PE10-005

GM

4/14/2010

ATTACHMENT Q

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F. 285

SUMMARY

UNEXPECTED POWER STEERING FAILURE STUDY

OBJECT

The object of this study was to assess representative drivers' reactions and force output capabilities when confronted with an unexpected power steering failure.

EQUIPMENT

The required transducers and a 6-channel Brush recorder were installed in a 1969 Oldsmobile 98, with one channel set to record each of the following:

Steer Torque	$\pm$ 50 ft-lbs.
Steer Angle	$\pm$ 180° or 360°
Lateral Acceleration	$\pm$ 1.0 g
Fore-Aft Acceleration	$\pm$ 0.5 g
Velocity	0-50 mph
Brake Usage	Off-On

The mode of failure approximated a belt failure or pump failure. This was accomplished by placing an air-conditioning clutch on the power steering pump. This clutch could be engaged or disengaged by a switch which was concealed on the passenger side of the car. A switch connected to the ignition was also present to simulate engine failure, but this was not used during the experiment. Consequently, the drivers always had the ability to keep the car moving if they chose to use the accelerator.

The test courses were set up on the VDTA at the GM Proving Ground in Milford. The courses were outlined with traffic cones, plus metal guard rails in the critical areas where the failures would occur.

The experiment consisted of three phases; Intersection, Serpentine I, and Serpentine II. Each of these phases is described below.

TEST PROCEDURE

Subjects were told they were taking part in a speed holding and steering smoothness experiment. In all of the tests, each subject had the power steering failed in only the intersection or serpentine course, but not in both. During the experiment, subjects were given the chance to familiarize themselves with the course before the power steering was failed. After the first failure, each subject was then given a few runs through the course without the power steering being failed so as to reduce his expectancy of the next failure. The second time the power steering was failed was the final failure for each subject. For some subjects a second "surprise" was not possible. Guard rails were used to outline the sections of the courses in which the failures occurred to provide "realistic" motivation.

CONCLUSIONS

All men were capable of performing all tests. Men are therefore not instrumental in determining a critical effort value. Women shall most likely be the prime determiners of the minimum effort level the driving population would exert under these circumstances.

Serpentine I was too easy for even the women subjects. Even though 21% of the women exceeded their static hold levels during the maneuver, the course was judged too easy. This can be judged from Figure 2 and Figure 4.

The Intersection test required much more torque and allowed all women subjects to apply as much force as they chose in an attempt to complete the maneuver. However, the fact that the speed during the Intersection maneuver was only 7-10 mph allowed many subjects the alternative of stopping the car before hitting the rail, instead of turning through the intersection (3/16). See Table 1.

Serpentine II was designed to be more difficult than Serpentine I, being designed such that approximately 50% of all women should find it difficult to complete the course, based on known static hold data. However, 35% of the subjects were motivated to exert higher efforts during the maneuver than they were capable of during the static hold test (See Figures 2 and 4). There was, however, no significant correlation (r = .019) between effort in the maneuver and static hold effort (See Figure 3). Some subjects were motivated to exert higher efforts during the maneuver, but it cannot be said that the weak subjects raised their maximum levels under conditions of high motivation. That is, the 10th percentile subject on the static hold test was not necessarily the 10th percentile subject in the Serpentine II maneuver.

The lowest effort in Serpentine II was 240 in-lbs., or 30 lbs. rim force. This was the effort exerted by one of the women who did not successfully complete the course.

The total static hold distribution agreed closely with studies done by other researchers, therefore, the test sample of women had approximately the same distribution of static effort capability as the general population of women. Subjects for Serpentine II seemed stronger than subjects in Serpentine I study. See Figures 5 and 6.

APPLICATION OF RESULTS

The results of this study are being used as the basis for determining the criteria used to evaluate vehicle power-off steering effort for the 1970 Proving Ground Product Evaluation Program.

Two tests are being conducted on all vehicles in the evaluation. One is to measure peak efforts exerted in driving the "A" Curve with power inoperative. This is the test that has been used in the past and is being used again this year. It is a situation similar to the Intersection test in this study - a low speed, right angle maneuver. The other test being conducted is to slowly apply and release steering torques to the steering wheel of the car and plot steady-state lateral acceleration versus torque for a range of $\pm$ 1/4 g lateral acceleration (at 30 mph). This is a test similar to the Serpentine tests used in this study.

The results of this study are being used to determine the maximum allowable rim force on the steady-state torque versus lateral acceleration test. Since the lowest torque exerted by the women in our study was 240 in-lb (on a 16" wheel) the maximum allowable rim force level on the steer torque versus lateral acceleration curves at 1/4 g was taken to be 30*lb. Essentially, this means that any vehicle that requires more than 30*lb rim force to attain 1/4 g is judged to have excessive steer effort power-off.

The "A" Curve is similar to the Intersection test. Our results on this test indicate that steer effort was not the dominant variable in this situation, as 13/16 women elected to stop the car rather than turn, even though the engine was still running. Consequently, we were not able to determine a maximum allowable effort level for the "A" Curve test. The judgments are then being made on a relative basis, that is, relative to the best competitive car in a given evaluation group. To do this, use has been made of an existing principle in psychophysics or experimental psychology. A number of studies have been made to determine the ratio of a just noticable difference in a stimulus. This ratio is known as a Weber ratio. It has been found to be essentially independent of nominal value. That is, subjects have been found capable of identifying a 31 gram weight from a 30 gram weight, a 62 gram weight from a 60 gram weight, and a 93 gram weight from a 90 gram weight. Realizing that this 3% ratio was for lifting weights in a laboratory situation, we have chosen a 25% difference to be a readily noticable difference in steering effort. This is conservative and a more exact percentage will be determined by an experiment in the future. This 25% noticable difference ratio is also used in evaluating the steady-state lateral acceleration tests when the levels required are less than the absolute maximum level of 30*lb.

Fredrick W. Hill
Vehicle Dynamics Laboratory

A. Paul Lawrence
Vehicle Dynamics Laboratory

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F-285

* The actual number used as a criterion is 27 lb, which includes a provision for a 10% increase in torque due to transient maneuvers preceeding the steacy-state value.

TABLE 1. SUMMARY OF RESULTS

STUDY	APARATUS	SUBJECTS	RESULTS
INTERSECTION	Std. Oldsmobile Gear 26 psi F, 26 psi R Right Angle Intersection Course [See Figure 1]	8 Men	1. All subjects completed course successfully. 2. $\bar{\tau}$ = 425 in-lb, s.d. = 61 in-lb.
		8 Women	1. Two trials per subject (total = 8x2 = 16) 2. Three (3) successful trials 3. Twelve (12) stops in the Intersection. 4. 1/16 subject froze and hit guard rail. 5. $\bar{\tau}$ = 230 in-lb, s.d. = 87 in-lb.
SERPENTINE I	Std. Oldsmobile Gear 26 psi F, 26 psi R Rail disp. = 10 ft [See Figure 1]	8 Men	1. All subjects completed course successfully. 2. $\bar{\tau}$ = 217 in-lb, s.d. = 16 in-lb.
		8 Women	1. All subjects completed course successfully. 2. $\bar{\tau}$ = 211 in-lb, s.d. = 25 in-lb.
SERPENTINE II	11-1 Gear 20 psi F, 26 psi R Rail Disp. = 5 ft. [See Figure 1]	16 Women	1. Two trials per subject (total = 16x2 = 32). 2. 29 successful completions of course. 3. 2/32 deviated slightly off-course. 4. 1/32 subject hit guard rail. 5. 2/32 subjects slowed down considerably. 6. 1/32 subject stopped completely in course. 7. $\bar{\tau}$ = 322 in-lb, s.d. = 38 in-lb.
STATIC CAPABILITIES	Test car with power inoperative - u = 0 [See Figure 4]	All Women Subjects (32 Women)	1. Peak $\bar{\tau}_{avg}$ = 428 in-lb, $s.d._{avg}$ = 98 in-lb. 2. Hold $\bar{\tau}_{avg}$ = 298 in-lb, $s.d._{avg}$ = 90 in-lb.

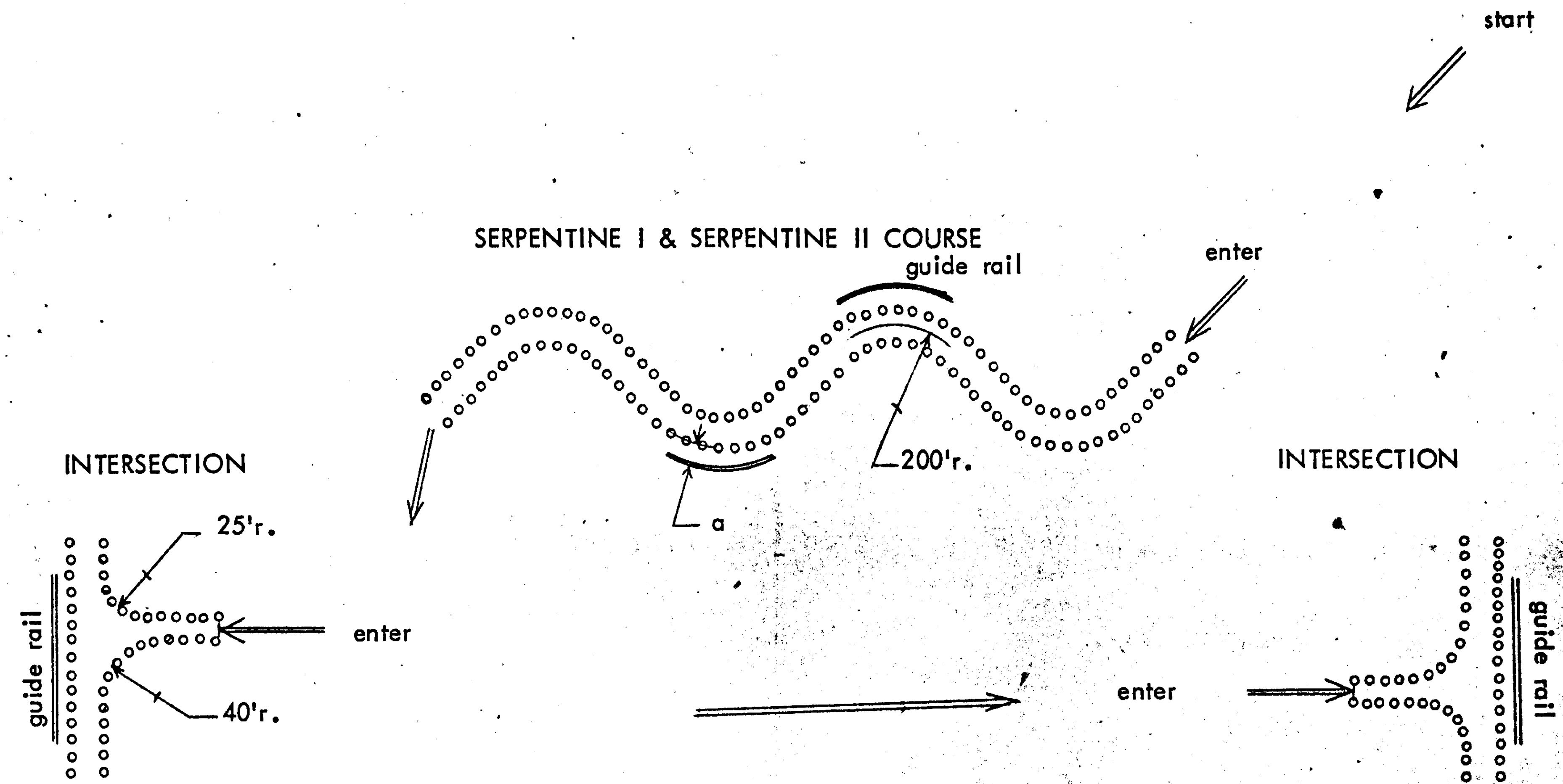


DIAGRAM OF COURSES USED IN
SURPRISE POWER STEERING FAILURE STUDY
ON VDTA.

FIGURE 1

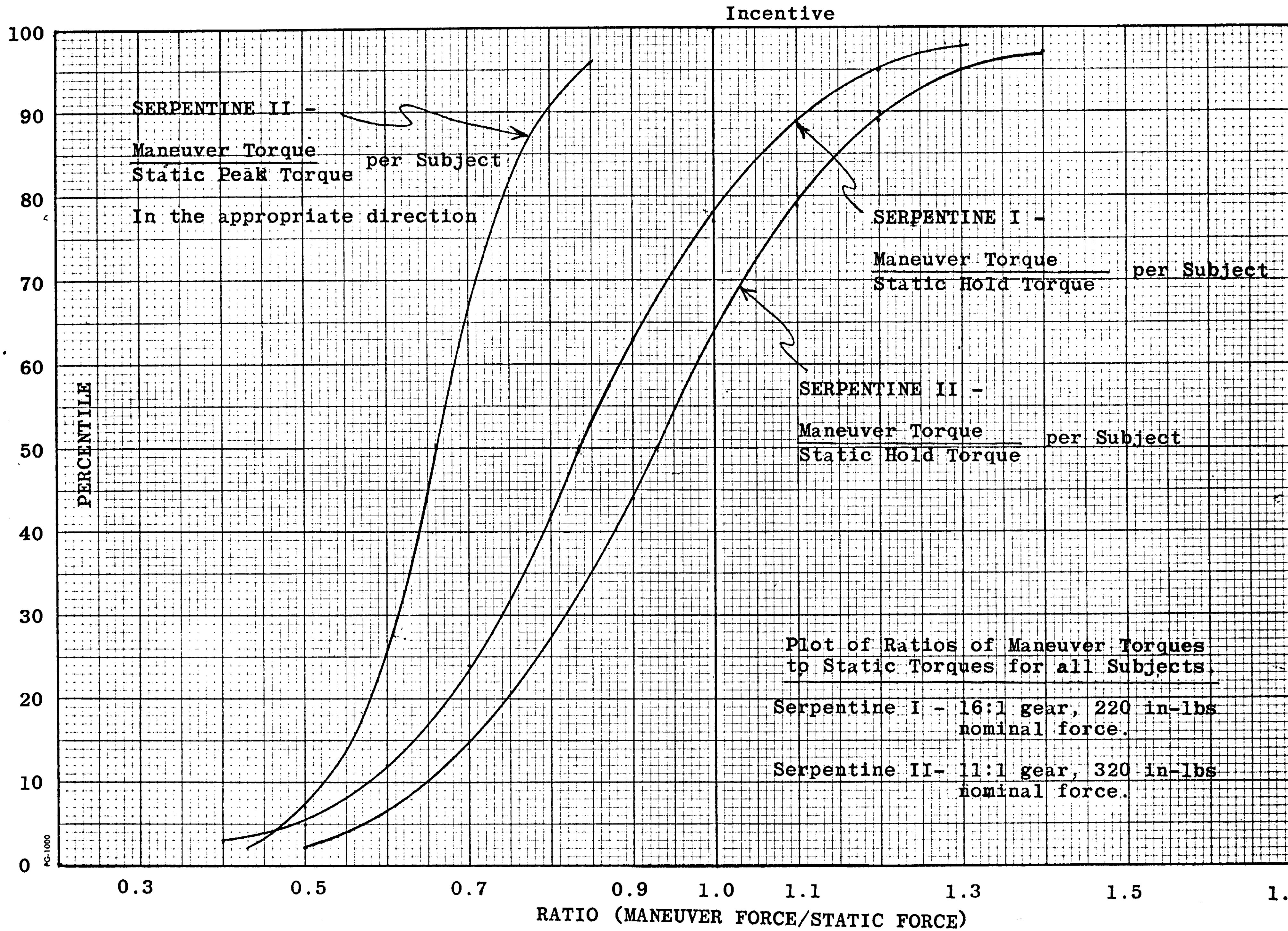

Incentive
SERPENTINE II -
Maneuver Torque / Static Peak Torque per Subject
In the appropriate direction
SERPENTINE I -
Maneuver Torque / Static Hold Torque per Subject
SERPENTINE II -
Maneuver Torque / Static Hold Torque per Subject
Plot of Ratios of Maneuver Torques to Static Torques for all Subjects.
Serpentine I - 16:1 gear, 220 in-lbs nominal force.
Serpentine II- 11:1 gear, 320 in-lbs nominal force.
PERCENTILE
0
10
20
30
40
50
60
70
80
90
100
0.3
0.5
0.7
0.9
1.0
1.1
1.3
1.5
1.7
RATIO (MANEUVER FORCE/STATIC FORCE)

FIGURE 2

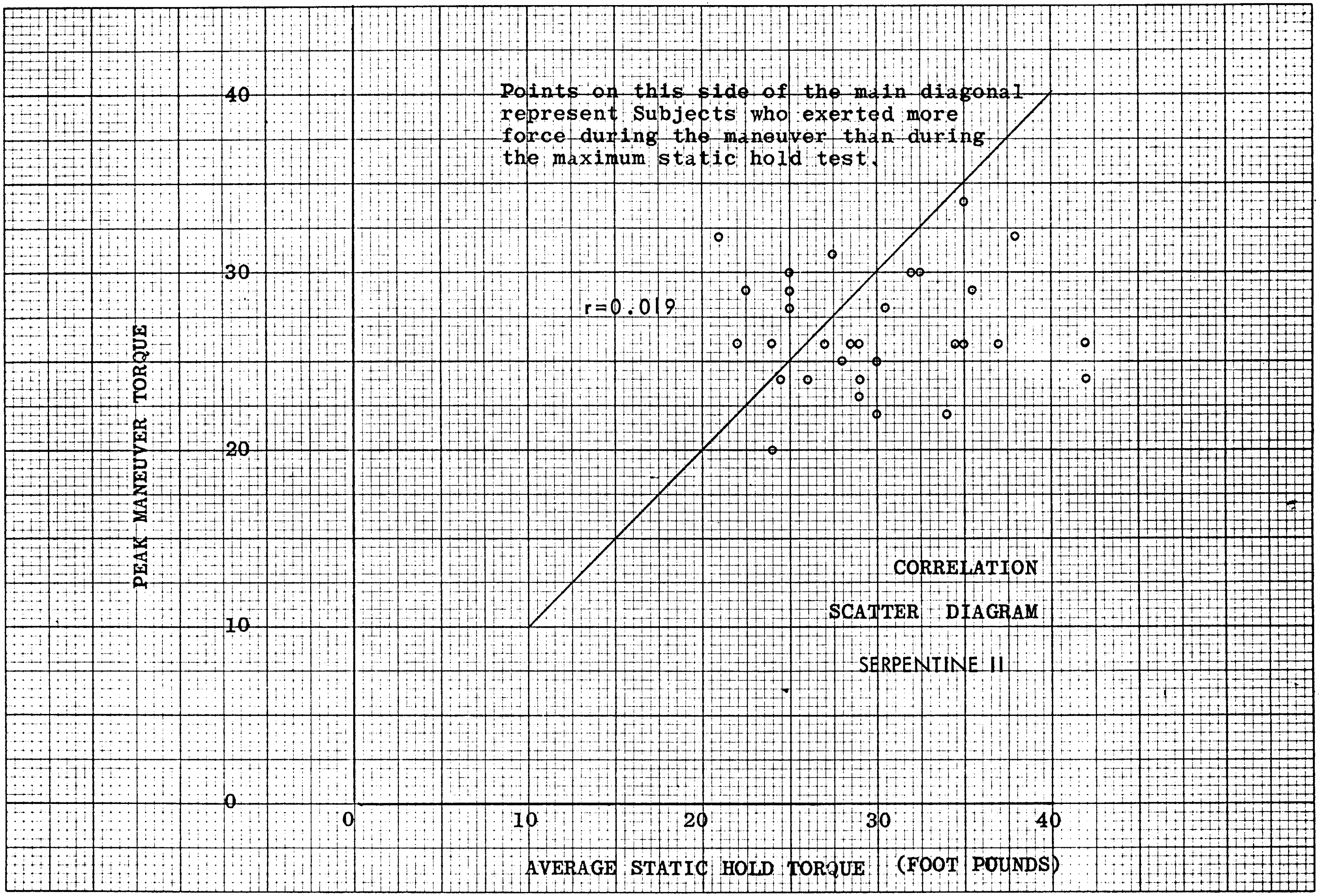


FIGURE 3

PG-1000

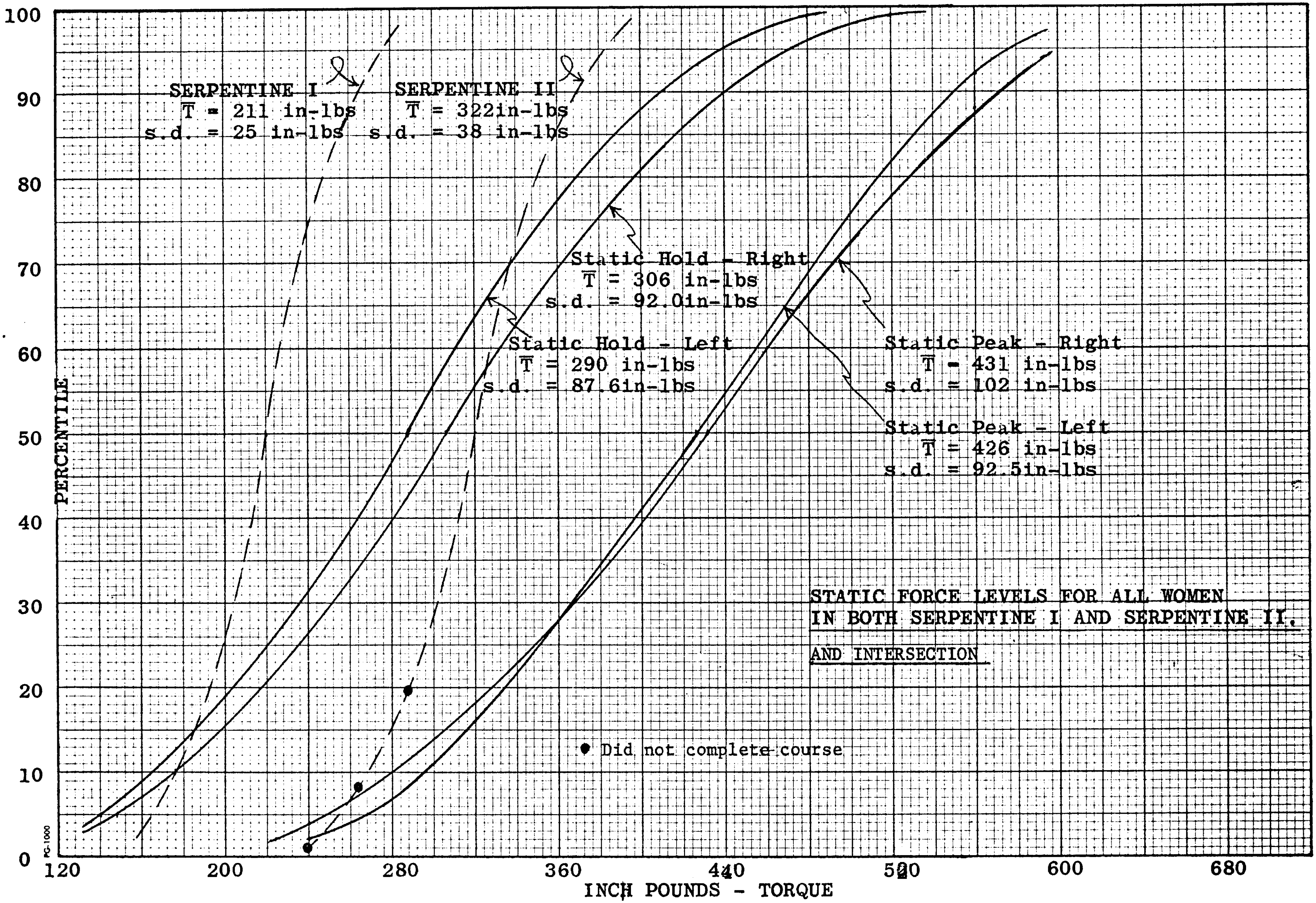
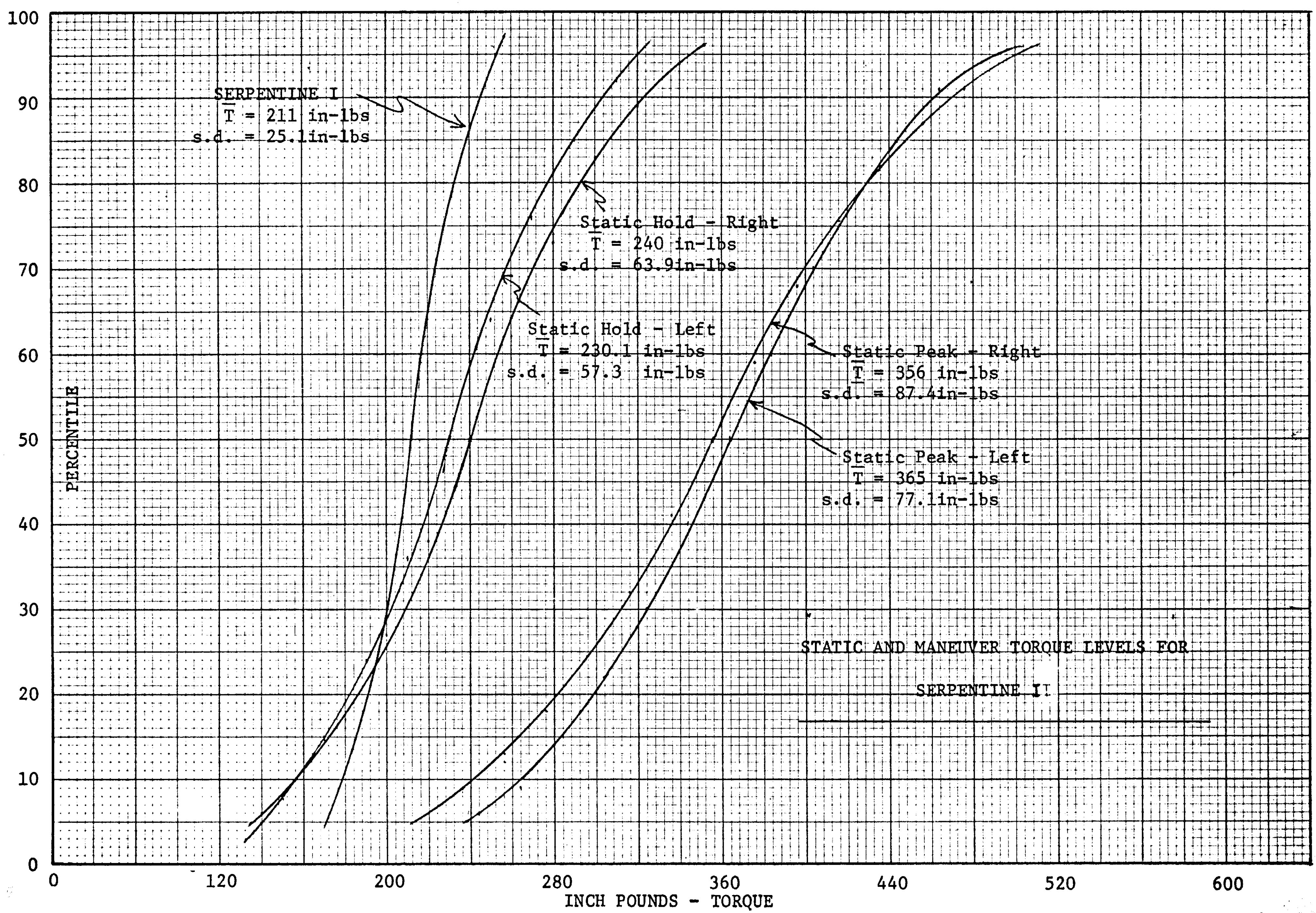

SERPENTINE I
T̄ = 211 in-lbs
s.d. = 25 in-lbs
SERPENTINE II
T̄ = 322in-lbs
s.d. = 38 in-lbs
Static Hold - Right
T̄ = 306 in-lbs
s.d. = 92.0in-lbs
Static Hold - Left
T̄ = 290 in-lbs
s.d. = 87.6in-lbs
Static Peak - Right
T̄ = 431 in-lbs
s.d. = 102 in-lbs
Static Peak - Left
T̄ = 426 in-lbs
s.d. = 92.5in-lbs
STATIC FORCE LEVELS FOR ALL WOMEN
IN BOTH SERPENTINE I AND SERPENTINE II.
AND INTERSECTION
● Did not complete course
PERCENTILE
0
10
20
30
40
50
60
70
80
90
100
120
200
280
360
440
520
600
680
INCH POUNDS - TORQUE

FIGURE 4



STATIC AND MANEUVER TORQUE LEVELS FOR SERPENTINE I

FIGURE 5

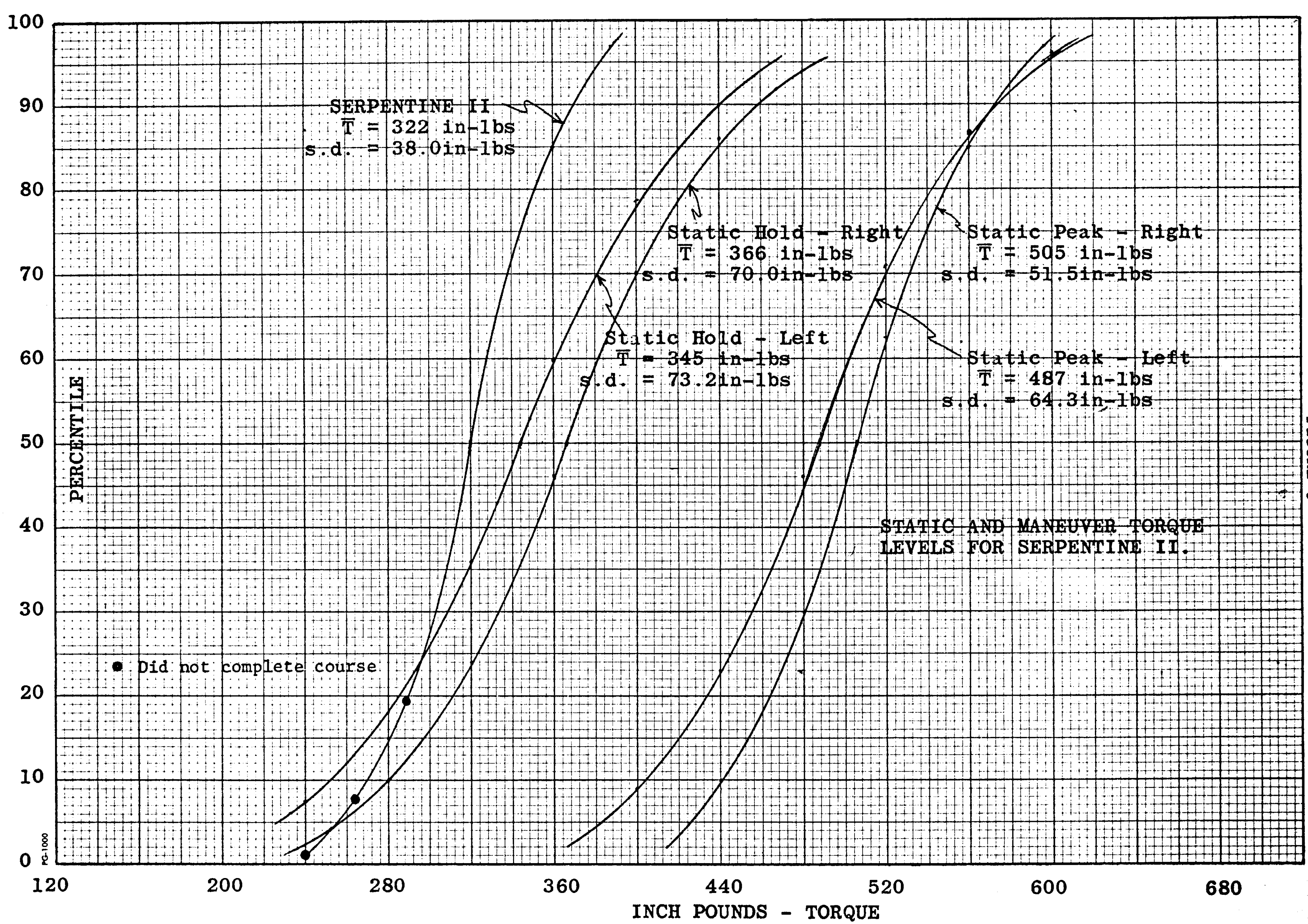

SERPENTINE II
$\overline{T}$ = 322 in-lbs
s.d. = 38.0in-lbs
Static Hold - Right
$\overline{T}$ = 366 in-lbs
s.d. = 70.0in-lbs
Static Peak - Right
$\overline{T}$ = 505 in-lbs
s.d. = 51.5in-lbs
Static Hold - Left
$\overline{T}$ = 345 in-lbs
s.d. = 73.2in-lbs
Static Peak - Left
$\overline{T}$ = 487 in-lbs
s.d. = 64.3in-lbs
STATIC AND MANEUVER TORQUE
LEVELS FOR SERPENTINE II.
● Did not complete course
PERCENTILE
100
90
80
70
60
50
40
30
20
10
0
120
200
280
360
440
520
600
680
INCH POUNDS - TORQUE
PG-1000

FIGURE 6

PE10-005

GM

4/14/2010

ATTACHMENT Q

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OLDS 1014

OLDSMOBILE DIVISION

GENERAL MOTORS CORPORATION

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TO R. A. Dorshimer ADDRESS

FROM D. L. Nordeen ADDRESS

SUBJECT POWER-OFF STEERING EFFORT DATE January 9, 1970

This letter outlines the status of this program and the presentation planned for the General Technical Committee on this subject. Both the work to be done and the proposed GTC presentation have become better defined with both subjects being discussed in several informal meetings among the Proving Ground, Saginaw Steering Gear and Oldsmobile and at the December Chassis Subcommittee Meeting.

