turn (Heavily Load Tire on LO - CO)	2.86%
SP - CO Turn	2.65%

Table C.13. Difference Between Right Turning (TR) and Left Turning (TL) Stopping Distance on High and Low Coefficient Surfaces. Average of 2nd. and 3rd. Effectiveness Test.

VEHICLE	HI - CO (TR - TL)		LO - CO (TR - TL)	
Monte Carlo	1.6 ft.	(2.3%)	12.6 ft.	(11.6%)
Ford LTD	0.1 ft.	(0.1%)	6.6 ft.	(5.2%)
Bobcat Wagon	4.3 ft.	(5.8%)	8.3 ft.	(7.1%)
Pacer	7.6 ft.	(10.5%)	13.2 ft.	(8.6%)
Nova Anti-lock	3.7 ft.	(5.2%)	0.3 ft.	(0.3%)
	Average	4.8%	Average	8.2%

Table C.14. Difference Between Right Turning (TR) and Left Turning (TL) Stopping Distance on the Split Coefficient Surfaces with the High Coefficient Surface on the Vehicles Right Side (HI - R) and on the Vehicles Left Side (HI - L). Average of 2nd. and 3rd. Effectiveness Test.

VEHICLE	SP - CO HI - R (TR - TL)		SP - CO HI - L (TR - TL)	
Monte Carlo	4.4 ft.	(4.0%)	8.2 ft.	(7.8%)
Ford LTD	16.6 ft.	(14.6%)	-1.6 ft.	(1.3%)
Bobcat Wagon	12.7 ft.	(12.0%)	-0.7 ft.	(0.6%)
Pacer	17.7 ft.	(13.7%)	-1.4 ft.	(1.0%)
Nova Anti-lock	-16.9 ft.	(13.0%)	25.9 ft.	(21.6%)
	Average	11.5%	Average	6.5%

Table C.15. Differences Between Right Turning (TR) and Left Turning (TL) Stopping Distances on the Split Coefficient Surface with the Heavily Load Tire on the High Coefficient Side (HLTR - HRTL) and on the Low Coefficient Side (HRTR - HLTL).

VEHICLE	SP - CO (HLTR - HRTL)		SP - CO (HRTR - HLTL)	
Monte Carlo	5.4 ft.	(5.0%)	7.2 ft.	(6.8%)
Ford LTD	11.6 ft.	(10.2%)	3.4 ft.	(2.7%)
Bobcat Wagon	7.0 ft.	(6.6%)	5.0 ft.	(4.4%)
Pacer	5.5 ft.	(4.2%)	10.9 ft.	(8.0%)
Nova Anti-lock	-1.0 ft.	(0.7%)	10.0 ft.	(8.3%)
	Average	5.3%	Average	6.0%

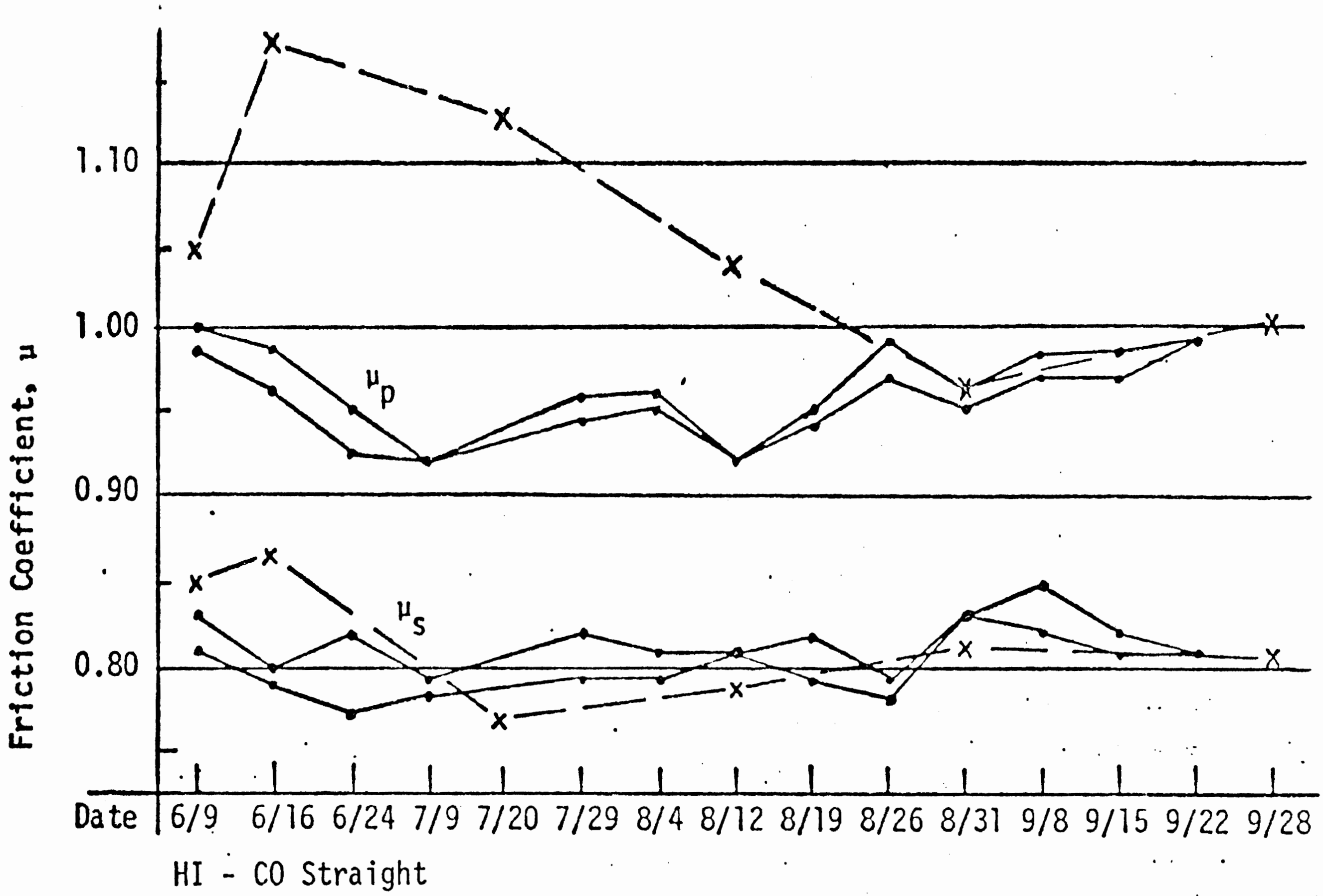
Table C.16. Difference in Stopping Distance in the Split Coefficient Straight Line Braking Test with the High Coefficient Surface on the Right and Left Side of the Vehicle [(HI - L) - (HI - R)]. Average of 2nd. and 3rd. Effectiveness Test.

Difference in Straight Line (ST) and In-A-Turn (T) Stopping Distance (T - ST) on the Split Coefficient Surfaces. T is the Average of all SP - CO In-A-Turn Test and ST is the Average of Both Straight Line Test in the 2nd. and 3rd. Effectiveness Test.

VEHICLE	SP - CO [(HI - L) - (HI - R)]		SP - CO (T - ST)	
Monte Carlo	0.7 ft.	(0.6%)	2.3 ft.	(2.1%)
Ford LTD	0.9 ft.	(0.7%)	3.0 ft.	(2.4%)
Bobcat Wagon	0.5 ft.	(0.4%)	-0.8 ft.	(0.7%)
Pacer	5.5 ft.	(4.6%)	15.3 ft.	(12.6%)
Nova Anti-lock	2.7 ft.	(2.2%)	13.3 ft.	(10.9%)
	Average	1.8%	Average	5.7%

Peak and Slide Surface Friction Measurements

Peak and slide surface friction measurements were made on the several test surfaces used at the Bendix Automotive Proving Grounds once each week during which vehicle test were conducted. Measurements were made with the DOT Surface Friction Dynamometer, SFD, and with the Bendix ASTM skid trailer. Both machines utilized the ASTM E-501 test tire loaded to 1100 pounds with a tire pressure of 24 psi: This data is graphed in Figures C.1 through C.6. Data from the Bendix skid trailer is incomplete because of several break downs during the test period. Data points for the Bendix skid trailer are the average values of the left and right wheels over one to three runs. Both data points are ploted for the two runs made on each date with SFD. No data was taken with the Bendix skid trailer on the Split Coefficient Curved Test Surface because it was impossible to operate the trailer in a straight path with both its wheels on the curved test surface over a distance long enough to obtain a measurement.



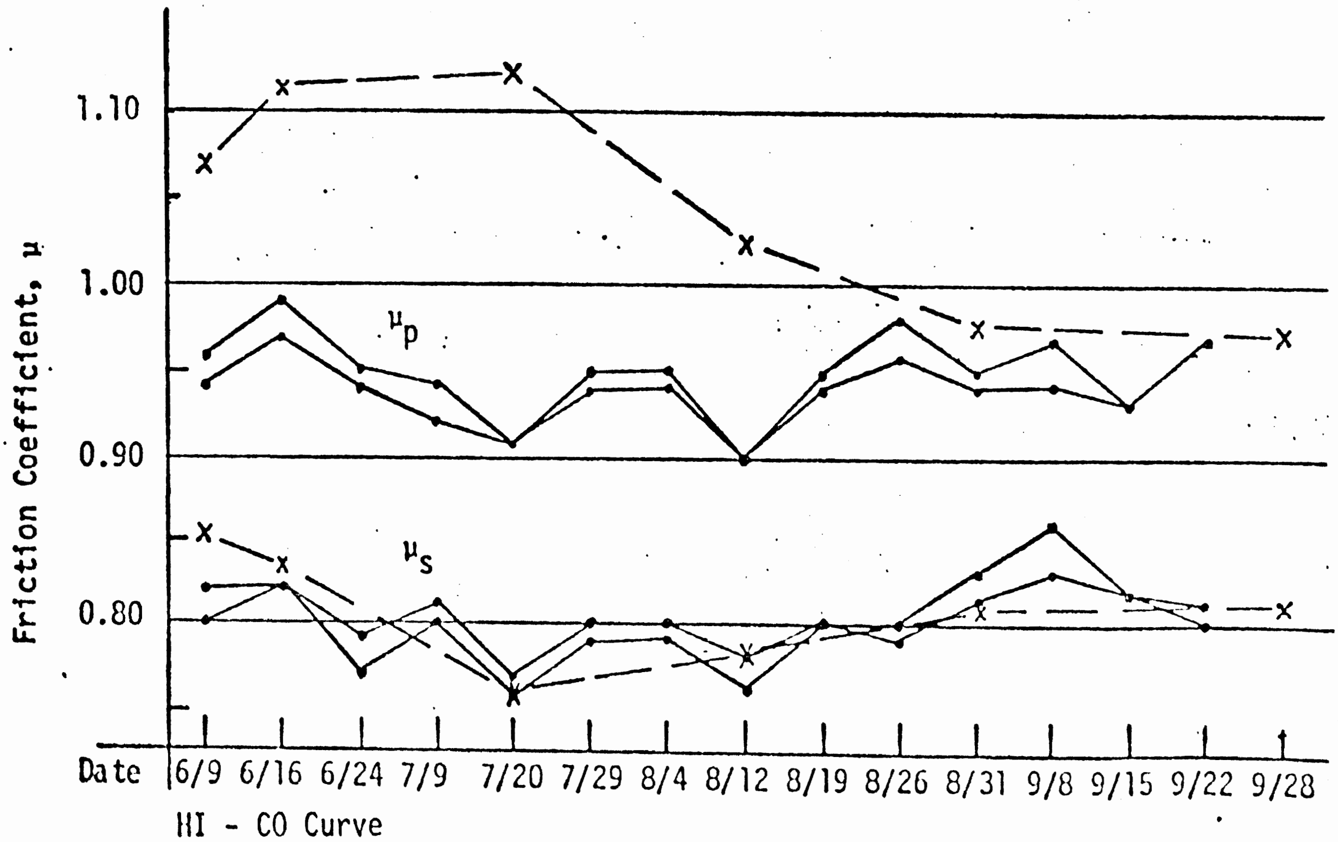


Figure C.1. Peak and Slide Surface Friction Measurements on High Coefficient Straight and Curve Test Surfaces. (.) Dot Surface Friction Dynamometer. (x) Bendix Skid Trailer.

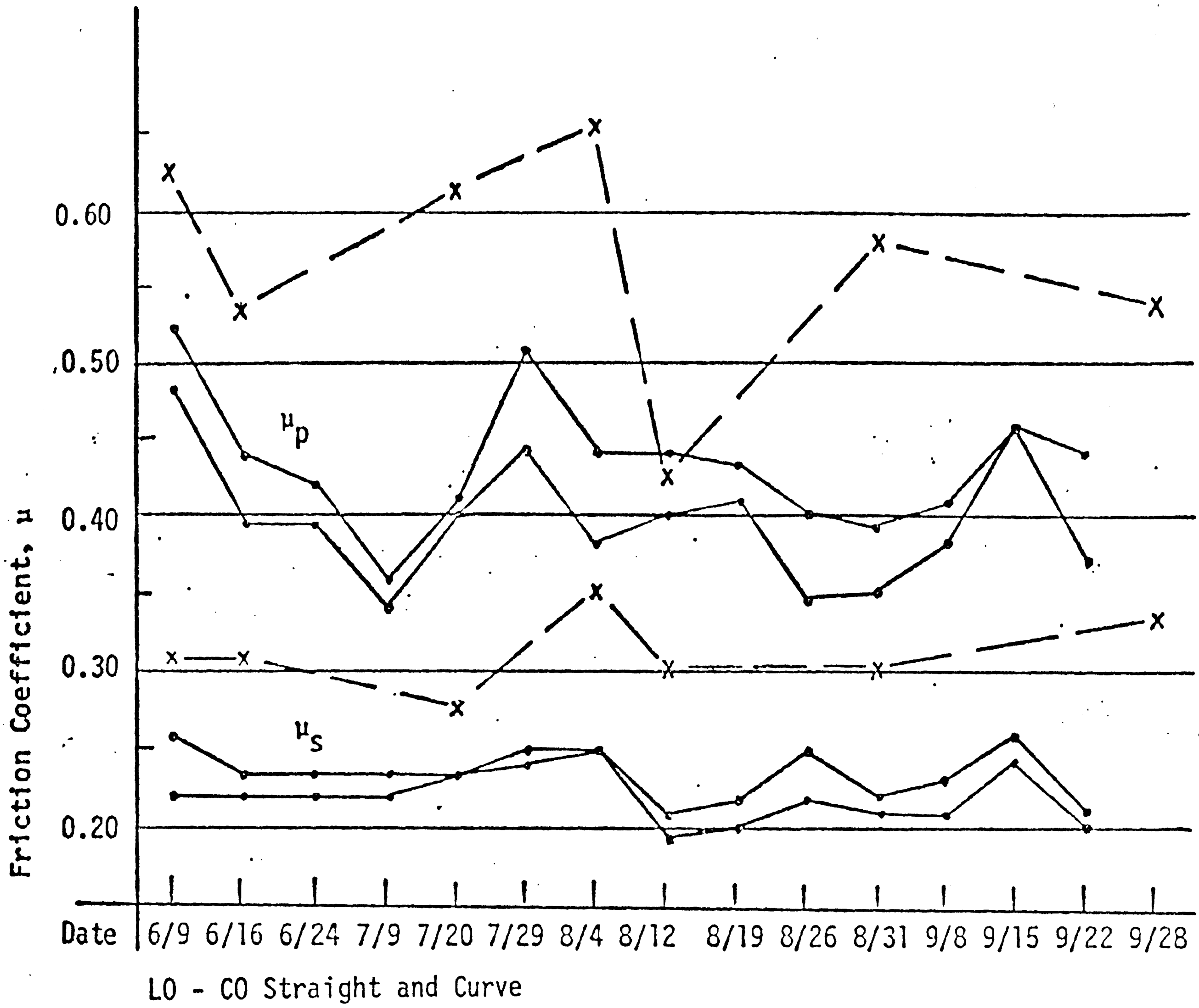


Figure C.2. Peak and Slide Surface Friction Measurements on the Low Coefficient Straight and Curve Test Surfaces. (.) Dot Surface Friction Dynamometer. (x) Bendix Skid Trailer.

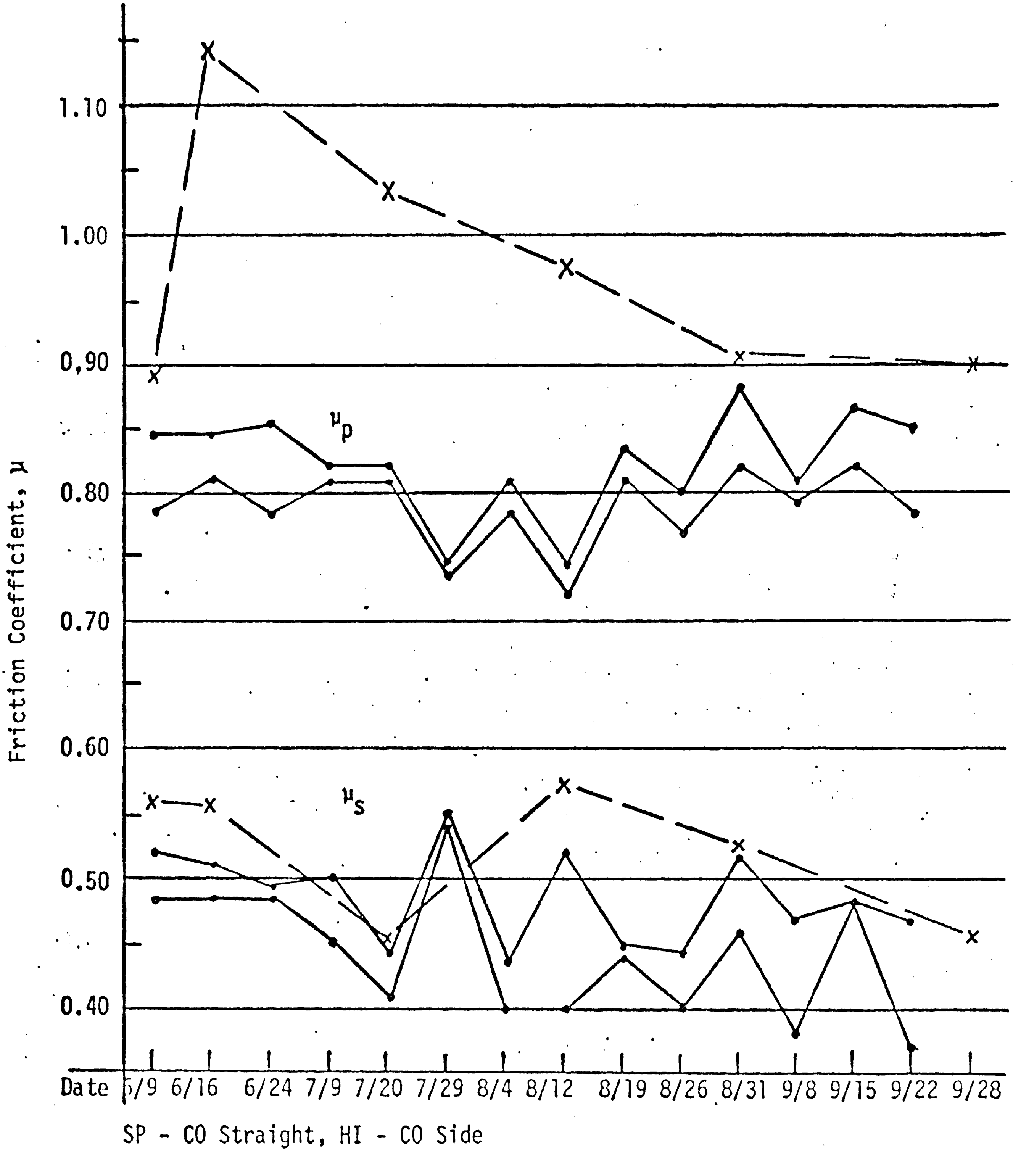


Figure C.3. Peak and Slide Surface Friction Measurements on the High Coefficient Side of the Straight Split Coefficient Test Surface. (·) Dot Surface Friction Dynamometer. (x) Bendix Skid Trailer.

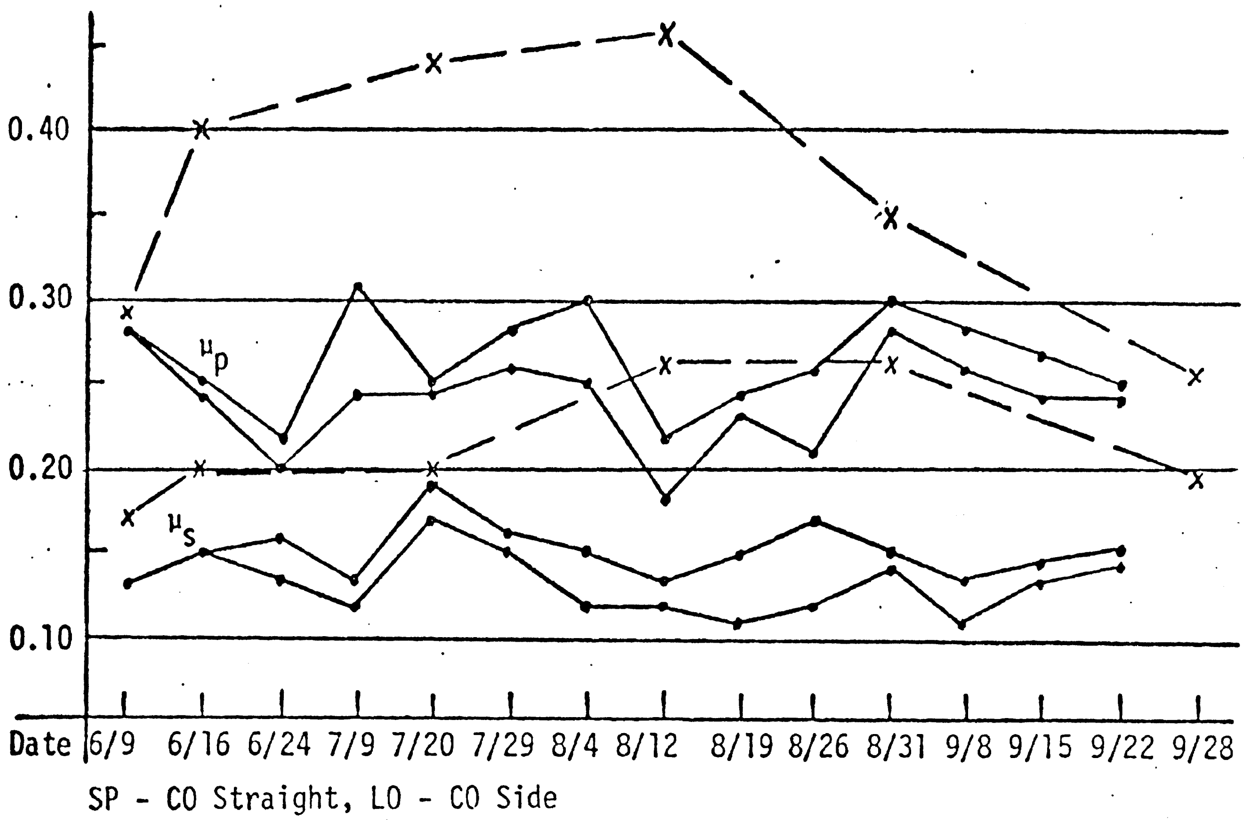


Figure C.4. Peak and Slide Surface Friction Measurements on the Low Coefficient Side of the Straight Split Coefficient Test Surface. (·) Dot Surface Friction Dynamometer. (x) Bendix Skid Trailer.

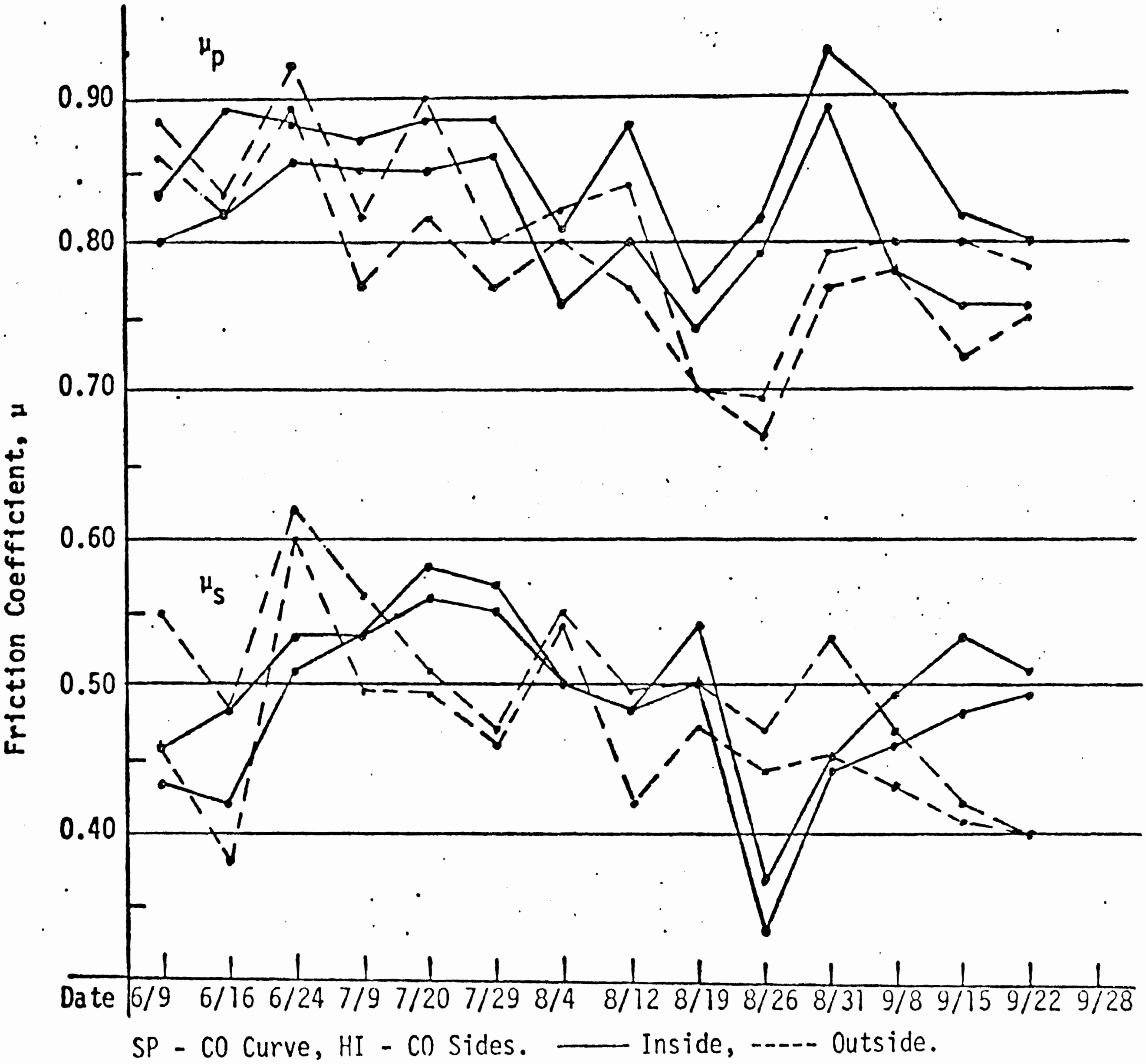


Figure C.5. Peak and Slide Surface Friction Measurements on the Two High Coefficient Sides of the Curved Split Coefficient Test Surface. Measurements made with the Dot Surface Friction Dynamometer.

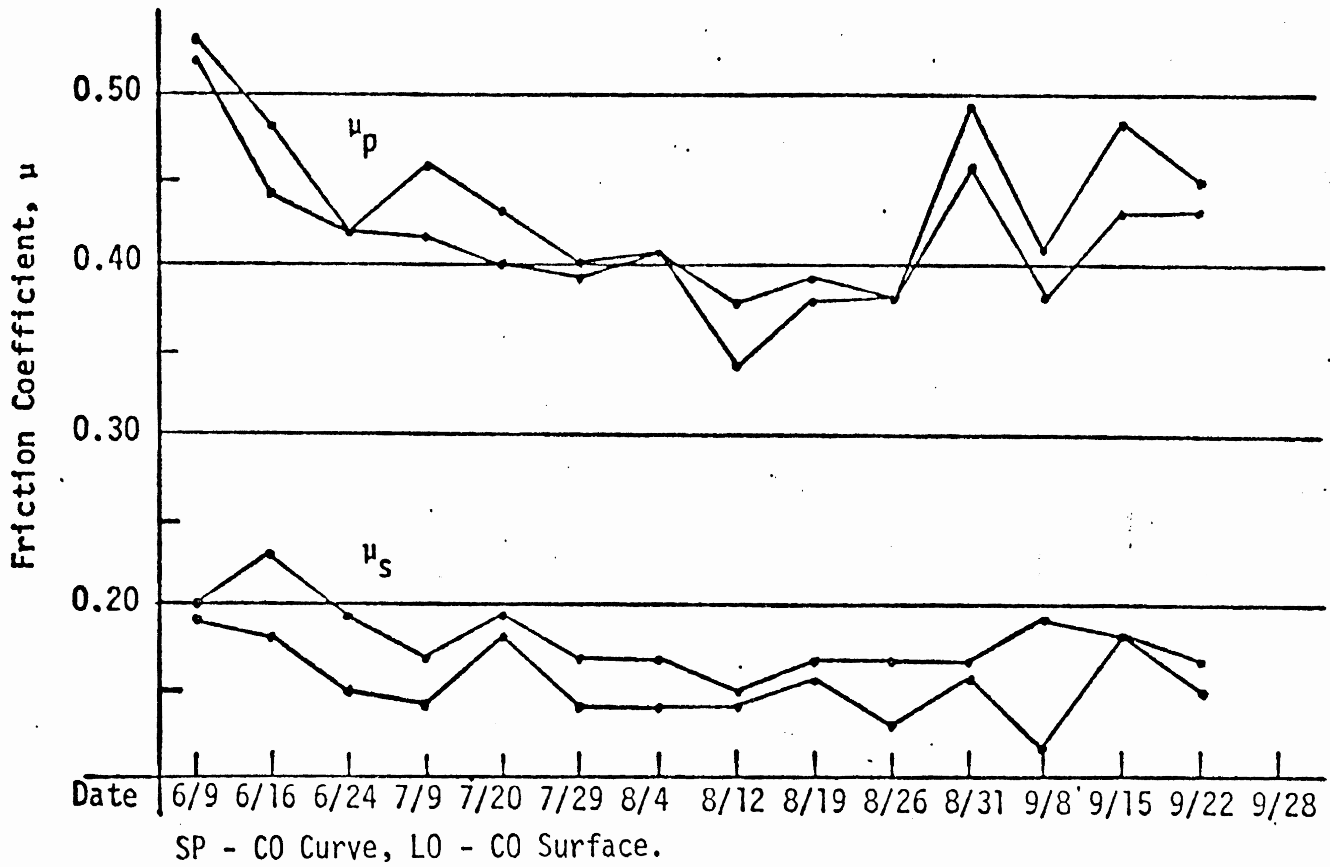


Figure C.6. Peak and Slide Surface Friction Measurements on the Low Coefficient Part of the Curved Split Coefficient Test Surface. Measurements Mark with the Dot Surface Friction Dynamometer.

Surface Friction Characterization as a Function of Velocity and Vertical Tire Load.

Peak friction of the dry asphalt and wet jennite straight line test surfaces at the Bendix Automotive Proving Grounds was measured as a function of tire load and velocity for application of the Braking Efficiency Technique (ref1). This data is plotted in Figures C.7 through C.9. The curves plotted are a least squares fit of the expression $\mu = Av^2 + Bv + C$ to the data points plotted. The equation of each curve is given in the figures. The three figures give data collected on the same surfaces on three different dates, June 8, July 19, and October 3, 1977.

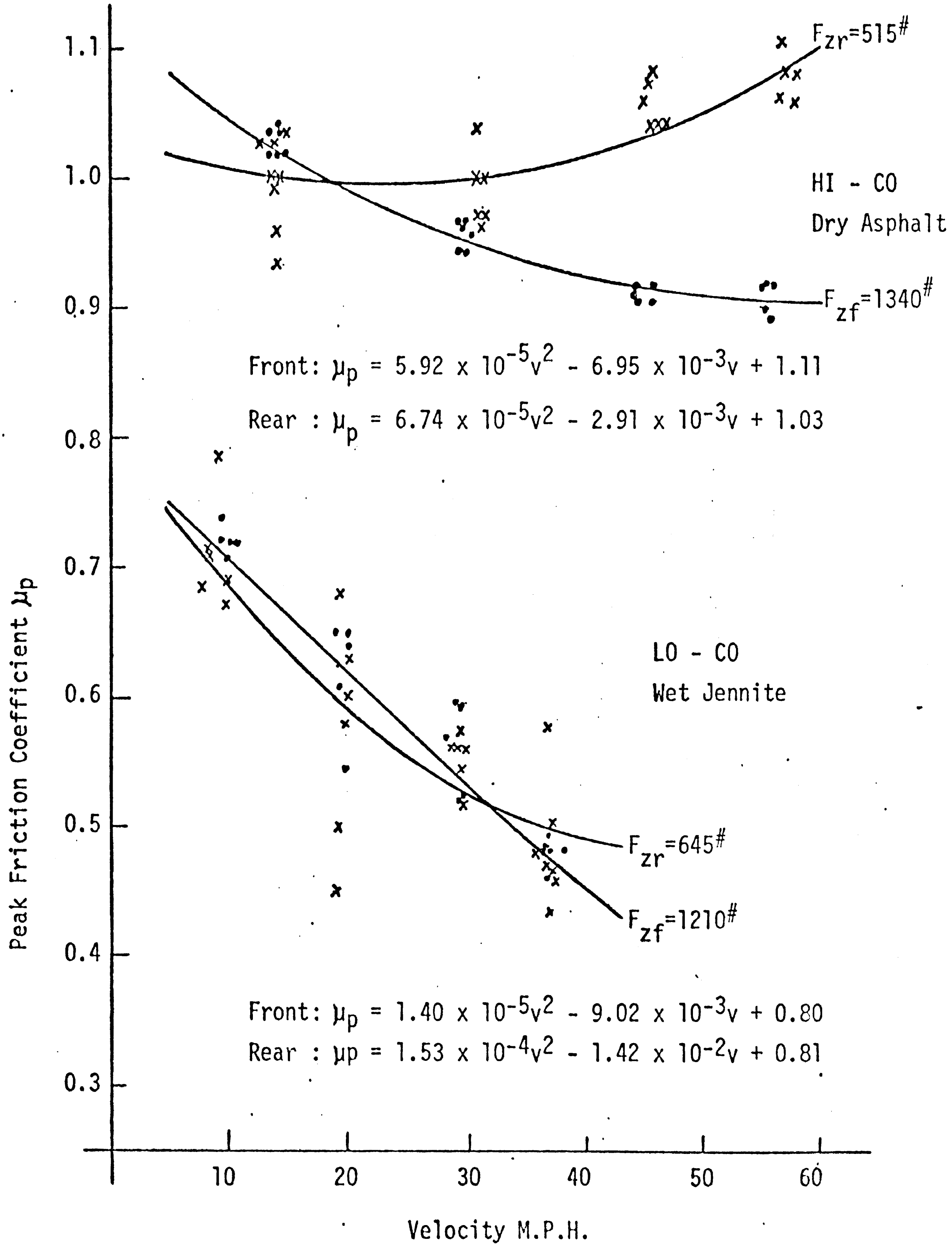


Figure C.7. Surface Friction Dynamometer Peak Friction Measurements on Dry Asphalt and Wet Jennite Taken on June 8, 1977 at the Bendix Antomotive Proving Grounds.

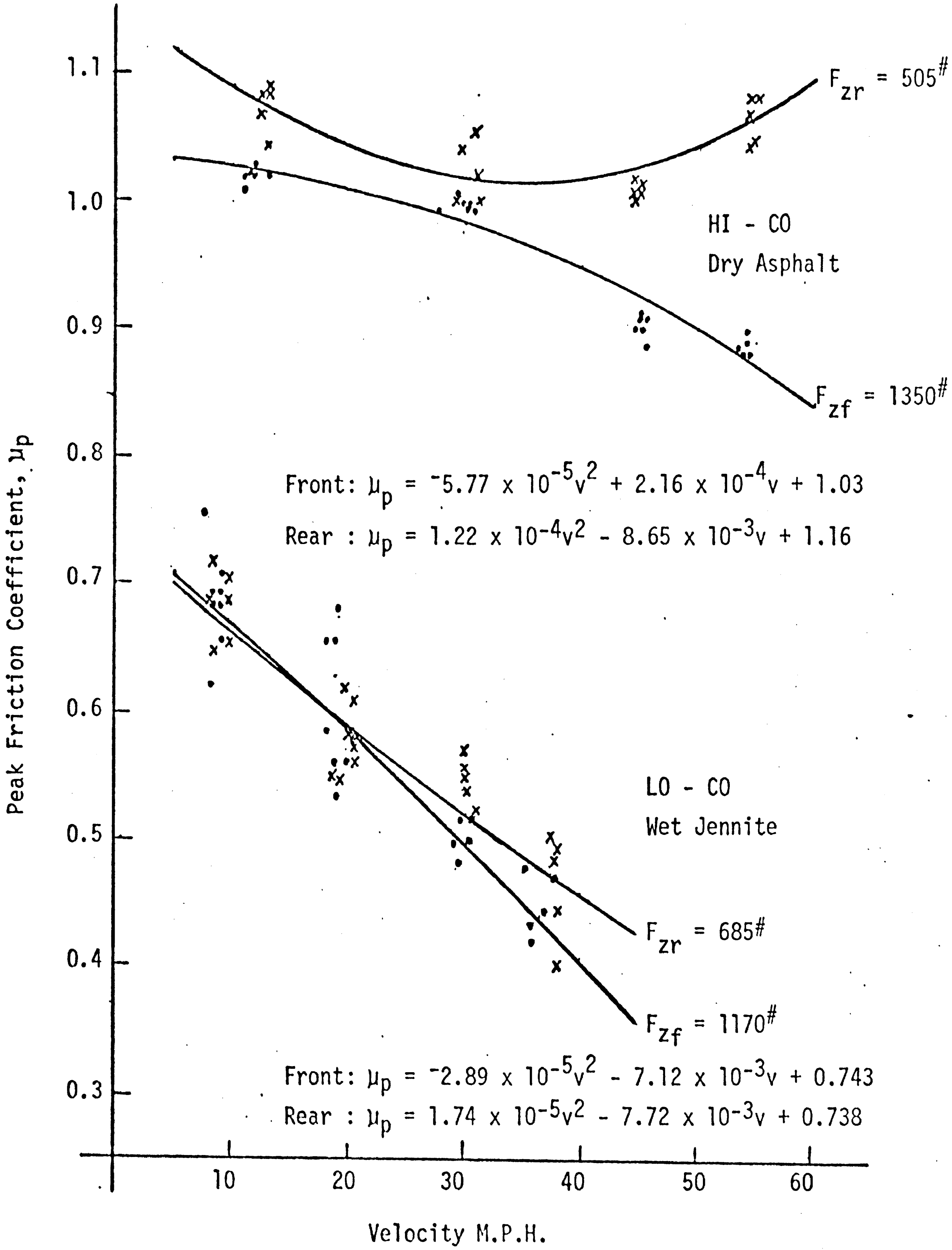


Figure C.8. Surface Friction Dynamometer Peak Friction Measurements on Dry Asphalt and Wet Jennite Taken on July 15, 1977 at the Bendix Automotive Proving Grounds.

