Development of Car/Trailer Handling and Braking Standards. Vol. IV: Technical Report for Phase II – Front Wheel Drive Tow Cars
NTIS, November 1979

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PB80-196645

DEVELOPMENT OF CAR/TRAILER HANDLING AND BRAKING STANDARDS

Volume IV: Technical Report for Phase II—Front Wheel Drive Tow Cars

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Contract No. DOT HS-7-01720
Contract Amt. $245,544

November 1979
FINAL REPORT

Prepared For
U.S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
Washington, D.C. 20591

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT-HS-805 329		PB80 296645

4. Title and Subtitle	5. Report Date
Development of Car/Trailer Handling and Braking Standards. Vol. IV: Technical Report for Phase II-Front Wheel Drive Tow Cars	November 1979
	6. Performing Organization Code
7. Author(s) Richard H. Klein and Henry T. Szostak	8. Performing Organization Report No. TR-1114-1-IV
9. Performing Organization Name and Address Systems Technology, Inc. 13766 South Hawthorne Boulevard Hawthorne, California 90250	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DOT-HS-7-01720
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration Office of Passenger Vehicle Research Washington, D. C. 20590	13. Type of Report and Period Covered Final Report 9/77 - 11/79
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report verifies the handling and braking performance requirements proposed in Vol. II for passenger cars towing trailers. This includes straight line braking, trailer swing stability, tow car steady turn stability, and combined brake-in-turn stability. Over 500 combinations vehicle tests with three trailers and two front wheel drive tow cars (in 34 different configurations), plus the results of previous trailer towing research have been integrated into proposed performance criteria, and a compliance format based on tow car and trailer characteristics. For straight line braking performance a combination-vehicle (CV) deceleration criteria of 0.4g is recommended. A tow car weight requirement based on trailer brake capability is presented to insure the CV will meet this deceleration requirement. For unbraked trailers the tow car gross weight rating should never be less than 1.5 times the trailer weight. For trailer swing stability the safety-related performance measure is damping ratio, or the equivalent cycles to one-half amplitude. A minimum damping ratio of 0.15 (or 3/4 cycles to 1/2 amplitude) is recommended. Test procedures and analysis curves are presented which can be used to determine damping ratio for each trailer. In this case a minimum hitch load criteria based on tow car weight is suggested to insure performance compliance. For tow car stability a tentative performance criteria of maintaining a positive tow car understeer gradient up to and including 0.3g cornering is recommended. This requirement sets a limit on the maximum allowable hitch load for a given weight tow car, and is a function of load leveling torque applied by a weight distributing hitch. Due to the compatability of these latter

(Continued)

17. Key Words	18. Distribution Statement
trailer, trailer towing, vehicle dynamics, test procedures, handling, braking, combination vehicle, standards	Document is available to the public through National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ABSTRACT (Concluded)

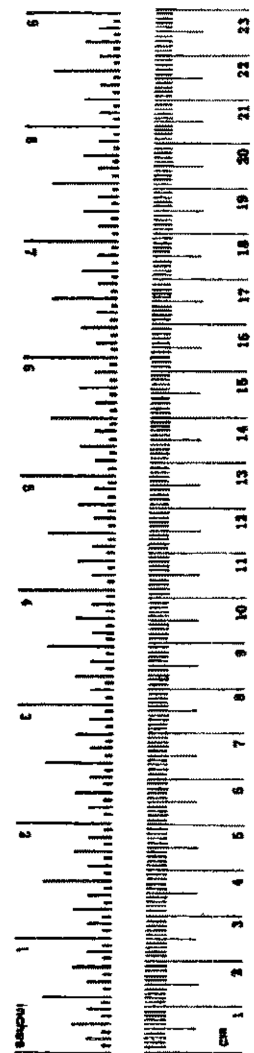
two handling requirements, they have been integrated into a hitch load versus tow car weight graph unique to each trailer. Use of this graph by a user or manufacturer will define the proper hitch load range for a given tow car size and/or help specify the minimum weight tow car for a given trailer.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

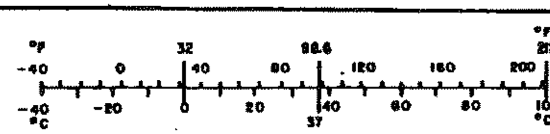
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FOREWORD

This document comprises Vol. IV of a four volume technical report aimed at developing car/trailer handling and standards. A condensed executive summary of the entire program and key results is given in Vol. I. Volume II contains the main technical discussion and summary test results with three rear wheel drive tow cars. Volume III contains appendicies providing raw data and other supportive material for the Phase I tests. Results of Phase II testing, with two front wheel drive tow cars is presented in this volume. These tests represent a validation of the requirements proposed in Vol. II.

The research program was accomplished by Systems Technology, Inc., Hawthorne, California, for the Office of Passenger Vehicle Research of the National Highway Traffic Safety Administration, under Contract DOT-HS-7-01720. The contract technical manager was Dr. J. Kanianthra, and the STI project engineer was Mr. R. Klein. The STI Technical Director was Mr. I. L. Ashkenas.

Significant contributions made by STI staff members include Mr. H. T. Szostak for test direction and data analysis, Mr. L. Ingersoll for vehicle instrumentation and maintenance, Mr. S. Whitfield for test driving, and Ms. S. A. Riedel for development of the automated data reduction techniques.

Special acknowledgement is given for the fine cooperation and assistance extended to this program by the following organizations and individuals:

- Mr. J. Abromavage, U-Haul International
  Chairman of Trailer Hitch Sub-Committee of the
  SAE On-Highway Recreational Vehicle Committee
- Mr. R. Madison, Consultant for the Recreational
  Vehicle Industry Association
- Mr. R. Wilkinson
  Fleetwood Enterprises
- Mr. J. Shumway
  Prowler Industries
- Mr. R. Franke
  Coachman Industries
- Mr. J. Carr
  Shasta Trailers
- Mr. C. Keck and Mr. S. Kulp
  Holiday Rambler

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- Mr. D. Swanson and Mr. L. Huetsch
  Atwood Mobil Products
- Mr. R. Chirakos
  Dexter Axle Co.
- Mr. L. Caldwell
  Eaz-Lift
- Mr. E. Kuma
  Cal-Camp Industries

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SECTION I

INTRODUCTION

This report presents results of a second phase of a program to develop braking and handling performance criteria, and compliance formats for passenger cars towing trailers. In the first phase of the study (described in Vols. II and III) a full range of trailers were tested with three different tow cars representing the intermediate (Chevrolet Monte Carlo), compact (Plymouth Volare), and sub-compact (Ford Mustang) vehicle classes; the selection being based on weight difference and manufacturer.

During this, and the previous Ref. 1 study, it was determined that weight distribution plays a significant role in trailer towing handling and braking. Consequently, increasing hitch load, and/or load leveling, significantly alters the tow vehicle stability and stopping distance. For example, the use of load leveling to obtain a "level" car/trailer attitude does not provide equal weight transfer when the front springs have a higher rate than the rear springs; stopping distance is unfavorably affected with uneven front/rear brake proportioning; and higher than normal throttle application (due to trailer load) affects steering characteristics in steady turns. Because of these factors it appeared desirable to expand the research tests to include trailer towing test procedures for front-wheel drive vehicles. These vehicles typically have a very uneven (63/37) front/rear weight distribution, and are becoming a large portion of the in-use population.

In regard to the trailers capable of being towed by this subcompact vehicle class, structural and engine power capabilities limit the overall trailer weight and hitch load. Consequently, tests were made with three trailers at various weights to uncover the limitations.

Following the format of Vol. II (for the 3 rear wheel drive vehicles) this report is organized according to the 4 key test procedures. These comprise straight line brake (for stopping performance), pulse steer (for trailer swing performance), constant radius circle (for tow car stability), and brake-in-turns (for combined longitudinal and lateral stability and performance). Results of each procedure, with comparison to the rear wheel drive test cars, are presented in individual sections. For summary, the test program overview is presented first, and the overall conclusions and recommendations are presented last.

SECTION II

TEST PROGRAM

This second phase of the test program sponsored under the Ref. 2 contract involved testing two additional passenger cars with three trailers. This section presents data for these vehicles and the test matrix of combination-vehicle configurations.

A. TOW VEHICLES AND TRAILER SELECTION

Two subcompact front-wheel drive vehicles were selected. These were the new GM X body, a Chevrolet Citation, and a Plymouth Horizon. As noted in Table 1, the Citation weighs about 500 lbs more than the Horizon and has a higher front weight distribution.

Based on structural and suspension limitations it is not possible to tow more than Class II trailers (3500 lbs) with these subcompacts. In fact, the manufacturers do not recommend towing any trailer over 1000 lbs unless the tow car has some trailering options. Even with this, the user is cautioned never to tow any trailer over 2000 lbs! For example, Chevrolet provides the following caution in their owners manual:

> CAUTION: Do not try to tow any trailer over 2,000 pounds (900 kilograms) gross trailer weight (1,000 pounds (450 kilograms) for California emission equipped cars with air conditioning) no matter what trailer towing equipment is installed. This could seriously affect your car's performance, durability or handling, which could result in personal injury.

However, in order to determine the maximum allowable trailer weights and hitch loads, three single axle trailers were selected. As noted in Table 2, these represented a non-braked utility trailer (GVWR 2600 lb), a camper trailer with surge brakes, (GVWR 2100 lb), and a light weight, electric braked, travel trailer (GVWR 3000 lb). Load leveling could not be used with the subcompact vehicles since they can not accomodate a third class hitch, however, air shocks were available for the Citation and provided the capability to maintain a constant rear suspension ride height with up to 350 lbs hitch load. The Horizon did not have an air shock replacement.

TABLE 1. TEST TOW CARS (FRONT WHEEL DRIVE)

VEHICLE TYPE (GVWR)	SIZE	CURB WEIGHT/ TEST WEIGHT[a] (lbs)	WHEELBASE (in.)	TIRES[b]	WEIGHT DISTRIBUTION F/R[c]
1979 Chevrolet Citation (3571)	Sub-Compact	2722/3200	105.	P185/80R-13 TPC 1029	62/38
1978 Plymouth Horizon (3165)	Sub-Compact	2250/2675	99.	P155/80R-13	58/42

[a]Includes driver (180 lbs), instrumentation (275 lbs), hitch, and one-half fuel.

[b]Inflation pressures: 35/35 (cold inflation pressure for max. rated load).

[c]At test weight

TABLE 2. TEST TRAILERS

TYPE	MANUFACTURER/ MODEL	OVERALL LENGTH	TEST WEIGHT / GVWR	AXLES	BRAKES	TIRES (PRESSURE)
Utility	U-Haul/AV	11 ft 6 in.	2600 1500/2600 1000	1	None	6:70 × 15 LT LRC (45 psi)
Camper	Starcraft Starmaster 6	15 ft 3 in.	1600/2090	1	Surge 7 × 1.75	5:30 × 12 LRC (80 psi)
Small Travel	CAL-CAMP	16 ft 4 in.	2400 3000/3000	1	Electric 10 × 2 (Kelsey-Hayes)	7:00 × 14 LRC (36 psi)

B. TEST CONFIGURATION SUMMARY

A total of 34 different combination-vehicle configurations were tested. These were obtained by varying trailer weight, hitch load, and trailer brake capability on the three test trailers pulled by two tow cars. The exact configurations are listed in Table 3 along with the test procedures applied. A thorough discussion of each test procedure is given in Vol. II.

TABLE 3. FULL SCALE TEST SUMMARY

TRAILER	TEST CONFIGURATION						TEST PROCEDURES											
	WEIGHT	HITCH LOAD	AIR SHOCKS		BRAKES		CRT		PS		SLB		BIT		BTA		OTHER	
							C	P	C	P	C	P	C	P	C	P	C	P
Utility	1000	0		N	N					×								
		10	Y	N	N				×	×								
	1500	0	N	N	N			×	×	×	×	×						
		5	Y	N	N		×	×	×	×	×							
		10	Y	N	N		×	×	×	×	×	×						
		15	Y	N	N		×	×	×	×	×	×	×	×				
		20	Y	N	N		×	×										
	2600	5		N	N					×								
		10	Y	N	N				×	×	×	×						
Camper	1600	0	N	N	–				×	×								
		5	Y	N	–				×	×								
		10	Y	N	Y	Y	×	×	×	×	×	×			×			×
		10	Y		N						×		×					
		15	Y	N	Y	Y			×	×				×				
Travel	2400	5	Y	N	–				×	×								
		10	Y	N	0%	N					×			×				×
		10	Y	N	50%						×							
		10	Y	N	100%	Y	×	×			×	×	×	×	×			×
		15	Y	N	–				×	×								
	3000	10		N												×		

Hitch Load = Percent trailer weight

Air Shocks = Yes if used to level CV, No if not used

CRT = Constant radius turn (400 ft diameter)

PS = Pulse steer at 55 mph

SLB = Straight line brake from 40 mph

BIT = Brake in turn, 40 mph, 0.3 g turn

BTA = Trailer-alone brake

Other = 0.6 g tow car brake capability

C = Chevrolet; P = Plymouth

SECTION III

STRAIGHT LINE BRAKING

Based on the previous tests of eight trailers and three tow cars it was recommended (in the Vol. II report) that the straight line stopping performance for combination-vehicles be 134 ft from 40 mph. This corresponds to an average deceleration of 0.4g.

To insure compliance, it was further recommended that the tow car to trailer weight ratio, W_c/W_t, be proportion to the "trailer-alone" deceleration capability, $a_{x_{ta}}$. Specifically, W_c/W_t be greater than 2.1 minus 3.5 $a_{x_{ta}}$, i.e.,

$$\frac{W_c}{W_t} \geq 2.1 - 3.5\, a_{x_{ta}}$$

Basically, this requires the tow car to be at least 2.1 times the trailer weight if there are no trailer brakes. With trailer brakes providing a 0.43 g capability (a typical design) the trailer could actually be heavier than the tow car.

This braking expression was derived from a complete static braking model with 10 percent hitch load, non-optimum brake proportioning (60F/40R) and no load leveling (see Appendix D of Vol. III). It is more readily interpreted when illustrated graphically as in Fig. 1. In this plot, tow car to trailer weight ratios above the boundary would theoretically pass the stopping distance requirement, and weight ratios below (or inside) the shaded boundary would fail the requirement.

One of the key objectives of this second testing phase was to verify the proposed boundary, especially for unbraked trailers where the proposed standard could restrict some current designs (i.e., since some states allow 3000 lb unbraked trailers).

A second objective was to determine if the proposed requirements, based solely on rear wheel drive passenger cars, were also applicable to front wheel drive designs.

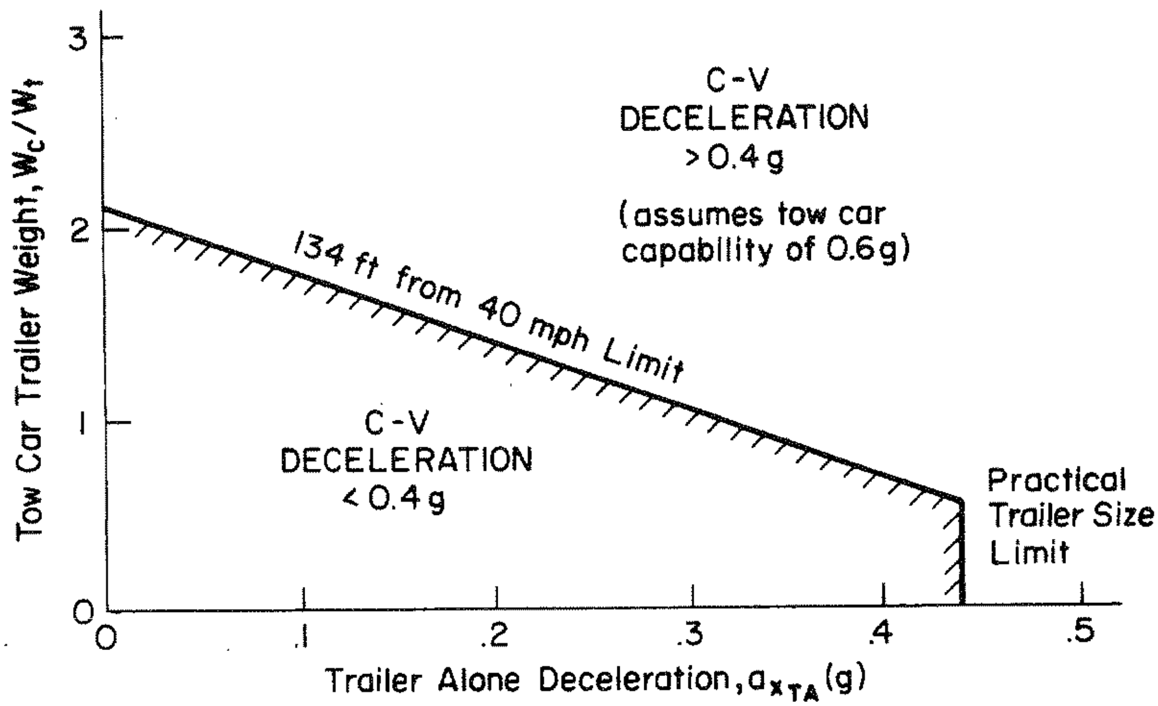


Figure 1. Recommended Tow Car/Trailer Weight Limit to Meet 0.4 g C-V Deceleration Requirement

As described in Vol. II, the straight line brake test procedure involves maximum performance stops from 40 mph. At least six replications are made, in which incipient tow car lockup is allowed, i.e., preferably 3 runs below lockup and 3 runs with partial lockup.

The average test results for each tow car and C-V are presented in Table 4 and 5. Individual test run data are presented in Appendix B of this volume. First, in regard to tow car alone performance, both vehicles met (or exceeded) the requirements of FMVSS-105-75. The Citation was close to the stopping distance requirement (89.3 ft average vs. 91 ft required) and the Horizon was well below (at 79.3 ft or 0.68 g average). In addition, the Citation exhibited a front wheel lockup limitation whereas the Horizon exhibited rear wheel lock-up. For optimum car alone performance, the front lock-up is

TABLE 4. COMBINATION VEHICLE STRAIGHT LINE STOPPING DISTANCE[a] RESULTS FOR CHEVROLET CITATION[b] - NO LOAD LEVELING-AIR SHOCKS ONLY

CONDITION / HITCH LOAD	UTILITY (NO BRAKES)			CAMPER (1600 lb)		TRAVEL (2400 lb)			CAR ALONE	
	1000	1500	2600	NO BRAKES	SURGE	NO BRAKES	58% BR	100% BR	BEFORE	AFTER
0		112 ± 2.7 / 6							88.0 ± 4.1 / 9	90.6 ± 4.3 / 6
5		117 ± 2.5 / 7								
10	107 ± 5.7 / 12	116 ± 4.6 / 6	155 ± 7.8 / 7	126 ± 6.3 / 8	113 ± 1.6 / 9	141 ± 6.0 / 9	114 ± 4.9 / 6	98 ± 1.7 / 5		
15		120 ± 4.5 / 6								

[a]Stopping distance, in feet, from 40 mph, mean ± std dev, Number of runs in corner; tow car lockup permitted.

[b]3200 lb test weight

TABLE 5. COMBINATION VEHICLE STRAIGHT LINE STOPPING DISTANCE[a] FOR PLYMOUTH HORIZON[b]. NO LOAD LEVELING. NO AIR SHOCKS.

CONDITION / HITCH LOAD	UTILITY			CAMPER, 1600 LB		TRAVEL, 2400 LB			CAR ALONE
	(MAXIMUM TOW CAR BRAKING)			NO BRAKES		100% BRAKES		NO BRAKES	
	1000 LB	1500 LB	2600 LB	MAXIMUM TOW CAR	.6 g TOW CAR	MAXIMUM TOW CAR	.6 g TOW CAR	.6 g TOW CAR	
0%		R 115. ± 1.93							R 79.3 ± 2.45
10%	R 88.2 ± 2.09	F 96.3 ± 2.75	F 128. ± .76	F or R 97.8 ± 2.82	118. ± 1.47	F 79.4 ± 1.89	86.9 ± 3.19	137. ± 1.83	
15%		F 99.3 ± 1.18							

[a]Stopping distance, in feet, from 40 mph, mean ± standard deviation of six tests at maximum deceleration, tow car lockup noted, i.e., R = Rear Wheel Lockup Limited and F = Front Wheel Lockup Limited.

[b]2675 lb test weight

desired. However, for trailer towing, the rear lock limitation is beneficial since the increased rear tire load provided by the trailer hitch load can be turned into braking force. On the other hand, a vehicle nominally exhibiting front wheel lock-up will lose overall braking capability when trailer towing since increasing hitch load continually unloads the front axle, thus making lock-up even more premature.

In regard to CV braking performance, most tests were performed with a 10 percent hitch load, however one trailer was tested at hitch loads from 0 to 15 percent (in 5 percent increments) to evaluate the differences due to tow car lock-up. Various trailer weights and braking capability were also tested in order to provide a comparison with Fig. 1. Since the performance boundary of Fig. 1 was based on a 0.6 g tow car (per 105-75) it was desirable to test both tow cars at this level. The Citation was already close enough, however the Horizon required reduced brake force levels in order to simulate the 0.6 g tow car. Stopping distances increased accordingly. Figures 2 and 3 compare the stopping distance results with the predicted performance boundary. Using these figures we will discuss the performance of each type of trailer brake system.

A. UNBRAKED TRAILERS

As noted previously, the recommended tow car to trailer weight ratio of 2.1 shown in Figs. 2 and 3 for unbraked trailers may be criticized since it would impact on some current trailers, and the boundary has not been adequately validated. Indeed, test results indicate that the performance of front wheel drive CV's exceed the predictions, and in fact, are performing with near-optimum brake force proportioning. For example, it was shown in Vol. II (Fig. 3) that a 1500 lb unbraked trailer could, ideally be stopped in 134 ft (at 0.4 g) by a 0.6 g tow car if the tow car weight was greater than 2150 lbs, i.e., a tow car to trailer weight ratio of 1.5. This is very close to the performance achieved by the Citation plus unbraked trailer combinations in Fig. 2.

To more accurately determine the weight ratio necessary to achieve a 134 ft stopping distance from 40 mph, we can plot stopping distance versus trailer to tow car weight ratio. This form of presentation provides a nearly

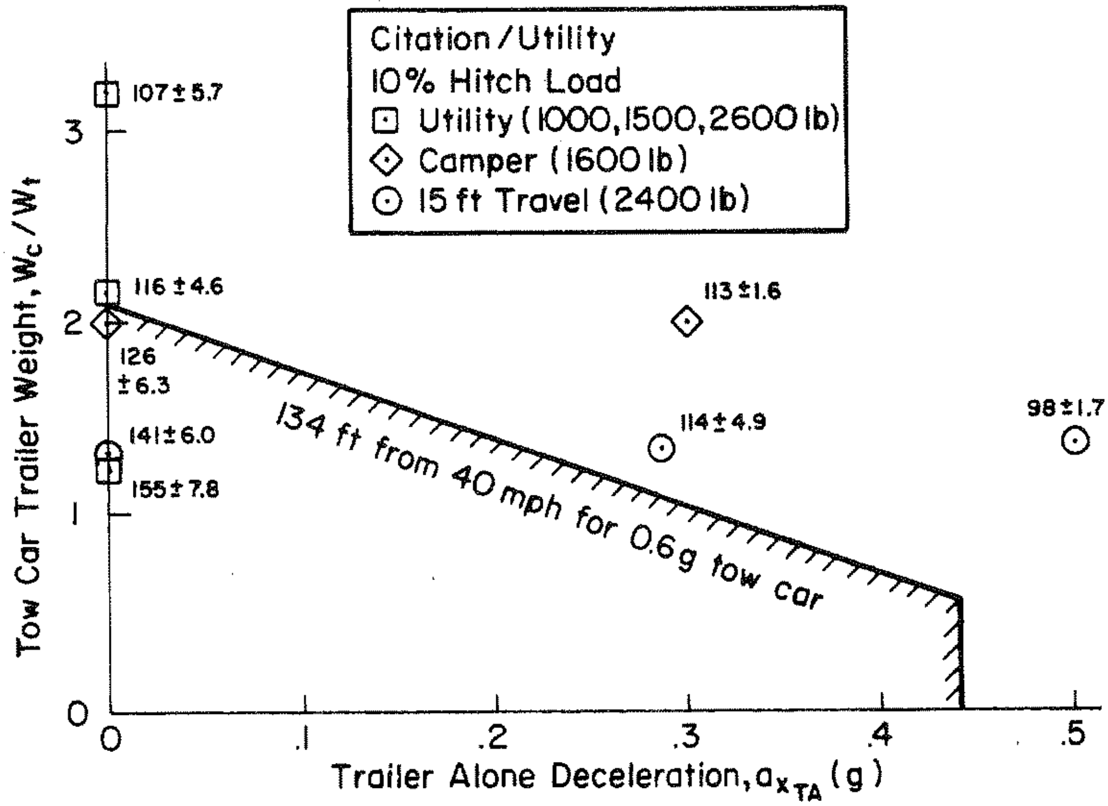


Figure 2. Comparison of Citation CV Straight Line Brake Performance with Proposed Criterion

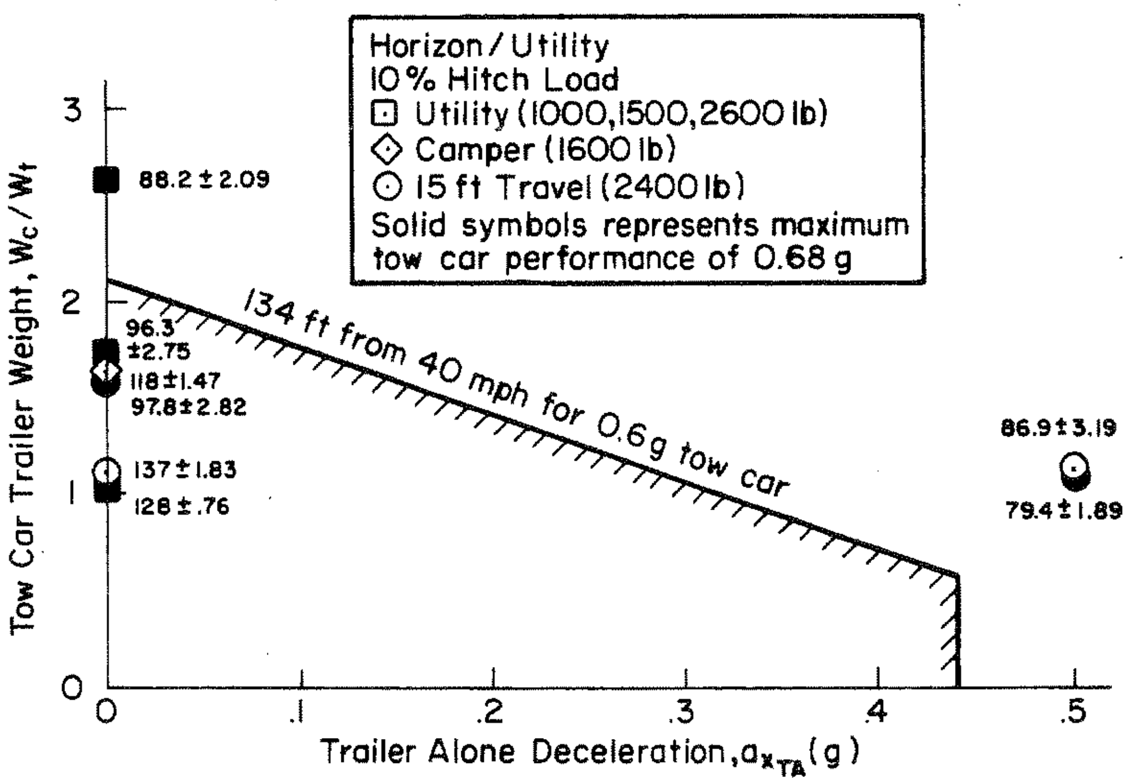


Figure 3. Comparison of Horizon CV Straight Line Brake Performance with Proposed Criterion

linear relationship such as shown by the dashed line in Fig. 4. The actual data very closely matches the optimum brake force curve and shows that the trailer should not weigh more than 67 percent of the tow car.

With higher car-alone performance, plus rear lock-up tendency, the Horizon with unbraked trailers provided even shorter stopping distances. This is shown in Fig. 5. Since all analysis and criterion must assume a tow car just meeting the FMVSS-105-75 requirement of 91 ft from 40 mph the open symbols shown in this figure represent that performance capability. These data points are also below (i.e., better than) the optimum brake force line because the rear lock-up tendency increases overall brake force as hitch load is increased. Only when hitch load exceeds 150 lbs does the front axle unload sufficiently to cause front wheel lock-up.

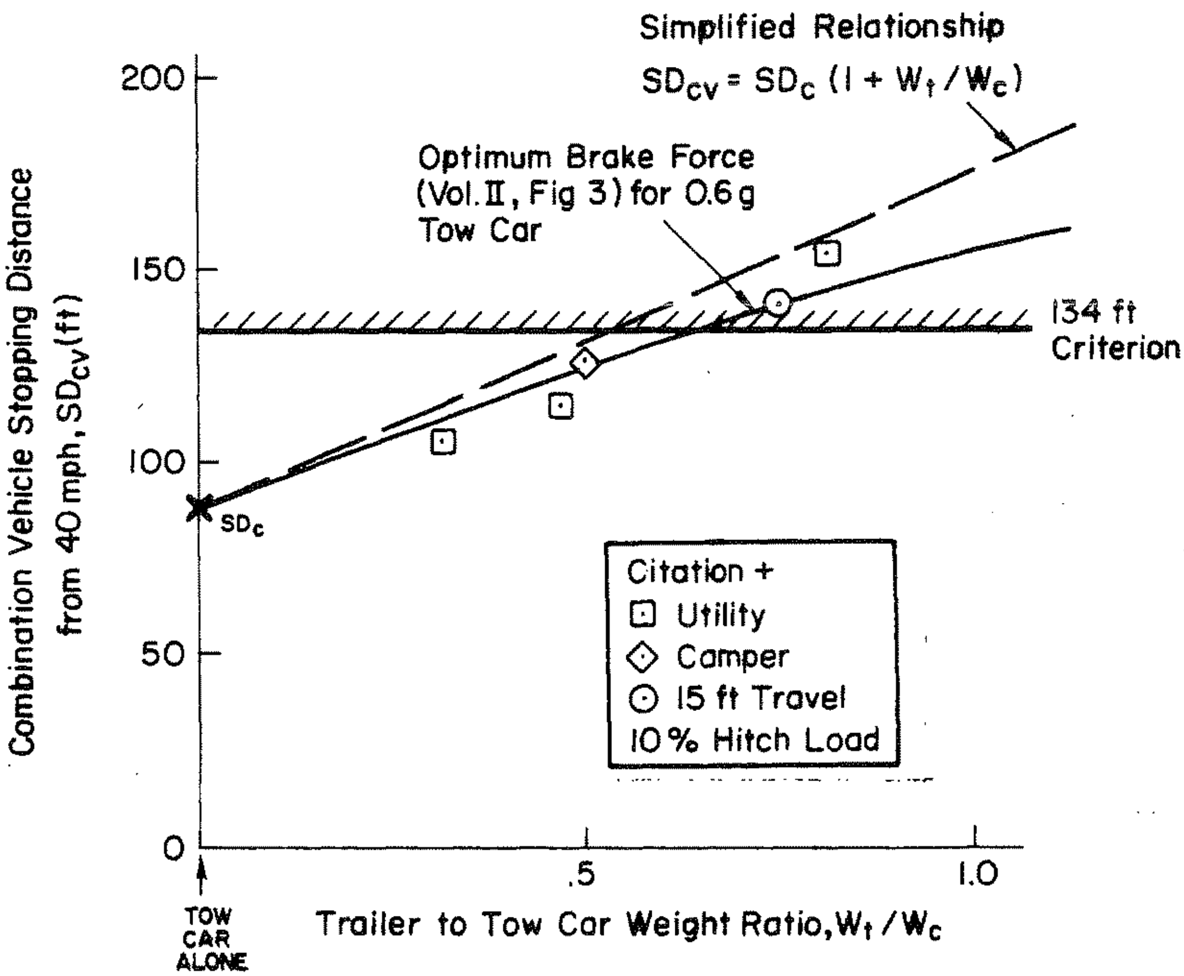


Figure 4. Unbraked Trailer Stopping Performance Versus Trailer to Tow Car Weight Ratio. Citation Tow Car.