There are at least five areas for further investigation:

(1) Development of a proposed power-off steering effort criteria (Olds, P.G., S.S.G.)

(2) Analysis and identification of tire and vehicle factors contributing to steering effort (P.G., S.S.G.)

(3) Measurement of power-off steering effort of General Motors and competitive vehicles and interpretation of the data (P.G.)

(4) Investigation of vehicle and tire changes to reduce steering effort with the constraints of existing tooling - for 1973-75 models (Olds, S.S.G.)

(5) Investigation of vehicle and tire changes to reduce steering effort without being restricted to use existing tooling - for 1975 models or later (Eng. Staff, Olds, S.S.G.)

The presentation to the GTC should include a discussion of all of these areas with emphasis on actions Management can take to reduce the steering effort through design changes and/or to conclude that power-off steering effort is not a problem. Since some of the information will not be available for several months, the presentation to the GTC should not be made until April at the earliest. Possibly, the Chassis Subcommittee should select the material, demonstrations and alternatives to be presented.

The existing knowledge and work remaining for each of the above areas is discussed in greater detail in Attachment I. Attachment II lists specific items that will be investigated by Saginaw Steering Gear, Proving Ground, Engineering Staff, and Oldsmobile. The program outlined in this letter has been discussed with Engineering Staff, Proving Ground and Saginaw Steering Gear with general agreement obtained.

Donald L. Nordeen

Donald L. Nordeen
Asst. Chassis Engineer

ch
Atts.

ATTACHMENT I

POWER-OFF STEERING EFFORT
Program, Demonstration and GTC Presentation

This attachment provides more detail regarding the General Motors program to establish steering effort criteria, identification of vehicle modifications and compromises to reduce steering effort, and the presentation of the problem and alternatives to the General Technical Committee to resolve this question.

The program is a Corporation program with project involvement at Oldsmobile, Chevrolet, Saginaw Steering Gear, Engineering Staff and the Proving Ground. There are at least five areas for further investigation:

(1) Development of a proposed power-off steering effort criteria.

(2) Analysis and identification of tire and vehicle factors contributing to steering effort.

(3) Measurement of power-off steering effort of General Motors and competitive vehicles and interpretation of the data.

(4) Investigation of vehicle and tire changes to reduce power-off steering effort within the constraints of existing tooling -- for 1973-1975 models.

(5) Investigation of vehicle and tire changes to reduce power-off steering effort without being restricted to use existing tooling -- for 1975 models or later.

The knowledge and work remaining for each of these areas is expanded below including which groups will undertake the various parts of the program.

Criteria

In the design of a power steering system, maximum attention and first priority should be given to the performance of the system with power assist operative. Further, the system should be designed for maximum reliability of the primary power system, thus making the failure of the power system a low-probability event. An estimate of the reliability of the power assist system will be made. With a high reliability of the power system, the power steering system need not be designed to provide full performance in the event of a failure of the primary power assist system. This is the philosophy employed in the design of the braking system and reflected in the brake system standards. Reduced braking performance is obtained in the event of power assist failure or of front or rear hydraulic system failure.

Similarly, the power steering system need not be designed for the simultaneous occurrence of a power system failure in an emergency driving circumstance. Since these two occurrences are nearly independent and each has low probability, the probability of the combination is extremely small. It seems rather that the power steering system design should allow a majority of drivers to complete the maneuver during which the failure of the power assist occurs, and to bring the vehicle safely to a stop. This means that the effort for normal maneuvers with power assist inoperative should be less than the steering capability of a majority of the driving population.

Only limited data exist, however, to define normal driving. Published data indicate that the lateral accelerations used in normal driving decrease as the speed increases. Since the stopping distance at lower vehicle speeds is short, a safety-related circumstance has not been identified with loss of power assist below 30 mph. It is therefore concluded that the most critical speed for loss of power assist is the 30-35 mph speed range. From existing data, it appears that 95% of the female drivers operate below 0.25g lateral acceleration in this speed range.

There are a number of questions regarding the existing data defining normal driving. Does the variation in lateral acceleration used by female drivers correlate with steering effort capabilities? (Do "weak" drivers operate at lower lateral accelerations?) Is the recorded lateral acceleration the maximum lateral acceleration observed during the corner or the average? Has the proper compensation for vehicle roll and road superelevation been made in the recorded data? What is the performance of the female drivers in making the critical driving maneuver (as selected for the steering system evaluation) with power assist operative? How much handling performance is lost if power assist is not operative?

The work at the Proving Ground to develop the performance criteria should continue with Oldsmobile assisting with vehicles and vehicle modifications. The approval of the criteria should be made the responsibility of the Chassis Subcommittee.

Steering Effort Analysis

Much of this work has already been completed by Chevrolet as part of their analysis of effort of manual steering vehicles. Their analysis included the development of a computer program to estimate steering effort from vehicle and tire parameters. An analysis by Oldsmobile, on a more limited basis, agrees with the conclusions from the Chevrolet study. These analyses can provide the basis for interpreting the steering effort data on GM and competitive vehicles and in indicating the vehicle and tire parameter changes which should result in reduced steering effort. The analysis has been verified by Chevrolet. This verification will be made more complete through the steering effort measurements by the Proving Ground on production and modified vehicles. The change in steering effort with tire wear will be measured by the Proving Ground. The change in efficiency of the steering gear with miles will be determined by Saginaw Steering Gear.

Steering Effort Measurements

Much of this work has been completed by the Proving Ground during their product performance evaluation of 1970 GM and competitive vehicles. The work remaining is the analysis of the data, repeat testing on certain vehicles to identify causes of discrepancies in the existing data, and correlation of the effort data with vehicle and tire parameters (at the minimum this should involve the measurement of overall steering ratio of selected 1970 vehicles). Steering effort measurements have already been completed on two vehicles with modified front suspensions. The first is one built by SSG for reduced manual steering effort and the second is one built by Engineering Staff which has a zero scrub radius. The Proving Ground will continue to make the steering effort measurements on vehicles with modified suspensions and/or different tires.

The Proving Ground will also undertake an analysis of power-on steering effort by tabulating such factors as steering torque gradient, maximum steering torque, and steering system hysteresis for the 1970 cars.

Vehicle and Tire Parameter Changes (Short Term)

Without changing the knuckle, control arms, and steering system layout, it should be possible to achieve some reduction in steering effort. Compensating changes may be required to maintain on-center stability, returnability, and minimum wheel fight in obtaining the reduced steering effort. It appears that suspension attachment point relocations, wheel alignment changes, and steering gear efficiency improvements are the most fruitful items for investigations. To maintain on-center stability and returnability, power steering valve changes, reduced friction in the steering gear (both forward and reverse) and reduced ball-joint friction are likely to be required. Since all of these changes tend to aggravate wheel fight, a steering system damper may be required. This will be a cooperative project among Oldsmobile and Saginaw Steering Gear.

Radial-ply tires will also be considered because the reduced camber stiffness should result in reduced steering effort, but with reduced vehicle understeer. The steering effort can also be reduced by increasing front tire inflation pressure which will also reduce vehicle understeer. In both cases, compensating changes, such as increased front roll understeer and/or aligning torque compliance steer, will be required to maintain current handling performance. This phase of the project will be handled by Oldsmobile with assistance from the Proving Ground in measuring tire properties and steering effort. The suspension modifications will be discussed with Chevrolet.

In evaluating the vehicle and tire parameter changes, careful attention will be given to all aspects of vehicle ride and handling to identify what compromises must be made to reduce steering effort.

Vehicle and Tire Parameter Changes (Long Term)

There is potential for further reduction in steering effort if knuckles, control arms, etc. can also be redesigned. The steering effort analysis indicates that moving the kingpin axis rearward with respect to the spindle axis allowing a large negative caster offset with a large positive caster angle should reduce the steering effort. The short term changes discussed above can also be incorporated. It may be possible to control the wheel fight by relocating the shock absorber from the control arm attachment to an attachment to the knuckle forward of the kingpin axis and inclined inward to the frame attachment. This could eliminate the need for a separate steering system damper.

Work to develop tires with reduced aligning torque should also be undertaken. Stability augmentation through the steering system should be investigated as this may allow reduction in effort through use of large negative caster without impairing on-center stability and returnability. These long-range projects will be undertaken by Engineering Staff with assistance from Saginaw Steering Gear and Oldsmobile Advance Design.

Again, careful attention should be given to all aspects of vehicle ride and handling to identify the compromises made to reduce steering effort.

Steering Effort Demonstrations

To provide a better comprehension of the steering effort problems, a demonstration is planned at the Proving Ground with the PG handling the arrangements for all engineering groups working on the problem. This demonstration will include the vehicle and courses used to obtain the steering effort capabilities, a Toronado provided by Olds and equipped with an electro-hydraulic power reserve system, and a vehicle (also provided by Olds) which has the maximum power-off effort allowed by the Proving Ground criteria (25 lb. rim force at 0.25g lateral acceleration). Because of the uncertainty of the weather occuring in the winter months, it is unlikely that this demonstration can be scheduled until March or April.

GTC Presentation

The timing for this presentation would be better for April or later when the weather is more certain for a good demonstration and when more results should be available. The proposed presentation should be reviewed by the Chassis Subcommittee. This procedure should allow resolution of the competing requirements of the presentation and should provide for the presentation of alternatives on which the GTC can act. The Chassis Subcommittee is an important group regarding the presentation. They are in the best position to select the subject content and alternatives to be presented and to select the person who can best make the presentation.

An outline for this presentation has been prepared and discussed among Oldsmobile, Saginaw Steering Gear and the Proving Ground. The preparation for the GTC presentation should continue, possibly at the direction of the Chairman of the Chassis Subcommittee.

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ATTACHMENT II

POWER-OFF STEERING EFFORT
Project Responsibilities

Oldsmobile

(1) Investigate vehicle modifications to reduce steering effort for the 1973-75 models.

(2) Provide Toronado equipped with electro-hydraulic power reserve system for demonstration.

(3) Assist the Proving Ground by providing vehicles and vehicle modifications for human factors studies.

(4) Maintain close contact with Engineering Staff on the project to reduce steering effort for the 1975 and later models.

(5) Determine magnitude of steering effort reduction with radial ply tires and with increased inflation and determine vehicle changes to maintain handling properties.

(6) Estimate the reliability of the power assist system.

Saginaw Steering Gear

(1) Determine efficiency change with miles of the power steering gear.

(2) Investigate methods for increasing the mechanical efficiency of the power steering gear.

(3) Investigate methods for reducing the zero-load friction of the steering gear.

(4) Provide steering linkage joints and ball joints with reduced friction.

(5) Investigate methods for reducing the hydraulic boost for small steering inputs.

(6) Hardware development for stability augmentation.

Proving Ground

(1) Development of proposed criteria for acceptable steering effort with power assist inoperative.

(2) Determine effect of tire wear on steering effort.

(3) Continued measurement of steering effort on 1970, 1971 and modified vehicles.

(4) Analysis of the test data - both power on and power off.

(5) Handle arrangements for the demonstration to the chassis engineers and the GTC.

Engineering Staff

(1) Investigate vehicle modifications to reduce steering effort for the 1975 and later models.

(2) Work with the tire companies on the development of tires with reduced aligning torque.

(3) Analysis of steering system augmentation proposals and further investigation of augmentation possibilities.

Chassis Subcommittee

(1) Select the criteria for acceptable steering effort with power assist inoperative.

(2) Approve the content of the presentation to the GTC on this problem.

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GM

4/14/2010

ATTACHMENT Q

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1970_02_03_fwh_memo

Fredrick W. Hill
February 3, 1970

FILE MEMO F-285

SUMMARY OF LITERATURE ON DRIVER LATERAL ACCELERATION BEHAVIOR

An investigation of available literature pertaining to the lateral acceleration behavior of the driving public indicates that there are few applicable articles available. There are a number of somewhat pertinent articles, but many of these are incomplete, inaccurate, or concern particular situations only. A review of the most pertinent and apparently accurate papers has resulted in the following conclusions pertinent to driver maximum lateral acceleration behavior.

1. The best study found indicating driver habits gives a "comfortable" lateral acceleration distribution at 30 mph for 25 women drivers with a mean = 0.187g and s.d. = 0.075. These were apparently not corrected for vehicle roll. A reduction in lateral acceleration corresponding to 8 deg/g roll stiffness gives a 50th percentile level of 0.164g and a 90th percentile level of 0.249g for women.

2. A review of highway design guides indicates the highest allowable lateral accelerations at design speeds are for intersection curves, with a nominal maximum of 0.22g at 30 mph.

3. These statements and others indicate that it is certainly conceivable that 10% of the women drivers would willingly attain 0.22-0.25g at 30 mph in an intersection turn on public roads without considering it excessive.

4. If steering effort tests and/or criteria are going to include situations that are somewhat beyond the "comfortable" region of lateral acceleration for this 10% of women drivers, a 0.25g maneuver at 30 mph can be considered conservative.

5. There is no known study which correlated lateral acceleration behavior and physical strength.

Some of the pertinent works are summarized on the following pages.

Malcolm L. Ritchie, et al, Ritchie Inc., Dayton, Ohio. "A Study of the Relation Between Forward Velocity and Lateral Acceleration in Curves During Normal Driving", Human Factors, 10(3), 1968, pp 255-258.

Vehicle Speed and lateral acceleration were monitored as fifty (25 male, 25 female) subjects drove a 110 mile course "comfortably" on public roads. Distributions of lateral acceleration versus speed were reported. (Apparently not corrected for accelerometer roll angle). The resulting distributions of lateral acceleration at 30 mph were, (See Figure 1)

Men: $\bar{a}_y = .216g$, s.d. = .085
Women: $\bar{a}_y = .187g$, s.d. = .075
] Not corrected for roll, apparently.

Corrected Percentiles:			Uncorrected:	
	Women	Men	Women	Men
10	.080	.093	.091	.106
50	.164	.190	.187	.216
90	.249	.286	.283	.326

J. G. Smith and J. E. Smith, "Lateral Forces on Vehicles During Driving," Automobile Engineer, December, 1967, p 510.

This paper describes work done on different London road systems ranging from expressway to urban routes. The lateral accelerations were presented as a percentage of the total distance traveled on a course. The speed on the course varied and the only speed datum recorded was the average speed = distance/time. This is influenced by stop signs, stop lights, traffic, etc.

Data that are of some interest are the results for one driver on the motorway (u avg. = 64 mph) and the fastest and slowest drivers on a rural route ($\bar{u}$ = 40.1 and 30.3 mph). (See Figure 2.) The data were corrected by the authors for lateral acceleration, but the correction was about 30% from measured, corresponding to 18 deg roll/g - excessive.

The only general interpretations of these data of interest are, that for comfortable, normal driving;

1) One (1) driver had lateral accelerations more than 0.05g during less than 5% of the distance traveled (at $\bar{u}$ = 64) on a highway.

2) The slowest driver on the rural route had lateral accelerations more than 0.09g during less than 5% of the distance traveled (at $\bar{u}$ = 30.3 mph) on rural roads.

3) The fastest driver on the rural route had lateral accelerations more than 0.25g during less than 5% of the distance traveled (at $\bar{u}$ = 40.1 mph) on the rural roads.

E. M. Bevilacqua and E. P. Percarpio, "The Introduction - Lubricated Friction of Rubber", Rubber Chemistry and Technology, Vol 41, No. 4, September 1968, p 832.

This paper discusses lateral accelerations acceptable to drivers in a curve. A distribution is presented and referenced, but does not really appear in the reference given - probably a typographical error. The curve and speeds used are not given, but this speed must be in the area of 20-30 mph (See Figure 3). The assumption is then made that this distribution (mean lateral acceleration ≃ 0.3g, 90th percentile ≃ 0.4g) is representative of the "driving public." This is an untenable assumption. The information in this distribution cannot be used because the speed is not given.

H. W. Kummer and W. E. Meyer, "Tentative Skid-Resistance Requirements for Main Rural Highways", National Cooperative Highway Research Program Report 37, 1967.

A breakdown of lateral acceleration levels into light, comfortable, moderate and excessive is made in a Table in this paper. This Table (See Figure 4) indicates 0.2g as the break point between "comfortable" and "moderate" and 0.3g as the break point between "moderate" and "excessive."

No indication of the effect of vehicle roll on measured lateral acceleration is made. The reference for the Table is a "personal conversation with P. C. Skeels". Mr. Skeels indicated that these remarks were based on a few engineers driving on Proving Ground road systems and the Table is not based on any intensive study. There is no indication that the results are speed dependent.

Highway design information incorporates some expected driver lateral acceleration behavior. As near as I can determine, the most popular design guide is "A Policy of Geometric Design of Rural Highways" by the American Association of State Highway Officials, 1965, (also 1954). These (and other works) indicate the minimum allowable radius at a given speed is a function of side friction factor (g's lateral acceleration) and super-elevation. Road design also includes determination of a total friction factor which includes a combination of cornering and stopping, such that the vector sum of the cornering and braking friction factors of the surface is below some minimum allowable friction coefficient of the road surface. The super-elevation rate e, is considered to have a practical maximum at .06-0.10 ft/ft depending on weather conditions, etc. The maximum side friction factor is indicated as 0.16 for 30 mph for a range of super-elevations for highway curves. It is pointed out that this is for open roads and not intersections.

D. W. Loutenheiser, Chief, Highway Design Division, Bureau of Public Roads, "Skid Resistance Values Used in Geometric Design," Proceedings, First International Skid Prevention Conference, Part II, 1959, p 573.

The Chief of the Highway Design Division of the Bureau of Public Roads indicates there are different criteria used for the design of curves at intersections. The super-elevation is limited at intersections. He indicates "the above values apply to open highway conditions for through traffic lanes. Curves at intersections are considered in a different design category because of the various approach warnings provided and the drivers' anticipation of more critical turning conditions within the intersection. In such cases, drivers accept and use a higher side friction in relation to speed than on open highway curves."

The design side friction factors for intersection curves are given as ranging from 0.32 at 15 mph to 0.16 at 40 mph. This corresponds to 0.32g and 0.16g lateral acceleration. A linear extrapolation would give 0.22g at 30 mph. He goes on to say "Such factors for the lower design speeds exceed the feeling of discomfort limits above mentioned for open highway curve operations, but for the low speeds involved, there remains a reasonable factor of safety. Operation on a minimum radius intersection curve at design speed, such as 150-foot radius at 25 mph may result in tire squeal and possibly some driver body sway, but the whole remains within safe operating limits."

(A 150-foot radius curve at 25 mph corresponds to 0.28g).

A design speed for a given curve is considered to be the speed that 92 to 98% of the driving population would stay below on that curve with the highway in normal conditions.

This paper indicates that the highest allowable road design lateral accelerations are for lower speed intersection curves. The guide indicates 0.22g at 30 mph as a practical maximum. The example given indicates a lateral acceleration higher than the design guide. It is not known how well the public roads actually conform to these guides.

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FIGURE 1

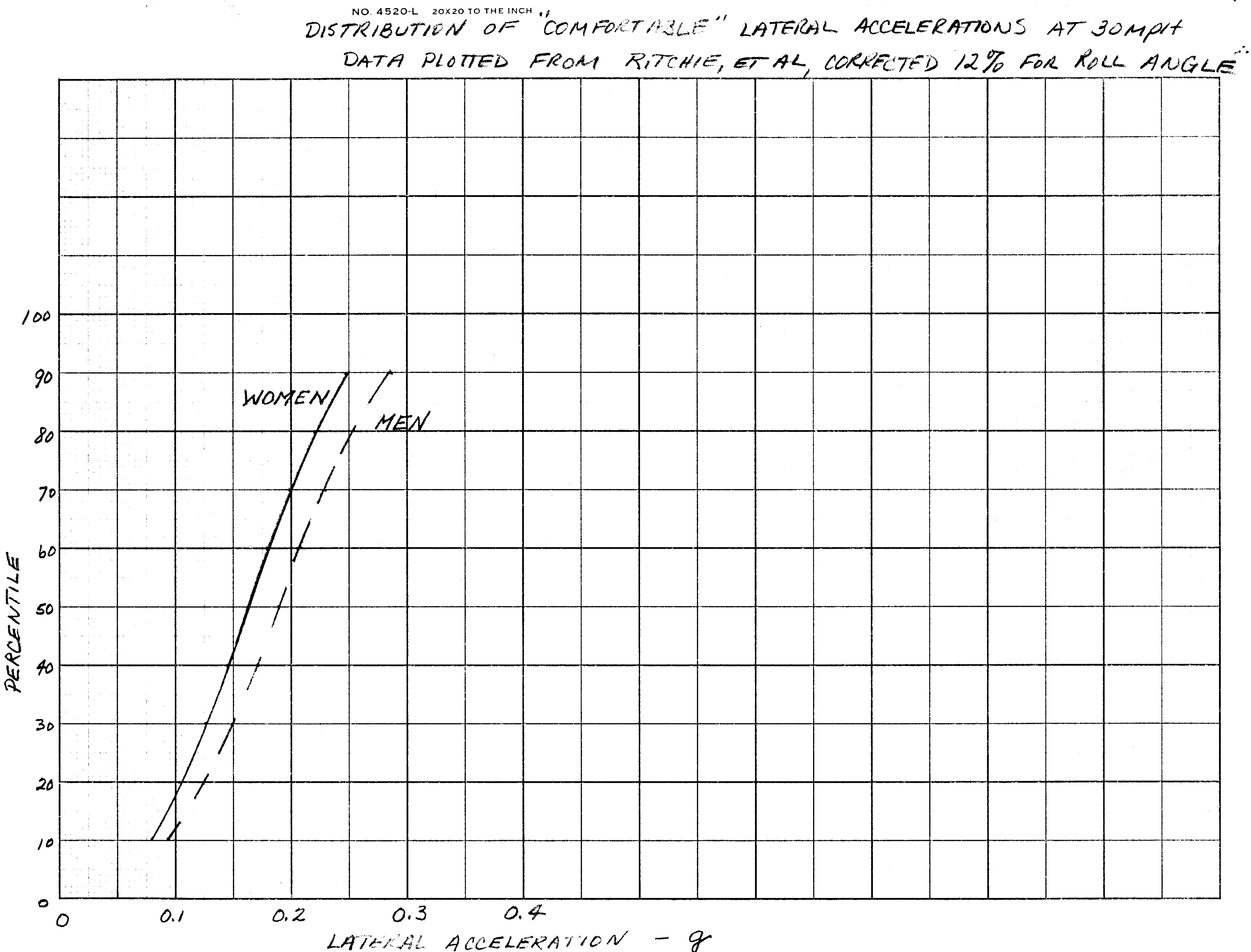

FIGURE 1

FIGURE 2

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DISTRIBUTION OF LATERAL ACCELERATION LEVEL EXPERIENCED OVER A PERCENT OF THE TOTAL DISTANCE TRAVELED

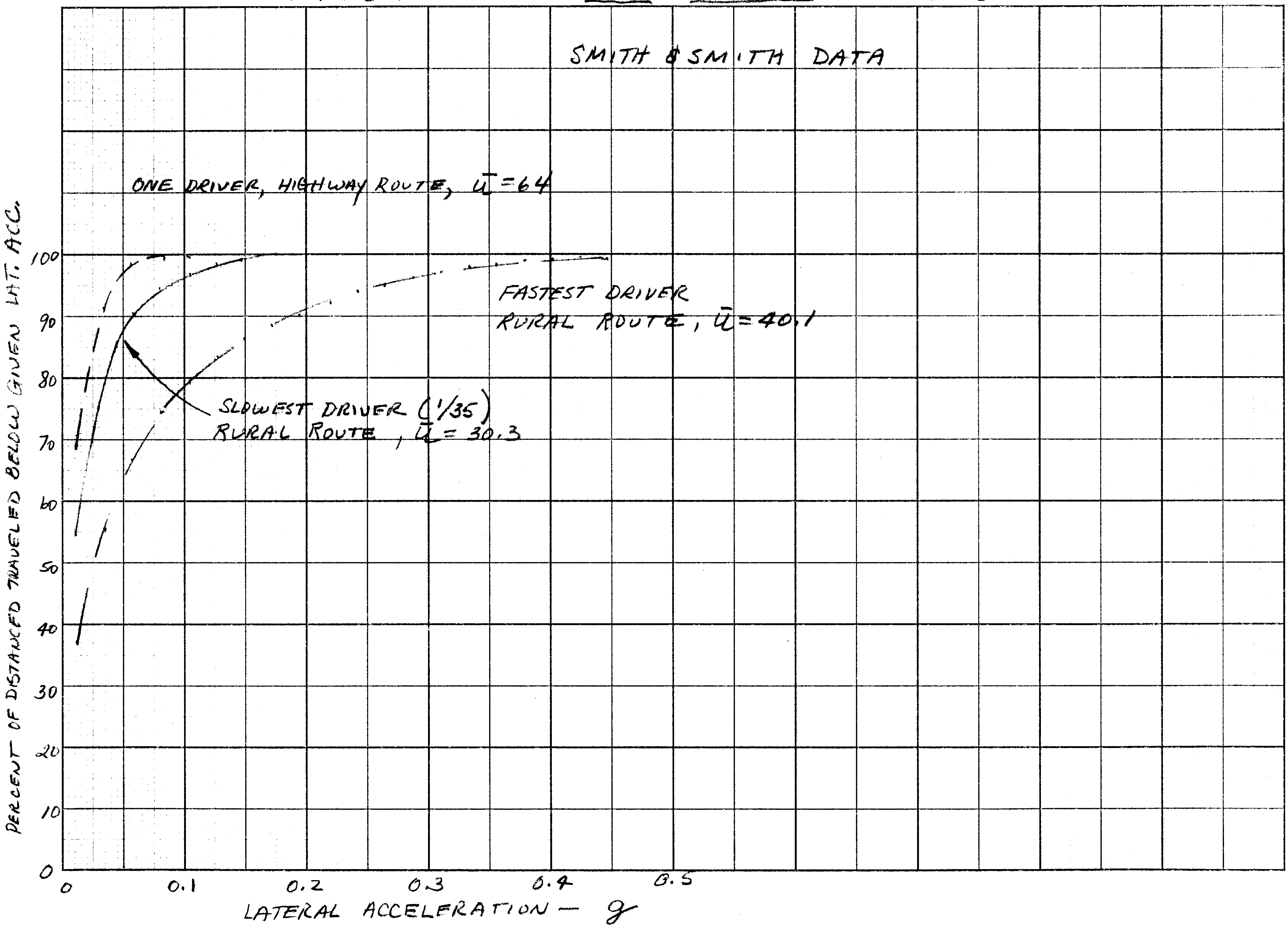

FIGURE 2

VOL 41, NO. 4, SEPT, 1968

TABLE II

ACCIDENT INCIDENCE[a]

Condition	Intersection	Nonintersection
Clear	1.36	1.73
Rain or snow	29.05[b]	62.07[b]

[a] Per million vehicles passing, at intersections; per million vehicle miles, away from intersections.

[b] As reported. We believe these figures should be divided by 5 on the basis of analysis of raw data kindly provided by Professor Michael. Conclusions are not altered by the changes.

The reasons for this are twofold. Pavements become more slippery when wet, and drivers do not adjust sufficiently to the lowered coefficients.

Useful research on traction requires consideration of the entire system of driver, vehicle, and road. When the normal requirements of driving have been established, realistic specifications can be set for friction coefficients to provide an adequate safety factor.

Comprehensive data required to determine those requirements precisely are not yet available for the United States, but the extensive studies at the Road Research Laboratory[6] (RRL) provide a good guide. Our experience in the collection of data for the present series of papers indicates reasonably good correspondence between qualitative ideas of police and highway officials and the estimates of the importance of road slipperiness given by Giles, Sabey, and Cardew[9,10]. Conclusions based on the RRL data will presumably require only slight modification as data become available for the United States.

The RRL has suggested a skid resistance of 60 as an as-laid criterion for road surfaces[11] (approximately, a friction coefficient of 0.67 at 7 mph[10]). The value of this criterion may be illustrated by Figure 1, in which data reported separately in the literature are displayed together to show graphically the physical requirements involved. This illustration relates driver tolerances, available coefficients, and skidding accidents. Each of these is plotted as a separate curve in the upper set; they are superimposed in the lower to emphasize the correspondence between them. The abscissa scale represents acceleration for the curves representing driver requirements, and available coefficient for those representing road properties and accident frequency. The available coefficient of friction is numerically equal to the acceleration in units of *g* when free sliding occurs, so these may be directly compared.

NOT THERE!