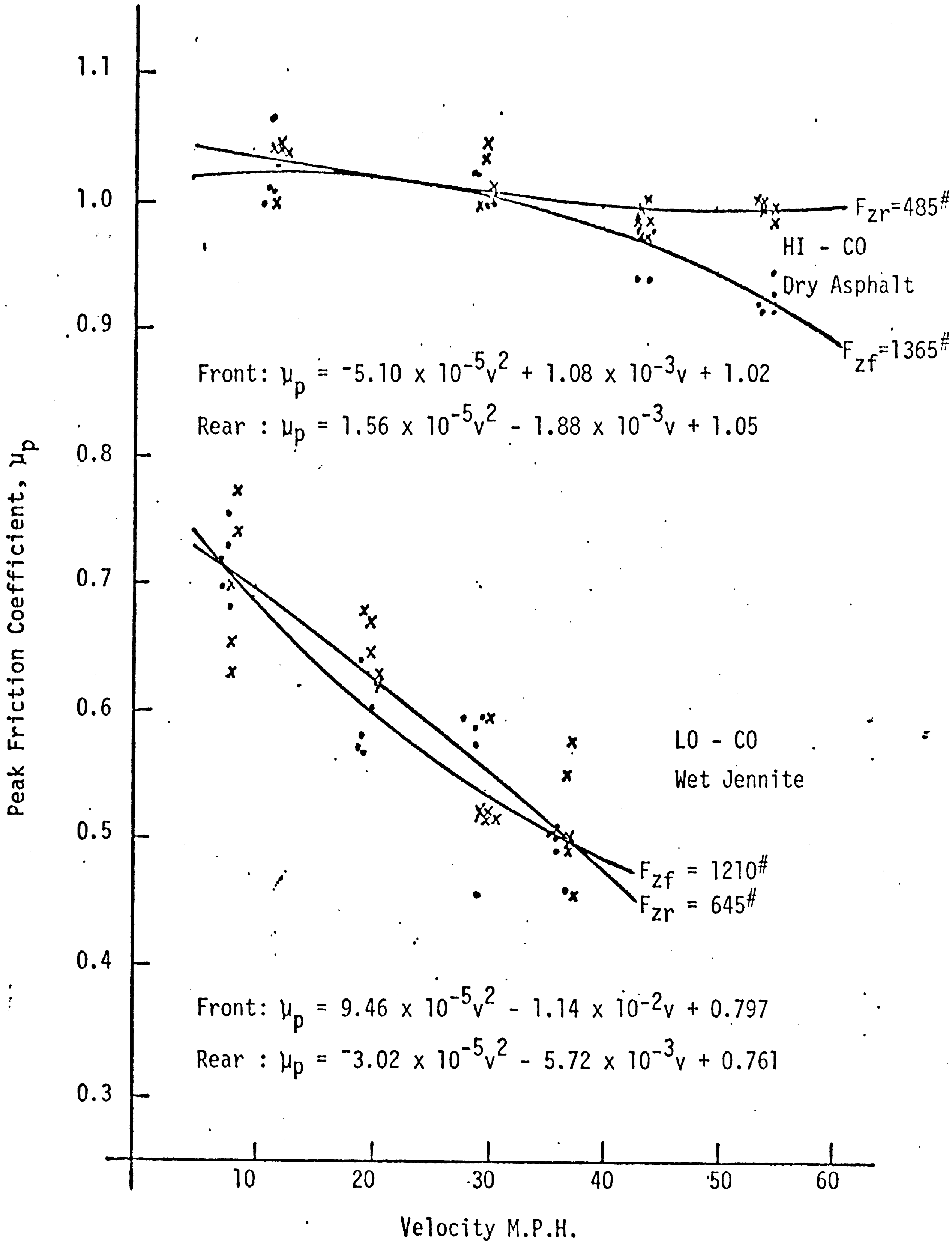


Figure C.9. Surface Friction Dynamometer Peak Friction Measurements on Dry Asphalt and Wet Jennite Taken on October 3, 1977 at the Bendix Automotive Proving Grounds.

BLANK

APPENDIX D

SIMULATION RESULTS USING DYNAMIC BRAKING MODEL

A tremendous amount of information was compiled during the simulation activities in this study - in the form of parametric inputs to the computer program, and in the form of processed and unprocessed simulated time histories. The purpose of this appendix is to present that information which supports the main text of the report, as well as simulation results which characterize braking performance by means other than stopping distance. Thus, documented here are the parameter values needed for the simulations, time histories which illustrate the nature of the anti-lock system that was modelled for this study, and processed data which quantify the capabilities of the vehicles to maintain a constant path-curvature when braking in a turn.

D.1 Vehicle and Tire Parameter Values. The definitions for the vehicle and tire parameters are provided in Reference [5]. Each vehicle required two sets of descriptors, one for the lightly - laden condition and the other for the GVW condition. Also needed were tables describing the spring rates at each wheel, the shock absorber characteristics, and the front end camber, caster, and toe data. The sources of this information are summarized in Table D.1. Following are the parameter values for each vehicle, consisting of:

1) Computer listings of non-tabular inputs, for both lightly-laden and GVW conditions,
2) tabular inputs, and
3) plots of the tire model characteristics, made at APL and based on the data published in Reference [7].

Table D.1. Sources of Vehicle and Tire Parameter Values

KEY: M - Measured at HSRI
E - Estimated from other parameter values
C - Calspan TIRF data
G - Generalized estimate
N - Value for Nova provided by APL
DC - Measured on Dodge Coronet
MS - Measured on 1971 Mustang
B - Measured on Brookwood station wagon
S - Specification

Parameter		Source				
APL No.	Symbol	Monte Carlo	Ford LTD	Chevy Nova	Bobcat Wagon	AMC Pacer
1	MS	M,E	M,E	M,E	M,E	M,E
2,3	MUF,MUR	E	E	E	E	E
4,5	ZF,ZR	M	M	M	M	M
6,7	A,B	M	M	M	M	M
8,9	TF,TR	S	S	S	S	S
10	TSR	M	M	M	E	M
11,13	IX,IZ	E	E	E	E	E
12	IY	M,E	M,E	M,E	M,E	M,E
14	IXZ	G	G	G	G	G
15	IR	DC	B	G	G	G
17	RF	M	M	M	E	M
19-22	AFKi	M	M	M	S	M
24	RR	M	M	M	S	M
25-28	CFiP,CRiP	M	M	M	G	M
30	KRS	DC	B	G	G	DC
31	RW	E	E	C	C	E
33	FOT	C	C	C	C	C
34-38	Ai	C	C	C	C	C
41	KSC	DC	G	G	G	G

Table D.1. (Cont.)

APL No.	Symbol	Monte Carlo	Ford LTD	Chevy Nova	Bobcat Wagon	AMC Pacer
42	NG	DC	B	S	S	DC
47	DC	E	E	E	E	E
49,50	IWF,IWR	E	B	E	E	E
51	IDR	DC	DC	DC	DC	DC
52	ARR	S	S	S	S	S
55	PT	S	S	S	S	S
56,57	YSAi	DC	G	G	G	G
58,59	PHSi	S	S	S	S	S
77-80	KTi	DC	DC	C	C	DC
85-88	Bi	C	C	C	C	C
92,93	DELF,DELR	M	M	M	E	M
130	AMCR	DC	G	G	G	G
131	ESP	G	G	G	G	G
132,133	KSLi	DC	B	DC	DC	DC
134,135	AAi	DC	B	N	DC	DC
136	CCR	DC	G	G	G	G
137	CFCR	DC	B	G	DC	DC
138	AP	DC	B	N	DC	DC
169	SNT	C	C	C	C	C
182-185	SII	C	C	C	C	C
196,197	EKI	G	G	G	G	G
202-205	APFi,APRi	C	C	C	C	C
206,207	MUSF,MUSR	C	C	C	C	C
219,220	FEEI	G	G	G	G	G
221,222	THEI	G	G	G	G	G
231,232	HI	DC	DC	DC	DC	DC
242,243	KCF,KCR	G	B	G	G	DC
244	KSR	G	B	G	G	DC
245-248	RBi	C	C	C	C	C
249-254	AFKi,ARKi	C	C	C	C	C
255-262	OFCi,ORCi	C	C	C	C	C
290	ROT	C	C	C	C	C
291-295	RAi	C	C	C	C	C

The data used to simulate the 1976 Monte Carlo is given in Tables D.2 - D.4 and Figures D.1 - D.3; the Ford LTD data is in Tables D.5 - D.7 and Figures D.4 - D.6; the Chevrolet Nova data is in Tables D.8 - D.10 and Figures D.7 - D.9; the data for the Mercury Bobcat is in Tables D.11 - D.13 and Figures D.10 - D.12; and the AMC Pacer data is in Tables D.14 - D.16 and Figures D.13 - D.15.

The tires from which the parameter values were measured were the following:

1) Uniroyal GR-70-15, which has TPC specification number of 1007, for the Monte Carlo,
2) Goodyear HR78x15 Custom Polysteel Radial, for the Ford LTD,
3) Goodyear E70x14, belted bias, for the Nova police package,
4) Firestone BR78x13 Steel Radial 500, for the Bobcat, and
5) Goodyear D78x14, Custom Power Cushion Polyglass, for the Pacer.

Parameter values selected to simulate the Kelsey-Hayes anti-lock system are listed in Table D.17, while the mathematical model of the system is in Appendix F.

D.2 Simulated Anti-lock Time Histories. Figure D.16 illustrates the operation of the anti-lock system by showing time histories of the primary dynamic variables. The inputs to the anti-lock controller are W and $\dot{W}$, shown in the units radians/sec and radians/sec/sec. (With the assumed rolling radius of 12.1 inches, a 10 m.p.h. speed at the tire surface corresponds to 14.5 rad/sec, and a 1.0g acceleration corresponds to 32 rad/sec/sec.) The manner in which the volume in the expansion chamber affects the pressure re-apply rate can be seen, as can the dependency of S (the logical variable which defines the status of the solenoid actuator) on H, the "HOLD ON" circuit output.

Table D.2. Parameter Values of the Monte Carlo, Under the Lightly Loaden Condition.

PARAMETER VALUES - MODEL C - VEHICLE MODEL - 1976 CHEVROLET MONTE CARLO

1	MS= 9.2800	2	MUF= 0.59000	3	MUR= 0.96000	4	ZF= 4.7000	5	ZR= 4.7000
6	A= 48.400	7	B= 67.600	8	TF= 61.900	9	TR= 60.700	10	TSR= 35.000
11	IX= 6000.0	12	IY= 32000.	13	IZ= 42000.	14	IXZ= 0.0	15	IR= 600.00
16	MODR= 30.000	17	WF= 36000.	18	STOP= 10.000	19	AKF1= 122.00	20	AKF2= 122.00
21	AKR3= 107.00	22	AKR4= 107.00	23	= 0.0	24	RR= 0.0	25	CF1P= 100.00
26	CF2P= 100.00	27	CR3P= 65.000	28	CR4P= 65.000	29	ZRAS= 0.0	30	KRS= 0.73000E-01
31	W= 14.000	32	SCAL= 3000.0	33	FOT= 0.50000	34	A0= 849.33	35	A1= 12.230
36	A2= 3907.9	37	A3= 0.18200	38	A4= -848.09	39	TIR = 0.0	40	TOR = 0.0
41	RSC= 500.00	42	NG= 16.000	43	= 0.0	44	= 0.0	45	= 0.0
46	= 0.0	47	IFW= 8.0000	48	IF = 0.0	49	IWF= 16.000	50	IWR= 16.000
51	IDR= 0.70000	52	ARR= 2.7300	53	TSF = 0.0	54	KFS = 0.0	55	PT= 1.1200
56	YSA1= 4.5900	57	YSA2= -4.5900	58	PHS1=-0.17000	59	PHS2= 0.17000	60	CTS= 1.0000
61	IDF= 0.0	62	ARF= 0.0	63	P-IN= 0.0	64	Q-IN= 0.0	65	R-IN= 0.0
66	U-IN= 40.000	67	V-IN= 0.0	68	W-IN= 0.0	69	X-IN= 0.0	70	Y-IN= 0.0
71	Z-IN= -17.939	72	THIN=-0.79477E-01	73	PHIN= 0.0	74	PSIN= 0.0	75	DT= 0.50000E-02
76	TN= 10.000	77	KT1= 1400.0	78	KT2= 1400.0	79	KT3= 1400.0	80	KT4= 1400.0
81	RPS1= 53.446	82	RPS2= 53.446	83	RPS3= 52.801	84	RPS4= 52.801	85	B1=-0.23990E-03
86	B2= 0.0	87	B3= 1.1810	88	B4= 0.30980E-07	89	D1DT= 0.0	90	D2DT= 0.0
91	D3DT= 0.0	92	DELF= 0.0	93	DELR= 0.0	94	DEL3= 0.0	95	PHDT= 0.0
96	PHIR= 0.0	97	DFW1= 0.0	98	DFW2= 0.0	99	U1PR= 0.0	100	U2PR= 0.0
101	U3PR= 0.0	102	U4PR= 0.0	103	S1PR= 0.0	104	S2PR= 0.0	105	S3PR= 0.0
106	S4PR= 0.0	107	PPRT= 1.0000	108	FREQ= 0.50000	109	RWSF= 15.000	110	TUMX= 0.0
111	KTJ= 0.0	112	VC= 0.0	113	MTSW= 1.0000	114	DSWM= 0.0	115	TST= 0.0
116	USLP= 100.00	117	CGAM= 0.0	118	CS= 0.0	119	TQR= 0.0	120	TUF= 0.0
121	PFL= 700.00	122	TI= 0.0	123	DSW= 0.0	124	= 0.0	125	IS5= 0.0
126	SW15= 0.0	127	PUSR= 0.0	128	VTPS= 1.0000	129	VHTP= 1.0000	130	AMCR= 0.85000E-01
131	ESP= 0.0	132	KSL1= 64000.	133	KSL2= 64000.	134	AA1= 6.6200	135	AA2= 6.6200
136	CCR= 11.000	137	CFCR= 54.000	138	AP= 5.2000	139	EP1= 0.0	140	EP2= 0.0
141	AERO= 0.0	142	VYW = 0.0	143	OMXW= 0.0	144	OMZW= 0.0	145	RHOA= 0.0
146	CYP = 0.0	147	CYR = 0.0	148	CZAL= 0.0	149	CZQ = 0.0	150	CLP = 0.0
151	CLR = 0.0	152	CMAL= 0.0	153	CMQ = 0.0	154	CNP = 0.0	155	CNR = 0.0
156	SF = 0.0	157	VLEN= 0.0	158	REWV= 0.0	159	= 0.0	160	= 0.0
161	= 0.0	162	= 0.0	163	= 0.0	164	= 0.0	165	= 0.0
166	= 0.0	167	= 0.0	168	= 0.0	169	SNT= 85.000	170	SNSO= 30.000
171	SNS1= 85.000	172	SNSR= 2.0000	173	DIST= 0.0	174	PL = 0.0	175	TSCP= 0.25000
176	= 1.0000	177	= 0.0	178	= 0.0	179	= 0.0	180	PASS= 0.0
181	= 0.0	182	SI1= 0.10400	183	SI2= 0.10400	184	SI3= 0.10400	185	SI4= 0.10400
186	= 0.0	187	= 0.0	188	= 0.0	189	= 0.0	190	= 0.0
191	= 0.0	192	MTCB= 0.20000	193	DCSW= 0.0	194	LDF= 0.0	195	LDRF= 0.0
196	EK1= 0.0	197	EK2= 0.0	198	BMPL= 0.0	199	BMPS= 0.0	200	BMPH= -1.5000
201	XB= 0.0	202	APF1= 1.0765	203	APF2=-0.86290E-04	204	APR1= 1.0765	205	APR2=-0.86290E-04
206	MUSF= 0.84880	207	MUSR= 0.84880	208	BCON= 0.30000E-01	209	FCSW= 0.0	210	=-0.94700E-04
211	=-0.94700E-04	212	= 0.0	213	= 0.0	214	= 0.0	215	= 0.0
216	= 0.0	217	= 0.0	218	= 0.0	219	FEE1= 0.0	220	FEE2= 0.0
221	THE1= 0.0	222	THE2= 0.0	223	= 0.0	224	= 0.0	225	= 0.0
226	= 0.0	227	= 0.0	228	= 0.0	229	= 0.0	230	= 0.0
231	H1= 400.00	232	H2= 400.00	233	LAMD= 1.0000	234	= 0.0	235	= 0.0
236	= 0.0	237	= 0.0	238	BR1= 1.0000	239	BR2= 1.0000	240	BR3= 1.0000
241	BR4= 1.0000	242	KCF= 0.0	243	KCR= 0.0	244	KSR= 0.0	245	RB1=-0.23990E-03
246	RB2= 0.0	247	RB3= 1.1810	248	RB4= 0.30980E-07	249	AFK1=-0.29352E-02	250	AFK2= 0.23424E-02
251	AFK3= 1.0440	252	ARK1=-0.29352E-02	253	ARK2= 0.23424E-02	254	ARK3= 1.0440	255	OFC0= 0.0
256	OFC1=-0.96984E-03	257	OFC2=-0.29304E-02	258	OFC3= -7.8840	259	ORC0= 0.0	260	ORC1=-0.96984E-03
261	ORC2=-0.29304E-02	262	ORC3= -7.8840	263	CP0F= 0.0	264	CP1F= 0.0	265	CP2F= 0.0
266	CP0R= 0.0	267	CP1R= 0.0	268	CP2R= 0.0	269	CR0F= 0.0	270	CR1F= 0.0
271	CR2F= 0.0	272	CR0R= 0.0	273	CR1R= 0.0	274	CR2R= 0.0	275	= 0.0
276	= 0.0	277	RMPN= 0.0	278	TQB0= 0.0	279	TQB1= 0.0	280	= 0.0
281	= 0.0	282	= 0.0	283	= 0.0	284	HFC= 0.0	285	HRC= 0.0
286	DRSW= 0.0	287	AXLE= 1.0000	288	DUAL= 0.0	289	TIRE= 4.0000	290	RUT = 0.50000
291	RA0 = 849.33	292	RA1 = 12.230	293	RA2 = 3907.9	294	RA3 = 0.18200	295	RA4 = -848.09

Table D.3. Parameter Values of the Monte Carlo, Under the GVW Condition.

PARAMETER VALUES - MODEL C - VEHICLE MODEL - 1976 CHEVROLET MONTE CARLO

1	MS= 12.940	2	MUF= 0.59000	3	MUR= 0.96000	4	ZF= 1.5000	5	ZR= 1.8000
6	A= 58.000	7	B= 58.000	8	TF= 61.900	9	TR= 60.700	10	TSR= 35.000
11	IX= 5000.0	12	IY= 55000.	13	IZ= 63000.	14	IXZ= 0.0	15	IR= 600.00
16	RSGR= 30.000	17	RF= 36000.	18	STOP= 10.000	19	AKF1= 108.00	20	AKF2= 108.00
21	AKF3= 320.00	22	AKR4= 320.00	23	= 0.0	24	RR= 0.0	25	CF1P= 100.00
26	CF2F= 100.00	27	CP3P= 65.000	28	CR4P= 65.000	29	ZBAS= 0.0	30	KRS= 0.73000E-01
31	FW= 14.000	32	SCAL= 3000.0	33	FOT= 0.50000	34	A0= 849.33	35	A1= 12.230
36	A2= 3907.9	37	A3= 0.18200	38	A4= -848.09	39	TIR = 0.0	40	TCR = 0.0
41	KSC= 500.00	42	NG= 16.000	43	= 0.0	44	= 0.0	45	= 0.0
46	= 0.0	47	IFW= 8.0000	48	IF = 0.0	49	IWF= 16.000	50	IWR= 16.000
51	ICP= 0.70000	52	ARR= 2.7300	53	TSF = 0.0	54	KFS = 0.0	55	PT= 1.1200
56	YSA1= 4.5900	57	YSA2= -4.5900	58	PHS1=-0.17000	59	PHS2= 0.17000	60	CTSW= 1.0000
61	ICF= 0.0	62	ARF= 0.0	63	P-IN= 0.0	64	Q-IN= 0.0	65	R-IN= 0.0
66	U-IN= 42.000	67	V-IN= 0.0	68	W-IN= 0.0	69	X-IN= 0.0	70	Y-IN= 0.0
71	Z-IN= -14.650	72	THIN=-0.12296	73	PHIN= 0.0	74	PSIN= 0.0	75	DT= 0.50000E-02
76	TN= 10.000	77	KT1= 1400.0	78	KT2= 1400.0	79	KT3= 1400.0	80	KT4= 1400.0
81	RPS1= 56.749	82	RPS2= 56.749	83	RPS3= 56.973	84	RPS4= 56.973	85	B1=-0.23990E-03
86	B2= 0.0	87	B3= 1.1810	88	B4= 0.30980E-07	89	D1DT= 0.0	90	D2DT= 0.0
91	D3DT= 0.0	92	DELF= -1.8000	93	DELR= -4.6000	94	DEL3= 0.0	95	PHCT= 0.0
96	PHIR= 0.0	97	DFW1= 0.0	98	DFW2= 0.0	99	U1PR= 0.0	100	U2PP= 0.0
101	U3PP= 0.0	102	U4PP= 0.0	103	S1PR= 0.0	104	S2PR= 0.0	105	S3PR= 0.0
106	S4PR= 0.0	107	PPPT= 1.0000	108	FREQ= 0.50000	109	RWSF= 15.000	110	TMAX= 0.0
111	KTC= 0.0	112	VC= 0.0	113	MTSW= 1.0000	114	DSWM= 67.000	115	TST= 0.0
116	DSLF= 0.50000	117	CGAM= 2.0000	118	CS= 2.0000	119	TCR= 0.0	120	TCF= 0.0
121	PFL= 700.00	122	T1= 0.0	123	DSW= 0.0	124	= 0.0	125	ISWS= 0.0
126	SW15= 0.0	127	PCSW= 0.0	128	VTPS= 3.0000	129	VHTP= 2.0000	130	AMCR= 0.85000E-01
131	ESF= 0.0	132	KSL1= 64000.	133	KSL2= 64000.	134	AA1= 6.6200	135	AA2= 6.6200
136	CCR= 11.000	137	CFCR= 54.000	138	AP= 5.2000	139	EP1= 0.0	140	EP2= 0.0
141	AERC= 0.0	142	VYW= 0.0	143	CMXW= 0.0	144	CMZW= 0.0	145	RHCA= 0.0
146	CYP = 0.0	147	CYR = 0.0	148	CZAL= 0.0	149	CZQ = 0.0	150	CLP = 0.0
151	CLR = 0.0	152	CMAL= 0.0	153	CMQ = 0.0	154	CNP = 0.0	155	CNR = 0.0
156	SF = 0.0	157	VLEN= 0.0	158	REWV= 0.0	159	= 0.0	160	= 0.0
161	= 0.0	162	= 0.0	163	= 0.0	164	= 0.0	165	= 0.0
166	= 0.0	167	= 0.0	168	= 0.0	169	SNT= 85.000	170	SNSO= 81.000
171	SNS1= 65.000	172	SNSW= 2.0000	173	DIST= 0.0	174	PL = 0.0	175	TSCP= 0.25000
176	= 1.0000	177	= 0.0	178	= 0.0	179	= 0.0	180	PASS= 0.0
181	= 0.0	182	SI1= 0.10400	183	SI2= 0.10400	184	SI3= 0.10400	185	SI4= 0.10400
186	= 0.0	187	= 0.0	188	= 0.0	189	= 0.0	190	= 0.0
191	= 0.0	192	MTOB= 0.20000	193	DCSW= 0.0	194	LDF= 0.0	195	LDRF= 0.0
196	EK1= 0.0	197	EK2= 0.0	198	BMPL= 0.0	199	BMPS= 0.0	200	BMPH= -1.5000
201	XB= 0.0	202	APF1= 1.0765	203	APF2=-0.86290E-04	204	APR1= 1.0765	205	APR2=-0.86290E-04
206	MUSF= 0.84880	207	MUSR= 0.84880	208	BCON= 0.30000E-01	209	FCSW= 0.0	210	=-0.94700E-04
211	=-0.94700E-04	212	= 0.0	213	= 0.0	214	= 0.0	215	= 0.0
216	= 0.0	217	= 0.0	218	= 0.0	219	FEE1= 0.0	220	FEE2= 0.0
221	THE1= 0.0	222	THE2= 0.0	223	= 0.0	224	= 0.0	225	= 0.0
226	= 0.0	227	= 0.0	228	= 0.0	229	= 0.0	230	= 0.0
231	H1= 400.00	232	H2= 400.00	233	LAMD= 1.0000	234	= 0.0	235	= 0.0
236	= 0.0	237	= 0.0	238	BR1= 1.0000	239	BR2= 1.0000	240	BR3= 1.0000
241	BR4= 1.0000	242	KCF= 0.0	243	KCR= 0.0	244	KSR= 0.0	245	RB1=-0.23990E-03
246	RB2= 0.0	247	RB3= 1.1810	248	RB4= 0.30980E-07	249	AFK1=-0.29352E-02	250	AFK2= 0.23424E-02
251	AFK3= 1.0440	252	ARK1=-0.29352E-02	253	ARK2= 0.23424E-02	254	ARK3= 1.0440	255	DFC0= 0.0
256	CFC1=-0.96984E-03	257	CFC2=-0.29304E-02	258	CFC3= -7.8840	259	DRC0= 0.0	260	DRC1=-0.96984E-03
261	CRC2=-0.29304E-02	262	CPC3= -7.8840	263	CP0F= 0.0	264	CP1F= 0.0	265	CP2F= 0.0
266	CP0R= 0.0	267	CP1R= 0.0	268	CP2R= 0.0	269	CR0F= 0.0	270	CR1F= 0.0
271	CR2F= 0.0	272	CR0R= 0.0	273	CR1R= 0.0	274	CR2R= 0.0	275	= 0.0
276	= 0.0	277	BMPN= 0.0	278	TQ30= 0.0	279	TQ31= 0.0	280	= 0.0
281	= 0.0	282	= 0.0	283	= 0.0	284	HFC= 0.0	285	HRC= 0.0
286	DRSW= 0.0	287	AXLE= 1.0000	288	DUAL= 0.0	289	TIRE= 4.0000	290	ROT = 0.50000
291	RA0 = 849.33	292	RA1 = 12.230	293	RA2 = 3907.9	294	RA3 = 0.18200	295	RA4 = -848.09

Table D.4. Tabular Inputs for Monte Carlo.

Spring Rates (Measured at HSRI)

Front δ (in.)	Front F (lbs)	Rear δ (in)	Rear F (lbs)
-100.	-4225.	-100.	-6264.
-10.	-4225.	-10.	-6264.
-2.75	-600.	-3.75	-750.
-2.3	-375.	-3.3	-353.
-1.72	-210.	0.0	0.0
0.0	0.0	4.75	508.
4.2	512.	5.	800.
4.5	800.	10.	6640.
10.	6080.	100.	6640.
100.	6080.		

Brake Torque (Measured at HSRI)

Front P (psi)	Front TQ (in-lbs)	Rear P(psi)	Rear TQ (in-lbs)
0.	0	0	0
150	0	150	0
1200	32000	800	6300
		1700	22000

Table D.4. (Cont.)

Shock Absorber Data (G)

Front and Rear: C = 3.0 lb/(in/sec) $\dot{\delta} < 0$
= 10.0 lb/(in/sec) $\dot{\delta} > 0$

Camber, Caster, and Toe Functions (Dodge Coronet, Ref. [5])

Displacement	Camber	Caster	Toe
0.	0.	.75	0.
1.	.41	.75	-.37
2.	.98	.75	-.57
3.	1.26	.75	-.85
4.	1.22	.75	-1.05
5.	.95	.75	-1.21
6.	.43	.75	-1.36

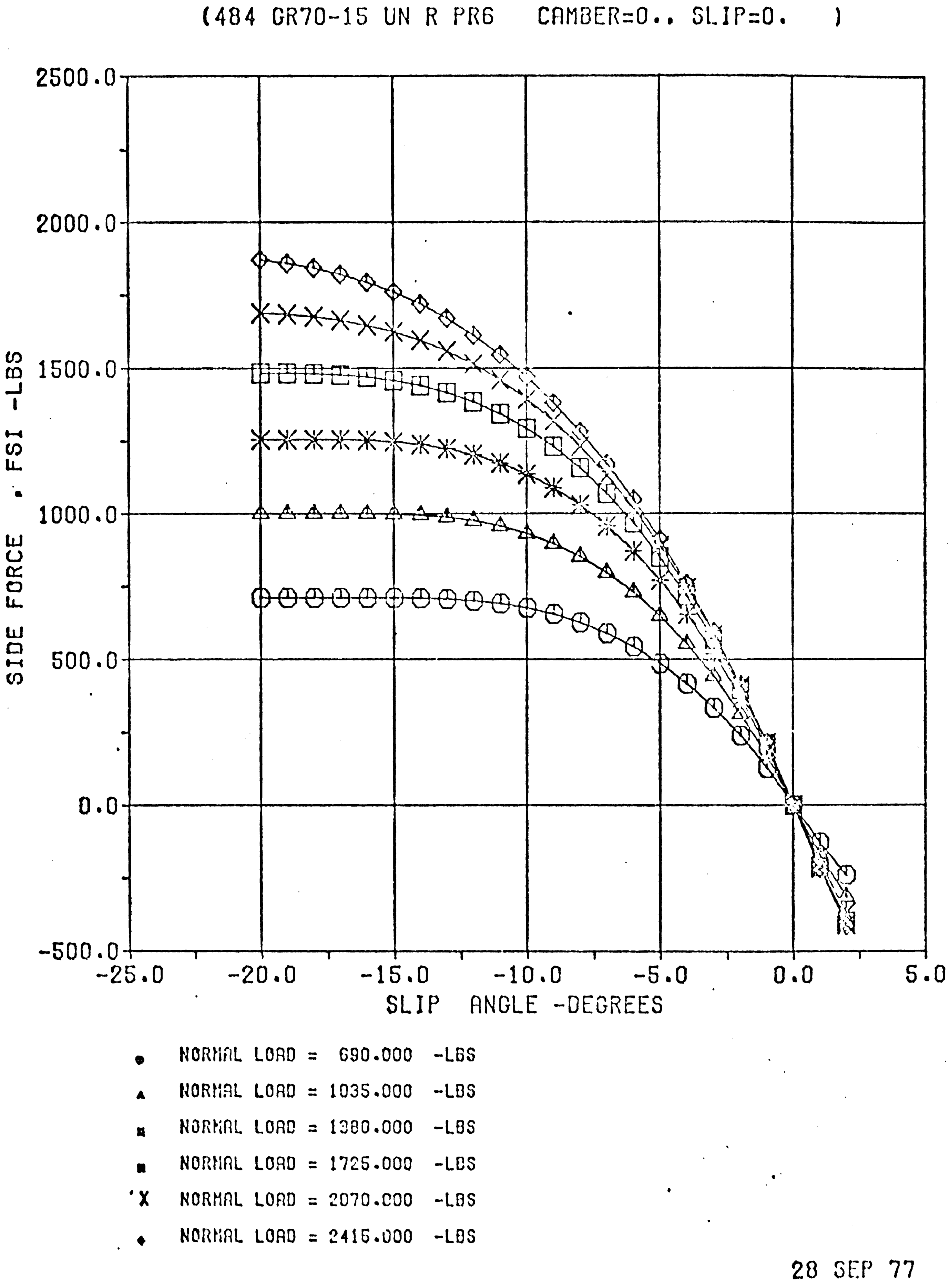


Figure D.1. Tire side force vs. slip angle, with normal load varying, for the Monte Carlo.

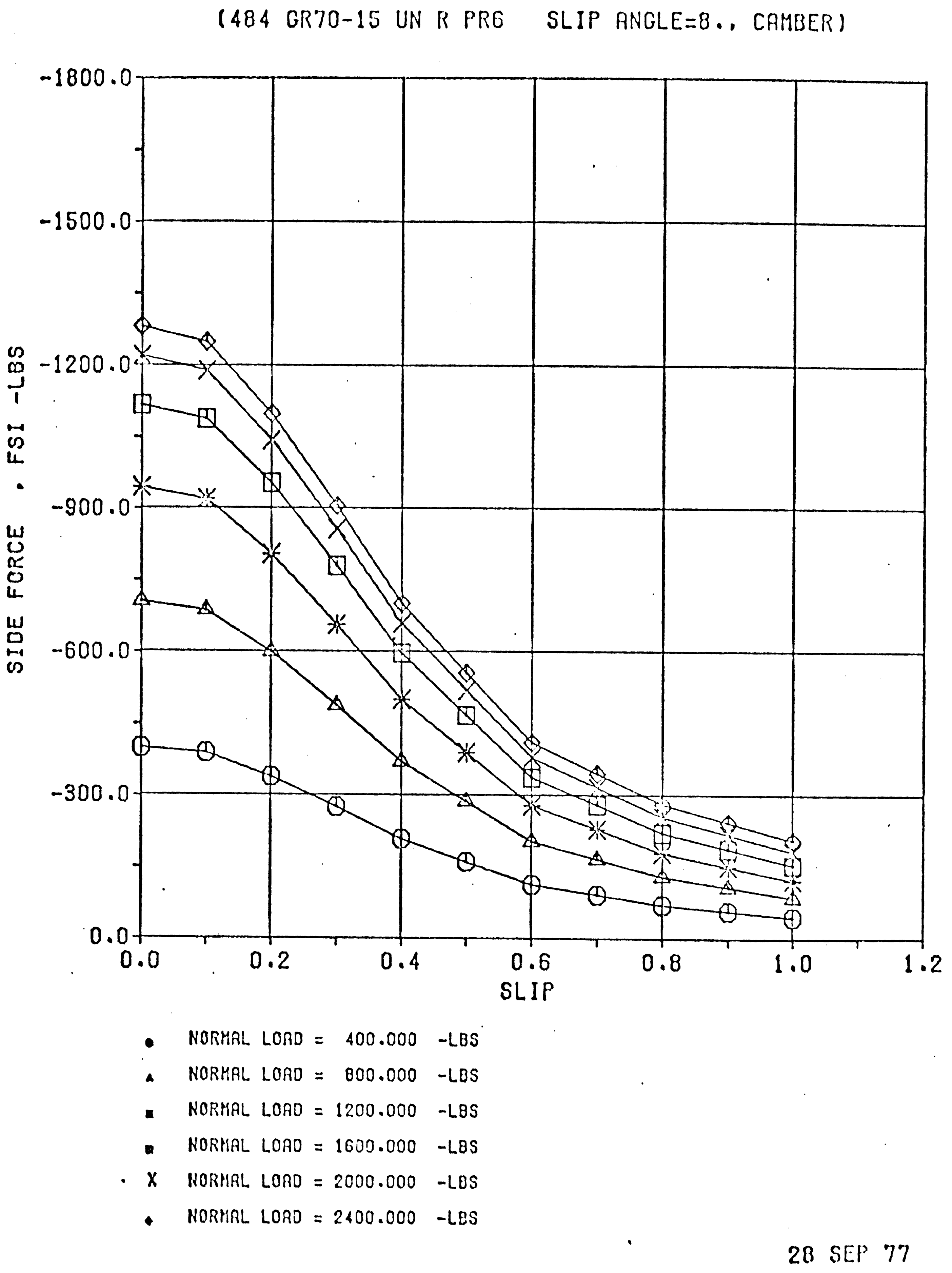


Figure D.2. Tire side force vs. slip ratio, with normal load varying, for the Monte Carlo.

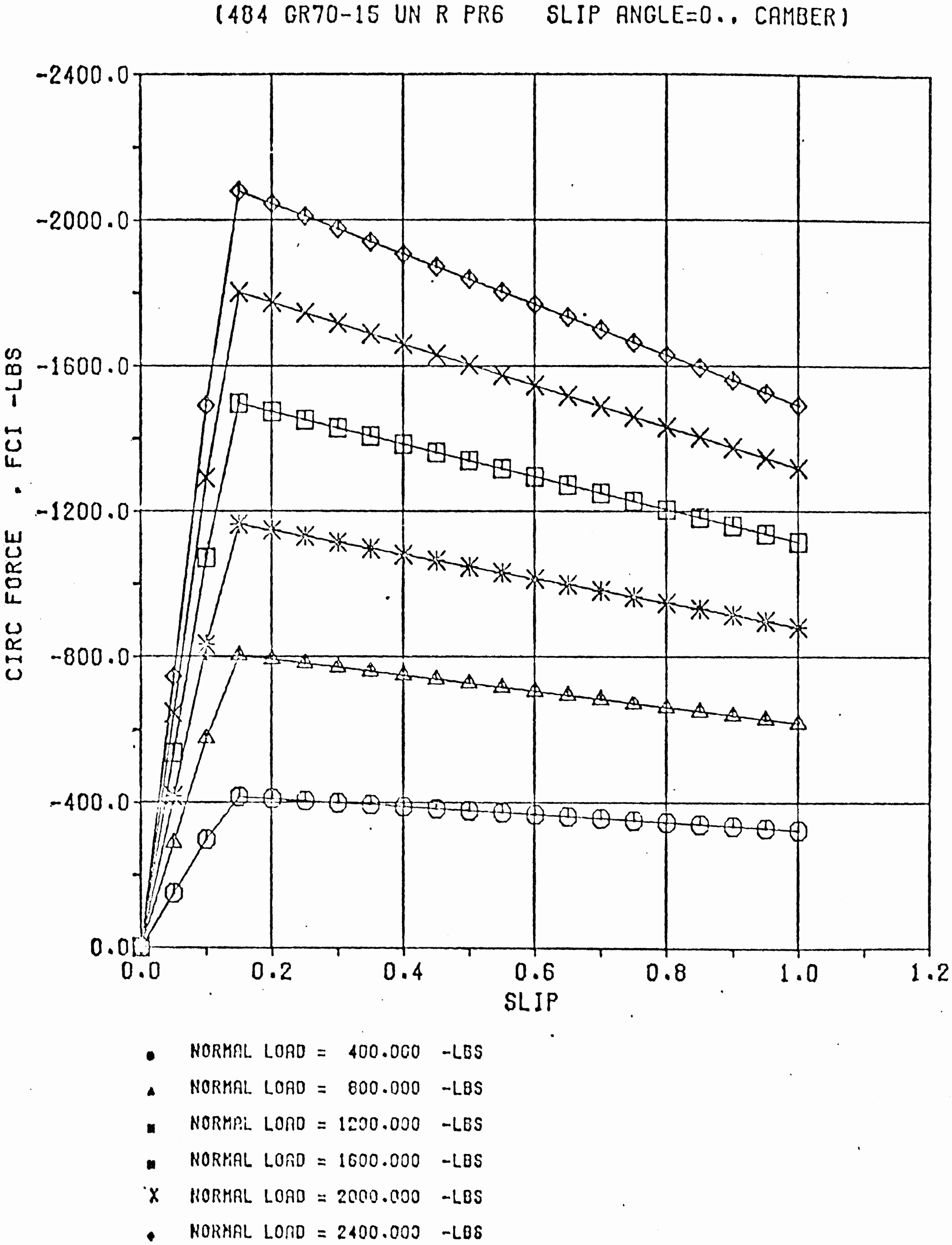


Figure D.3. Tire braking force vs. slip ratio, with normal load varying, for Monte Carlo.