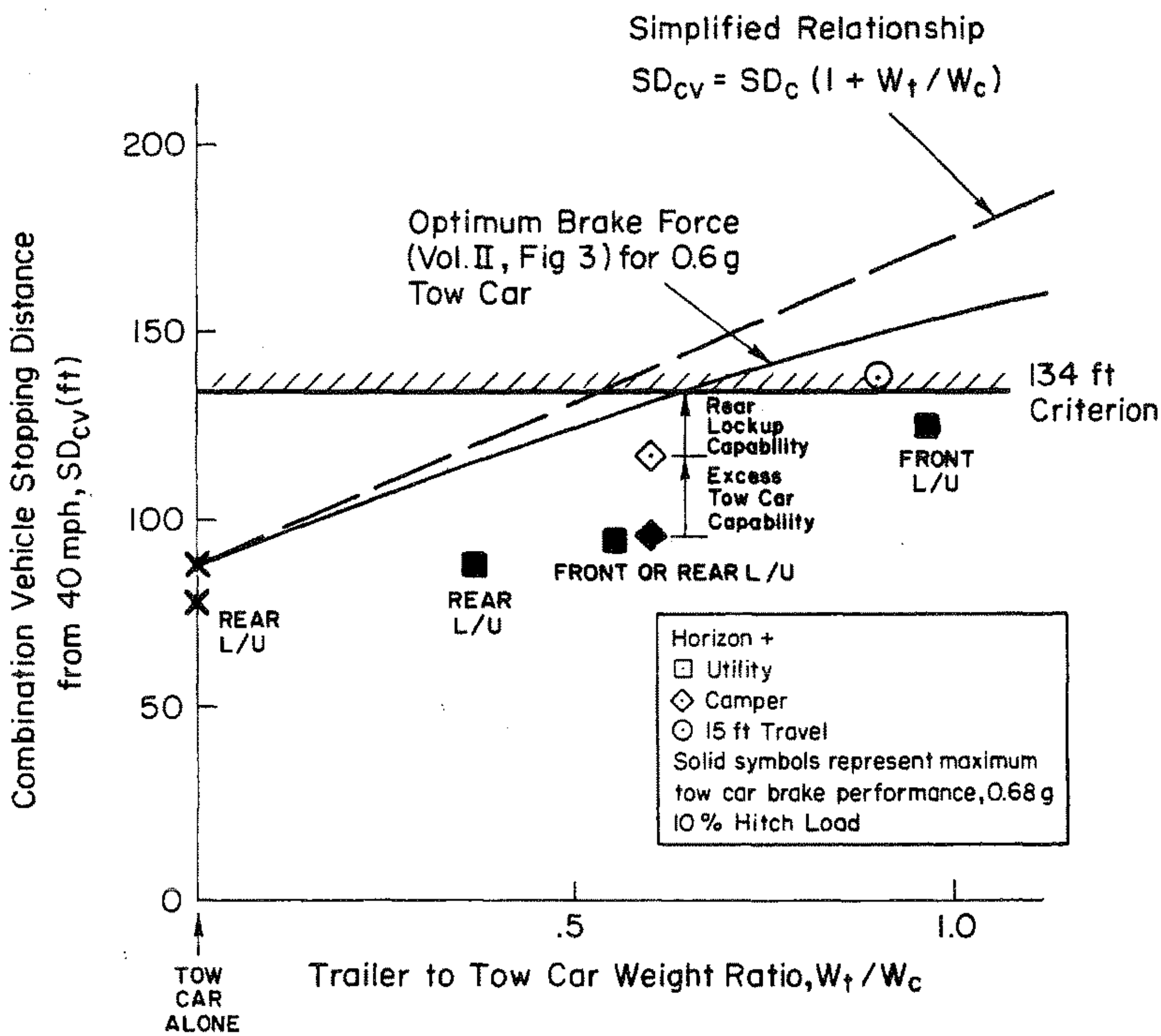


Figure 5. Unbraked Trailer Stopping Performance Versus Trailer to Tow Car Weight Ratio; Horizon Tow Car

The effects of hitch load (for both tow cars) are shown more directly in Fig. 6. The Citation follows the nominal (or anticipated) trend of increased stopping distance with increased hitch load. The Horizon exhibits the reverse trend at low hitch loads (due to increasing brake force capability at the rear) up to about 150 lbs at which point front lock-up occurs and further increases in hitch loads increase stopping distance.

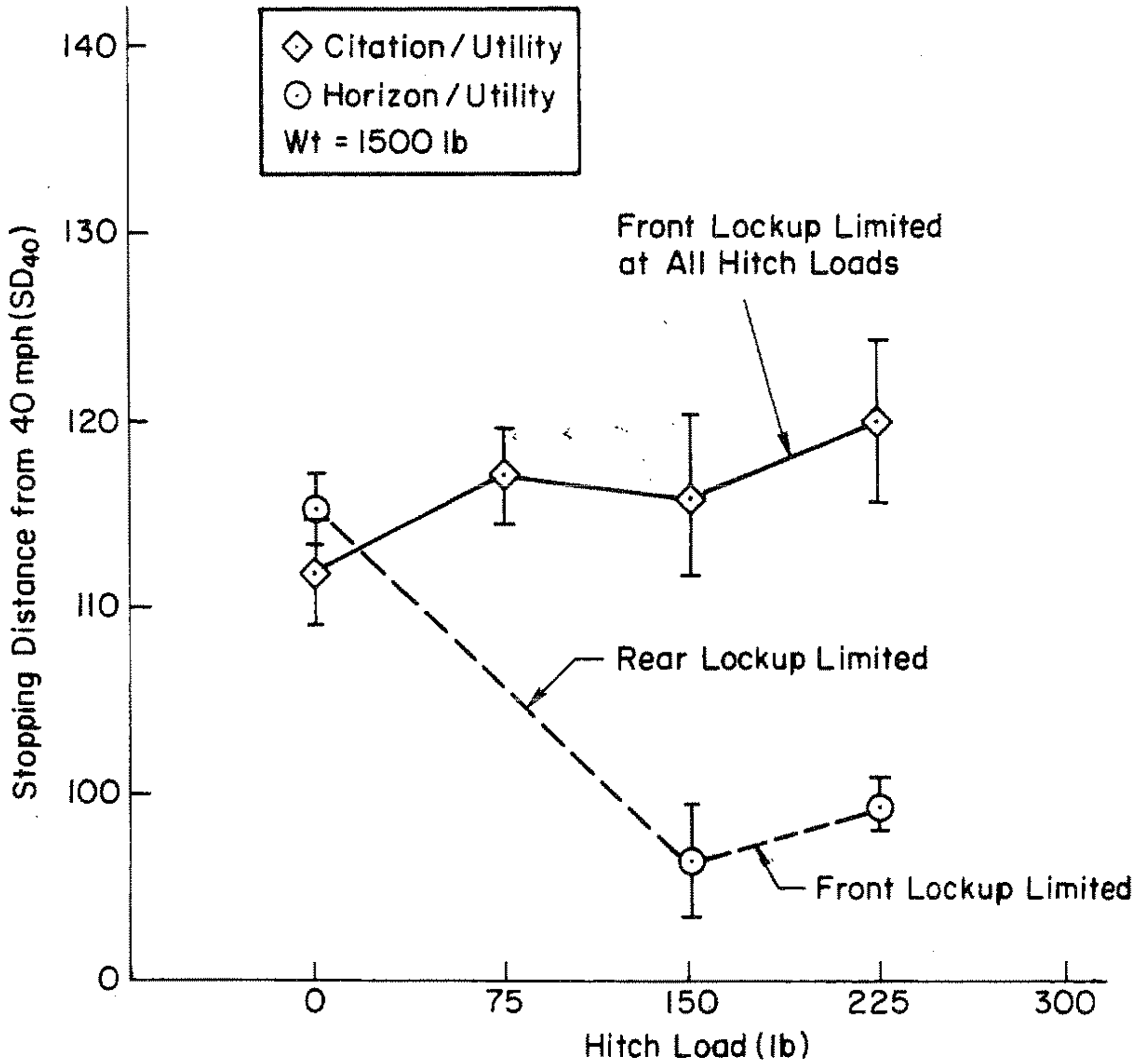


Figure 6. Effects of Hitch Load on Unbraked Trailer Stopping Distance

B. SURGE BRAKE TRAILER

Surge brakes on the camper trailer improved stopping distance from 126 ft to 113 ft. This is not as much as possible since the trailer alone brake capability was only 0.3 g. This value is based on the surge brake gain, G, the desired combination vehicle deceleration, $a_{x_{CV}}$, and the hitch load. Specifically, from Vol. II, pg. 32.

$$a_{x_{ta}} = \frac{a_{x_{CV}}[G/(1 + G)]}{1 - \frac{\%HL}{100}}$$

For this trailer the surge brake gain was determined to be 2.1 (see Appendix A) the hitch load was 10 percent, and desired deceleration criterion was 0.4 g. Inserting these figures yields a trailer alone deceleration capability of 0.296 g.

It was also shown in Vol. II that with surge brakes a surge trailer should stop in a distance equal to an unbraked trailer of weight:

$$W_{\text{No Brakes}} = \frac{W_{\text{With Surge}}}{G + 1}$$

or 516 lbs when G = 2.1. Referring back to Fig. 4, the surge brakes should, ideally, produce CV stopping distance of 100 ft, or 26 ft better than the no brake case. Since the actual improvement was only half this value the surge mechanism was not functioning as well as possible; probably due to onset delays (usually 0.3 sec) and sliding friction (see hystersis plot in Appendix A).

C. ELECTRIC BRAKES

Two configurations of electric brakes were tested; maximum and 58 percent. This latter represents a 0.29 g trailer alone capability and was set using the trailer alone calibration curve presented in Appendix A. The full trailer brakes provided 0.5 g capability at full GVWR (3000 lbs). As anticipated this maximum trailer alone level provided a CV capability well above the proposed 0.4 g requirement (refer to Figs. 2 and 3). At the reduced brake force level the CV was still able to exceed 0.4 g.

These results are consistent with the recommendations of Vol. II that no more than 1500 lbs should be supported by each 10 in. brake. At 1200 lbs per brake, the test trailer was well below the maximum recommended.

A summary of the straight line braking results, and implications for modifying the tow car to trailer weight recommendations are presented in Section VII.

The primary problem that will occur in meeting the straight line brake and brake in turn requirements is specifying the tow car weight necessary for unbraked trailers. This occurs because some states allow unbraked trailers up to 3000 lb. For example, it was recommended in Phase I, for rear wheel drive tow cars, that the tow car be a minimum of 2.1 times the trailer weight. In this phase we have determined that for front wheel drive cars this multiplier can be reduced to 1.5. This value definitely represents a lower bound, since it represents optimum brake force at both front and rear. If we hope to meet (or exceed) a 0.4 g CV deceleration requirement with all tow vehicles, the 2.1 value represents a more conservative recommendation. However, even assuming the more optimistic value of 1.5, the 3000 lb unbraked trailers would have to be towed by at least a compact sized vehicle (GVWR $\geq$ 4500 lb). If such a restriction is not possible, the overall stopping distance requirement will have to be relaxed. This would, however, be inconsistent with the stopping capability of braked trailer combinations.

For braked trailers the recommended tow car to weight ratio selected above can be reduced by a factor of 3.5 times the "trailer-alone" braking capability (in g units), i.e.,

$$\frac{W_c}{W_t} \geq 1.5 - 3.5\, a_{x_{ta}}$$

Current contemporary trailer manufacturers are providing 0.43 g capability, and test results from both phases showed 5 out of 7 trailers (with brakes) exceeding this value. Only when the trailer weight exceeded 1500 lb per each 2" × 20" brake did a trailer not meet 0.43 g. Assuming this trailer design criterion there would be no restriction on minimum tow car weight.

SECTION IV

TRAILER DAMPING PERFORMANCE

It was previously shown by test data in Vol. II that several key factors influence the trailer swing damping. In terms of providing an improvement in damping these were as follows:

- Increase tow car to trailer weight ratio (i.e., larger car or smaller trailer).
- Increase hitch load.
- Decrease moment of inertia about c.g. (i.e., reduce barbell effect).
- Reduce speed.

In addition it was shown, analytically, that increasing trailer effective tongue length, ℓ_2, and increasing trailer tire cornering stiffness, $Y\alpha_3$, were also beneficial. Test data provided in this second test phase show that front wheel drive vehicles support the previous conclusions.

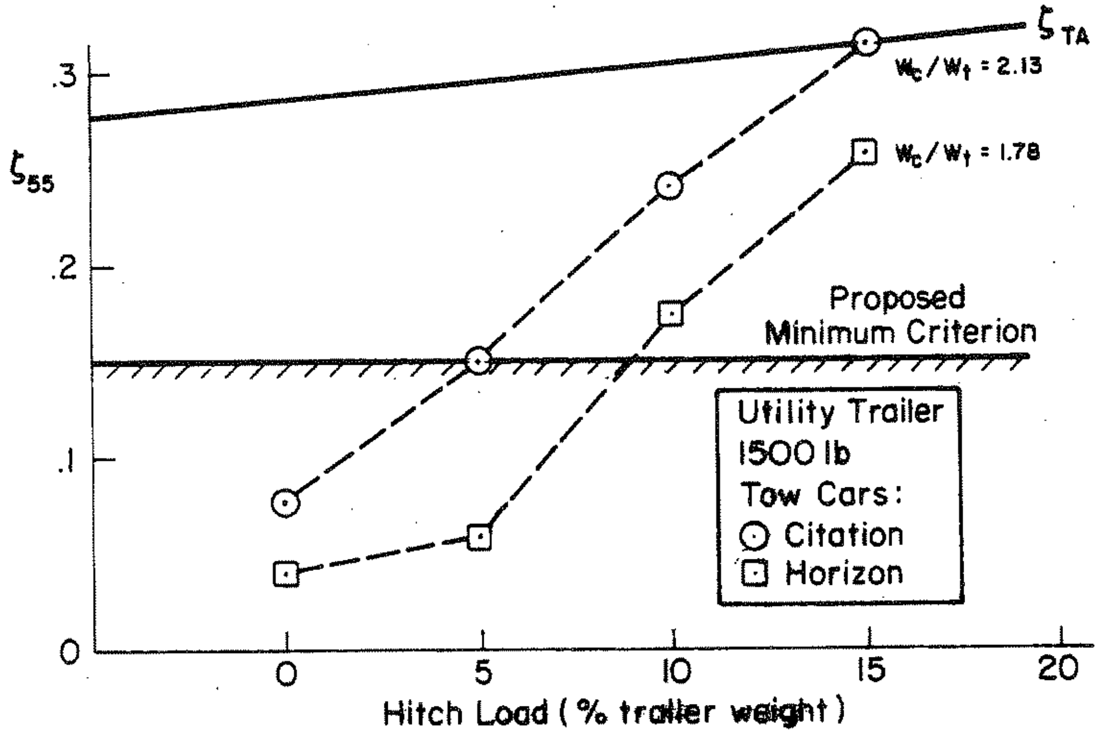
Twenty-eight combination-vehicle configurations were tested with the two front wheel drive tow cars and three trailers. Hitch loads were the primary variable, although trailer weight was varied with the utility trailer, and speed was varied for most configurations. Load leveling (via a weight distributing hitch) or sway dampers were not used. The average trailer damping ratio for each of these configurations is presented in Table 6. These data were derived from four individual test runs (see Appendix D) using a time series least squares fit to a pure second order system response.

The trends in trailer damping (at 55 mph) as a function of hitch load are graphically presented in Figs. 7a, b, and c for the three trailers. As expected, increased hitch load is the primary factor in improving trailer damping. In addition, it can be seen that for a given hitch load, the heavier tow car provides higher trailer damping.

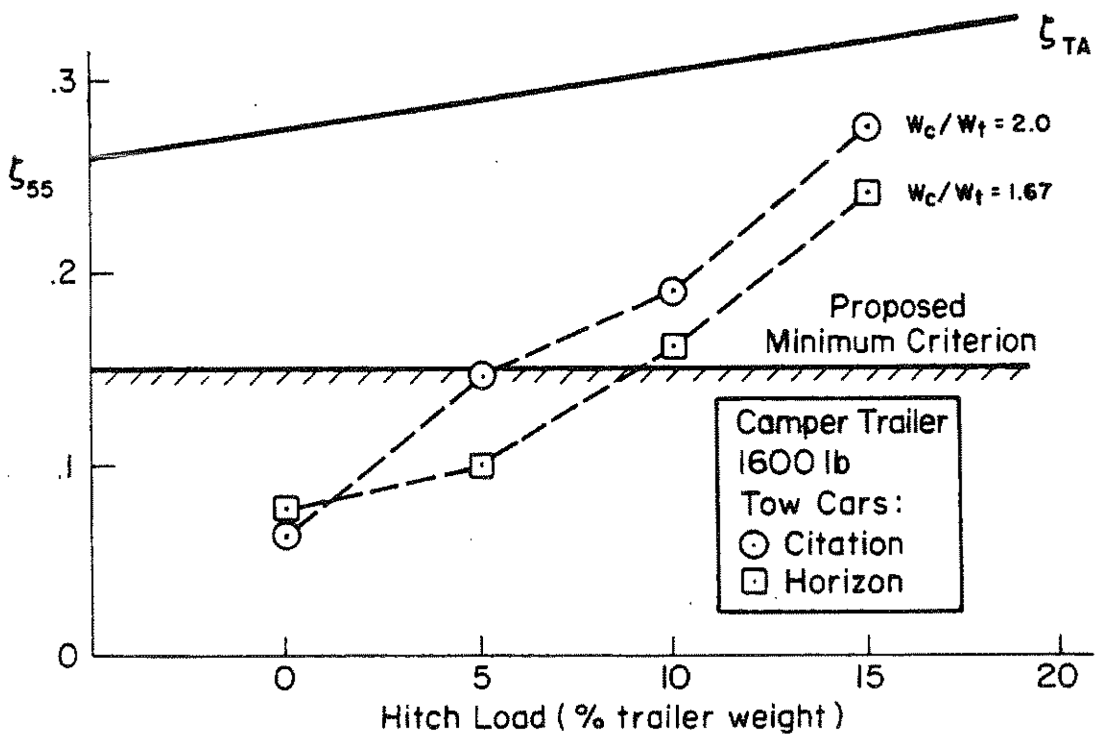
Also shown on Figs. 7a, b, and c are lines representing the maximum and minimum damping ratios. The former represents the analytical

TABLE 6. TRAILER DAMPING RATIO DERIVED FROM PULSE STEER TESTS

TRAILER	TRAILER WEIGHT	TOW CAR/ TRAILER WEIGHT RATIO	HITCH LOAD/SPEED											
			0			5			10			15		
			35	45	55	35	45	55	35	45	55	35	45	55
Utility	1000	3.20							.370	.343	.327			
		2.68			.095				.256	.181	.165			
	1500	2.13	.154	.116	.076	.361	.255	.148	.320	.274	.240	.407	.424	.317
		1.78	.166	.088	.039	.183	.104	.055	.320	.224	.173	.448	.308	.254
	2600	1.23							.344	.244	.183			
		1.03						.052	.225	.153	.101			
Camper	1600	2.0	.231	.114	.062	.236	.183	.143	.321	.248	.190	.511	.335	.274
		1.67	.234	.142	.076	.198	.157	.100	.322	.228	.161	.416	.288	.242
16 Ft Travel	2400	1.33				.196	.165	.098	.276	.193	.138	.318	.234	.217
		1.12				.231	.145	.067	.280	.212	.128	.331	.243	.194

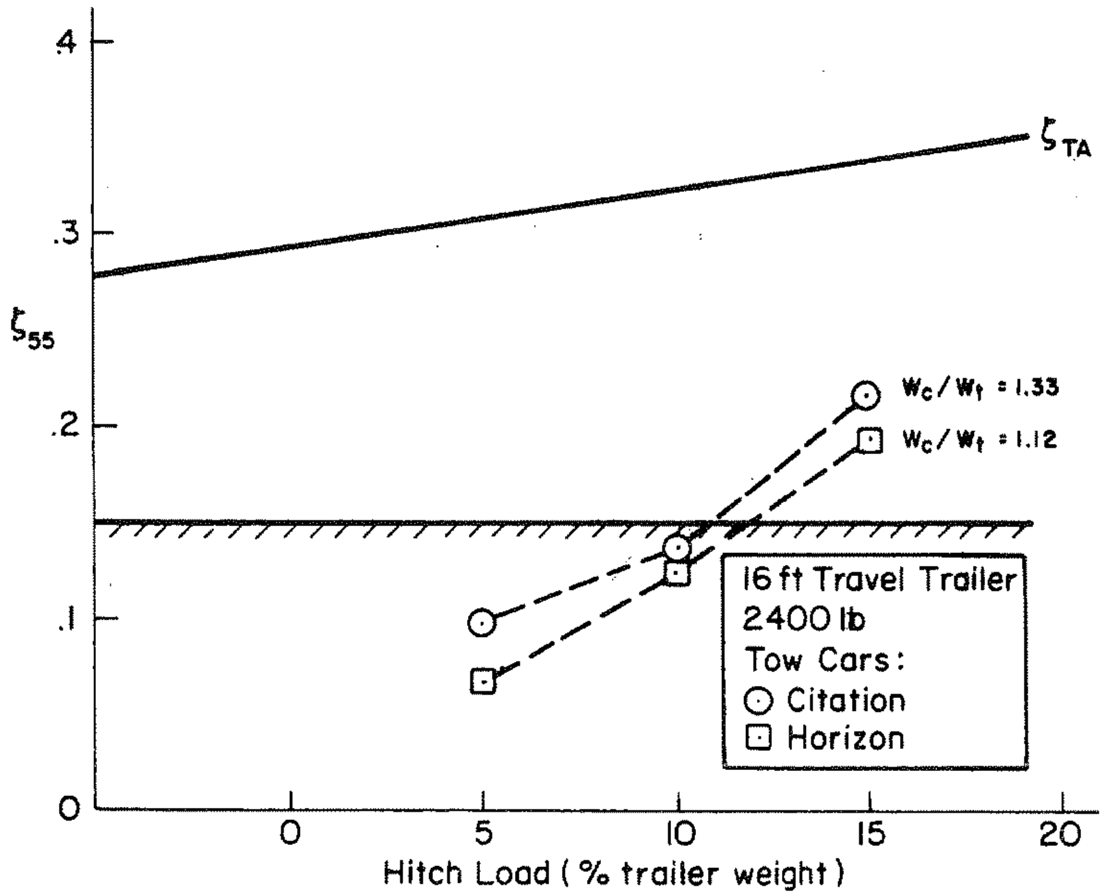


a) Utility Trailer



b) Camper Trailer

Figure 7. Trailer Damping of Combination-Vehicle at 55 mph as Function of Hitch Load



c) Travel Trailer

Figure 7. (Concluded)

"trailer-alone" damping ratio. This corresponds to the maximum damping that each trailer could achieve, if, for example, it were pulled by a tow car of infinite mass, or if there was no lateral movement of the hitch point. In effect, it is a locus of hitch loads for a given trailer that locates the center of percussion (for forces applied at the trailer tires) at the hitch point. The latter line, drawn across at $\zeta = 0.15$, represents the proposed damping criterion. Where this line intersects a line connecting the data points represents the minimum allowable hitch load for that particular tow car to trailer weight ratio. Other tow car to trailer weight ratios can be derived by extrapolating the damping ratio points at other hitch loads. This has been accomplished and presented in Fig. 8 for each trailer, respectively. A comparison to analytical predictions can now be made.

Since two of the three test trailers used in this phase were also tested in Phase I with rear wheel drive tow cars, the Vol. II results have been overplotted on Figs. 8a and 8b. For example, in Fig. 8a, this comparison shows the FWD tow cars to be less prone to trailer swing than their RWD counterparts. In other words, the FWD tow car would allow a lighter hitch load than that necessary on an equivalent weight RWD tow car.

The analytically derived boundary lines are also shown on Fig. 8a and 8b. These lines were computed from the following equation previously presented in Vol. II:

$$\zeta_{cv} = \underbrace{\frac{\sqrt{\ell_2^3 Y_{\alpha 3}}}{U_o\sqrt{2I_{t_h}}}}_{\substack{\text{Trailer Alone}\\ \text{Damping Ratio,}\\ \zeta_{TA}}} - \underbrace{\left\{\frac{I_{t_o} - \frac{W_t \ell_2^2}{g}\left[\frac{HL}{100} - \left(\frac{HL}{100}\right)^2\right]}{I_{t_h}}\right\}}_{\text{Hookup Factor}} \underbrace{C_1 \frac{W_t}{W_c}}_{\substack{\text{Tow Car}\\ \text{Sensitivity}}}$$

For the previous work an "average" tow car sensitivity constant of 3.7 was used. This value resulted in the predicted damping either matching or paralleling the full scale data. For the front wheel drive tow cars it appears that a lower value of C_1 (less tow car sensitivity) is more

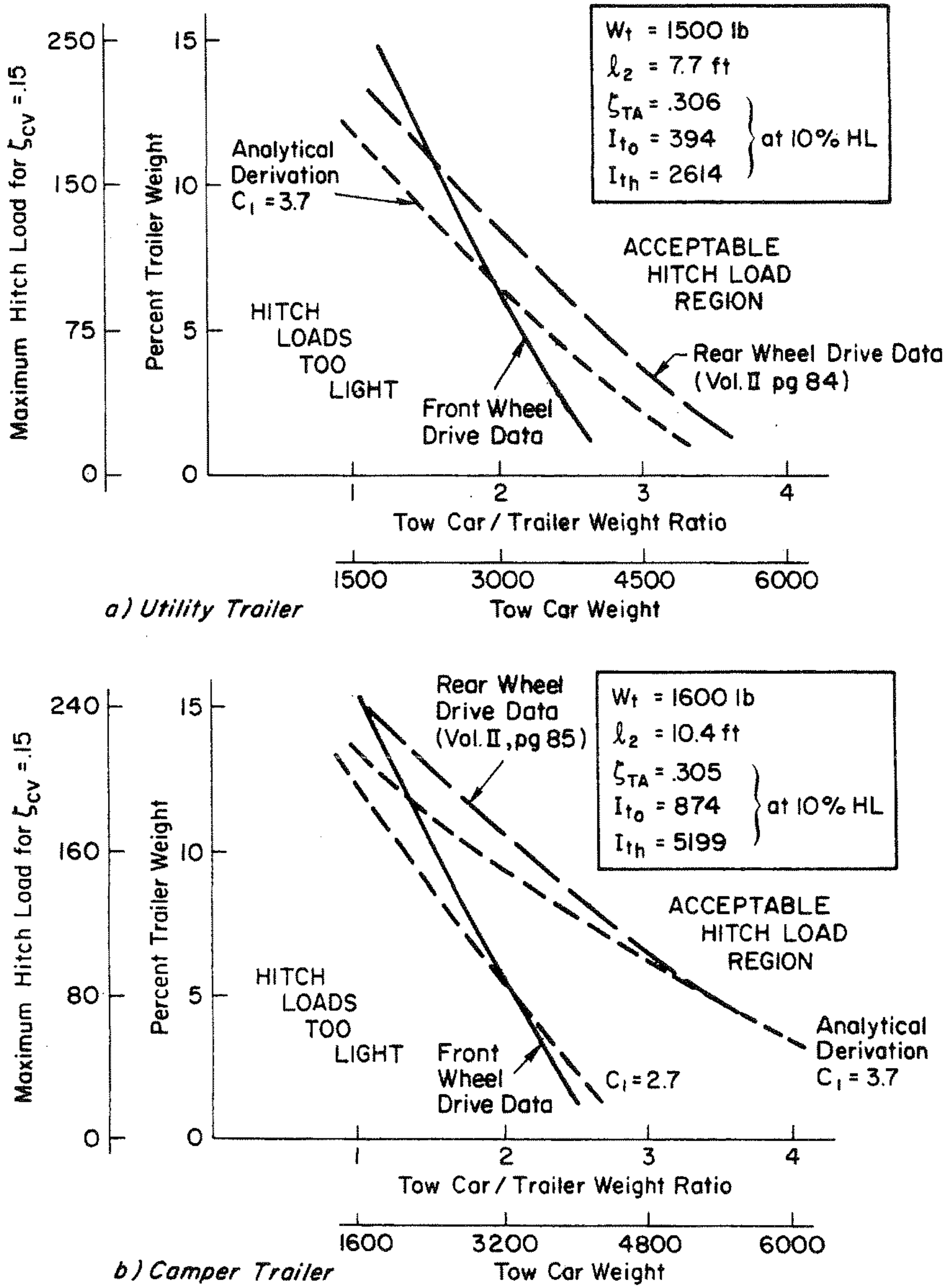
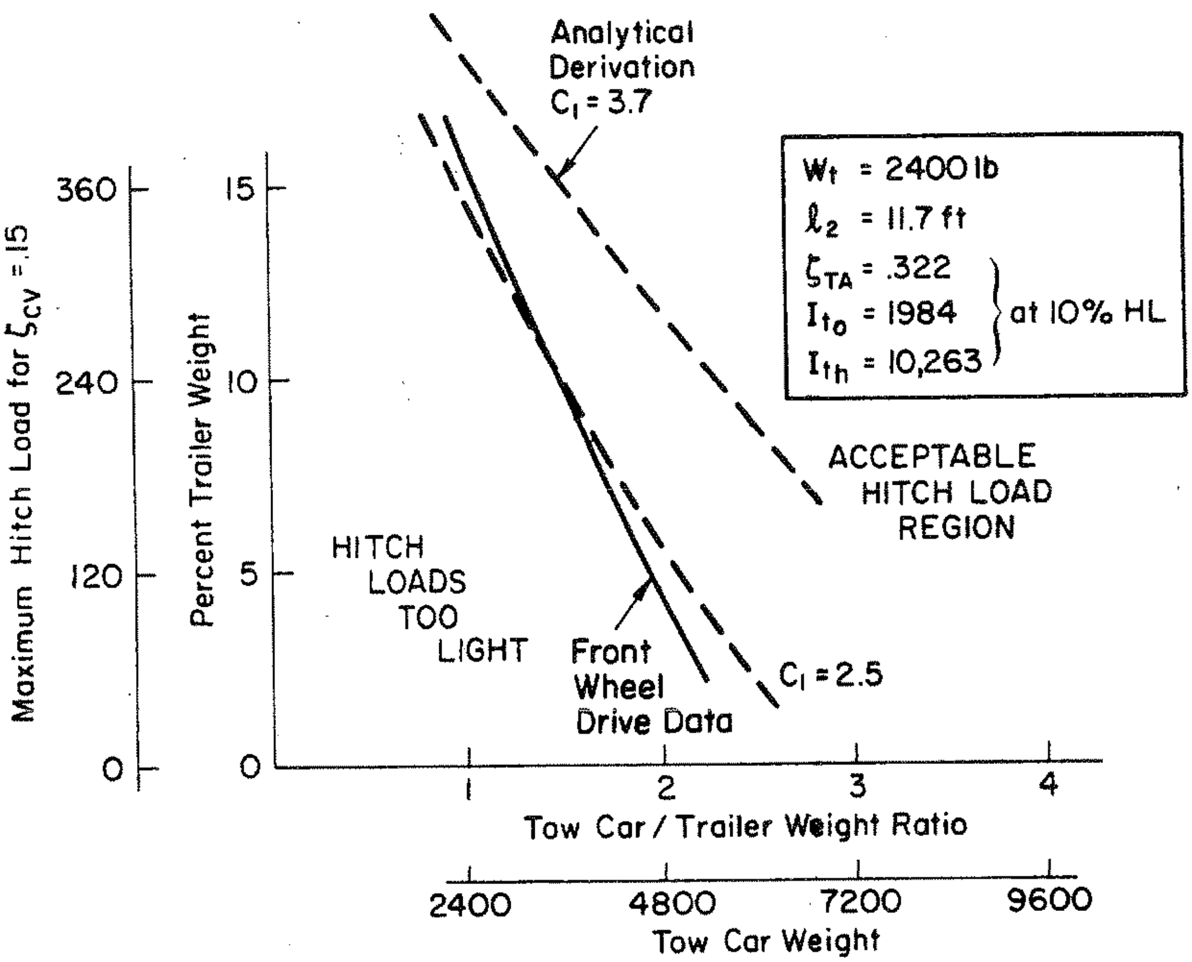


Figure 8. Minimum Hitch Load Boundary Necessary for Trailer Damping of 0.15 at 55 mph



c) 16 ft Travel Trailer

Figure 8. (Concluded)

appropriate. Analytically derived curves using these lower values of C_1 are shown in Figs. 8b and 8c to illustrate the comparison with full scale data.