Curve 1 shows total accelerations acceptable to drivers[12], based on *ca.* 800 observations of vehicles rounding a curve; Curve 2 is the distribution of coefficients available on wet roads, based on approximately 950 sites in Germany[13], the United States[14], and Great Britain[15], discussed in more detail in part III of this series.

?

Although Curve 1 represents only one driving condition, rounding a curve, it indicates accelerations *acceptable to drivers* and may therefore be considered to represent a probable distribution of accelerations required by the driving population. Some approximations were necessary for the comparison in Curve 2 because it is not known how the German and English reference tread stocks relate to each other, but errors from this cause will be small.

It follows then, that where these curves overlap, the probability of trouble exists. This is made abundantly clear by Curve 3 which is the likelihood of a skidding accident, determined independently[10] by investigation of 219 actual accident sites. The abrupt change in slope occurs where Curves 1 and 2 cross, and Curve

FIGURE 3

as a whole parallels the high side of the demand curve closely. It is obvious then that a substantial fraction of drivers will encounter a substantial fraction of roads on which serious danger exists of an accident caused by skidding due to a low coefficient. The areas of Curves 1 and 2 which overlap indicate the fractions of drivers and roads involved. About half of all paved roads are sufficiently slippery to be potentially hazardous when wet. More importantly, about 90% of all drivers may encounter slippery wet roads.

This probably occurs because people drive on wet roads nearly exactly as they do on dry. In 1956 Stohner[16] reported quantitative support for the widespread belief that drivers do not change their driving habits or speeds on wet roads, Figure 2. Moreover, average driving speeds are increasing at a rate of about one mile per hour per year[17], Figure 3, so that the problem becomes more acute as time passes. We have discussed this briefly in a recent review[18]; there are essentially no studies of which we are aware concerned with habits of drivers

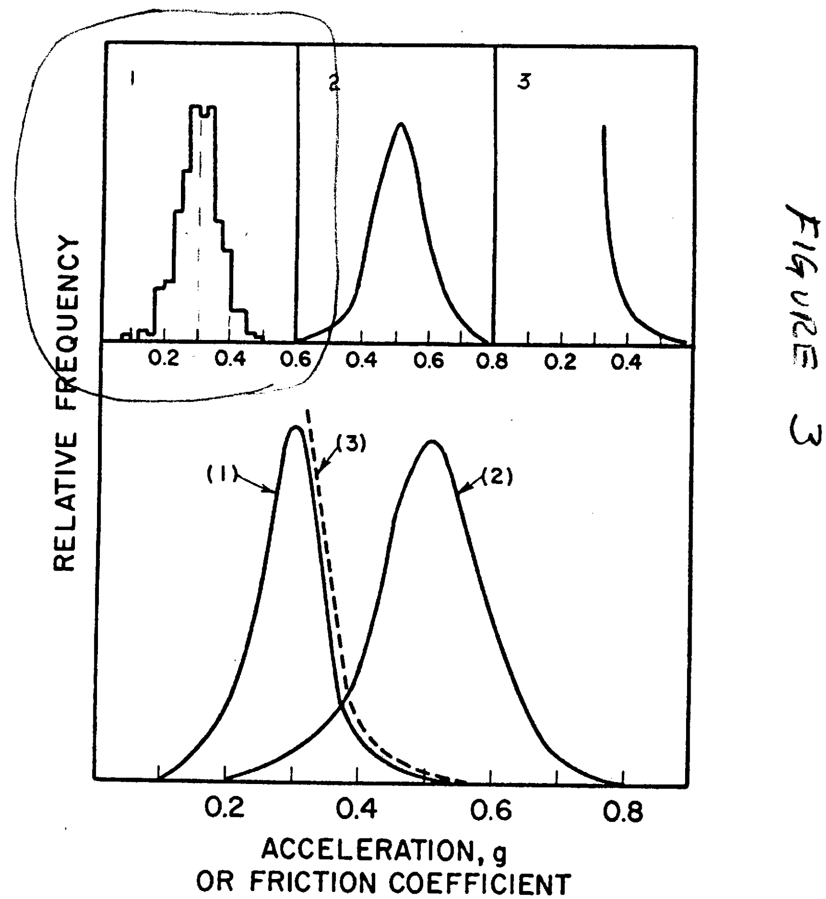

FIG. 1.—Driver requirements, road characteristics and probability of accidents. Curve 1: acceptable accelerations; Curve 2: composite data on friction levels on wet roads; Curve 3: likelihood of an accident. Curves displayed separately in upper level, on same axes in lower. Sources of data given in text.

FIGURE 4

was 6, or approximately the same as on the winding mountain road of the first test trip.

Figure 55 shows the deceleration pattern of Driver C, again obtained with the pendulum decelerometer during the 276-mile trip of Figure 54. Note the two peaks at relative decelerations (or friction numbers) of 10 and 20, the lower value being caused by routine speed changes due to road design and traffic, the higher one by full stops due to traffic, STOP signs, or traffic signals. In 6 of the 122 applications the traffic situation required severe decelerations of 40 or above (see also Table 10). Two of these cases were due to driver inattention, and four were due to unexpected acts by other traffic participants. The speeds were below 20 mph in every case.

By turning the decelerometer 90° the author measured the range of lateral decelerations on straightaways and curves and found that the friction number (in this case cornering slip number) at 50 mph did not exceed 10 on straightaways (a reflection of small steering corrections and body lean), approached 20 at speeds of 70 mph, and did not exceed 25 to 30 on curves, hence is generally lower than the brake slip number towards the end of a stop.

Although the number of possible combinations of factors which can affect the driver deceleration pattern is much too large to all have been encountered in a few tests (which in addition were carried out with the driver's knowledge), the tentative conclusions from Figures 52 to 55 do suggest the approximate range of frictional needs for normal driving. Again a friction number of 40 emerges as satisfying the needs of normal traffic. The only exceptions are decelerations which lead to a full stop. Here friction levels up to 50 may be called for towards the end of the stop, either to compensate for the lower deceleration levels selected at the beginning of the braking process or to correct for errors or misjudgment which might have occurred during the earlier portion of the maneuver.

The results of this study are in general agreement with the severity of braking and cornering which drivers accept as less than uncomfortable. The guidelines of Table 11 are derived from driver opinion and are being used by automobile manufacturers (50). The table indicates that drivers appear to have a higher "built-in" tolerance for deceleration during braking than in cornering. The question of whether this pattern can be interpreted to mean

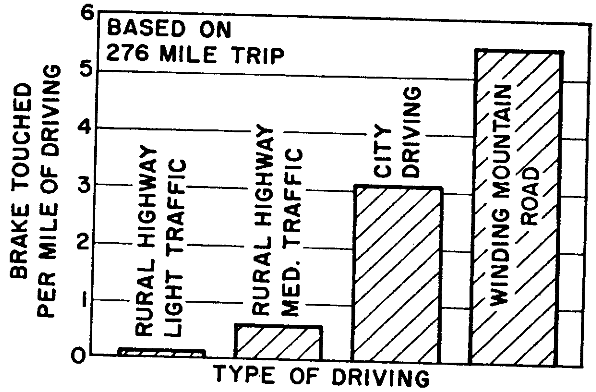

Figure 54. Brake application frequency as function of traffic and highway geometry.

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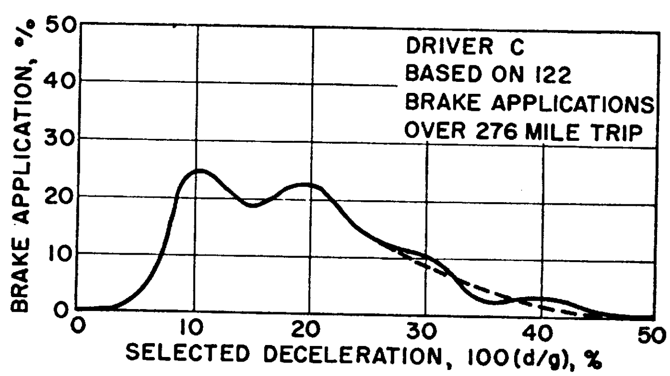

Figure 55. Driver behavior pattern during braking on cross-country trip.

FIGURE 4

TABLE 11

CLASSIFICATION OF DECELERATION SEVERITY IN BRAKING AND CORNERING BY DRIVER OPINION

DECELERATION, 100 (d/g) (%)	d (FT/SEC^2)	FRICTION NUMBER	DRIVER OPINION: BRAKING	DRIVER OPINION: CORNERING
0–10	0– 3.2	10	Light	Light
10–15	3.2– 4.8	15	Light	Comfortable
15–20	4.8– 6.4	20	Comfortable	Comfortable
20–25	6.4– 8.0	25	Comfortable	Moderate
25–30	8.0– 9.6	30	Comfortable	Moderate
30–35	9.6–11.2	35	Moderate	Excessive
35–40	11.2–12.8	40	Moderate	Excessive
40–45	12.8–14.4	45	Moderate	—
45–50	14.4–16.1	50	Excessive	—
>50	>16.1	>50	Excessive	—

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ATTACHMENT Q

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ADDENDUM

FILE MEMO F-285

Fredrick W. Hill
February 6, 1970

SUMMARY OF LITERATURE ON DRIVER LATERAL ACCELERATION BEHAVIOR

An additional article in the area of driver lateral acceleration behavior has come to my attention. The data are presented in a form somewhat different from the previous articles, but allow similar interpretation. The results of this article do not contradict any of the conclusions reached in the memo, but it does present a detailed and complete study.

Taragin, A., "Driver Performance on Horizontal Curves," Proceedings, Third Annual Meeting of Highway Research Board, 1954, p 446.

This study determined "mean speeds" at different points around a number of curves on two-lane rural highways, primarily in New York State. A description of the procedure and other pertinent sections of the article are attached.

This is probably the best and most complete study I have come across, but not all sections are applicable to the investigation of driver lateral acceleration behavior. Before indicating the results of this study, some limitation as to the applicability of the results for our purposes is in order.

The drivers were not identified (intentionally so they would drive normally), therefore, women and men were not separable. Speeds measured were average speeds at 10 points in the curves. While there is an indication that the speeds did not change much in the curves, any instantaneous changes in speed would introduce a squared effect on lateral acceleration or side friction factor. Few of the results are given in terms of complete distributions, only means and 90 and 95th percentiles. This could have apparently been presented, however, as there are an indicated 125 vehicles counted at each curve. This (and most others) is an old article - 1954. Road design techniques may have changed since then, but even if they did, the older (pre 1954) roads still exist. My guess is that people's speed versus radius of curvature behavior has certainly not decreased, but possibly increased since 1954 due to higher attainable vehicle speeds. Consequently, the results of this study, for the conditions under which it was made, should indicate lateral acceleration levels that may be even higher today.

Pertinent Results of the Study:

1. On "sharper" curves, a number of drivers exceed the road design speeds. For radii of curvature less than 750 feet, at least 10% of the drivers exceeded the design speed. (See Figure 6, p 152)

2. Interpreting this figure in the study (Figure 6, p 452), the mean driver's lateral acceleration (actual side friction factor) at 30 mph was approximately .23g ($R \simeq 260$ feet) and the 90th percentile driver's actual side friction factor was approximately 0.27 ($R \simeq 220$ feet). Similarly, lateral acceleration levels for 30 mph can be interpreted from Figure 8, p 456. For a radius of curvature corresponding to 30 mph for the 50th percentile driver ($R \simeq 280$ feet), the mean driver's side friction coefficient was approximately 0.19, and the 90th percentile driver's side friction coefficient was approximately0.30. Due to the number of variables and their inter-relations, and the statistical variations, an infinite number of similar (but not identical) conclusions can be reached.

3. Super-elevation has a negligible effect on measured driver speed in curves. Curvature has a "well defined" linear relationship with speed. Therefore, for two curves with the same curvature, drivers will use a lower coefficient of side friction (lateral acceleration) on the more steeply banked curve.

4. One of the study's conclusions is that "ten percent of the drivers develop a coefficient of side friction of 0.3 or more on horizontal curves sharper than 15 degrees."

I believe this conclusion is a typographical error, as it is not substantiated in the text. However, it is indicated in the text (Figure 8, p 456) that for curvatures greater than 10 degrees (mean speed between 39 and 25) the mean side friction factor varied from approximately .10 to .21 and the 90th percentile friction factor varied from .24 to .35.

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EXERPTS FROM

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Publication 324

and northerly to a point 0.10 of a mile north of State Trunk Highway 23:

(c) Thirty-five miles per hour from a point 0.10 of a mile north of State Trunk Highway 23, northerly to a point 0.80 of a mile north of State Trunk Highway 23;

(d) Forty-five miles per hour from a point 0.80 of a mile north of State Trunk Highway 23, northerly to a point 0.15 of a mile south of County Trunk Highway "A";

(e) Thirty-five miles per hour from a point 0.15 of a mile south of County Trunk Highway "A", northerly to a point 0.10 of a mile north of U. S. Highway 16;

(f) Forty miles per hour from a point 0.10 of a mile north of U. S. Highway 16, northerly to a point 0.35 of a mile north of U. S. Highway 16.

Speed Zone Declaration—Location No. 5, U. S. Highway 51—At Lake Kegonsa (Dane County)

Fifty miles per hour from a point 0.22 of a mile southeast of its intersection with the town road on the line common to Sections 22 and 23, Township 6 North, Range 10 East, southerly to a point 400 feet southeast of its intersection with the town road on the line common to Sections 25 and 26 of Said Township, except that the stated speed limit for northbound traffic only shall terminate at a point 0.29 of a mile southeast of its intersection with the town road on the line common to Sections 22 and 23 of said Township.

Speed Zone Declaration—Location No. 6, Old U. S. Highway 41—From Village of Menomonee Falls to Milwaukee-Waukesha County Line

(a) Fifty miles per hour from the Waukesha-Milwaukee county line northerly to a point 1,000 feet southeast of County Trunk Highway "W";

(b) Thirty-five miles per hour from a point 1,000 feet southeast of County Trunk Highway "W" northerly to a point 800 feet southeast of the town road on the line common to Sections 13 and 14, T 8 N, R 20 E;

(c) Forty-five miles per hour from a point 800 feet southeast of the town road on the line common to Sections 13 and 14, T 8 N, R 20 E, northerly to a point 600 feet northwest of said town road;

(d) Fifty miles per hour from a point 600 feet northwest of the town road on the line common to Sections 13 and 14, T 8 N, R 20 E, northerly to a point 350 feet southeast of County Trunk Highway "YY";

(e) Thirty-five miles per hour from a point 350 feet southeast of County Trunk Highway "YY" northerly to the south corporate limits of the Village of Menomonee Falls.

Driver Performance on Horizontal Curves

A. Taragin, *Highway Engineer*
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THIS report deals with the performance of passenger cars on horizontal curves having a range in minimum sight distances from 200 to 655 feet and in curvature from 3 to 29 degrees. The locations studied were on two-lane highways primarily in New York and Maryland, supplemented by locations in Illinois, Minnesota, and South Carolina. A total of 8,400 free-moving passenger car speeds were observed on the inside lanes of 35 different curves and on the outside lanes of 33 of these curves.

The analyses include investigations of the coefficient of side friction that vehicles actually develop in traversing horizontal curves; the effect of superelevation on driver behavior; sight distance as related to curvature; speed as related to sight distance and curvature; and passenger-car speeds as compared to various standards for safe speeds as based on stopping distances.

● EXISTING highway systems are conglomerations of varied geometric designs. Some sections are designed in accordance with the most-modern standards to accommodate large volumes of traffic at relatively high speeds, but these are by far in the minority. The largest mileage of our highway system is of two-lane design, often inadequate for the volume of traffic carried. In many areas the most-common deficiency is insufficient sight distance for safe operation at desired speeds on vertical and horizontal curves.

The effect of vertical curves on driver behavior and vehicle speeds was discussed in a paper presented by B. A. Lefeve at the 32d annual meeting of the Highway Research Board in January 1953. The problem of horizontal curvatures and their effects on driver performance is presented in this report.

STUDY PROCEDURE

Driver performance and passenger-car speeds were recorded on a number of horizontal curves with minimum sight distances ranging from 200 to 655 feet. Study locations were confined to sections of two-lane highway on which it might be expected that driver performance would be affected by horizontal curvature, superelevation, or limitation of the sight distance. In no case did the approach grade exceed 3 percent, and no section had a vertical curvature in combination with the horizontal curvature.

All locations were on rural highways removed from the influence of intersections and with a minimum of interference from roadside development. The study included only passenger cars, and to insure that none were influenced by other vehicles traveling in the same direction, those following another vehicle within a time spacing of 6 seconds were excluded.

The study was conducted in two phases. The first phase was initiated in 1951 in cooperation with the New York Bureau of Highway Planning and included studies of driver behavior on 15 horizontal curves. At these curves speeds were recorded for each vehicle at 100-foot intervals over a distance of 1,000 feet, starting 500 feet ahead of the centers of the curves and ending 500 feet beyond the centers. This included the entire lengths of the curves which were from 400 to 900 feet long. Observations of vehicle speeds on the approaches, however, were not included in this study. The data were obtained in such a manner that the variation in speed on each curve could be related to the variation in the sight distance on the curve. The results obtained by this phase of the study are discussed in the first part of the report.

To supplement the data obtained in New York, the second phase of the study made use of data from studies conducted at 20 locations in Maryland, Illinois, Minnesota, and South Carolina. This phase consisted of determining passenger-car speeds at one point on each curve, viz., at the point of minimum sight distance. The data collected at these locations were combined with the New York data for the greater portion of this report.

The data at each study site were divided into the following two groups for analysis: Group I, data for vehicles traveling in the inside lane of the curve; Group II, data for vehicles traveling in the outside lane of the curve.

The inside lane of a curve has a slightly sharper curvature and shorter radius than the outside lane. This difference should be kept in mind in the consideration of the results, because the curvatures as reported are those as measured to the centerline of the pavement. Sight distance measurements were made separately for each direction of travel, at the center of the lane, from a height of 4½ feet to an object 4 inches high in the same lane.

The speeds of approximately 125 free-moving passenger cars (not meeting another vehicle and more than 6 seconds behind the preceding vehicle) were observed for each study. Satisfactory data were obtained for the inside lanes of 35 different curves and for the outside lanes of 33 of these curves involving 8,400 vehicles. Table 1 contains a general description of each location and the observed speed data at the point of minimum sight distance on the inside lanes. Table 2 shows the same information for the outside lanes. In these two tables the locations have been arranged in order by the magnitude of the minimum sight distances (Column 8).

NEW YORK STUDIES

As has been mentioned, the studies in New York consisted of recording vehicle speeds in each of the two lanes over 100-foot sections for a distance of 1,000 feet including the sharpest sections of the horizontal curves. The individual car speeds were obtained by measuring the time it took vehicles to travel the 100-foot distances between the stations on each curve. A distribution of vehicle speeds and the average speed was thus obtained for vehicles while in each of the ten 100-foot sections. Using sight distances recorded separately for each direction of travel, the design speed based on AASHO standards for nonpassing sight distances only was deter-

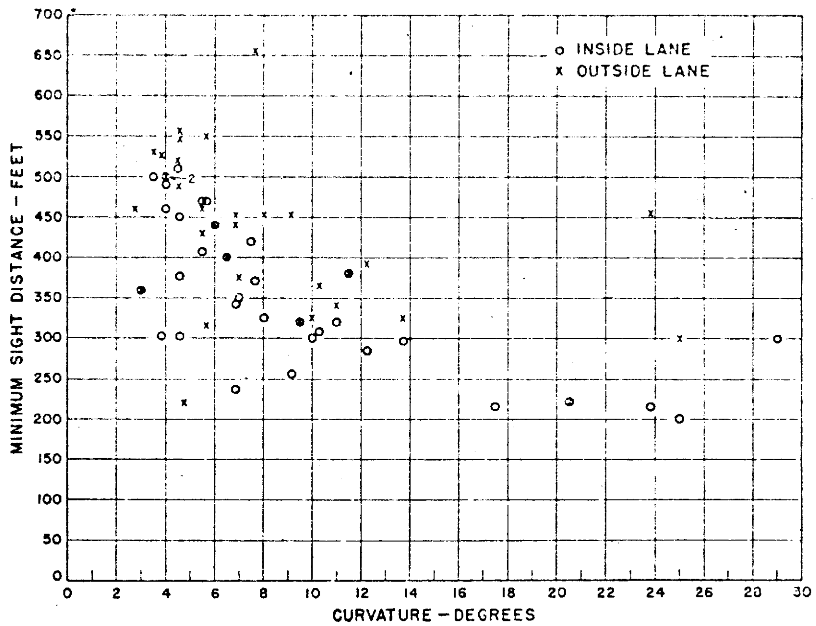


Figure 5. Relation between minimum sight distance and curvature.

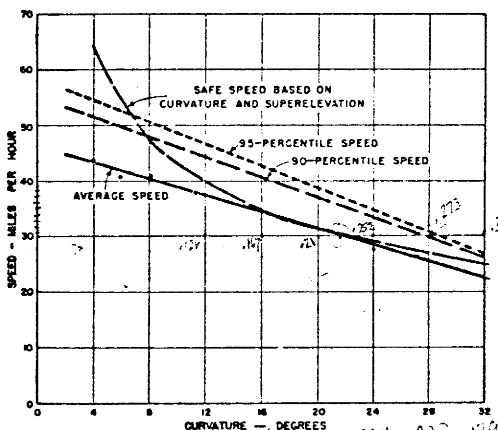


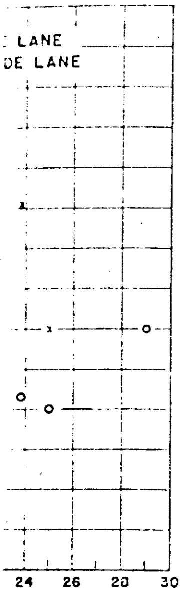
Figure 6. Relation between speed and horizontal curvature.

try to provide adequate sight distance for safe operation at those speeds. It is important, therefore, to determine to what extent drivers influence their speeds by the combination of curvature and superelevation and by the available sight distances.

SPEED AS RELATED TO DEGREE OF CURVATURE

The speeds at which drivers operated on the curves of various degrees are shown by Figure 6. Separate curves are shown for the average speed, the 90-percentile speed, and the 95-percentile speed. The points for these curves were plotted by combining the data shown in Tables 3 and 4. For this purpose it was found to be unnecessary to plot the data for the inside lanes, as shown by Table 3, separately from the data for the outside lanes, as shown by Table 4, because for the same curve the average difference was only 0.2 mph.

Points are shown only for the average speed for each of the curvature groups in the tables. The point shown for a curvature of 16 to 20 deg. represents only one location, whereas all the other points represent data averaged for 7 to 20 locations. The points for the 90- and 95-percentile curves are not shown, but they fell as close to the respective curves as those for the average speeds. Points representing speeds at the individual curves as well as those for the groups also came remarkably close to the curves.



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TO DEGREE OF CURVATURE

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only for the average speed ture groups in the tables. r a curvature of 16 to 20 one location, whereas all esent data averaged for 7 e points for the 90- and are not shown, but they espective curves as those els. Points representing al curves as well as those came remarkably close to

TABLE 3
COEFFICIENT OF SIDE FRICTION AS RELATED TO SPEED ON HORIZONTAL CURVES
Inside curve lane on two-lane highways

Curvature group (1)	Super-elevation (2)	Minimum S. D. (3)	Study site No. (4)	Speed at minimum sight distance: Avg. (5)	Speed at minimum sight distance: 90% (6)	Speed at minimum sight distance: 95% (7)	Coefficient of side friction: Avg. speed (8)	Coefficient of side friction: 90% speed (9)	Coefficient of side friction: 95% speed (10)
deg.-min.	*ft. per ft.*	*feet*		*mph*	*mph*	*mph*			
1. 3-50	0.014	303	11	46.6	55.1	58.5	0.083	0.122	0.139
4-35	0.021	377	21	51.7	58.3	60.2	0.122	0.161	0.173
4-35	0.028	303	12	40.8	46.5	49.0	0.061	0.088	0.101
3-00	0.030	360	19	40.9	53.1	59.0	0.029	0.069	0.092
3-30	0.040	500	33	45.5	54.0	56.4	0.043	0.077	0.088
Avg. 3-54	0.027	369		45.1	53.4	56.6	0.066	0.103	0.119
4-00	0.042	490	32	39.5	49.5	57.0	0.031	0.073	0.110
4-35	0.049	450	28	45.0	52.5	58.5	0.059	0.099	0.134
4-00	0.052	460	29	45.0	55.0	58.9	0.043	0.090	0.110
4-00	0.060	500	34	40.2	48.7	50.6	0.016	0.051	0.060
4-30	0.062	510	35	43.5	53.0	54.6	0.038	0.086	0.095
Avg. 4-13	0.053	482		42.6	51.7	55.9	0.037	0.079	0.101
2. 5-40	0.033	407	24	43.5	49.4	52.4	0.093	0.129	0.149
6-52	0.036	236	5	38.6	46.3	47.6	0.084	0.136	0.146
5-30	0.042	470	31	41.0	51.8	53.8	0.066	0.130	0.144
5-30	0.042	435	26	37.5	46.5	48.3	0.048	0.097	0.108
6-52	0.042	342	17	41.6	46.8	49.1	0.097	0.134	0.152
Avg. 6-05	0.039	378		40.4	48.1	50.2	0.077	0.125	0.140
6-00	0.062	440	27	42.5	55.0	57.3	0.065	0.150	0.168
6-30	0.062	400	23	42.5	50.5	53.4	0.075	0.132	0.155
5-40	0.069	469	30	43.9	49.7	52.1	0.059	0.095	0.111
Avg. 6-03	0.064	436		43.0	51.7	54.3	0.067	0.125	0.145
3. 8-02	0	324	16	44.3	52.0	53.7	0.184	0.254	0.271
9-10	0.042	256	6	41.4	47.5	49.1	0.141	0.200	0.216
7-00	0.052	350	18	41.5	49.5	52.2	0.089	0.149	0.171
Avg. 8-04	0.031	310		42.4	49.7	51.7	0.139	0.202	0.221
7-30	0.062	420	25	39.2	48.7	50.6	0.072	0.146	0.162
7-40	0.064	371	20	40.6	46.7	48.9	0.084	0.132	0.150
9-30	0.073	320	14	37.8	45.0	47.6	0.086	0.152	0.179
Avg. 8-13	0.066	370		39.2	46.8	49.0	0.081	0.144	0.165
4. 10-18	0.038	308	13	41.9	46.3	47.1	0.174	0.220	0.229
12-15	0.045	285	7	35.7	41.5	42.9	0.137	0.201	0.218
13-44	0.068	297	8	40.4	49.7	52.9	0.194	0.329	0.381
Avg. 12-06	0.050	297		39.3	45.8	47.6	0.166	0.248	0.271
10-00	0.073	300	10	35.5	44.0	46.4	0.074	0.153	0.179
11-00	0.073	320	15	36.0	45.0	46.8	0.094	0.187	0.208
11-30	0.080	380	22	40.5	49.5	52.4	0.140	0.250	0.289
Avg. 10-50	0.075	333		37.3	46.2	48.5	0.101	0.195	0.223
5. 17-30	0.062	215	2	36.5	44.0	45.0	0.211	0.335	0.352
6. 29-00	0.062	300	9	25.1	29.7	31.5	0.151	0.236	0.274
23-50	0.077	215	3	31.5	36.2	38.1	0.200	0.289	0.328
Avg. 26-25	0.070	258		28.3	33.0	34.8	0.177	0.266	0.304
25-00	0.083	200	1	23.7	28.9	29.4	0.081	0.161	0.170
20-30	0.083	220	4	28.0	34.5	36.0	0.103	0.202	0.227
Avg. 22-45	0.083	210		25.8	31.7	32.7	0.094	0.184	0.201

The method of least squares was used to fit a straight line, a hyperbola, and a parabola to the data for the individual locations. The straight-line relation between speed and curvature was found to give the best fit. The resulting equations with the corresponding standard errors and coefficients of correlations are shown below where V is the speed

TABLE 4

COEFFICIENT OF SIDE FRICTION AS RELATED TO SPEED ON HORIZONTAL CURVES

Outside curve lane on two-lane highways

Curvature group (1)	Super-elevation (2)	Minimum S. D. (3)	Study site No. (4)	Speed at minimum sight distance: Avg. (5)	90% (6)	95% (7)	Coefficient of side friction: Avg. speed (8)	90% speed (9)	95% speed (10)
deg.-min.	*ft. per ft.*	*feet*		*mph*	*mph*	*mph*			
1. 3-50	0.014	526	11	46.3	53.0	55.5	0.082	0.112	0.124
4-35	0.021	546	21	46.9	52.5	53.7	0.097	0.127	0.133
4-35	0.028	489	12	42.4	47.2	50.4	0.068	0.091	0.108
3-00	0.030	360	19	34.9	44.7	47.9	0.013	0.040	0.050
3-30	0.040	530	33	45.0	56.0	58.7	0.041	0.086	0.099
Avg. 3-54	0.027	490		43.1	50.7	53.2	0.058	0.090	0.102
4-00	0.042	500	32	39.0	49.5	53.1	0.029	0.072	0.090
4-35	0.049	557	28	45.5	52.0	53.0	0.062	0.096	0.101
2-45	0.052	460	29	48.0	58.0	60.9	0.022	0.056	0.067
4-00	0.060	500	34	43.0	52.0	54.9	0.016	0.066	0.081
4-30	0.062	520	35	43.0	54.0	57.2	0.035	0.091	0.110
Avg. 3-58	0.053	507		43.7	53.1	55.8	0.036	0.078	0.091
2. 5-40	0.033	550	24	46.0	52.9	56.2	0.107	0.153	0.177
6-52	0.036	452	5	36.9	42.1	43.9	0.073	0.106	0.119
5-30	0.042	460	26	38.0	47.5	49.9	0.051	0.103	0.118
5-30	0.042	430	31	40.5	49.0	51.0	0.063	0.112	0.125
6-52	0.042	439	17	40.4	48.2	50.9	0.089	0.114	0.166
Avg. 6-05	0.039	466		40.4	47.9	50.4	0.077	0.124	0.141
6-00	0.062	440	27	40.0	50.0	50.6	0.050	0.113	0.118
6-30	0.062	400	23	41.5	51.0	53.7	0.069	0.136	0.157
4-45	0.062	220	2	38.0	43.0	46.5	0.018	0.041	0.058
5-40	0.069	316	30	41.5	47.4	49.7	0.045	0.080	0.095
Avg. 5-35	0.063	344		40.2	47.8	50.1	0.042	0.086	0.101
3. 8-02	0	452	16	40.3	47.0	49.3	0.153	0.208	0.228
9-10	0.042	453	6	40.7	47.1	49.5	0.136	0.196	0.221
7-00	0.052	375	18	42.0	47.5	53.9	0.092	0.133	0.186
Avg. 8-04	0.031	427		41.0	47.2	50.9	0.128	0.179	0.213
7-40	0.064	655	20	46.3	53.0	56.0	0.128	0.188	0.217
9-30	0.073	320	14	37.0	44.2	46.3	0.079	0.144	0.165
Avg. 8-35	0.068	487		41.6	48.6	51.2	0.106	0.169	0.195
4. 10-18	0.038	377	13	37.0	44.2	46.5	0.127	0.197	0.222
12-15	0.045	391	7	35.2	40.4	42.9	0.132	0.189	0.218
13-44	0.068	323	8	41.2	46.9	48.6	0.205	0.285	0.311
Avg. 12-06	0.050	364		37.8	43.8	46.0	0.152	0.221	0.249
10-00	0.073	325	10	37.5	44.3	45.5	0.091	0.156	0.169
11-00	0.073	340	15	35.0	42.0	43.8	0.085	0.154	0.174
11-30	0.080	380	22	39.0	48.0	49.3	0.124	0.230	0.247
Avg. 10-50	0.075	348		37.2	44.8	46.2	0.100	0.179	0.196
6. 23-50	0.077	455	3	32.2	36.2	37.8	0.212	0.289	0.319
20-30	0.083	220	4	30.0	35.0	37.2	0.132	0.210	0.248
25-00	0.083	300	1	22.6	28.5	29.4	0.066	0.155	0.170
Avg. 22-45	0.083	260		26.3	31.8	33.3	0.101	0.186	0.212

in miles per hour and D is the curvature in degrees.