Table D.5. Parameter Values Needed to Simulate the Ford LTD, Under the Lightly Loaded Condition.

PARAMETER VALUES - MODEL C - VEHICLE MODEL - 1976 FORD LTD

1	MS= 11.410	2	MUF= 0.63500	3	MUR= 1.0350	4	ZF= 10.800	5	ZR= 10.800
6	A= 52.100	7	B= 68.900	8	TF= 64.100	9	TR= 64.300	10	TSR= 45.500
11	IX= 8100.0	12	IY= 46000.	13	IZ= 57000.	14	IXZ= 0.0	15	IR= 750.00
16	RDCR= 30.000	17	RF= 0.23000E 06	18	STOP= 10.000	19	AKF1= 120.00	20	AKF2= 120.00
21	AKR3= 115.00	22	AKR4= 115.00	23	= 0.0	24	RR= 0.0	25	CF1P= 160.00
26	CF2P= 160.00	27	CR3P= 55.000	28	CR4P= 55.000	29	ZBAS= 0.0	30	KRS= 0.30000E-01
31	RW= 13.980	32	SCAL= 3000.0	33	FOT= 0.50000	34	A0= 1767.6	35	A1= 13.170
36	A2= 3211.1	37	A3=-0.13000E-01	38	A4= 44.460	39	TIR = 0.0	40	TOR = 0.0
41	KSC= 8000.0	42	NG= 16.000	43	= 0.0	44	= 0.0	45	= 0.0
46	= 0.0	47	IFW= 10.000	48	IF = 0.0	49	IWF= 15.000	50	IWR= 15.000
51	IDR= 0.70000	52	ARR= 2.7500	53	TSF = 0.0	54	KFS = 0.0	55	PT= 0.50000
56	YSA1= 0.50000	57	YSA2=-0.50000	58	PHS1=-0.17000	59	PHS2= 0.17000	60	CTSW= 1.0000
61	IDF= 0.0	62	ARF= 0.0	63	P-IN= 0.0	64	Q-IN= 0.0	65	R-IN= 0.0
66	U-IN= 40.000	67	V-IN= 0.0	68	W-IN= 0.0	69	X-IN= 0.0	70	Y-IN= 0.0
71	Z-IN= -23.547	72	THIN=-0.10437	73	PHIN= 0.0	74	PSIN= 0.0	75	DT= 0.50000E-02
76	TN= 10.000	77	KT1= 1038.0	78	KT2= 1038.0	79	KT3= 1038.0	80	KT4= 1038.0
81	RPS1= 55.641	82	RPS2= 55.641	83	RPS3= 54.688	84	RPS4= 54.688	85	B1=-0.23610E-03
86	B2= 0.0	87	B3= 1.1490	88	B4= 0.36330E-07	89	D1DT= 0.0	90	D2DT= 0.0
91	D3DT= 0.0	92	DELF= 0.0	93	DELR= 0.0	94	DEL3= 0.0	95	PHDT= 0.0
96	PHIR= 0.0	97	DFW1= 0.0	98	DFW2= 0.0	99	U1PR= 0.0	100	U2PR= 0.0
101	U3PR= 0.0	102	U4PR= 0.0	103	S1PR= 0.0	104	S2PR= 0.0	105	S3PR= 0.0
106	S4PR= 0.0	107	PPRT= 1.0000	108	FREQ= 0.50000	109	RWSF= 0.0	110	TQMX= 0.0
111	KTQ= 0.0	112	VC= 0.0	113	MTSW= 1.0000	114	DSWM= 0.0	115	TST= 0.0
116	DSLP= 100.00	117	CGAM= 0.0	118	CS= 0.0	119	TQR= 0.0	120	TQF= 0.0
121	PFL= 200.00	122	T1= 0.0	123	DSW= 0.0	124	= 0.0	125	ISW5= 0.0
126	SW15= 0.0	127	PQSW= 0.0	128	VTPS= 1.0000	129	VHTP= 1.0000	130	AMCR= 0.60000E-01
131	ESP= 0.20000	132	KSL1= 90000.	133	KSL2= 90000.	134	AA1= 6.3000	135	AA2= 6.3000
136	CCP= 11.000	137	CFCR= 77.000	138	AP= 5.8000	139	EP1= 0.0	140	EP2= 0.0
141	AERO= 0.0	142	VYW = 0.0	143	OMXW= 0.0	144	OMZW= 0.0	145	RHOA= 0.0
146	CYP = 0.0	147	CYR = 0.0	148	CZAL= 0.0	149	CZQ = 0.0	150	CLP = 0.0
151	CLR = 0.0	152	CMAL= 0.0	153	CMQ = 0.0	154	CNP = 0.0	155	CNR = 0.0
156	SF = 0.0	157	VLEN= 0.0	158	REWV= 0.0	159	= 0.0	160	= 0.0
161	= 0.0	162	= 0.0	163	= 0.0	164	= 0.0	165	= 0.0
166	= 0.0	167	= 0.0	168	= 0.0	169	SNT= 85.000	170	SNSJ= 30.000
171	SNS1= 85.000	172	SNSW= 2.0000	173	DIST= 0.0	174	PL = 0.0	175	TSCP= 0.25000
176	= 1.0000	177	= 0.0	178	= 0.0	179	= 0.0	180	PASS= 0.0
181	= 0.0	182	SI1= 0.11300	183	SI2= 0.11300	184	SI3= 0.11300	185	SI4= 0.11300
186	= 0.0	187	= 0.0	188	= 0.0	189	= 0.0	190	= 0.0
191	= 0.0	192	MTQB= 0.20000	193	DCSW= 0.0	194	LDF= 0.0	195	LDRF= 0.0
196	EK1= 0.0	197	EK2= 0.0	198	BMPL= 0.0	199	BMPS= 0.0	200	BMPH= -1.5000
201	X6= 0.0	202	APF1= 1.1027	203	APF2=-0.10180E-03	204	APR1= 1.1027	205	APR2=-0.10180E-03
206	MUSF= 0.73390	207	MUSR= 0.73390	208	BCON= 0.30000E-01	209	FCSW= 0.0	210	=-0.38160E-04
211	=-0.38160E-04	212	= 0.0	213	= 0.0	214	= 0.0	215	= 0.0
216	= 0.0	217	= 0.0	218	= 0.0	219	FEE1= 0.0	220	FEE2= 0.0
221	THE1= 0.0	222	THE2= 0.0	223	= 0.0	224	= 0.0	225	= 0.0
226	= 0.0	227	= 0.0	228	= 0.0	229	= 0.0	230	= 0.0
231	H1= 400.00	232	H2= 400.00	233	LAMD= 1.0000	234	= 0.0	235	= 0.0
236	= 0.0	237	= 0.0	238	BR1= 1.0000	239	BR2= 1.0000	240	BR3= 1.0000
241	BR4= 1.0000	242	KCF= 0.0	243	KCR= 0.0	244	KSR= 0.0	245	RB1=-0.23610E-03
246	RB2= 0.0	247	PB3= 1.1490	248	RB4= 0.36330E-07	249	AFK1=-0.27310E-02	250	AFK2= 0.23120E-02
251	AFK3= 0.82800	252	ARK1=-0.27310E-02	253	ARK2= 0.28120E-02	254	ARK3= 0.82800	255	DFC0= 0.0
256	DFC1=-0.11250E-02	257	DFC2=-0.20180E-02	258	DFC3= -7.0080	259	DRC0= 0.0	260	DRC1=-0.11250E-02
261	DRC2=-0.20180E-02	262	DRC3= -7.0080	263	CP0F= 0.0	264	CP1F= 0.0	265	CP2F= 0.0
266	CP0R= 0.0	267	CP1R= 0.0	268	CP2R= 0.0	269	CR0F= 0.0	270	CR1F= 0.0
271	CR2F= 0.0	272	CR0R= 0.0	273	CR1R= 0.0	274	CR2R= 0.0	275	= 0.0
276	= 0.0	277	BMPN= 0.0	278	TOB0= 0.0	279	TOB1= 0.0	280	= 0.0
281	= 0.0	282	= 0.0	283	= 0.0	284	HFC= 0.0	285	HRC= 0.0
286	DRSW= 0.0	287	AXLE= 1.0000	288	DUAL= 0.0	289	TIRE= 4.0000	290	ROT = 0.50000
291	RA0 = 1767.6	292	RA1 = 13.170	293	RA2 = 3211.1	294	RA3 =-0.13000E-01	295	RA4 = 44.460

Table D.6. Parameter Values Needed to Simulate the Ford LTD, Under the GVW Condition.

PARAMETER VALUES - MODEL C - VEHICLE MODEL - 1976 FORD LTD

1	MS= 14.330	2	MUF= 0.63500	3	MUR= 1.0350	4	ZF= 8.2000	5	ZR= 8.4000
6	A= 59.700	7	B= 61.300	8	TF= 64.100	9	TR= 64.300	10	TSR= 45.500
11	IX= 11000.	12	IY= 68000.	13	IZ= 78000.	14	IXZ= 0.0	15	IR= 750.00
16	ROOR= 30.000	17	RF= 0.23000E 06	18	STOP= 10.000	19	AKF1= 120.00	20	AKF2= 120.00
21	AKR3= 226.00	22	AKR4= 226.00	23	= 0.0	24	RR= 0.0	25	CF1P= 160.00
26	CF2P= 160.00	27	CR3P= 55.000	28	CR4P= 55.000	29	ZBAS= 0.0	30	KRS= 0.33000E-01
31	RW= 13.980	32	SCAL= 3000.0	33	FOT= 0.50000	34	A0= 1767.6	35	A1= 13.170
36	A2= 3211.1	37	A3=-0.13000E-01	38	A4= 44.460	39	TIR = 0.0	40	TOR = 0.0
41	KSC= 8000.0	42	NG= 16.000	43	= 0.0	44	= 0.0	45	= 0.0
46	= 0.0	47	IFW= 10.000	48	IF = 0.0	49	IWF= 15.000	50	IWR= 15.000
51	IDR= 0.70000	52	ARR= 2.7500	53	TSF = 0.0	54	KFS = 0.0	55	PT= 0.50000
56	YSA1= 0.50000	57	YSA2=-0.50000	58	PHS1=-0.17000	59	PHS2= 0.17000	60	CTSW= 1.0000
61	IDF= 0.0	62	ARF= 0.0	63	P-IN= 0.0	64	Q-IN= 0.0	65	R-IN= 0.0
66	U-IN= 40.000	67	V-IN= 0.0	68	W-IN= 0.0	69	X-IN= 0.0	70	Y-IN= 0.0
71	Z-IN= -20.743	72	THIN=-0.76733E-01	73	PHIN= 0.0	74	PSIN= 0.0	75	DT= 0.50000E-02
76	TN= 10.000	77	KT1= 1038.0	78	KT2= 1038.0	79	KT3= 1038.0	80	KT4= 1038.0
81	RPS1= 55.641	82	RPS2= 55.641	83	RPS3= 54.688	84	RPS4= 54.688	85	B1=-0.23610E-03
86	B2= 0.0	87	B3= 1.1490	88	B4= 0.36330E-07	89	D1DT= 0.0	90	D2DT= 0.0
91	D3DT= 0.0	92	DELF= -1.6000	93	DELR= -4.0000	94	DEL3= 0.0	95	PHDT= 0.0
96	PHIR= 0.0	97	DFW1= 0.0	98	DFW2= 0.0	99	U1PR= 0.0	100	U2PR= 0.0
101	U3PR= 0.0	102	U4PR= 0.0	103	S1PR= 0.0	104	S2PR= 0.0	105	S3PR= 0.0
106	S4PR= 0.0	107	PPRT= 1.0000	108	FREQ= 0.50000	109	RWSF= 0.0	110	TCMX= 0.0
111	KTC= 0.0	112	VC= 0.0	113	MTSW= 1.0000	114	DSWM= 0.0	115	TST= 0.0
116	DSLP= 100.00	117	CGAM= 0.0	118	CS= 0.0	119	TQR= 0.0	120	TCF= 0.0
121	PFL= 200.00	122	T1= 0.0	123	DSW= 0.0	124	= 0.0	125	ISWS= 0.0
126	SW15= 0.0	127	PGSW= 0.0	128	VTPS= 1.0000	129	VHTP= 1.0000	130	AMCR= 0.60000E-01
131	ESP= 0.20000	132	KSL1= 90000.	133	KSL2= 90000.	134	AA1= 6.3000	135	AA2= 6.3000
136	CCR= 11.000	137	CFCR= 77.000	138	AP= 5.8000	139	EP1= 0.0	140	EP2= 0.0
141	AERO= 0.0	142	VYW = 0.0	143	OMXW= 0.0	144	OMZW= 0.0	145	RHOA= 0.0
146	CYP = 0.0	147	CYR = 0.0	148	CZAL= 0.0	149	CZQ = 0.0	150	CLP = 0.0
151	CLR = 0.0	152	CMAL= 0.0	153	CMQ = 0.0	154	CNP = 0.0	155	CNR = 0.0
156	SF = 0.0	157	VLEN= 0.0	158	REWV= 0.0	159	= 0.0	160	= 0.0
161	= 0.0	162	= 0.0	163	= 0.0	164	= 0.0	165	= 0.0
166	= 0.0	167	= 0.0	168	= 0.0	169	SNT= 35.000	170	SNSO= 30.000
171	SNS1= 35.000	172	SNSW= 2.0000	173	DIST= 0.0	174	PL = 0.0	175	TSCP= 0.25000
176	= 1.0000	177	= 0.0	178	= 0.0	179	= 0.0	180	PASS= 0.0
181	= 0.0	182	SI1= 0.11300	183	SI2= 0.11300	184	SI3= 0.11300	185	SI4= 0.11300
186	= 0.0	187	= 0.0	188	= 0.0	189	= 0.0	190	= 0.0
191	= 0.0	192	MTQB= 0.20000	193	DCSW= 0.0	194	LDF= 0.0	195	LDRF= 0.0
196	EK1= 0.0	197	EK2= 0.0	198	BMPL= 0.0	199	BMPS= 0.0	200	BMPH= -1.5000
201	XB= 0.0	202	APF1= 1.1027	203	APF2=-0.10180E-03	204	APR1= 1.1027	205	APR2=-0.10180E-03
206	MUSF= 0.73390	207	MUSR= 0.73390	208	BCON= 0.30000E-01	209	FCSW= 0.0	210	=-0.38160E-04
211	=-0.38160E-04	212	= 0.0	213	= 0.0	214	= 0.0	215	= 0.0
216	= 0.0	217	= 0.0	218	= 0.0	219	FEE1= 0.0	220	FEE2= 0.0
221	THE1= 0.0	222	THE2= 0.0	223	= 0.0	224	= 0.0	225	= 0.0
226	= 0.0	227	= 0.0	228	= 0.0	229	= 0.0	230	= 0.0
231	H1= 400.00	232	H2= 400.00	233	LAMD= 1.0000	234	= 0.0	235	= 0.0
236	= 0.0	237	= 0.0	238	BR1= 1.0000	239	BR2= 1.0000	240	BR3= 1.0000
241	BR4= 1.0000	242	KCF= 0.0	243	KCR= 0.0	244	KSR= 0.0	245	RB1=-0.23610E-03
246	RB2= 0.0	247	RB3= 1.1490	248	RB4= 0.36330E-07	249	AFK1=-0.27310E-02	250	AFK2= 0.28120E-02
251	AFK3= 0.82800	252	ARK1=-0.27310E-02	253	ARK2= 0.28120E-02	254	ARK3= 0.82800	255	OFC0= 0.0
256	OFC1=-0.11250E-02	257	OFC2=-0.20180E-02	258	OFC3= -7.0080	259	ORC0= 0.0	260	ORC1=-0.11250E-02
261	ORC2=-0.20180E-02	262	ORC3= -7.0080	263	CP0F= 0.0	264	CP1F= 0.0	265	CP2F= 0.0
266	CP0R= 0.0	267	CP1R= 0.0	268	CP2R= 0.0	269	CR0F= 0.0	270	CR1F= 0.0
271	CR2F= 0.0	272	CR0R= 0.0	273	CR1R= 0.0	274	CR2R= 0.0	275	= 0.0
276	= 0.0	277	BMPN= 0.0	278	TQB0= 0.0	279	TQB1= 0.0	280	= 0.0
281	= 0.0	282	= 0.0	283	= 0.0	284	HFC= 0.0	285	HRC= 0.0
286	DRSW= 0.0	287	AXLE= 1.0000	288	DUAL= 0.0	289	TIRE= 4.0000	290	RCT = 0.50000
291	RA0 = 1767.6	292	RA1 = 13.170	293	RA2 = 3211.1	294	RA3 =-0.13000E-01	295	RA4 = 44.460

Table D.7. Tabular Inputs for Ford LTD.

Spring Rates (Measured at HSRI)

Front δ (in)	Front F (lbs)	Rear δ (in)	Rear F (lbs)
-100.	-7360.	-100.	-6903.
-10.	-7360.	-10.	-6903.
-3.5	-860.	-4.	-903.
-3.	-360.	-3.5	-403.
0.	0.	0.	0.
3.	360.	4.	460.
3.8	520.	10.	1150.
10.	1760.	100.	1150.
100.	1760.		

Brake Torque (Measured at HSRI)

Front P (psi)	Front TQ (in-lbs)	Rear P (psi)	Rear TQ (in-lbs)
0.	0.	0.	0.
150.	0.	150.	0.
1400.	40000.	925.	10500.
		1500.	10500.

Shock Absorber Data (G)

Front & Rear: C = 3.0 lb/(in/sec) $\dot{\delta} < 0$

= 10.0 lb/(in/sec) $\dot{\delta} > 0$

Table D.7. (Cont.)

Camber, Caster, and Toe Functions (Brookwood Wagon)

Displacement	Camber	Caster (G)	Toe
0.	0.	1.	0.
1.	0.85	1.	-0.24
2.	1.68	1.	-0.53
3.	2.18	1.	-0.73
4.	2.43	1.	-0.89
5.	2.47	1.	-1.01
6.	2.29	1.	-1.10
7.	1.96	1.	-1.17

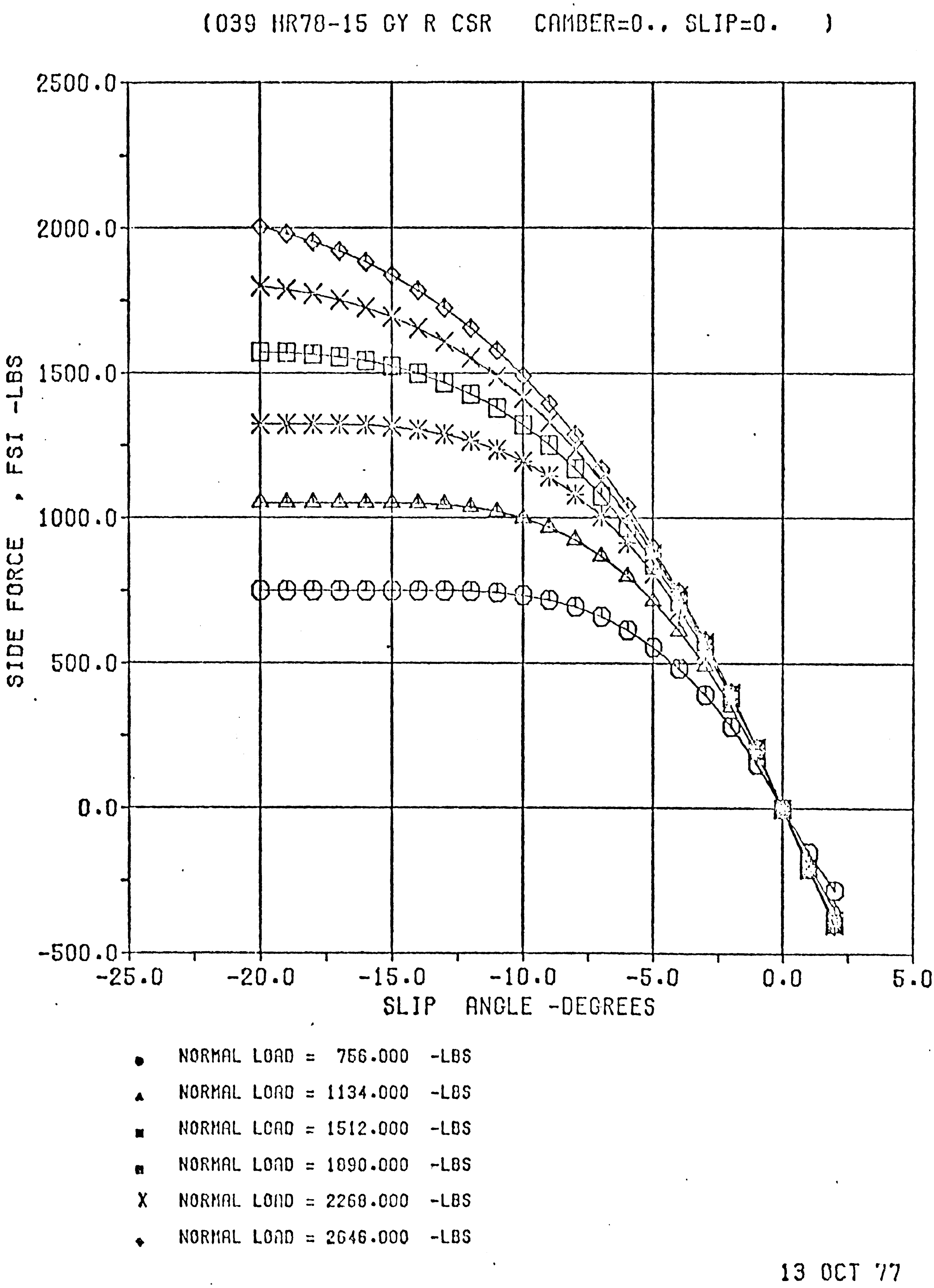


Figure D.4. Tire side force vs. slip angle with normal load varying, for the Ford LTD.

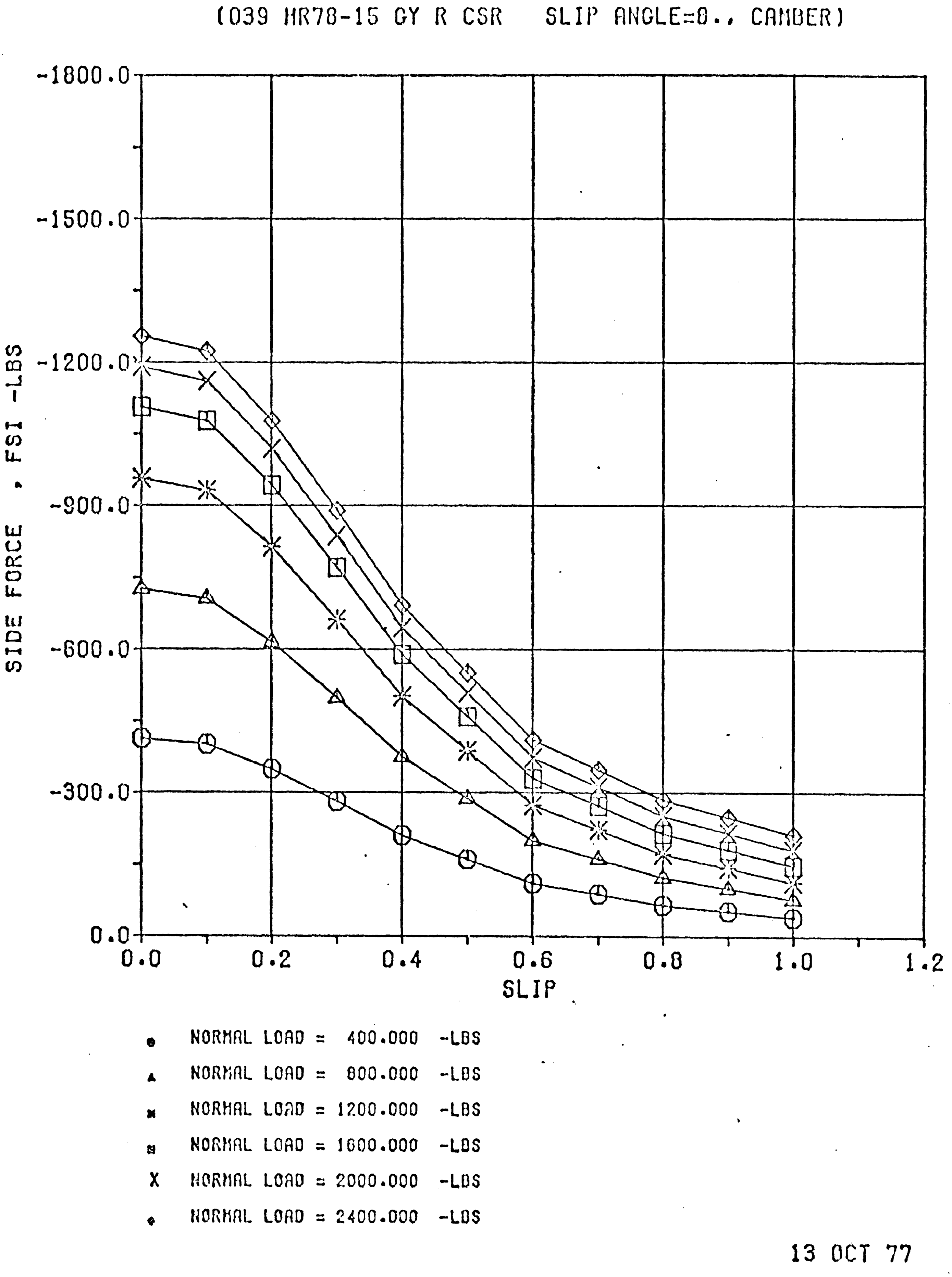


Figure D.5. Tire side force vs. slip ratio, with normal load varying, for the Ford LTD.

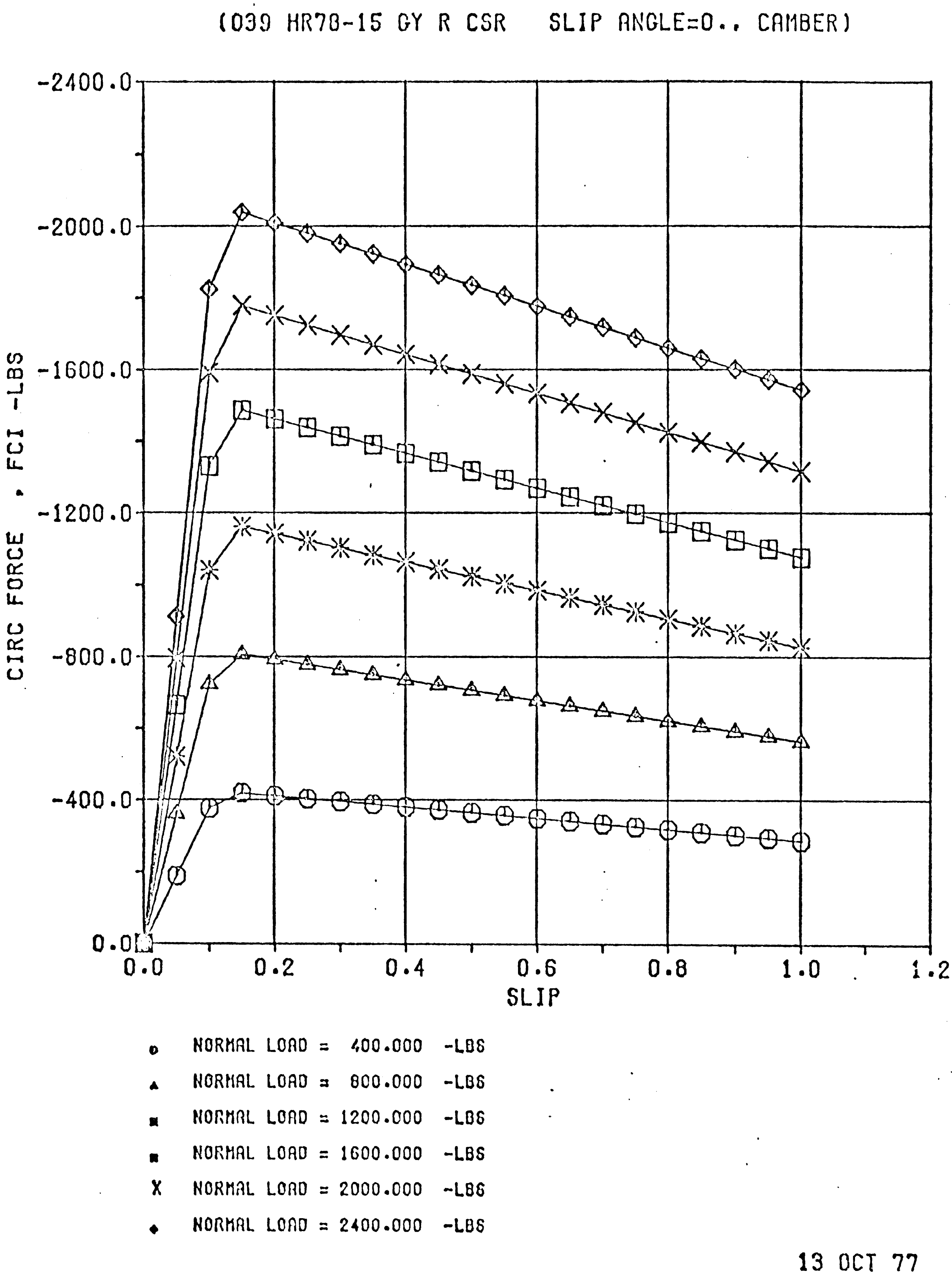


Figure D.6. Tire braking force vs. slip ratio, with normal load varying, for the Ford LTD.

Table D.8. Parameter Values Needed to Simulate the Nova, Under the Lightly Loaded Condition.

PARAMETER VALUES - MODEL C - VEHICLE MODEL - 1976 CHEVROLET NOVA

1	MS= 9.4500	2	MUF= 0.55000	3	MUR= 0.89000	4	ZF= 8.2000	5	ZR= 8.1000
6	A= 47.900	7	B= 63.100	8	TF= 61.300	9	TR= 59.000	10	TSR= 43.500
11	IX= 5900.0	12	IY= 33500.	13	IZ= 42500.	14	IXZ= 0.0	15	IR= 500.00
16	ROCF= 30.000	17	RF= 0.41000E 06	18	STOP= 10.000	19	AKF1= 155.00	20	AKF2= 155.00
21	AKR3= 145.00	22	AKR4= 145.00	23	= 1.0000	24	RR= 62000.	25	CF1P= 60.000
26	CF2F= 60.000	27	CR3P= 65.000	28	CR4P= 65.000	29	ZBAS= 0.0	30	KFS= 0.0
31	RW= 12.760	32	SCAL= 3000.0	33	FOT= 0.50000	34	A0= 733.23	35	A1= 13.550
36	A2= 2976.0	37	A3= 1.4660	38	A4= 6135.9	39	TIR = 0.0	40	TCR = 0.0
41	KSC= 500.00	42	NG= 24.000	43	= 0.0	44	= 0.0	45	= 0.0
46	= 0.0	47	IFW= 8.0000	48	IF = 0.0	49	IWF= 10.000	50	IWR= 10.000
51	IDR= 0.70000	52	ARR= 3.0800	53	TSF = 0.0	54	KFS = 0.0	55	PT= 0.21000
56	YSA1= 5.0000	57	YSA2= -5.0000	58	PHS1=-0.17000	59	PHS2= 0.17000	60	CTSW= 1.0000
61	IOF= 0.0	62	ARF= 0.0	63	P-IN= 0.0	64	Q-IN= 0.0	65	R-IN= 0.0
66	U-IN= 40.000	67	V-IN= 0.0	68	W-IN= 0.0	69	X-IN= 0.0	70	Y-IN= 0.0
71	Z-IN= -20.106	72	THIN=-0.22655E-01	73	PHIN= 0.0	74	PSIN= 0.0	75	DT= 0.50000E-02
76	TN= 10.000	77	KT1= 1281.0	78	KT2= 1281.0	79	KT3= 1281.0	80	KT4= 1281.0
81	RPS1= 59.225	82	RPS2= 59.225	83	RPS3= 58.517	84	RPS4= 58.517	85	B1=-0.63180E-04
86	B2= 0.0	87	B3= 1.0750	88	B4=-0.58050E-07	89	D1DT= 0.0	90	D2DT= 0.0
91	D3DT= 0.0	92	DELF= 0.0	93	DELR= 0.0	94	DEL3= 0.0	95	PHDT= 0.0
96	PHIF= 0.0	97	DFW1= 0.0	98	DFW2= 0.0	99	U1PR= 0.0	100	U2PR= 0.0
101	U3PR= 0.0	102	U4PR= 0.0	103	S1PR= 0.0	104	S2PR= 0.0	105	S3PR= 0.0
106	S4PR= 0.0	107	PPRT= 1.0000	108	FREQ= 0.50000	109	RWSF= 0.0	110	TQMX= 0.0
111	KTC= 0.0	112	VC= 0.0	113	MTSW= 1.0000	114	DSWM= 0.0	115	TST= 0.0
116	DSLP= 100.00	117	CGAM= 0.0	118	CS= 0.0	119	TQR= 0.0	120	TQF= 0.0
121	PFL= 200.00	122	T1= 0.0	123	DSW= 0.0	124	= 0.0	125	ISW5= 0.0
126	SW15= 0.0	127	PCSW= 0.0	128	VTPS= 1.0000	129	VHTP= 1.0000	130	AMCR= 0.70000E-01
131	ESP= 0.0	132	KSL1= 56000.	133	KSL2= 56000.	134	AA1= 6.2500	135	AA2= 6.2500
136	CCR= 11.000	137	CFCR= 70.000	138	AP= 7.0000	139	EP1= 0.0	140	EP2= 0.0
141	AERO= 0.0	142	VYW = 0.0	143	CMXW= 0.0	144	CMZW= 0.0	145	RHOA= 0.0
146	CYP = 0.0	147	CYR = 0.0	148	CZAL= 0.0	149	CZQ = 0.0	150	CLP = 0.0
151	CLR = 0.0	152	CMAL= 0.0	153	CMQ = 0.0	154	CNP = 0.0	155	CNR = 0.0
156	SF = 0.0	157	VLEN= 0.0	158	REWV= 0.0	159	= 0.0	160	= 0.0
161	= 0.0	162	= 0.0	163	= 0.0	164	= 0.0	165	= 0.0
166	= 0.0	167	= 0.0	168	= 0.0	169	SNT= 85.000	170	SNSO= 31.000
171	SNS1= 85.000	172	SNSW= 2.0000	173	DIST= 0.0	174	PL = 0.0	175	TSCP= 0.25000
176	= 1.0000	177	= 0.0	178	= 0.0	179	= 0.0	180	PASS= 0.0
181	= 0.0	182	SI1= 0.15800	183	SI2= 0.15800	184	SI3= 0.15800	185	SI4= 0.15800
186	= 0.0	187	= 0.0	188	= 0.0	189	= 0.0	190	= 0.0
191	= 0.0	192	MTOB= 0.20000	193	DCSW= 0.0	194	LDF= 0.0	195	LDRF= 0.0
196	EK1= 0.0	197	EK2= 0.0	198	BMPL= 0.0	199	BMPS= 0.0	200	BMPH= -1.5000
201	XB= 0.0	202	APF1= 1.3102	203	APF2=-0.27600E-03	204	APR1= 1.3102	205	APR2=-0.27600E-03
206	MUSF= 0.93320	207	MUSR= 0.93320	208	BCON= 0.30000E-01	209	FCSW= 0.0	210	=-0.14940E-03
211	=-0.14940E-03	212	= 0.0	213	= 0.0	214	= 0.0	215	= 0.0
216	= 0.0	217	= 0.0	218	= 0.0	219	FEE1= 0.0	220	FEE2= 0.0
221	THE1= 0.0	222	THE2= 0.0	223	= 1.0000	224	= 0.0	225	= 0.0
226	= 0.0	227	= 0.0	228	= 0.0	229	= 0.0	230	= 0.0
231	H1= 400.00	232	H2= 400.00	233	LAMD= 1.0000	234	= 0.0	235	= 0.0
236	= 0.0	237	= 0.0	238	BR1= 1.0000	239	BR2= 1.0000	240	BR3= 1.0000
241	BR4= 1.0000	242	KCF= 0.0	243	KCR= 0.0	244	KSR= 0.0	245	RB1=-0.63180E-04
246	RB2= 0.0	247	RB3= 1.0750	248	RB4=-0.58050E-07	249	AFK1=-0.27936E-02	250	AFK2= 0.24828E-02
251	AFK3= 1.9320	252	ARK1=-0.27936E-02	253	ARK2= 0.24828E-02	254	ARK3= 1.9320	255	OFC0= 0.0
256	OFC1=-0.12024E-02	257	OFC2=-0.15336E-02	258	OFC3= -7.2960	259	ORC0= 0.0	260	ORC1=-0.12024E-02
261	ORC2=-0.15336E-02	262	ORC3= -7.2960	263	CP0F= 0.0	264	CP1F= 0.0	265	CP2F= 0.0
266	CP0R= 0.0	267	CP1R= 0.0	268	CP2R= 0.0	269	CR0F= 0.0	270	CR1F= 0.0
271	CR2F= 0.0	272	CR0R= 0.0	273	CR1R= 0.0	274	CR2R= 0.0	275	= 0.0
276	= 0.0	277	BMPN= 0.0	278	TOB0= 0.0	279	TOB1= 0.0	280	= 0.0
281	= 0.0	282	= 0.0	283	= 0.0	284	HFC= 0.0	285	HRC= 0.0
286	DASW= 0.0	287	AXLE= 1.0000	288	DUAL= 0.0	289	TIRE= 4.0000	290	ROT = 0.50000
291	RA0 = 733.23	292	RA1 = 13.550	293	RA2 = 2976.0	294	RA3 = 1.4660	295	RA4 = 6135.9

Table D.9. Parameter Values Needed to Simulate the Nova, Under the GVW Condition.