In the previous figures the trailer weight has been constant and the beneficial effects of increased tow car weight illustrated. The same trends hold true if, for a given tow car, the trailer weight is decreased. Verification of this trend is shown in Fig. 9 for the variable weight utility trailer. These results are as anticipated since a lighter trailer reduces the hookup factor and tow car sensitivity terms in the equation for combination vehicle damping ratio.

The effects of speed on trailer damping is the last discussion item. Speed adjustment curves such as derived in Vol. II, Appendix E are valuable for use in adjusting data points taken at off-nominal speeds, in predicting the maximum safe speed (for $\zeta_{CV} = .15$), or the speed for trailer instability, i.e., $\zeta_{CV} = 0$. Since the previous curves were based on computer simulation and verified by only a few full scale tests it was desired, in this test phase, to check and refine the curves.

The data from Table 6 for 35, 45, and 55 mph (for each trailer at 10 percent hitch load) have been plotted in Fig. 10 for the two tow cars. Also shown on Fig. 10 are the speed adjustment curves used in Vol. II. The new curves are slightly shallower (less speed sensitivity) but do follow the shape of the previous curves. Using these new curves (or the ones sketched parallel) it is possible to estimate the speed at which a given trailer will cross the (proposed) minimum stability boundary and/or the unstable boundary. For example, Table 7 predicts these speeds for each CV configurations. Speed limitations such as suggested by Table 7 are another approach to a trailer safety standard, however, from an enforcement standpoint it would be more desirable to limit the hitch load so that the minimum safe speed is always equal to or greater than 55 mph.

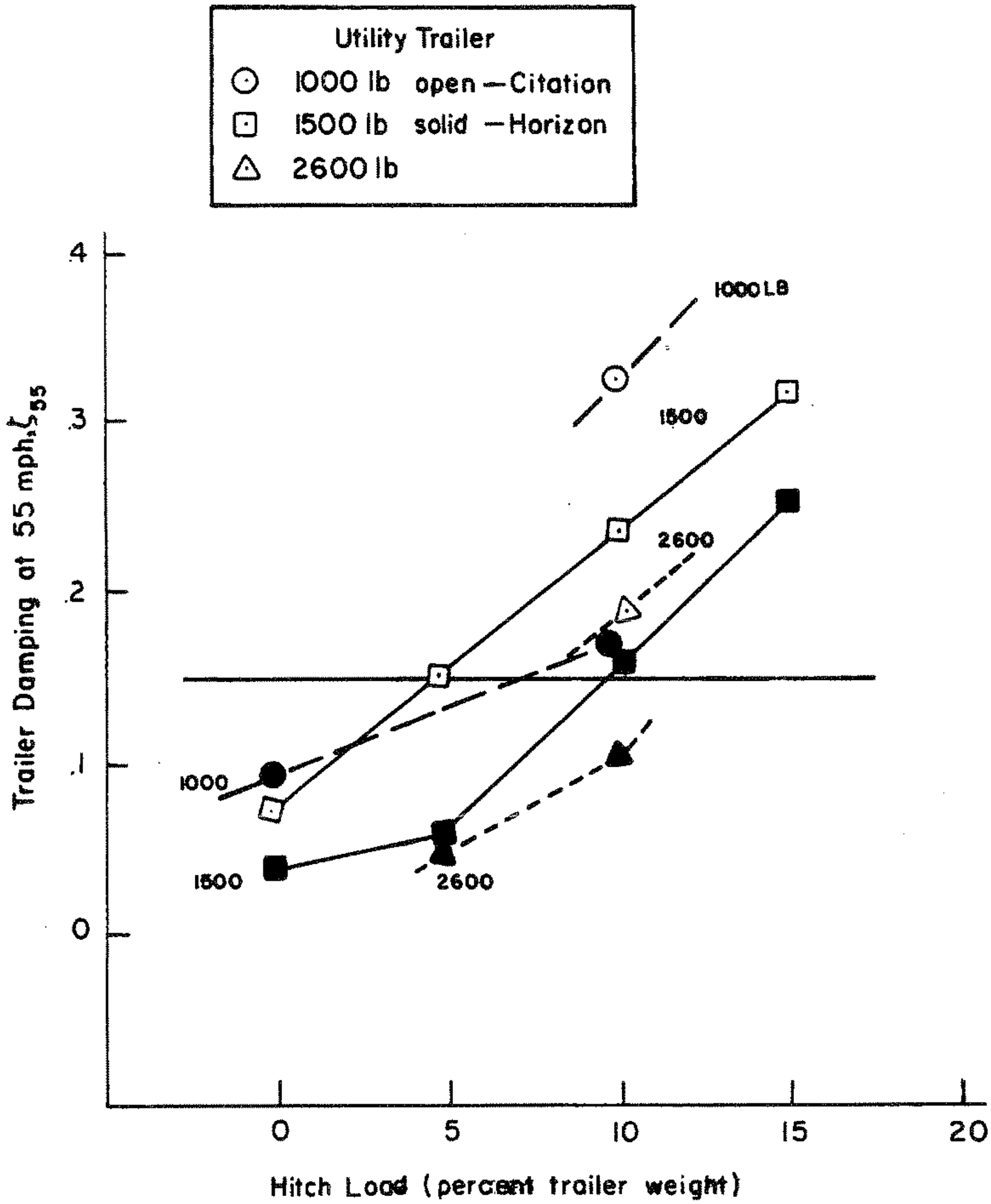


Figure 9. Damping of Utility Trailer at Various Trailer Weights and Hitch Loads

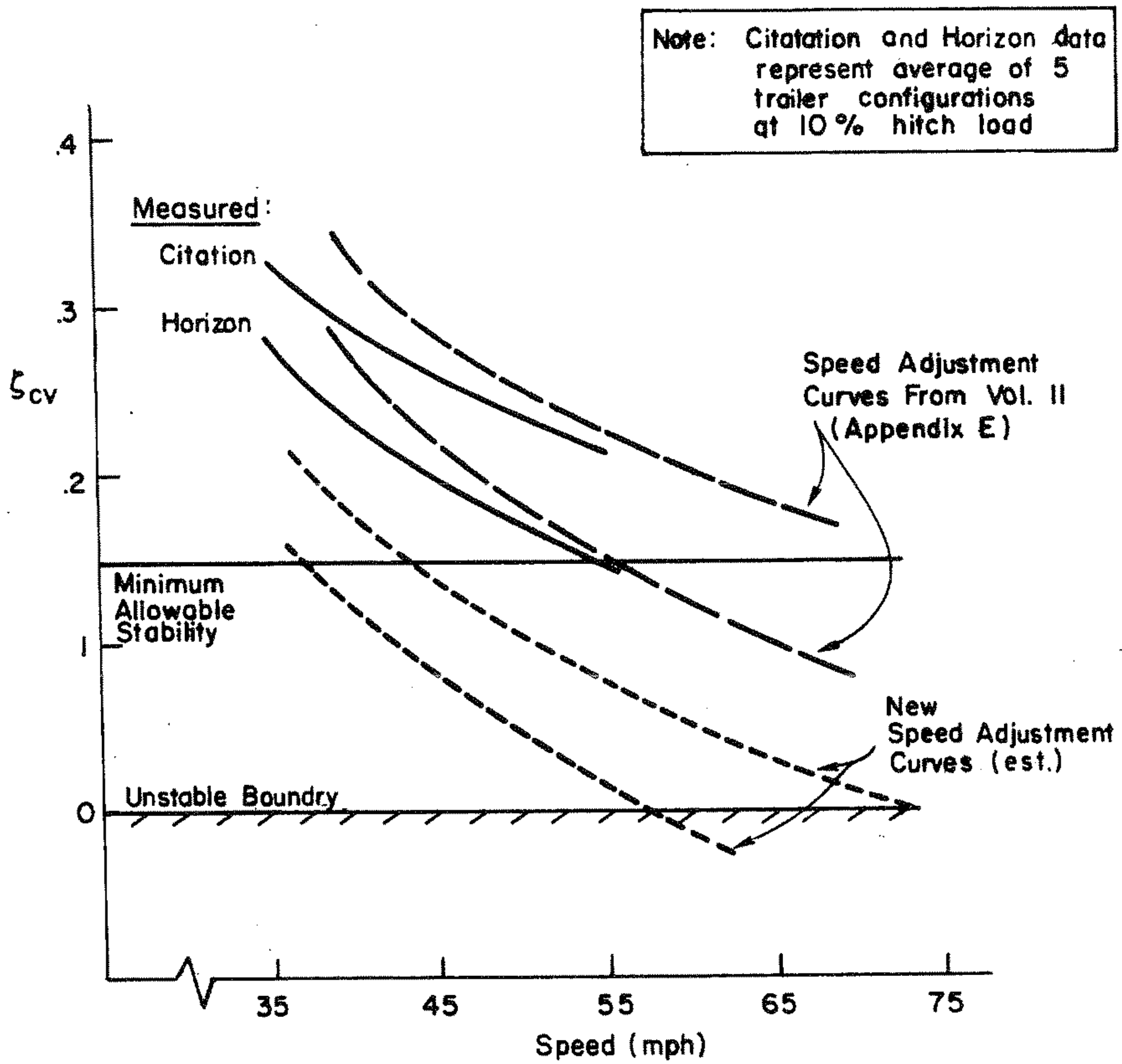


Figure 10. Speed Adjustment Curves Derived from Full Scale Tests

TABLE 7. ESTIMATED MAXIMUM SAFE SPEED AND UNSTABLE SPEED FOR EACH C-V CONFIGURATION

TOW CAR	TRAILER	HITCH LOAD	SPEED FOR ζ = .15	UNSTABLE SPEED (MPH)
Citation	Utility 1000	10	> 80	> 80
	1500	10	70	> 80
		5	54	> 80
		0	43	73
	2600	10	57	> 80
	Camper 1600	10	68	> 80
		5	54	> 80
		0	42	69
	Travel 2400	15	73	> 80
		10	53	> 80
		5	47	79
Horizon	Utility 1000	10	58	> 80
		0	46	78
	1500	10	62	> 80
		5	41	67
		0	39	63
	2600	10	47	79
		5	40	66
	Camper 1600	10	57	> 80
		5	47	79
		0	43	73
	Travel 2400	15	68	> 80
		10	51	> 80
		5	42	70

Note: Assumes low g cornering; speeds will be significantly lower if lateral acceleration exceeds 0.3 g or if trailer swing exceeds 10 deg.

SECTION V

TOW CAR STEADY-STATE TURN STABILITY

In Vol. II it was shown, both analytically and with test results, that adding hitch load reduced the tow car understeer. This reduction is amplified at higher lateral acceleration levels, and when load leveling is added. The performance measures used for evaluating these effects were understeer gradient at low lateral acceleration, K_o, the lateral acceleration at which understeer gradient becomes zero, $a_{y_{K=O}}$, and the lateral acceleration for incipient jackknife, $a_{y_{JK}}$. The tentative, or proposed handling requirement was that the tow car maintain positive understeer gradient up to and including 0.3 g lateral acceleration and that it not jackknife at 0.5 g. It was determined that by limiting the maximum hitch load this requirement could be met or exceeded. Consequently the proposed maximum hitch load versus tow car to trailer weight ratio boundary shown in Fig. 11 was derived. It was the objective of the tests described in this phase to check these boundaries for front wheel drive vehicles.

Fourteen different combination vehicle configurations, plus tow car alone, were tested for understeer gradient using the constant radius circle test procedure. Basically this was done at various hitch loads without load leveling, however one configuration, designed for demonstration only, included load leveling of sufficient magnitude to raise the rear axle of the Citation off the ground. This was done to illustrate how unsafe such a condition would be. Results of these tests are given in Table 8. Individual steer vs. lateral acceleration plots are given in Appendix E. The key conclusions can be summarized as follows:

- All configurations (without load leveling) exhibited positive understeer up to and including 0.45 g.
- All configurations exhibited a decrease in understeer with increasing hitch load.
- Load leveling such as to totally unload the rear axle produced a combination so oversteering that jackknife occurred at 0.1 g cornering!

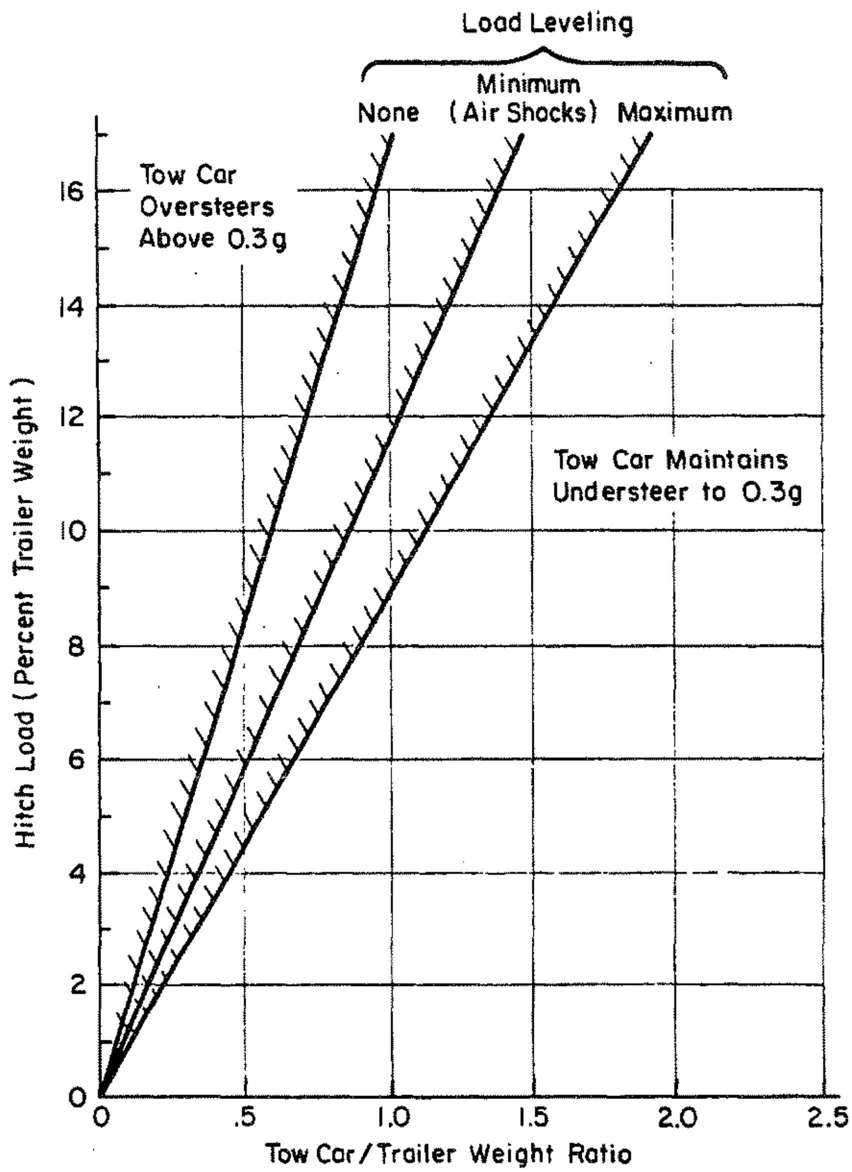


Figure 11. Proposed Maximum Allowable Hitch Load Boundary to Provide Understeering Tow Car up to 0.3 g Cornering (from Vol. II, pg 112)

TABLE 8

TOW CAR UNDERSTEER — CONSTANT RADIUS CIRCLE TEST RESULTS

TOW CAR/ TRAILER	WEIGHT	HITCH LOAD	TOW CAR FRONT/REAR WEIGHT DISTRIBUTION	UNDERSTEER GRADIENT FOR $a_y \leq .45$ g (deg/g)	UNDER-STEER GRADIENT, $a_y \leq .3$ g (deg/g)	LATERAL ACCEL., NEUTRAL STEER $a_{y_{K=0}}$	REMARKS
Citation Alone	3200	0	62/38	5.51	5.19	All > .45	Before trailer testing
				5.80	4.84		After trailer testing
Utility	1500	5	60/40	4.18	3.21		Increasing understeer at 0.40 g
		10	57/43	4.11	2.87		Increasing understeer at 0.40 g
		15	55/45	4.25	2.79		Increasing understeer at 0.35 g
		20	52/48	3.43	2.43		
Camper	1600	10	57/43	5.60	4.04		
Travel	2400	10	54/46	3.79	3.48		Data only to 0.3 g
		0 (+5000 ft-lbs Load Leveling)	80/0 (EST)	−32.	−32.	0	Rear wheels off ground. Maximum speed on 200 ft circle 17 mph, or .1 g. Demonstration Only.
Horizon Alone	2675		58/42	5.16	4.64		Initial Test
				4.59			Test after utility and camper tests
Utility	1500	0	58/42	5.16	5.06		
		5	56/44	5.95	4.63		
		10	54/46	5.0	3.59		
		15	52/48	4.43	4.01		
		20	50/50	4.40	3.11		
Camper	1600	10	54/46	4.19	3.42		
Travel	2400	10	52/48	2.9			Constant speeds and coast down
				2.83			Continuous speed up
				2.86			Continuous coast down

The key results have been graphically presented in Fig. 12. It is obvious that, to the extent of the hitch loads that can be practically applied, there is no problem with oversteer or jackknife with the subcompact front-wheel drive cars.

There are two basic reasons for this positive result. First, since FWD cars normally come with 58 to 62 percent of the curb weight on the front axle, the addition of nominal hitch loads never results in more than 50 percent of the tow car weight on the rear axle. Recall from Vol. II that rear drive tow cars achieved an oversteer/jackknife response only when about 60 percent of the tow car weight was on the rear axle. For the two FWD tow cars, the worst case loading (300 lb hitch load) resulted in only 52/48 front to rear weight distribution for the Citation and a 50/50 distribution for the Horizon. The second reason for solid understeer with all configurations is that forward traction applied at the front tires. Knowing how the traction ellipse limits operate, it is easy to see how traction applied at the front wheels will increase understeer. In addition, the bigger the trailer drag load, the more traction is needed at the front wheels.

With regard to the proposed maximum hitch load boundary, Fig. 13 shows that all configurations fall in the allowable hitch load region. To intersect this boundary the Horizon would have to tow the 2400 lb travel trailer at an 18 percent hitch load (or 432 lbs) or load up the utility trailer to 2150 lbs and use a 20 percent hitch load (again a 430 lb hitch load). The Citation would require a 512 lb hitch load to intersect the boundary. Both are far beyond the manufacturer's recommendation and beyond what could practically be applied without scraping the rear bumper on the ground.

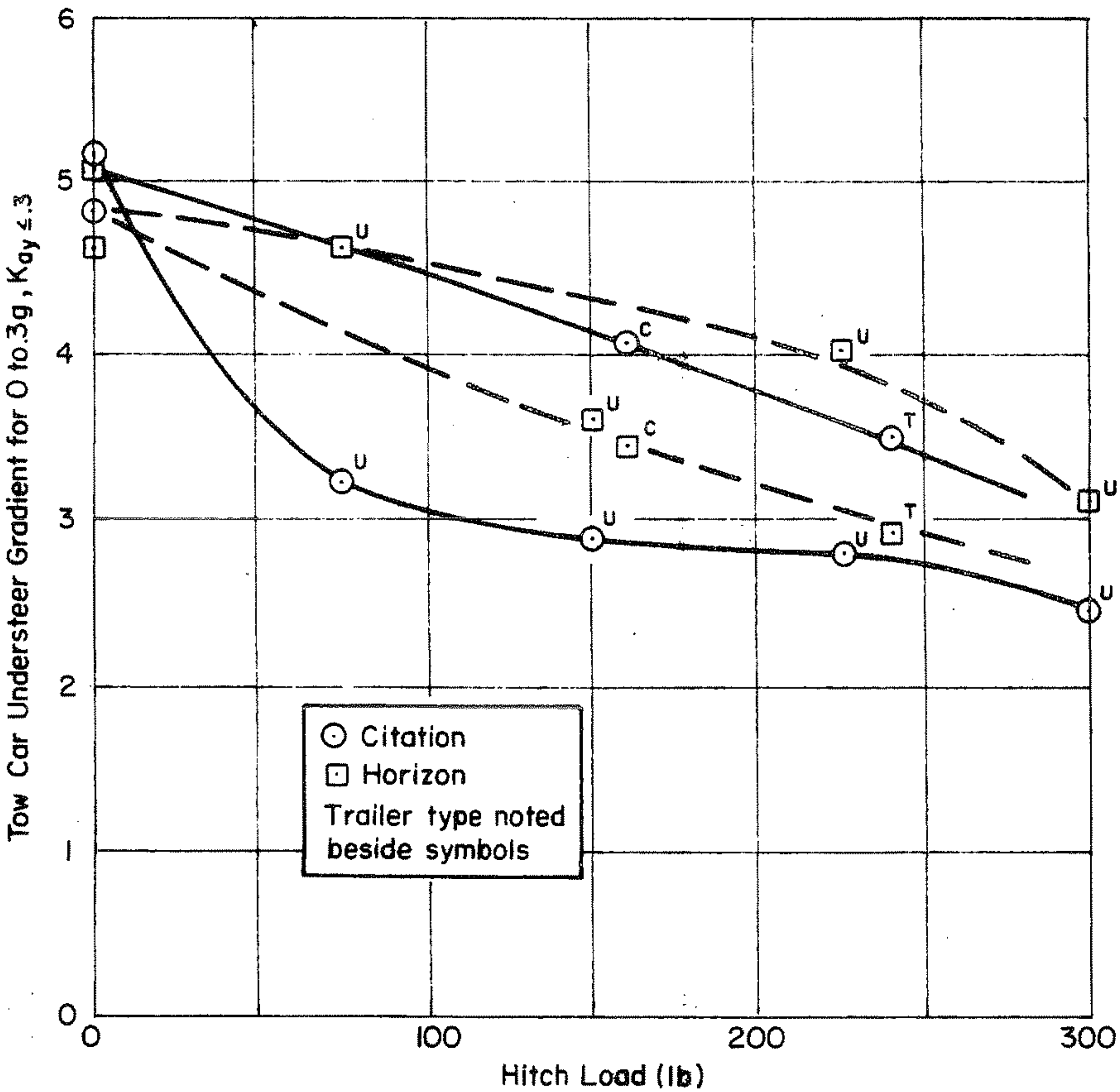


Figure 12. Variation in Tow Car Understeer Gradient with Hitch Load

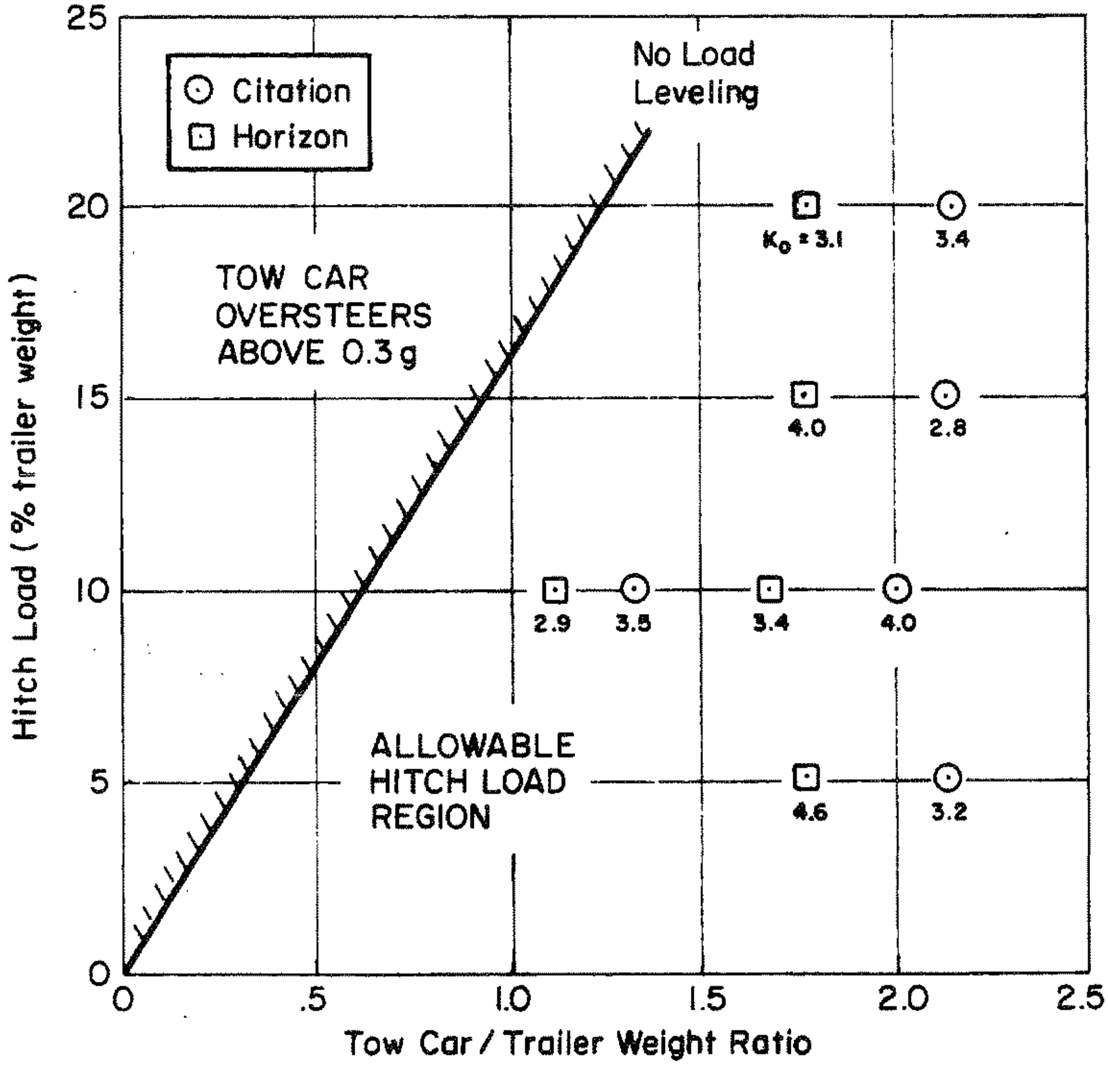


Figure 13. Comparison of Understeer Results with Proposed Maximum Hitch Load Boundary

SECTION VI

COMBINED BRAKING AND CORNERING

The final combination-vehicle test procedure was aimed at uncovering any tow car and/or trailer stability problems during a brake-in-turn maneuver. In Vol. II it was recommended that 0.4 g deceleration during 0.3 g cornering be demonstrated. It was further stated that if the tow car and trailer could meet the previous three requirements (of Sections III, IV, and V) it would be able to perform this brake-in-turn maneuver without transient oversteer tendencies (defined as a yaw rate/speed change of 0.3 deg/sec/mph) for more than one second. Testing in this second phase was to verify this proposed standard for front wheel drive tow cars.

All test runs are identified in Table 9 and 10 for the two tow cars. Results indicated on these tables include stopping distance from 40 mph, average maximum deceleration level, $a_{x_{max}}$, yaw rate per speed slope, $\Delta r/\Delta u$, time duration of yaw rate change, and effective turn radius (computed from peak $r/u \times 57.3$). Ideally the turn radius would remain constant at 355 ft, consequently any transient oversteer tendencies will appear as a tightening of the turn circle, i.e., a reduction in turn radius.

None of the test runs shown in Tables 8 or 9 showed any jackknife tendency or exceeded the transient oversteer requirement. In general, both tow vehicles exhibited front lockup during the maneuver. Locking this axle (or a wheel on this axle) minimizes any oversteer tendency. However, not all configurations were able to achieve a 0.4 g average deceleration. This occurred for the unbraked trailer combinations and is due to the reduction in tow car deceleration capability in going from straight ahead to a 0.3 g turn. For example, the Citation changed from 0.6 g straight ahead to 0.47 g in a turn and the Horizon changed from 0.68 g to 0.52 g. For the Citation plus utility trailer the deceleration changed from 0.46 g (116 ft) straight ahead to 0.37 in the turn. For the Horizon/Utility combination the reduction was from 0.56 g to only 0.44 g since the tow vehicle alone started with greater capacity. The travel trailer with no brakes also did not make 0.4 g however this could not be achieved even in the straight ahead test.