Speed	*Equation*	*Standard error (adjusted)*	*Coefficient of correlation (adjusted)*
		mph.	
Average	$V_a = 46.26 - 0.746D$	3.15	0.819
90-percentile	$V_{90} = 55.22 - 0.909D$	3.29	0.858
95-percentile	$V_{95} = 58.46 - 1.000D$	3.51	0.863

The high coefficients of correlation as found for these equations indicate that operating speeds are closely related to the degree of curvature for the range between 2-deg. and 30-deg. curves included in this study. The average speed is lowered by 3 mph. for each 4 deg. that the curvature increases, and the 95-percentile speed is lowered by 1 mph. for each 1-deg. increase in curvature.

Coefficient of side friction		
speed	90% speed (9)	95% speed (10)
82	0.112	0.124
97	0.127	0.133
68	0.091	0.108
13	0.040	0.050
41	0.086	0.099
58	0.090	0.102
029	0.073	0.090
062	0.096	0.101
022	0.056	0.067
016	0.066	0.081
035	0.091	0.110
036	0.078	0.091
107	0.153	0.177
073	0.106	0.119
051	0.103	0.118
063	0.112	0.125
039	0.114	0.166
077	0.124	0.141
050	0.113	0.118
069	0.136	0.157
018	0.041	0.058
045	0.080	0.095
042	0.086	0.101
153	0.208	0.228
136	0.196	0.221
092	0.133	0.186
128	0.179	0.213
128	0.188	0.217
079	0.144	0.165
106	0.169	0.195
127	0.197	0.222
.132	0.189	0.218
205	0.285	0.311
.152	0.221	0.249
.091	0.156	0.169
.085	0.154	0.174
.124	0.230	0.247
.100	0.179	0.196
.212	0.289	0.319
.132	0.210	0.248
.066	0.155	0.170
.101	0.186	0.212

of correlation as found ndicate that operating ated to the degree of ge between 2-deg. and d in this study. The d by 3 mph. for each 4 ure increases, and the lowered by 1 mph. for n curvature.

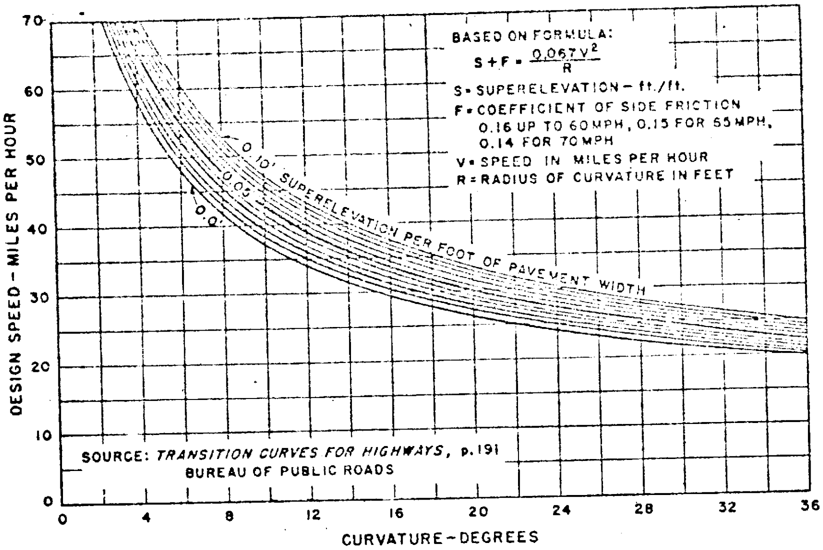

Figure 7. Maximum curvature for various assumed design speeds.

Superimposed on Figure 6 is a curve showing speeds that are presumed to be safe for the various degrees of curvature. These "safe" speeds are based on the average superelevation for each of the curvature groups in Tables 3 and 4 and the current standards of highway design as shown in Figure 7. This is a curved relation between speed and curvature, whereas the actual performance of drivers is a straight-line relation. A driver traveling at the average speed of all free-moving vehicles does not exceed what is considered a safe speed on any of the curves. The fastest 10 percent of the drivers, however, do exceed the safe speeds on curves sharper than 8 deg., and on curves sharper than 16 deg. the average driver travels at about the safe speed, indicating that nearly half of the drivers exceed the safe speed. At individual locations included in this study, 10 percent of the drivers exceeded the safe speed by as much as 10 mph. It is apparent, therefore, that when the road is clear and dry many drivers actually utilize a coefficient of side friction which exceeds that intended in modern highway design. Normally a low value of side friction is purposely used in design to provide some margin of safety. To reduce the needed side friction, highway designers make use of superelevation. Generally, however, the superelevation is limited to a maximum of 0.10 foot per foot, and even on the sharpest curves included in this study the maximum was only 0.083.

The family of curves on Figure 7, used to represent current design practices, is based on a safe coefficient of side friction of 0.16 for speeds up to 60 mph. 0.15 for 65 mph. and 0.14 for 70 mph.

COEFFICIENT OF SIDE FRICTION UTILIZED

One of the factors of highway design for which factual data have been seriously lacking is the coefficient of side friction that vehicles actually develop as they negotiate various curves. From the data recorded for this study and by using the following basic formula, the coefficients of side friction developed on the horizontal curves included in this study were determined:

$$F = \frac{0.067V^2}{R} - S$$

where,

F = coefficient of side friction
V = speed, miles per hour
R = radius of curve, feet
S = superelevation, feet per foot

The basic data for each of the curves included in the study and the calculated coefficients of side friction are shown in Table 3 for the inside lanes and in Table 4 for the

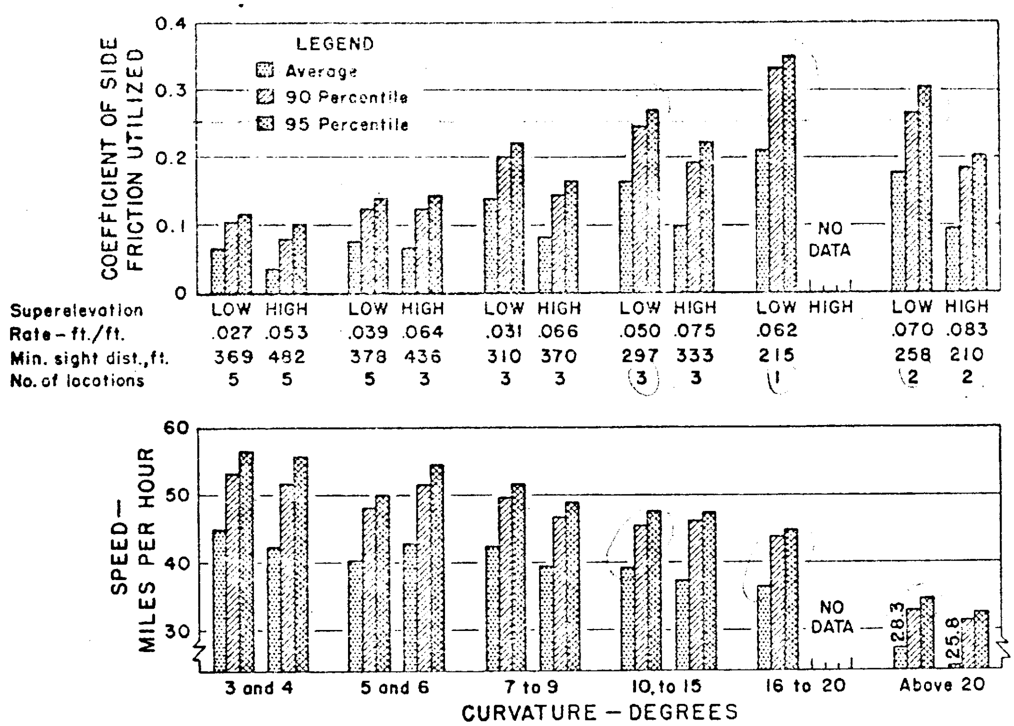

Figure 8. Relation between speed, coefficient of side friction, and superelevation for inside lanes of horizontal curves on two-lane highways.

outside lanes. In these tables the horizontal curves have first been arranged in groups according to degree of curvature. Each of these groups has been further divided into two subgroups, the first subgroup including curves having relatively low superelevations and the other including curves having the higher superelevations.

The superelevations used to separate the data into the subgroups were related to the curvatures. For 3- and 4-deg. curves the division was made at a superelevation of about 0.04 foot per foot. This value increases as the degree of curvature increases, and for the sharper curves the division was made at about 0.08 foot per foot. The coefficients of side friction are shown for the average speed, for the 90-percentile speed, and for the 95-percentile speed on each curve.

Figures 8 and 9 were plotted from the average values for each group in Tables 3 and 4. The values for the superelevations and minimum sight distances are averages for each group of curves. Figure 8 is for the inside lanes of the curves, whereas Figure 9 is for the outside lanes. The lower portion of these figures shows the average and the 90- and 95-percentile speeds for each curvature group. The top portion of the figures shows the corresponding coefficient of side friction utilized in negotiating the various curves at the indicated speeds.

It may be noted from Figures 8 and 9 that the operating speeds are about the same on horizontal curves of similar degree, regardless of the superelevations, within the limits of this study. This appears to be true for both the inside and outside lanes. The amount of superelevation, therefore, had little or no effect on the operating speeds.

Since superelevation had little effect on operating speed, it follows that the utilized coefficient of side friction was lower when the superelevation was high than when it was low. For example, for the inside lanes (Figure 8) on curves of 10 to 15 deg. the side friction for drivers traveling at the average speed was 0.17 when the superelevation was 0.050 foot

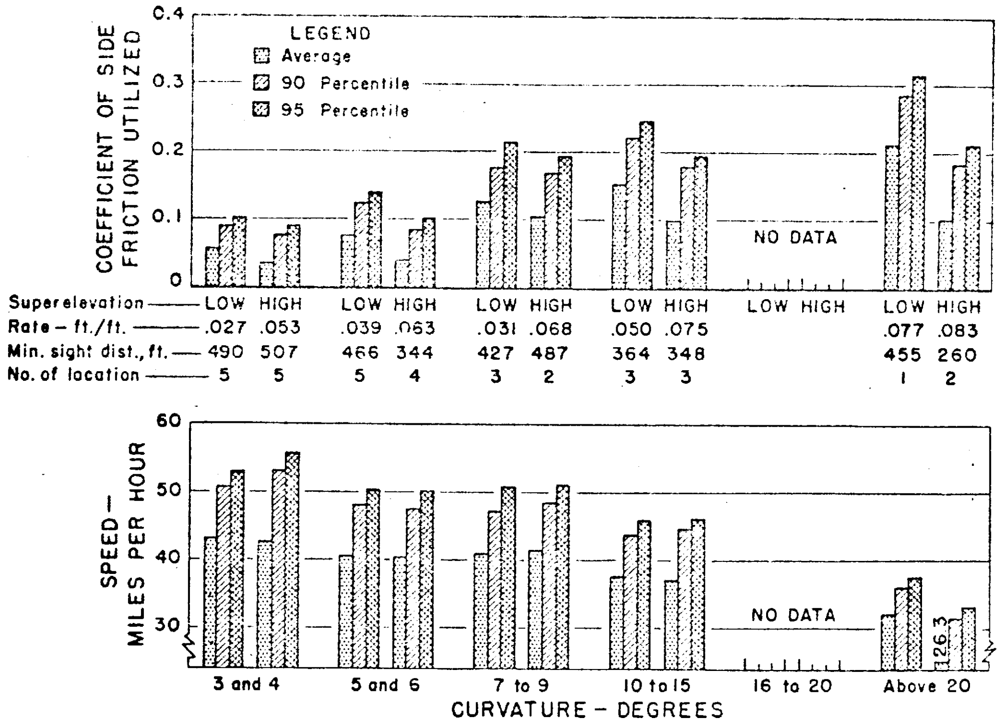

Figure 9. Relation between speed, coefficient of side friction, and superelevation for outside lanes of horizontal curves on two-lane highways.

per foot and 0.10 when the superelevation was 0.075 foot per foot. The high-speed drivers developed higher coefficients of side friction. Likewise, the drivers traveling at the 95-percentile speed had coefficients of side friction averaging 0.28 when the superelevation was 0.050 and coefficients of 0.22 when the superelevation was 0.075 foot per foot. In both of these cases the difference in side friction between the low and higher superelevations was about the same, being 0.06 in the one example and 0.07 in the other. On curves of less than 7 deg. the difference was less, being in the neighborhood of 0.02 or 0.03.

These figures also show that the utilized coefficient of side friction generally increased as the degree of curvature increased, and that the coefficient was slightly lower for the outside than for the inside lanes.

CRITICAL CRITERION OF SUPERELEVATION

Since it was found that curvature affected the operating speeds on horizontal curves but that superelevation had little or no effect, the analysis was directed to the percentage of vehicles that exceeded safe speeds based on curvature and superelevation. Superelevation is normally expressed in units of feet per foot of pavement width and the curvature in degrees. To facilitate the determination of the number of vehicles that were operating at unsafe speeds in relation to the geometric features of the highway, it was found desirable to express the superelevation in terms of feet per foot of pavement width *per degree of curvature*, a term hereafter identified as the "unit of superelevation." An extremely high degree of correlation was found to exist when this unit of superelevation was related to the percentage of vehiclesxc eceding the "safe" speed. Figure 10 shows this relation.

The abscissa on Figure 10 is the unit of superevlevation just discussed. The ordinate shows the percentage of vehicles exceeding the safe speed. Only one curve is shown for both lanes of travel, because when individual curves were drawn for the inside and outside lanes, the curves coincided. This is easily understood if

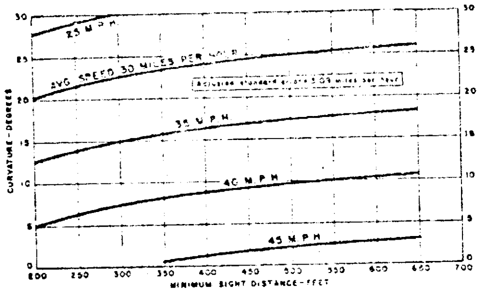

Figure 18. Relation between minimum sight distance, curvature, and average speed for horizontal curves on two-lane roads.

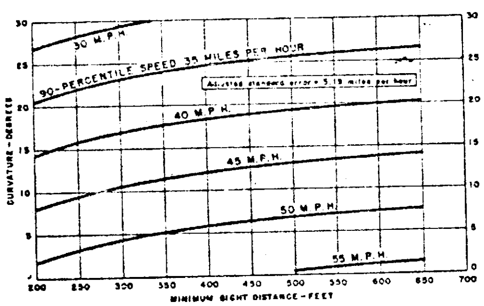

Figure 19. Relation between minimum sight distance, curvature, and 90-percentile speed for horizontal curves on two-lane roads.

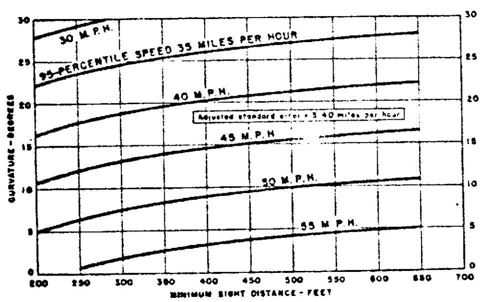

Figure 20. Relation between minimum sight distance, curvature, and 95-percentile speed for horizontal curves on two-lane roads.

method of least squares to the basic data for the inside and outside lanes combined. The curves on each figure represent speed contours. Shown on each figure is also the standard error within which the speeds can be assumed to be correct.

These figures show that the sight distance has a comparatively small effect on vehicle speeds, whereas curvature has a considerable effect. With a constant curvature the average change in speed is about 0.8 mph for each 100-foot change in sight distance. With a constant sight distance the average speed changes uniformly about 0.7 mph. for each 1-deg. change in curvature. Based on the relation between sight distance and curvature, however, a 3-deg. change in curvature, which causes a 2.1-mph. change in speed, is necessary to produce a change in sight distances sufficient to cause a change in speed of 0.8 mph. Curvature, therefore, causes nearly three times as great a change in speed as sight distance, under comparable conditions. This is as true for the 90- and 95-percentile speeds as for the average speed.

SUMMARY AND FINDINGS

This report deals with the performance of passenger cars on horizontal curves having a range in minimum sight distances from 200 to 655 feet and in curvature from 3 to 29 deg. The locations studied were on two-lane highways primarily in New York and Maryland, supplemented by locations in Illinois, Minnesota, and South Carolina. A total of 8,400 free-moving passenger car speeds were observed on the inside lanes of 35 different curves and on the outside lanes of 33 of these curves.

The analyses include investigations of the coefficient of side friction that vehicles actually develop in traversing horizontal curves; the effect of superelevation on driver behavior; sight distance as related to curvature; speed as related to sight distance and curvature; and passenger-car speeds as compared to various standards for safe speeds as based on stopping distances.

The data indicate the following for the conditions of speed and sight distance generally prevailing in the areas where the studies were conducted:

1. Drivers of free-moving passenger cars do not change their speeds appreciably after entering a horizontal curve. Any adjustment in speed that is made because of curvature or limited sight distance is made on the approach to the curve. Observations of vehicle speeds on the approaches were not included in this study.

2. Speeds in the outside lanes were about the same as those in the inside lanes despite the fact that minimum sight distances were, on an average, 20 percent greater in the outside lanes than in the inside lanes of the curves

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included in these studies. Operating conditions, as far as the minimum sight distance is concerned, were more critical for the inside lanes than for outside lanes, especially on the sharper curves.

3. The amount of superelevation on the curves studied had no effect on vehicle speeds. For this reason the utilized coefficient of side friction on the same degree of curvature is lower when the superelevation is high than when it is low. Ten percent of the drivers develop a coefficient of side friction of 0.3 or more on horizontal curves sharper than 15 deg. A coefficient of side friction of 0.16, however, is rarely exceeded on curves of 6 deg. or less.

4. Superelevation as normally used in terms of feet per foot of pavement width without regard to the sharpness of the curve bears no relation to the percentage of vehicles exceeding the safe speed based on curvature, superelevation, and coefficient of side friction. A close correlation exists, however, between the superelevation per foot of width per degree of curvature and the percentage of vehicles exceeding the computed safe speed based on curvature and superelevation. The term "unit superelevation" has been applied to this expression. The analysis indicates that few vehicles exceed a safe speed on horizontal curves designed with a unit superelevation of more than 0.005 foot per foot of width per degree of curvature. This is a simple unit to apply in the design of horizontal curves.

5. The minimum sight distance on horizontal curves is not necessarily controlled by or related to the degree of curvature. On the curves studied, however, there was a general tendency for the flatter curves (those of longer radii) to have the longer minimum sight distances.

6. Operating speed and degree of curvature are closely related, and the relation is linear. Drivers do not drive at the extremely high speed permitted by the design on easy curves, and exceed the design speed on sharp curves sometimes by as much as 10 mph.

7. Considering curvature and sight distance only, curvature has a much-greater effect on vehicle speed than sight distance.

8. Driver performance on horizontal curves is such that when the minimum sight distance is 400 feet or longer, few drivers exceed what can be considered a safe speed, regardless of which of the commonly employed factors are used in computing stopping distances. With the shorter sight distances, however, most drivers stay within a speed from which they could come to a stop within the available sight distance only if no allowance is made for perception and reaction time. Between these two extremes the percentage of vehicles exceeding the safe speed depends on the criterion used to determine the safe speed.

From these studies it appears that sight distances should be at least 400 feet (if measured from a height of 4½ feet to 4 inches) on horizontal curves on main rural highways if drivers are to be expected to stop when an object suddenly appears in their lane.

COMPARISON OF DRIVER BEHAVIOR ON HORIZONTAL AND VERTICAL CURVES

Along with the study carried out as a coöperative project between the Bureau of Public Roads and the New York Department of Public Works, a companion study on vertical curves was included in the program. The results of the studies on vertical curves were reported at the January 1953 annual meeting of the Highway Research Board by B. A. Lefeve. It is interesting to compare the results of these two studies.

Following is a comparison of vehicle speeds on vertical and horizontal curves having the same minimum sight distance:

Minimum sight distance[a]	*Average speed*		*95-percentile speed*	
	Vertical curves	*Horizontal curves*	*Vertical curves*	*Horizontal curves*
feet	*mph.*	*mph.*	*mph.*	*mph.*
200	42	30	54	37
300	45	37	56	46
400	46	41	57	51
500	46	43	58	54

[a] Sight distance in both cases measured to a 4-inch object.

It will be noted that with the same minimum sight distance, vehicle speeds are considerably lower on horizontal curves than on vertical curves. The difference in speed is greater when the sight distance is low than when it is high. This tends to confirm Conclusion 7 (above) that sight distance has only a minor influence on speeds on horizontal or vertical curves. If sight distance were the controlling factor there would be the same reduction in speed with a reduction in sight distance on the vertical curves as on the horizontal curves.

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ATTACHMENT Q

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Fredrick W. Hill
Vehicle Dynamics Laboratory
May 11, 1970

FILE MEMO F-285

STEERING EFFORTS - POWER ASSIST FAILURE

Attached is a series of tracings of steering torque recordings for some females in the 30 mph, 0.3g cornering test. I arbitrarily looked at these and tabulated the maximum torque level each woman held or exceeded for one second or longer. This is an arbitrary way of viewing the data. These **torques had a distribution described by:**

$\bar{\tau}$ = **average across 10 subjects of the torque held** or exceeded for 1 second.

= 18.6 ft-lb => 27.9 lb rim

σ = 4.1 ft-lb => 6.1 lb rim

(Harvard static hold over 5 sec, $\bar{\tau}$ = 25.8 ft-lb, σ = 7 ft-lb)

This compares to the distribution of peak maneuvering effort levels of:

$\bar{\tau}$ =26.8 ft-lb => 40.2 lb rim

σ = 3.3 ft-lb => 4.0 lb rim

The shape of the torque curves are different from subject to subject. It appears from viewing the traces that $\int_{t_1}^{t_2} \tau \, dt$ is about constant.

On the pages following the sketched traces, I have tried to prove that the $\int_{t_1}^{t_2} \tau \, dt$ would be constant for this maneuver, within the control limits of speed and lateral displacement in the lane. I was not quite able to finish the analytical proof, but intuition and scrutiny of a number of torque traces does imply that the average torque over the time required for the maneuver is approximately constant. I don't know what to do with that "fact" at this time.

Fredrick W. Hill
Vehicle Dynamics Laboratory

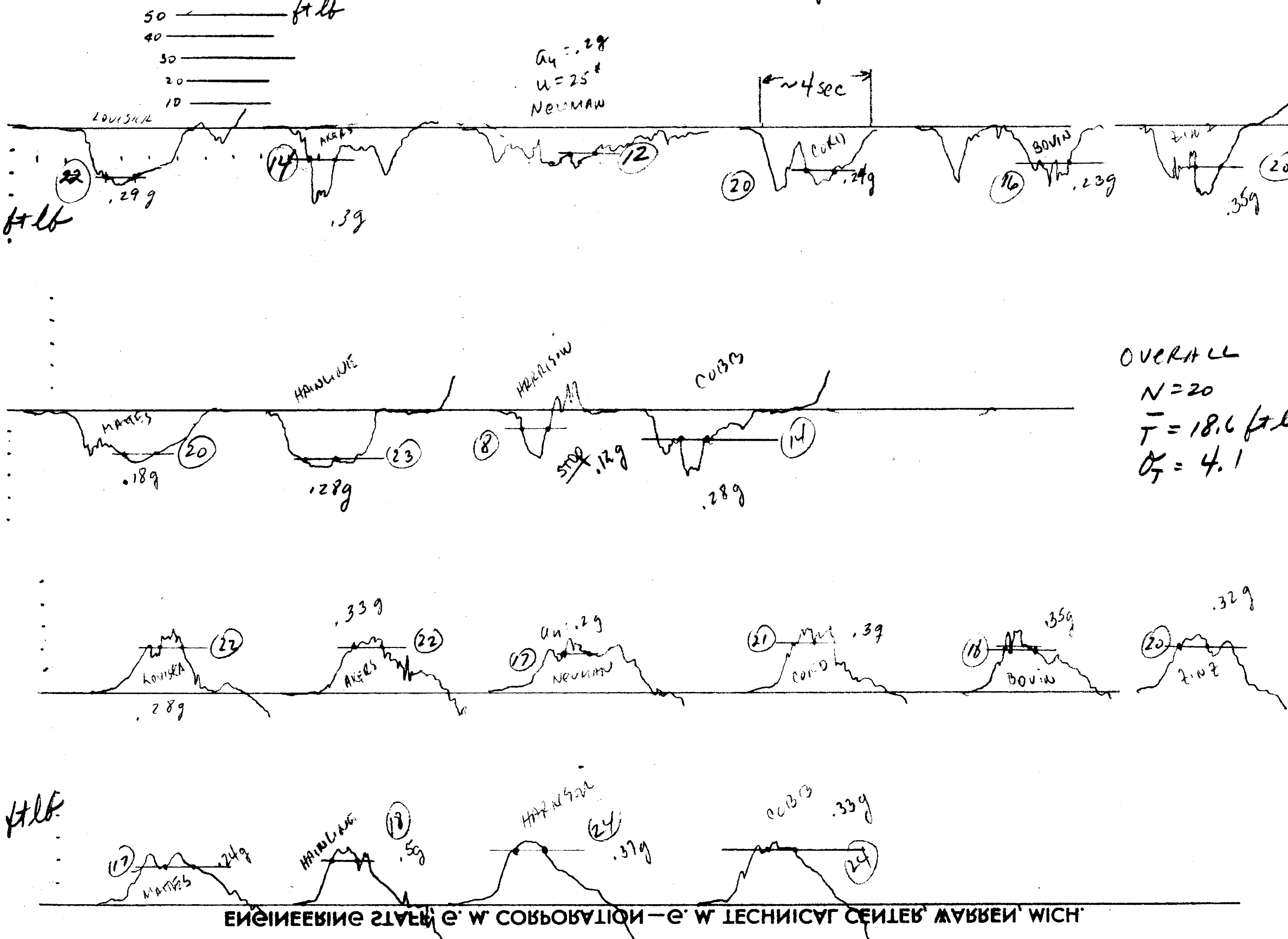
FWH/var

Attachments

F-285

Max torque level held or exceeded for 1 sec.

30 mph, 0.3g Cornering
Power Assist Failure, Modified Car

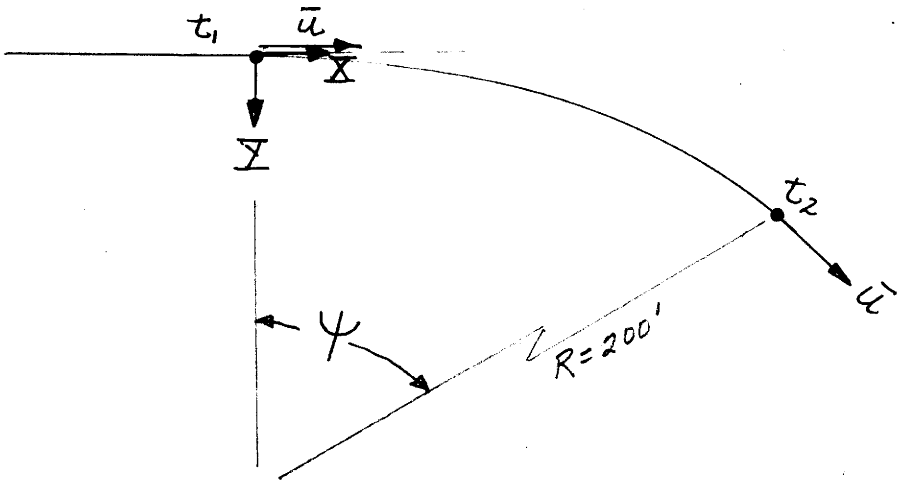


$\bar{\tau}$ = 17.0 ft lb
σ_τ = 4.6

OVERALL
N = 20
$\bar{T}$ = 18.6 ft lb
σ_T = 4.1

$\bar{\tau}$ = 20.3 ft lb
σ_τ = 2.6

Consider the test maneuver - failed curve only:



The car is going straight till time t_1. At that time, the steering assist is deactivated and a turn started. The turn is completed at t_2 and the steering wheel is returned to straight ahead. The car then follows a straight path. The speed is "constant" and the path is "well defined" within a 12-foot lane. The required lateral accelerations histories should be similar from run to run.

Let ψ = angle of turn R = 200 ft fadius

$\bar{u}$ = initial and final vector velocity, $\bar{u}$ is in direction of car longitudinal axis at beginning and end as car is going straight at both beginning and end.

The amount of work involved in getting from the state at t_1 to the state at t_2 =

$$W = \frac{1}{2} M \bar{u}_2^2 - \frac{1}{2} M \bar{u}_1^2 = \Delta \text{ ENERGY}$$

at $t = t_1$,

$$\bar{u}_1 = u \bar{X} + 0 \bar{Y}$$

at $t = t_2$,

$$\bar{u}_2 = u \cos\psi \bar{X} + u \sin\psi \bar{Y}$$

$$W_X = \frac{1}{2} M u_{2x}^2 - \frac{1}{2} M u_{1x}^2 = \frac{1}{2} M u^2 (\cos^2\psi - 1) = -\frac{1}{2} M u^2 \sin^2\psi$$

$$W_Y = \frac{1}{2} M (u^2 \sin^2\psi - 0) = \frac{1}{2} M u^2 \sin^2\psi$$

$$W_{TOTAL} = \sqrt{W_x^2 + W_y^2} = \frac{\sqrt{2}}{2} M u^2 \sin^2\psi$$

If the initial and final velocities are the same and friction losses are neglected (or constant) the total work done on the car should be the same for all runs. If the efficiency of the steering system remains constant, the total work done on the steering wheel should also be the same from run to run.