PARAMETER VALUES - MODEL C - VEHICLE MODEL - 1976 CHEVROLET NOVA

1	MS= 11.230	2	MUF= 0.55000	3	MUR= 0.89000	4	ZF= 8.1000	5	ZR= 8.2000
6	A= 57.200	7	B= 53.800	8	TF= 61.300	9	TR= 59.000	10	TSR= 43.500
11	IX= 7500.0	12	IY= 44700.	13	IZ= 52900.	14	IXZ= 0.0	15	IR= 500.00
16	ROCR= 30.000	17	RF= 0.41000E 06	18	STOP= 10.000	19	AKF1= 155.00	20	AKF2= 155.00
21	AKR3= 145.00	22	AKR4= 145.00	23	= 1.0000	24	RR= 62000.	25	CF1P= 60.000
26	CF2P= 60.000	27	CR3P= 65.000	28	CR4P= 65.000	29	ZBAS= 0.0	30	KRS= 0.0
31	RW= 12.780	32	SCAL= 3000.0	33	FOT= 0.50000	34	A0= 733.23	35	A1= 13.550
36	A2= 2976.0	37	A3= 1.4660	38	A4= 6135.9	39	TIR = 0.0	40	TCR = 0.0
41	KSC= 500.00	42	NG= 24.000	43	= 0.0	44	= 0.0	45	= 0.0
46	= 0.0	47	IFW= 8.0000	48	IF = 0.0	49	IWF= 10.000	50	IWR= 10.000
51	ICR= 0.70000	52	ARR= 3.0800	53	TSF = 0.0	54	KFS = 0.0	55	PT= 0.21000
56	YSA1= 5.0000	57	YSA2= -5.0000	58	PHS1=-0.17000	59	PHS2= 0.17000	60	CTSW= 1.0000
61	IDF= 0.0	62	ARF= 0.0	63	P-IN= 0.0	64	Q-IN= 0.0	65	R-IN= 0.0
66	U-IN= 40.000	67	V-IN= 0.0	68	W-IN= 0.0	69	X-IN= 0.0	70	Y-IN= 0.0
71	Z-IN= -19.975	72	THIN= 0.16294E-02	73	PHIN= 0.0	74	PSIN= 0.0	75	DT= 0.50000E-02
76	TN= 10.000	77	KT1= 1281.0	78	KT2= 1281.0	79	KT3= 1281.0	80	KT4= 1281.0
81	RPS1= 59.225	82	RPS2= 59.225	83	RPS3= 58.517	84	RPS4= 58.517	85	B1=-0.63180E-04
86	B2= 0.0	87	B3= 1.0750	88	B4=-0.58050E-07	89	D1DT= 0.0	90	D2DT= 0.0
91	D3DT= 0.0	92	DELF=-0.10000E 00	93	DELR= -1.8000	94	DEL3= 0.0	95	PHDT= 0.0
96	PHIR= 0.0	97	DFW1= 0.0	98	DFW2= 0.0	99	U1PR= 0.0	100	U2PR= 0.0
101	U3PR= 0.0	102	U4PR= 0.0	103	S1PR= 0.0	104	S2PR= 0.0	105	S3PR= 0.0
106	S4PR= 0.0	107	PPRT= 1.0000	108	FREQ= 0.50000	109	RWSF= 0.0	110	TQMX= 0.0
111	KTC= 0.0	112	VC= 0.0	113	MTSW= 1.0000	114	DSWM= 0.0	115	TST= 0.0
116	DSLF= 100.00	117	CGAM= 0.0	118	CS= 0.0	119	TQR= 0.0	120	TCF= 0.0
121	PFL= 1200.0	122	T1= 0.0	123	DSW= 0.0	124	= 0.0	125	ISWS= 0.0
126	SW15= 0.0	127	PCSW= 0.0	128	VTPS= 1.0000	129	VHTP= 1.0000	130	AMCR= 0.70000E-01
131	ESP= 0.0	132	KSL1= 56000.	133	KSL2= 56000.	134	AA1= 6.2500	135	AA2= 6.2500
136	CCK= 11.000	137	CFCR= 70.000	138	AP= 7.0000	139	EP1= 0.0	140	EP2= 0.0
141	AERC= 0.0	142	VYW = 0.0	143	OMXW= 0.0	144	OMZW= 0.0	145	RHOA= 0.0
146	CYP = 0.0	147	CYR = 0.0	148	CZAL= 0.0	149	CZQ = 0.0	150	CLP = 0.0
151	CLR = 0.0	152	CMAL= 0.0	153	CMQ = 0.0	154	CNP = 0.0	155	CNR = 0.0
156	SF = 0.0	157	VLEN= 0.0	158	REWV= 0.0	159	= 0.0	160	= 0.0
161	= 0.0	162	= 0.0	163	= 0.0	164	= 0.0	165	= 0.0
166	= 0.0	167	= 0.0	168	= 0.0	169	SNT= 85.000	170	SNSO= 30.000
171	SNS1= 85.000	172	SNSW= 2.0000	173	DIST= 0.0	174	PL = 0.0	175	TSCP= 0.25000
176	= 1.0000	177	= 0.0	178	= 0.0	179	= 0.0	180	PASS= 0.0
181	= 0.0	182	SI1= 0.15800	183	SI2= 0.15800	184	SI3= 0.15800	185	SI4= 0.15800
186	= 0.0	187	= 0.0	188	= 0.0	189	= 0.0	190	= 0.0
191	= 0.0	192	MTQB= 0.20000	193	DCSW= 0.0	194	LDF= 0.0	195	LDRF= 0.0
196	EK1= 0.0	197	EK2= 0.0	198	BMPL= 0.0	199	BMPS= 0.0	200	BMPH= -1.5000
201	XE= 0.0	202	APF1= 1.3102	203	APF2=-0.27600E-03	204	APR1= 1.3102	205	APR2=-0.27600E-03
206	MUSF= 0.93320	207	MUSR= 0.93320	208	BCON= 0.30000E-01	209	FCSW= 0.0	210	=-0.14940E-03
211	=-0.14940E-03	212	= 0.0	213	= 0.0	214	= 0.0	215	= 0.0
216	= 0.0	217	= 0.0	218	= 0.0	219	FEE1= 0.0	220	FEE2= 0.0
221	THE1= 0.0	222	THE2= 0.0	223	= 1.0000	224	= 0.0	225	= 0.0
226	= 0.0	227	= 0.0	228	= 0.0	229	= 0.0	230	= 0.0
231	H1= 400.00	232	H2= 400.00	233	LAMD= 1.0000	234	= 0.0	235	= 0.0
236	= 0.0	237	= 0.0	238	BR1= 1.0000	239	BR2= 1.0000	240	BR3= 1.0000
241	BR4= 1.0000	242	KCF= 0.0	243	KCR= 0.0	244	KSR= 0.0	245	RB1=-0.63180E-04
246	RB2= 0.0	247	RB3= 1.0750	248	RB4=-0.58050E-07	249	AFK1=-0.27936E-02	250	AFK2= 0.24828E-02
251	AFK3= 1.9320	252	APK1=-0.27936E-02	253	ARK2= 0.24828E-02	254	ARK3= 1.9320	255	CFCO= 0.0
256	OFC1=-0.12024E-02	257	CFC2=-0.15336E-02	258	CFC3= -7.2960	259	ORCO= 0.0	260	ORC1=-0.12024E-02
261	ORC2=-0.15336E-02	262	ORC3= -7.2960	263	CPOF= 0.0	264	CP1F= 0.0	265	CP2F= 0.0
266	CPOR= 0.0	267	CP1R= 0.0	268	CP2R= 0.0	269	CROF= 0.0	270	CR1F= 0.0
271	CR2F= 0.0	272	CROR= 0.0	273	CR1R= 0.0	274	CR2R= 0.0	275	= 0.0
276	= 0.0	277	BMPN= 0.0	278	TQB0= 0.0	279	TQB1= 0.0	280	= 0.0
281	= 0.0	282	= 0.0	283	= 0.0	284	HFC= 0.0	285	HRC= 0.0
286	DRSW= 0.0	287	AXLE= 1.0000	288	DUAL= 0.0	289	TIRE= 4.0000	290	ROT = 0.50000
291	RA0 = 733.23	292	RA1 = 13.550	293	RA2 = 2976.0	294	RA3 = 1.4660	295	RA4 = 6135.9

Table D.10. Tabular Inputs for Chevrolet Nova.

Spring Rates (Measured at HSRI)

Front δ (in)	Front F (lbs)	Rear δ (in)	Rear F (lbs)
-100.	-2500.	-100.	-2086.
-10.	-2500.	-10.	-2086.
-0.5	-125.	-2.3	-440.
0.0	0.0	-0.85	-130.
0.2	40.	0.0	0.0
4.4	690.	4.9	700.
5.4	1140.	5.4	960.
10.	3210.	10.	3352.
100.	3210.	100.	3352.

Brake Torque (Measured at HSRI)

Front P (psi)	Front TQ (in-lbs)	Rear P (psi	Rear TQ (in-lbs)
0.	0.	0.	0.
50.	0.	80.	0.
800.	15000.	590.	5900.
1400.	27000.	900.	13400.
		1400.	25500.

Table D.10. (Cont.)

<u>Shock Absorber Data</u> (Measured by Systems Technology, Inc)

Front		Rear	
C = 2.9	$\dot{\delta} < -17.$	C = 3.5	$\dot{\delta} < 0$
C = 6.6	$-17 < \dot{\delta} < 0.$	C = 19.	$0 < \dot{\delta} < 20.$
C = 28.	$0 < \dot{\delta} < 5.8$	C = 2.2	$20 < \dot{\delta} < 36.$
C = 6.0	$5.8 < \dot{\delta} < 40.$	C = 9.0	$36 < \dot{\delta} < 57.$
C = 13.	$40. < \dot{\delta}$	C = 20.	$57 < \dot{\delta}$

Camber, Caster, and Toe Functions (Measured by Systems Technology, Inc)

(Functions approximated by third-order polynomials)

Polynomial Coefficients:

Camber	Caster	Toe
C0 = .976	C0 = 1.0	C0 = -.136
C1 = -.0147	C1 = -.951	C1 = -.227
C2 = -.156	C2 = -.0292	C2 = -.0471
C3 = -.0115	C3 = 0	C3 = 0

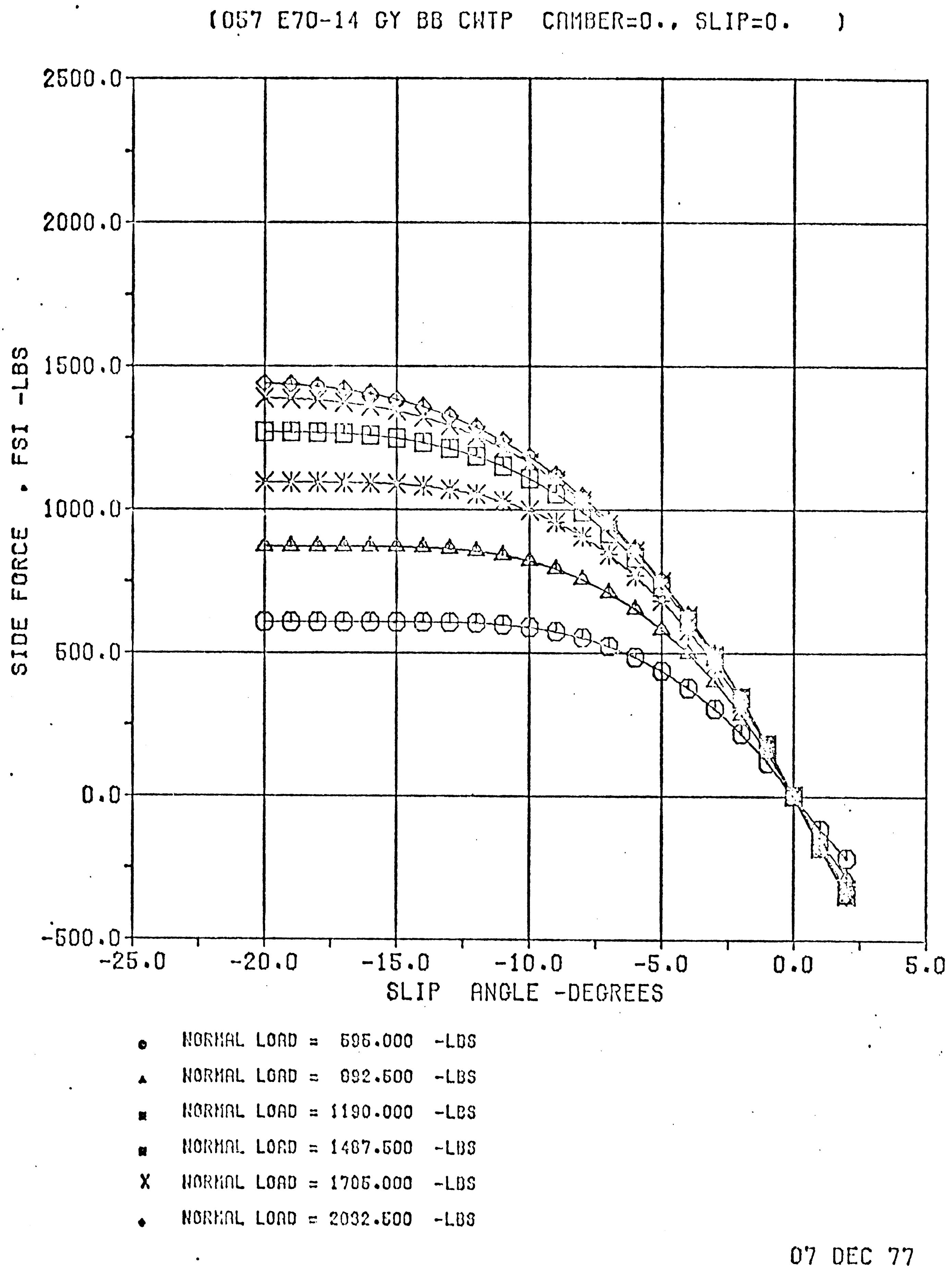


Figure D.7. Tire side force vs. slip angle, with normal load varying, for the Chevrolet Nova.

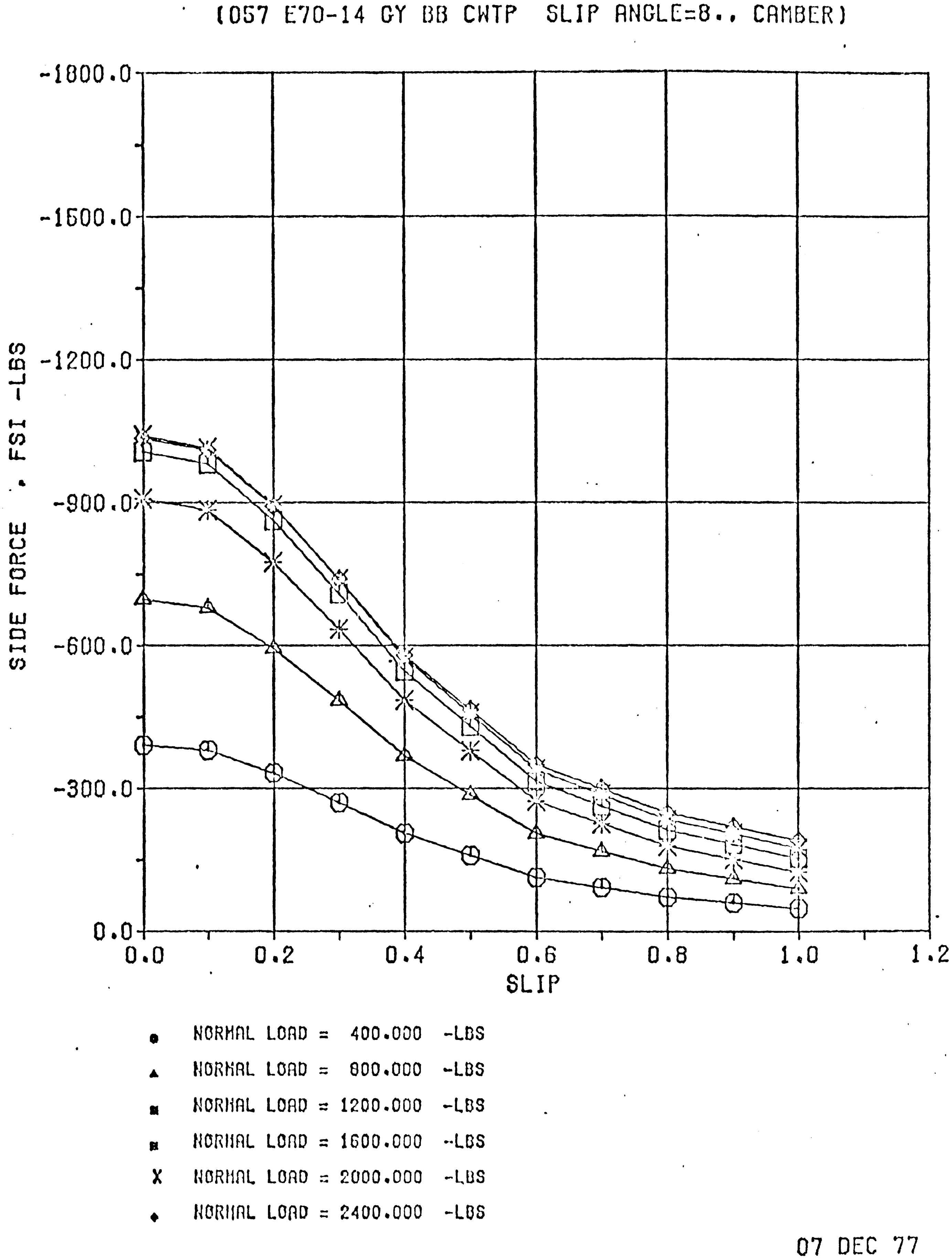


Figure D.8. Tire side force vs. slip, with normal load varying, for the Chevrolet Nova.

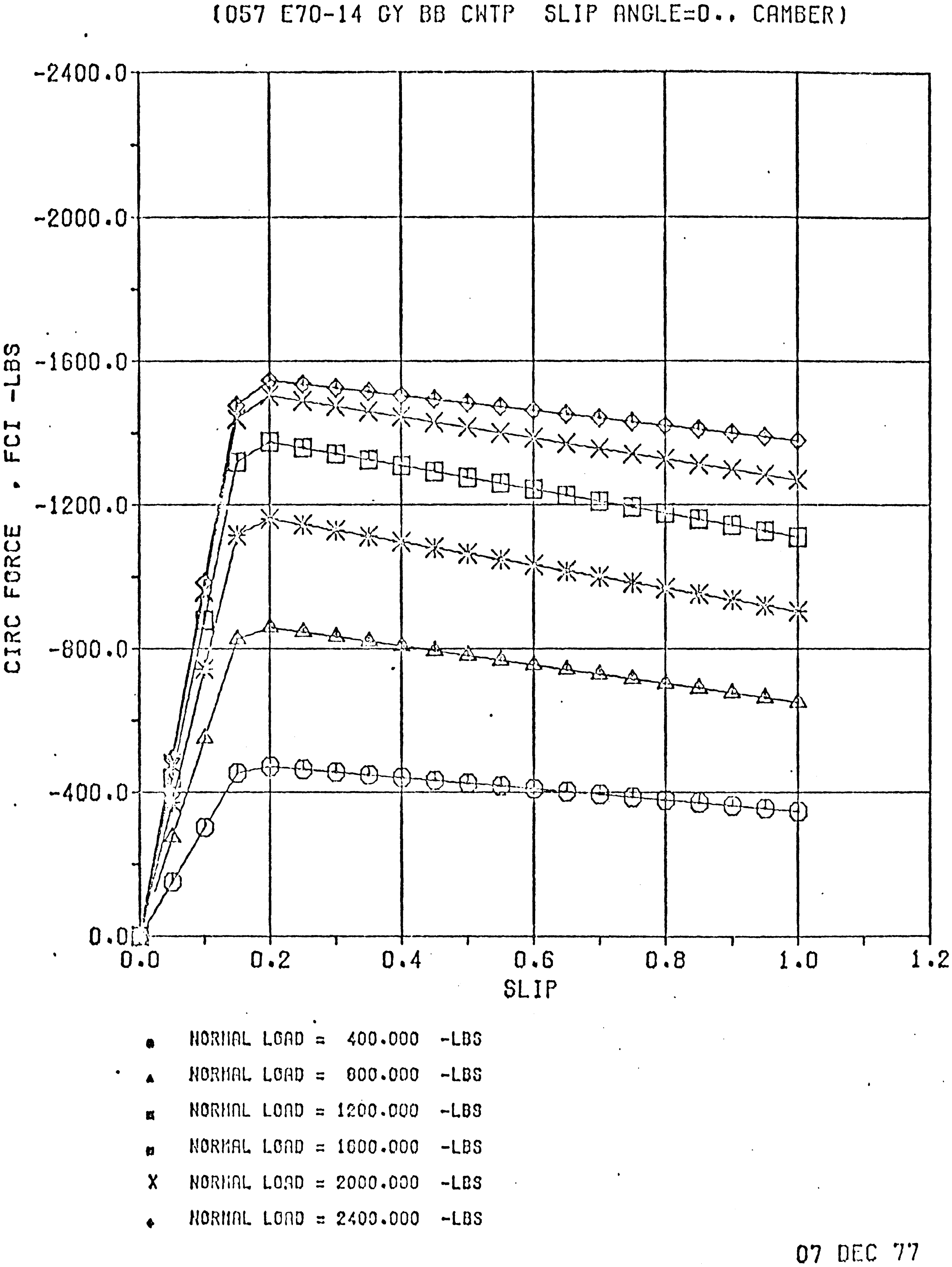


Figure D.9. Tire braking force vs. slip ratio, with normal load varying, for the Chevrolet Nova.

Table D.11.. Parameter Values Needed to Simulate the Bobcat Wagon, in the Lightly Loaded Condition.

PARAMETER VALUES - MODEL C - VEHICLE MODEL - 1977 MERCURY BOBCAT WAGON

1	TS= 7.2700	2	MUF= 0.45500	3	MUR= 0.73400	4	ZF= 12.000	5	ZR= 12.000
6	A= 43.000	7	B= 49.900	8	TF= 55.000	9	TR= 55.800	10	TSP= 42.200
11	IX= 3700.0	12	IY= 20600.	13	IZ= 28000.	14	IXZ= 0.0	15	IR= 200.00
16	ROOF= 30.000	17	RF= 0.18000E 06	18	STOP= 10.000	19	AKF1= 118.00	20	AKR2= 118.00
21	AKR3= 149.00	22	AKR4= 149.00	23	= 0.0	24	PR= 0.0	25	CT1P= 50.000
26	CR2P= 50.000	27	CR3P= 50.000	28	CR4P= 50.000	29	ZBAS= 0.0	30	KRS= 0.0
31	TW= 11.770	32	SCAL= 3000.0	33	POT= 0.50000	34	A0= 2055.5	35	A1= 6.7100
36	A2= 2324.8	37	A3= 0.17400	38	A4= -677.34	39	TIR = 0.0	40	TOS = 0.0
41	KSC= 150.00	42	NG= 24.000	43	= 0.0	44	= 0.0	45	= 0.0
46	= 0.0	47	IFW= 6.0000	48	IF = 0.0	49	IWF= 9.4000	50	IWR= 9.4000
51	IDF= 0.70000	52	ARR= 3.1800	53	TSF = 0.0	54	KPS = 0.0	55	PT= 0.15000
56	YSA1= 4.6000	57	YSA2= -4.6000	58	PHS1=-0.17000	59	PHS2= 0.17000	60	CTSW= 1.0000
61	IDR= 0.0	62	ARF= 0.0	63	P-IN= 0.0	64	Q-IN= 0.0	65	R-IN= 0.0
66	U-IN= 40.000	67	V-IN= 0.0	68	W-IN= 0.0	69	X-IN= 0.0	70	Y-IN= 0.0
71	Z-IN= -22.823	72	THIN=-0.35949E-01	73	PHIN= 0.0	74	PSIN= 0.0	75	DT= 0.50000E-02
76	TM= 10.000	77	KT1= 865.00	78	KT2= 865.00	79	KT3= 865.00	80	KT4= 865.00
81	RPS1= 65.208	82	RPS2= 65.208	83	RPS3= 64.858	84	RPS4= 64.858	85	B1=-0.35040E-04
86	B2= 0.0	87	B3= 0.91500	88	B4=-0.29500E-07	89	D1DT= 0.0	90	D2DT= 0.0
91	D3DT= 0.0	92	DELF= 0.0	93	DELR= 0.0	94	DEL3= 0.0	95	PHDT= 0.0
96	PHIP= 0.0	97	DFW1= 0.0	98	DFW2= 0.0	99	U1PR= 0.0	100	U2PR= 0.0
101	U3PP= 0.0	102	U4PP= 0.0	103	S1PR= 0.0	104	S2PR= 0.0	105	S3PR= 0.0
106	S4PP= 0.0	107	PPRT= 1.0000	108	FREQ= 0.50000	109	RWSF= 0.0	110	TOMX= 0.0
111	KTO= 0.0	112	VC= 0.0	113	MTSW= 1.0000	114	DSWM= 0.0	115	TST= 0.0
116	DSLP= 100.00	117	CGAM= 0.0	118	CS= 0.0	119	TQR= 0.0	120	TQF= 0.0
121	PTL= 200.00	122	T1= 0.0	123	DSW= 0.0	124	= 0.0	125	ISWS= 0.0
126	SWIS= 0.0	127	POSW= 0.0	128	VTPS= 1.0000	129	VHTP= 1.0000	130	AMCF= 0.60000E-01
131	RCP= 0.0	132	KSL1= 56000.	133	KSL2= 56000.	134	AA1= 6.6000	135	AA2= 6.6000
136	CCP= 11.000	137	CFCP= 54.000	138	AP= 5.2000	139	FP1= 0.0	140	FP2= 0.0
141	AERO= 0.0	142	VYW = 0.0	143	OMXW= 0.0	144	OMZW= 0.0	145	RHOA= 0.0
146	CYP = 0.0	147	CYR = 0.0	148	CZAL= 0.0	149	CZO = 0.0	150	CLP = 0.0
151	CLR = 0.0	152	CMAL= 0.0	153	CMO = 0.0	154	CNP = 0.0	155	CNR = 0.0
156	SP = 0.0	157	VLEV= 0.0	158	REWV= 0.0	159	= 0.0	160	= 0.0
161	= 0.0	162	= 0.0	163	= 0.0	164	= 0.0	165	= 0.0
166	= 0.0	167	= 0.0	168	= 0.0	169	SNT= 85.000	170	SNSO= 30.000
171	SNS1= 85.000	172	SNSW= 2.0000	173	DIST= 0.0	174	PL = 0.0	175	TSCP= 0.25000
176	= 1.0000	177	= 0.0	178	= 0.0	179	= 0.0	180	PASS= 0.0
181	= 0.0	182	SI1= 0.22800	183	SI2= 0.22800	184	SI3= 0.22800	185	SI4= 0.22800
186	= 0.0	187	= 0.0	188	= 0.0	189	= 0.0	190	= 0.0
191	= 0.0	192	MTQB= 0.20000	193	DCSW= 0.0	194	LDF= 0.0	195	LDRF= 0.0
196	BK1= 0.0	197	RK2= 0.0	198	PMPL= 0.0	199	BMPS= 0.0	200	SMPH= -1.5000
201	XB= 0.0	202	APF1= 1.1210	203	APF2=-0.20870E-03	204	APR1= 1.1210	205	APP2=-0.20870E-03
206	MUSF= 0.81100	207	MUSP= 0.81100	208	BCON= 0.30000E-01	209	FCSW= 0.0	210	=-0.14490E-03
211	=-0.14490E-03	212	= 0.0	213	= 0.0	214	= 0.0	215	= 0.0
216	= 0.0	217	= 0.0	218	= 0.0	219	FEE1= 0.0	220	FEE2= 0.0
221	THE1= 0.0	222	THE2= 0.0	223	= 0.0	224	= 0.0	225	= 0.0
226	= 0.0	227	= 0.0	228	= 0.0	229	= 0.0	230	= 0.0
231	H1= 400.00	232	H2= 400.00	233	LAMD= 1.0000	234	= 0.0	235	= 0.0
236	= 0.0	237	= 0.0	238	BP1= 1.0000	239	BP2= 1.0000	240	BP3= 1.0000
241	BP4= 1.0000	242	KCF= 0.0	243	KCR= 0.0	244	KSR= 0.0	245	RB1=-0.35040E-04
246	RB2= 0.0	247	RB3= 0.91500	248	RB4=-0.29500E-07	249	APK1=-0.34740E-02	250	APK2= 0.30624E-02
251	ARK3= 0.45600	252	ARK1=-0.34740E-02	253	ARK2= 0.30624E-02	254	ARK3= 0.45600	255	OFC0= 0.0
256	OFC1=-0.15732E-02	257	OFC2=-0.32916E-02	258	OPC3= -5.4240	259	ORC0= 0.0	260	OFC1=-0.15732E-02
261	OPC2=-0.32916E-02	262	OPC3= -5.4240	263	CP0F= 0.0	264	CP1P= 0.0	265	CP2F= 0.0
266	CP0R= 0.0	267	CP1R= 0.0	268	CP2R= 0.0	269	CROP= 0.0	270	CR1F= 0.0
271	CR2F= 0.0	272	CR0R= 0.0	273	CR1R= 0.0	274	CR2R= 0.0	275	= 0.0
276	= 0.0	277	DMPN= 0.0	278	TQB0= 0.0	279	TQB1= 0.0	280	= 0.0
281	= 0.0	282	= 0.0	283	= 0.0	284	HFC= 0.0	285	HRC= 0.0
286	DBSW= 0.0	287	AXLE= 1.0000	288	DUAL= 0.0	289	TIRE= 4.0000	290	ROT = 0.50000
291	RA0 = 2055.5	292	RA1 = 6.7100	293	RA2 = 2324.8	294	RA3 = 0.17400	295	RA4 = -677.34

Table D.12. Parameter Values Needed to Simulate the Bobcat Wagon, in the GVW Condition.

PARAMETER VALUES - MODEL C - VEHICLE MODEL - 1977 MERCURY BOBCAT WAGON

1	MS= 8.8700	2	MUF= 0.45500	3	MUR= 0.73400	4	ZF= 12.000	5	ZR= 12.250
6	A= 51.800	7	B= 44.900	8	TF= 55.000	9	TR= 55.800	10	TSF= 42.200
11	IX= 5100.0	12	IY= 30700.	13	IZ= 37500.	14	IXZ= 0.0	15	IP= 200.00
16	ROOP= 30.000	17	RF= 0.18000E 05	18	STOP= 10.000	19	AKF1= 118.00	20	AKF2= 118.00
21	AKR3= 149.00	22	AKR4= 149.00	23	= 0.0	24	FR= 0.0	25	CF1F= 50.000
26	CF2F= 50.000	27	CR3R= 50.000	28	CR4R= 50.000	29	ZBAS= 0.0	30	KRS= 0.0
31	RW= 11.770	32	SCAL= 3000.0	33	POT= 0.50000	34	A0= 2055.5	35	A1= 6.7100
36	A2= 2324.8	37	A3= 0.17400	38	A4= -677.34	39	TIR = 0.0	40	TOR = 0.0
41	KSC= 150.00	42	NG= 24.000	43	= 0.0	44	= 0.0	45	= 0.0
46	= 0.0	47	IFW= 6.0000	48	IF = 0.0	49	TWF= 9.4000	50	TWR= 9.4000
51	IDR= 0.70000	52	ARR= 3.1800	53	TSF = 0.0	54	KFS = 0.0	55	RT= 0.15000
56	YSA1= 4.6000	57	YSA2= -4.6000	58	PHS1=-0.17000	59	PHS2= 0.17000	60	CTSW= 1.0000
61	IDF= 0.0	62	APF= 0.0	63	P-IN= 0.0	64	Q-IN= 0.0	65	R-IN= 0.0
66	U-IN= 40.000	67	V-IN= 0.0	68	W-IN= 0.0	69	X-IN= 0.0	70	Y-IN= 0.0
71	Z-IN= -22.773	72	THIN=-0.27445E-01	73	PHIN= 0.0	74	PSIN= 0.0	75	DT= 0.50000E-02
76	TF= 10.000	77	KT1= 865.00	78	KT2= 865.00	79	KT3= 865.00	80	KT4= 865.00
81	RPS1= 65.208	82	RPS2= 65.208	83	RPS3= 64.858	84	RPS4= 64.858	85	B1=-0.35040E-04
86	B2= 0.0	87	B3= 0.91500	88	B4=-0.29500E-07	89	D1DT= 0.0	90	D2DT= 0.0
91	D3DT= 0.0	92	DEL2=-0.37000	93	DELR= -1.7700	94	DEL3= 0.0	95	PHDT= 0.0
96	PHIR= 0.0	97	DFW1= 0.0	98	DFW2= 0.0	99	U1PR= 0.0	100	U2PR= 0.0
101	U3PR= 0.0	102	U4PR= 0.0	103	S1PR= 0.0	104	S2PR= 0.0	105	S3PR= 0.0
106	S4PR= 0.0	107	PPRT= 1.0000	108	FREQ= 0.50000	109	RWSF= 0.0	110	TQMX= 0.0
111	KTQ= 0.0	112	VC= 0.0	113	MTSW= 1.0000	114	DSWM= 0.0	115	TST= 0.0
116	DSLP= 100.00	117	CGAM= 0.0	118	CS= 0.0	119	TQR= 0.0	120	TQF= 0.0
121	RTL= 350.00	122	T1= 0.0	123	DSW= 0.0	124	= 0.0	125	ISWS= 0.0
126	SW15= 0.0	127	POSW= 0.0	128	VTPS= 1.0000	129	VHTP= 1.0000	130	AMCP= 0.60000E-01
131	TSP= 0.0	132	KSL1= 56000.	133	KSL2= 56000.	134	AA1= 6.6000	135	AA2= 6.6000
136	CCP= 11.000	137	CFCR= 54.000	138	AP= 5.2000	139	FP1= 0.0	140	FP2= 0.0
141	APRO= 0.0	142	YYW = 0.0	143	OMXW= 0.0	144	OMZW= 0.0	145	PHO1= 0.0
146	CYP = 0.0	147	CYR = 0.0	148	CZAL= 0.0	149	CZQ = 0.0	150	CLP = 0.0
151	CLR = 0.0	152	CMAL= 0.0	153	CMQ = 0.0	154	CNP = 0.0	155	CNR = 0.0
156	SF = 0.0	157	VLEN= 0.0	158	REWV= 0.0	159	= 0.0	160	= 0.0
161	= 0.0	162	= 0.0	163	= 0.0	164	= 0.0	165	= 0.0
166	= 0.0	167	= 0.0	168	= 0.0	169	SNT= 85.000	170	SNSO= 30.000
171	SNS1= 85.000	172	SNSW= 2.0000	173	DIST= 0.0	174	PL = 0.0	175	TSCP= 0.25000
176	= 1.0000	177	= 0.0	178	= 0.0	179	= 0.0	180	PATS= 0.0
181	= 0.0	182	SI1= 0.22800	183	SI2= 0.22800	184	SI3= 0.22800	185	SI4= 0.22800
186	= 0.0	187	= 0.0	188	= 0.0	189	= 0.0	190	= 0.0
191	= 0.0	192	MTQB= 0.20000	193	DCSW= 0.0	194	LDF= 0.0	195	LDRF= 0.0
196	ZK1= 0.0	197	ZK2= 0.0	198	BMPL= 0.0	199	BMPS= 0.0	200	BMPH= -1.5000
201	XB= 0.0	202	APF1= 1.1210	203	APF2=-0.20870E-03	204	APR1= 1.1210	205	APR2=-0.20870E-03
206	MUSF= 0.81100	207	MUSR= 0.81100	208	BCON= 0.30000E-01	209	FCSW= 0.0	210	=-0.14490E-03
211	=-0.14490E-03	212	= 0.0	213	= 0.0	214	= 0.0	215	= 0.0
216	= 0.0	217	= 0.0	218	= 0.0	219	FER1= 0.0	220	FER2= 0.0
221	THE1= 0.0	222	THE2= 0.0	223	= 0.0	224	= 0.0	225	= 0.0
226	= 0.0	227	= 0.0	228	= 0.0	229	= 0.0	230	= 0.0
231	H1= 400.00	232	H2= 400.00	233	LAMD= 1.0000	234	= 0.0	235	= 0.0
236	= 0.0	237	= 0.0	238	BR1= 1.0000	239	BR2= 1.0000	240	BR3= 1.0000
241	BR4= 1.0000	242	KCF= 0.0	243	KCR= 0.0	244	KSR= 0.0	245	BB1=-0.35040E-04
246	BB2= 0.0	247	BB3= 0.91500	248	BB4=-0.29500E-07	249	AFK1=-0.34740E-02	250	AFK2= 0.30624E-02
251	AFK3= 0.45600	252	ARK1=-0.34740E-02	253	ARK2= 0.30624E-02	254	ARK3= 0.45600	255	OFC0= 0.0
256	OFC1=-0.15732E-02	257	OFC2=-0.32916E-02	258	OFC3= -5.4240	259	ORC0= 0.0	260	ORC1=-0.15732E-02
261	ORC2=-0.32916E-02	262	ORC3= -5.4240	263	CP0F= 0.0	264	CP1F= 0.0	265	CP2F= 0.0
266	CP0R= 0.0	267	CP1R= 0.0	268	CP2R= 0.0	269	CF0F= 0.0	270	CF1F= 0.0
271	CF2F= 0.0	272	CR0R= 0.0	273	CR1R= 0.0	274	CR2R= 0.0	275	= 0.0
276	= 0.0	277	BMPN= 0.0	278	TOB0= 0.0	279	TOB1= 0.0	280	= 0.0
281	= 0.0	282	= 0.0	283	= 0.0	284	HFC= 0.0	285	HRC= 0.0
286	DPSW= 0.0	287	AXLE= 1.0000	288	DUAL= 0.0	289	TIRE= 4.0000	290	ROT = 0.50000
291	PA0 = 2055.5	292	PA1 = 6.7100	293	PA2 = 2324.8	294	PA3 = 0.17400	295	PA4 = -677.34

Table D.13. Tabular Inputs for the Bobcat Wagon.

Spring Rates (Based on MVMA Specifications)

Front δ (in)	Front F (lbs)	Rear δ (in)	Rear F (lbs)
-100.	-2000.	-100.	-3000.
-10.	-2000.	-10.	-3000.
-2.5	-295.	-2.5	-370.
0.0	0.0	0.0	0.0
3.5	413.	3.5	520.
10.	2500.	10.	3500.
100.	2500.	100.	3500.

Brake Torque (Measured at HSRI)

Front P (psi)	Front TQ (in-lbs)	Rear P (psi)	Rear TQ (in-lbs)
0.	0.	0.	0.
50.	0.	50.	0.
1800.	17000.	900.	3500.
		1800.	1050.

Shock Absorber Data (Measured from 1971 Mustang)

Front

$C = 3.55 \quad \dot{\delta} > 24$

$C = 1.44 \quad \dot{\delta} < 24$

Rear

$C = 4.6 \quad \dot{\delta} > 25.5$

$C = 3.48 \quad 12 < \dot{\delta} < 25.5$

$C = 5.94 \quad 0 < \dot{\delta} < 12$

$C = 2.13 \quad \dot{\delta} < 0$

Table D.13. (Cont.)

Camber, Caster, and Toe Data (1971 Mustang)

Displacement	Camber	Toe	Caster (Not Measured)
-2.82	-1.52	- .54	.75
-1.82	-0.70	-0.44	.75
-0.82	0.03	-0.35	.75
0.	0.5	-0.2	.75
0.18	0.6	-0.17	.75
1.18	1.03	0.05	.75
2.18	1.07	0.3	.75
3.18	1.07	0.61	.75
4.18	1.45	1.2	.75

(290 BR78-13 FI R RDC CAMBER=0., SLIP=0.)