TABLE 9. BRAKE IN TURN RESULTS FOR CITATION

TOW CAR	TRAILER	WEIGHT	HITCH LOAD	dr/du (deg/ft)	Δt (sec)	RMIN (ft)	S_{40}	AVG $a_{x_{max}}$ (g)	RUN NO.	TURN DIR.	LOCK UP	PEDAL FORCE
Citation	None	3200	0		0	—	108		12	L	N	
					0.7	200	100		13	R	RF	
					Abort		—		14	L	N	
					Abort		—		15	Press	Too Low	
							116	.47 g	16	L	N	
				0		—	124		17	R	N	
				0		—	117		18	L	N	
				0		—	120		19	R	N	
				0	—	—	120		20	L	N	
	Utility (No Brakes)	1500	15%	0.8	0.5	204	134		41B	L	LF	30 lb
				0	—	—	159		42	R	N	
				0.5	0.5	253	145	.37 g	43	L	LF	
				0	—	—	143		44	R	N	
				0.34	0.9	201	138		45	L	N	
				0	—	—	144		46	R	N	
	Camper (No Brakes)	1600	15%	0	—	—	132		143	L	N	
				0	—	—	131		144	L	LF	
				0	—	—	147		145	L	BF	
				0	—	—	140		146	L	N	
				0	—	—	141		147	L	BF	43 lb
				0	—	—	125	.39 g	148	L	LF	
				0	—	—	130		149	L	LF	37 lb
				0	—	—	140		150	L	N	35 lb
				0	—	—	142		151	R	BF	30 lb
				0	—	—	143		152	L	N	
				0	—	—	150		153	R	N	
	Travel 100% Brakes	2400	10%	0	—	—	86.8		215	R	BT	35 lb
				0	—	—	106		216	R	BT	35 lb
				0	—	—	99.6	.57 g	217	L	BT	35 lb
				0	—	—	86.1		218	R	BT	35 lb
				0	—	—	96.9		219	L	BT	35 lb
				0	—	—	93.9		220	R	BT	35 lb

TABLE 10. BRAKE IN TURN RESULTS FOR HORIZON

TOW CAR	TRAILER	WEIGHT	HITCH LOAD	dr/du (deg/ft)	Δt (sec)	R_{MIN} (ft)	S_{40}	AVG $a_{x_{max}}$ (g)	RUN NO.	TURN DIR.	LOCK UP	PEDAL FORCE
Horizon	None	2675	0	1.0	0.4	185	87.1		12	L	LR	87 lb
				1.0	0.4	193	98.3		13	L	LR	75 lb
				0	—	—	114		14	L	N	62 lb
				0.7	0.4	238	112	.52 g	15	L	N	65 lb
				0	—	—	108		16	R	N	67 lb
				0	—	—	103		17	L	N	67 lb
				0	—	—	99.3		18	R	N	67 lb
				0.5	0.4	256	102		19	R	N	65 lb
	Utility (No Brakes)	1500	15%	0	—	—	129		47	L	LF	70 lb
				0	—	—	114		48	L	N	70 lb
				0	—	—	123		49	R	N	70 lb
				0	—	—	125	.44 g	50	R	N	70 lb
				0	—	—	117		51	L	N	70 lb
				0	—	—	118		52	R	N	70 lb
	Camper (No Brakes)	1600	15%	0	—	—	160		96	L	Press	Too Low
				0	—	—	122		97	L	N	85 lb
				0	—	—	120		98	R	N	83 lb
				0.13	0.5	278	119		99	L	BF	88 lb
				0	—	—	118	.44 g	100	R	N	83 lb
				0	—	—	116		101	L	N	83 lb
				0	—	—	123		102	R	N	88 lb
				0	—	—	122		103	L	N	85 lb
				0	—	—	124		104	R	N	85 lb
	Travel (No Brakes)	2400	10%	0	—	—	142		192	R	N	
				0	—	—	139		193	L	LF	95 lb
				0	—	—	151		194	R	BF, BR	93 lb
				0	—	—	144	.38 g	195	L	BF	93 lb
				0	—	—	150		196	R	BF	90 lb
				0	—	—	132		197	L	BF	90 lb
	100% Brake			0	—	—	100		198	R	BT	83 lb
				0	—	—	99	.54 g	199	L	N	85 lb

Based on these results it is not necessarily possible to demonstrate a 0.4 g deceleration during a 0.3 g turn (especially for unbraked trailers) even though the CV can pass the previous three handling and braking requirements. Rather than revising the straight line requirement upward it is recommended that the demonstration test be revised downward from "0.4 g" to a "maximum deceleration (with tow car lock-up) or 0.4 g; whichever occurs first."

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

This final phase in the development of handling and braking standards for passenger cars towing trailers has tested two front wheel drive subcompacts plus three nominal trailers in over 30 combination vehicle configurations. Results have verified and revised the previous results and recommendations, especially with regard to unbraked trailers. In fact, the front wheel drive vehicles make better tow cars than their rear wheel drive counterparts. This is due to their nominally high front weight bias which becomes more evenly distributed when a hitch load is added. This improves braking, tow car stability, and trailer swing.

This section reviews the suggested handling and braking criteria and means for insuring compliance presented in Vol. II and shows how conservative these boundaries will be for front wheel drive tow cars. In addition, an integrated handling standard is derived for the three trailers tested in this phase. Plots such as these can be derived by trailer manufacturers and are recommended for each trailer model as a means for implementing the proposed standards.

A. HANDLING AND BRAKING PERFORMANCE CRITERIA

The following performance criteria were previously recommended for passenger car/trailer combinations:

- All combination-vehicles shall be capable of stopping within 134 ft from 40 mph, i.e., average deceleration of 0.4 g.
- All trailers of a combination shall exhibit a minimum trailer swing damping ratio of 0.15 (i.e., 3/4 cycles to one-half amplitude) at 55 mph.
- All tow cars of a combination shall exhibit a positive understeer gradient up to and including 0.3 g cornering.
- All combination-vehicles shall demonstrate 0.4 g deceleration during 0.3 g cornering without incurring transient oversteer (increased yaw rate) for longer than 1 sec duration.

All these requirements can be met by proper selection of a trailer for a given tow car size (i.e., weight) and proper setting of hitch load.

B. MEANS FOR INSURING COMPLIANCE

The above requirements can be insured by specifying a tow car to trailer weight ratio as a function of trailer brake capacity (for braking tests) and of hitch load (for handling tests). Each is discussed below.

1. Braking

The primary problem that will occur in meeting the straight-line brake and brake in turn requirements is specifying the tow car weight necessary for unbraked trailers. This occurs because some states allow unbraked trailers up to 3000 lb. For example, it was recommended in Phase I, for rear wheel drive tow cars, that the tow car be a minimum of 2.1 times the trailer weight. In this phase we have determined that for front wheel drive cars this multiplier can be reduced to 1.5. This value definitely represents a lower bound since it represents optimum brake force at both front and rear. If we hope to meet (or exceed) a 0.4 g CV deceleration requirement with all tow vehicles, the 2.1 value represents a more conservative recommendation. However, even assuming the more optimistic value of 1.5, the 3000 lb unbraked trailers would have to be towed by at least a compact sized vehicle (GVWR ≥ 4500 lbs). If such a restriction is not possible, the overall stopping distance requirement will have to be relaxed. This would, however, be inconsistent with the stopping capability of braked trailer combinations.

For braked trailers the recommended tow car to weight ratio selected above can be reduced by a factor of 3.5 times the "trailer-alone" braking capability (in g units), i.e.,

$$\frac{W_c}{W_t} \geq 1.5 - 3.5\, a_{x_{ta}}$$

Current contemporary trailer manufacturers are providing 0.43 g capability, and test results from both phases showed 5 out of 7 trailers (with brakes) exceeding this value. Only when the trailer weight exceeded 1500 lbs per each 2" X 10" brake did a trailer not meet 0.43 g. Assuming this trailer design criteria there would be no restriction on minimum tow car weight.

2. Handling

Trailer and stability can be insured by specifying a minimum hitch load boundary as a function of the tow car to trailer weight ratio for each trailer model. A different model would be defined as a change in weight, effective tongue length, tires, and/or moment of inertia. Methods have been presented in Vol. II, in Ref. 3, and by the Recreational Vehicle Manufacturers Association (RVIA) to analytically derive this boundary. However, some full scale CV tests are necessary to properly coalesce the analytical and emperical results. Front wheel drive cars will have a lower tow car sensitivity factor than rear wheel drive tow cars.

Tow car stability can be insured by specifying a fixed maximum hitch load boundary as a function of tow car to trailer weight ratio, for various values of load leveling. Three values have been illustrated; none (using air shocks only) minimum (based on using air shocks to their fullest and then adding leveling torque as necessary to relevel the CV), and maximum (based on no air shocks and leveling torque such as to transfer 25 percent of the hitch load to the front axle). Based on results presented in this volume, front wheel drive tow cars will find these boundaries somewhat conservative.

Combining the trailer and tow car stability boundaries results in an integrated handling compliance plot for each trailer. Figure 14a, b, and c show examples of this format for the three trailers tested in this phase. Note that the minimum tow car size is equal to greater than the trailer weight; a good rule of thumb. Also, the front wheel drive tow cars allow a lighter hitch load than an equal weight front wheel drive car. In either case the optimum hitch load for the minimum weight tow car is about 15 percent. This figure is another common rule of thumb. Increasing the tow vehicle weight rating quickly opens up the allowable hitch load region. This consistency implies a proper selection of the performance criteria.

Although the trailer examples presented in Fig. 14 give a good overall picture of the tow car/trailer tradeoffs, application by a user probably

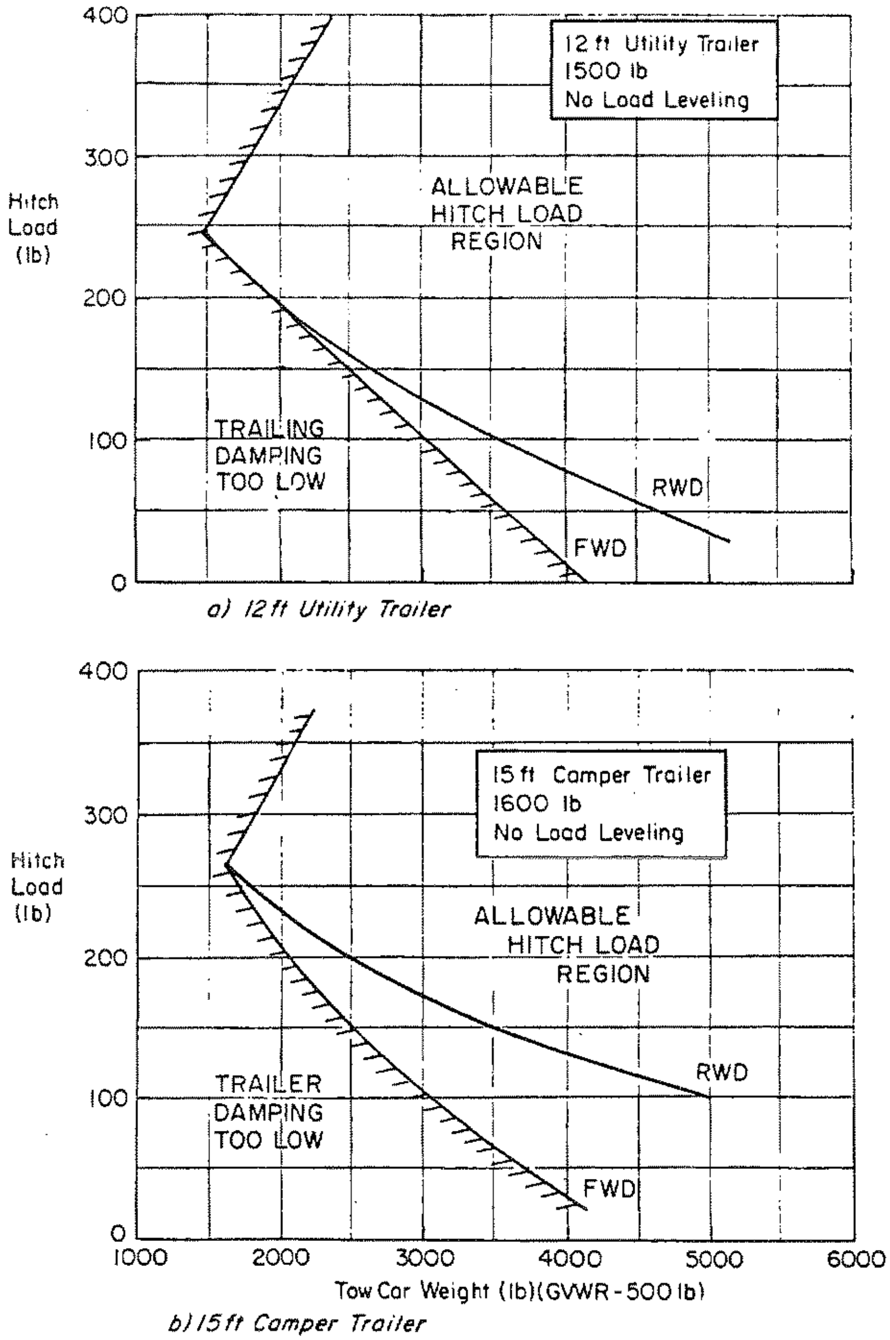
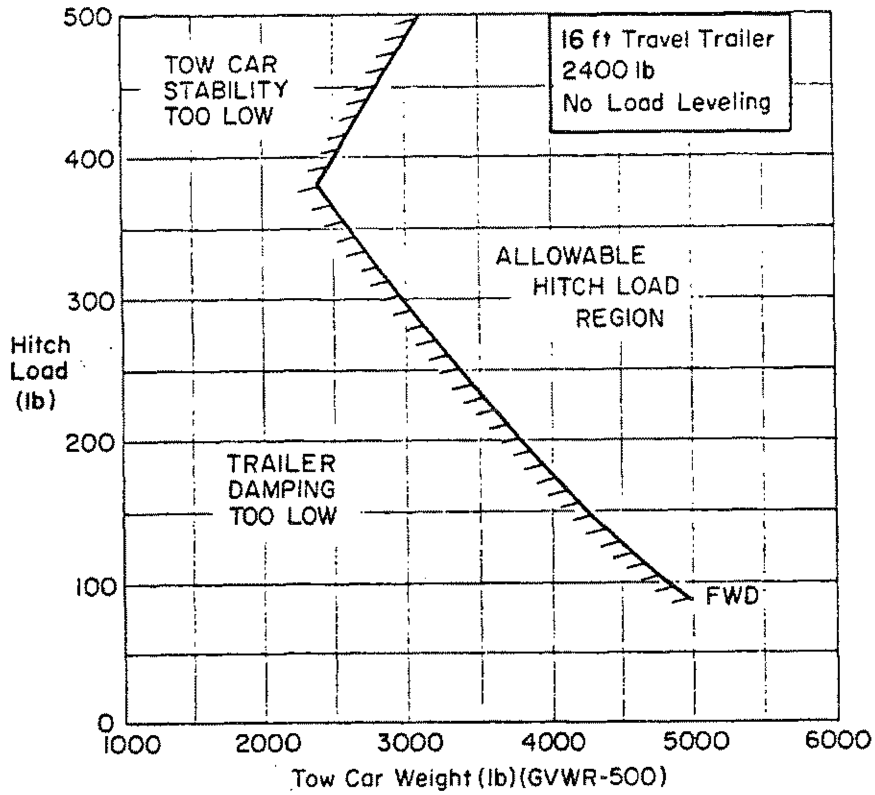


Figure 14. Recommended Integrated Trailer Handling Standard Examples



c) 16 ft Travel Trailer

Figure 14. (Concluded)

always will start with a specific tow car. In this case, the upper hitch load limit may be dictated by the tow car manufacturer due to limitations of power, cooling, structure, etc. Generally, the manufacturer's limit will occur prior to reaching the stability limit. For example, many subcompacts recommend hitch loads no more than 100 lb; whereas Fig. 14 would allow up to 400 lb. In short, manufacturers' maximum hitch load recommendations should always take precedence.

3. Handling and Braking

No additional handling requirements appear necessary in order to meet the brake in turn performance requirements. However, unbraked trailers weighing more than 67 percent of the tow car cannot decelerate at a 0.4 g average. Since tow car lockup determines the transient tow car stability change it is recommended that if the CV cannot decelerate at 0.4 g, the test be conducted at the maximum deceleration with lockup of one wheel on one axle permitted. In effect, the combined handling and braking performance criteria stated previously should be changed to read:

> All combination-vehicles should demonstrate maximum deceleration (with tow car lockup) or 0.4 g deceleration (whichever occurs first) during 0.3 g cornering, without incurring transient oversteer for longer than 1 sec duration.

If additional tests are conducted with passenger cars that exhibit rear wheel lockup (in straight ahead braking) it is recommended that they be tested with minimum hitch load trailers in order to represent the worst case condition. Previously, with front wheel lockup tendency, the maximum hitch load configurations (with no trailer brakes) represented the worst case.

REFERENCES

1. Klein, Richard H., and Henry T. Szostak, Effects of Weight Distributing Hitch Torque on Car/Trailer Directional Control and Braking, DOT HS-803 248, Oct. 1977.

2. "Car/Trailer Handling Standards Development," NHTSA Contract DOT-HS-7-01720, 27 September 1977.

3. Klein, Richard H., and Henry T. Szostak, "Determination of Trailer Stability Through Simple Analytical Methods and Test Procedures," SAE Paper 790186, in Dynamics of Wheeled Recreational Vehicles, SAE SP-443, Feb. 1979, pp. 47-53.

APPENDIX A

TOW VEHICLE AND TRAILER SPECIFICATIONS

This appendix contains all the relevant specifications, measured parameter values, and vehicle equipment descriptions for the two tow vehicles and three trailers used in this final test program phase. These data are presented in Tables A-1 and A-2, respectively.

Individual tow car and trailer braking test results are presented in Fig. A-1 for the Horizon, Figs. A-2 and A-3 for the surge brake gain of the camper trailer, and Fig. A-4 for the electric brake travel trailer.

Since several questions have come up regarding trailer roll-steer effects, the roll steer coefficient of the travel trailer was determined in Fig. A-5 to be 0.3 deg/deg.

TABLE A-1. TEST VEHICLE SPECIFICATIONS

SPECIFICATIONS	TOW CARS	
	DOWN-SIZED COMPACT	SUB-COMPACT
Vehicle	1979-1980 Chevrolet Citation 4 Door Sedan	1979 Plymouth Horizon 4 Door Sedan
GVWR Front Rear Vehicle Cargo Capacity Passengers Trunk	3571 lb 2000 lb 1571 lb 895 lb 5 Passengers 150 lb	3115 lb 1700 lb 1465 lb 715 lb 4 Passengers 115 lb
Curb Weight Front Rear Total	 1740 lb 990 lb 2730 lb	 1425 lb 875 lb 2300 lb
Test Weight (including driver but without hitch head) Front Rear Total	 1935 lb 1200 lb 3135 lb	 1560 lb 1115 lb 2675 lb
Tire Make Size Nom Pressure Load range Load capacity Construction of Casing Rim Width	Uniroyal Fastrak Radial P 185/80 R 13 26 psi B 1301 lb at 35 psi 2 ply Fiberglass Belts 1 ply Polyester 5.5"	Firestone Deluxe Champion Radial P155/80 R 13 29 psi B 959 lb at 35 psi 2 ply Fiberglass Belts 1 ply Polyester 4.5"
Steering Type Overall ratio Hysteresis with no load (at steering wheel)	Saginaw Power Boosted Rack and Pinion 17.5 ±2.25 deg	Saginaw Power Boosted Rack and Pinion 18.0 ±2.25 deg
Wheelbase, ℓ_1 Overhang to ball hitch, ℓ_h Wheel Track, Front Rear	104.9" 48" 58.7" 57.0"	99.2" 35" 55.5" 55.1"
Front Suspension Springs Anti Roll Bar	Macpherson Struts Lower A-Arms Coil Yes	Macpherson Struts Lower A-Arms Coil Yes
Rear Suspension Springs Anti Roll Bar	Beam axle on trailing arms, plus Panhard Rod Coil Yes	Semi-independent trailing arms Coil Yes, via beam interconnection of trailing arms
Rear Shock Absorbers Added for Hitch Load Capacity	Delco "Air Lift"	No Air Shocks available
Brakes Front Rear	Vacuum Boosted Disc Drum	Manual Operated Disc Drum
Engine and Transmission	173 C.I.D. V-6 Automatic Transmission	105 C.I.D. 4 Cylinder Engine Automatic Transmission

TABLE A-2. TEST TRAILER SPECIFICATIONS

TYPE	MFG. MODEL	WEIGHT SPECIFICATIONS					BRAKES MFG./SIZE/ACTUATION
		EMPTY	TEST	GVWR	GAWR	HITCH LOAD	
Utility	U-Haul 5 × 8 3533AV3894	920	1500	2600	UNK	10 Percent	None
Camper	Starcraft Starmaster 6 1977	1430	1600	2090	2090	180 to 300 curb maximum	Bendix, Drum, Surge 7 × 1.75
16 Ft Travel	Cal-Camp. Mustang 1510	2200	2400	2400	3000		Kelsey Hayes 10 × 2 in. Drum, Electric

a) Weight and Brakes

TYPE	WHEELBASE, ℓ_2, AXLE ℄ TO BALL HITCH	LENGTH BETWEEN TANDEM AXLES	TRACK WIDTH	TRAILER BOX LENGTH × WIDTH	TONGUE WIDTH	OVERALL HEIGHT	FLOOR TO GROUND HEIGHT	OVERALL LENGTH
Utility	92"	NA	75"	94" × 60"	41"	81.5"	15.5"	11'-6"
Camper	125"	NA	56.375"	124.5" × 80"	50"	53.5"	15.5"	15'-3"
16 Ft Travel	140.5"	NA	66"	159" × 80"	33"	99"	20"	16'-4"

b) Geometry

TYPE	TIRES						SUSPENSION TYPE
	MFR., MODEL	SIZE	RATED LOAD CAPACITY	CASING CONSTRUCTION	REC. TIRE PRESS.	WHEEL RIM WIDTH	
Utility	Goodyear U-Haul Traction Hi-Miler	670-15LT	"C" 1530 lb at 45 psi	Bias 4 ply nylon	45 psi	5.25"	Solid beam axle Leaf springs Compression shackles
Camper	Goodyear Hi-Lander CT	5:30-12	"C" 1045 lb at 80 psi	Bias ply	80 psi	—	Solid beam axle Leaf springs
16 Ft Travel	Bridge-Stone	7:00 × 14	"C" 1430 lb at 36 psi	4 ply Polyester 2 ply nylon belt	36 psi	5.0"	Solid beam axle Leaf springs Compression shackles

c) Tires and Suspension

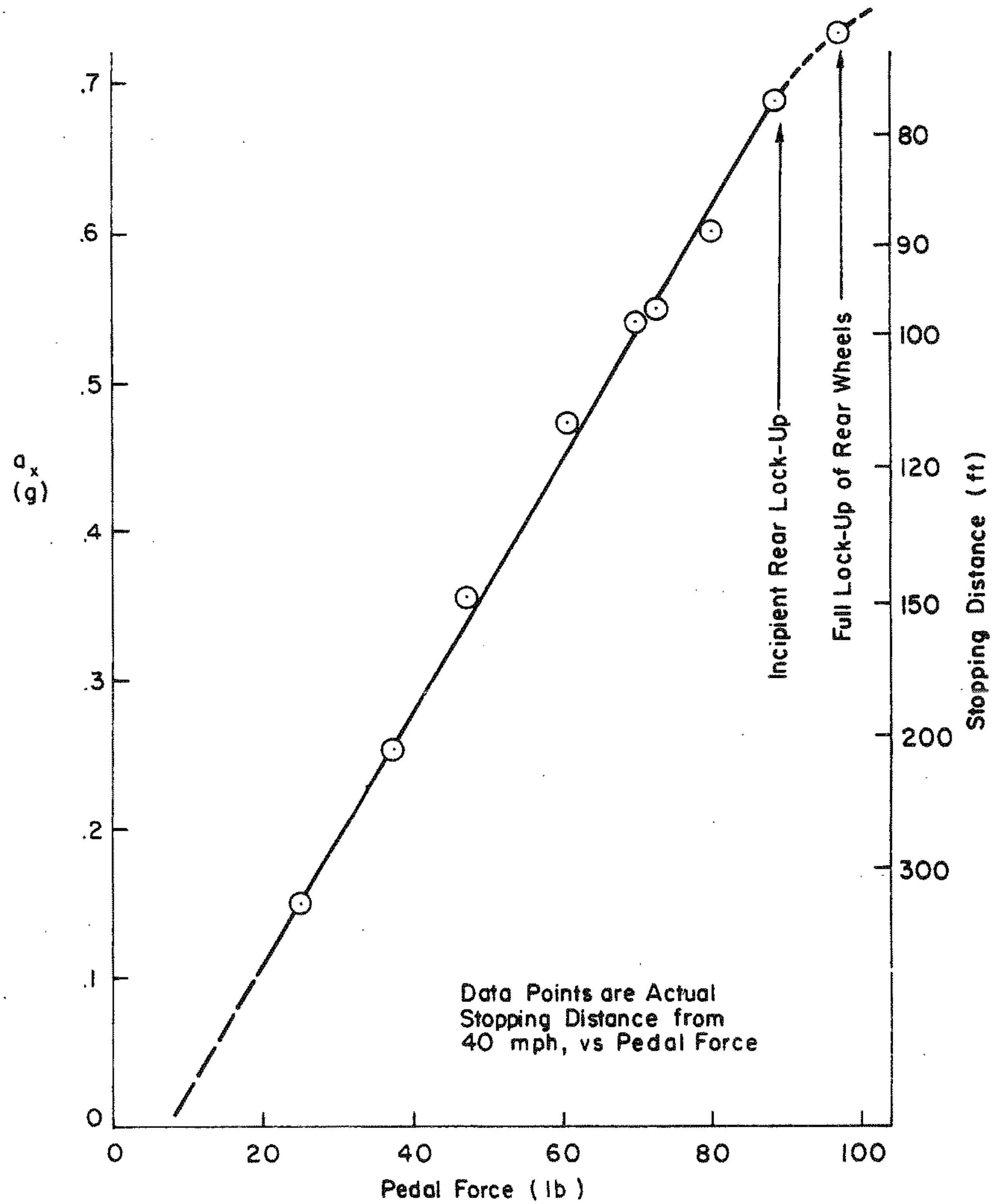


Figure A-1. Plymouth Horizon Brake Gain Test Data Run Nos.: 124-132

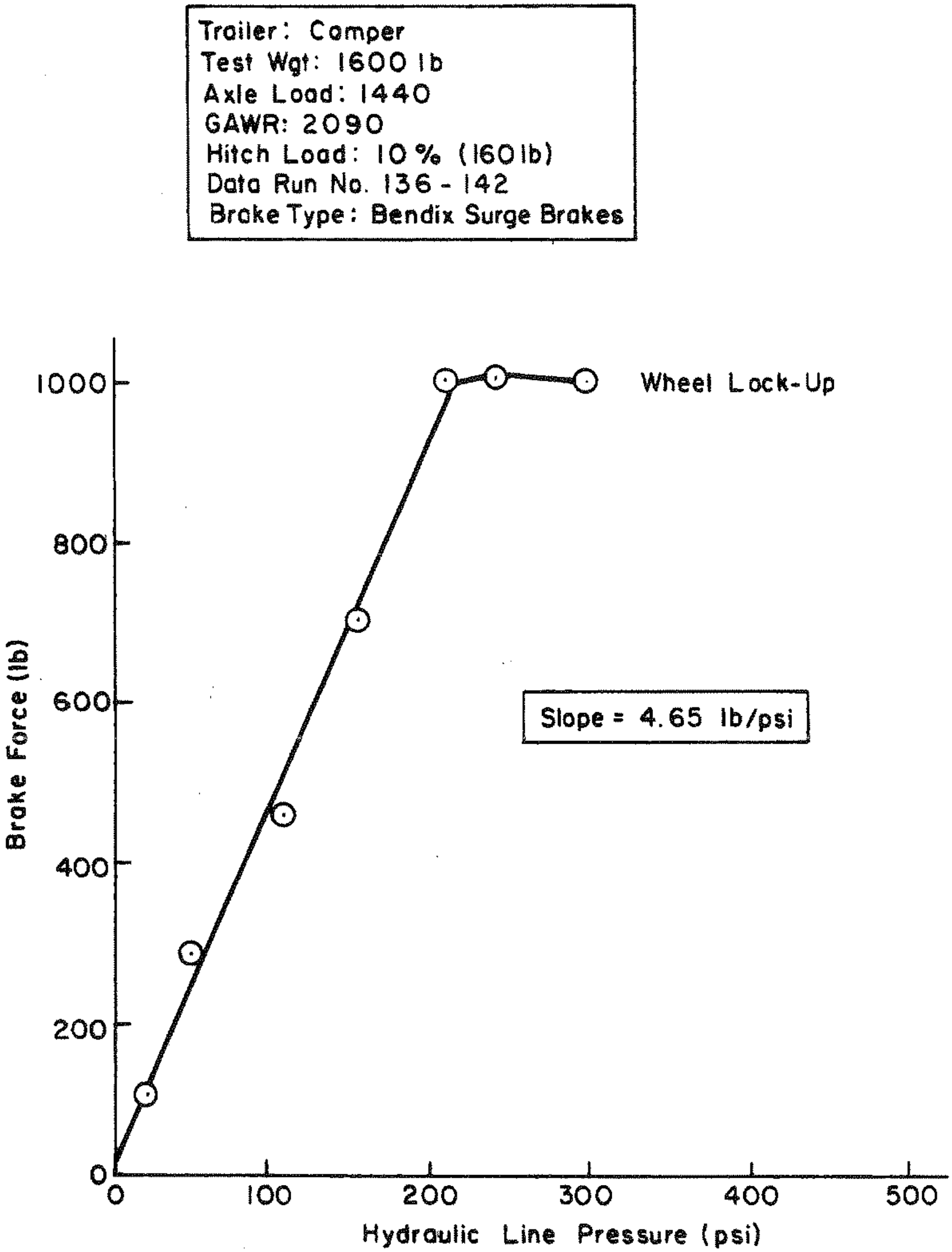


Figure A-2. Brake Force vs. Hydraulic Line Pressure for Surge Brake Trailer

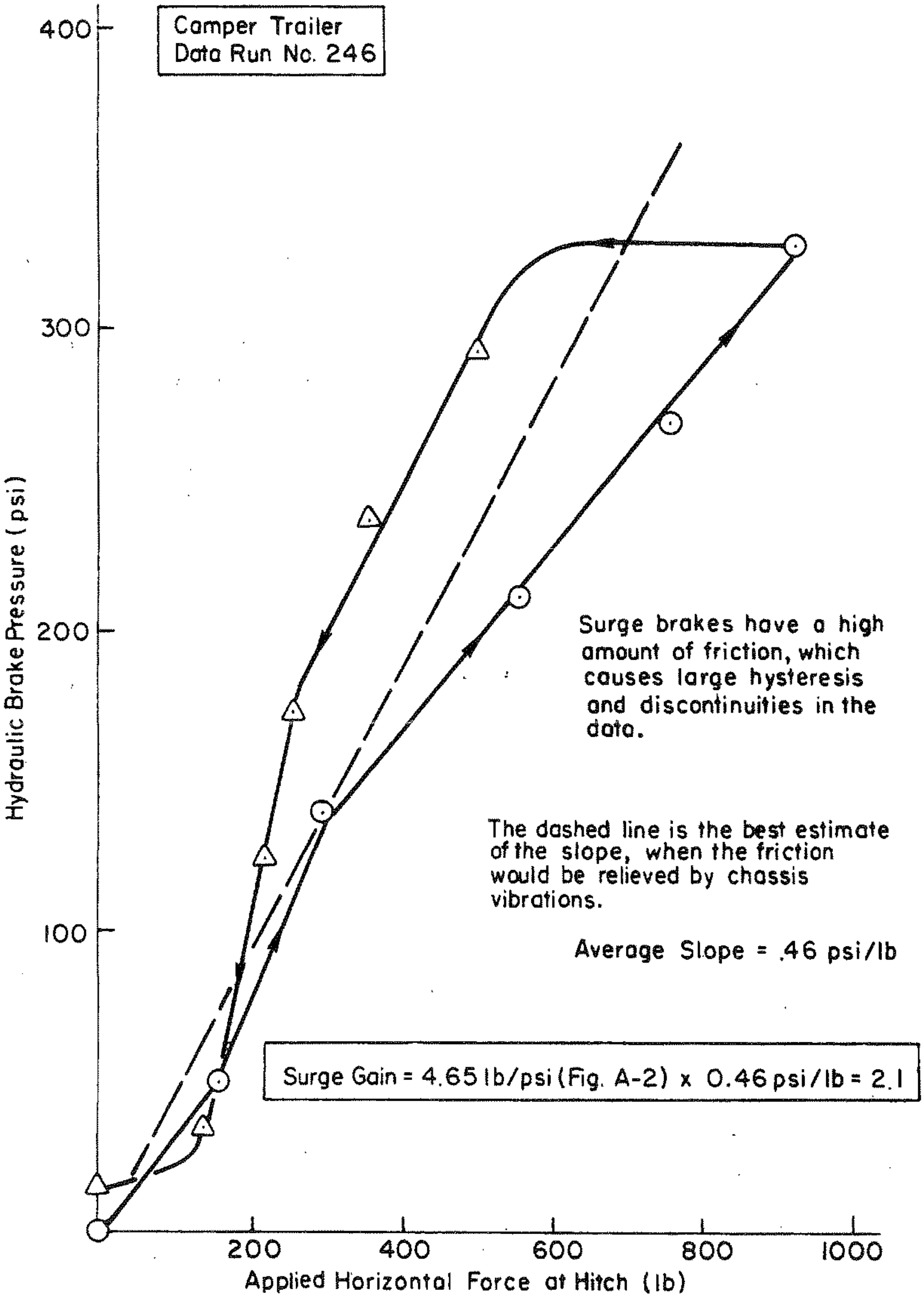


Figure A-3. Hydraulic Brake Pressure vs. Applied Horizontal Hitch Force for Surge Brake Trailer