Consider work done on the steering wheel

$$W_\delta = \int_{t_1}^{t_2} \tau \frac{d\delta}{dt}\, dt \qquad \begin{matrix} \delta = \text{steering wheel angle} \\ \tau = \text{steering torque} \end{matrix}$$

by the previous discussion

$$W_\delta = C_e W - C_f = \text{Constant} = K$$

C_e: efficiency; C_f: friction losses

We also know that

$$\int_{t_1}^{t_2} \frac{d\delta}{dt}\, dt = \delta\Big]_{t_1}^{t_2} = \delta(t_2) - \delta(t_1) = 0 - 0 = 0 = \text{constant}$$

Consequently:

$$\int_{t_1}^{t_2} \tau \frac{d\delta}{dt}\, dt = \text{constant}$$

and

$$\int_{t_1}^{t_2} \frac{d\delta}{dt}\, dt = \text{constant}$$

Therefore ?

$$\int_{t_1}^{t_2} \tau\, dt \overset{?}{=} \text{constant}$$

I can't prove the last step

FWH/var
F-285

PE10-005

GM

4/14/2010

ATTACHMENT Q

15 C

1970_06_07_apl_memo

GM
General Motors Proving Grounds

Milford, Michigan 48042

Date: June 7, 1970

Subject: Maximum Steering Wheel Rim Force

To: D. L. Nordeen, Assistant Chassis Engineer
Oldsmobile Division
Lansing, Michigan

Dick Rasmussen informed me that you were interested in the maximum steering wheel rim force which men were capable of generating. I can make an estimate of this force based on the Static Turn distribution from the Surprise Failure study done this past year.

At the conclusion of the surprise failure test, all subjects were asked to turn the steering wheel to the right and left as hard as they could. The power assist was inoperative. Hand positions during maximum torque were along lines inclined 45° to the left and right of the vertical for the right and left turning directions respectively. Subjects' hands were positioned diametrically opposite each other. Peak instantaneous torque and a level of torque which could be held for 3 seconds, called hold torque, were recorded.

A total of 16 men produced 58 readings in each of the PEAK and HOLD conditions. The distributions of efforts proved to be normal and these distributions are shown in the accompanying diagram. From these distributions the 95%-ile subjects may be interpolated. Since an 8 inch radius steering wheel was used in the test, all torques, shown in inch-pounds, should be divided by 8 to get the corresponding pounds of rim force. It should be noted that our equipment was only calibrated to read as high as 600 inch-lbs (75 lbs rim force). However, only one subject was able to hold the meter over the scale limit.

Summary of Data - Static Distribution (Surprise Failure - GMPG) July, 1969

Peak Capability (Pounds of Rim Force)

	Mean	Std. Dev.	N	95%-ile
Left	51.7	8.6	29	66.3
Right	50.8	8.2	29	65.6

Hold Capability (Pounds of Rim Force)

	Mean	Std. Dev.	N	95%-ile
Left	34.1	8.2	29	48.1
Right	35.4	7.4	29	46.9

Summary of Harvard School of Public Health, "Vehicle Handling: Force Capabilities for Braking and Steering", May, 1969, investigated only the force capabilities of women and not men, so the study is irrelevant to your question.

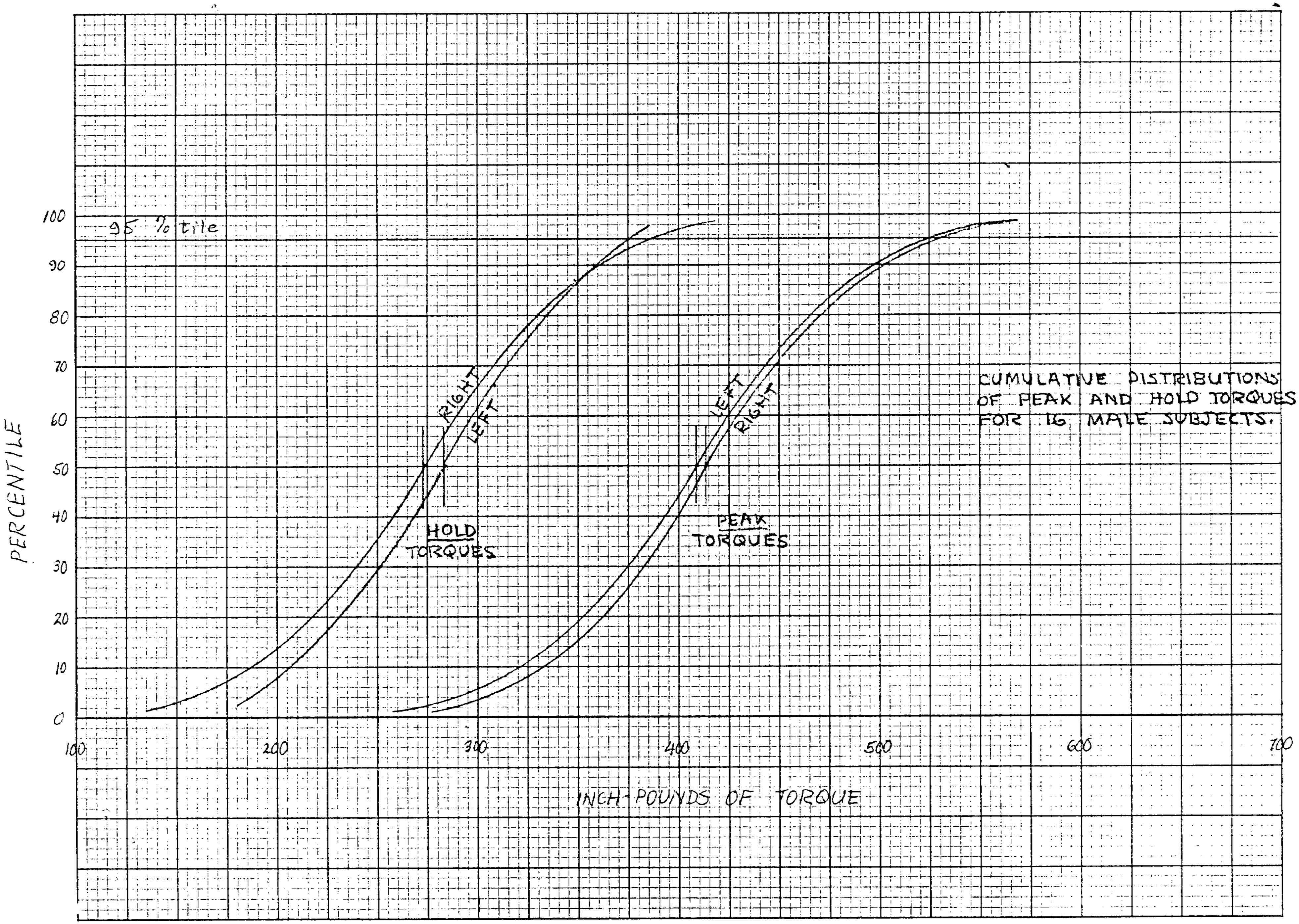
A. P. Lawrence

A. Paul Lawrence
Vehicle Dynamics Laboratory

APW/jmj

Attachment

cc: R. T. Bundorf
✓R. E. Rasmussen



95 %tile
PERCENTILE
100
90
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
700
INCH-POUNDS OF TORQUE
RIGHT
LEFT
HOLD TORQUES
LEFT
RIGHT
PEAK TORQUES
CUMULATIVE DISTRIBUTIONS OF PEAK AND HOLD TORQUES FOR 16 MALE SUBJECTS.

PE10-005

GM

4/14/2010

ATTACHMENT Q

15 C

1974_02_22_hkm_memo

-122/74

File F-866

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DO NOT REMOVE

The attached data sheets summarize steering effort data obtained by the Vehicle Dynamics Laboratory on 1970 - 1973 model year passenger cars. This information was utilized in response to the NHTSA Information Request for steering effort data. Steering wheel rim force in pounds, vehicle front wheel weight and loading are shown, where available, for the three standard tests performed. These include dynamic effort measured using the unconstrained (S-turn) path method at speeds of 10 and 30 mph and static effort. The test procedures used are documented in Report No. PG-31415 (VDL File No. F-544). Data was obtained for each vehicle from the references listed on each data sheet.

H. K. Mueller

CP 153 Rev.
Prtd. U.S.A.

SUMMARY

Model Year	Power On 10 MPH (lb. / Data Pts.)	Power On 30 MPH (lb. / Data Pts.)	Power On Static (lb. / Data Pts.)	Power On Wt. Dist. Max / Min	Power Off 10 MPH (lb. / Data Pts.)	Power Off 30 MPH (lb. / Data Pts.)	Power Off Static (lb. / Data Pts.)	Power Off Wt. Dist. Max / Min	Manual 10 MPH (lb. / Data Pts.)	Manual 30 MPH (lb. / Data Pts.)	Manual Static (lb. / Data Pts.)	Manual Wt. Dist. Max / Min
1973	3-4 lb. / 3	3 lb. / 3	4-5 lb. / 2	2772 / 2505	36-94 lb / 7	24-46 lb / 7	None	3262 / 2505	10-21 lb / 7	6-14 lb / 7	18-46 lb / 7	2640 / 1010
1972	2-3 lb. / 5	2 lb / 5	None	2970 / 2370	39-71 lbs / 7	21-40 lbs / 9	None	3196 / 2350	None	None	None	N/A
1971	3 lb. / 1	2 lb / 1	None	2426	None	None	None	N/A	11-19 lbs / 5	9-13 lbs / 6	None	2478 / 1758
1970	None	None	None	N/A	A curve only	12-38 lb / 39	None	3060 / 2198	A curve only	8-11 lbs / 6	None	2224 / 1810
Totals: Range (lb)	2-4	2-3	4-5		36-94	12-46	None		10-21	6-14	18-46	
Totals: Data Pts.	9	9	2		14	55			12	19	7	
Weight Range: Max	2970	2970	2970		3262	3262	3262		2640	2640	2640	
Weight Range: Min	2370	2370	2370		2198	2198	2198		1010	1010	1010	

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1973 Vehicles

		Power on			Power off or Manual							
Vehicle	Steering	10 MPH	30 MPH	Static	10 MPH	30 MPH	Static	FWW	Loading			Reference
Olds 98 4DHT	P	–	–	–	55	36	–	2800	1 pass + EQ.			PG 33485 F-725
Eldorado 2DHT	P	–	–	–	94	46	–	3262	"			"
DeVille 4DHT	P	–	–	–	71	32	–	2966	"			"
Century Wagon	M	–	–	–	20	12	46	2388	"			"
Chevelle 2DHT	M	–	–	–	18	11	39	2131	"			"
Apollo 4DS	M	–	–	–	16	10	38	2146	"			"
Vega 2DHB	M	–	–	–	10	6	30	1455	"			"
G-20 Sportvan	P	4	3	5	36	24	–	2772	2 pass			PG 33120 F-693
Cutlass 4DS	P	–	–	–	46	24	–	2540	1 pass + EQ.			PG 32069 F-660
Toronado	P	–	–	–	57	36	–	3116	"			"
Toronado	P	3	3	4	–	–	–	3102	"			PG 31743 F-624
Vista Cruiser Wagon	M	–	–	–	21	14	45	2640	GVW			PG 31453 F-614
Monte Carlo	P	3	3	–	58	31	–	2505	1 pass + EQ.			PG 31437 F-611
Chevette	M	–	–	–	16	4	27	1276	1 pass + EQ.			Small car survey
Opel Kadett (74)	M	–	–	–	11	7	18	1010	"			"
Vauxhall ('75 PT)	M	–	–	–	10	6	21	990	"			"

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1972 VEHICLES

		POWER ON			POWER OFF OR MANUAL								
VEHICLE	STEERING	10 MPH	30 MPH	STATIC	10 MPH	30 MPH	STATIC	FWW	LOADING				REFERENCE
OLDS 88 4 DR.	P	–	–		71	36	–	2700	1 PASS + EQ.				PG 31563 F-612
CUTLASS	P	–	–	–	39	21	–	2350	"				"
DEVILLE	P	–	–	–	–	32	–	2930	1 PASS + EQ.		+1° CASTER		PG 31569 F-590
ELDORADO	P	–	–	–	–	38	–	3196	"		+1° CASTER		"
OLDS 98 4 DR.	P	3	2	–	63	40	–	2848	1 PASS + EQ.				PG 31556 F-621
OLDS "A"	P	2	2	–	42	22	–	2370	2 PASS + EQ.				PG 31123 BUBOLZ F-575
OLDS "B"	P	3	2	–	61	36	–	2636	"				"
OLDS "C"	P	3	2	–	63	37	–	2703	"				"
OLDS "E"	P	2	2	–	53	31	–	2970	"				"

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1971 VEHICLES

VEHICLE	STEERING	POWER ON 10 MPH	POWER ON 30 MPH	POWER ON STATIC	POWER OFF OR MANUAL 10 MPH	POWER OFF OR MANUAL 30 MPH	POWER OFF OR MANUAL STATIC	FLW	LOADING			REFERENCE
~~OLDS 88 (B)~~	~~P~~	~~3~~	~~2~~	~~3~~	~~–~~	~~27~~	~~–~~	~~?~~	~~1 PASS + EQ. NEW TIRES~~			PG 31415 F-544
~~CUTLASS (A)~~	~~P~~	~~2.5~~	~~2~~	~~3~~	~~–~~	~~24~~	~~–~~	~~?~~	~~"~~	~~"~~		"
~~CUTLASS (A)~~	~~M~~	~~+~~	~~–~~	~~–~~	~~19~~	~~12~~	~~44~~	~~?~~	~~"~~	~~"~~		"
CUTLASS 2DHT	M	–	–	–	–	M 10	–	2345	2 PASS + EQ.			PG-30693 F-549
CUTLASS	M	–	–	–	14 M 18	9 M 12	–	2278 2478	2 PASS + EQ.			PG-30801 F-556
CHEVELLE 4DR.	M	–	–	–	M 14	M 10	–	2052	"			"
NOVA 2DR	M	–	–	–	M 11	M 9	–	1758	"			"
CUTLASS	P	3	2	–	–	–	–	2426	2 PASS + EQ.			F-513 "
CUTLASS	M	–	–	–	M 19	M 13	–	2415	2 PASS + EQ.			PG-29873 F-421

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1970 Vehicles

Vehicles	Steering	Power On: 10 MPH	30 MPH	Static	Power Off/Manual: 10 MPH	30 MPH	Static	FWW	Loading			Reference
Impala	P					19		2292	2 PASS + EQ.			PG 28590 F-335
Catalina	P					23		2475				
Bel Air	M					M 10		2185				
Malibu	P M					19 M 8		2198 1986				
Tempest	P M					23 M 8		2402 2020				
Cutlass	P					19	NOT [illegible]	2277				
Skylark	P M					21 M 10	 NOT [illegible]	2225 2165				
Olds F85	M					M 11		2224				
Delta 88	P					24		2504				
LaSabre	P					24	[illegible]	2471				
Nova	P M					12 M 8		2230 1810				
Kingswood Wag.	P					20		2316				
Estate Wag.	P					25		2535				
Executive Wag.	P					21		2556				
Chevelle Concours Wag.	P					14		2246				
Tempest Wag.	P					21		2360				
Buick Sportwagon	P					18		2240				
Cutlass Wag.	P					21		2258				
DeVille	P					28		2918				
Electra LTD	P					27		2844				
Olds 98	P					28		2795				

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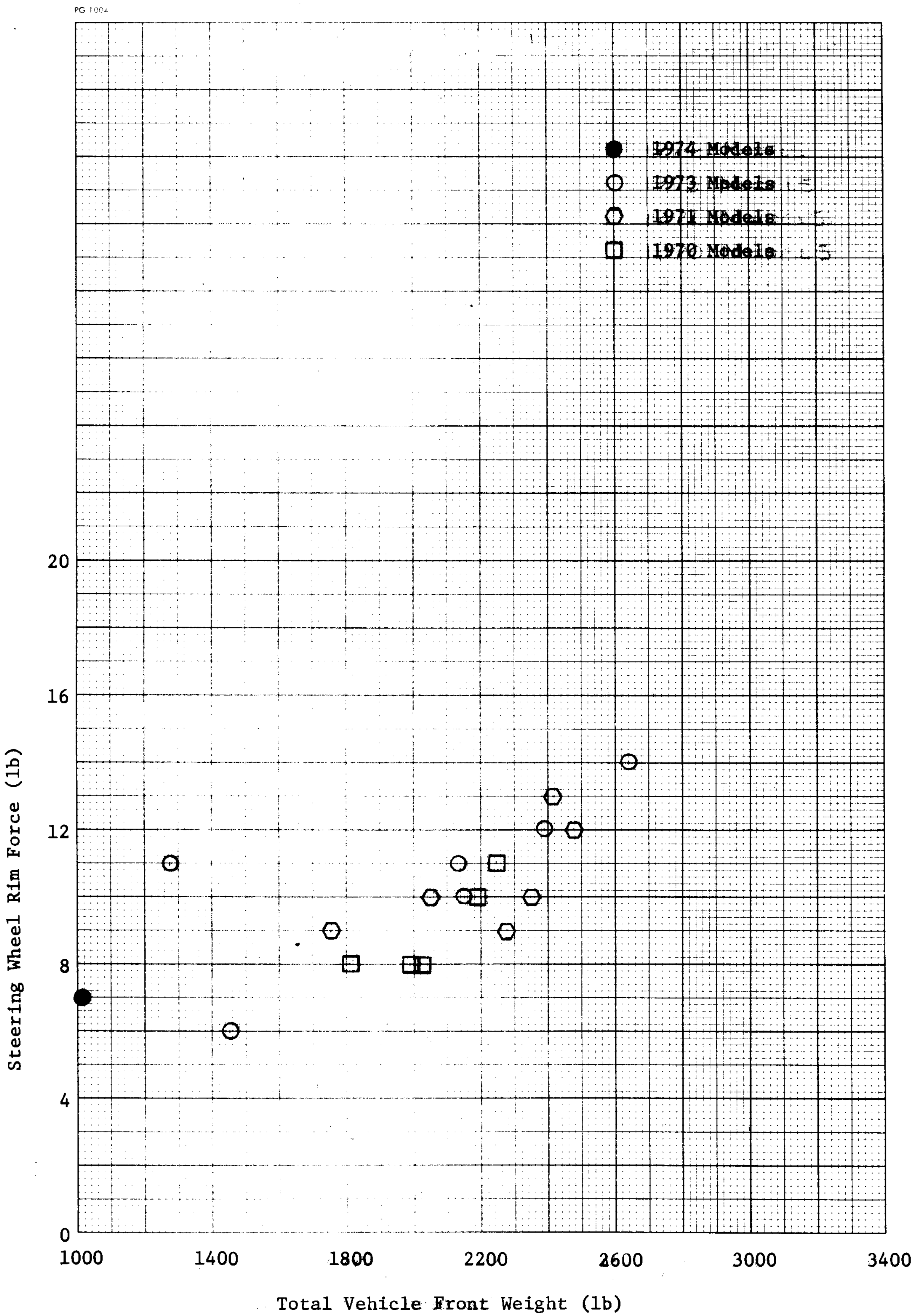
1970 Vehicles

		Power On			Power Off or Manual							
Vehicle	Steering				10 MPH	30 MPH	Static	FWW	Loading			Ref.
Bonneville	P					24		2788				
Delta 88 Cus.	P					25		2755				
Wildcat	P					22		2704				
Cutlass 442	P					23		2510				
GS-455	P					20		2460				
Caprice	P					29		2725				
Monte Carlo	P					24		2505				
Gran Prix	P					23		2535				
Electra 2 DR Coupe	P					26 ~~28~~		2700 ~~2826~~	2 Pass + EQ. FRL			PG 28567
Electra 4 DR.	P					24 ~~27~~		2680 ~~2870~~	"			"
Electra 4 DR SED	P					21 24		2692 ~~2838~~	"			"
Electra 4 DR. HT	P					23 ~~26~~		2700 ~~2894~~	"			"
DeVille	P					32 30		2816	+1° Caster. (2 Pass + EQ.) -1° Caster "			PG-28337
Eldorado	P					38 37		3060	+1° Caster " -1° Caster "			"