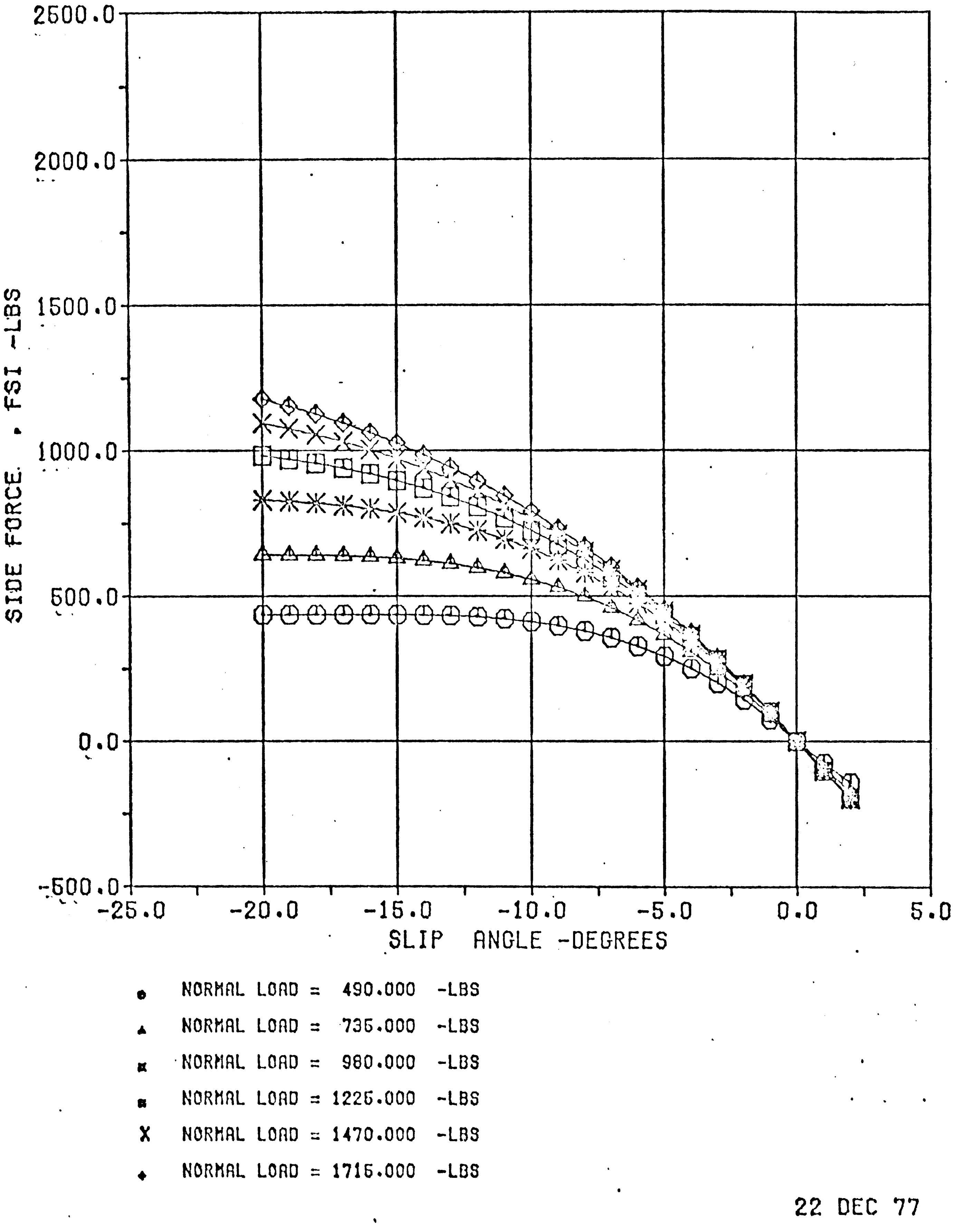


Figure D.10. Tire side force vs. slip angle, with normal load varying, for the Mercury Bobcat.

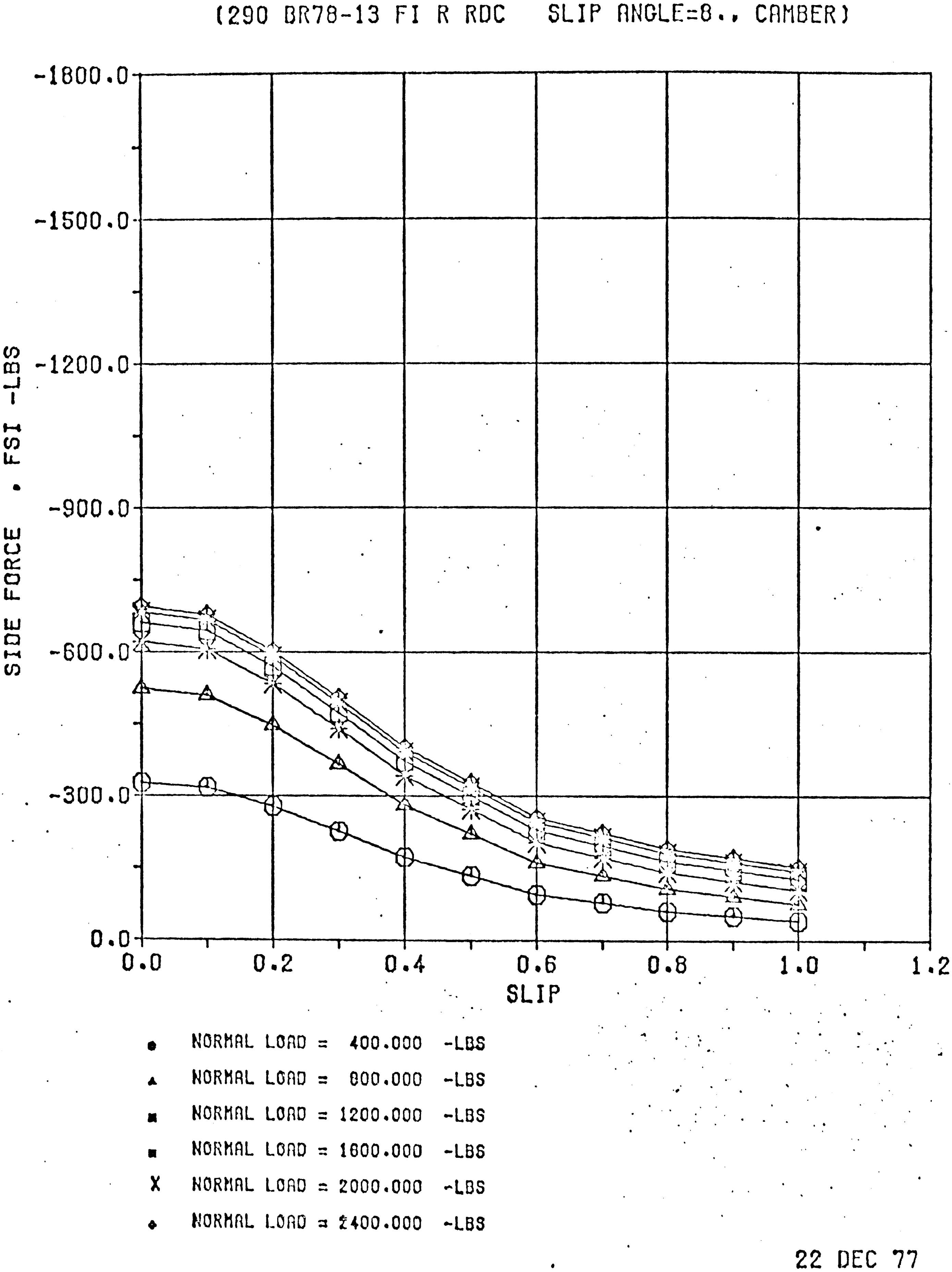


Figure D.11. Tire side force vs. slip ratio, with normal load varying, for the Mercury Bobcat.

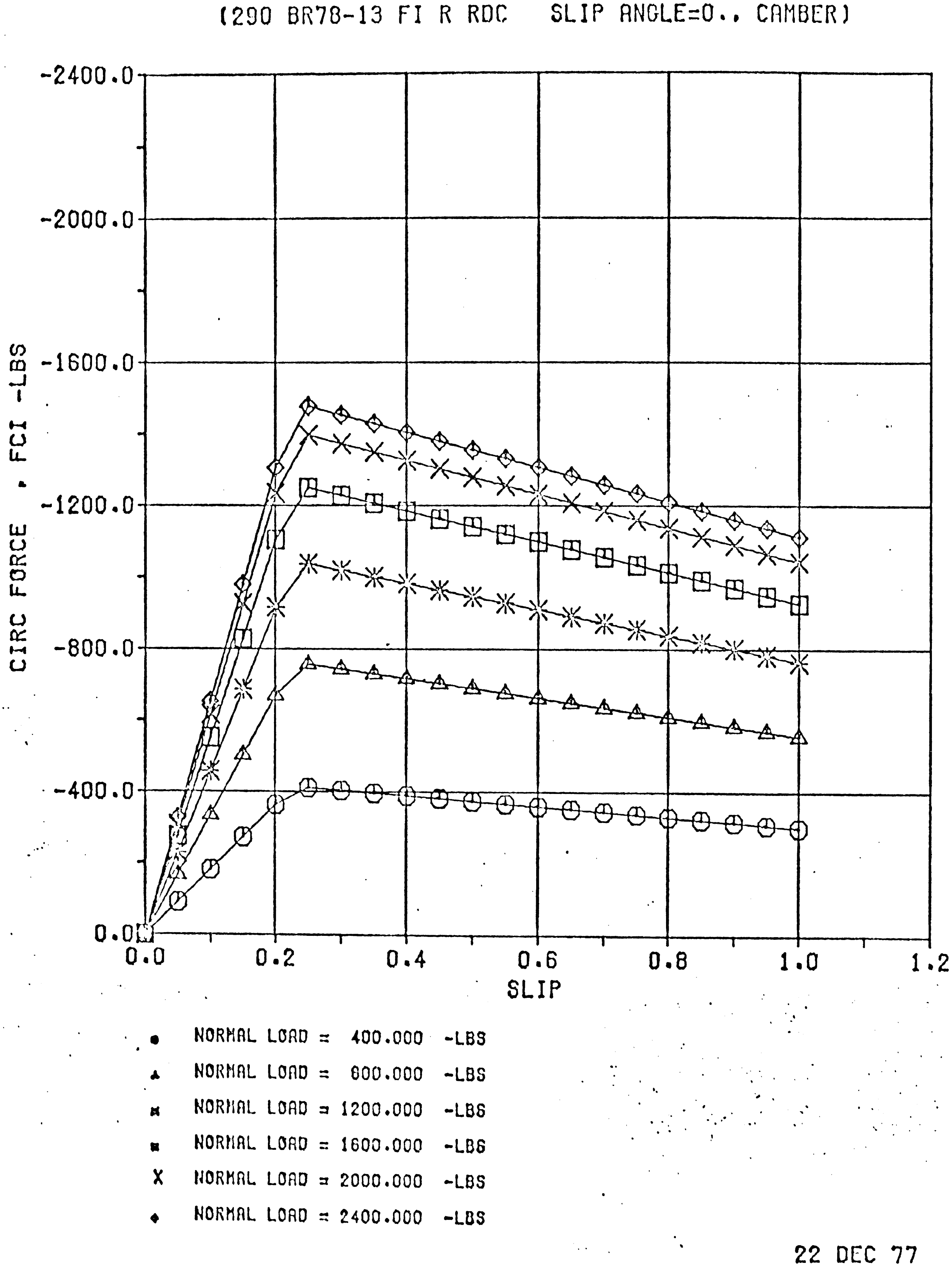


Figure D.12. Tire braking force vs. slip ratio, with normal load varying, for the Mercury Bobcat.

Table D.14. Parameter Values Needed to Simulate the AMC Pacer, Under the Lightly Loaded Condition.

PARAMETER VALUES - MODEL C - VEHICLE MODEL - 1977 AMC PACER

1	MS= 8.4500	2	MUF= 0.49600	3	MUR= 0.80300	4	ZF= 11.650	5	ZR= 11.650
6	A= 43.300	7	B= 56.700	8	TF= 61.500	9	TR= 60.000	10	TSR= 46.500
11	IX= 6500.0	12	IY= 21000.	13	IZ= 27000.	14	IXZ= 0.0	15	IR= 600.00
16	ROCR= 30.000	17	RF= 0.0	18	STOP= 10.000	19	AKF1= 116.00	20	AKF2= 116.00
21	AKR3= 105.00	22	AKR4= 105.00	23	= 0.0	24	RR= 0.0	25	CF1P= 70.000
26	CF2P= 70.000	27	CR3P= 60.000	28	CR4P= 60.000	29	ZBAS= 0.0	30	KRS= 0.20000E-01
31	RW= 12.920	32	SCAL= 3000.0	33	FOT= 0.50000	34	A0= 3445.0	35	A1= 6.2000
36	A2= 2452.5	37	A3= 1.5040	38	A4= 4286.6	39	TIR = 0.0	40	TOR = 0.0
41	KSC= 8000.0	42	NG= 14.000	43	= 0.0	44	= 0.0	45	= 0.0
46	= 0.0	47	IFW= 6.0000	48	IF = 0.0	49	IWF= 9.4000	50	IWR= 9.4000
51	IDR= 0.70000	52	ARR= 3.0800	53	TSF = 0.0	54	KFS = 0.0	55	PI= 0.23000
56	YSA1= 4.6000	57	YSA2= -4.6000	58	PHS1=-0.13000	59	PHS2= 0.13000	60	CTSW= 1.0000
61	IDF= 0.0	62	ARF= 0.0	63	P-IN= 0.0	64	Q-IN= 0.0	65	R-IN= 0.0
66	U-IN= 40.000	67	V-IN= 0.0	68	W-IN= 0.0	69	X-IN= 0.0	70	Y-IN= 0.0
71	Z-IN= -23.713	72	THIN=-0.82156E-01	73	PHIN= 0.0	74	PSIN= 0.0	75	DT= 0.50000E-02
76	TN= 10.000	77	KT1= 1112.0	78	KT2= 1112.0	79	KT3= 1112.0	80	KT4= 1112.0
81	RPS1= 58.660	82	RPS2= 58.660	83	RPS3= 57.967	84	RPS4= 57.967	85	B1=-0.39760E-03
86	B2= 0.0	87	B3= 1.2740	88	B4= 0.75170E-07	89	D1DT= 0.0	90	D2DT= 0.0
91	D3DT= 0.0	92	DELF= 0.0	93	DELR= 0.0	94	DEL3= 0.0	95	PHDT= 0.0
96	PHIR= 0.0	97	DFW1= 0.0	98	DFW2= 0.0	99	U1PR= 0.0	100	U2PR= 0.0
101	U3PR= 0.0	102	U4PR= 0.0	103	S1PR= 0.0	104	S2PR= 0.0	105	S3PR= 0.0
106	S4PR= 0.0	107	PPRT= 1.0000	108	FRFO= 0.50000	109	RWSF= 15.000	110	TQMX= 0.0
111	KTQ= 0.0	112	VC= 0.0	113	MTSW= 1.0000	114	DSWM= 0.0	115	TST= 0.0
116	DSLP= 100.00	117	CGAM= 0.0	118	CS= 0.0	119	TCR= 0.0	120	TQF= 0.0
121	PFL= 200.00	122	T1= 0.0	123	DSW= 0.0	124	= 0.0	125	ISW5= 0.0
126	SW15= 0.0	127	PQSW= 0.0	128	VTPS= 1.0000	129	VHTP= 1.0000	130	AMCR= 0.50000E-01
131	ESP= 0.28000	132	KSL1= 56000.	133	KSL2= 56000.	134	AA1= 6.6000	135	AA2= 6.6000
136	CCR= 11.000	137	CFCR= 54.000	138	AP= 5.2000	139	EP1= 0.0	140	EP2= 0.0
141	AERO= 0.0	142	VYW = 0.0	143	OMXW= 0.0	144	OMZW= 0.0	145	RHOA= 0.0
146	CYP = 0.0	147	CYR = 0.0	148	CZAL= 0.0	149	CZQ = 0.0	150	CLP = 0.0
151	CLR = 0.0	152	CMAL= 0.0	153	CMQ = 0.0	154	CNP = 0.0	155	CNR = 0.0
156	SF = 0.0	157	VLEN= 0.0	158	REWV= 0.0	159	= 0.0	160	= 0.0
161	= 0.0	162	= 0.0	163	= 0.0	164	= 0.0	165	= 0.0
166	= 0.0	167	= 0.0	168	= 0.0	169	SNT= 85.000	170	SNSO= 30.000
171	SNS1= 85.000	172	SNSW= 2.0000	173	DIST= 0.0	174	PL = 0.0	175	TSCF= 0.25000
176	= 1.0000	177	= 0.0	178	= 0.0	179	= 0.0	180	PASS= 0.0
181	= 0.0	182	SI1= 0.18400	183	SI2= 0.18400	184	SI3= 0.18400	185	SI4= 0.18400
186	= 0.0	187	= 0.0	188	= 0.0	189	= 0.0	190	= 0.0
191	= 0.0	192	MTQB= 0.20000	193	DCSW= 0.0	194	LDF= 0.0	195	LDRF= 0.0
196	EK1= 0.0	197	EK2= 0.0	198	BMPL= 0.0	199	BMPS= 0.0	200	BMPH= -1.5000
201	XB= 0.0	202	APF1= 1.1862	203	APF2=-0.28670E-03	204	APR1= 1.1862	205	APR2=-0.28670E-03
206	MUSF= 0.89900	207	MUSR= 0.89900	208	BCON= 0.30000E-01	209	FCSW= 0.0	210	=-0.19700E-03
211	=-0.19700E-03	212	= 0.0	213	= 0.0	214	= 0.0	215	= 0.0
216	= 0.0	217	= 0.0	218	= 0.0	219	FEE1= 0.0	220	FEE2= 0.0
221	THE1= 0.0	222	THE2= 0.0	223	= 0.0	224	= 0.0	225	= 0.0
226	= 0.0	227	= 0.0	228	= 0.0	229	= 0.0	230	= 0.0
231	H1= 400.00	232	H2= 400.00	233	LAMD= 1.0000	234	= 0.0	235	= 0.0
236	= 0.0	237	= 0.0	238	BR1= 1.0000	239	BR2= 1.0000	240	BR3= 1.0000
241	BR4= 1.0000	242	KCF=-0.39000E-04	243	KCR=-0.33000E-04	244	KSR= 0.21000E-04	245	RB1=-0.39760E-03
246	RB2= 0.0	247	RB3= 1.2740	248	RB4= 0.75170E-07	249	AFK1=-0.31692E-02	250	AFK2= 0.27792E-02
251	AFK3= 1.4880	252	ARK1=-0.31692E-02	253	ARK2= 0.27792E-02	254	ARK3= 1.4880	255	OFC0= 0.0
256	OFC1=-0.15252E-02	257	OFC2=-0.88092E-03	258	OFC3= -5.2680	259	ORC0= 0.0	260	ORC1=-0.15252E-02
261	ORC2=-0.88092E-03	262	ORC3= -5.2680	263	CP0F= 0.0	264	CP1F= 0.0	265	CP2F= 0.0
266	CP0R= 0.0	267	CP1R= 0.0	268	CP2R= 0.0	269	CR0F= 0.0	270	CR1F= 0.0
271	CR2F= 0.0	272	CR0R= 0.0	273	CR1R= 0.0	274	CR2R= 0.0	275	= 0.0
276	= 0.0	277	BMPN= 0.0	278	TQB0= 0.0	279	TQB1= 0.0	280	= 0.0
281	= 0.0	282	= 0.0	283	= 0.0	284	HFC= 0.0	285	HRC= 0.0
286	DRSW= 0.0	287	AXLE= 1.0000	288	DUAL= 0.0	289	TIRE= 4.0000	290	POT = 0.50000
291	RA0 = 3445.0	292	RA1 = 6.2000	293	RA2 = 2452.5	294	RA3 = 1.5040	295	RA4 = 4286.6

Table D.15. Parameter Values Needed to Simulate the AMC Pacer, Under the GVW Condition.

PARAMETER VALUES – MODEL C – VEHICLE MODEL – 1977 AMC PACER

1	MS= 10.070	2	MUF= 0.49600	3	MUR= 0.80300	4	ZF= 10.500	5	ZR= 10.600
6	A= 49.000	7	B= 51.000	8	TF= 61.500	9	TR= 60.000	10	TSR= 46.500
11	IX= 7600.0	12	IY= 28000.	13	IZ= 34000.	14	IXZ= 0.0	15	IR= 600.00
16	RCCR= 30.000	17	RF= 0.0	18	STOP= 10.000	19	AKF1= 107.00	20	AKF2= 107.00
21	AKR3= 105.00	22	AKR4= 105.00	23	= 0.0	24	RR= 0.0	25	CF1P= 70.000
26	CF2P= 70.000	27	CR3P= 60.000	28	CR4P= 60.000	29	ZBAS= 0.0	30	KRS= 0.20000E-01
31	PW= 12.920	32	SCAL= 3000.0	33	FOT= 0.50000	34	A0= 3445.0	35	A1= 6.2000
36	A2= 2452.5	37	A3= 1.5040	38	A4= 4286.6	39	TIR = 0.0	40	TOR = 0.0
41	KSC= 6000.0	42	NC= 14.000	43	= 0.0	44	= 0.0	45	= 0.0
46	= 0.0	47	IFW= 6.0000	48	IF = 0.0	49	IWF= 9.4000	50	IWR= 9.4000
51	IDR= 0.70000	52	ARR= 3.0800	53	TSF = 0.0	54	KFS = 0.0	55	PT= 0.23000
56	YSA1= 4.6000	57	YSA2= -4.6000	58	PHS1=-0.13000	59	PHS2= 0.13000	60	CTSW= 1.0000
61	IDF= 0.0	62	ARF= 0.0	63	P-IN= 0.0	64	Q-IN= 0.0	65	R-IN= 0.0
66	U-IN= 40.000	67	V-IN= 0.0	68	W-IN= 0.0	69	X-IN= 0.0	70	Y-IN= 0.0
71	Z-IN= -22.482	72	THIN=-0.46783E-01	73	PHIN= 0.0	74	PSIN= 0.0	75	DI= 0.50000E-02
76	TN= 10.000	77	KT1= 1112.0	78	KT2= 1112.0	79	KT3= 1112.0	80	KT4= 1112.0
81	RPS1= 58.660	82	RPS2= 58.660	83	RPS3= 57.967	84	RPS4= 57.967	85	B1=-0.39760E-03
86	B2= 0.0	87	B3= 1.2740	88	B4= 0.75170E-07	89	D1DT= 0.0	90	D2DT= 0.0
91	D3DT= 0.0	92	DELF=-0.60000	93	DELR= -2.3500	94	DEL3= 0.0	95	PHDT= 0.0
96	PHIR= 0.0	97	DFW1= 0.0	98	DFW2= 0.0	99	U1PR= 0.0	100	U2PR= 0.0
101	U3PR= 0.0	102	U4PR= 0.0	103	S1PR= 0.0	104	S2PR= 0.0	105	S3PR= 0.0
106	S4PR= 0.0	107	PPRT= 1.0000	108	FRFQ= 0.50000	109	RWSF= 15.000	110	TQMX= 0.0
111	KTC= 0.0	112	VC= 0.0	113	MTSW= 1.0000	114	DSWM= 0.0	115	TST= 0.0
116	DSLP= 100.00	117	CGAM= 0.0	118	CS= 0.0	119	TCR= 0.0	120	TUF= 0.0
121	PFL= 200.00	122	T1= 0.0	123	DSW= 0.0	124	= 0.0	125	ISW5= 0.0
126	SW15= 0.0	127	PQSW= 0.0	128	VTPS= 1.0000	129	VHTP= 1.0000	130	AMCR= 0.60000E-01
131	FSP= 0.28000	132	KSL1= 56000.	133	KSL2= 56000.	134	AA1= 6.6000	135	AA2= 6.6000
136	CCR= 11.000	137	CFCR= 54.000	138	AP= 5.2000	139	EP1= 0.0	140	EP2= 0.0
141	AERO= 0.0	142	VYW = 0.0	143	OMXW= 0.0	144	OMZW= 0.0	145	RHOA= 0.0
146	CYP = 0.0	147	CYR = 0.0	148	CZAL= 0.0	149	CZQ = 0.0	150	CLP = 0.0
151	CLR = 0.0	152	CMAL= 0.0	153	CMQ = 0.0	154	CNP = 0.0	155	CNR = 0.0
156	SF = 0.0	157	VLEN= 0.0	158	REWV= 0.0	159	= 0.0	160	= 0.0
161	= 0.0	162	= 0.0	163	= 0.0	164	= 0.0	165	= 0.0
166	= 0.0	167	= 0.0	168	= 0.0	169	SNT= 85.000	170	SNS0= 30.000
171	SNS1= 85.000	172	SNSW= 2.0000	173	DIST= 0.0	174	PL = 0.0	175	TSCP= 0.25000
176	= 1.0000	177	= 0.0	178	= 0.0	179	= 0.0	180	PASS= 0.0
181	= 0.0	182	SI1= 0.18400	183	SI2= 0.18400	184	SI3= 0.18400	185	SI4= 0.18400
186	= 0.0	187	= 0.0	188	= 0.0	189	= 0.0	190	= 0.0
191	= 0.0	192	MTQB= 0.20000	193	DCSW= 0.0	194	LDF= 0.0	195	LDRF= 0.0
196	EK1= 0.0	197	EK2= 0.0	198	BMPL= 0.0	199	BMPS= 0.0	200	BMPH= -1.5000
201	XB= 0.0	202	APF1= 1.1862	203	APF2=-0.28670E-03	204	APR1= 1.1862	205	APR2=-0.28670E-03
206	MUSF= 0.89900	207	MUSR= 0.89900	208	BCON= 0.30000E-01	209	FCSW= 0.0	210	=-0.19700E-03
211	=-0.19700E-03	212	= 0.0	213	= 0.0	214	= 0.0	215	= 0.0
216	= 0.0	217	= 0.0	218	= 0.0	219	FEE1= 0.0	220	FEE2= 0.0
221	THE1= 0.0	222	THE2= 0.0	223	= 0.0	224	= 0.0	225	= 0.0
226	= 0.0	227	= 0.0	228	= 0.0	229	= 0.0	230	= 0.0
231	H1= 400.00	232	H2= 400.00	233	LAMD= 1.0000	234	= 0.0	235	= 0.0
236	= 0.0	237	= 0.0	238	BR1= 1.0000	239	BR2= 1.0000	240	BR3= 1.0000
241	BR4= 1.0000	242	KCF=-0.39000E-04	243	KCR=-0.33000E-04	244	KSR= 0.21000E-04	245	RB1=-0.39760E-03
246	RB2= 0.0	247	RB3= 1.2740	248	RB4= 0.75170E-07	249	AFK1=-0.31692E-02	250	AFK2= 0.27792E-02
251	AFK3= 1.4880	252	ARK1=-0.31692E-02	253	ARK2= 0.27792E-02	254	ARK3= 1.4880	255	OFC0= 0.0
256	OFC1=-0.15252E-02	257	OFC2=-0.88092E-03	258	OFC3= -5.2680	259	ORC0= 0.0	260	ORC1=-0.15252E-02
261	ORC2=-0.88092E-03	262	ORC3= -5.2680	263	CP0F= 0.0	264	CP1F= 0.0	265	CP2F= 0.0
266	CP0R= 0.0	267	CP1R= 0.0	268	CP2P= 0.0	269	CR0F= 0.0	270	CR1F= 0.0
271	CR2F= 0.0	272	CR0R= 0.0	273	CR1R= 0.0	274	CR2R= 0.0	275	= 0.0
276	= 0.0	277	BMPN= 0.0	278	TQB0= 0.0	279	TQB1= 0.0	280	= 0.0
281	= 0.0	282	= 0.0	283	= 0.0	284	HFC= 0.0	285	HRC= 0.0
286	DRSW= 0.0	287	AXLE= 1.0000	288	DUAL= 0.0	289	TIRE= 4.0000	290	RCT = 0.50000
291	RA0 = 3445.0	292	RA1 = 6.2000	293	RA2 = 2452.5	294	RA3 = 1.5040	295	RA4 = 4286.6

Table D.16. Tabular Inputs for AMC Pacer

Spring Rates (Measured at HSRI)

Front δ (in)	Front F (lbs)	Rear δ (in)	Rear F (lbs)
-100.	-5565.	-100.	-2993.
-10.	-5565.	-10.	-2993.
-3.2	-465.	-3.	-420.
-3.	-315.	-2.6	-273.
0.0	0.0	0.0	0.0
2.75	350.	3.5	368.
10.	1271.	5.	660.
100.	1271.	10.	1633.
		100.	1633.

Brake Torque (Measured at BAPG)

Front P (psi)	Front TQ (in-lbs)	Rear P (psi)	Rear TQ (in-lbs)
0.	0.	0.	0.
50.	0.	150.	0.
1150.	20500.	1200.	9500.

Shock Absorber Data (G)

Front & Rear

C = 3.0 $\qquad \dot{\delta} < 0$

C = 10.0 $\qquad \dot{\delta} > 0$

Table D.16. (Cont.)

Camber, Caster, and Toe Functions (Dodge Coronet, Ref. [5])

Displacement	Camber	Caster	Toe
0.	0.	0.75	0.
1.	0.41	0.75	-0.37
2.	0.98	0.75	-0.57
3.	1.26	0.75	-0.85
4.	1.22	0.75	-1.05
5.	0.95	0.75	-1.21
6.	0.43	0.75	-1.36

(OG2 D78-14 GY BB CPCP CAMBER=0., SLIP=0.)

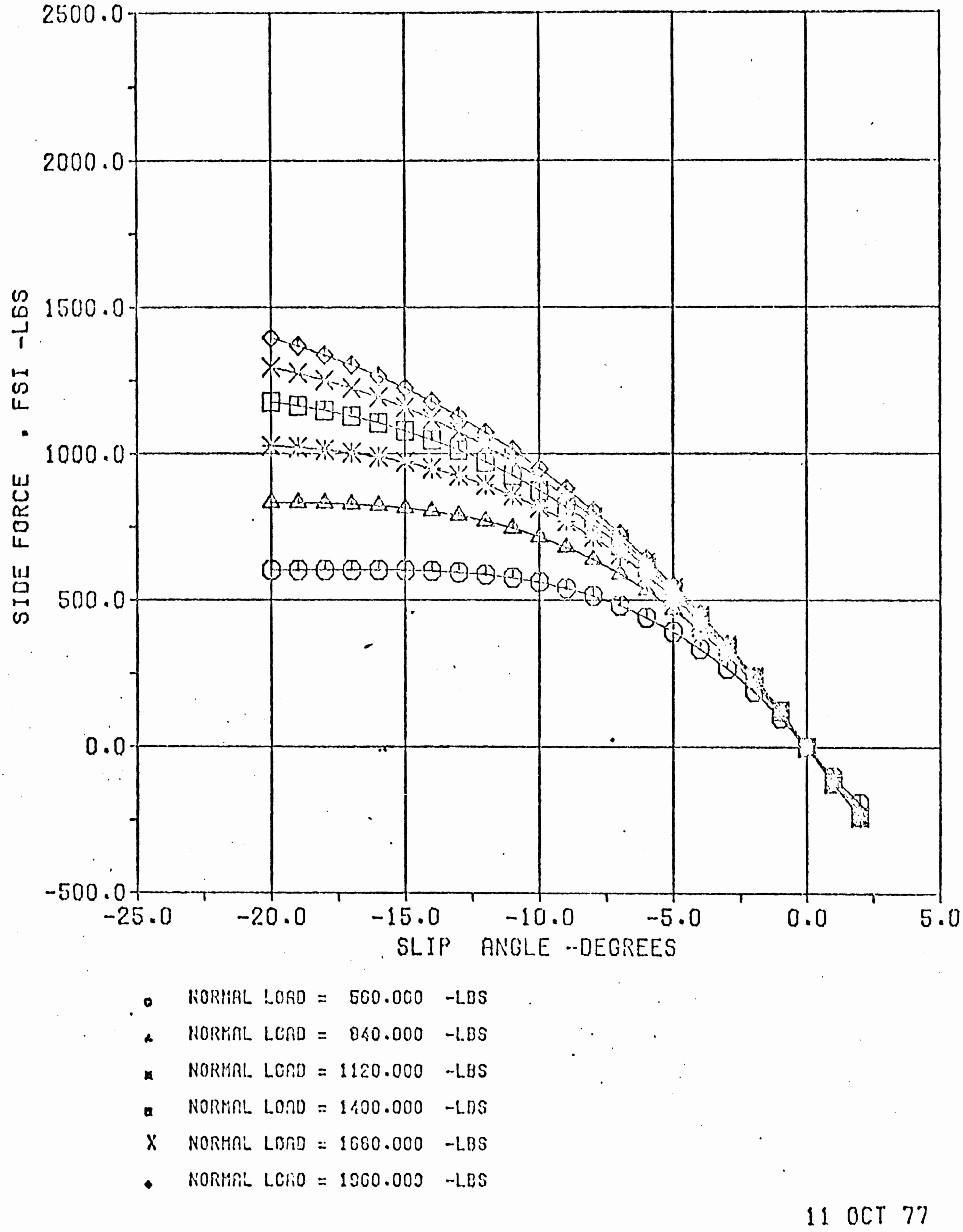


Figure D.13. Tire side force vs. slip angle, with normal load varying, for the AMC Pacer.

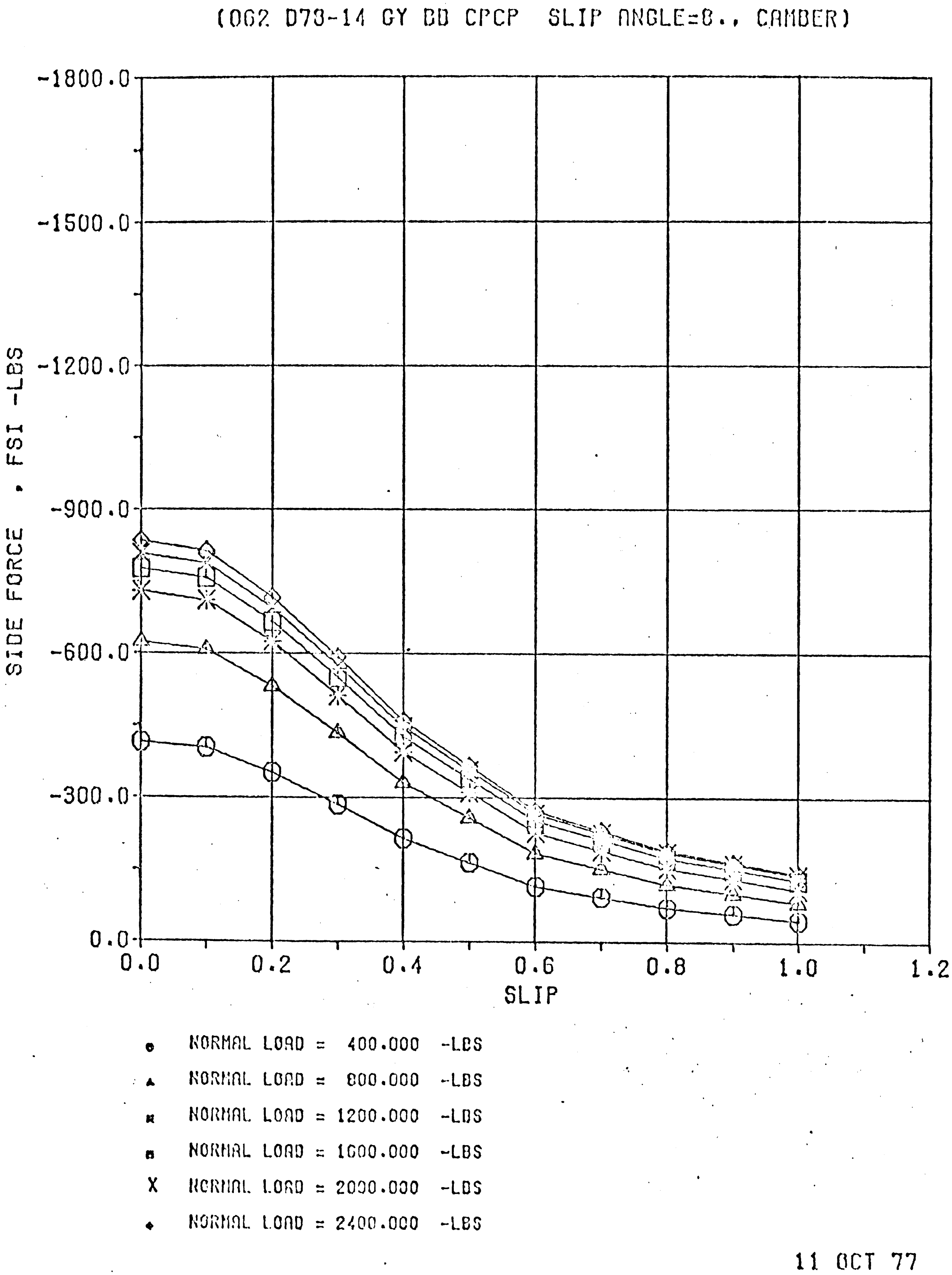


Figure D.14. Tire side force vs. slip ratio, with normal load varying, for the AMC Pacer.