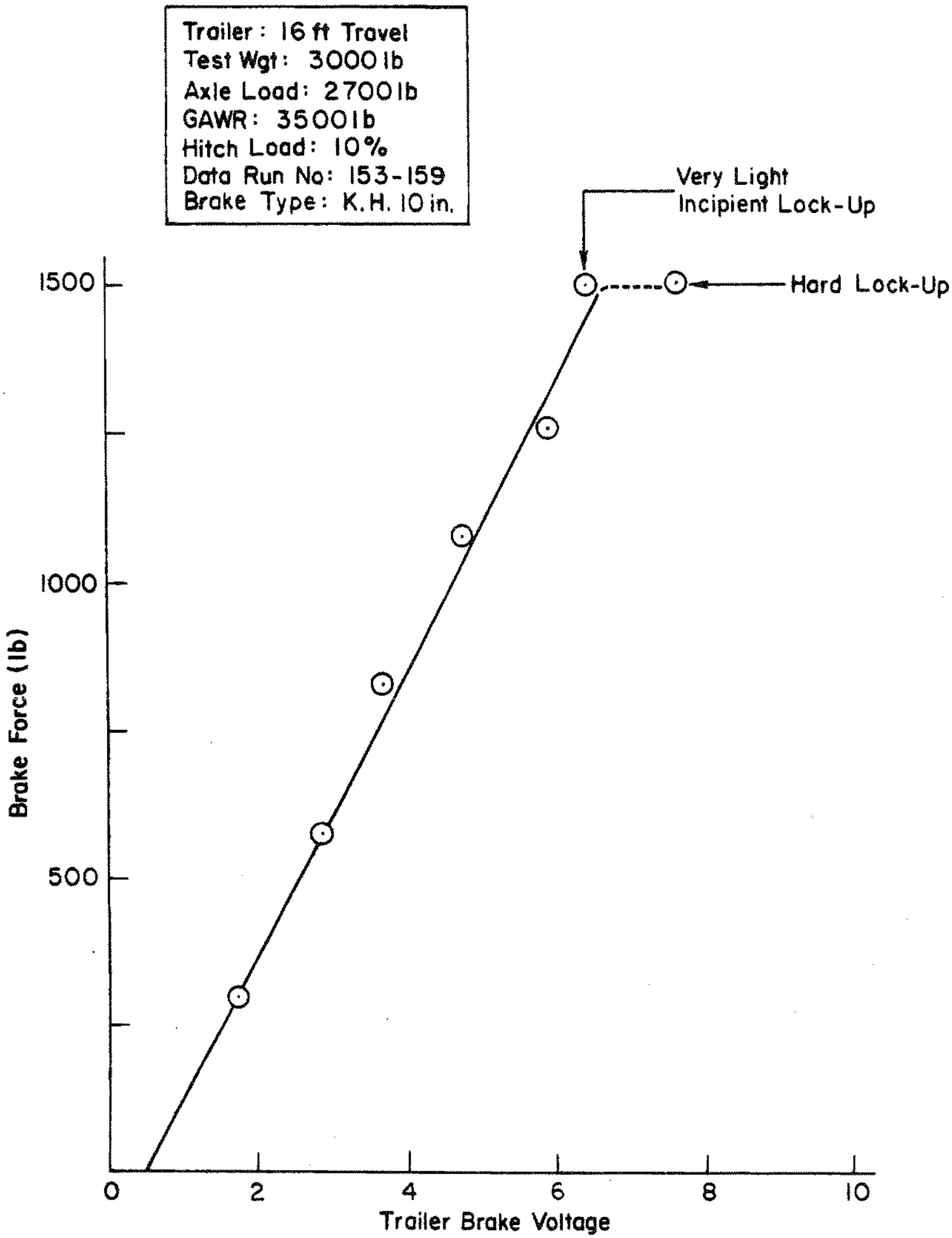


Figure A-4. Brake Force vs. Applied Trailer Brake Voltage
for 16' Travel Trailer

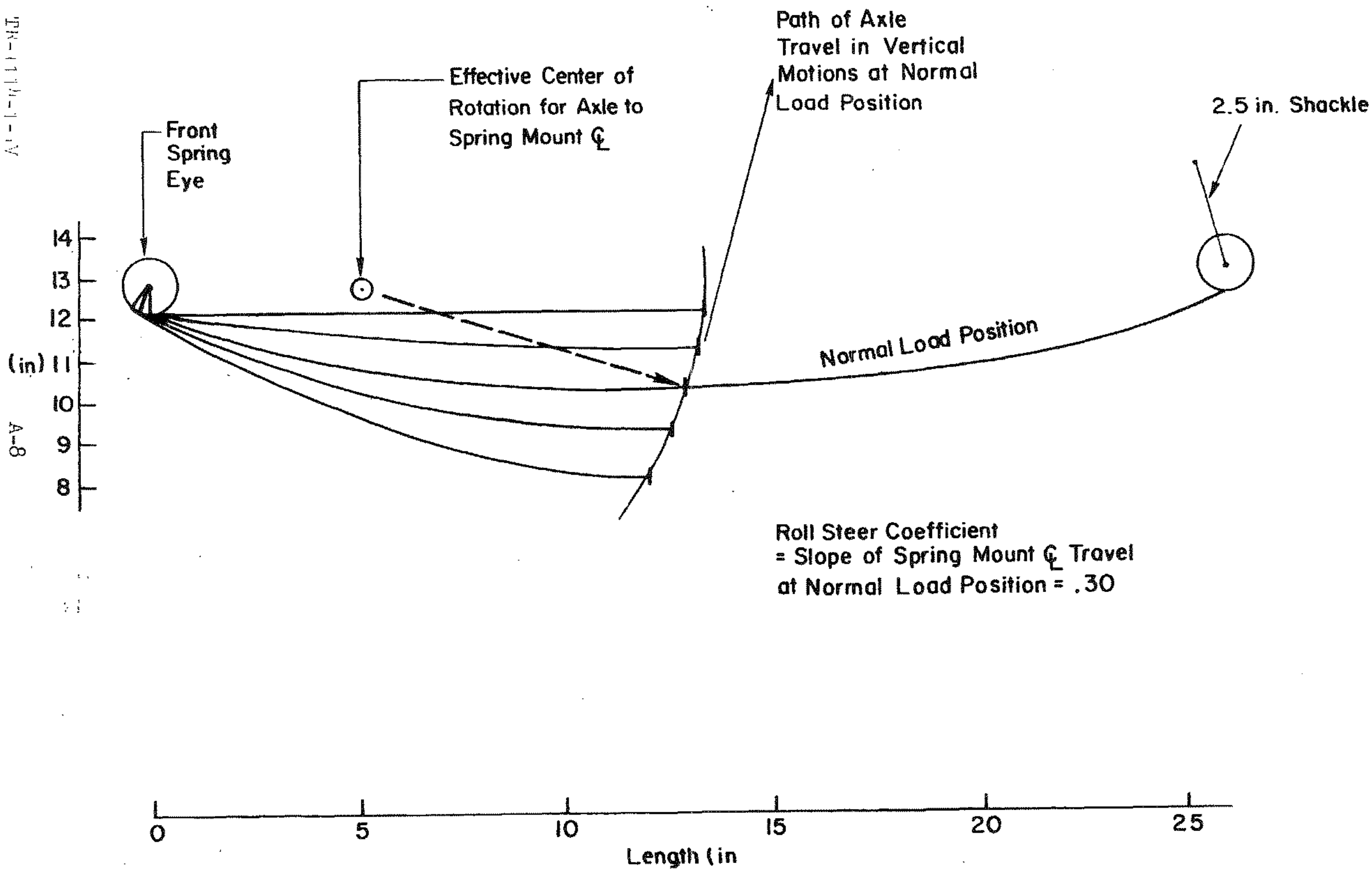


Figure A-5. 16' Travel Trailer Leaf Spring Suspension Geometry as Measured on Test Trailer

APPENDIX B

RUN LOG SUMMARY

This appendix contains a complete listing of all tests recorded on FM tape. Tables B-1 and B-2 detail the exact run numbers associated with each test. These run numbers can then be associated with tape footage numbers on two FM tapes by reference to the raw run logs kept with the FM tapes. A description of the FM tapes (i.e., sensors, scale factors, center frequency, etc.) was given in Vol. III, Appendix B.

TABLE B-1. CITATION TEST RUNS

TRAILER	PERCENT HL	SLB	OTHER	BIT	PST	CRT
None Car-Alone	—	1-10		12-20		11, 21 Low Gain
U-HAUL						
1000 lb	10	22-35			36-39	
1500 lb	20					40
1500 lb	15	47-52		416-46	53-57	41a
1500 lb	10	61-67			58-59	68
1500 lb	5	70-78			79-80	69 Low Gain
1500 lb	0	85-91			81-84	
2600 lb	10	96-104			92-95	
CAMPER						
1600 lb	15				105-106	
	10	112-121	136-142 (BTA)		108-111	107
	5				122-123	
	0				124-126	
No Brakes	10	127-135		143-153 Low Gain		
No Brakes Rerun	10	154-161				
U-HAUL						
1500 lb Rerun	10	162-172				
TRAVEL						
2400 lb	10		173-183a (BTA)		186-191	183b-185 Low Gain
100% Br.	10	214 201-205		215-220		
0% Br.	10	192-200				
50% Br.	10	206-213				
	5				227-231	
	15				224-226	
None Car Alone		232-241				243 Low Gain
Surge Br. Gain			246(BTA)			
Wheels Off Gr. + T.T.						247

TABLE B-2. PLYMOUTH HORIZON TEST RUNS

TRAILER	PERCENT HL	SLB	OTHER	BIT	PST	CRT
None Car-Alone		1-11	(Br. Gain) 124-132	12-19		20 (Hi Gain) 133 (Low Gain)
U-HAUL						
1500 lbs	20					35 (Hi Gain)
	15	36-44		47-52	45-46	53 (Low Gain)
	10	54-60			61-63	64 (Low Gain)
	5				66-68	65 (Low Gain)
	0	74-82			69-72	73 (Low Gain)
U-HAUL						
2600 lb	5				203-204	
	10	86-95			83-85	
CAMPER						
1600 lb	15			96-104	105-106	
	10	109-114 134-146	(SLB .6 g Tow Car) 147-152		107-108	115 (Low Gain)
	5				116-118	
	0				119-123	
TRAVEL						
3000 lb	10	(BTA) 153-159				
TRAVEL						
2400 lb	15				160-162	
	5				163-167	
	10	168-176	(.6 g T.C. and 100% T.T. Br. SLB) 177-182	192 197 Note	189-191	200 Step Sp. and Coast-Down
	10		(.6 g T.C. No T.T. Br. SLB) 183-188	198-199 100% TB		201 Contin. Sp. and Coast-Down

APPENDIX C

STRAIGHT LINE BRAKE TEST DATA

Table C-1 and C-2 present all tow vehicle alone and combination vehicle data for the Citation and Horizon, respectively.

TABLE C-1. STRAIGHT LINE BRAKE DATA FOR CHEVROLET CITATION

RUN NO.	TOW VEHICLE	TRAILER	WEIGHT	CONDITIONS		PEDAL FORCE	LOCK-UP	SD40	AVG ± STD. DEV.
				HITCH LOAD	LOAD LEVELING				
1	Citation	None	3200	–	–	45	NO	98.9	Press too low
2	Alone					57	RF	93.1	
3	(3200 lbs)					50	NO	94.3	88.0 ± 4.1
4						50	NO	85.9	
5	Before CV					51	NO	84.8	86.9 ± 4.0
6	Tests					52	NO	85.4	(No Lock-Up)
7						53	NO	87.9	
8						53	NO	82.8	
9						52	LF	92.1	
10						57	RF	86.1	
232	Citation	None	3200	–	–	50	NO	116	Press too low
233	Alone					50			
234						70	BF	90.7	
235	After CV					65			
236	Tests					65			
237						65	NO	86.9	90.6 ± 4.3
238						65	NO	84.4	
239						65	LF	92.2	
240						65	LF	93.1	
241						65	LF	96.1	
22	Citation	U-Haul	1000	10	NO	48	NO	118	
23						48	NO	101	
24						50	BF	107	
25						45	BF	113	
26						45	RF	106	
27						40	RF INC.	101	107
28						40	NO	107	± 5.7
29						40	BF	108	106
30						40	LF	109	±7.5
31						38	LF	Abort	(No Lock-Up)
32						35	NO	102	
33						–	NO	Abort	
34						38	NO	112	
35						38	NO	98.4	
47			1500	15	NO	38	NO	118	
48						35	NO	117	
49						37	NO	115	120 ± 4.5
50						44	BF	117	117 ± 1.5
51						40	BF	127	(No Lock-Up)
52						38	BF	123	

TABLE C-1. CONTINUED

RUN NO.	TOW VEHICLE	TRAILER	WEIGHT	CONDITIONS: HITCH LOAD	CONDITIONS: LOAD LEVELING	PEDAL FORCE	LOCK-UP	SD40	AVG ± STD. DEV.
61	Citation	U-Haul	1500	10	NO	40	NO	124	
62						38	NO	116	
63						×	NO	Abort	116 ± 4.6
64						38	NO	110	
65						40	NO	116	
66						40	NO	114	
67						40	NO	115	
162	Rerun Same Condition Switched Front/Rear Tires					40	NO	120	
163						47	NO	115	
164						47	NO	114	
165						52	NO	115	
166						55	NO	113	114 ± 3.6
167						58	NO	111	
168						63	NO	109	114 ± 3.4
169						67	NO	111	(No Lock)
170						73	BF	119	
171						70	BF	117	
172						65	RF	Abort	
70	Citation	U-Haul	1500	5	NO	40	NO	120	
71						37	NO	Abort	
72						37	NO	115	
73						×	NO	114	
74						40	NO	120	117 ± 2.5
75						37	NO	118	117 ± 2.7
76						42	NO	Abort	(No Lock)
77						42	NO	115	
78						45	RF	118	
85			1500	0	NO	40	NO	Abort	
86						40	NO	108	
87						40	NO	112	
88						40	NO	113	112 ± 2.7
89						40	NO	110	111 ± 2.0
90						40	NO	112	(No Lock)
91						40	RF	116	
96			2600	10	NO	43	RF	143	
97						35	RF	145	
98						33	RF	Abort	
99						32	NO	Abort	155 ± 7.8
100						30	NO	158	
101						30	NO	157	159 ± 2.5
102						30	NO	158	(No Lock-Up)
103						35	NO	161	
104						30	NO	163	

TABLE C-1. Continued

RUN NO.	TOW VEHICLE	TRAILER	WEIGHT	CONDITIONS HITCH LOAD	CONDITIONS LOAD LEVELING	PEDAL FORCE	LOCK-UP	SD40	AVG ± STD. DEV.
112	Citation	Camper with Surge Brakes	1600	10	NO	45	BF	111	
113						38	NO	113	
114						35	BF	116	
115						38	BF	Abort	113 ± 1.6
116						30	NO	115	
117						33	NO	112	113 ± 1.2
118						35	NO	112	(No Lock-Up)
119						33	NO	113	
120						33	NO	114	
121						40	BF	114	
127	Citation	Camper No Brakes	1600	10	NO	42	NO	121	
128						43	RF	128	
129						43	RF	126	
130						35	NO	121	126 ± 6.3
131						35	NO	128	
132						37	NO	132	126 ± 7.4
133						33	NO	137	(No Lock-Up)
134						35	NO	Abort	
135						42	NO	118	
154	Rerun Same Condition Front/Rear Tires Switched					40	NO	135	
155						40	NO	124	
156						40	NO	120	
157						50	NO	120	
158						50	NO	123	123 ± 5.3
159						45	NO	120	Same/No
160						43	RF	119	Lock-Up
161						52	NO	120	
201	Citation	16' Travel	2400 Full Brakes	10		×	NO	Abort	
202						37	LF, LT	97.7	
203						37	BF, BT	97.0	
204						38	BF, RT	97.3	98 ± 1.7
205						35	BF, RT	96.9	Including
214						37	RT	101	Lock-Up
206	Citation	16'	58% Brakes (700 lb)	10		37	NO	121	
207						36	—	Abort	
208						35	—	114	
209						38	—	111	114 ± 4.9
210						37	—	Abort	
211						36	—	118	
212						37	—	108	
213						35	—	111	

TABLE C-1. CONCLUDED

RUN NO.	TOW VEHICLE	TRAILER	CONDITIONS					LOCK-UP	SD40	AVG ± STD. DEV.
			WEIGHT	HITCH LOAD	LOAD LEVELING	PEDAL FORCE				
192	Citation	16' Travel	No Brakes	10		37	NO	146	
193						45		139	
194						50	LF	143	
195						47		136	
196						47	BF	149	141 ± 6.0
197						40		141	138 ± 5.3
198						40		132	(No Lock-Up)
199						40		133	
200						40	RF	146	

TABLE C-2. STRAIGHT LINE BRAKE DATA FOR PLYMOUTH HORIZON

RUN NO.	TRAILER WEIGHT	HITCH LOAD %	PEDAL FORCE	LOCK-UP	SD_{40}	AVERAGE OF BEST SIX	TEST RUN STOPPING DISTANCE NOT USED
1			32.5		220		
2			57.5		—		Brake Pressure Too
3	None		70		115		Low
4			85		94		
5	Car Alone		95		84		
6	Before CV		95		78.7		
7	Tests		97.5	LR	81.2	79.33	
8			95	LR	79.7		
9			90		82.9	±2.45	
10			92.5		76.6		
11			92.5		76.9		
23	U-Haul	10	65		159		
24	(1000 lb)		80		—		
25			75		122		Brake Pressure Too
26			85		109		Low
27			95		101		
28			95		—		
29			102.5		90.95		
30			102.5		89.8	88.16	
31			105		86.85		
32			100		89.0	±2.09	
33			100		85.45		
34			107.5	LR,RR	86.9		
36	U-Haul	15	100		110		Initial Run
37	(1500 lb)		102.5		—		Brake Action Released
38			100	RF	98.2		
39			100	RF	99.65	99.34	
40			97.5	RF	102		Inconsistant Run
41			92.5		98.6	±1.18	
42			95		101.3		
43			95		98.4		
44			92.5		99.9		
54	U-Haul	10	95		102		Initial Run
55	(1500 lb)		95		99.6	96.30	
56			95		94.6		
57			95		95.2		
58			100		97.5	±2.75	
59			97.5		98.6		
60			102.5	LF	92.3		

TABLE C-2. Continued

RUN NO.	TRAILER WEIGHT	HITCH LOAD %	PEDAL FORCE	LOCK-UP	SD_{40}	AVERAGE OF BEST SIX	TEST RUN STOPPING DISTANCE NOT USED
74	U-Haul	0	*	LR,RR	CV		Jack Knifed
75	(1500 lb)		80		116		
76			80		116.5	115.38	
77			80		113.8		
78			80		115.5		
79			80		117.5	±1.93	
80			85		116.6		
81			80				Inconsistent Run
82			80		112.4		
86	U-Haul	10	80				
87	(2600 lb)		80			127.87	Low Brake Pressure
88			85		126.7		
89			90	LF,RF	129.0		
90						±0.76	No Brake Action
91			90		127.7		
92			90		127.7		
93			95		128.3		
94			97.5		127.8		
95			92.5				Inconsistent run
109	Camper	10	85		113		
110	(1600 lb)		90		110		
111			90		113		
112	No		90		109		
113	Brakes		90		113		Brake Pressure
114			90		112		Too Low
			Rerun				
134			85		No Act.		
135			85		122		
136			90		108		
137			95		108		
138			95		105		
139			100		100.7		
140			100		100	97.79	
141			105				No Brake Action
142			102.5		95.8		
143			105	LR	93.3	±2.82	
144			105	LF			Inconsistent Run
145			100		97.6		
146			100		99.33		

*No Force on paper.

TABLE C-2. Concluded

RUN NO.	TRAILER WEIGHT	HITCH LOAD %	PEDAL FORCE	LOCK-UP	SD_{40}	AVERAGE OF BEST	TEST RUN STOPPING DISTANCE NOT USED
147	Camper	10	82.5		117.05	117.68	
148	(1600 lb)		85		118.2		
149	No Brakes		85		117.36	±1.47	
150	.6 g Tow		85		117.74		
151	Car		85		120.1		
152			87.5		115.65		
168	Travel	10	92.5		87		Low Brake Pressure
169	Trailer		102.5	RF	84		Inconsistent Run
170	(2400 lb)		95		82.0	79.43	
171	100%		100		78.3		
172	Brakes		97.5	RF			Inconsistent Run
173			97.5	RF	80.6	±1.89	
174			95		77.8		
175			95		77.3		
176			95		80.6		
177	Travel	10	80		87.7		
178	Trailer		82.5		82.6	86.86	
179	(2400 lb)		85		87.1		
180	100%		85		91.5	±3.19	
181	Brakes		85		83.95		
182	.6 g Tow		87.5		88.3		
	Car						
183	Travel	10	80		134.9		
184	Trailer		80		138.9	137.22	
185	(2400 lb)		80		137.2		
186	No Trailer		82.5		136.4	±1.83	
187	Brakes		80		139.8		
188	.6 g Tow		75		136.1		
	Car						

APPENDIX D

TRAILER DAMPING RATIO DATA

This appendix presents individual pulse steer test results for all combination-vehicles. Table D-1 presents the Citation tests and D-2 the Horizon tests. Both damping ratio (ζ) and natural frequency (ω_n), in radians/sec are given. The four run average was used in deriving the trends presented in Section IV The individual test data were derived by fitting a pure second order system to the measured hitch angle response. Examples of this fitting procedure are shown in Fig. D-1 through D-4 for the Horizon/Utility trailer at 0, 5, 10, and 15 percent hitch loads respectively.

TABLE D-1. COMBINATION-VEHICLE DAMPING RATIO RESULTS WITH CHEVROLET CITATION

TRAILER	TRAILER WEIGHT	HITCH LOAD (%)	RUN NUMBER	SPEED (MPH)	ζ	ω_n	AVERAGE ζ	AVERAGE ω_n
Utility	1000	10	36	55	.375	5.76	.327	6.28
			37	55	.248	7.15		
			38 A	55	.405	6.42		
			B	55	.321	5.92		
			C	55	.356	6.21		
			D	55	.256	6.24		
			39	45	.343	6.17	.343	6.17
	1500	15	54 A	55	.324	6.47		
			B	55	.287	6.26		
			C	55	.246	5.31		
			D	55	.198	5.95		
			55	45	.442	6.88		
			56 A	35	.382	7.71	.407	7.59
			B	35	.431	7.46		
			C	45	.357	7.48	.424	7.28
			D	45	.473	7.47		
			57 A	55	.258	7.49	.317	6.21
			B	55	.589	5.75		
		10	58 A	35	.320	4.02	.320	4.02
			B	45	.274	7.10	.274	7.10
			59 B	55	.28	—	.25	
			C	55	.25	—		
			D	55	.21	—		
		5	79 A	35	.301	4.69	.361	5.17
			B	35	.420	5.65		
			C	45	.266	5.97	.255	5.36
			D	45	.243	4.75		
			80 A	55	.252	4.52	.148	5.44
			B	55	.132	5.34		
			C	55	.096	6.15		
			D	55	.113	5.74		

TABLE D-1. CONTINUED

TRAILER	TRAILER WEIGHT	HITCH LOAD (%)	RUN NUMBER	SPEED (MPH)	ζ	ω_n	AVERAGE ζ	AVERAGE ω_n
Utility	1500	0	81 A	35	.203	5.08	.154	5.13
			B	35	.105	5.18		
			82 A	45	.128	5.27	.116	5.31
			B	45	.104	5.35		
			C	55	.071	5.47	.076	5.51
			83 A	55	.087	5.35		
			B	55	.065	5.81		
			84	55	.083	5.42		
	2600	10	92 A	35	.248	5.21	.344	5.25
			B	35	.466	4.90		
			C	35	.302	5.52		
			D	35	.360	5.37		
			E	45	.346	5.30	.244	5.21
			F	45	.342	5.11		
			93 A	55	.183	5.55	.183	5.40
			B	55	.189	5.50		
			C	55	.212	5.34		
			D	55	.153	5.40		
			94 A	55	.178	5.45		
			B	55	.167	5.56		
			C	55	.199	5.17		
			D	55	.161	5.54		
			95 A	55	.183	5.24		
			B	55	.205	5.19		
Camper	1600	15	105 A	35	.572	4.61	.511	4.81
			B	35	.449	5.01		
			C	45	.296	5.13	.335	4.76
			D	45	.352	4.85		
			E	45	.361	4.37		
			F	45	.330	4.69		
			106 A	55	.253	5.01	.274	4.77
			B	55	.276	4.95		
			C	55	.292	4.36		
			D	55	.275	4.75		

TABLE D-1. CONTINUED

TRAILER	TRAILER WEIGHT	HITCH LOAD (%)	RUN NUMBER	SPEED (MPH)	ζ	ω_n	AVERAGE ζ	AVERAGE ω_n
Camper	1600	10	108 A	35	.291	5.35	.321	4.85
			B	35	.355	4.84		
			C	35	.304	4.89		
			D	45	.286	4.50	.248	4.53
			E	45	.247	4.60		
			F	45	.207	4.77		
			109 A	45	.220	4.62		
			B	45	.250	4.51		
			C	45	.244	4.43		
			110 A	45	.295	5.00		
			B	45	.294	4.59		
			C	45	.282	4.68		
			D	45	.258	4.40		
			E	45	.249	4.50		
			F	45	.254	4.40		
			G	45	.236	4.40		
			H	35	.388	4.45		
			111 A	55	.182	4.65	.190	4.48
			B	55	.211	4.38		
			C	55	.177	4.56		
			D	55	.191	4.32		
		5	122 A	35	.250	4.41	.236	4.54
			B	35	.211	4.88		
			C	35	.242	4.36		
			D	35	.242	4.50		
			E	45	.167	4.44	.183	4.43
			F	45	.199	4.42		
			123 A	55	.142	4.28	.143	4.05
			B	55	.151	3.83		
			C	55	.149	3.97		
			D	55	.131	4.10		
		0	124 A	35	.199	4.34	.231	4.33
			B	35	.154	4.26		
			C	35	.349	4.26		
			D	35	.221	4.45		
			E	45	.120	4.25	.114	4.24
			F	45	.116	4.25		
			G	45	.105	4.21		

TRAILER	TRAILER WEIGHT	HITCH LOAD (%)	RUN NUMBER	SPEED (MPH)	ζ	ω_n	AVERAGE ζ	AVERAGE ω_n
Camper (Cont)	1600	0	125 A	55	.081	3.95	.062	3.99
			B	55	.060	3.93		
			126 A	55	.062	4.20		
			B	55	.043	3.87		
Travel	2400	10	186 A	35	.281	4.06	.276	4.00
			B	35	.271	3.94		
			C	45	.209	3.50	.193	3.82
			D	45	.176	4.14		
			187 A	55	.114	4.01	.138	3.96
			B	55	.137	4.00		
			188 A	55	.129	4.01		
			B	55	.142	4.14		
			C	55	.119	4.16		
			D	55	.145	3.64		
			E	55	.195	3.72		
			189 A	55	.148	4.10		
			B	55	.118	3.78		
			190 A	55	.112	4.19		
			B	55	.156	3.78		
			C	55	.137	3.91		
			191 A	55	.086	4.09		
			B	55	.198	3.85		
		15	224 A	35	.318	4.21	.318	4.21
			B				.234	3.91
			C	45	.201	4.19		
			D	45	.266	3.67		
			225 A	55	.178	4.18	.217	3.91
			B	55	.219	3.62		
			226 A	55	.184	4.11		
			B	55	.250	3.81		
			C	55	.253	3.81		
		5	227 A	35	.177	4.14	.196	4.31
			B	35	—	—		
			C	35	.195	4.25		
			D	35	.217	4.54		
			228 A	45	.163	3.72	.165	3.71
			B	45	.167	3.70		
			229	55	.094	4.11	.098	3.92
			230 A	55	.154	3.85		
			B	55	.141	3.97		
			C	55	.082	4.04		
			231 A	55	.065	3.84		
			B	55	.083	3.76		
			C	55	.064	3.86		