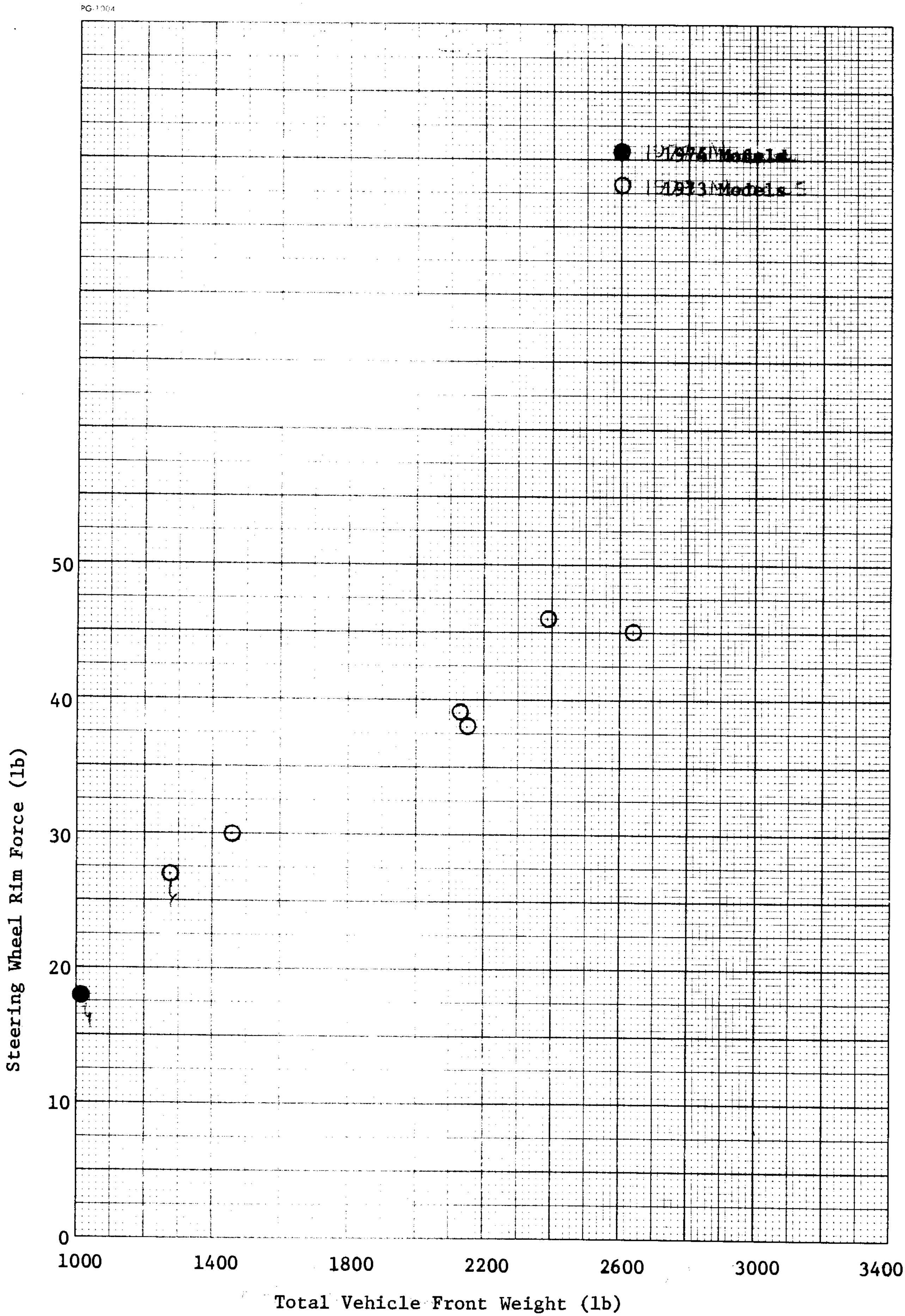
MANUAL STEER RIM FORCE - 30 MPH

0.25 g STEADY STATE LATERAL ACCELERATION



MANUAL STEER RIM FORCE - STATIONARY

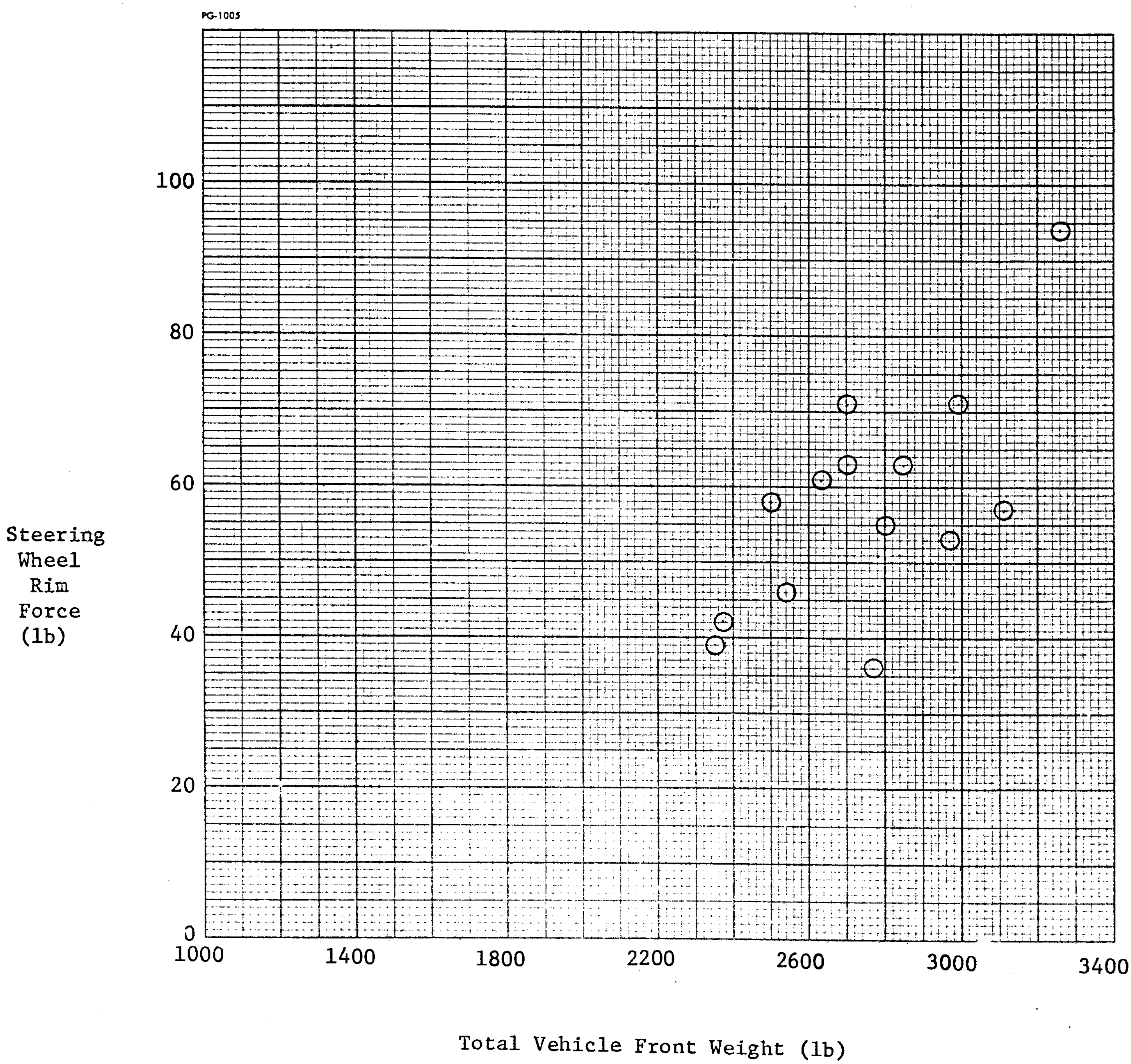
3M MEDIUM GRIT SURFACE



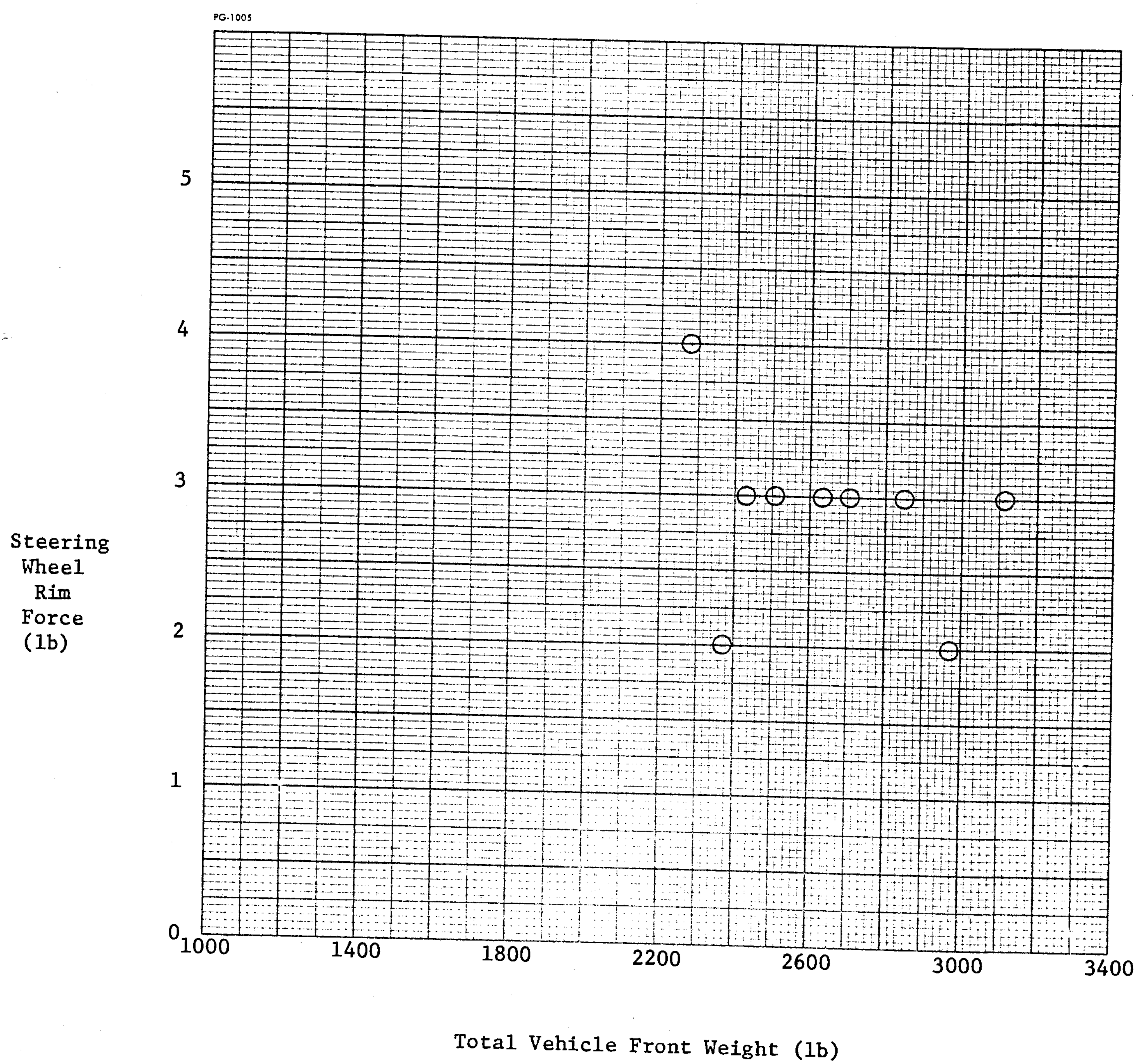
HKM

Vehicle	Car No.	Str Wheel Dia (in)		10 MPH (.25G) Torque (in-lbs) CW	10 MPH (.25G) Torque (in-lbs) CCW	10 MPH (.25G) Force (lbs) CW	10 MPH (.25G) Force (lbs) CCW	30 MPH (.25G) Torque (in-lbs) CW	30 MPH (.25G) Torque (in-lbs) CCW	30 MPH (.25G) Force (lbs) CW	30 MPH (.25G) Force (lbs) CCW	Static Torque (in-lbs) CW	Static Torque (in-lbs) CCW	Static Force (lbs) CW	Static Force (lbs) CCW
1974 Ford	49102	14	①	117	118	16.7	16.9	57	74	8.1	10.6	265	260	37.9	37.1
Mustang II	F 1735 lb	(Manual)	②	118	123	16.9	17.6	69	74	9.9	10.6	265	260	37.9	37.1
L-4	R 1505 lb	24.2:1	③	112	128	16.0	18.3	58	72	8.3	10.3	270	265	38.6	37.9
	T 3240 lb	overall	$\bar{x}$			16.5	17.6	(17.0)		8.8	10.5	9.6	31.8	38.1	37.4
			σ			0.5	0.7			1.0	0.2			0.4	0.5
1974 Vega	4404	A = 14½	①	88	92	12.4	12.9	51	55	7.2	7.7	260	230	36.5	32.3
Sim. 2+2 L-4		B = 14	②	88	88	12.4	12.4	47	53	6.6	7.4	250	230	35.1	32.3
28:1 (73 "A" Prod)	F 1650	Avg = 14.25	③	85	89	11.9	12.5	44	52	6.2	7.3	255	245	35.8	34.4
	R 1540	r = 7.125	$\bar{x}$			12.2	12.6	(12.4)		6.7	7.5	7.10	34.4	35.8	33.0
BR70-13 Firestone	T 3190		σ =			0.3	0.3			0.5	0.2			0.7	1.2
1974 Vega	"	"	①	106	105	14.9	14.7	52	59	7.3	8.3	265	270	37.2	37.9
Sim 2+2 L-4			②	95	97	13.3	13.6	56	59	7.9	8.3	260	265	36.5	37.2
24:1 (Index 390-A)			③	110	95	15.4	13.3	55	59	7.7	8.3	260	280	36.5	39.3
			$\bar{x}$			14.5	13.9	(14.[illegible])		7.6	8.3	8.0	37.4	36.7	38.1
BR70-13 Firestone			σ			1.1	0.7			0.3	0			0.4	1.1
1974 Vega	"	"	①	103	101	14.5	14.2	66	56	9.3	7.9	285	305	40.0	42.8
Sim. 2+2 L-4			②	108	105	15.2	14.7	68	56	9.5	7.9	285	293	40.0	41.1
20.9:1 (Prod.)			③	112	102	15.7	14.3	68	57	9.5	8.0	285	290	40.0	40.7
			$\bar{x}$			15.1	14.4	14.8		9.4	7.9	8.6	40.8	40.0	41.5
BR70-13 Firestone			σ			0.6	0.3			0.1	0.1			0	1.1
1974 Vega	4404	"	①	140	127	19.6	17.8	74	78	10.4	11.0	390	425	54.7	59.6
Sim. 2+2 V-8			②	133	126	18.7	17.7	74	82	10.4	11.5	393	395	55.2	55.4
20.9:1 (Prod)			③	144	125	20.2	17.5	79	75	11.1	10.5	390	407	54.7	57.1
	F 1921 R 1584		$\bar{x}$			19.5	17.7	(18.6)		10.6	11.0	(10.8)	(56.2)	54.9	57.4
BR70-13 Firestone	T 3505		σ			0.8	0.2			0.4	0.5			0.3	2.1
1974 Vega	"	"	①	111	128	15.6	18.0	79	74	11.1	10.4	325	350	45.6	49.1
Sim. 2+2 V-8			②	117	119	16.4	16.7	76	72	10.7	10.1	340	335	47.7	47.0
24:1 (Index 390-A)			③	122	118	17.1	16.6	75	68	10.5	9.5	335	345	47.0	48.4
			$\bar{x}$			16.4	17.1	(16.8)		10.8	10.0	(10.4)	(47.5)	46.8	48.2
BR70-13 Firestone			σ			0.8	0.8			0.3	0.5			1.1	1.1
1974 Vega	"	"	①	103	104	14.5	14.6	66	61	9.3	8.6	275	280	38.6	39.3
Sim 2+2 V-8			②	99	103	13.9	14.5	63	61	8.8	8.6	265	265	37.2	37.2
28:1 (73 "A" Prod)			③	95	103	13.3	14.5	68	61	9.5	8.6	255	275	35.8	38.6
			$\bar{x}$			13.9	14.5	(14.2)		9.2	8.6	(8.9)	(37.8)	37.2	38.4
			σ			0.6	0.1			0.4	0			1.4	1.1

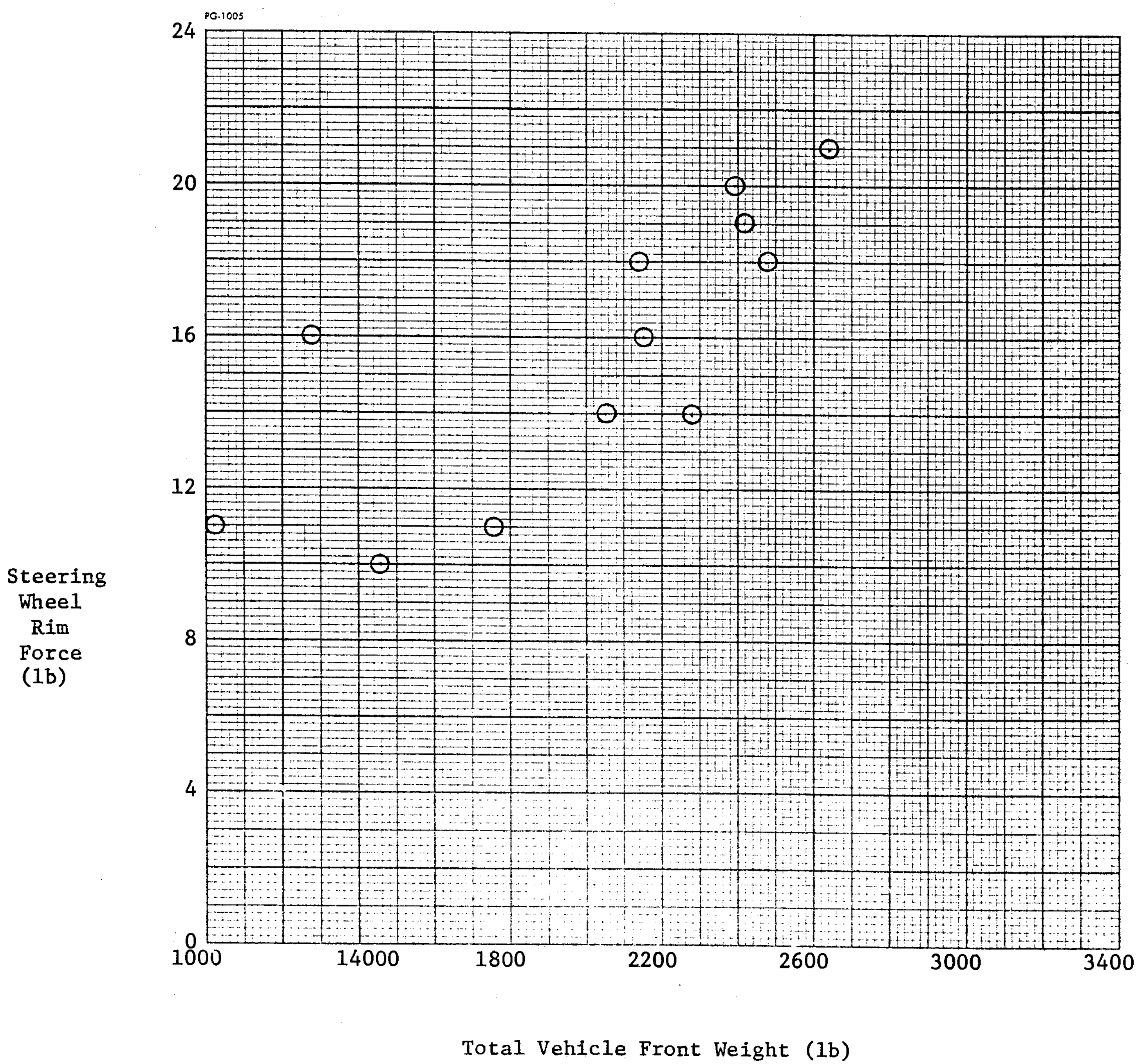
Power Off Rim Force vs
Total Vehicle Front Weight
10 MPH
0.25g Steady State Lateral Acceleration

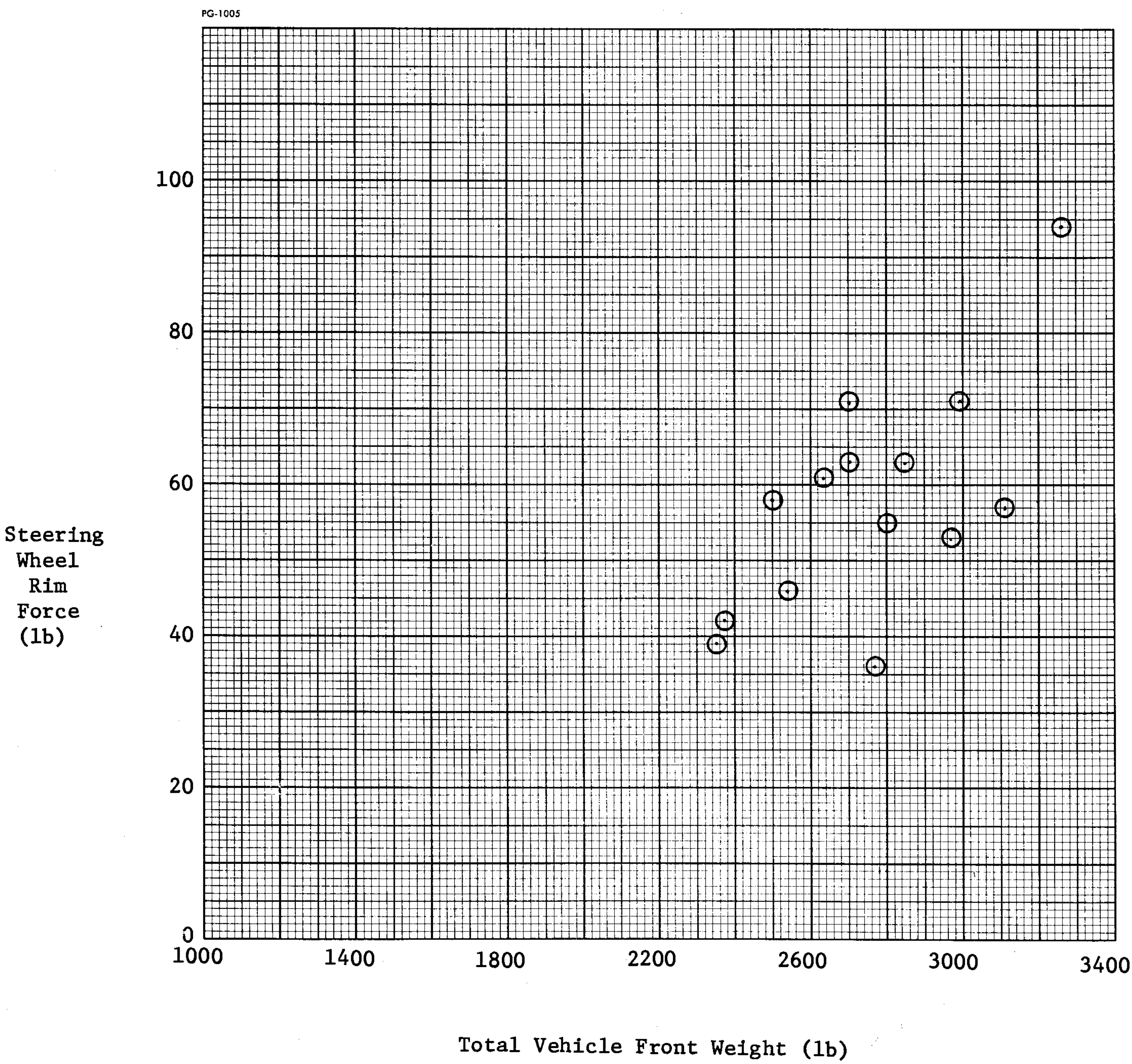


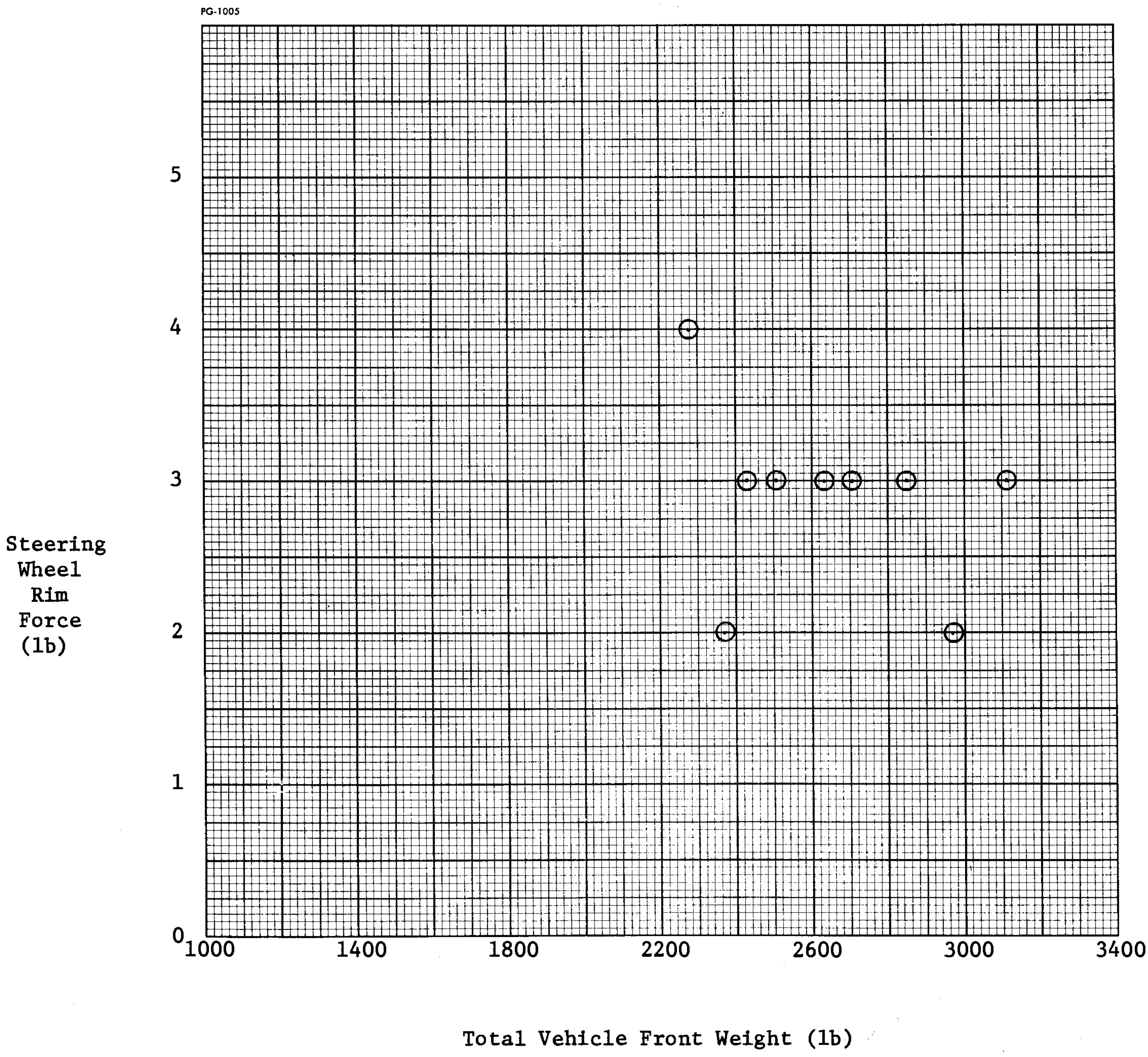
Power On Rim Force vs
Total Vehicle Front Weight
10 MPH
0.25 g Steady State Lateral Acceleration

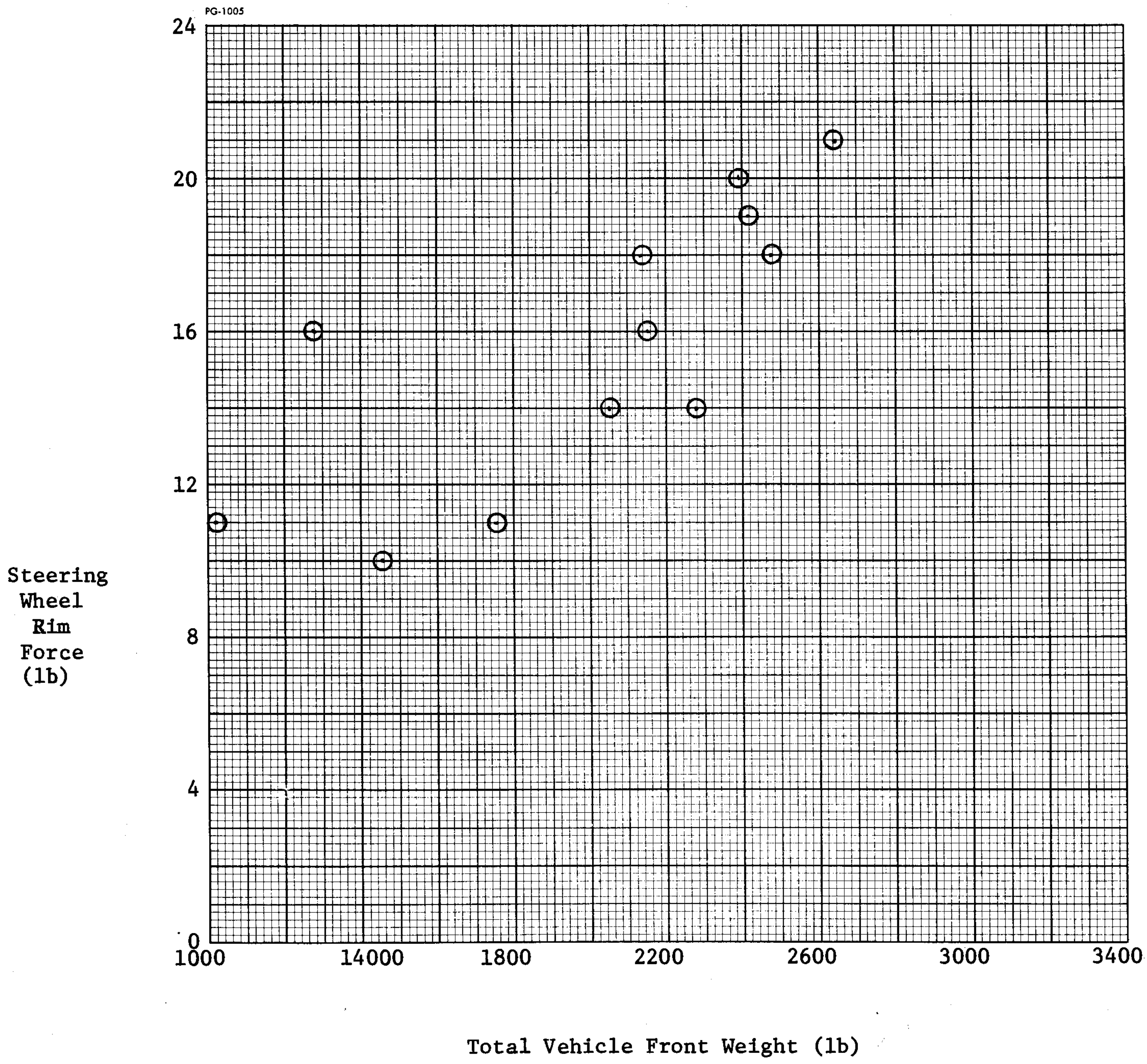


Rim Force for Manual Steering Vehicles vs.
Total Vehicle Front Weight
10 MPH
0.25 g Steady State Lateral Acceleration




PG-1005
Steering
Wheel
Rim
Force
(lb)
100
80
60
40
20
0
1000
1400
1800
2200
2600
3000
3400
Total Vehicle Front Weight (lb)

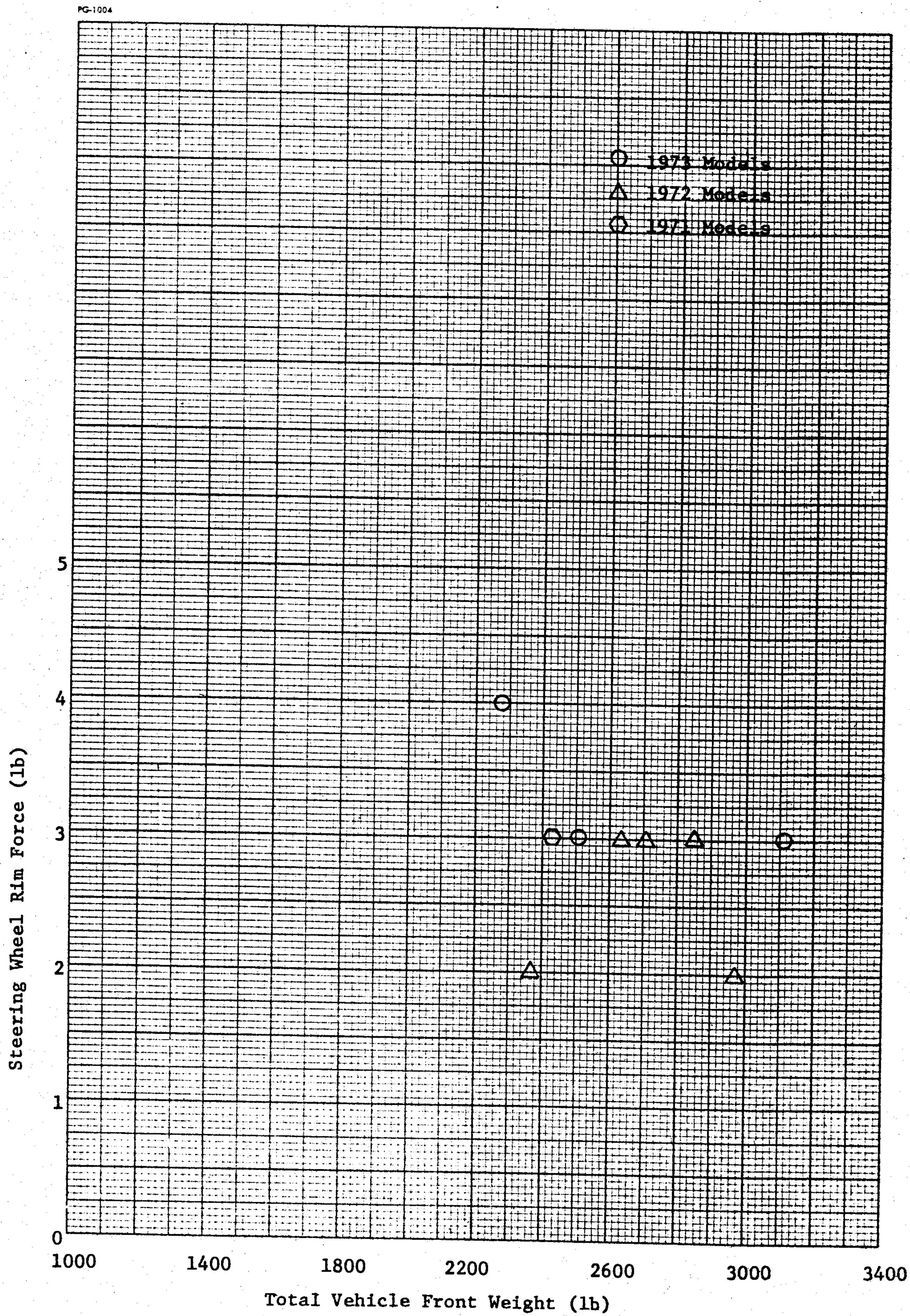

PG-1005
Steering
Wheel
Rim
Force
(lb)
0
1
2
3
4
5
1000
1400
1800
2200
2600
3000
3400
Total Vehicle Front Weight (lb)



PG-1005
24
20
16
12
8
4
0
Steering
Wheel
Rim
Force
(lb)
1000
14000
1800
2200
2600
3000
3400
Total Vehicle Front Weight (lb)