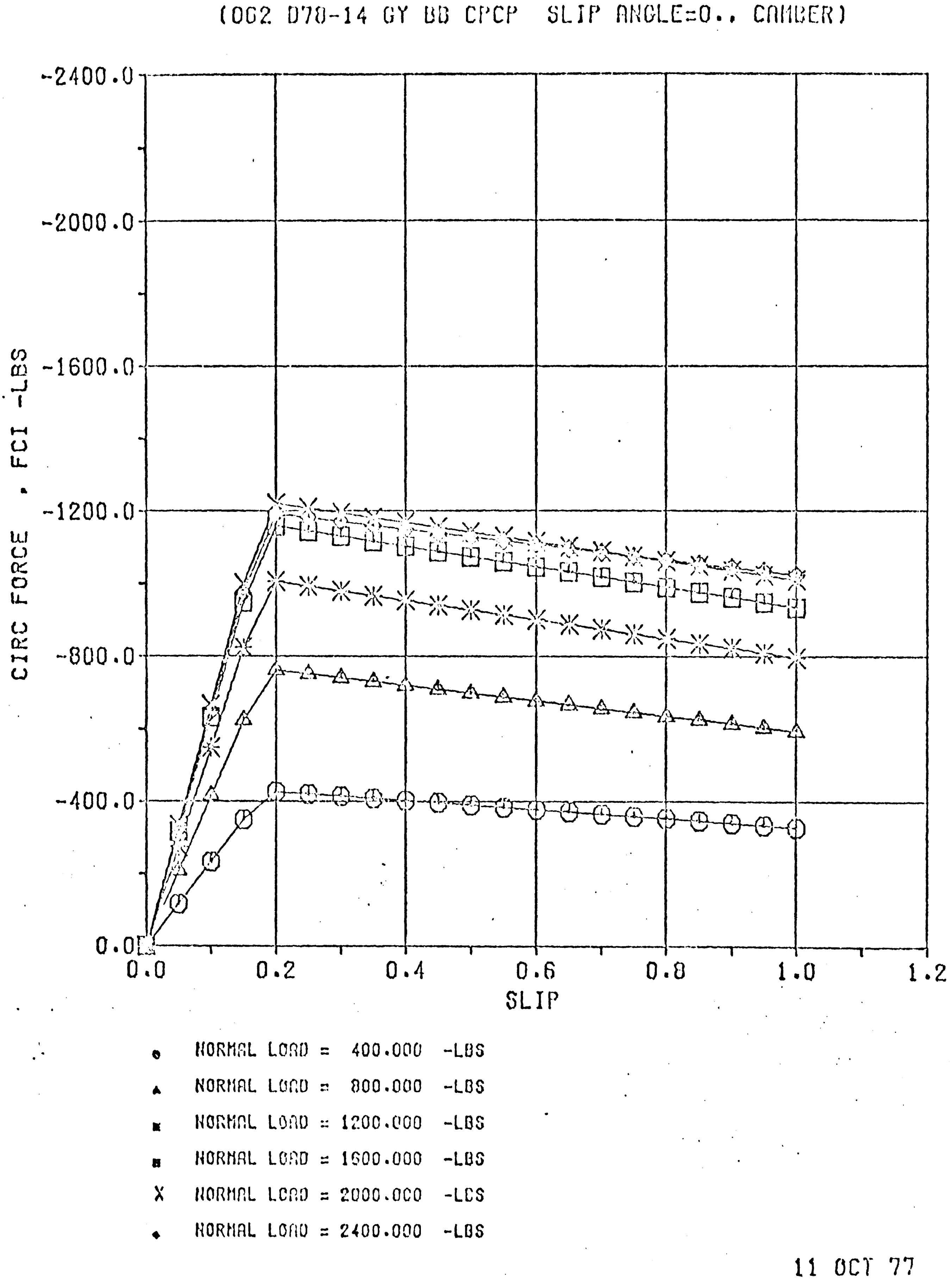


Figure D.15. Tire braking force vs. slip ratio, with normal load varying, for the AMC Pacer.

Table D.17. Antilock Parameter Values. Unless noted otherwise, the values below were estimated from recorded time histories of the line pressure, "HOLD ON" circuit voltage, and wheel spin velocities.

C1	= 140.*	volts/sec
C2	= 420.*	volts/sec
C3	= 10.	volts/sec
C4	= 0.4*	volts·sec/rad
HO	= -8.	volts
HTH	= -1.5	volts
HTL	= -2.5	volts
K1	= 1.	volume/(sec·psi)
K2	= 5.	volume/(sec·$\sqrt{psi}$)
K3	= 7500.	psi/sec
TAU1	= .09	sec
TAU2	= .014	sec/$\sqrt{psi}$
RRW	= 12.1	in
VO	= -20.	volume

*These values were set by trial and error to better match the recorded time histories, and to match the simulated Nova performance to the simulated Bobcat performance.

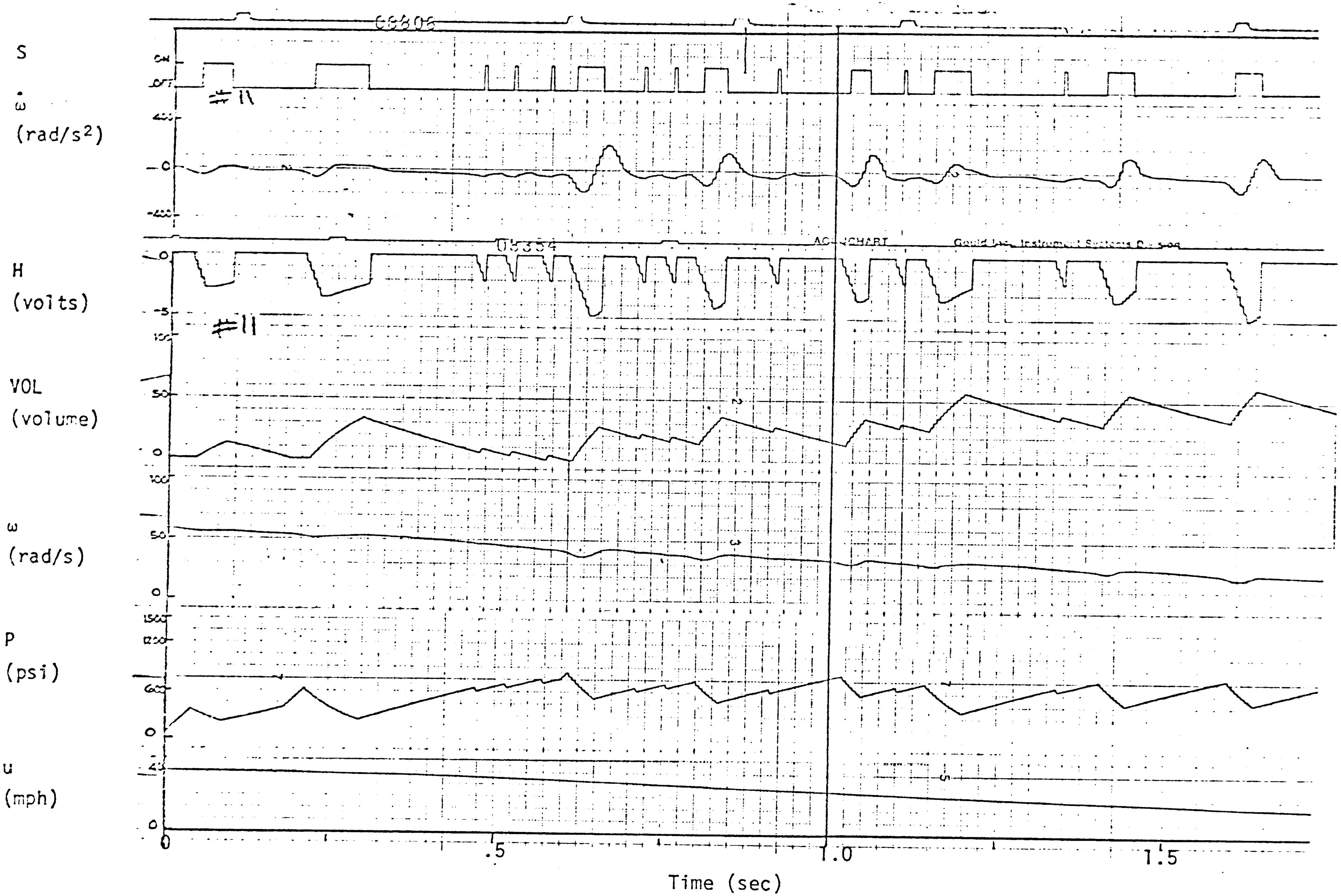


Figure D.16. Simulated time histories of antilock variables.

Figure D.17 depicts the simulated time histories of the longitudinal slip ratios of the four individual wheels, along with the history of the vehicle deceleration, for the case of the non-anti-lock equipped Nova. The vehicle is operating under the baseline conditions defined for the sensitivity studies in Sections 3.4.2 and 3.5.1 in the main report, which are that of GVW loading, braking in a turn such that iniatially the vehicle is faced with a 0.2g lateral acceleration, and having a road surface with high friction properties. We see that during the first 0.25 seconds, the slip ratio is larger for the wheels on the right-hand side of the car, as would be expected due to the initial lateral acceleration. From the time history of the right-front wheel, we see that at a slip ratio of about 15%, the wheel quickly decelerates towards lockup. The tire data shown back in Figure D.9 indicates that the maximum braking force occurs at 20% slip, but that the force/slip function changes slope at 15% slip, such that the slip ratio is much more senstive to the braking torque at values over 15% than at values less than 15%. After the first 0.5 seconds, the right-front wheel is locked up, the left-front tire is producing a braking force very near the traction limit of which it is capable (about 95% of the maximum), and both rear wheels are rotating with identical slip ratio's, such that the tires are producing slightly less braking force (75-80% of the maximum).

Similar traces are shown in Figure D.18, for the same braking condition but for the case of the Nova equipped with a two-module anti-lock system in which each axle is separately controlled. With both the front and rear axles, we see that the right wheels cycle at slip ratio's between 10% and 25%, while the left wheels, loaded by the lateral acceleration of the turning maneuver, cycle between slip ratio's of 7% and 15%. Clearly the tire adhesion capabilities on the loaded side are not being as effectively utilized as they were in the case of the vehicle with no anti-lock system. The vehicle deceleration fluctuated between .5 and .8 g's, as opposed to the more or less constant value of .75 g's achieved with the non-anti-lock equipped car.

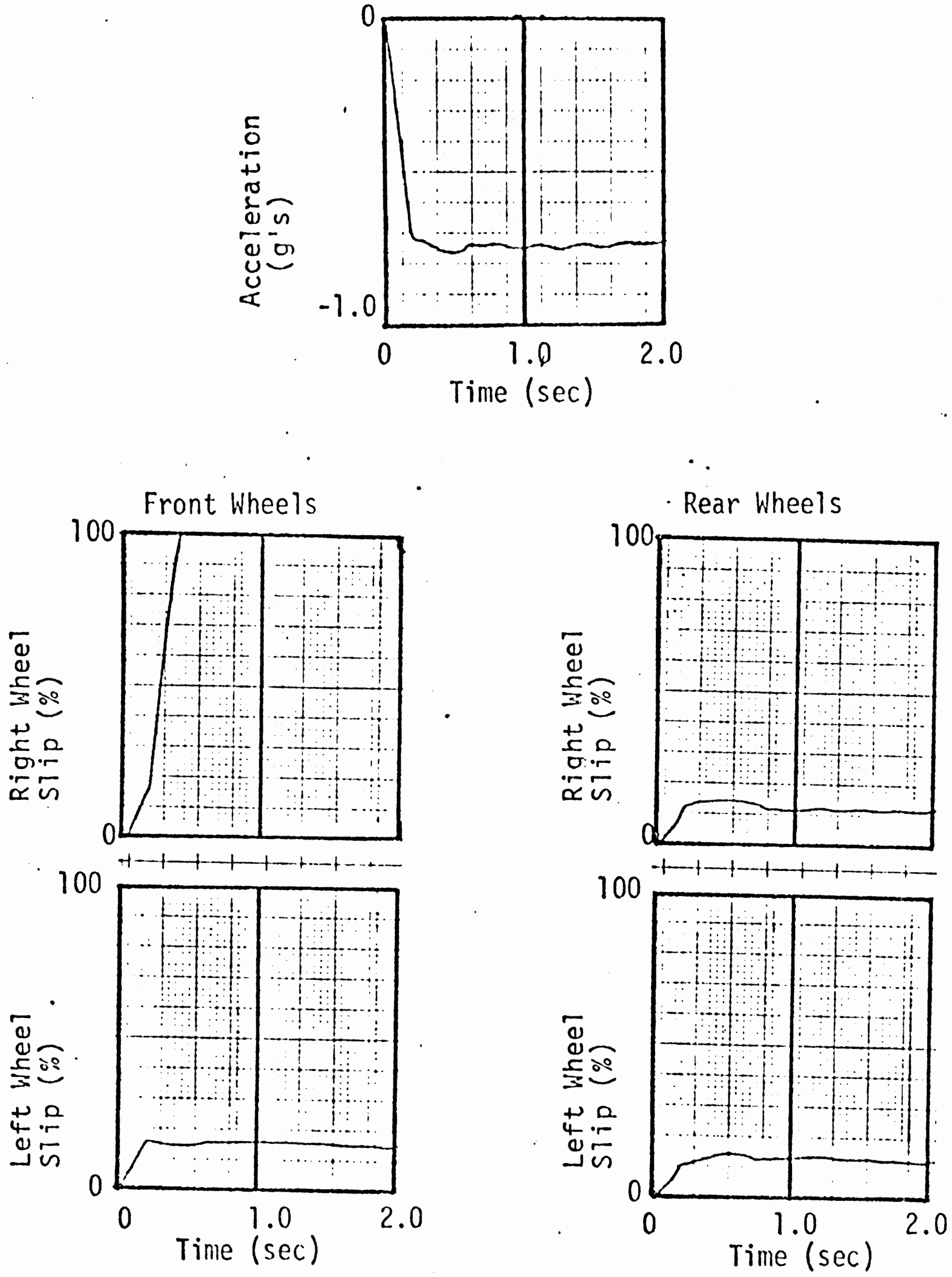


Figure D.17. Simulated time histories of the four wheel-slip ratios and of the vehicle deceleration for the non-antilock-equipped Nova.

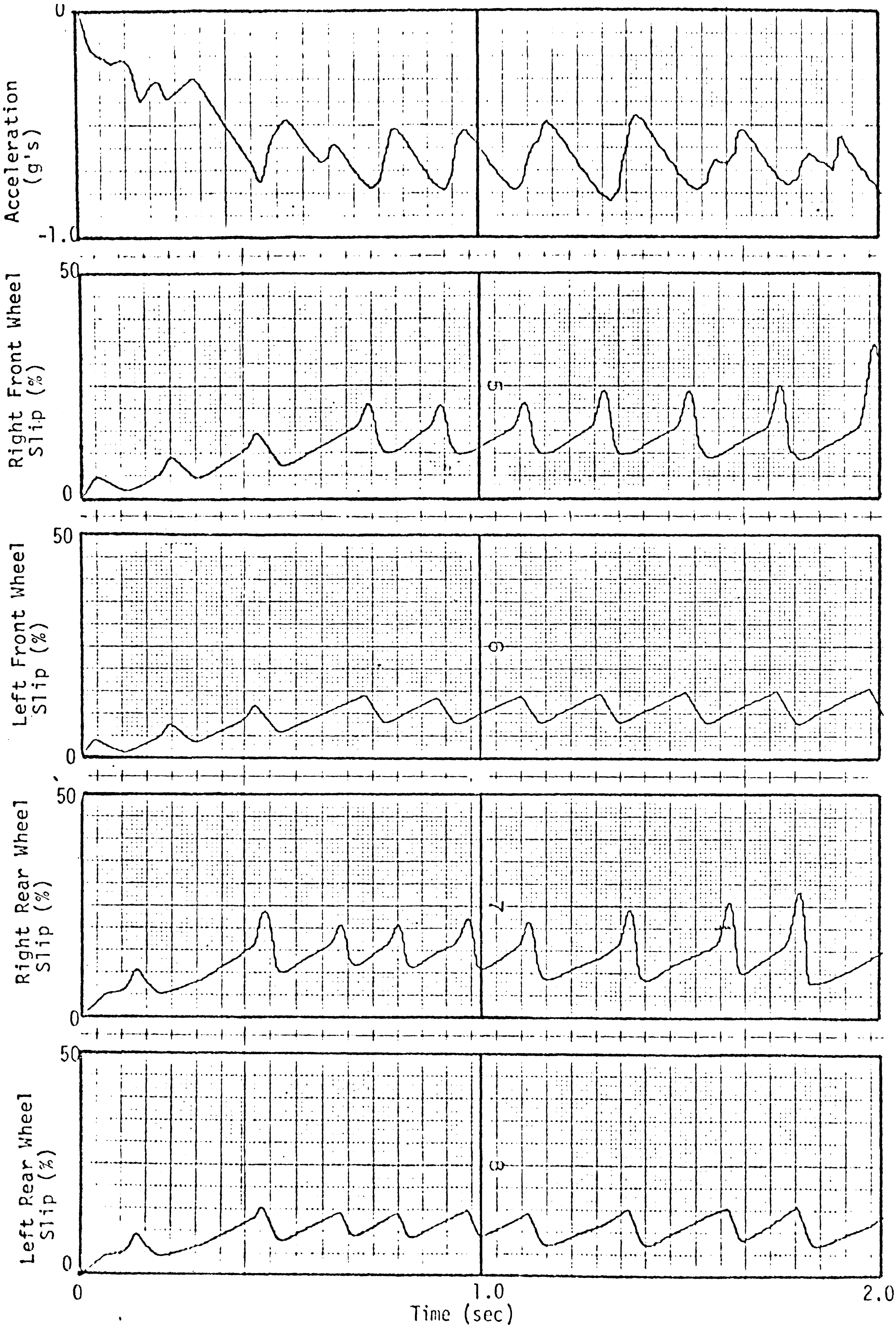


Figure D.18. Simulated time histories of the four wheel-slip ratios and of the vehicle deceleration for the Nova equipped with a two-module antilock system.

The behaviour of the three-module anti-lock system, in which the front wheels are independently controlled, is shown in Figure D.19. The conditions are the same as for the preceding two figures. Here, we can see that both front wheels are operating over the same ranges of slip ratio, and that the vehicle deceleration fluctuates with much smaller variations than in the case of the two-module system.

Figure D.20 shows the behaviour of the four-module anti-lock system, which controls each wheel independently, under the same baseline conditions. Although both rear wheels are now cycling in the same manner, we see little change from the three-module system in either the character or the level of the vehicle deceleration history. This is because the rear loading of the vehicle is so light compared to the front that small changes in rear-wheel braking efficiency are not significant.

D.3 Path Curvature Performance. All of the conventionally braked vehicles were found to lose their path curvature during the braking in a turn simulations which were discussed in Sections 3.4.2 and 3.5.1. This tendency is illustrated for the Nova in Figures D.21 and D.22, which depict the trajectory of the sprung mass center during the maneuvers under the conditions of GVW loading and a high friction surface. Figure D.22, which concerns the limit braking performance, actually shows a negative curvature. This is because the right-front wheel locks up while the left-front tire operates very near its peak traction capabilities (see Figure D.17). Thus a force imbalance exists which acts to turn the car to the left - the opposite direction of the original turn. The Nova without any anti-lock system was the only vehicle which reversed direction, as the left-front tire was not operating at peak traction levels with the other cars, under any of the conditions.

Figures D.23 and D.24 show the trajectories of the two- and three-module anti-lock equipped Novas, under the same baseline conditions. We see that the two-module equipped vehicle maintains the original curvature very well, but has a longer stopping distance than the

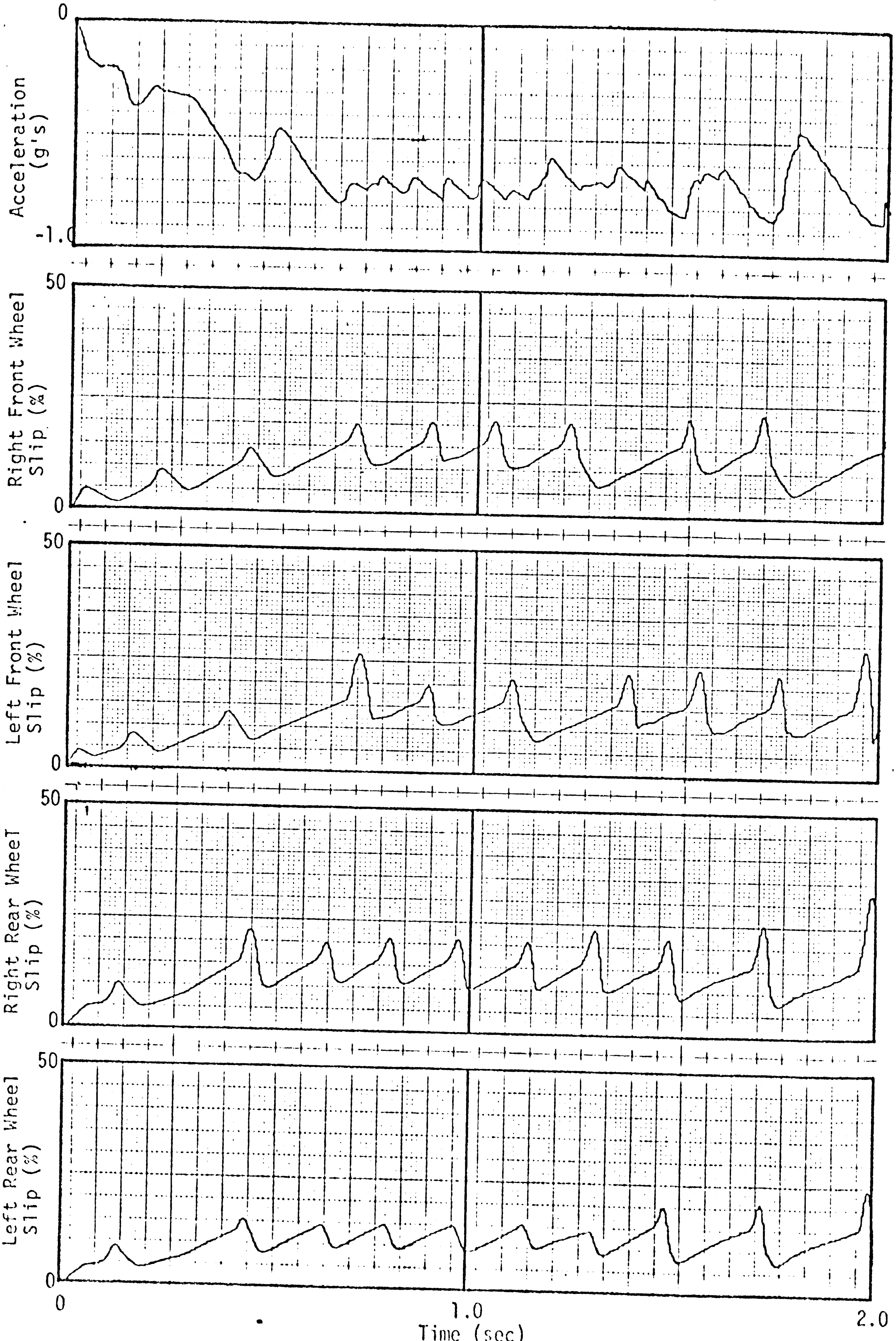


Figure D.19. Simulated time histories of the four wheel-slip ratios and of the vehicle deceleration for the Nova equipped with the three-module antilock system.

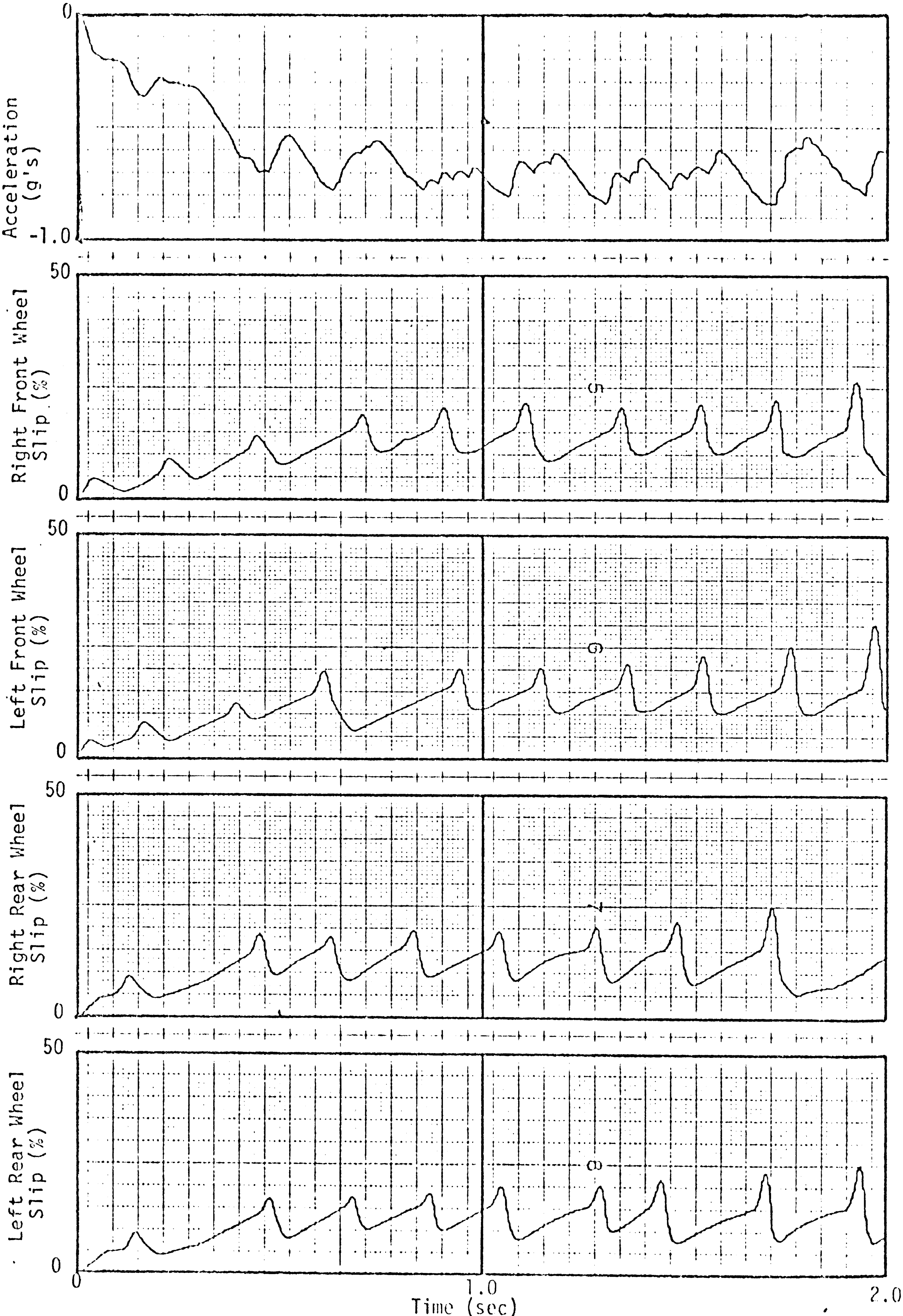


Figure D.20. Simulated time histories of the four wheel-slip ratios and of the vehicle deceleration for the Nova equipped with the four-module antilock system.

DATE: 1/23/78

Y*E-2	X*E-3
0.027	0.426
0.122	0.703
0.207	0.848
0.322	0.989
0.467	1.129
0.642	1.268
0.847	1.407
1.079	1.545
1.321	1.675
1.560	1.794
1.791	1.903
2.007	2.002
2.200	2.092
2.365	2.172
2.502	2.242
2.611	2.302
2.695	2.353
2.757	2.394

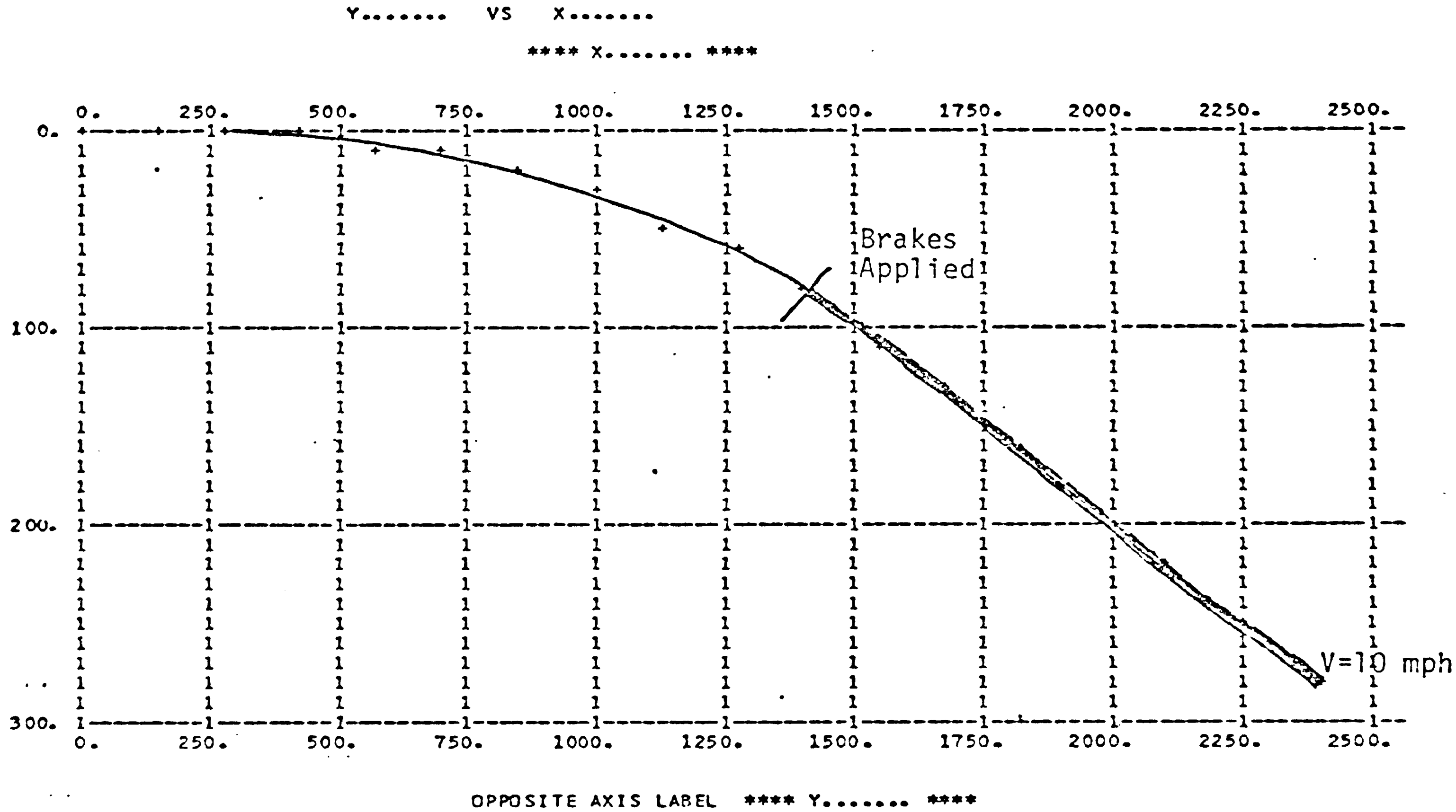


Figure D.21. Trajectory of the sprung mass center of the non-antilock-equipped Nova during a sub-limit braking-in-a-turn maneuver.

DATE: 1/23/78

Y*E-2	X*E-3
0.027	0.426
0.121	0.708
0.207	0.848
0.321	0.989
0.466	1.129
0.641	1.268
0.847	1.407
1.078	1.545
1.314	1.674
1.534	1.791
1.728	1.897
1.892	1.992
2.021	2.075
2.119	2.148
2.234	2.259

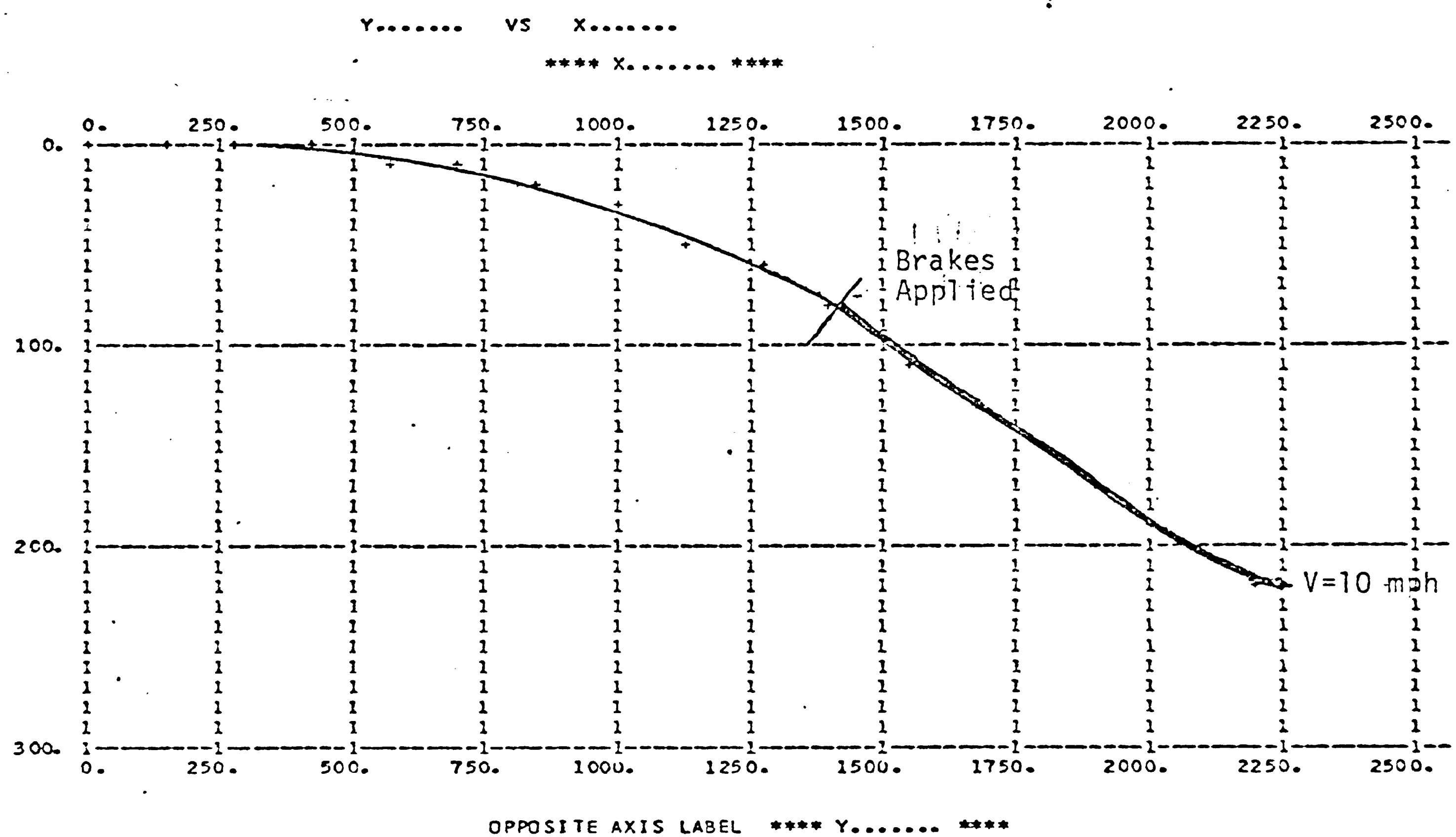


Figure D.22. Trajectory of the sprung mass center of the non-antilock-equipped Nova during a limit braking-in-a-turn maneuver.

DATE: 1/23/78

Y*E-2	X*E-3
0.042	0.497
0.121	0.703
0.265	0.848
0.320	0.989
0.385	1.059
0.547	1.198
0.638	1.268
0.737	1.338
0.843	1.407
0.955	1.477
1.074	1.545
1.197	1.612
1.325	1.678
1.454	1.741
1.566	1.803
1.719	1.862
1.850	1.918
1.983	1.972
2.114	2.023
2.244	2.071
2.372	2.117
2.500	2.161
2.623	2.202
2.744	2.240
2.860	2.276
2.972	2.309
3.079	2.340
3.179	2.368
3.275	2.394

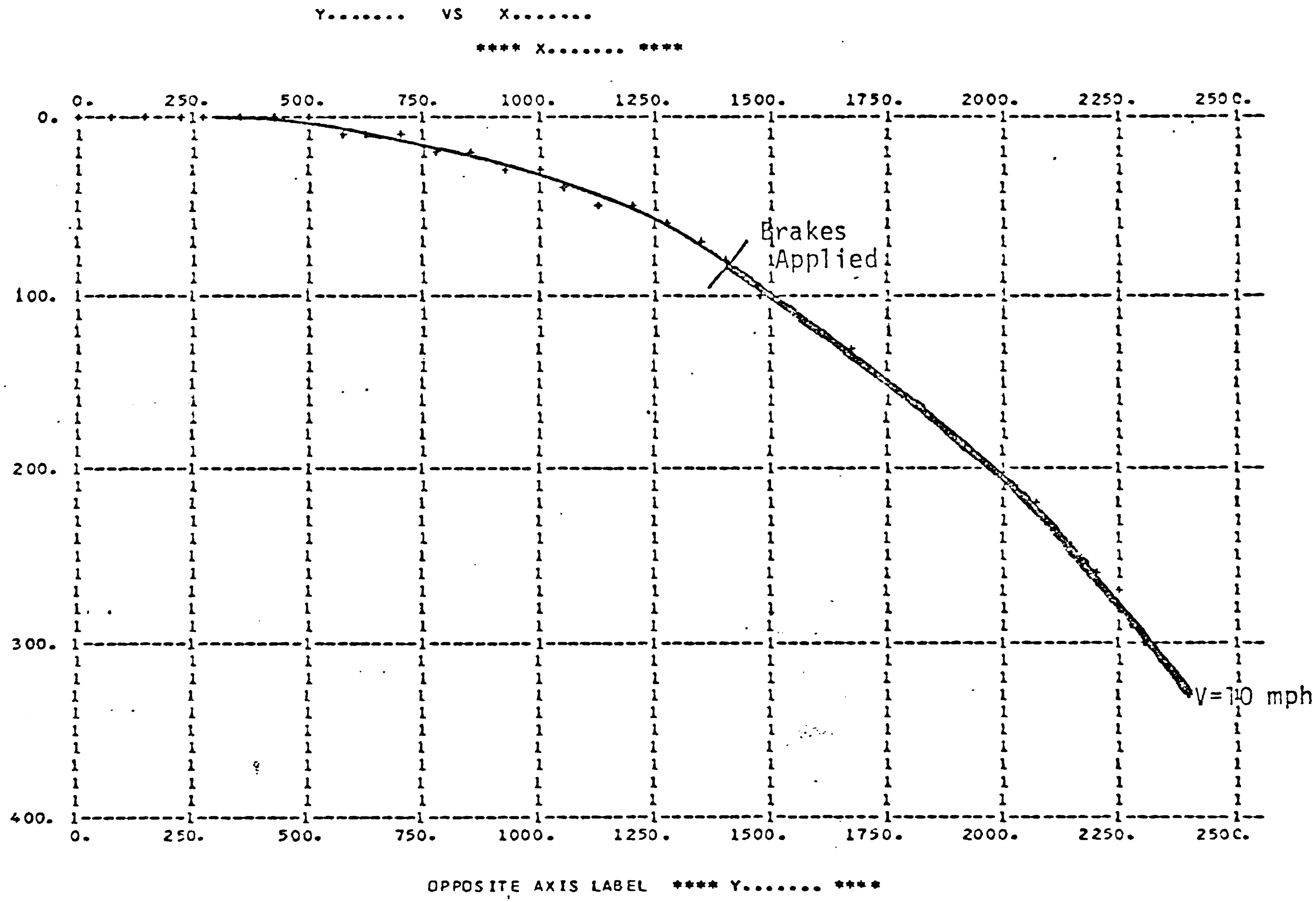


Figure D.23. Trajectory of the sprung mass center of the two-module antilock-equipped Nova during braking in a turn.