TABLE D-2. COMBINATION VEHICLE DAMPING RATIO RESULTS WITH PLYMOUTH HORIZON

TRAILER	TRAILER WEIGHT	HITCH LOAD (%)	RUN NUMBER	SPEED (MPH)	ζ	ω_n	AVERAGE ζ	AVERAGE ω_n
Utility	1000	10	21 A	35	.251	6.63	.256	6.74
			B	35	.261	6.85		
			C	45	.187	6.76	.181	6.88
			D	45	.175	7.00		
			22 A	55	.160	6.72	.165	6.79
			B	55	.154	6.67		
			C	55	.162	6.91		
			D	55	.184	6.87		
		0	202 A	55	.089	6.44		
			B	55	.107	6.34		
			C	55	.089	6.39		
			D	55	.096	6.27		
	1500	15	45 A	35	.534	6.45	.448	6.53
			B	35	.361	6.61		
			C	45	.337	6.80	.308	6.62
			D	45	.279	6.43		
			46 A	55	.272	6.32	.254	6.50
			B	55	.249	6.34		
			C	55	.262	6.15		
			D	55	.259	6.53		
			E	55	.230	7.15		
		10	61 A	35	.353	6.26	.320	6.40
			B	35	.287	6.54		
			C	45	.235	6.32	.224	6.37
			D	45	.213	6.41		
			62 A	55	.156	6.72	.173	6.50
			B	55	.161	6.57		
			C	55	.197	6.45		
			D	55	.192	6.09		
			63 A	55	.185	6.59		
			B	55	.144	6.57		
		5	66 A	35	.143	6.10	.183	6.11
			B	35	.222	6.12		
			C	45	.106	5.98	.104	5.98
			D	45	.101	5.97		

TABLE D-2. CONTINUED

TRAILER	TRAILER WEIGHT	HITCH LOAD (%)	RUN NUMBER	SPEED (MPH)	ζ	ω_n	AVERAGE ζ	AVERAGE ω_n
Utility (Cont)	1500	5	67 A	55	.044	5.71	.055	5.91
			B	55	.042	5.92		
			68 A	55	.063	6.03		
			B	55	.072	5.99		
		0	69 A	35	.176	6.32	.166	6.24
			B	35	.155	6.16		
			C	45	.092	6.07	.088	6.04
			D	45	.084	6.00		
			71 A	55	.042	5.79	.039	5.68
			B	55	.032	6.01		
			C	55	.036	5.61		
			72 A	55	.045	5.40		
			B	55	.039	5.60		
	2600	10	83 A	35	.213	5.66	.225	5.77
			B	35	.228	5.76		
			C	35	.232	5.92		
			D	35	.228	5.73		
			84 A	45	.153	5.52	.153	5.53
			B	45	.152	5.49		
			C	45	.154	5.55		
			D	45	.152	5.56		
			85 A	55	.098	5.51	.101	5.47
			B	55	.105	5.56		
			C	55	.095	5.47		
			D	55	.104	5.32		
		5	203 A	55	.056	4.66	.052	4.60
			204 A	55	.047	4.53		
Camper	1600	15	105 A	35	.500	4.60	.416	4.76
			B	35	.368	4.83		
			C	35	.380	4.86		
			D	45	.295	4.77	.288	4.65
			E	45	.281	4.52		
			106 A	55	.222	4.63	.242	4.52
			B	55	.248	4.62		
			C	55	.252	4.41		
			D	55	.254	4.59		
			E	55	.236	4.36		

TABLE D-2. CONTINUED

TRAILER	TRAILER WEIGHT	HITCH LOAD (%)	RUN NUMBER	SPEED (MPH)	ζ	ω_n	AVERAGE ζ	AVERAGE ω_n
Camper (Cont)	1600	10	107 A	55	.143	4.80	.161	4.86
			B	55	.158	4.84		
			C	55	.185	5.06		
			D	55	.157	4.76		
			108 A	35	.336	4.55	.322	4.46
			B	35	.308	4.36		
			C	45	.237	4.49	.228	4.52
			D	45	.219	4.54		
		5	116 A	35	.192	4.94	.198	4.92
			B	35	.204	4.89		
			C	45	.165	4.56	.157	4.68
			D	45	.148	4.79		
			117 A	55	.110	4.60	.100	4.66
			B	55	.100	4.71		
			C	55	.109	4.58		
			D	55	.100	4.66		
			118 A	55	.088	4.67		
			B	55	.091	4.73		
		0	119 A	35	.206	4.91	.234	4.81
			B	35	.261	4.70		
			120 A	55	.074	4.44	.076	4.42
			121 A	55	.075	4.52		
			122 A	55	.080	4.36		
			123 A	55	.075	4.35		
Travel	2400	15	160 A	35	.357	3.81	.331	3.98
			B	35	.305	4.15		
			C	45	.250	3.88	.243	3.91
			D	45	.236	3.94		
			161 A	55	.194	4.29	.194	4.35
			B	55	.216	4.42		
			C	55	.150	4.42		
			162 A	55	.170	4.42		
			B	55	.216	4.17		
			C	55	.220	4.37		

TABLE D-2. CONCLUDED

TRAILER	TRAILER WEIGHT	HITCH LOAD (%)	RUN NUMBER	SPEED (MPH)	ζ	ω_n	AVERAGE	
							ζ	ω_n
Travel (Cont)	2400	5	163 A	35	.206	4.34	.231	4.24
			B	35	.256	4.14		
			C	45	.146	4.19	.145	4.10
			D	45	.144	4.00		
			164 A	55	.058	4.24	.067	4.05
			B	55	.091	4.07		
			165 A	55	.063	4.00		
			166 A	55	.080	3.95		
			167 A	55	.066	4.15		
			B	55	.055	4.11		
			C	55	.058	3.85		
		10	189 A	35	.259	4.30	.280	4.26
			B	35	.301	4.22		
			C	45	.228	4.09	.212	4.15
			D	45	.196	4.21		
			190 A	55	.142	4.20	.128	4.12
			B	55	.131	4.00		
			191 A	55	.118	4.25		
			B	55	.125	4.06		
			C	55	.124	4.09		

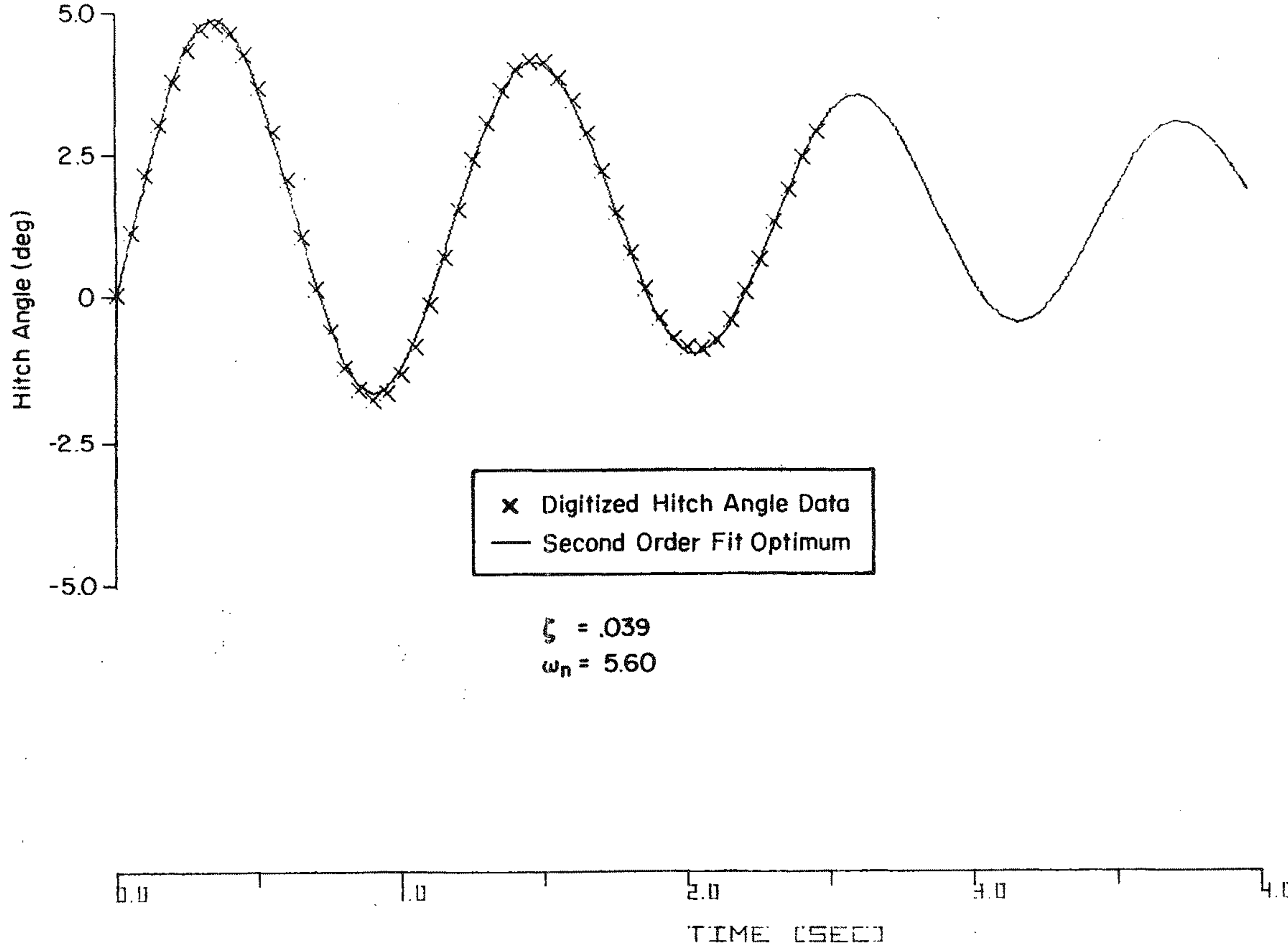


Figure D-1. Run 72, Horizon with 1500 lb U-Haul 0 Percent HL

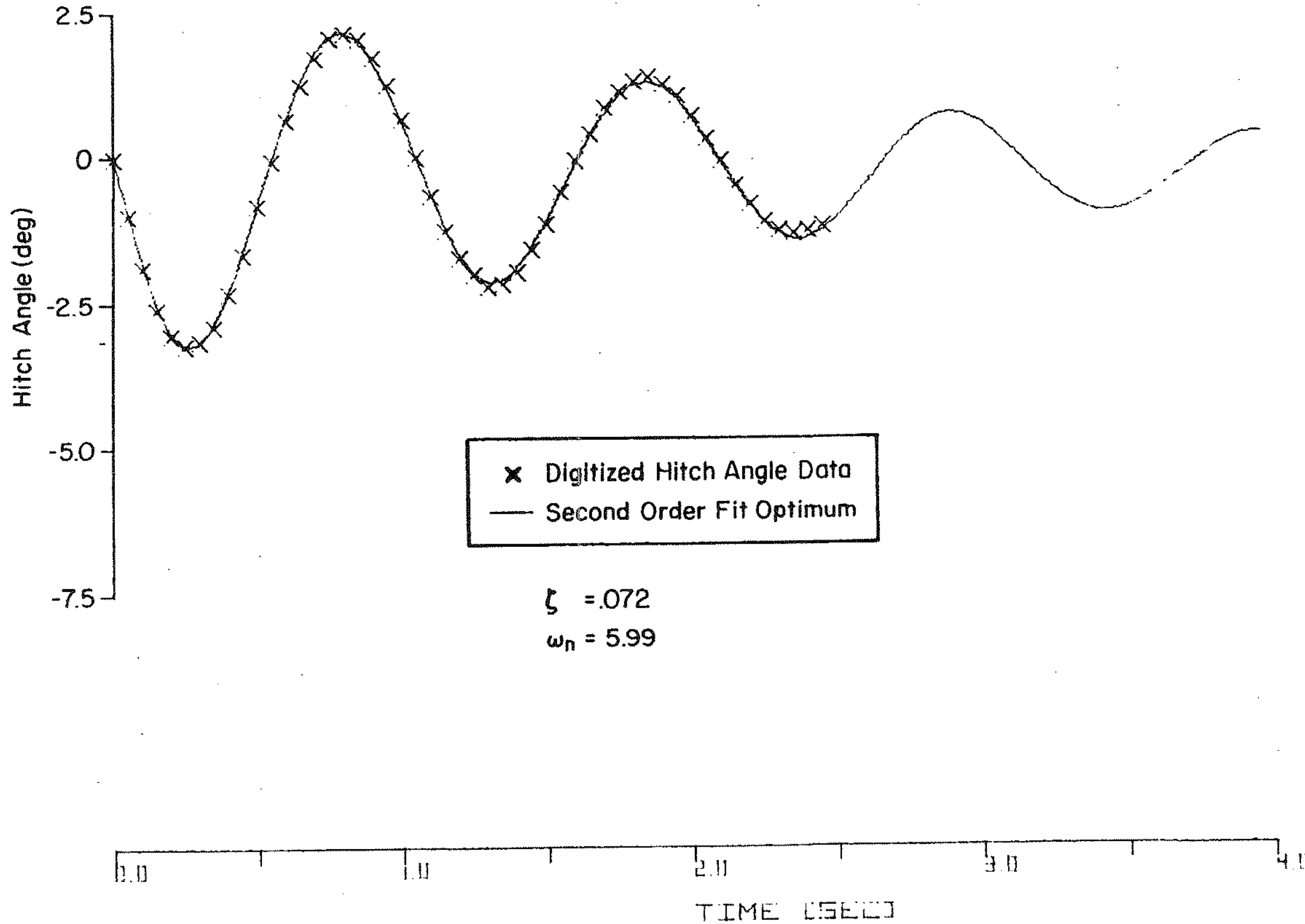


Figure D-2. Run 68, Horizon with 1500 lb U-Haul 5 Percent HL

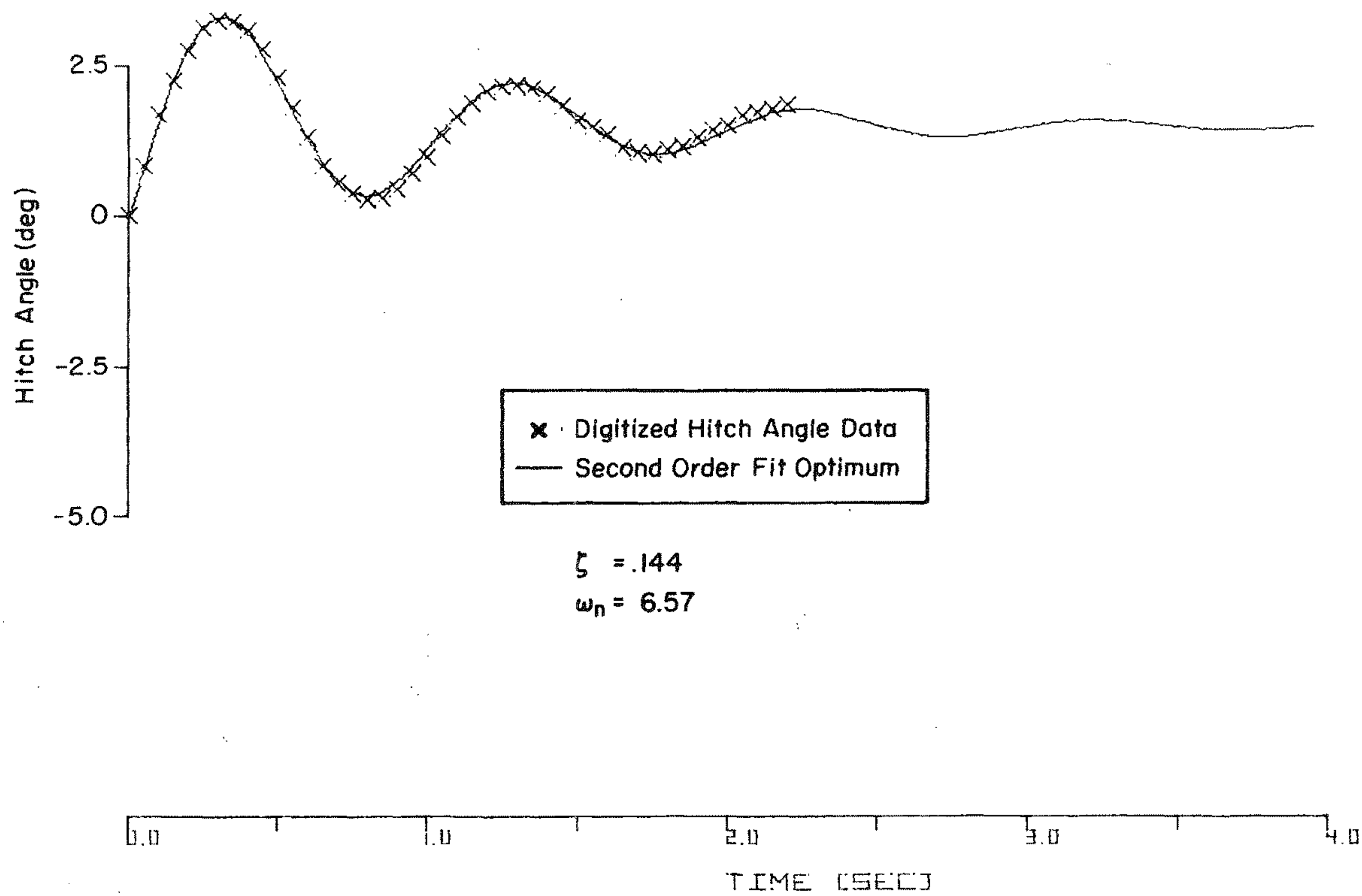


Figure D-3. Run 63, Horizon with 1500 lb U-Haul 10 Percent HL

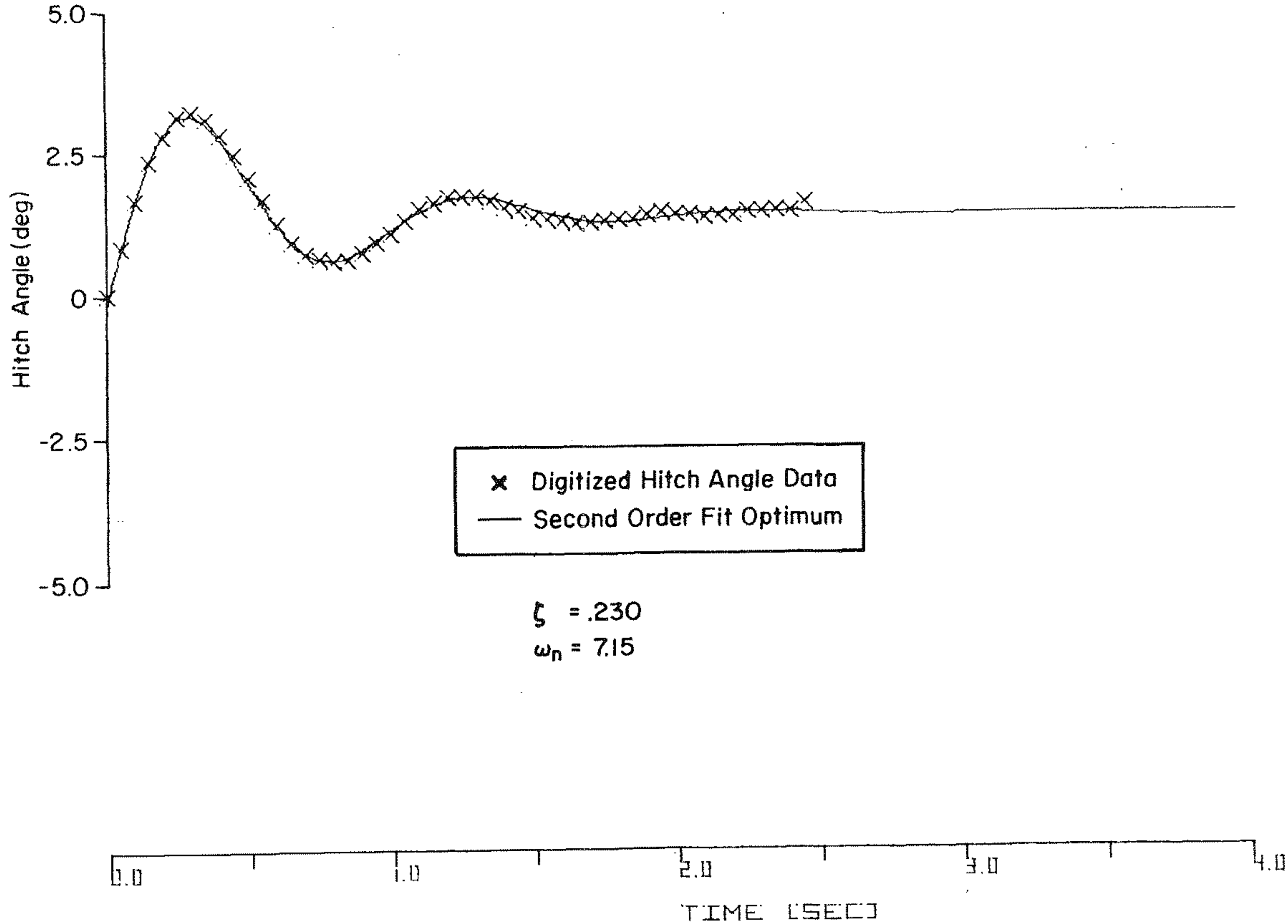


Figure D-4. Run 46, Horizon with 1500 lb U-Haul 15 Percent HL

APPENDIX E

TOW CAR STABILITY FACTOR DATA

This appendix presents constant radius circle (CRT) test results for all combination vehicles. In this test the speed and steering wheel angle are measured as the vehicle is maintained on a 200' radius circle. The driver attempted to maintain steady conditions at 15, 20, 25, 27-1/2, 30, 32-1/2, 35 and 37-1/2 mph. Lateral acceleration is then calculated from the average speed in any segment, i.e., $a_y = \frac{U^2}{R}$. The average steering wheel angle was determined for the same speed segment. This is all a completely automated analysis procedure in which the FM data is digital and then averaged by digital computer.

The understeer gradient is then determined from the slope of the steering wheel angle divided by steering ratio vs. lateral acceleration. Since the slope changes above 0.3 g the slope from 0 to 0.3 g, as well as the overall slope (from 0 to 0.45 g) was measured.

In Figures E-1 through E-18 the line drawn through the data points represents a last square fit to the complete data set. The slope from 0 to 0.3 g is not drawn; only the slope is given.

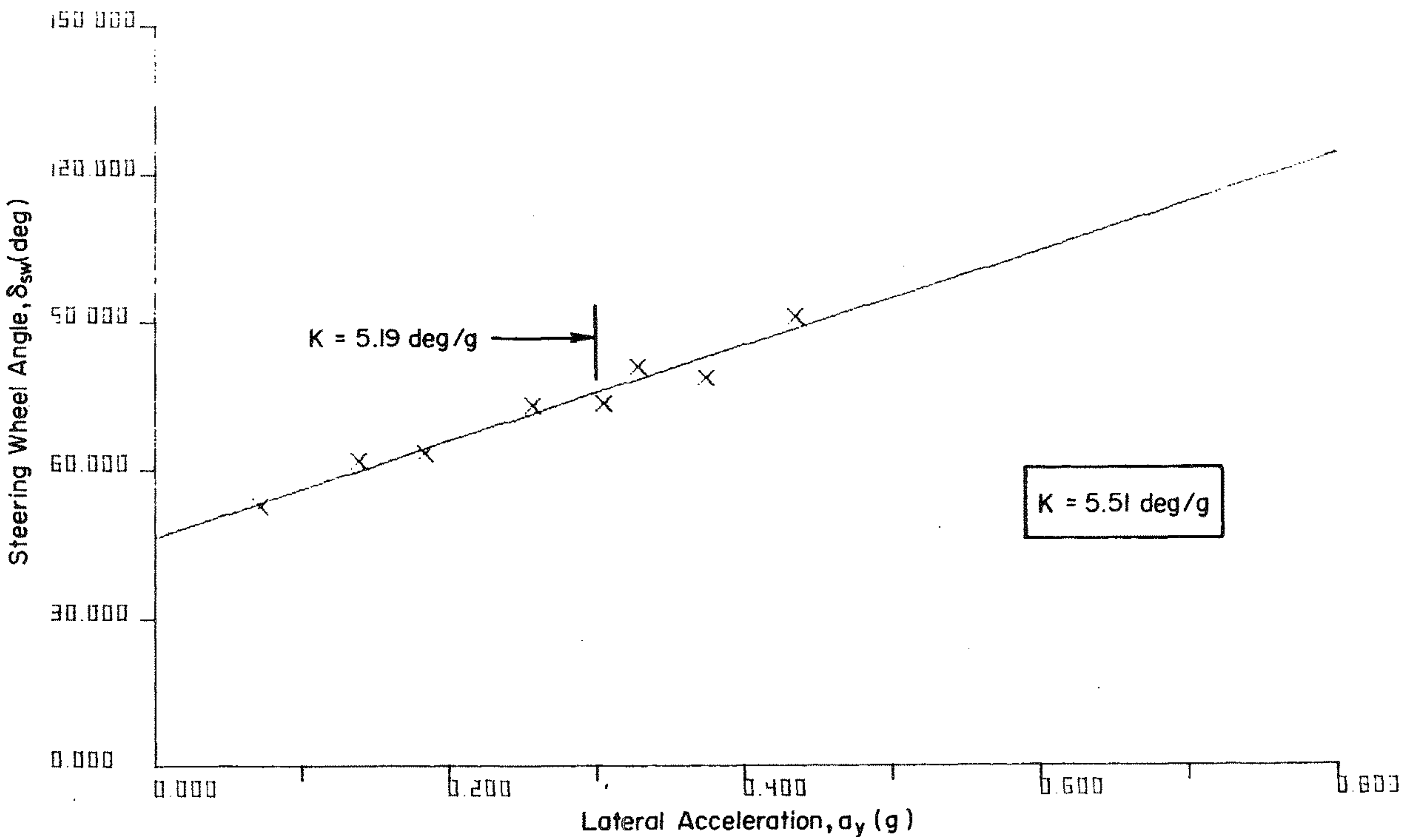


Figure E-1. Understeer Gradient for Citation Alone, Run 21

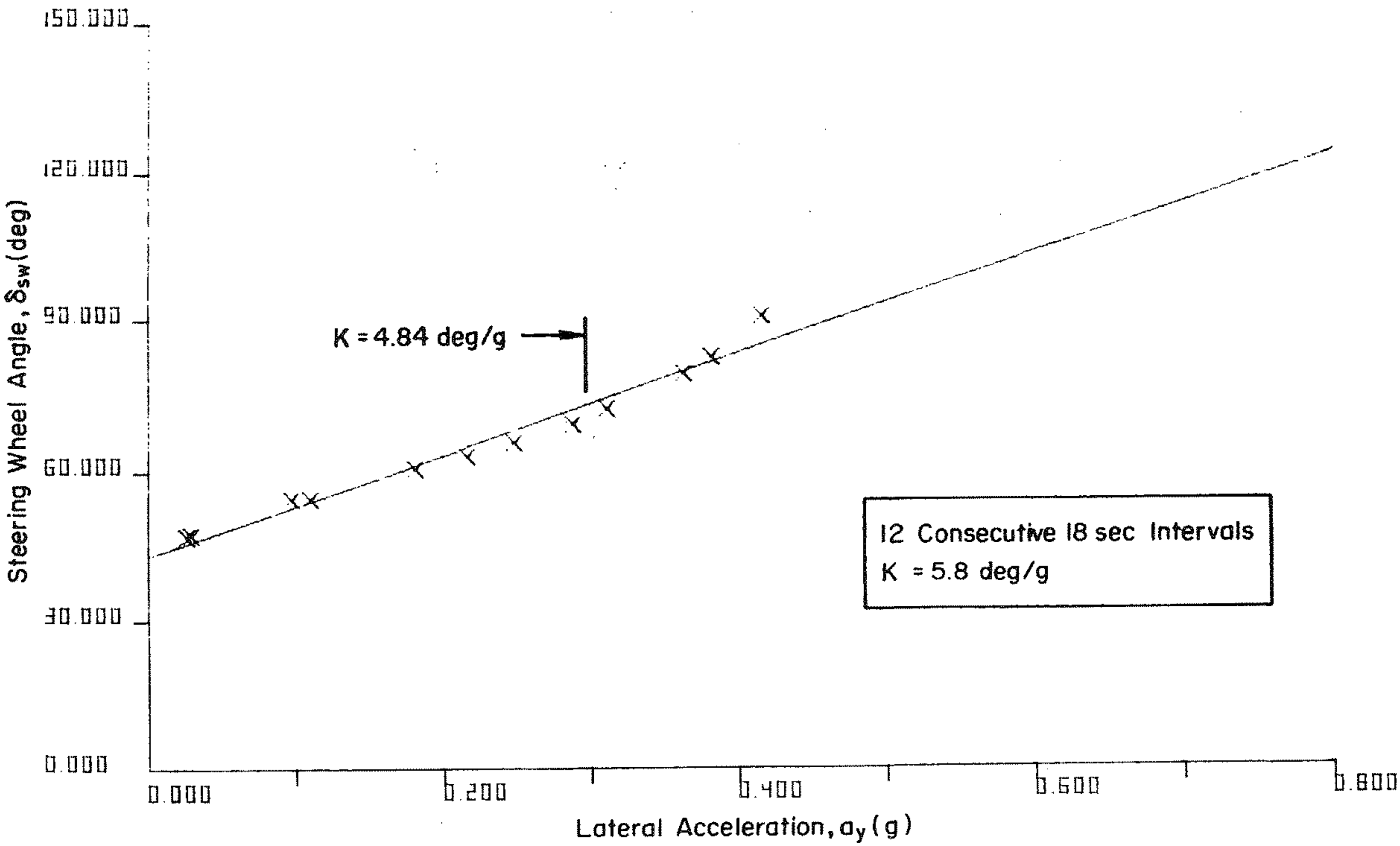


Figure E-2. Understeer Gradient for Citation Alone — After Trailer Tests, Run 243