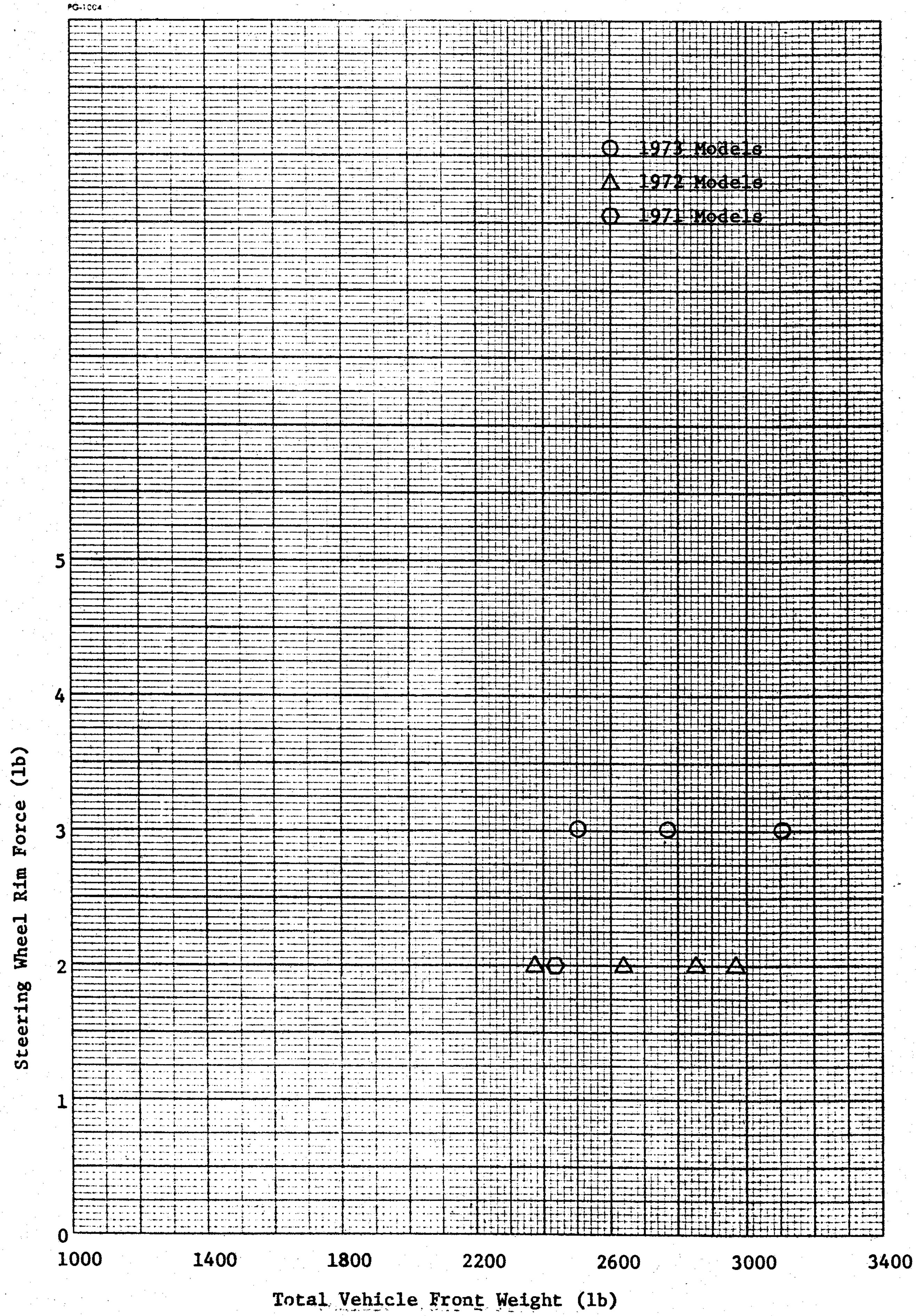
POWER ON RIM FORCE - 10 MPH

0.25 g STEADY STATE LATERAL ACCELERATION



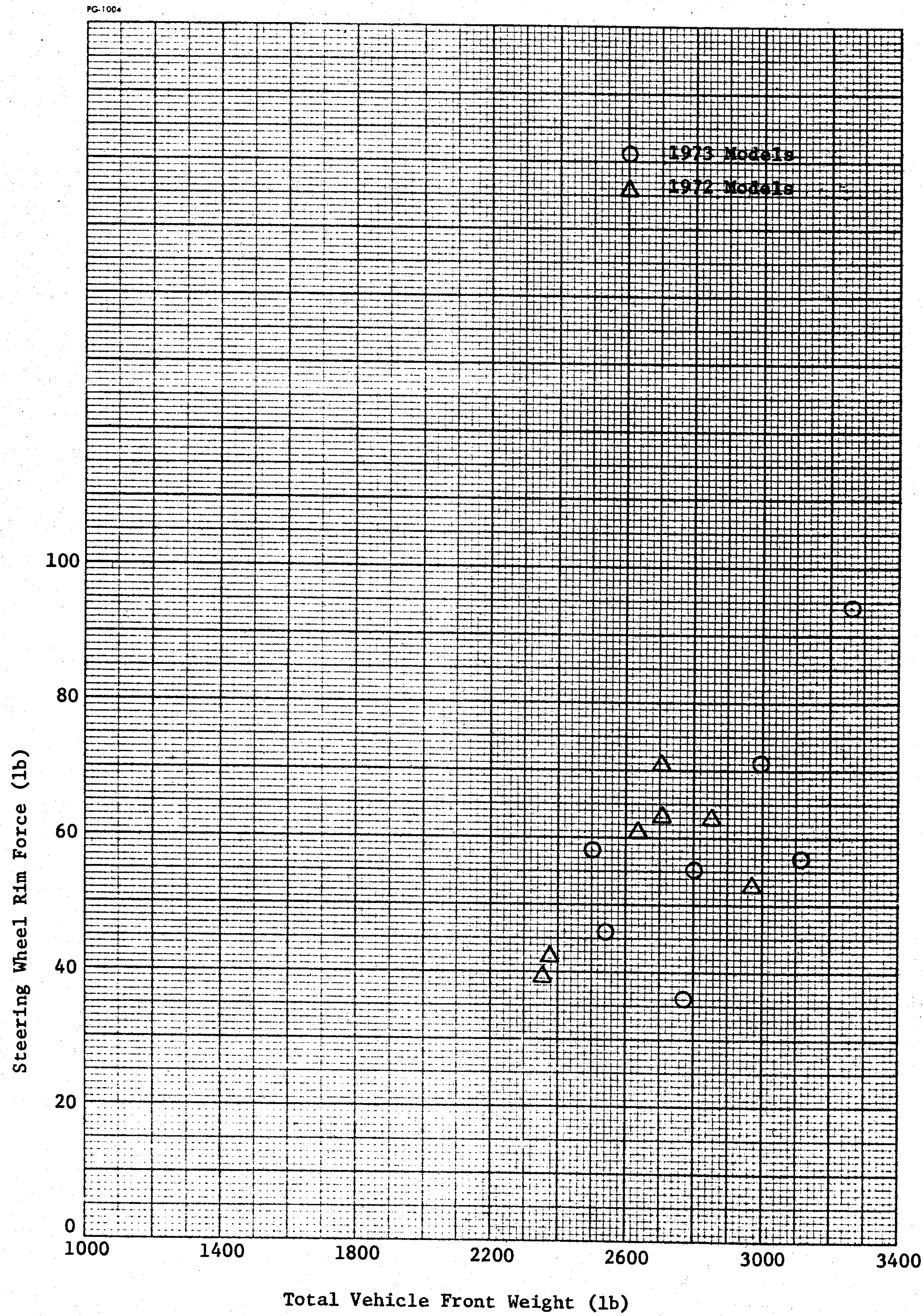
POWER ON RIM FORCE - 30 MPH

0.25 g STEADY STATE LATERAL ACCELERATION



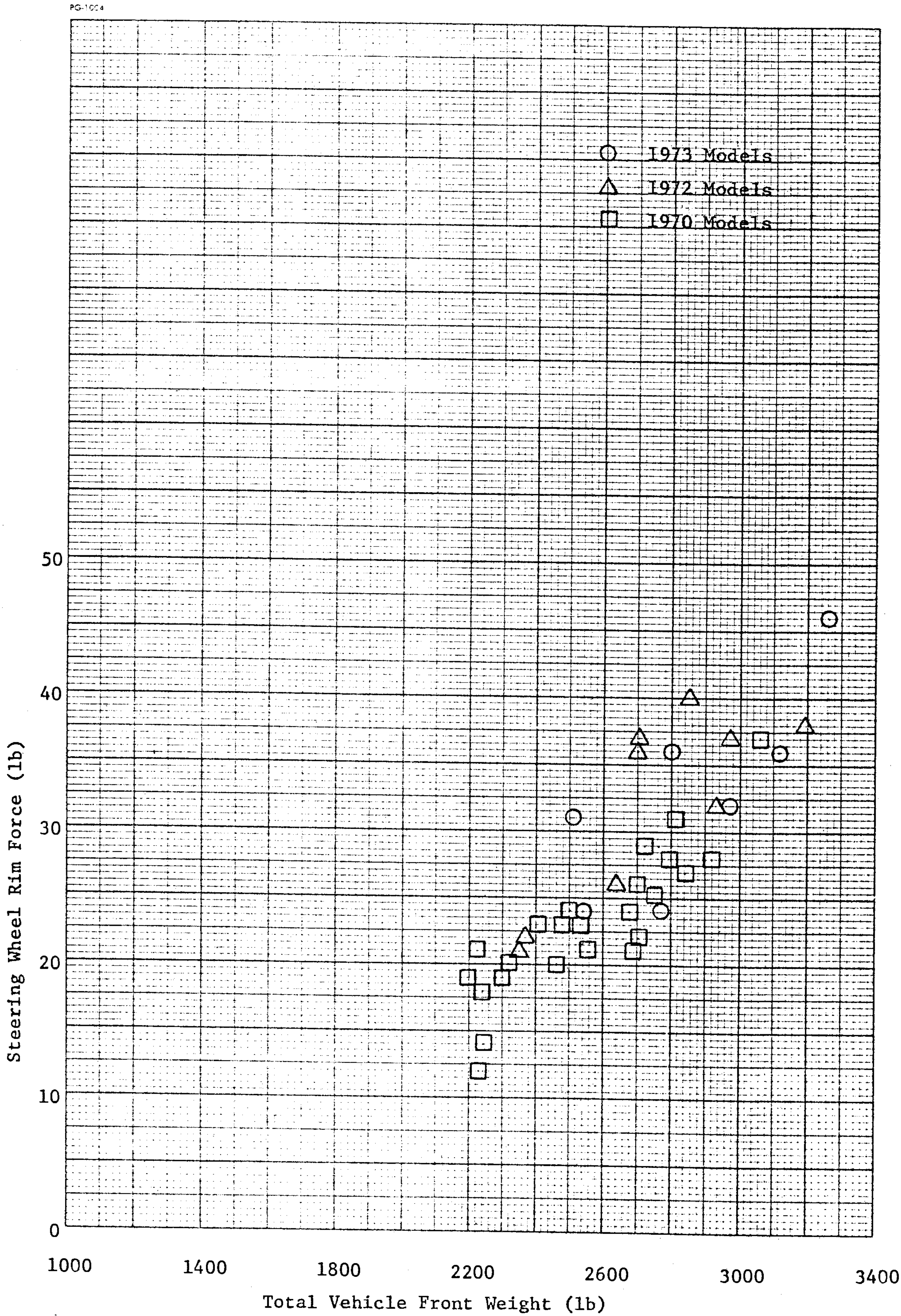
POWER OFF RIM FORCE - 10 MPH

0.25 g STEADY STATE LATERAL ACCELERATION



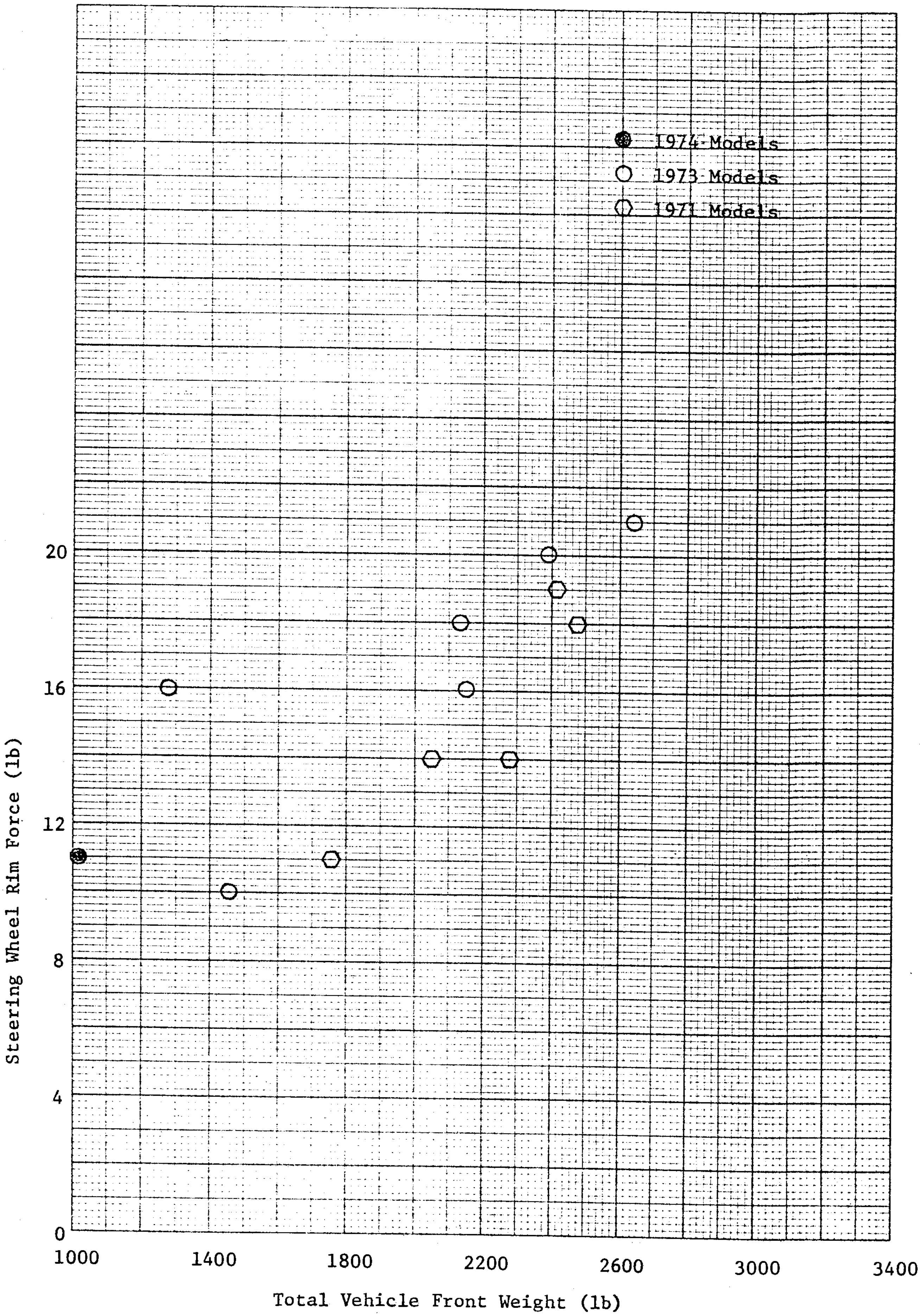
POWER OFF RIM FORCE - 30 MPH

0.25 g STEADY STATE LATERAL ACCELERATION



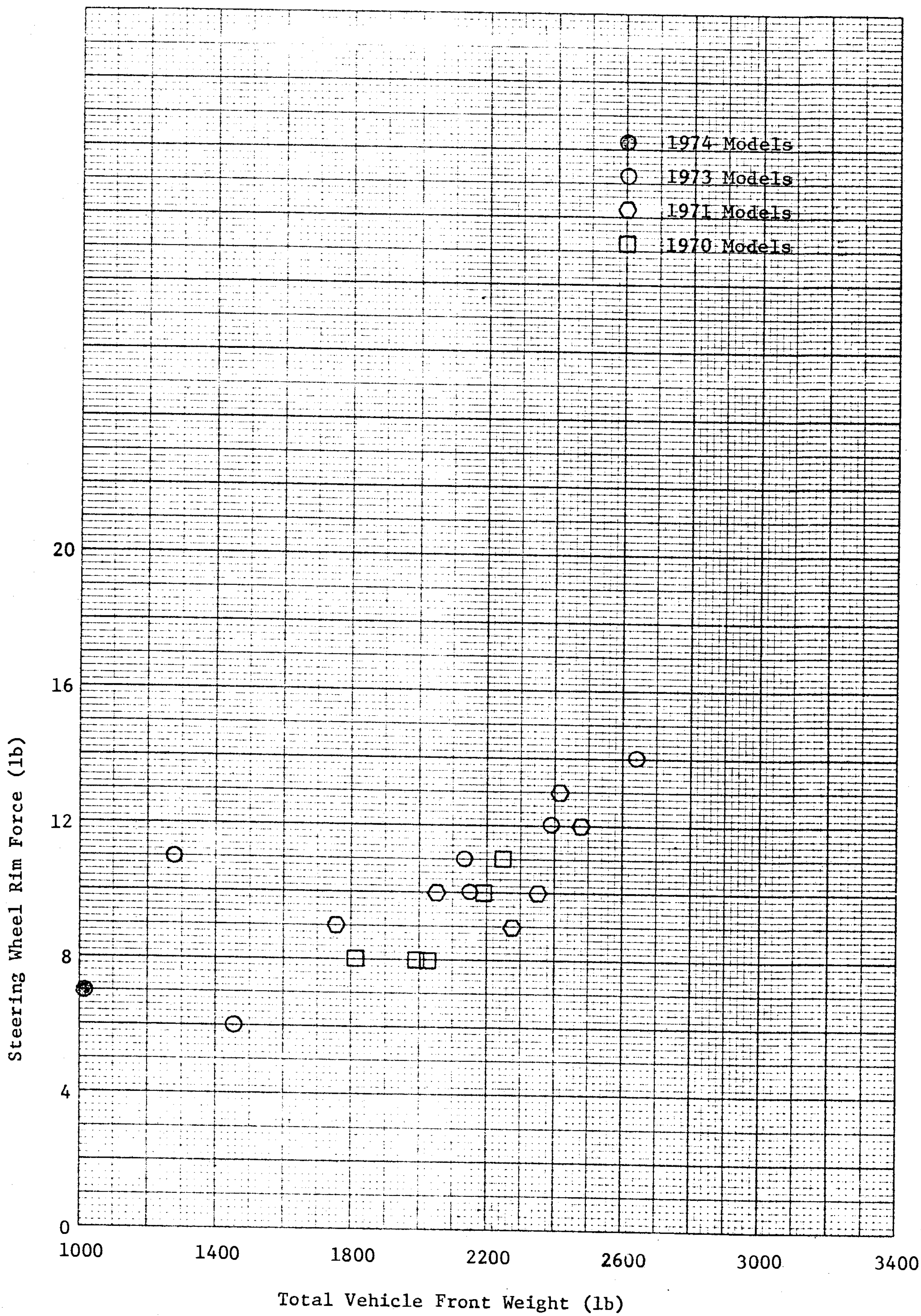
MANUAL STEER RIM FORCE - 10 MPH

0.25 g STEADY STATE LATERAL ACCELERATION



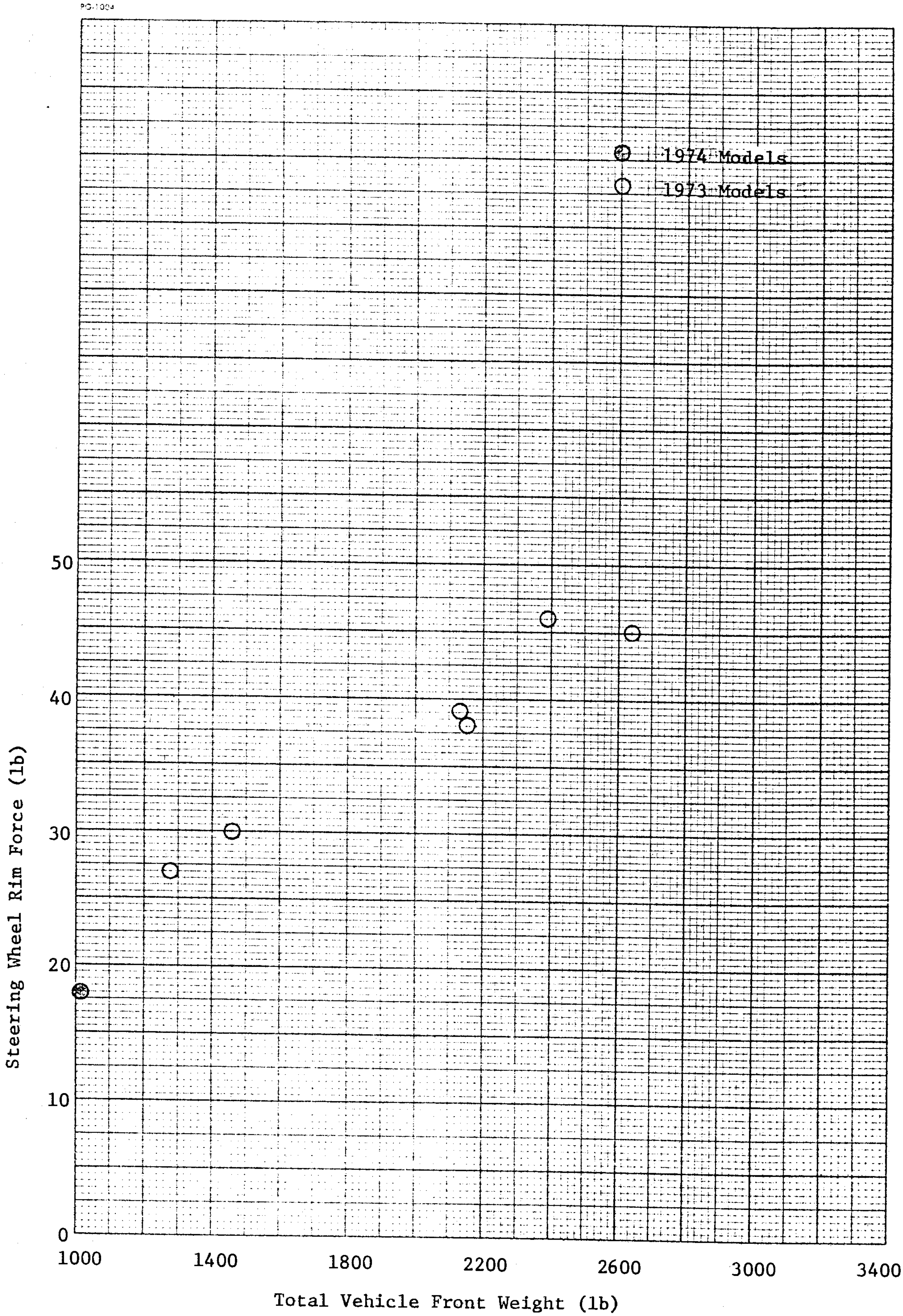
MANUAL STEER RIM FORCE - 30 MPH

0.25 g STEADY STATE LATERAL ACCELERATION



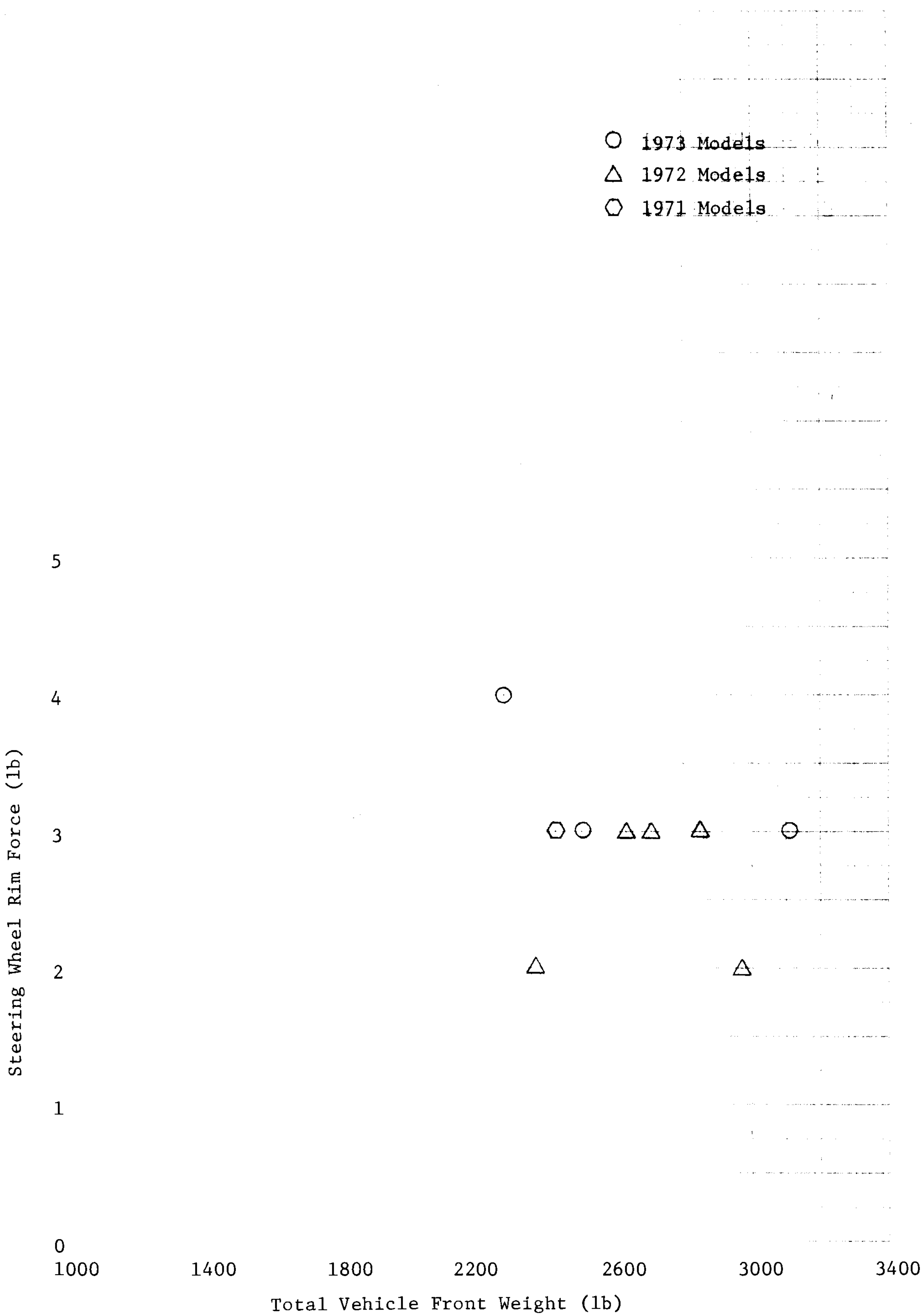
MANUAL STEER RIM FORCE - STATIONARY

3M MEDIUM GRIT SURFACE



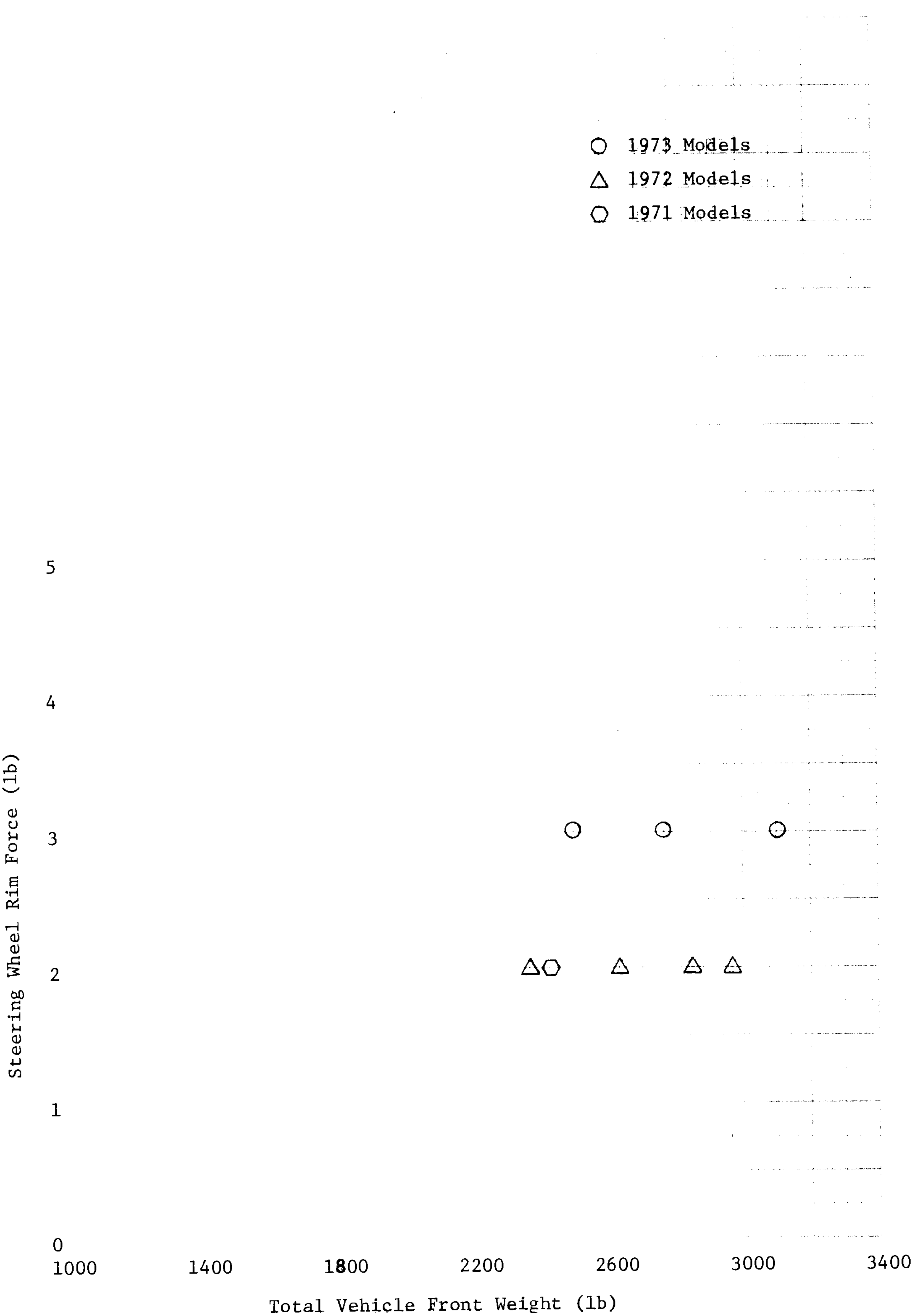
POWER ON RIM FORCE - 10 MPH

0.25 g STEADY STATE LATERAL ACCELERATION



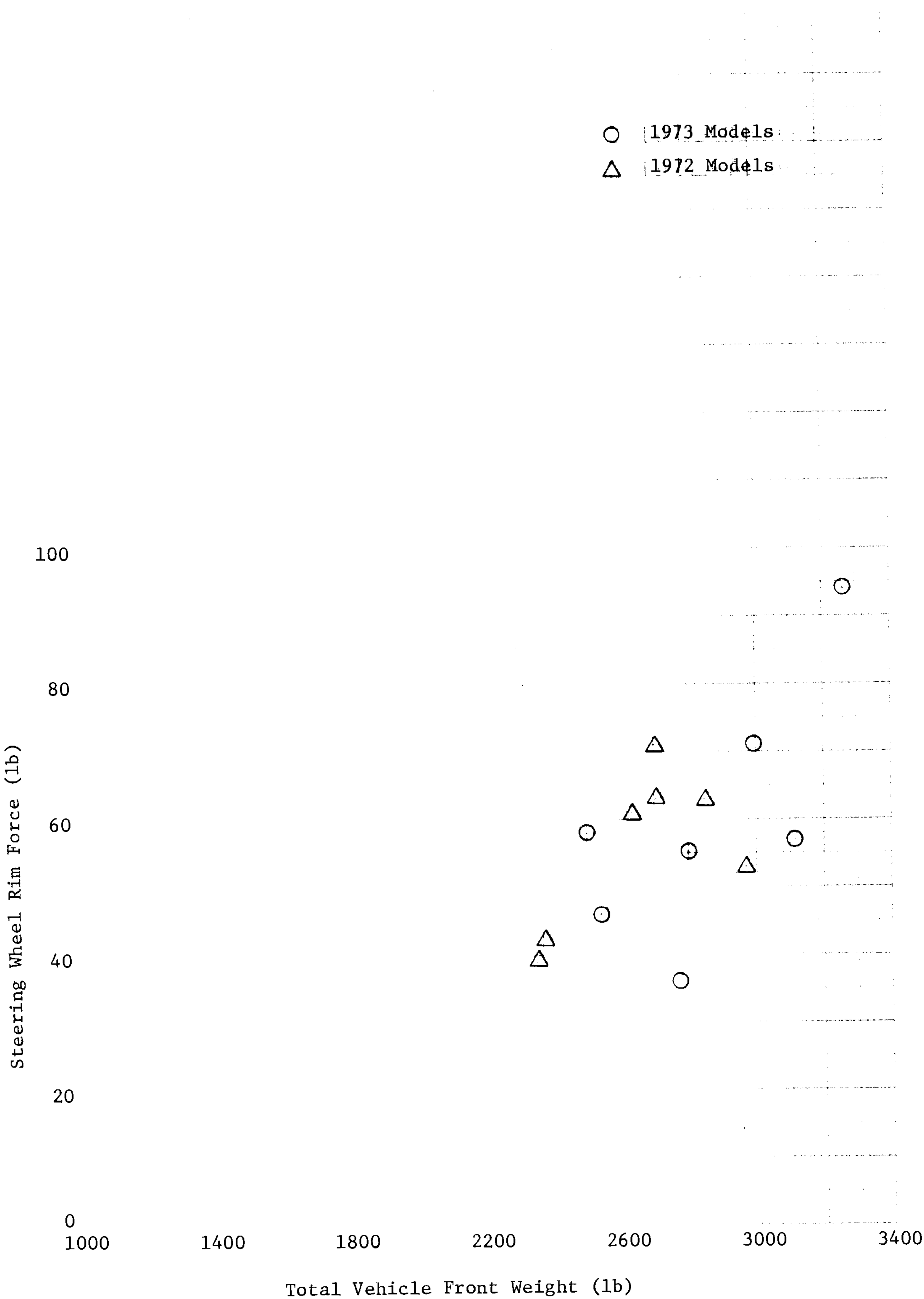
POWER ON RIM FORCE - 30 MPH

0.25 g STEADY STATE LATERAL ACCELERATION

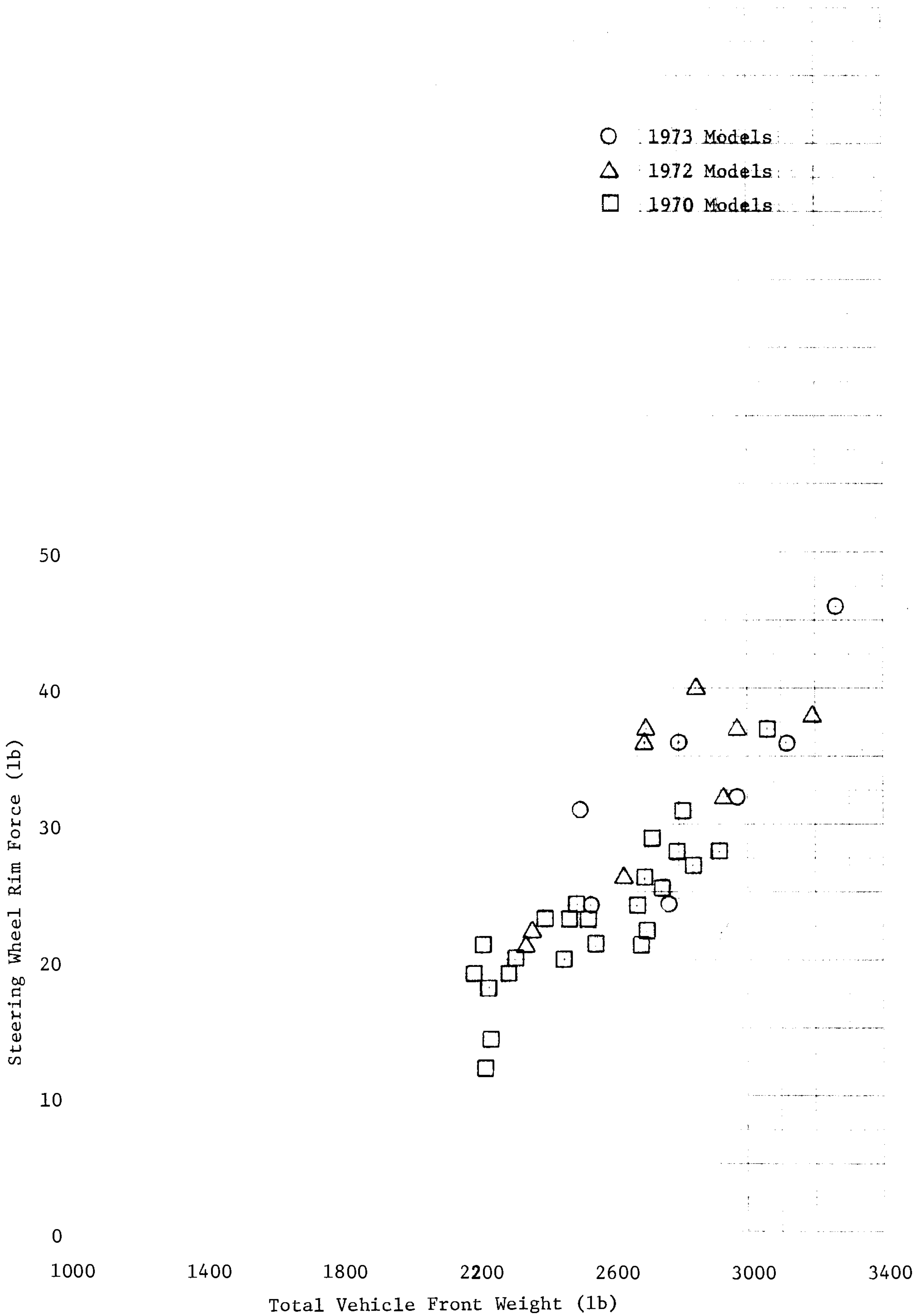


POWER OFF RIM FORCE - 10 MPH

0.25 g STEADY STATE LATERAL ACCELERATION

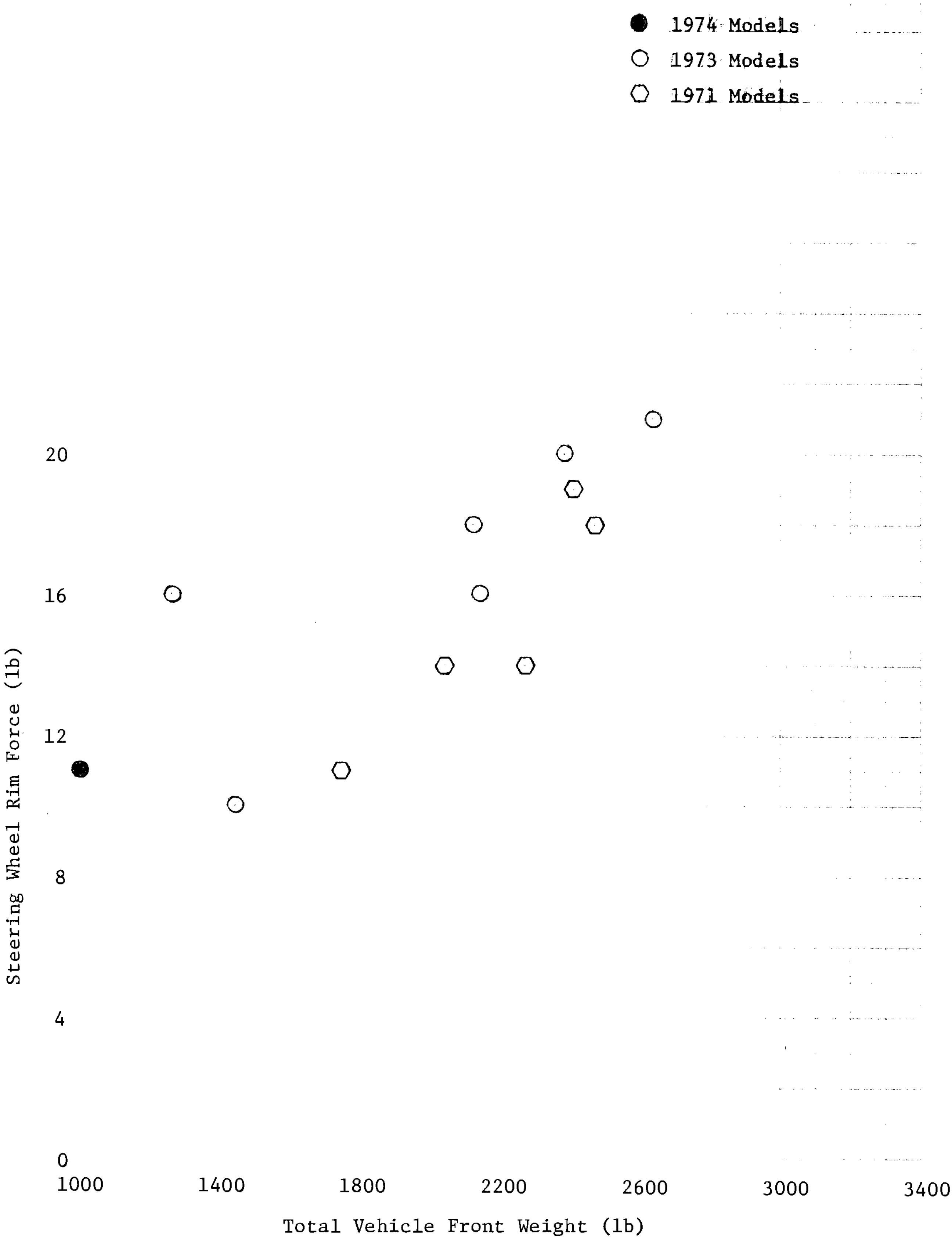


POWER OFF RIM FORCE - 30 MPH
0.25 g STEADY STATE LATERAL ACCELERATION



MANUAL STEER RIM FORCE - 10 MPH

0.25 g STEADY STATE LATERAL ACCELERATION



PE10-005

GM

4/14/2010

ATTACHMENT Q

15 C

1974_02_25_Steering_Effort_Comments

F-866

OUTLINE

COMMENTS OF GENERAL MOTORS CORPORATION WITH RESPECT TO STEERING EFFORT

I. Description

II. Summary of General Motors Information

A. Nature of GM criteria for steering effort
B. Difficulty with guideline establishment
C. Factors influencing effort performance
D. Nature of the GM test
E. Reason for no 1974 model data
F. Considerations in effort regulation

III. General Comments

A. Historical background in effort testing
B. Driver capability situation
C. Typical steering force test result-raw data-effort versus front weight
D. Field data-MIC file, Indiana data, 1241 data

IV. Specific Comments

A. List NHTSA questions
B. Respond specifically to each in turn.

V. Brief summary of position.

DRAFT
Feb. 25, 1974

COMMENTS OF

GENERAL MOTORS CORPORATION

WITH RESPECT TO

STEERING EFFORT

COMMENTS OF GENERAL MOTORS CORPORATION

WITH RESPECT TO STEERING EFFORT

DESCRIPTION

The National Highway Traffic Safety Administration (NHTSA) is considering rule making action in the area of steering effort. A request for performance and technical information on this subject was sent to Mr. E. N. Cole by Mr. Robert Carter, Associate Administrator, Motor Vehicle Programs. Steering effort data and design guidelines were requested for standing vehicles and those operating at various speeds. Data applicable to loss of pump driving power, loss of hydraulic fluid, speed, tire inflation, misalignment, loading, steering column angle, braking, and road roughness are desired.

SUMMARY OF GENERAL MOTORS INFORMATION

1. General Motors does not have established guidelines for steering effort performance. Steering effort performance for manual and power steering vehicles is established mainly through subjective evaluation and judgment of what is commercially acceptable to the driving public. In addition, a steering rim force test procedure has been developed so that vehicles can be objectively compared. During the development of a new chassis design, these tests are performed for comparison with previous models as well as competition.

2. Various attempts to establish steering effort guidelines based on driver force capability have yielded widely divergent results. Human effort research is complicated by many experimental and measurement problems. These include motivation, learning, anthropometry, task requirements, the

nature of the performance metric, and statistical problems inherent with defining the performance of extremes in the driver population distribution. When all attempts to measure driver force capability are compared, it is clear that these factors have a major influence on the results observed and experiments truly representative of the field situation have yet to be run.

3. The highest effort requirements are encountered for low speed maneuvers at moderately high lateral accelerations in large front-heavy vehicles where power assistance has been lost due to pump belt breakage, engine stall, or other malfunction. These effort levels are influenced mostly by front wheel weight and steering ratio although caster alignment setting; tire type, pressure, and wear state; and steering system mechanical efficiency also contribute to a minor degree. If there is a safety problem associated with power-off steering effort, this should be most often observed where large front-heavy cars are operated by relatively weak female drivers. Little accident data is available where loss of power assist is alleged to be a causal factor. However, those cases which have been reviewed fail to show a preponderance of the weak female-big car situation. Drivers and vehicles involved in loss of power assist accidents appear to be representative of the entire driver-vehicle population. That is, half of the involved drivers are males and most of the vehicles are moderately sized. This suggests that change in effort resulting from a loss of power assistance may be a stronger causal factor than the magnitude of the failed power effort. Therefore, improvement in the present system

might best be achieved by continuing to minimize the frequency of power assistance failure and training drivers to cope with cars when failures occur, rather than attempting to regulate levels of power-off effort.

4. The current General Motors test for steering force performance includes static measurement of the force-steering wheel angle relationship for a stationary vehicle and dynamic measurement of the force-lateral acceleration relationship for quasi-steady state conditions at 10 mph and 30 mph. The road test is conducted on a large paved surface where a driver can slowly apply steering wheel angle at constant vehicle speed through the range of ±0.45 G lateral acceleration without concern for the resulting vehicle path. The road test is applicable to manual and power steering vehicles including the case of simulated power failure through removal of the pump drive belt. The static test is not run in the power-off condition since these data are not of any apparent significance to safety or customer convenience.

   The plots made in the vehicle during these maneuvers are interpreted in various ways. Gradients and points of inflection might be tabulated for tests of power steering cars. For manual steering cars or simulated power-off tests, force levels at 0.25 G are frequently tabulated. This point was arbitrarily selected for vehicle comparison to provide the most repeatable data in a condition that is close to the most severe case for many vehicles. Vehicles tested in a power-off condition exhibit a large band of steer force-lateral acceleration hysteresis. The value tabulated represents the force required to gradually achieve a 0.25 G lateral acceleration. Due to hysteresis, much less force is required to hold the vehicle at that condition. These data are therefore difficult to compare with human strength measurements. If power should fail during a 0.25 G maneuver, less than the indicated force is required to sustain the maneuver. A driver required to quickly initiate a 0.25 G maneuver with failed power steering will apply more than the indicated force due to inertia and damping effects.

5. Since there were no major chassis model changes represented in 1974 GM passenger cars, no quantity of data exists at this time for this model year. Data for recent models will be presented as a function of front wheel weight. These plots can probably be used to estimate the performance of 1974 model cars.

6. NHTSA should carefully consider the consequences of restrictive regulation of steering effort performance for manual steering cars and the power-off condition for power steering cars. An attempt to modify the existing state-of-the-art with a restrictive regulation could leave manufacturers between two undesirable alternatives of providing costly backup systems for cars or increasing steering gear ratios. A significant increase in steering ratio, resulting from an unrealistic effort requirement, could lead to a decrease in maneuverability and accident avoidance capability. The few accidents related to loss of power assistance would not appear to justify a general degradation of vehicle capability. Similarly, the cost/benefit ratio of a backup system should be carefully evaluated.

GENERAL COMMENTS

Motor vehicles must obviously be designed so that the forces required for control are in all situations compatible with operator capabilities. Establishing objective proof of compatibility is difficult and must necessarily involve an objective vehicle test procedure, knowledge of available data on human capability, review of field performance and accident data. Driving experience with a variety of vehicles is also helpful when all of these clinical data are finally combined and interpreted.

Critical conditions for power steering failures which might lead to a design guide are extremely difficult to define. General Motors does not believe the state-of-the-art in this area is sufficiently well advanced to permit such definitions, nor does the accident picture appear to warrant concern. The following paragraphs will define the state-of-the-art in the areas of objective vehicle testing, human steering force capabilities measurement, current levels of steering effort on GM vehicles, and results of accident data file searches for accidents associated with loss of power steering.

Steering Effort Objective Tests

General Motors has used a variety of test procedures over a period of years to objectively evaluate steering system performance. Up to the late 1960's, steering effort tests were run with an instrumented steering wheel that could be readily adapted to any vehicle steering system. Peak steering torques were read on a meter as a test driver maneuvered the vehicle along a painted road course approximating a cosine-like path at a fixed speed. Static effort was also measured with this system. The equipment was developed when many vehicles still had manual steering.

As power steering became more prevalent, a new approach to steering system testing was developed. Earlier torque wheels scaled for manual systems were not suitable for power system evaluation. A new torque wheel with a more versatile transducer was designed to adapt to the steering shaft spline. The earlier test procedure required considerable driver skill for speed and path control. An improved test procedure was developed to be less dependent on the driver and provide more than a single numerical evaluation of peak steering force. Force data are now recorded on an X-Y plotter in the car as a function of lateral acceleration. Steady state lateral acceleration is accurately calculated as the product of vehicle velocity and yaw rate obtained from an onboard gyro. The driver's task is simply to maintain speed and slowly rotate the steering wheel at about 30°/sec while the plotter traces a loop of steering torque vs lateral acceleration in the range of ± 0.45 G. Tests are repeated several times and the results treated statistically. Speeds of 30 mph are used to represent normal driving and speeds of 10 mph represent parking lot maneuvering. This approach requires a large paved area such as the Vehicle Dynamics Test Area at the GM Proving Ground. A detailed procedure is in Appendix A.

Driver Capability

A survey of the literature shows several studies that attempt to define human effort capability. These include work done at Harvard(1)*, Ford(2) and Man Factors, Inc.(3). General Motors has conducted similar studies and additional work where driver motivation levels higher than those in the published literature are believed to have been achieved. When the results and methodology of all studies are compared, it is evident that human capability observed in any experiment is strongly influenced by the nature of the experimental procedure.

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*Numbers in parentheses ( ) indicate reports listed in the Reference.