CATE: 1/25/78

Y*E-2	X*E-3
0.043	0.497
0.122	0.708
0.206	0.848
0.322	0.969
0.391	1.059
0.467	1.129
0.642	1.268
0.741	1.336
0.847	1.407
0.960	1.477
1.079	1.545
1.201	1.612
1.327	1.678
1.454	1.741
1.562	1.802
1.709	1.860
1.835	1.916
1.957	1.968
2.077	2.018
2.194	2.066
2.307	2.110
2.417	2.152
2.523	2.191
2.624	2.227
2.719	2.261
2.806	2.292
2.892	2.321
3.041	2.370
3.105	2.391

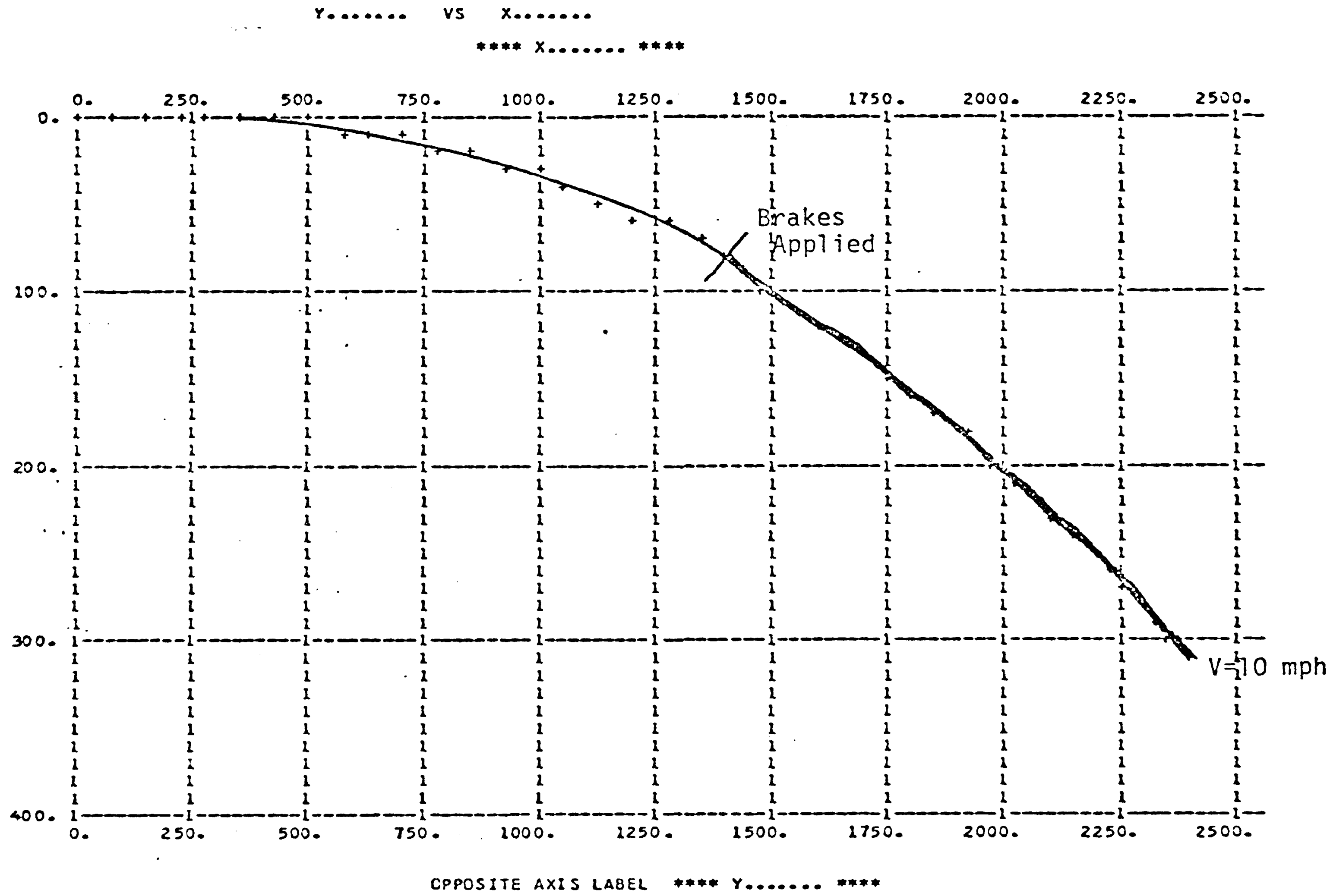


Figure D.24. Trajectory of the sprung mass center of the three-module antilock-equipped Nova during braking in a turn.

non-anti-lock equipped vehicle. The three-module equipped vehicle shows an improved stopping distance, but also shows some loss of path curvature.

The path-holding performance of the Nova was illustrated in Section 3.5.1 for all of the conditions simulated by considering the normalized curvature ($R_0 \cdot (1/R)$), averaged over the first one second of each braking maneuver. When this quantity is plotted as a function of the average deceleration, A_X, a series of simulations, in which the brake line pressure is increased with each subsequent simulation, defines a series of points which can be quickly inspected to determine the behaviour of the vehicle during braking in a turn maneuvers, with the steer angle fixed. Plots of this type were made for the four vehicles with non-anti-lock brakes used for the in-depth test program. They are presented here as Figures D.25 - D.28.

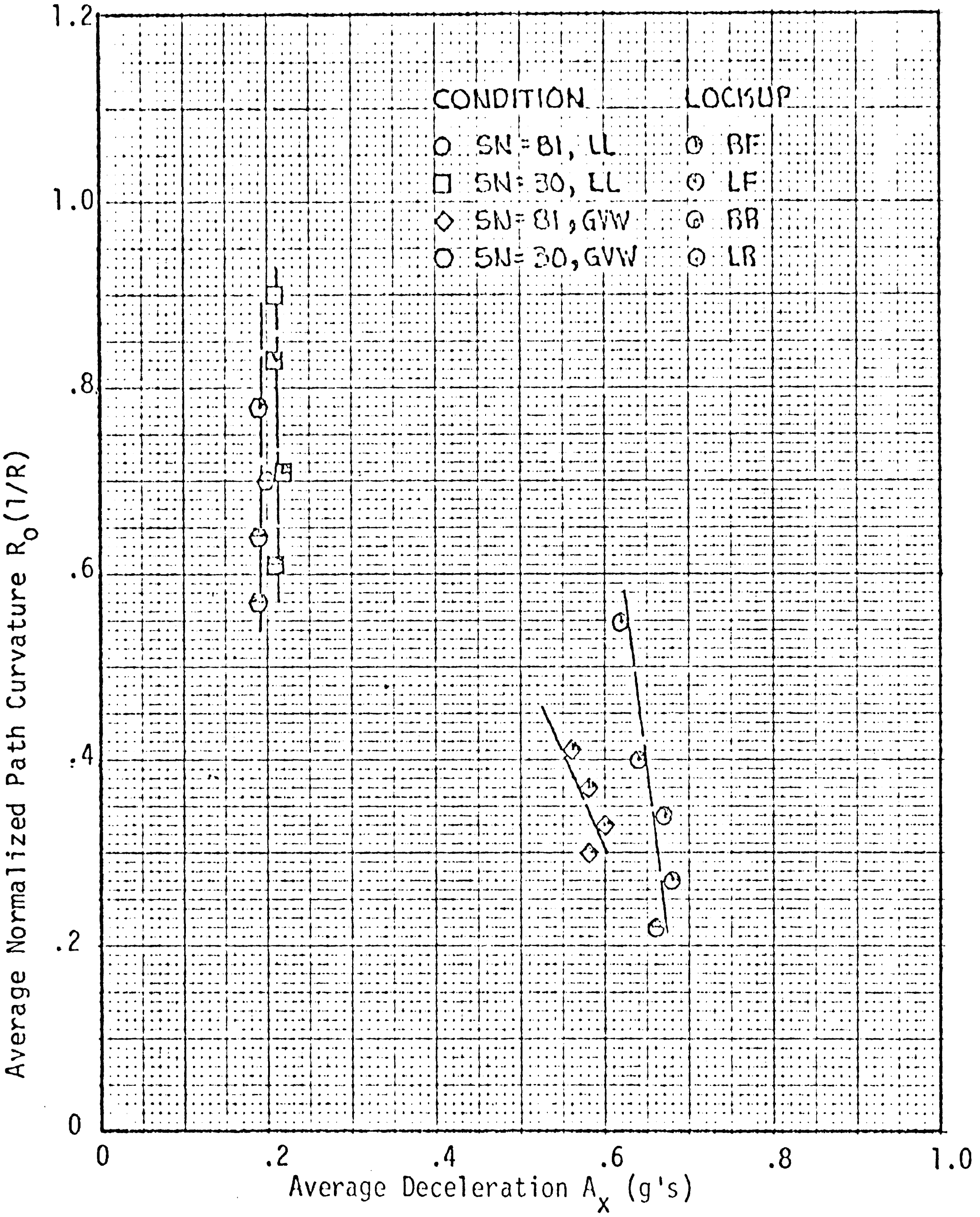


Figure D.25. Simulated path curvature of Mercury Bobcat wagon during braking-in-a-turn maneuvers.

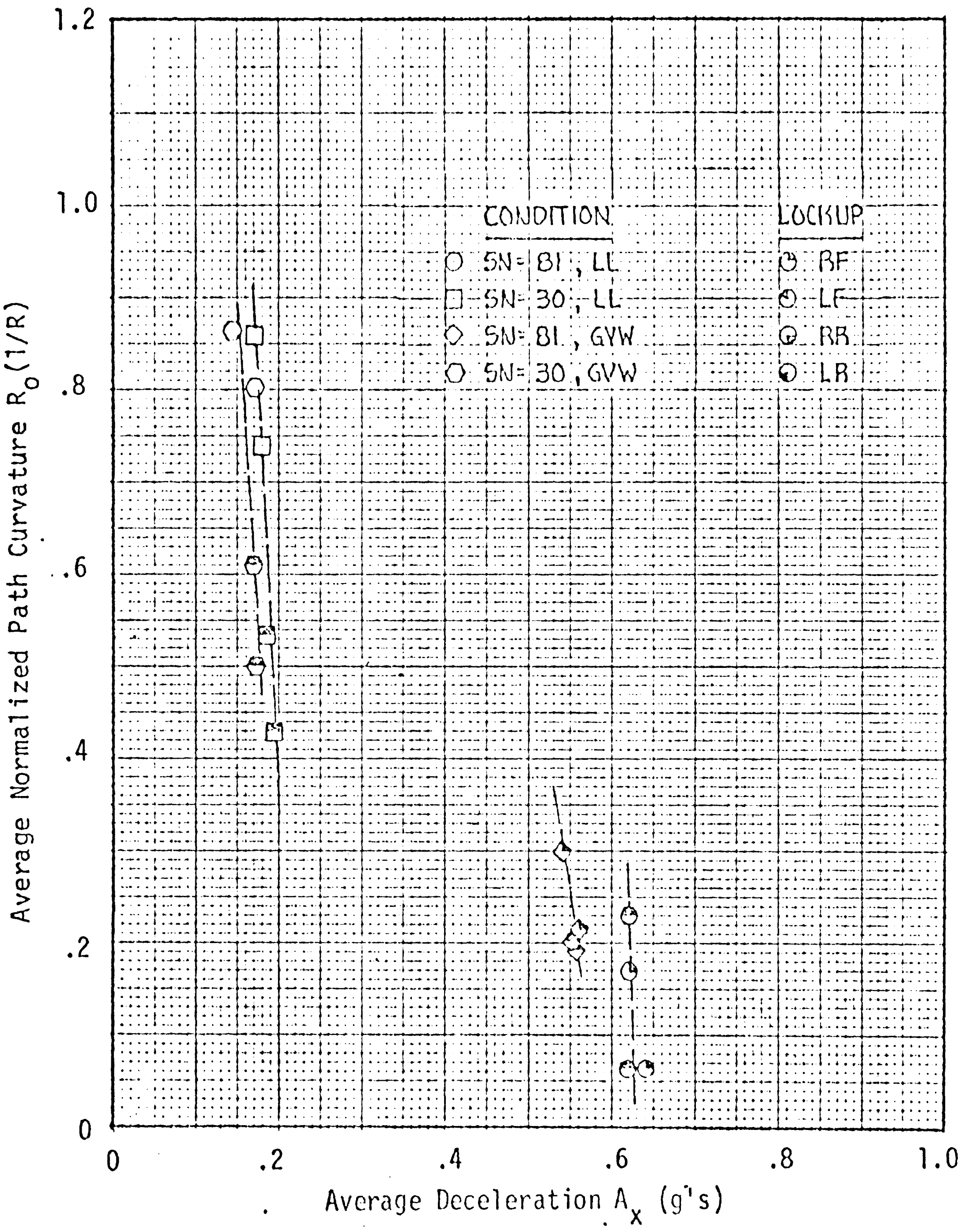


Figure D.26. Simulated path curvature of AMC Pacer during braking-in-a-turn maneuvers.

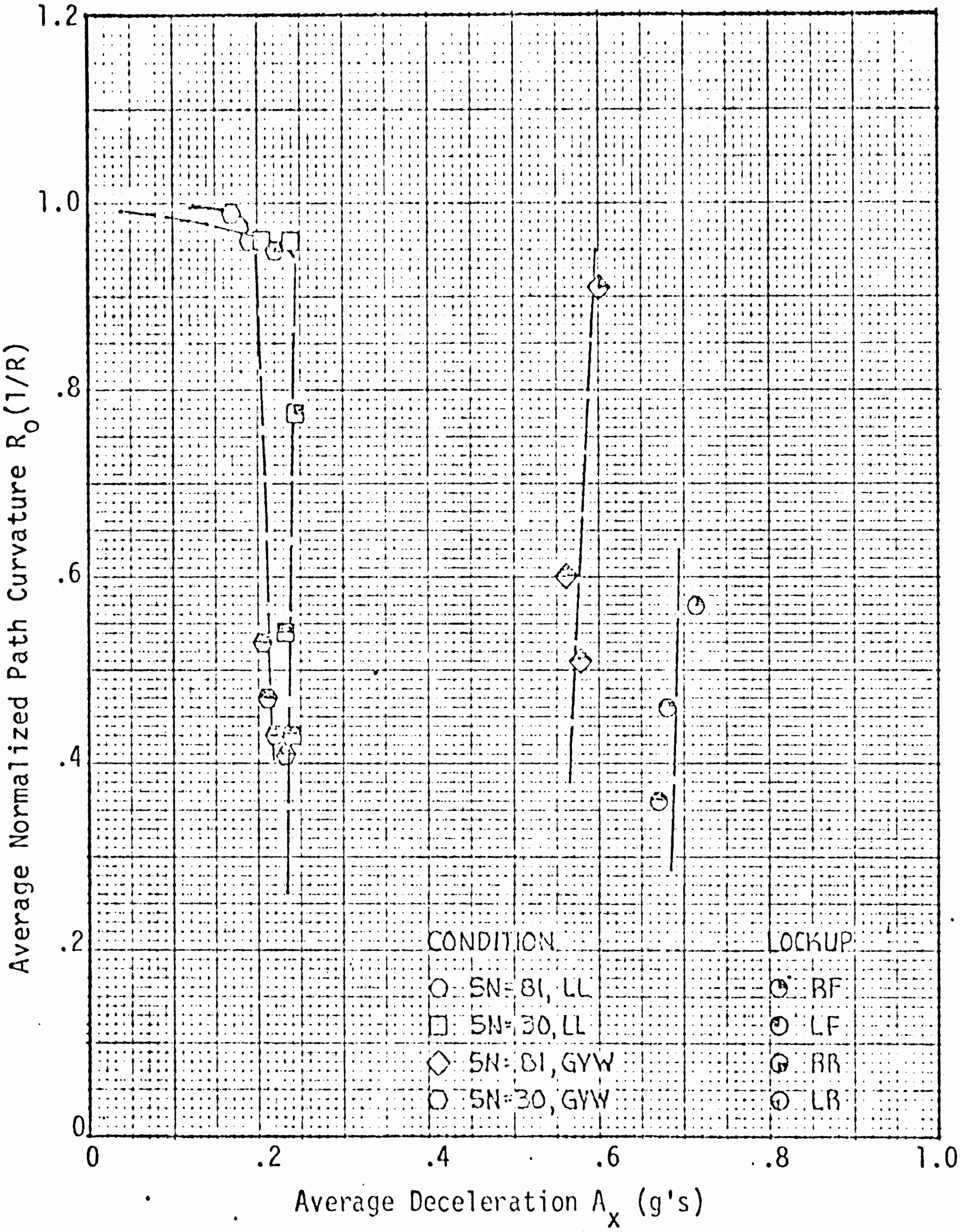


Figure D.27. Simulated path curvature of Ford LTD during braking-in-a-turn maneuvers.

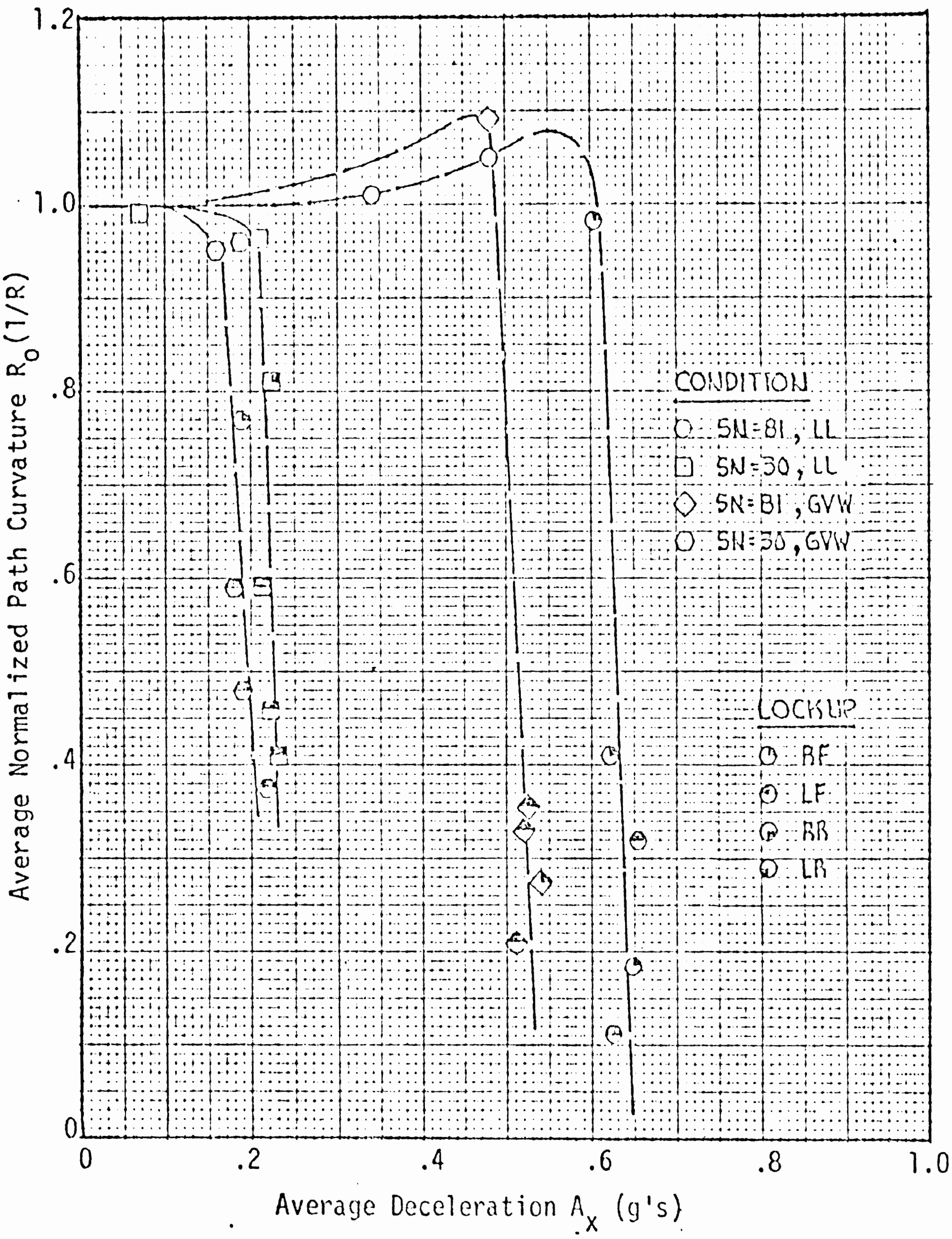


Figure D.28. Simulated path curvature of Chevrolet Monte Carlo during braking in a turn.

APPENDIX E

A LOOK AT THE ACCURACY OF SIMPLIFIED METHODS FOR COMPUTING REFERENCE VEHICLE IDEAL STOPPING DISTANCE FOR THE BRAKING EFFICIENCY TEST TECHNIQUE.

Under a research contract with the National Highway Traffic Safety Administration, Contract No. DOT-HS-031-3-765, the Highway Safety Research Institute of the University of Michigan advanced the "Braking Efficiency Test Technique" and developed hardware for obtaining accurate peak friction measurements of road surfaces as a function of tire load and vehicle velocity. This hardware is generally referred to as the Surface Friction Dynamometer or the SFD. The results of this work were reported in report No. DOT-HS-801-551 dated March 1976 and titled "Braking Efficiency Test Technique".

In this technique the measured stopping performance of vehicles on a given surface is compared to the ideal stopping performance of a hypothetical reference vehicle on the same surface. The performance measure or "Braking Efficiency" is the ratio of the ideal stopping distance of the reference vehicle to the measured stopping distance of the real vehicle expressed in a percentage. Thus:

$$\text{Braking Efficiency} = \frac{\text{Ideal Stopping Distance}}{\text{Measured Stopping Distance}} \times 100\% \qquad \text{(E-1)}$$

The dimensions (weight, wheelbase, longitudinal and vertical center of gravity location) of the reference vehicle are established as average values representing the total U.S. passenger vehicle population. The ASTM E-501 tire is defined as the reference tire. The ideal stopping distance of the reference vehicle is computed assuming optimum utilization of the available tire/road friction, where the peak friction is defined by an equation of the form $\mu_p = Av^2 + Bv + C$. The constants A, B, and C are derived from a least squares fit of this curve to the peak friction measurements made with the SFD using the ASTM E-501 tire. A minimum of five peak friction measurements are taken at each of four velocities spanning the range of velocities experienced by the real vehicles in the braking test and at each of two tire loads nominally equal to the front and rear tire loads the reference vehicle would achieve while braking on the test surface. The two tire loads are determined as the front and rear tire loads the reference vehicle would experience in a constant deceleration stop where the deceleration is the value which would accure if the reference vehicles weight were equally distributed between its four tires and the friction level were equal to the nominal value, μ_{nom}. The μ_{nom} value is defined as the peak friction of the surface averaged over five SFD measurements which are made with a tire load equal to one fourth of the reference vehicle's weight and at a velocity equal to 0.707 times the initial velocity used in the braking test. Thus the surface friction characterization requires a minimum of forty-five SFD measurements deriving from (2 loads x 4 speeds x 5 repeats) + (5 μ_{nom} runs). These measurements constitute the bulk of the effort in applying the Braking Efficiency Technique.

In the current contract the complete matrix of peak surface friction measurements required for application of the Braking Efficiency Technique were made with the SFD on dry brushed concrete and on wet jennite at the Chrysler Proving Grounds and on dry asphalt and on wet jennite at Bendix Automotive Proving Grounds (BAPG). At BAPG the measurements were repeated three times on each surface over a four month period. These data, along with measurements made in 1975 at BAPG during the Braking Efficiency Test Technique Contract on dry asphalt, dry jennite, wet asphalt, and wet jennite, constitute a substantial bank of data on the peak friction characteristics of a variety of surfaces to which the braking efficiency computation has been applied. Table E.1, along with the following discussion, provides a summery of these data and suggests a means by which the mechanics of applying the Braking Efficiency Technique may be simplified considerably. Specifically this data set indicates that an adequate value for the ideal stopping distance of the reference vehicle is obtained, for the surfaces represented, simply by employing μ_{nom} (one tire load and one velocity) in the computation of the ideal stopping distance from the simple expression:

$$DI = \frac{Vo^2 \text{ (m.p.h.)}}{29.94\, \mu_{nom}} \qquad \text{(E-2)}$$

Table E.1 Data Comparing Methods of Computing the Ideal Stopping Distance of the Reference Vehicle

	1	2	3	4	5	6	7	8
SURFACE	V_o MPH	DI FEET	DI_n FEET	Δn FEET	DI_a FEET	Δa FEET	μ_{nom}	μ_{avg}
BAPG Dry Asphalt 1975	63.0	139.2	141.0	-1.8	137.1	2.1	0.940	0.967
BAPG Dry Jennite 1975	57.0	121.5	121.9	-0.4	119.4	2.1	0.890	0.909
BAPG Wet Asphalt 1975	42.5	80.9	78.3	2.6	79.5	1.4	0.770	0.759
BAPG Wet Jennite 1975	30.0	57.0	60.1	-3.1	55.9	1.1	0.500	0.538
BAPG Dry Asphalt June 1977	60.0	124.7	128.6	-3.9	121.4	3.3	0.935	0.990
BAPG Dry Asphalt July 1977	60.0	125.2	126.6	-1.4	120.5	4.7	0.950	0.998
BAPG Dry Asphalt Oct. 1977	60.0	122.9	119.5	3.4	120.7	2.2	1.006	0.996
BAPG Wet Jennite June 1977	40.0	96.3	92.6	3.7	91.5	4.8	0.577	0.585
BAPG Wet Jennite July 1977	40.0	101.7	113.7	-12.0	92.9	8.8	0.470	0.575
BAPG Wet Jennite Oct. 1977	40.0	94.5	91.8	2.7	89.4	5.1	0.582	0.598
Chrysler Dry Concrete 1976	60.0	127.9	126.0	1.9	122.6	5.3	0.954	0.981
Chrysler Wet Jennite 1976	40.0	76.7	75.9	0.8	73.2	3.5	0.704	0.730
				-0.63 Avg.		3.7 Avg.		

This expression is derived assuming that the tire/road friction coefficient is constant and equal to μ_{nom}.

Table E.1 summerizes results obtained with the twelve sets of data which have been collected by HSRI for application of the Braking Efficiency Technique. Column 1 gives the initial velocity, Vo, employed on each of the surfaces. Column 2 gives the ideal stopping distances, DI, computed per the Braking Efficiency Technique. Column 3 gives the ideal stopping distance DI_n computed with equation E-2, and the difference, $DI - DI_n$, is tabulated in column 4. Column 5 gives the ideal stopping distance, DI_a, computed with equation F-2 with μ_{nom} replaced by μ_{avg}, that is the average value of the surface friction measurements made at the two values of tire load and fror velocities. The differences $DI - DI_a$ are listed in column 6. Column 7 and 8 give the values of μ_{nom} and μ_{avg} respectively.

Referring to column 4, i.e. $DI - DI_n$, the largest difference value is found for the wet jennite data taken in July 1977. While this difference value is a rather large twelve feet, the difference for all others is less than four feet. Furthermore in six cases DI is greater than DI_n and in the other six cases DI is less than DI_n. On the average the difference is only -0.63 feet. The average magnitude of the difference is only 3.1 feet. Although the differences between values of μ_{nom} and μ_{avg} is not very large the computed stopping distance differences in column 6 are seen to be all the same polarity, i.e. DI larger than DI_a, with the average difference equal to 3.7 feet, indicating that statiscally μ_{nom} is a better value to use than μ_{avg}.

Thus these data indicate that utilizing μ_{nom} in equation E-2 to compute the ideal stopping distance of the reference vehicle is sufficiently accurate to be a cost-effective approach; one which should be investigated further before any large scale application of the Braking Efficiency Method is initiated.

Figures E.1 through E.4 contain plots of the data collected by HSRI during the Braking Efficiency Technique Contract. These figures along with figure 3.1 and figures C.7, C.8, and C.9 which contain the data collected at the Chrysler Proving Grounds and at the Bendix Automotive Proving Grounds, respectively, during this contract present the complete set of data collected by HSRI for application of the Braking Efficiency Test Technique from which Table E.1 was derived.

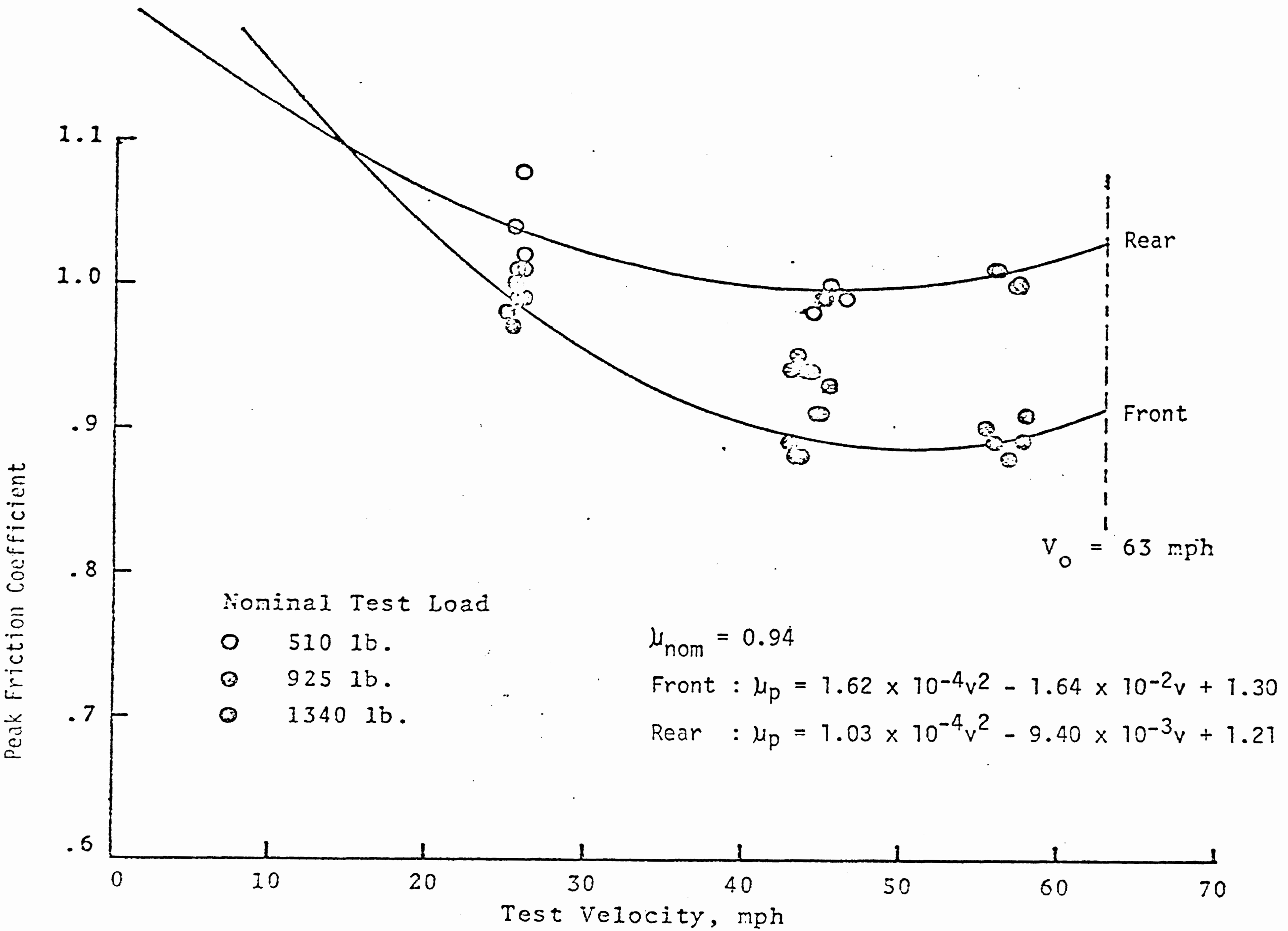


Figure E.1. DOT Surface Friction Dynomometer Peak Friction Measurements on Dry Asphalt at Bendix Automotive Proving Grounds, 1975.

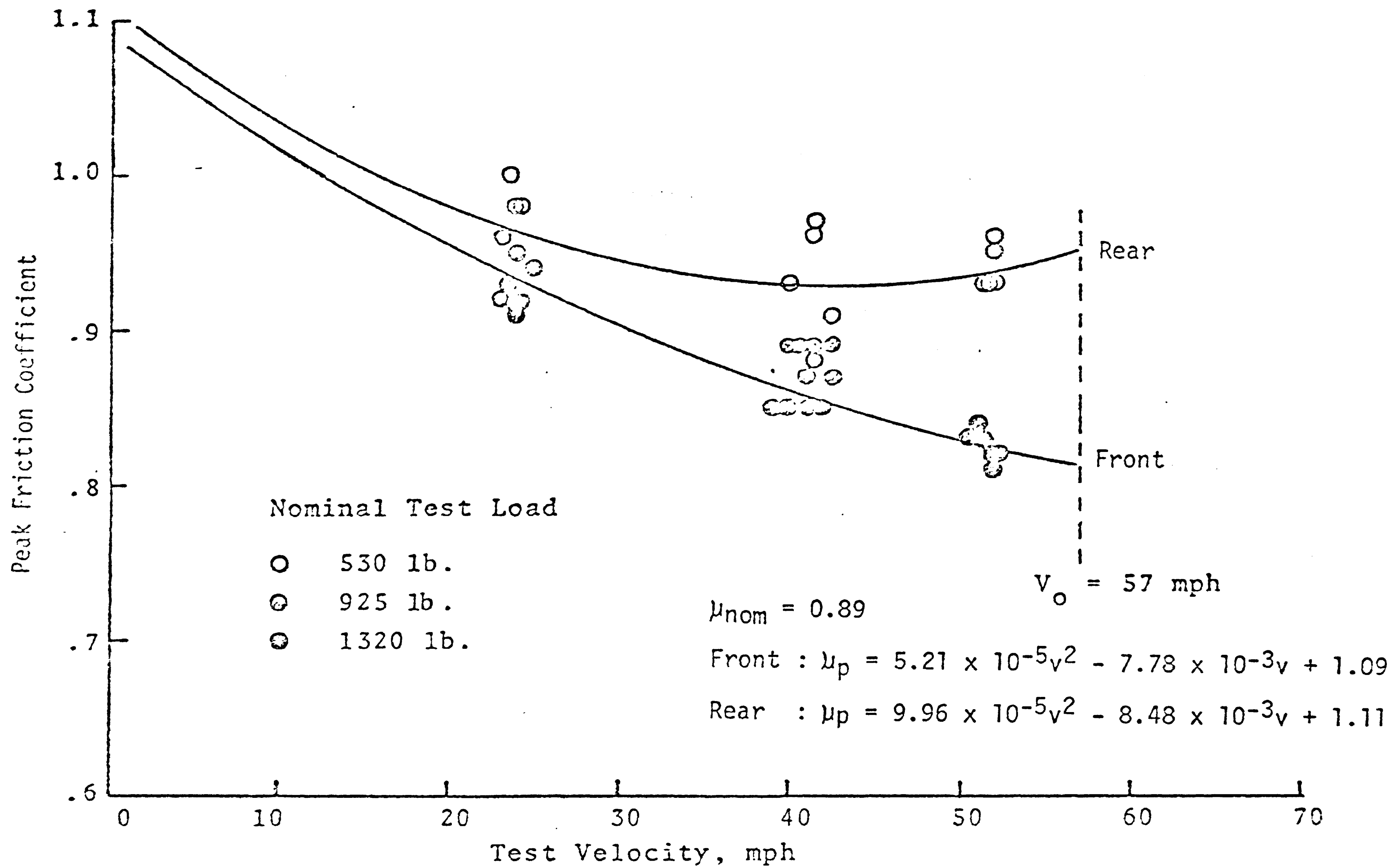


Figure E.2. DOT Surface Friction Dynomometer Peak Friction Measurements on Dry Jennite at Bendix Automotive Proving Grounds, 1975.

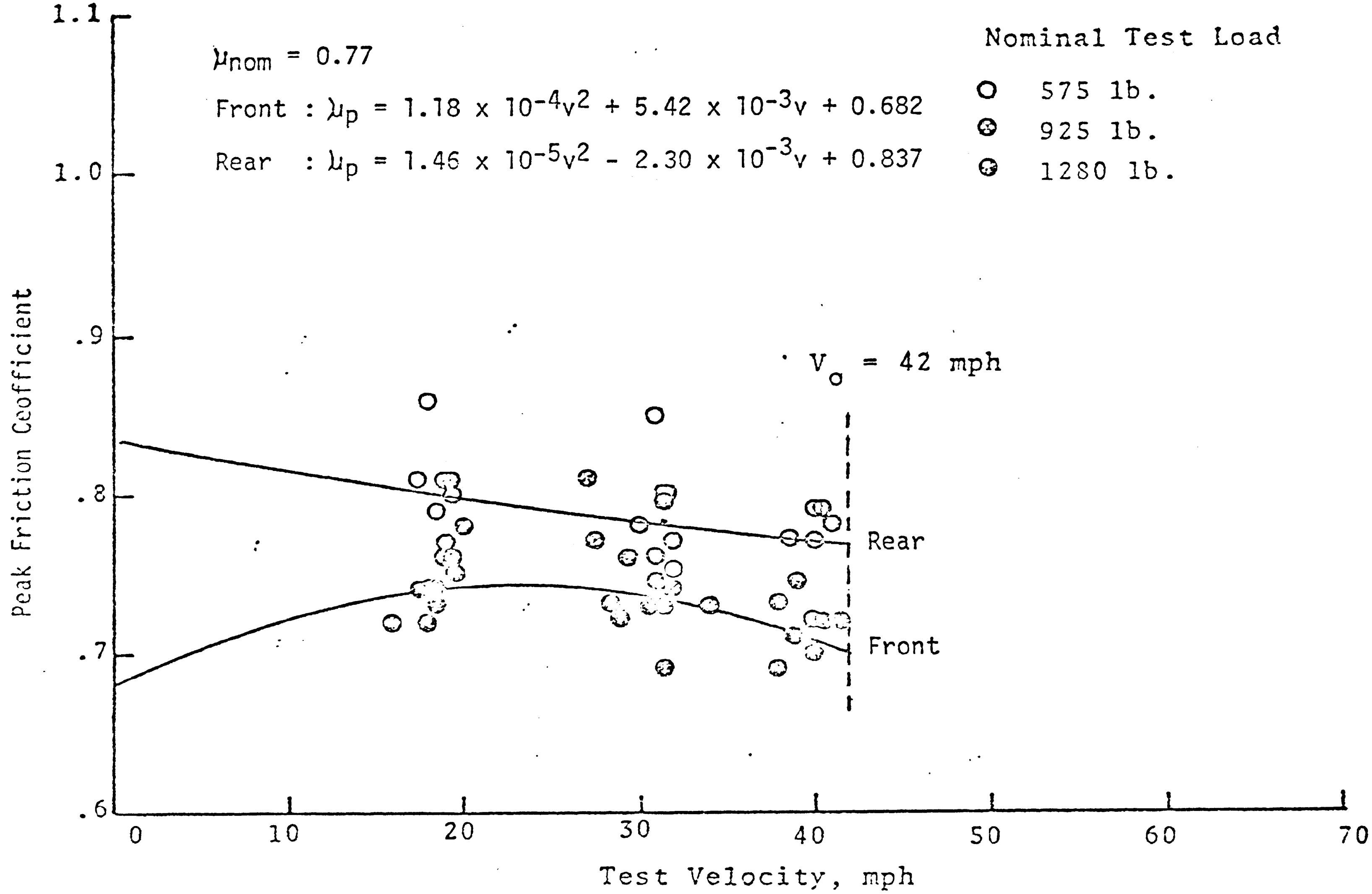


Figure E.3. DOT Surface Friction Dynomometer Peak Friction Measurements on Wet Asphalt at Bendix Automotive Proving Grounds, 1975.