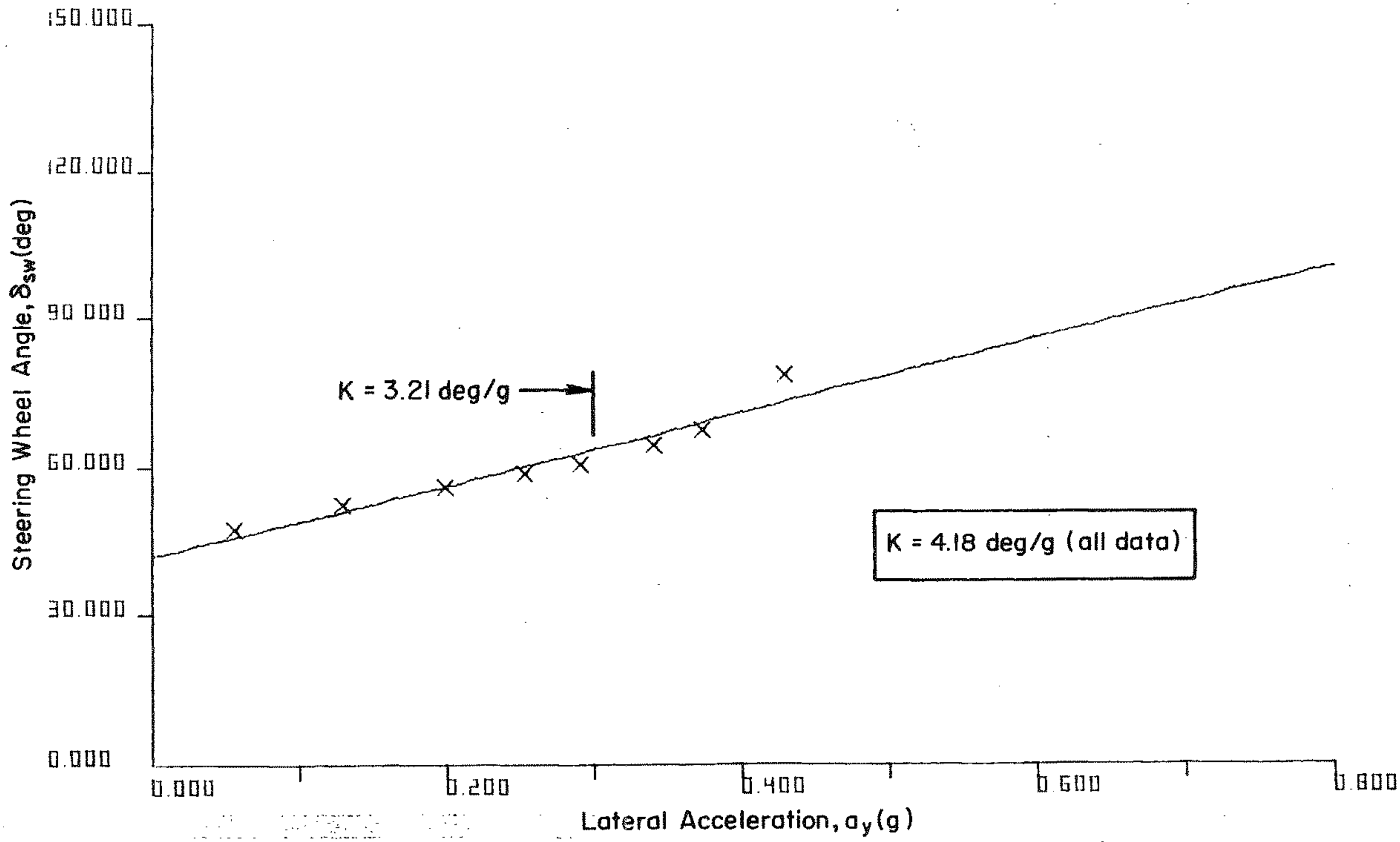


Figure E-3. Understeer Gradient for Citation with 1500 lb U-Haul, 5 percent Hitch Load, Run 69

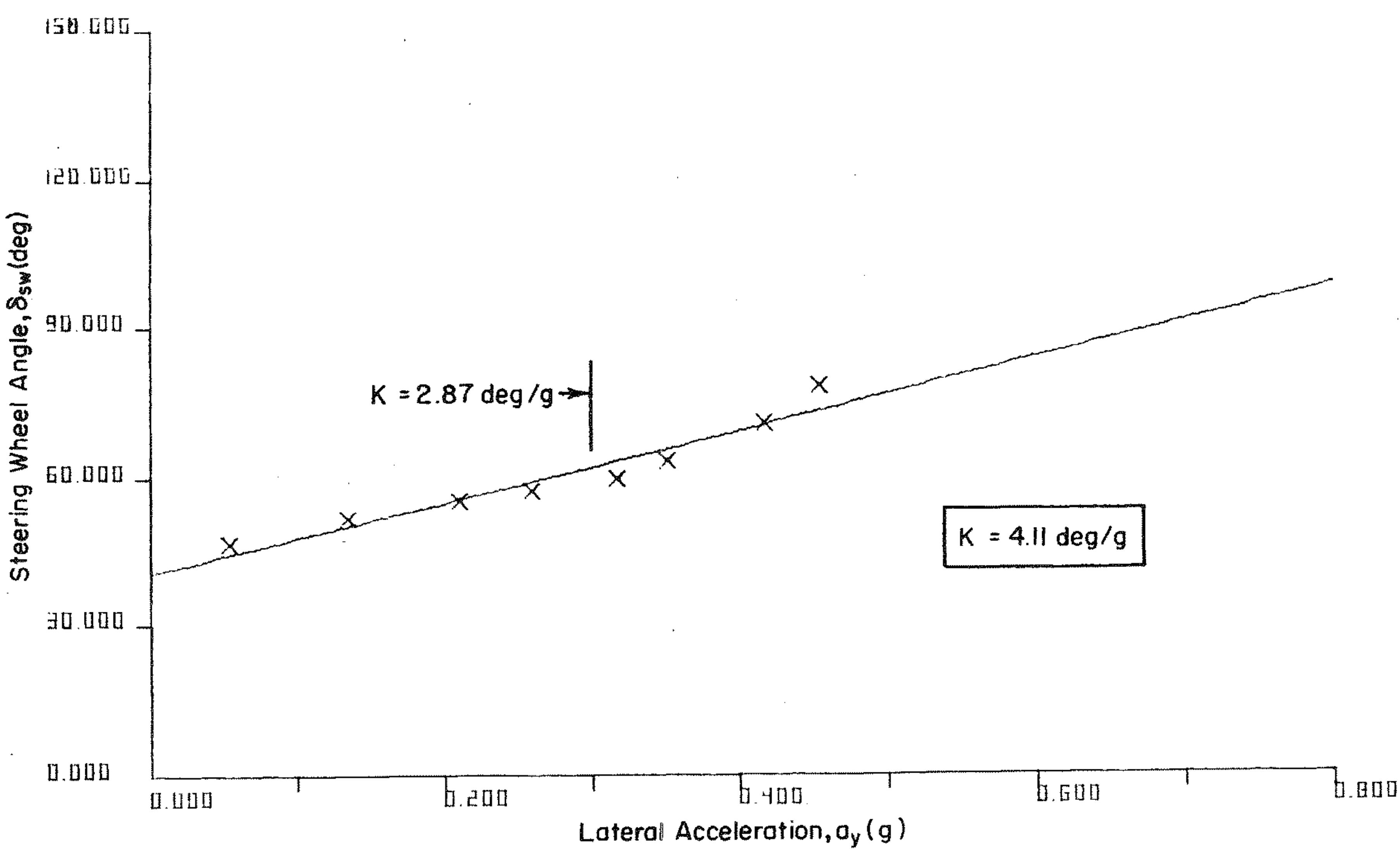


Figure E-4. Understeer Gradient for Citation with 1500 lb U-Haul, 10 percent Hitch Load, Run 68

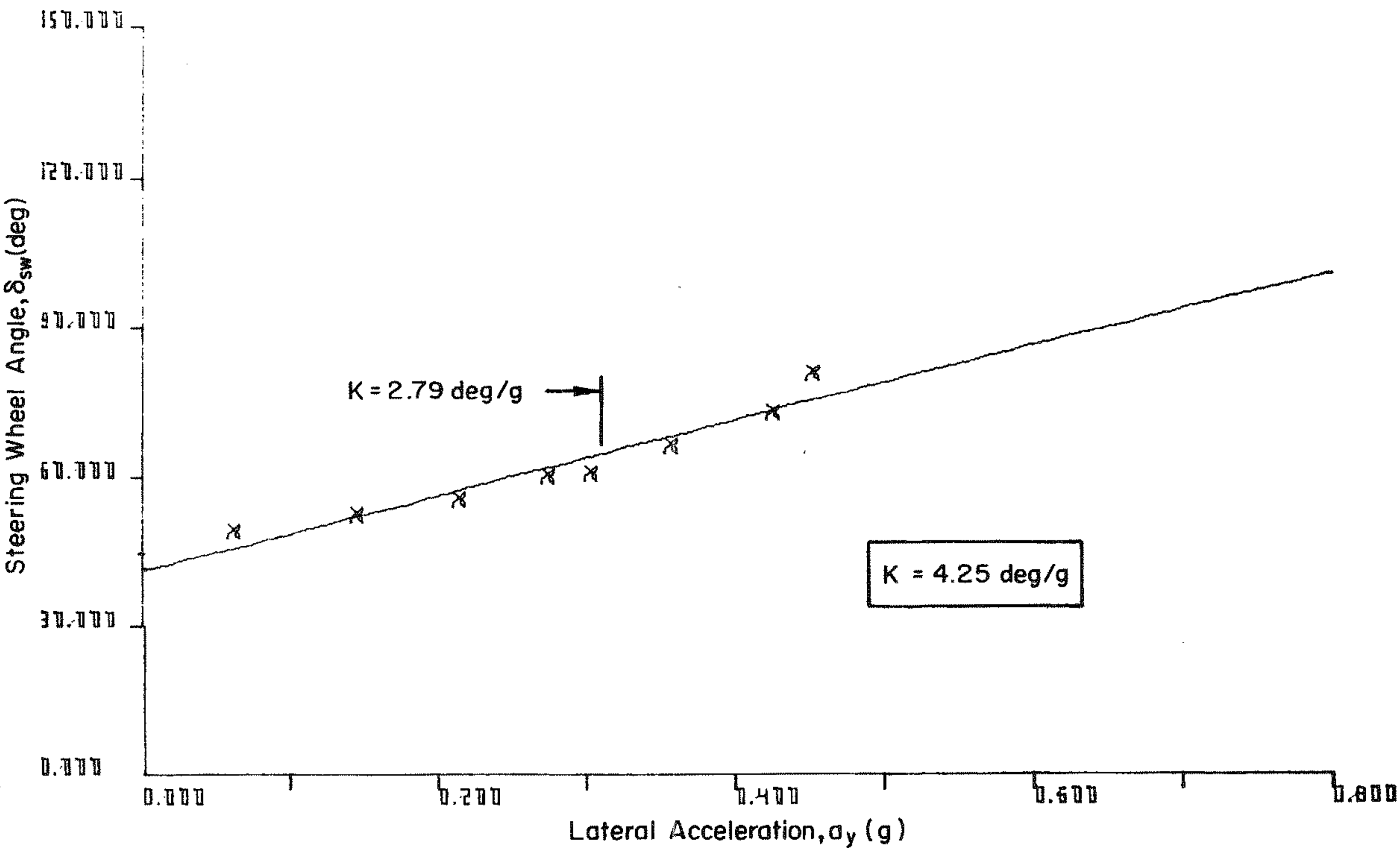


Figure E-5. Understeer Gradient for 1500 lb U-Haul, 15 percent Hitch Load, Run 41a

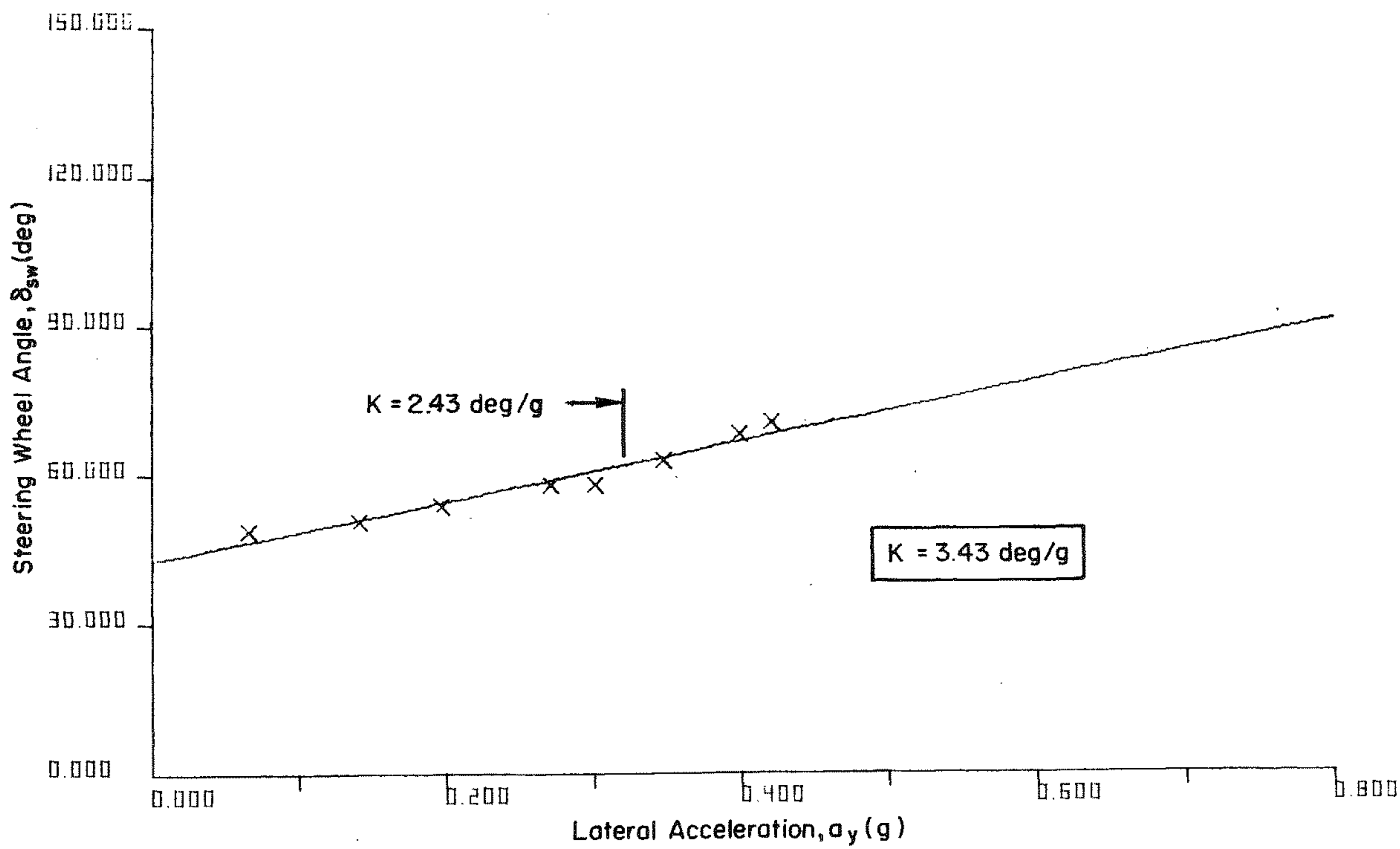


Figure E-6. Understeer Gradient for Citation with 1500 lb U-Haul, 20 percent Hitch Load, Run 40

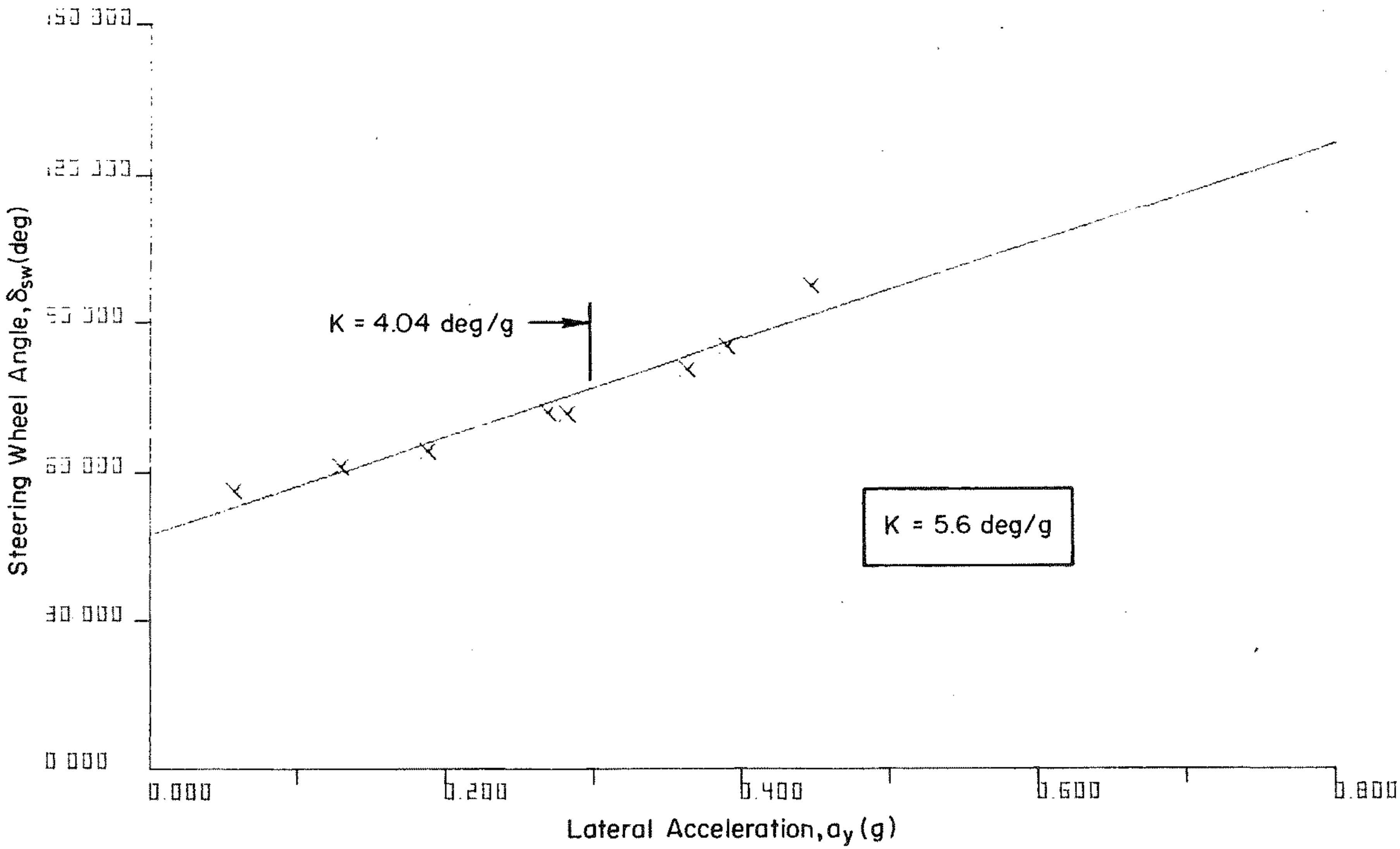


Figure E-7. Understeer Gradient for Citation with 1600 lb Camper, 10 Percent Hitch Load, Run 107

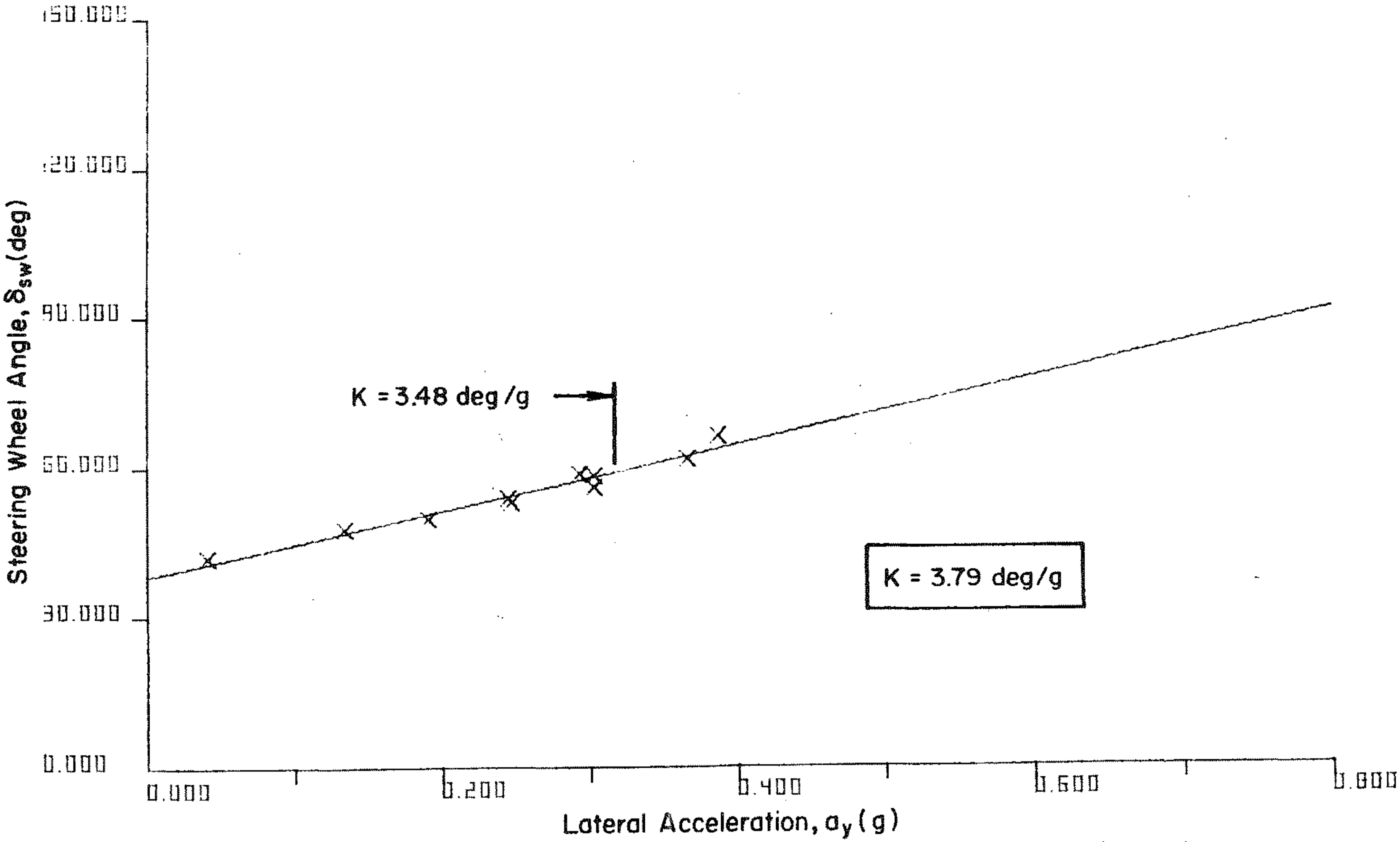


Figure E-8. Understeer Gradient for Citation with 2400 lb Travel, 10 percent Hitch Load; Runs 183b, 184, and 185

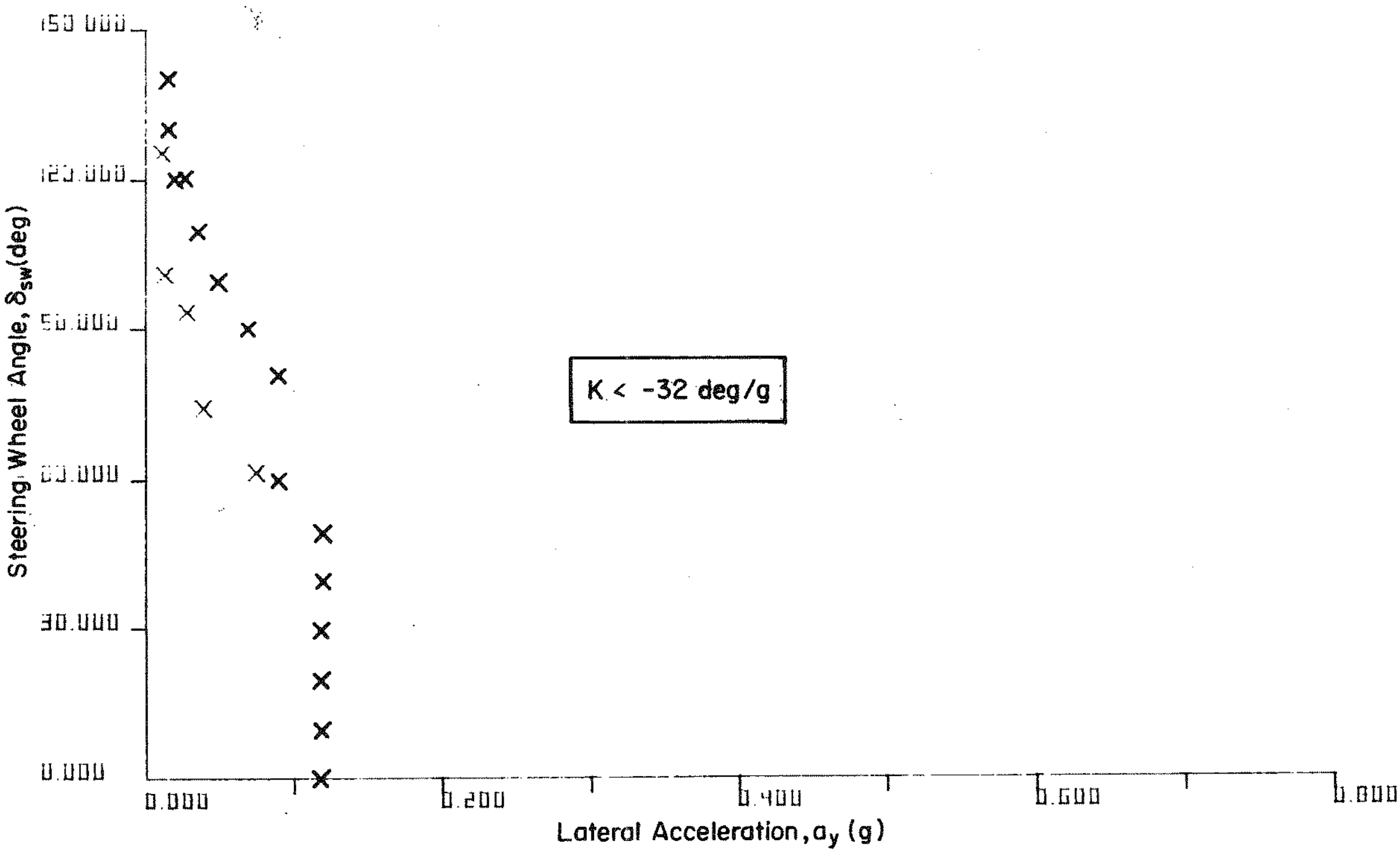


Figure E-9. Understeer Gradient for Citation with Travel Trailer, Rear Wheels Off Ground, Run 247

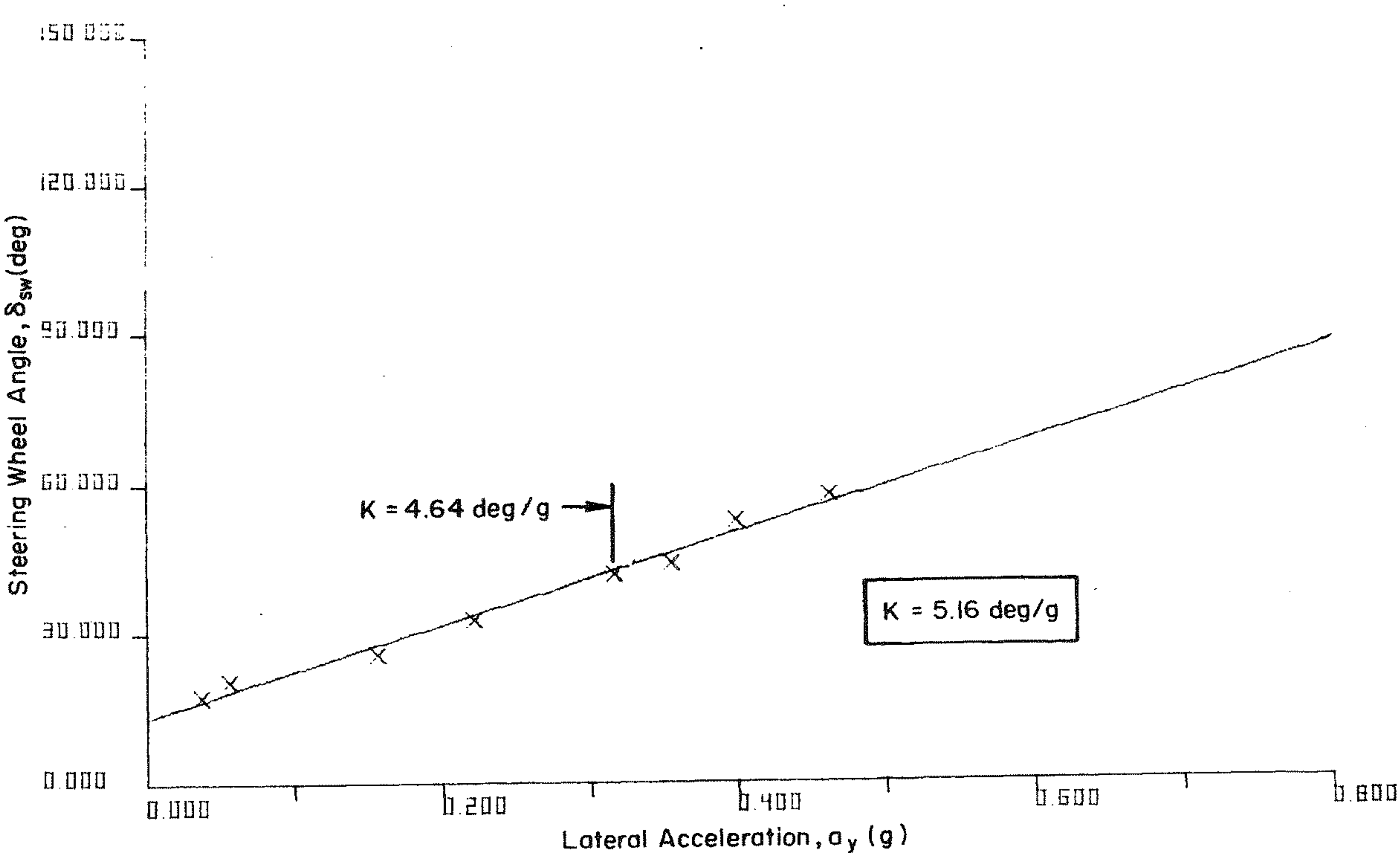


Figure E-10. Understeer Gradient for Horizon Alone, Run 20

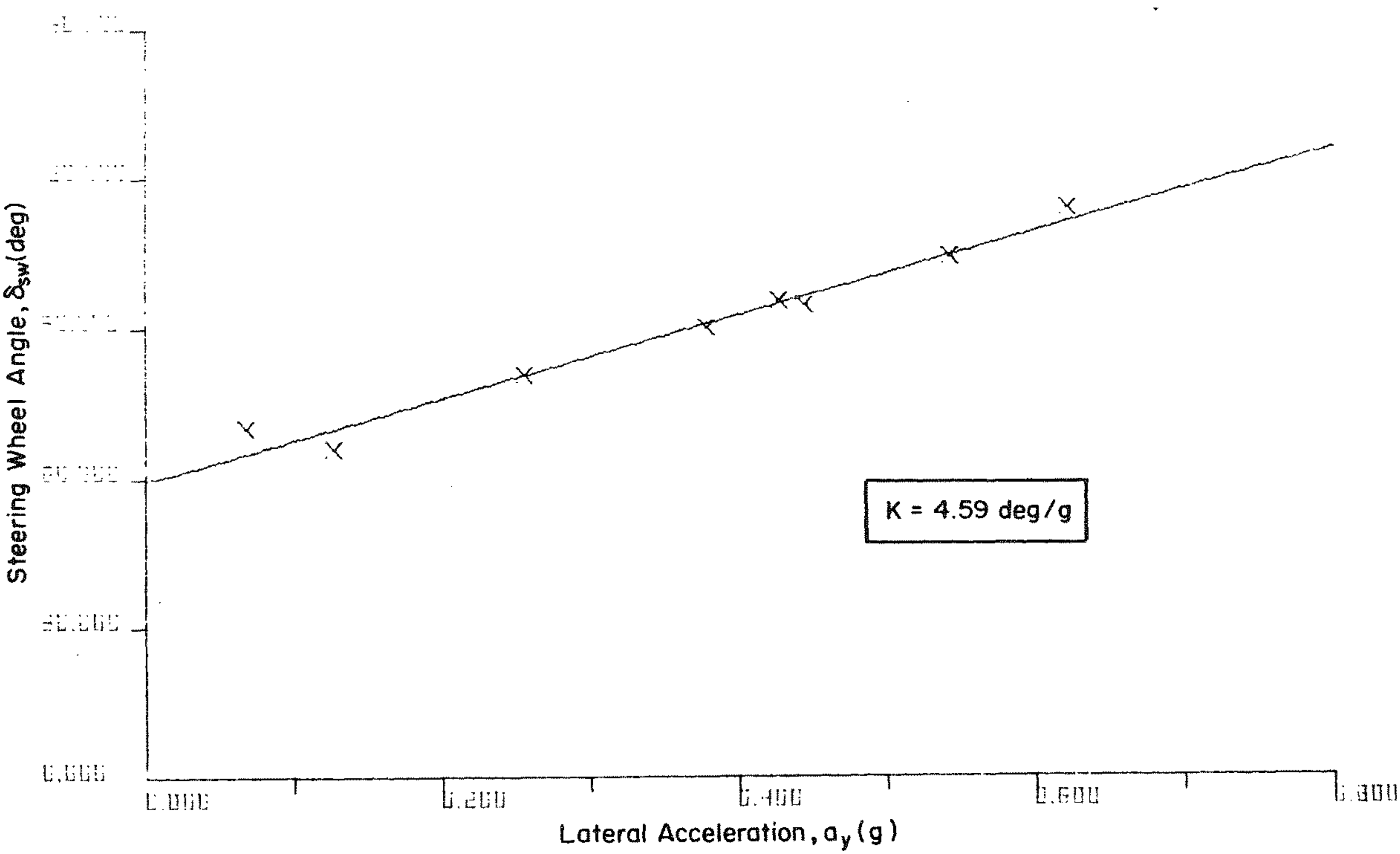


Figure E-11. Understeer Gradient for Horizon Alone — After Utility and Camper Trailer Tests, Run 133

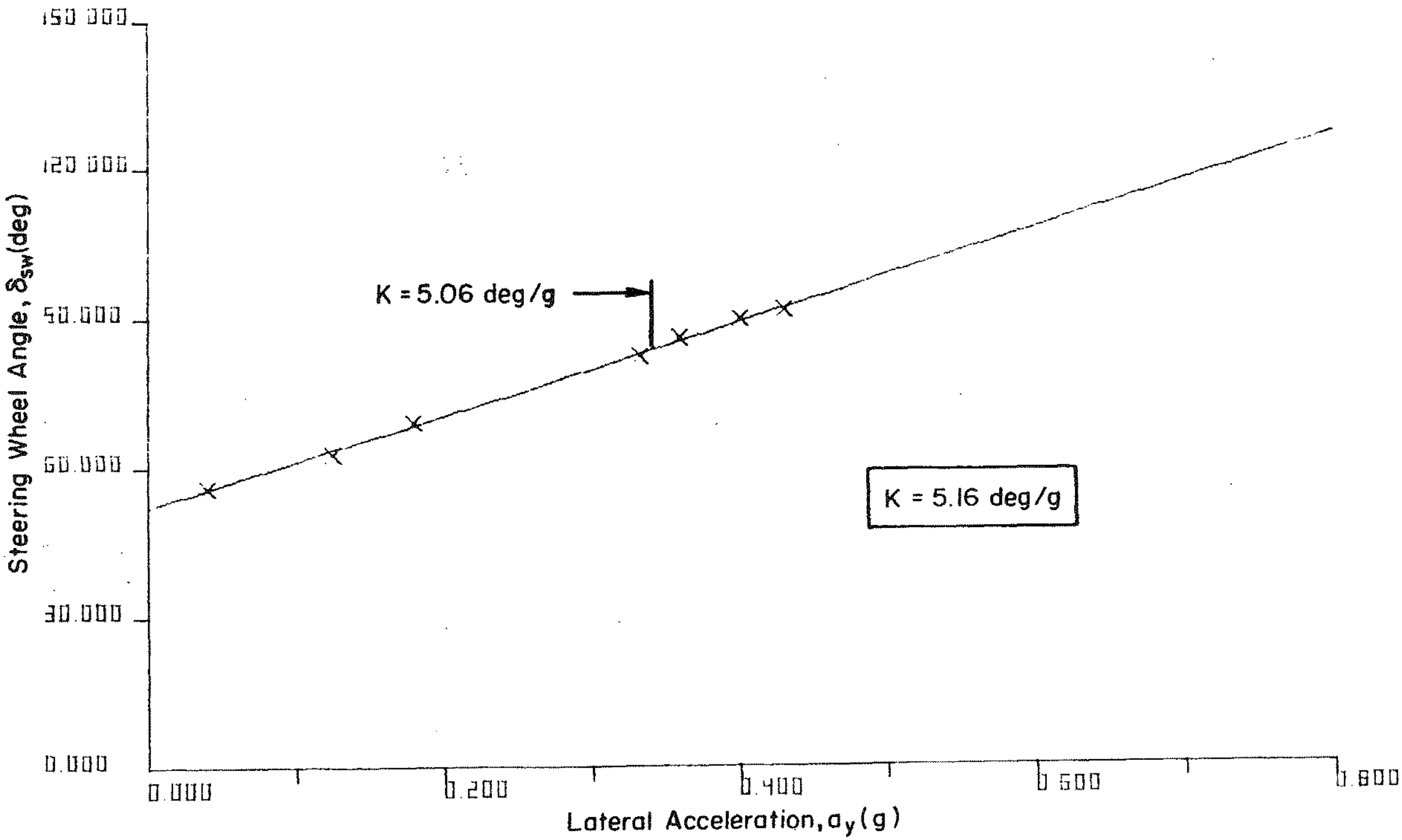


Figure E-12. Understeer Gradient for Horizon with 1500 lb U-Haul, 0 percent Hitch Load, Run 73

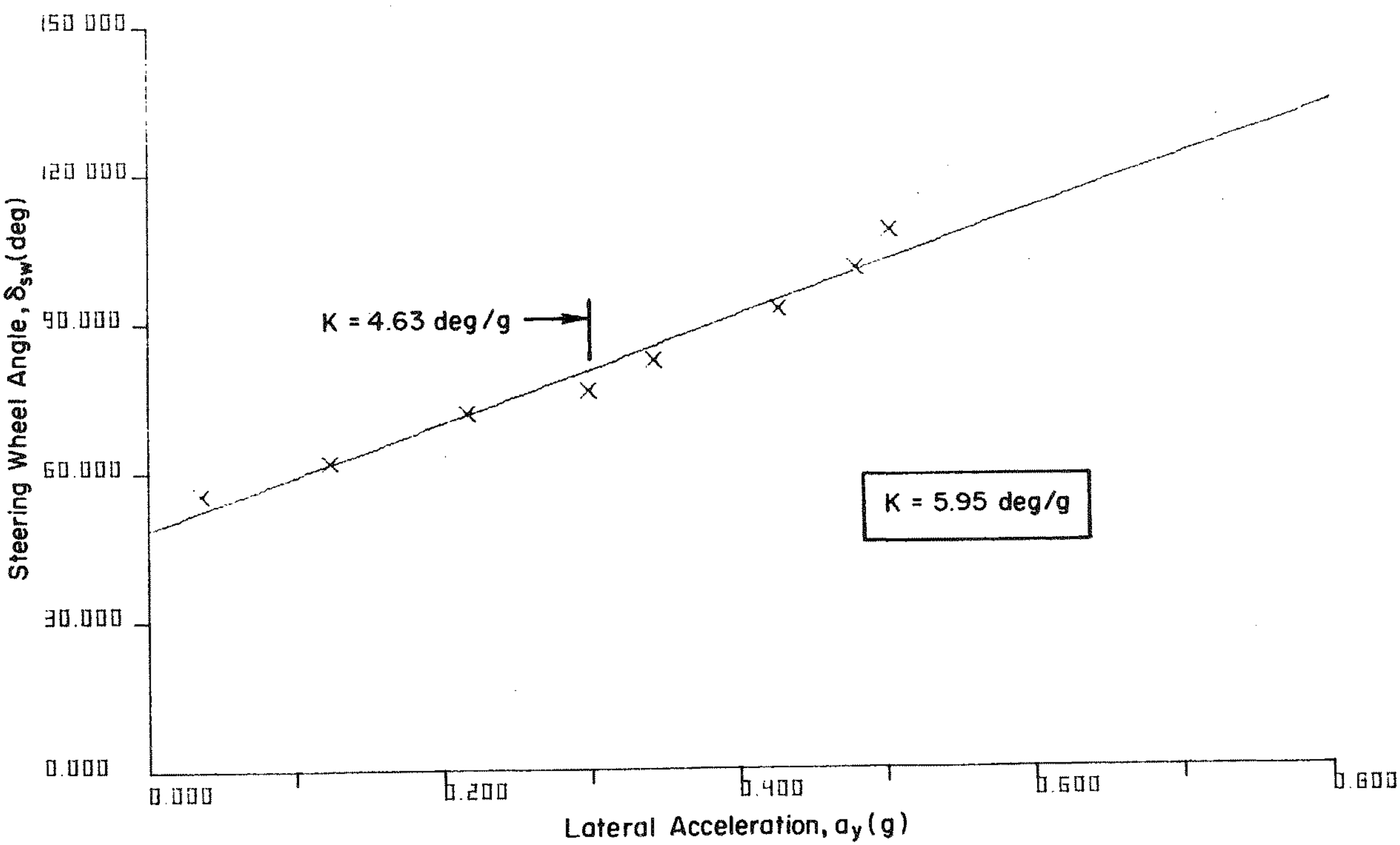


Figure E-13. Understeer Gradient for Horizon with 1500 lb U-Haul, 5 percent Hitch Load, Run 65

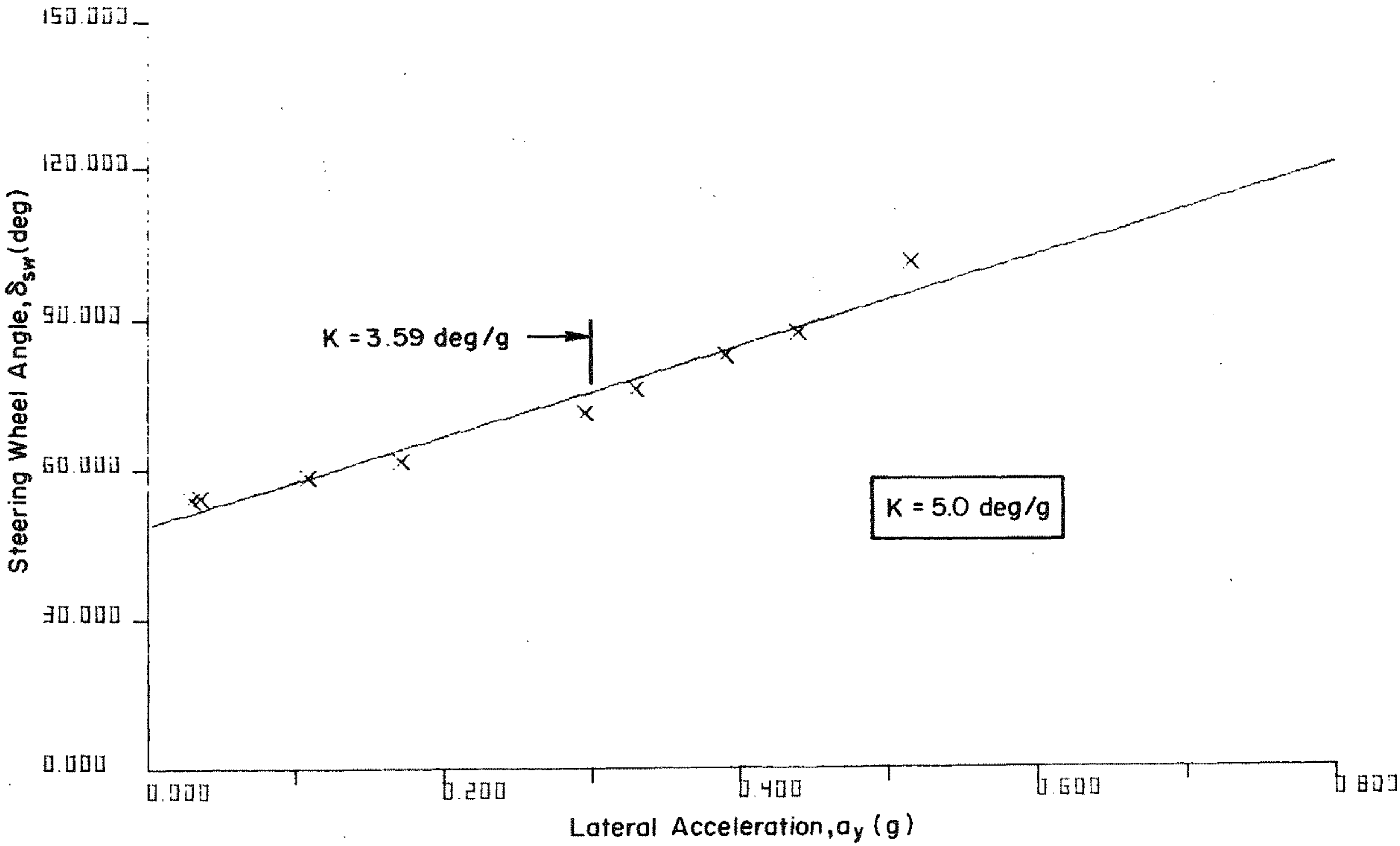


Figure E-14. Understeer Gradient for Horizon with 1500 lb U-Haul, 10 percent Hitch Load, Run 64

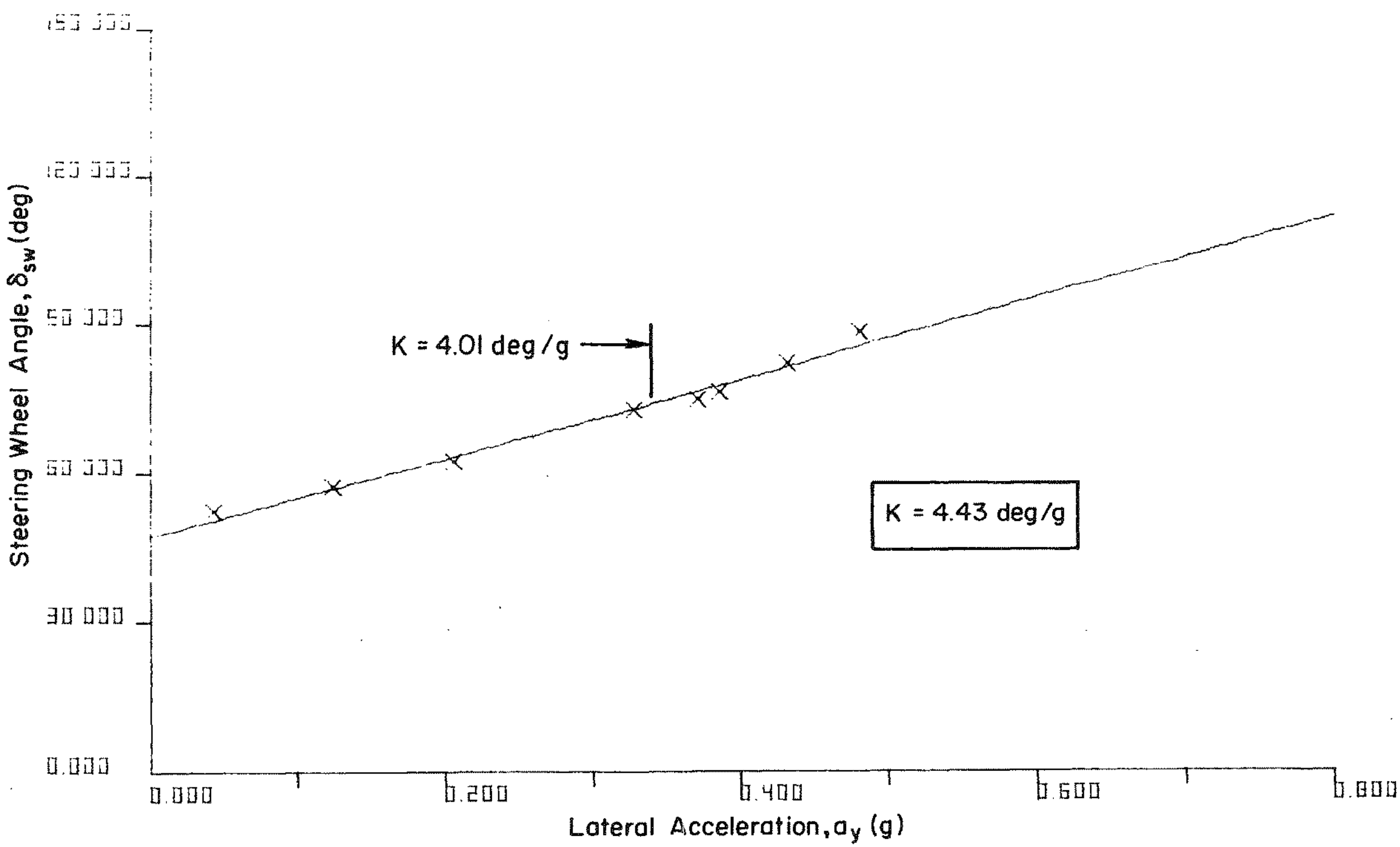


Figure E-15. Understeer Gradient for Horizon with 1500 lb U-Haul, 15 percent Hitch Load, Run 53

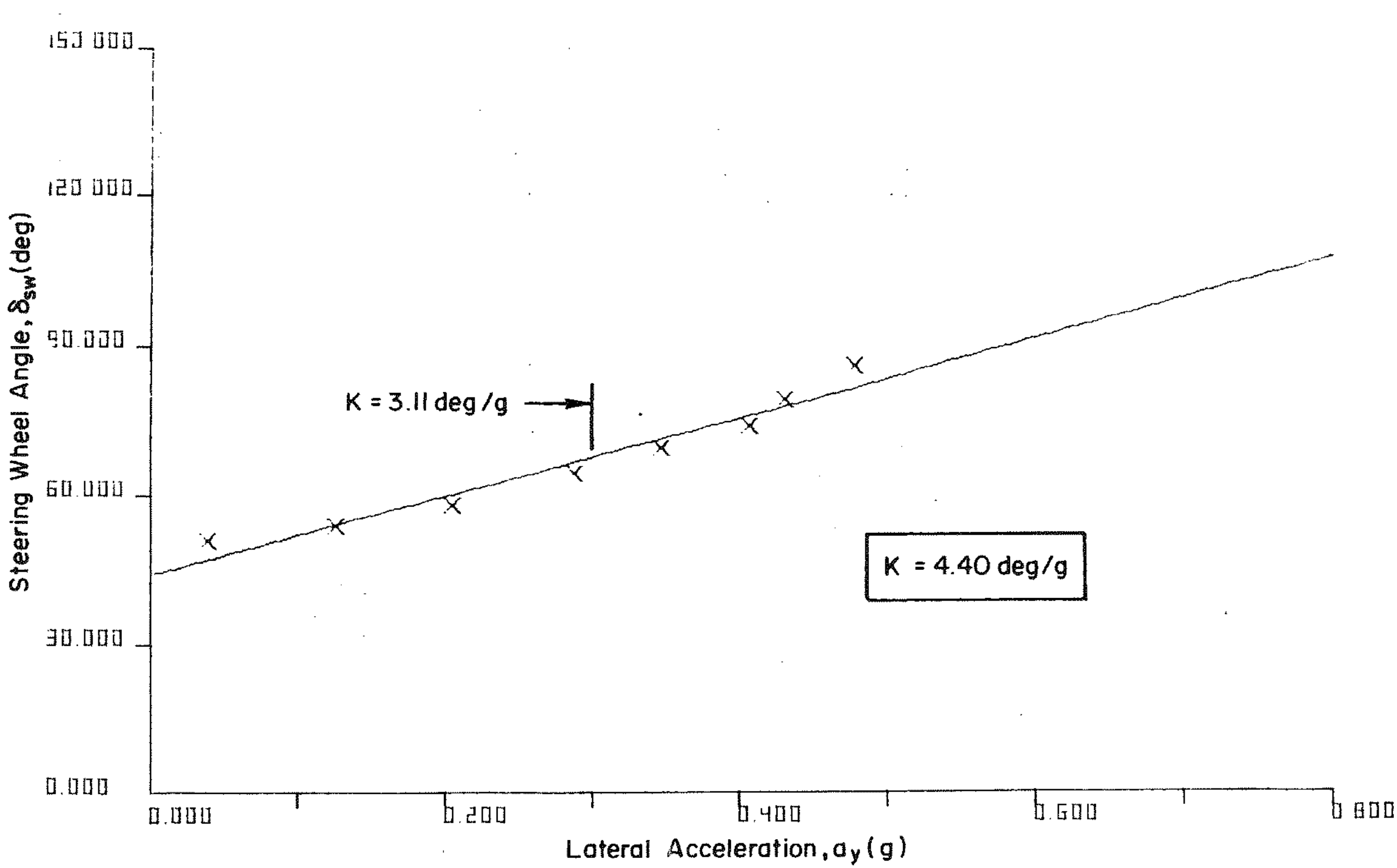


Figure E-16. Understeer Gradient for Horizon with 1500 lb U-Haul, 20 percent Hitch Load, Run 35

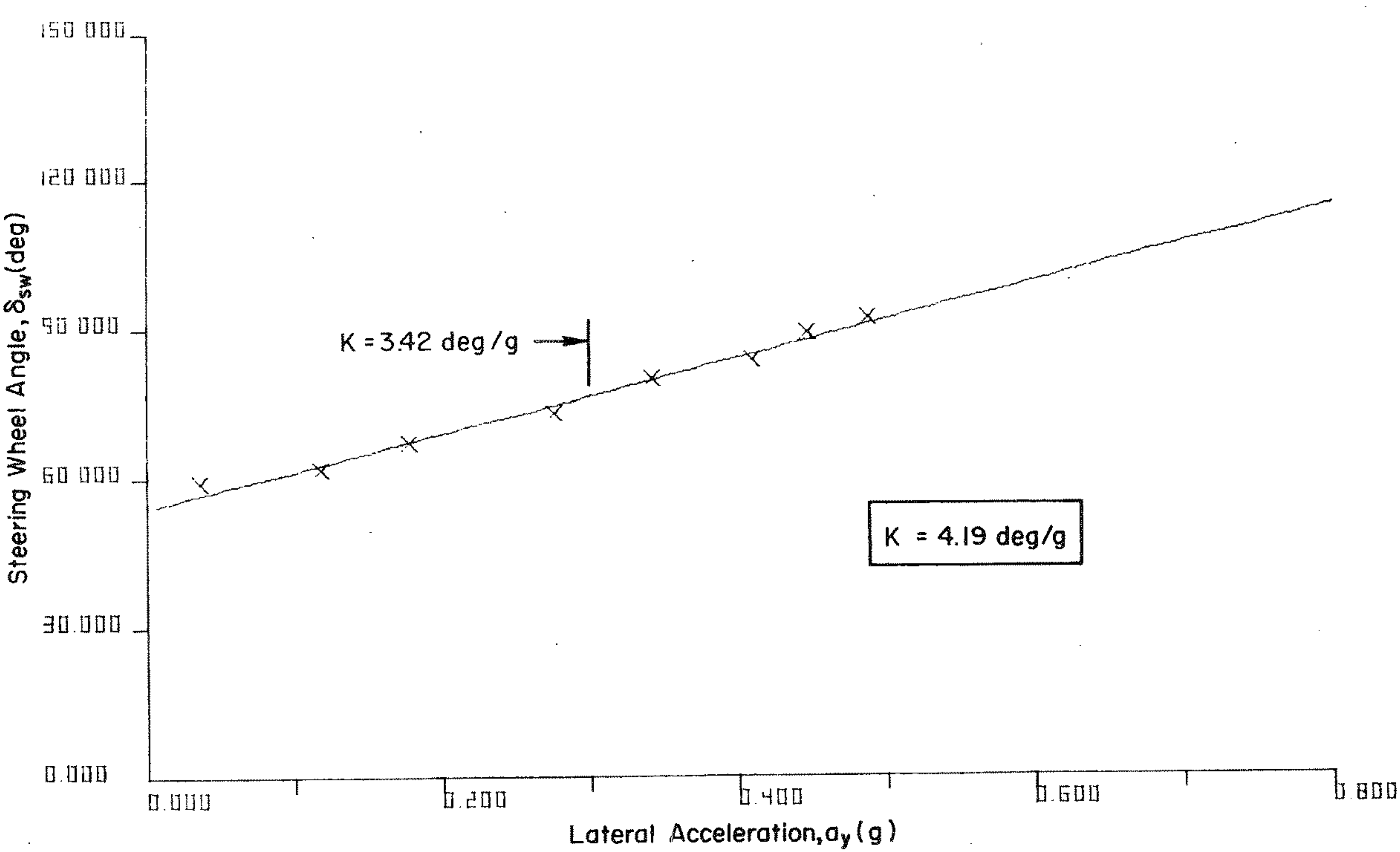


Figure E-17. Understeer Gradient for Horizon with 1600 lb Camper, 10 percent Hitch Load, Run 115

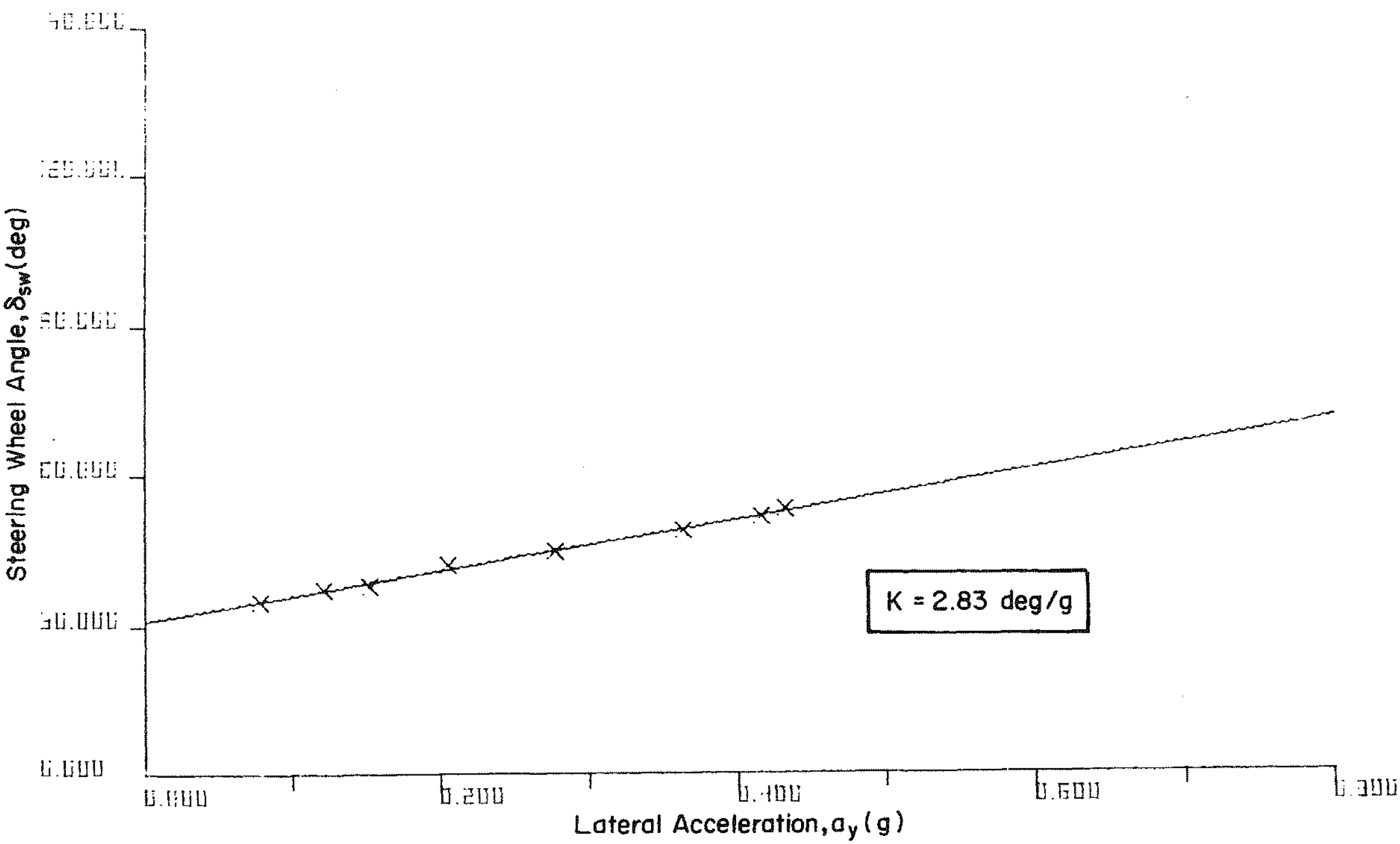


Figure E-18. Understeer Gradient for Horizon with 2400 lb Travel, 10 percent Hitch Load, Run 201