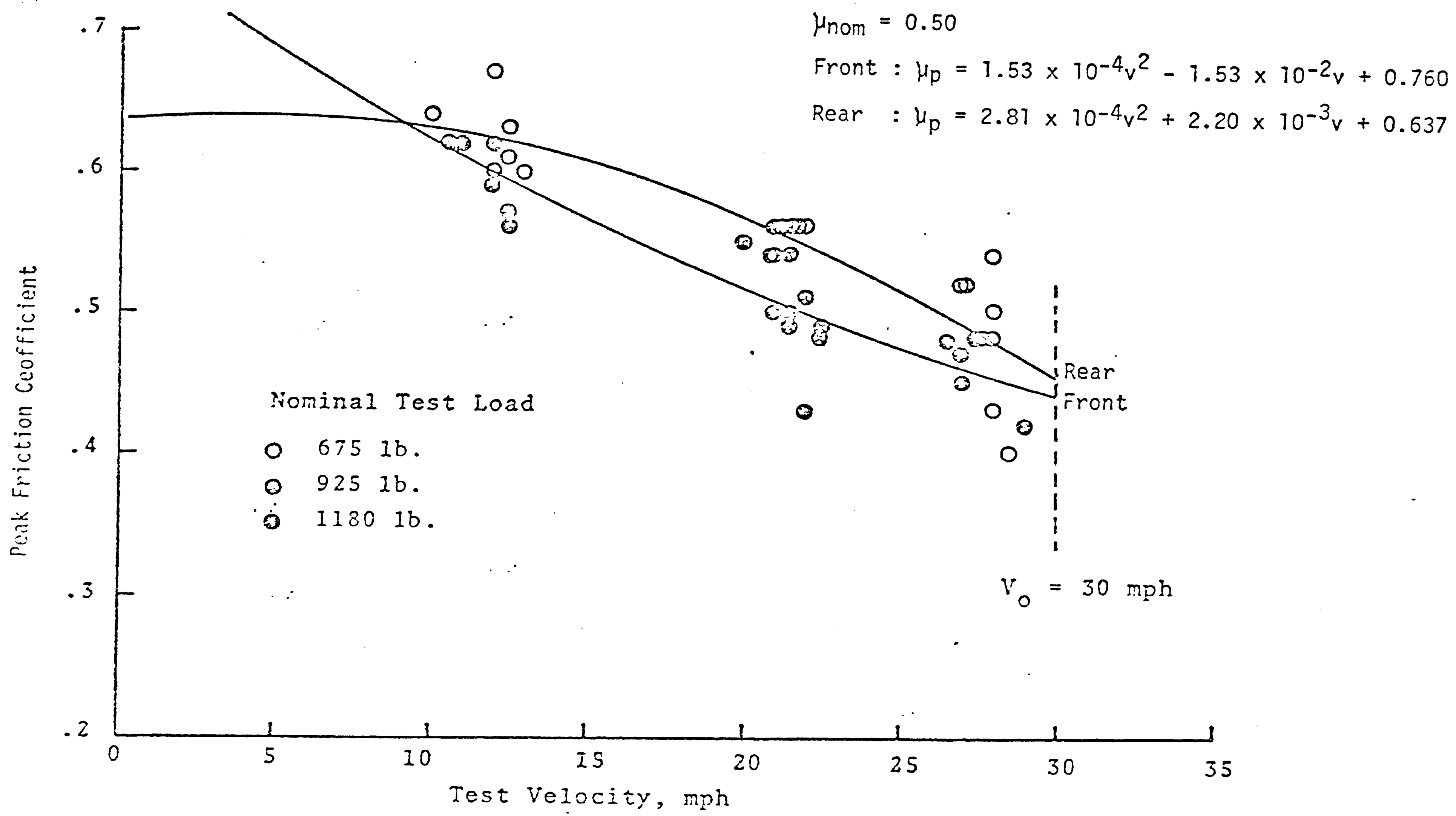


Figure E.4. DOT Surface Friction Dynamometer Peak Friction Measurements on Wet Jennite at Bendix Automotive Proving Grounds, 1975.

APPENDIX F

ANTILOCK BRAKING MODEL

The antilock system model used in this study is based on a device designed and marketed by the Kelsey-Hayes Company, which was installed on the 1976 Nova included in the in-depth test program. The system has actually been used by Kelsey-Hayes in three following configurations:

1. one (computer and modulator) unit which controls both rear brakes,

2. two units, one controlling the rear brakes and the other controlling the front brakes, and

3. three units, one controlling the rear brakes and the other two independently controlling each of the front brakes.

The units required for any of the above systems are identical, so only one mathematical model of the system's function is required. The same model is also used for a fourth set-up which was considered in this study, namely

4. four units, each controlling one brake independently.

Each unit consists of two components which combine to regulate the brake line pressure. The first component, a pressure modulator, is a mechanical device which contains a solenoid which is activated by the second component, an electronic controller. The pressure modulator has three modes of operation which are modeled in this appendix. They are:

1. No modulation - Brake line pressure is unchanged from the proportioned level.

2. Pressure release - When the solenoid is activated, the brake line pressure is reduced.

3. Pressure re-apply - When the solenoid is turned off, the brake line pressure is allowed to build up to the proportioned level.

The electronic controller includes a tachometer which senses the spin rate of the wheel whose brake is being controlled. (When one unit is controlling two brakes, the average of the two wheel spin rates is sensed.) A signal is then generated which is proportional to the wheel spin acceleration. The spin rate and spin acceleration are the inputs to the logic circuits, which then activate or de-activate the solenoid in the pressure modulator when appropriate.

The equations which describe the operation of the antilock units are presented in the next two sections, and the components are explained in more detail. The parameters needed to define the mathematical model are presented in Table F.1. The FORTRAN subroutine which implements the model is listed in the form in which it now appears in the APL Hybrid Computer Vehicle Handling Program, documented by Reference [6].

F.1 Pressure Modulator

The actual pressure modulator is a mechanical device which performs several tasks, some of which are of no interest when conducting a study of the nature of that described in this report. Figure F.1 depicts a simplified concept of the device, which bears little resemblance to the actual module, but which serves to illustrate the behavior of the unit more clearly, especially with regard to the mathematical model.

At the start of a braking maneuver, the antilock system is not in operation, the logical variable ANT1 = F, and the brake pressure is equal to the proportioned pressure. As shown in Figure F.1A, the piston in the expansion chamber holds a check valve open, thereby directly connecting the input line to the output line.

Table F.1. Antilock Variable and Parameter Listing.

Type: ℓ - logical variable d - dynamic variable c - constant

Parameter	Type	Units	Description
A	ℓ		T when $\dot{\omega} \cdot RW \geq 1$ g
AH	ℓ		T when $\dot{\omega} \cdot RW \geq 4.5$ g
ANTI	ℓ		T after antilock unit is in operation
C1	c	volts/sec	basic charge down rate of H
C2	c	volts/sec	high charge down rate of H
C3	c	volts/sec	gain for $\dot{\omega}$ term in discharge rate of H
D	ℓ		T when $\dot{\omega} \cdot RW \leq -1.5$ g
DH	ℓ		T when $\dot{\omega} \cdot RW \leq -4.0$ g
g	c	in/sec^2	gravitational constant = 386.0
H	d	volts	output of 'HOLD ON' circuit
HO	c	volts	saturation level of H
HTH, HTL	c	volts	high and low threshold levels in 'HOLD ON' circuit
K1	c	vol/sec/psi	constant in flow rate relation when S = T
K2	c	vol/sec/$\sqrt{psi}$	constant in flow rate relation when S = F
K3	c	psi/sec	high rate of brake pressure increase
L	ℓ		T when $\omega \cdot RW \leq 70.4$ (70.4 in/sec = 4.0 mph)
P	d	psi	brake line pressure; output of pressure modulator
PP	d	psi	proportioned pressure; input to pressure modulator
RW	c	in	gain set at assumed rolling radius
S	ℓ		T when solenoid is on
t	d	sec	time
V	d	vol	volume of fluid in expansion chamber

Table F.1. (Cont.)

Parameter	Type	Units	Description
V_0	c	vol	initial volume of fluid in expansion chamber
τ_1	c	sec	time constant of pressure modulator when S = T
τ_2	c	$sec/\sqrt{psi}$	time constant of pressure modulator when S = F
ω	d	rad/sec	spin velocity of wheel (average value when two wheels are involved)
ω_D, ω_{DH}	d	rad/sec	reference ramps, triggered by D and DH, respectively

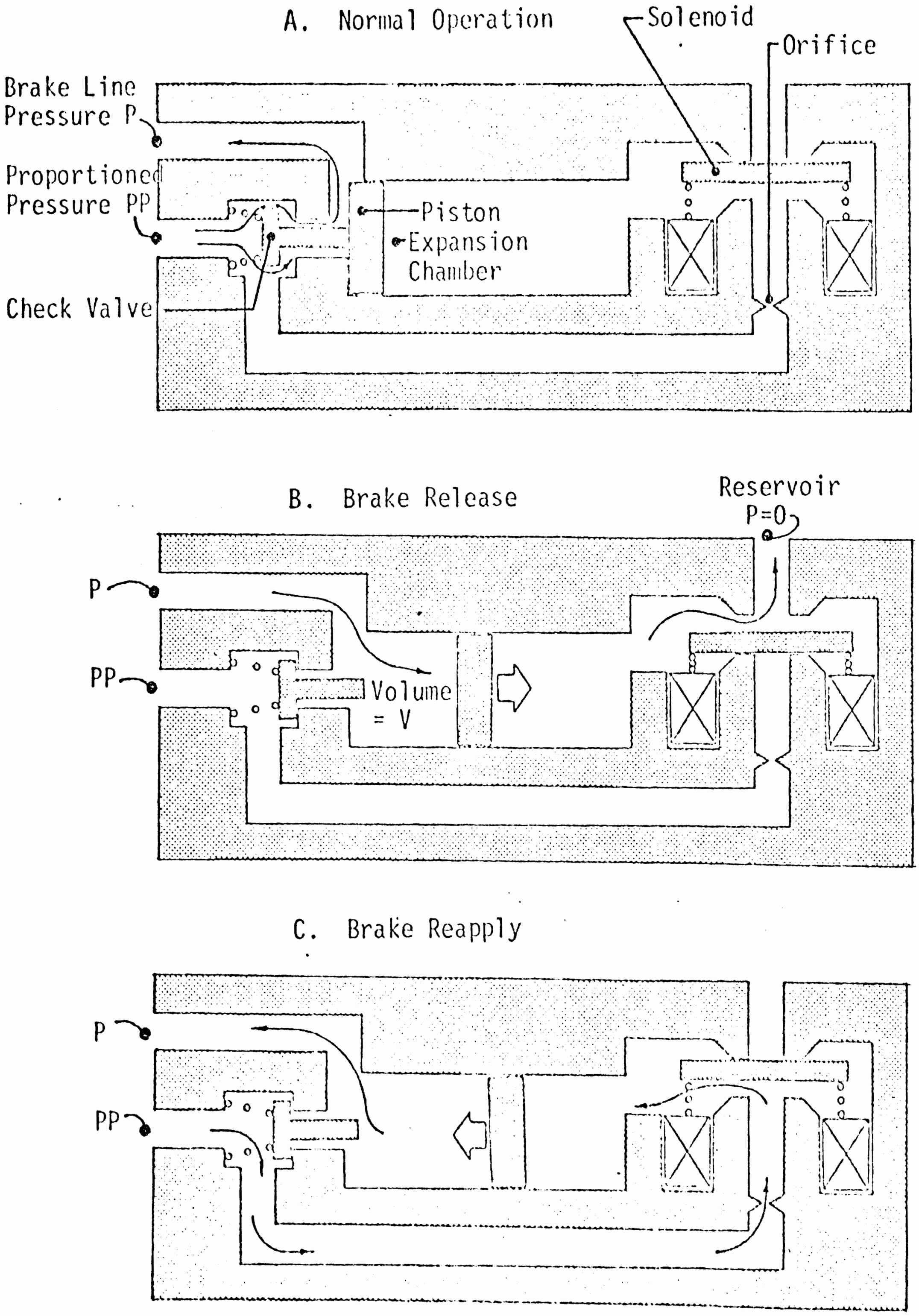


Figure F.1. Operation modes of the pressure modulator.

When the solenoid is turned on (S=T), the configuration is that shown in Figure F.1B. The pressure supply to the right-hand side of the piston is cut off, and the fluid to the right of the piston is allowed to escape to the reservoir. This causes the piston to move to the right as shown, which closes the check valve and completely seals the fluid from the master cylinder (or the proportioning valve, if there is one) from the brake line pressure. The brake line pressure drops as the fluid escapes into the expansion chamber, to the left of the piston. This action is modeled by a fluid capacitor discharging through a fluid resistor. The flow is assumed to be laminar, which results in the linear relation

$$P = -P/\tau_1 \quad (S=T) \tag{F.1}$$

where τ_1 is a function of the line dimensions, the stiffness of the line and chamber materials, the brake fluid properties, etc. The volume of fluid in the expansion chamber is given by the relation

$$\dot{V} = K_1 P \tag{F.2}$$

When the solenoid is then turned off, as depicted in Figure F.1C, fluid from the proportioning valve enters the expansion chamber on the right side of the piston, whereupon the fluid on the left side of the piston is forced back to the brake line. The rate at which the pressure is re-applied is slowed somewhat by the presence of an orifice, as shown in the figure. Due to the presence of the orifice, the relation describing the re-apply rate has a quadratic form, viz.

$$\dot{P} = \sqrt{PP-P}/\tau_2 \quad (S=F,\ V>0) \tag{F.3}$$

where τ_2 depends on the same type of characteristics as τ_1, as well as the orifice characteristics. The equation describing the volume of fluid to the left of the piston in the expansion chamber is

$$\dot{V} = -K_2 \sqrt{PP-P} \tag{F.4}$$

If the piston moves all the way to the left side of the chamber, indicated by the condition V=0, the check valve is opened, as shown originally in Figure F.1A. When this happens, the pressure rate increases drastically until the brake line pressure reaches the proportioned pressure. This is approximated as

$$\dot{P} = K3 \quad (P<PP) \tag{F.5}$$

If P does reach PP, then the antilock is re-initialized.

$$\begin{array}{ll} \text{if} & P \geq PP \\ \text{then} & ANTI = F \\ & P = PP \\ & V = V_0 \end{array} \tag{F.6}$$

F.2 Electronic Controller Logic

The logical variable D is turned on when the wheel acceleration drops below -1.5 g/RW, and stays set until the wheel acceleration is greater than -1.5 g/RW and the wheel rotational velocity is greater than a reference ramp which is triggered when D is turned on.

The logical variable DH works in a similar manner, except the acceleration level is -4 g/RW.

The logical variable S indicates the state of the solenoid. S is the output of the electronic section of the antilock module, and the only input to the pressure modulator. S is primarily determined by the 'HOLD ON' circuit, although the 'HOLD ON' circuit can be overridden by two other logical variables, AH, which automatically turns off S, and DH, which automatically turns it on.

The logical variables A and AH are both activated when wheel acceleration exceeds 1.0 g/RW or 4.5 g/RW, respectively.

The low velocity indicator, L, is activated when wheel velocity is below 4.0 mph/RW. ω_D is the value of a reference ramp, which is triggered when D changes from F to T. Otherwise, ω_D follows ω.

$$D = F \;, \quad \omega_D = \omega$$

$$D = T \;, \quad \dot{\omega}_D = -1.5 \cdot g/RW$$

ω_{DH} is the same, only with respect to DH.

$$DH = F \;, \quad \omega_{DH} = \omega$$

$$DH = T \;, \quad \dot{\omega}_{DH} = -4.0 \cdot g/RW.$$

F.3 HOLD ON Circuit

The HOLD ON circuit provides most of the logic determining whether to turn the solenoid on or off. This is done by generating a voltage H and comparing it with one of two threshold voltages. The equation which describes H depends on all of the logical variables. The threshold voltage is also determined by the logical variables. The various combinations are summarized in Table F.2, along with S, the output of the controller. Note that H is a negative voltage, and saturates at the value H_o.

F.4 FORTRAN Implementation of Antilock Model

The subroutine KHALS (Kelsey-Hayes Antilock System), which was added to the hybrid computer vehicle handling program at APL during this project, is listed on the following pages.

Table F.2. Summary of Antilock Controller Logic.

Control Variables							H (Saturates at H_o)	S
D	DH	L	A	AH	$H-H_{TH}$	$H-H_{Th}$		
T	F	F	F	F	>0	--	$\dot{H}= -C_1$	F
					<0			T
		T					$\dot{H}= -C_2$	
					>0			F
--	T	--	--		--		see comment*	T
	F			T			H=0	F
F				F		>0		
						<0	$\dot{H}=C_3+C_4\cdot\dot{\omega}$	T
--			T					
						>0	H=0	F

*DH has no effect on H, which is determined by the D.E. relevant to the other logical variables.

```
C     SUBROUTINE KHALS
      SUBROUTINE KHALS
      COMMON/TIMBLK/JJTIME,TIME,DT
      COMMON/SP7BLK/N1,N2,IPOT(120),IPOTAU(120),PARAM(400)
      COMMON/CFRC/ SL(4),SEP(4),CFCOEF(4),ARPS(4)
      COMMON/SPINS/ARPSDT(4),PF,PFR,AVRPS(4),AVRPSD(4),
     1              ARPSD(4),ARPSDH(4),HDOT(4)
      COMMON/ALVARS/AA(4),AAH(4),ANTLK(4),DD(4),DDH(4),AL(4),SA(4),
     1              HC(4),BRKPSI(4),PROPSI(4),RATPSI(4),VOL(4),VOLDOT(4)
      COMMON/ALCONS/AK1,AK2,AK3,C1,C2,C3,C4,H0,HTH,HTL,TAU1,TAU2,RRW
      COMMON/PRESS/PRF,PLF,PRR,PLR
      DATA G/386.4/
      DIMENSION STORE(5,4),DUMMY(4)
      DIMENSION A(4),AH(4),ANTILK(4),D(4),DH(4),L(4),S(4)
      LOGICAL A,AH,ANTILK,D,DH,L,S
C  *******************************************************************
C  **********  KELSEY-HAYES ANTI-LOCK SYSTEM  **********
C
C  **********  DYNAMIC VARIABLES  **********
C
C  AVRPS(K)     : AVERAGE WHEEL VELOCITY(RAD/SEC)
C  ARPSD(K)     : REFERENCE RAMP TRIGGERED BY D(K)
C  ARPSDH(K)    : REFERENCE RAMP TRIGGERED BY DH(K)
C  AVRPSD(K)    : AVERAGE WHEEL ACCELERATION(RAD/SEC/SEC)
C  HC(K)        : OUTPUT OF 'HOLD ON CIRCUIT' (VOLTS)
C  PROPSI(K)    : PROPORTIONAL PRESSURE-INPUT TO MODULATOR(PSI)
C  BRKPSI       : BRAKE PRESSURE-OUTPUT OF MODULATOR(PSI)
C  VOL(K)       : VOLUME OF FLUID IN EXPANSION CHAMBER(ARBITRARY UNITS)
C
C  **********  LOGICAL VARIABLES  **********
C
C  AA(K)        : TRUE WHEN AVERAGE WHEEL ACCELERATION(IN/SEC/SEC).GE. 1 GEE
C  AAH(K)       : TRUE WHEN AVERAGE WHEEL ACCELERATION(IN/SEC/SEC).GE.4.5 GEES
C  DD(K)        : TRUE WHEN AVERAGE WHEEL DECELERATION(IN/SEC/SEC) .LE. -1.5 GEES
C  DDH(K)       : TRUE WHEN AVERAGE WHEEL DECELERATION(IN/SEC/SEC) .LE. -4.0 GEES
C  AL(K)        : TRUE WHEN AVERAGE WHEEL VELOCITY(IN/SEC).LE. 4MPH
C  SA(K)        : TRUE WHEN SOLENIOD IS 'ON'
C  ANTLK(K)     : TRUE AFTER SOLENIOD HAS BEEN TURNED ON IN RUN
C
C  **********  CONSTANTS  **********
C
C  C1           : BASIC CHARGE DOWN RATE OF 'HC'(VOLTS/SEC)
C  C2           : HIGH CHARGE DOWN RATE OF 'HC'(VOLTS/SEC)
C  C3           : BASIC DISCHARGE RATE OF 'HC'(VOLTS/SEC)
C  C4           : GAIN FOR WHEEL ACCELERATION TERM IN DISCHARGE
C                 RATE OF 'HC'(VOLT-SEC)
C  AK1          : RATIO OF FLOW RATE TO PRESSURE DROP(VOL/SEC/PSI)
C                 (SOLENIOD ON)
C  AK2          : RATIO OF FLOW RATE TO PRESSURE DROP(VOL/SEC/PSI)
C                 (SOLENIOD OFF)
C  AK3          : HIGH RATE OF BRAKE PRESSURE INCREASE(PSI/SEC)
C  TAU1         : TIME CONSTANT OF PRESSURE MODULATOR(SEC)(SOLENIOD ON)
C  TAU2         : TIME CONSTANT OF PRESSURE MODULATOR(SEC)(SOLENIOD OFF)
C  RRW          : ASSUMED CONSTANT ROLLING RADIUS(IN)
C  H0           : SATURATION LEVEL FOR OUTPUT OF 'HOLD ON CIRCUIT' (VOLTS)
C  HTH          : HIGH THRESHOLD LEVEL IN 'HOLD ON CIRCUIT'(VOLTS)
C  HTL          :  LOW THRESHOLD LEVEL IN 'HOLD ON CIRCUIT'(VOLTS)
C
C  **********   ANTILOCK MODULE CONFIGURATION   **********
```

```
C
C  PARAM(223) = 1.
C                    TWO MODULES,ONE SENSING THE AVERAGE OF THE TWO REAR
C                    WHEEL SPIN RATES AND CONTROLLING THE REAR BRAKES, AND
C                    THE OTHER SENSING THE AVERAGE OF THE FRONT WHEEL SPIN
C                    RATES AND CONTROLLING THE FRONT BRAKES.
C              = 2.
C                    ONE MODULE, CONTROLLING THE REAR AXLE BRAKES, AND
C                    SENSING THE AVERAGE OF THE TWO REAR WHEEL SPIN RATES.
C              = 3.
C                    THREE MODULES, ONE SENSING THE AVERAGE OF THE TWO REAR
C                    WHEEL SPIN RATES AND CONTROLLING THE REAR BRAKES, AND
C                    THE OTHER TWO SENSING THE INDEPENDENT FRONT WHEEL SPIN
C                    RATES AND CONTROLLING THE CORRESPONDING INDEPENDENT
C                    FRONT BRAKES.
C              = 4.
C                    FOUR MODULES, EACH SENSING ONE WHEEL SPIN RATE AND
C                    CONTROLLING THE CORESSPONDING BRAKE.
C  ****************************************************************************
C
C        INITIALIZATION
C
      IF(TIME.GT.0.) GO TO 100
      DO 50 K=1,4
      A(K)=.FALSE.
      AH(K)=.FALSE.
      ANTILK(K)=.FALSE.
      D(K)=.FALSE.
      DH(K)=.FALSE.
      L(K)=.FALSE.
      S(K)=.FALSE.
      HC(K)=0.
      PROPSI(K)=0.
      AVRPS(K)=0.0
      AVRPSD(K)=0.0
      BRKPSI(K)=0.0
      RATPSI(K)=0.
      VOL(K)=-20.
      VOLDOT(K)=0.
      DUMMY(K)=0.0
 50   CONTINUE
      DO 30 J=1,5
      DO 31 K=1,4
      STORE(J,K)=0.0
 31   CONTINUE
 30   CONTINUE
100   CONTINUE
      IF(PARAM(223).NE.1.) GO TO 2000
      AVRPS(1)=(ARPS(1)+ARPS(2))/2.
      AVRPS(2)=(ARPS(3)+ARPS(4))/2.
      DO 20 I=1,2
      IF(I.EQ.1) K=1
      IF(I.EQ.2) K=3
      DUMMY(I)=(ARPSDT(K)+ARPSDT(K+1))/2.
      AVRPSD(I)=AVRPSD(I)+0.2*(DUMMY(I)-STORE(1,I))
      DO 21 J=1,4
      STORE(J,I)=STORE(J+1,I)
 21   CONTINUE
      STORE(5,I)=DUMMY(I)
 20   CONTINUE
```

```
      PROPSI(1)=PF
      PROPSI(2)=PFR
      GO TO 5000
 2000 IF(PARAM(223).NE.2.) GO TO 3000
      AVRPS(2)=(ARPS(3)+ARPS(4))/2.
      DUMMY(2)=(ARPSDT(3)+ARPSDT(4))/2.
      AVRPSD(2)=AVRPSD(2)+0.2*(DUMMY(2)-STORE(1,2))
      DO 22 J=1,4
      STORE(J,2)=STORE(J+1,2)
   22 CONTINUE
      STORE(5,2)=DUMMY(2)
      PROPSI(2)=PFR
      GO TO 5000
 3000 IF(PARAM(223).NE.3.) GO TO 4000
      AVRPS(1)=ARPS(1)
      AVRPS(2)=ARPS(2)
      AVRPS(3)=(ARPS(3)+ARPS(4))/2.
      DO 23 I=1,3
      K=I
      IF(I.EQ.3) K=I+1
      DUMMY(I)=(ARPSDT(I)+ARPSDT(K))/2.
      AVRPSD(I)=AVRPSD(I)+0.2*(DUMMY(I)-STORE(1,I))
      DO 24 J=1,4
      STORE(J,I)=STORE(J+1,I)
   24 CONTINUE
      STORE(5,I)=DUMMY(I)
   23 CONTINUE
      PROPSI(1)=PF
      PROPSI(2)=PF
      PROPSI(3)=PFR
      GO TO 5000
 4000 AVRPS(1)=ARPS(1)
      AVRPS(2)=ARPS(2)
      AVRPS(3)=ARPS(3)
      AVRPS(4)=ARPS(4)
      DO 25 I=1,4
      DUMMY(I)=ARPSDT(I)
      AVRPSD(I)=AVRPSD(I)+0.2*(DUMMY(I)-STORE(1,I))
      DO 26 J=1,4
      STORE(J,I)=STORE(J+1,I)
   26 CONTINUE
      STORE(5,I)=DUMMY(I)
   25 CONTINUE
      PROPSI(1)=PF
      PROPSI(2)=PF
      PROPSI(3)=PFR
      PROPSI(4)=PFR
 5000 CONTINUE
C
C          ELECTRONIC CONTROLLER LOGIC
C
      DO 200 K=1,4
      ARPSD(K)=AVRPS(K)-1.5*G*DT/RRW
      IF(.NOT.D(K)) ARPSD(K)=AVRPS(K)
      ARPSDH(K)=AVRPS(K)-4.*G*DT/RRW
      IF(.NOT.DH(K)) ARPSDH(K)=AVRPS(K)
      D(K)=.FALSE.
      IF(AVRPSD(K).LT.-1.5*G/RRW     .OR.AVRPS(K).LT.ARPSD(K))D(K)=.TRUE.
      DH(K)=.FALSE.
      IF(AVRPSD(K).LT.-4.*G/RRW     .OR.AVRPS(K).LT.ARPSDH(K))
```

```
    1   DH(K)=.TRUE.
        A(K)=.FALSE.
        IF(AVRPSD(K).GT.1.*G/RRW      ) A(K)=.TRUE.
        AH(K)=.FALSE.
        IF(AVRPSD(K).GT.4.5*G/RRW     ) AH(K)=.TRUE.
        L(K)=.FALSE.
        IF(AVRPS(K).LT.70.4/RRW     ) L(K)=.TRUE.
C
C          COMPUTE/HOLD ON/ CIRCUIT OUTPUT HC
C
        IF(AH(K)) GO TO 9
        IF(.NOT.(D(K).OR.L(K)).AND.HC(K).GT.HTH) GO TO 9
        IF(D(K)) HDOT(K)=-C1
        IF(D(K).AND.L(K)) HDOT(K)=-C2
        IF(A(K).OR..NOT.D(K))   HDOT(K)=C3+C4*AVRPSD(K)
        IF(D(K).OR.L(K).OR.HC(K).LE.HTL) GO TO 10
    9   HC(K)=0.
        HDOT(K)=0.
   10   HC(K)=HC(K)+HDOT(K)*DT
        IF(HC(K).LT.H0) HC(K)=H0
C
C          SET SOLENOID ON OR OFF
C
        IF(HC(K).GE.HTH) S(K)=.FALSE.
        IF(.NOT.(D(K).OR.L(K).OR.HC(K).LT.HTL)) S(K)=.FALSE.
        IF(DH(K)) S(K)=.TRUE.
        IF((D(K).OR.L(K)).AND.HC(K).LT.HTH) S(K)=.TRUE.
        IF(HC(K).LT.HTL) S(K)=.TRUE.
        IF(S(K)) ANTILK(K)=.TRUE.
        IF(.NOT.ANTILK(K)) BRKPSI(K)=PROPSI(K)
C
C          MODULATE BRAKE LINE PRESSURE
C
        IF(S(K)) GO TO 15
        RATPSI(K)=SQRT(PROPSI(K)-BRKPSI(K))/TAU2
        VOLDOT(K)=-AK2*SQRT(PROPSI(K)-BRKPSI(K))
        VOL(K)=VOL(K)+VOLDOT(K)*DT
        IF(VOL(K).GT.0.) GO TO 16
        VOL(K)=0.
        RATPSI(K)=AK3
        GO TO 16
   15   RATPSI(K)=-BRKPSI(K)/TAU1
        VOLDOT(K)=AK1*BRKPSI(K)
        VOL(K)=VOL(K)+VOLDOT(K)*DT
   16   BRKPSI(K)=BRKPSI(K)+RATPSI(K)*DT
        IF(BRKPSI(K).GT.PROPSI(K).OR..NOT.ANTILK(K)) BRKPSI(K)=PROPSI(K)
  200   CONTINUE
        DO 300 K=1,4
        IF  (A(K)) AA(K)=1.0
        IF(.NOT.A(K)) AA(K)=0.0
        IF(AH(K)) AAH(K)=1.0
        IF(.NOT.AH(K)) AAH(K)=0.0
        IF(ANTILK(K)) ANTLK(K)=1.0
        IF(.NOT.ANTILK(K)) ANTLK(K)=0.0
        IF(D(K)) DD(K)=1.0
        IF(.NOT.D(K)) DD(K)=0.0
        IF(DH(K)) DDH(K)=1.0
        IF(.NOT.DH(K)) DDH(K)=0.0
        IF(L(K)) AL(K)=1.0
        IF(.NOT.L(K)) AL(K)=0.0
```

```
      IF(S(K)) SA(K)=1.0
      IF(.NOT.S(K)) SA(K)=0.0
300   CONTINUE
      MODULE=PARAM(223)+0.5
      GO TO (1,2,3,4), MODULE
1     PRF=BRKPSI(1)
      PLF=BRKPSI(1)
      PRR=BRKPSI(2)
      PLR=BRKPSI(2)
      GO TO 5
2     PRF=PF
      PLF=PF
      PRR=BRKPSI(2)
      PLR=BRKPSI(2)
      GO TO 5
3     PRF=BRKPSI(1)
      PLF=BRKPSI(2)
      PRR=BRKPSI(3)
      PLR=BRKPSI(3)
      GO TO 5
4     PRF=BRKPSI(1)
      PLF=BRKPSI(2)
      PRR=BRKPSI(3)
      PLR=BRKPSI(4)
5     CONTINUE
      RETURN
      END
```

APPENDIX G

TEST SEQUENCE AND PROCEDURE

Fitted within the format of the existing Standard No. 105-75; Hydraulic Brake Systems, the test procedure is outlined below. Please note that section numbers S5, S6, etc., denote portions of the existing standard, some of which apply to the conducted test activity as is, while certain others are to be applied in the modified form which is presented. Please note that the following procedure format constitutes our view of hypothetical modifications to FMVSS 105-75 which were suitable for this research activity but not necessarily deserving of recommendation as means to enhance the safety quality of motor vehicles.

The scope, purpose, applications, and definitions of FMVSS 105-75, Sections S1 through S4, remain unchanged. The "Requirements" associated with additional tests, such as those being conducted here, would replace those specified in Sections S5.1.1.2 and S5.1.1.3. Instead of the standard's existing requirements pertaining to service brake system effectiveness, a set of additional requirements would be cited, perhaps in a table, covering the various test conditions under which stopping distances will be measured. Test conditions (appearing as Section S6 in the standard) will be followed as written in 105-75 except as regards certain conditions as follows:

S6.8 Wind Velocity. Tests will be conducted with prevailing steady wind velocities not exceeding 15 mph.

S6.9 Road Surface. Tests are to be conducted utilizing selected surfaces providing high, low, and split friction conditions, suitably layed-out to permit both straight-line braking and braking in a turn as described in S7.3 and S7.5. All test sections are to be 12 feet wide.

S6.10 Vehicle Position. The vehicle is aligned at the center of the roadway at the start of each brake application. Stops are made without any part of the vehicle leaving the roadway. Except as noted below, stops are made without lockup of two wheels on a single axle at speeds greater than 10 mph. There may also be any combination of controlled lockups on an antilock-equipped vehicle.

S6.12 Initial Brake Temperature. Initial brake temperature is to be not more than 200°F.

S6.13 Control Forces. The force applied to a brake control is not more than 150 lbs.

Test Procedures. Procedures to be employed cover the equivalent sections of FMVSS 105-75 from S7 through S7.8. The precise procedures of 105 are to be employed except as cited below:

S7, S7.1, S7.2 -- Per existing procedure.

S7.3 -- Service Brake System, First (Pre-Burnish) Effectiveness Tests. Stops are to be made according to the sequence of Table G.1 Tests No. 1 through 4.

Table G.1. Pre-Burnish Effectiveness Series

No.	Speed	Surface	Direction	Load
1	60 mph	Hi Friction	Straight	GVWR
2	40 mph	Lo Friction	Straight	GVWR
3	40 mph	Split (Hi-Rt)	Straight	GVWR
4	40 mph	Split (Hi-Lft)	Straight	GVWR

Effectiveness tests are to be run in a series of increasing pedal force application up to the condition at which two wheels on one axle are locked (with vehicle speed still above 10 mph) or up to a pedal force of 150 lbs. Two stops are then to be conducted at a pedal force which is the minimum practicable increment below that needed for axle lockup, with the total number of stops at each test condition not to exceed 10 (thus constraining the brake work history to a fixed maximum).

Driver adjustment of steering wheel is permitted throughout the stop. Test data from any stop in which the lane edge is transgressed is to be voided in the determination of minimum stopping distance.

The wet pavement conditions in all effectiveness tests are to be achieved using a continuous watering system or a truck-borne watering system wetting the test lane between test vehicle runs.

S7.4 Service Brake System - Burnish Procedure. The existing burnish procedure of S7.4.1 will be conducted (that is, pertaining to vehicles whose GVWR is 10,000 lbs or less).

S7.4.1.2 Brake Adjustment - Post-Burnish. (Per existing procedure.)

S7.5 Service Brake System - Second Effectiveness Test. Stops are to be made according to the sequence of Table G.2. Straight-line stops are to be conducted per the procedure outlined above, in S7.3.

Braking effectiveness in a turn tests (Nos. 6, 7, and 11 through 16) are conducted according to the procedure identified in S7.3 except that stops are made while the vehicle is traveling in a turn of 535-ft. radius. The vehicle is required to have been traveling along this curved path for a minimum of 2 seconds (at 40 mph) prior to initiating braking.

Table G.2. Post-Burnish (2nd) Effectiveness Series.

No.	Speed	Surface	Direction	Load
5	60 mph	Hi Friction	Straight	GVWR
6	40 mph	Hi Friction	Turn-Right	GVWR
7	40 mph	Hi Friction	Turn-Left	GVWR
8	40 mph	Lo Friction	Straight	GVWR
9	40 mph	Split (Hi-Rt)	Straight	GVWR
10	40 mph	Split (Hi-Lft)	Straight	GVWR
11	40 mph	Lo Friction	Turn-Right	GVWR
12	40 mph	Lo Friction	Turn-Left	GVWR
13	40 mph	Split (Hi-Rt)	Turn-Right	GVWR
14	40 mph	Split (Hi-Rt)	Turn-Left	GVWR
15	40 mph	Split (Hi-Lft)	Turn-Right	GVWR
16	40 mph	Split (Hi-Lft)	Turn-Left	GVWR

S7.6 First Reburnish. (Existing procedure will be conducted.)

S7.7 through S7.7.4 Parking Brake Tests. (These procedures were not conducted in this study, but would retain their position and format in a hypothetically-expanded standard.)

S7.8 Service Brake System - Lightly-Loaded Vehicle (Third Effectiveness) Test. Stops are to be made according to the sequence of Table G.3 per the procedures outlined in Section S7.3 (for straight-line stops) and in Section S7.5 (for stopping in a turn).

Table G.3. Third Effectiveness Series

No.	Speed	Surface	Direction	Load
17	60 mph	Hi Friction	Straight	Light
18	40 mph	Hi Friction	Turn-Right	Light
19	40 mph	Hi Friction	Turn-Left	Light
20	40 mph	Lo Friction	Straight	Light
21	40 mph	Split (Hi-Rt)	Straight	Light
22	40 mph	Split (Hi-Lft)	Straight	Light
23	40 mph	Lo Friction	Turn-Right	Light
24	40 mph	Lo Friction	Turn-Left	Light
25	40 mph	Split (Hi-Rt)	Turn-Right	Light
26	40 mph	Split (Hi-Rt)	Turn-Left	Light
27	40 mph	Split (Hi-Lft)	Turn-Right	Light
28	40 mph	Split (Hi-Lft)	Turn-Left	Light

S7.6 First Reburnish. (Existing procedure will be conducted.)

S7.7 through S7.7.4 Parking Brake Tests. (These procedures were not conducted in this study, but would retain their position and format in a hypothetically-expanded standard.)

S7.8 Service Brake System - Lightly-Loaded Vehicle (Third Effectiveness) Test. Stops are to be made according to the sequence of Table G.3 per the procedures outlined in Section S7.3 (for straight-line stops) and in Section S7.5 (for stopping in a turn).

Table G.3. Third Effectiveness Series

No.	Speed	Surface	Direction	Load
17	60 mph	Hi Friction	Straight	Light
18	40 mph	Hi Friction	Turn-Right	Light
19	40 mph	Hi Friction	Turn-Left	Light
20	40 mph	Lo Friction	Straight	Light
21	40 mph	Split (Hi-Rt)	Straight	Light
22	40 mph	Split (Hi-Lft)	Straight	Light
23	40 mph	Lo Friction	Turn-Right	Light
24	40 mph	Lo Friction	Turn-Left	Light
25	40 mph	Split (Hi-Rt)	Turn-Right	Light
26	40 mph	Split (Hi-Rt)	Turn-Left	Light
27	40 mph	Split (Hi-Lft)	Turn-Right	Light
28	40 mph	Split (Hi-Lft)	Turn-Left	Light