Motivation is one of the most dominant factors. It is difficult to achieve high motivation levels in an experiment using a steering buck. It is also difficult to achieve high motivation levels in vehicle studies because of potential hazards to drivers. GM work has indicated that many drivers will elect to stop a vehicle when steering assistance is lost at speeds in the 10 mph to 15 mph range. Drivers do not make a strong effort to use one mode of control when an effective alternative is available. Thus instrumented vehicle tasks of this nature have resulted in low observed steering force levels. GM studies run at higher speeds, in situations demanding that the driver exercise steering control, have indicated much higher efforts than those observed in GM low speed studies or those reported by other investigators.

The GM studies, run at higher speeds, illustrate another important aspect of driver force capability testing. Effort required to complete the desired task can affect the maximum effort levels determined. The GM study was run at two effort levels, but both within the capabilities of a majority of subjects. Two different maximum effort levels were observed.

Other experimental variables, such as the technique for measurement of maximum effort (sustained or peak), type of task (transient or near steady state), can all affect human capabilities measurements. It is likely that any practical experiment done on a proving ground will not duplicate behavior in a real potential precrash situation. Therefore, any determination of driver capability should be interpreted with caution.

Typical Steering Force Test Results

Raw data plots for the GM Steering Force Test Procedure are shown in Figures 1, 2, 3 and 4 for a static test on a manual gear car, dynamic test of a manual car, power-on, and power-off tests of a power gear car.

Tabulations of data taken with vehicles of various front wheel weights are shown in Figures 5, 6, 7 and 8 for the corresponding conditions. The conditions for tabulation (0.25 G lateral acceleration at 30 mph) were chosen somewhat arbitrarily as explained previously. Vehicles are all GM products from the past four model years.

Field Data

Data arising from customer usage of various vehicles is sure to be the most dependable source for direction on effective improvements to the vehicle system. The studies conducted at Indiana University[4] included the accident causation category of "binding (undue effort required)" which would seem applicable to the situation of excessive steering effort. No accidents of this category were tabulated among the 999 studied.

A review was made of the General Motors file of so-called "1241 forms". These forms are generally filed by the divisional zone offices as the result of an investigation of an alleged vehicle safety defect. Of a total of approximately 23,000 such forms, 210 (0.9%) were cases in which power steering failure was alleged and/or possible, and of these 82 (0.4%) were identified as cases where power steering failure was probably involved.

Maximum power-off effort studies have concentrated on females; and, based on strength studies, one would expect females to be over-represented in these cases. In addition, the power-off effort levels increase as front end weight increases, and one would expect an over-involvement of large cars. However, of the 82 cases where power steering failure was probably involved, only 24 (29%) of the drivers were female and only 3 were driving luxury sedans. Thus, it is apparent that power steering failures are a very small percentage of the incidents reported in this file and there is no evidence which would suggest weaker members of the population or heavy cars are over-involved. This would imply that some other aspect of power steering failure (rather than the magnitude of the effort) was involved.

Studies of MIC accident files have also been conducted. Of 7012 injury-only accidents, 46 (0.7%) cases were alleged to have had some form of power steering failure. Unfortunately, only allegations of the drivers are reported in this file. Without supporting material and independent verification of the loss of power steering, it is difficult to assess the allegations. None of the cases could be positively identified as having power steering failures.

SPECIFIC COMMENTS

The NHTSA has requested information on steering effort relating to 1974 passenger cars ranging from standard sized station wagon to subcompacts. Data was requested with regard to all steering systems available on a particular vehicle, as well as specific conditions of the test. Because of the minimal model changes for 1974, General Motors does not have data on any 1974 models. We will attempt to respond to the specific NHTSA questions with appropriate data from prior model years.

1. Stationary Vehicle Steering Effort - The NHTSA requested information on steering effort plotted vs steering wheel angle for a stationary vehicle. When power assist was available, additional data were requested with loss of power assist (loss of pump drive) and after loss of the hydraulic fluid.

The General Motors steering effort test procedure (Appendix A) has been used for most steering effort tests since 1970. However, standard practice has been to conduct the following tests on vehicles.

Type of Steering	Test Type	Data Taken
Manual	Stationary	Torque vs Steering Wheel Angle
	10 mph	Torque vs Lateral Acceleration
	30 mph	Torque vs Lateral Acceleration
Power On (Only When Requested)	10 mph	Torque vs Lateral Acceleration
	30 mph	Torque vs Lateral Acceleration
Power Off	10 mph	Torque vs Lateral Acceleration
	30 mph	Torque vs Lateral Acceleration

Thus, the only data for which steering effort vs steering wheel angle are available are for manual steer vehicles (Figure 1). This and all other steering data presented (Figures 1 through 8) were taken at two passenger load with new tires. All steering gear adjustments, wheel alignments and tire pressures were set to nominal specifications for the particular vehicle tested.

Stationary data are taken on a 3M grit surface so that tire-road interface effects are standardized. Data presented in Figure 5 are the mean of the clockwise and counterclockwise effort for a minimum of three trials. Data are calculated from the approximately constant effort level reached at higher steering wheel angles. Figure 2 shows a typical manual steer dynamic test, and Figure 6 summarizes the data for a number of 1970 through 1973 GM vehicles as a function of front weight. The data in Figures 6, 7 and 8 are also mean values of three or more clockwise and counterclockwise tests. To enable consistent comparisons between effort levels of various vehicles, curves are evaluated at 0.25 G steady state lateral acceleration.

Figures 3 and 4 show typical dynamic test data for power-on and power-off steering effort. Figures 7 and 8 are summaries of power-on and off effort levels for a number of 1970 through 1973 GM vehicles. Power-off effort levels are measured with the power steering pump belt removed. It is apparent from Figures 5, 6 and 8 that steering effort is a strong function of vehicle front end weight. Power steering vehicles of a front weight comparable to manual steering vehicles, have higher effort due primarily to the lower steering ratios used in power steering vehicles.

2. Steering Effort Design Guidelines - The NHTSA requested information on design guidelines used to determine maximum effort levels upon failure of power assist including results of any tests conducted in the development of these guidelines. General Motors does not now have a design guideline for maximum power-off steering effort. Clearly from the data in Figure 8, high efforts are incurred on our heavier

front weight vehicles. These effort levels could be expected to be higher at slow speeds or with the vehicle stationary.

High power-off effort must be balanced against ease of control for normal driving. The higher front weight vehicles would require a significant increase in steering ratio if their effort levels were to be reduced to levels quoted in Reference (3), for example. GM has performed a number of studies which measured driver performance for high numerical steering ratios (manual and power) vs lower steering ratios (power only). These studies confirm subjective opinions that high steering ratios result in a less maneuverable vehicle. Thus, General Motors has chosen to install lower numerical ratio steering gears in vehicles which offer power assist and to restrict manual steering to lighter front weight vehicles.

The accident data would appear to justify the design tradeoff chosen. The Indiana study, our MIC files and 1241 forms indicate from zero to 0.9% involvement of loss of power assist. These low involvement rates would not, in our opinion, justify increasing steering ratios to meet some particular maximum steering effort criteria. Such a design might seriously compromise the accident avoidance capability of our passenger cars and actually have a detrimental effect on the accident rate.

3. Vehicle Parameter Effects on Steering Effort - The NHTSA requested data on steering effort as affected by vehicle speed, tire inflation,

misalignment conditions, overloaded vehcles, tilt angle of the steering column, braking pressure and road roughness.

Vehicle Speed - Figures 9 through 11 show the effects of vehicle speed with data taken from various vehicles. Figures 9 and 10 show data at 10 and 30 mph for manual steering and power-off cases, respectively. Figure 11 shows data at speeds ranging from 20-40 mph for a power-off test. The data shown in Figure 9 is for the same vehicle whose static data are shown in Figure 1. Comparing these graphs, it is apparent that steering effort increases as speed decreases, with the most significant increases occurring below 10 mph.

Tire Inflation Pressure - Tires have a significant effect on steering effort primarily through the effects of aligning torque. Both rolling and non-rolling aligning torques are affected by tire parameters such as inflation pressure, wear state, size and type of tire. General Motors has no meaningful steering effort test data on the effects of these tire parameters. Although test data has been run, these effects are apparently smaller than test variability.

Suspension Alignment - Several aspects of suspension geometry can affect steering effort, including caster, kingpin inclination, spindle length and various geometric and compliance steer properties. Of these, only caster is directly affected by suspension alignment. The 30 mph test on a number of different vehicles has indicated that steering effort is increased (decreased) from 1 to 8% for increases (decreases) of 1 degree in caster angle about a nominal zero degree caster setting. No test data is available on the remainder of the suspension geometry effects. However, it is known that kingpin inclination and spindle length affect primarily static and low speed (less than 10 mph) efforts. Geometric and compliance steer properties affect primarily high speed (greater than 10 mph) effort levels.

Overloaded Vehicles - Although front end weight can have a significant effect on steering effort as shown by Figures 5 through 8, General Motors does not have steering effort test data on overloaded vehicles.

Tilt Angle of the Steering Column - Tilt angle of the steering column is a human factors item which has been studied by some researchers[(5)]. General Motors does not have any data on human capabilities with various column angles.

Braking Pressure - Braking pressure can affect steering effort--particularly stationary effort. General Motors, however, has no test data on steering effort with brakes applied.

Road Roughness - General Motors has no data on this aspect of steering effort.

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4. Treat, J. R. and Joscelyn, K. B., "Results of a Study to Determine Accident Causes"; SAE Preprint 730230, January 1973.

5. Dupuis, "Biomechanics and the Driver Area", VDI-Berichte Bd. 25, p. 1-15, 1957.

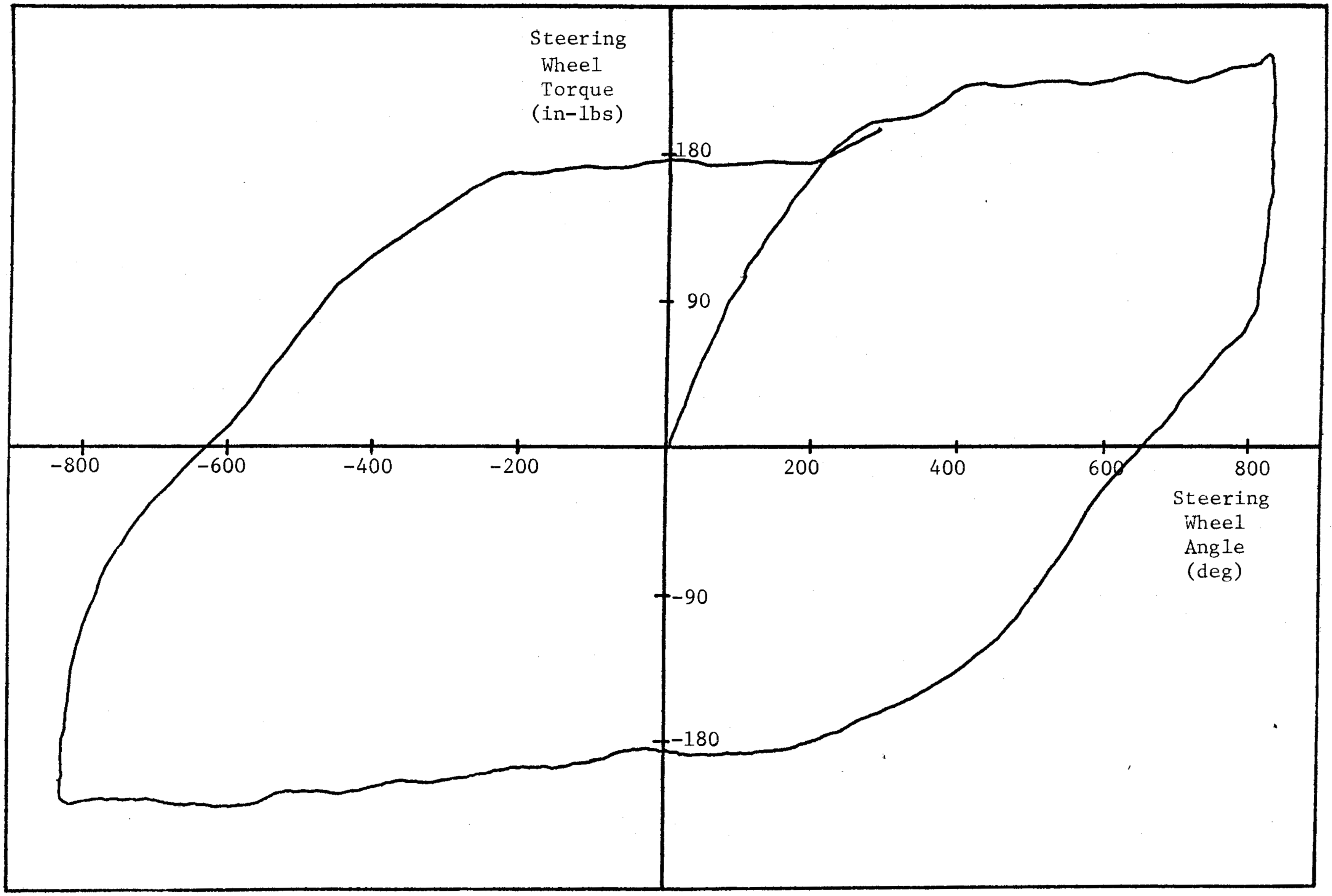


FIGURE 1

STATIONARY STEERING TORQUE VS. STEERING WHEEL ANGLE

MANUAL STEERING VEHICLE

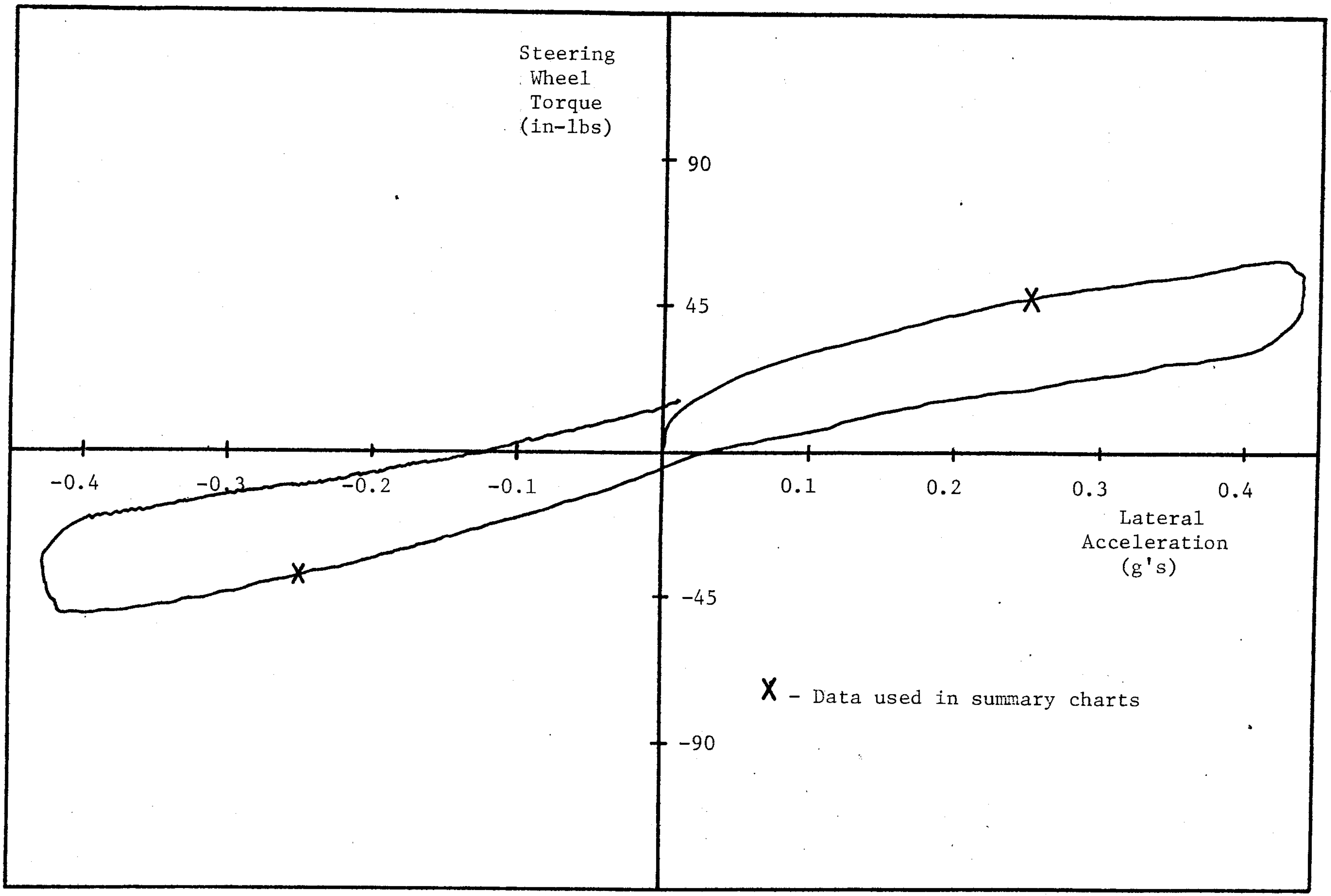


FIGURE 2

DYNAMIC STEERING TORQUE VS. LATERAL ACCELERATION

30 MPH - MANUAL STEERING VEHICLE

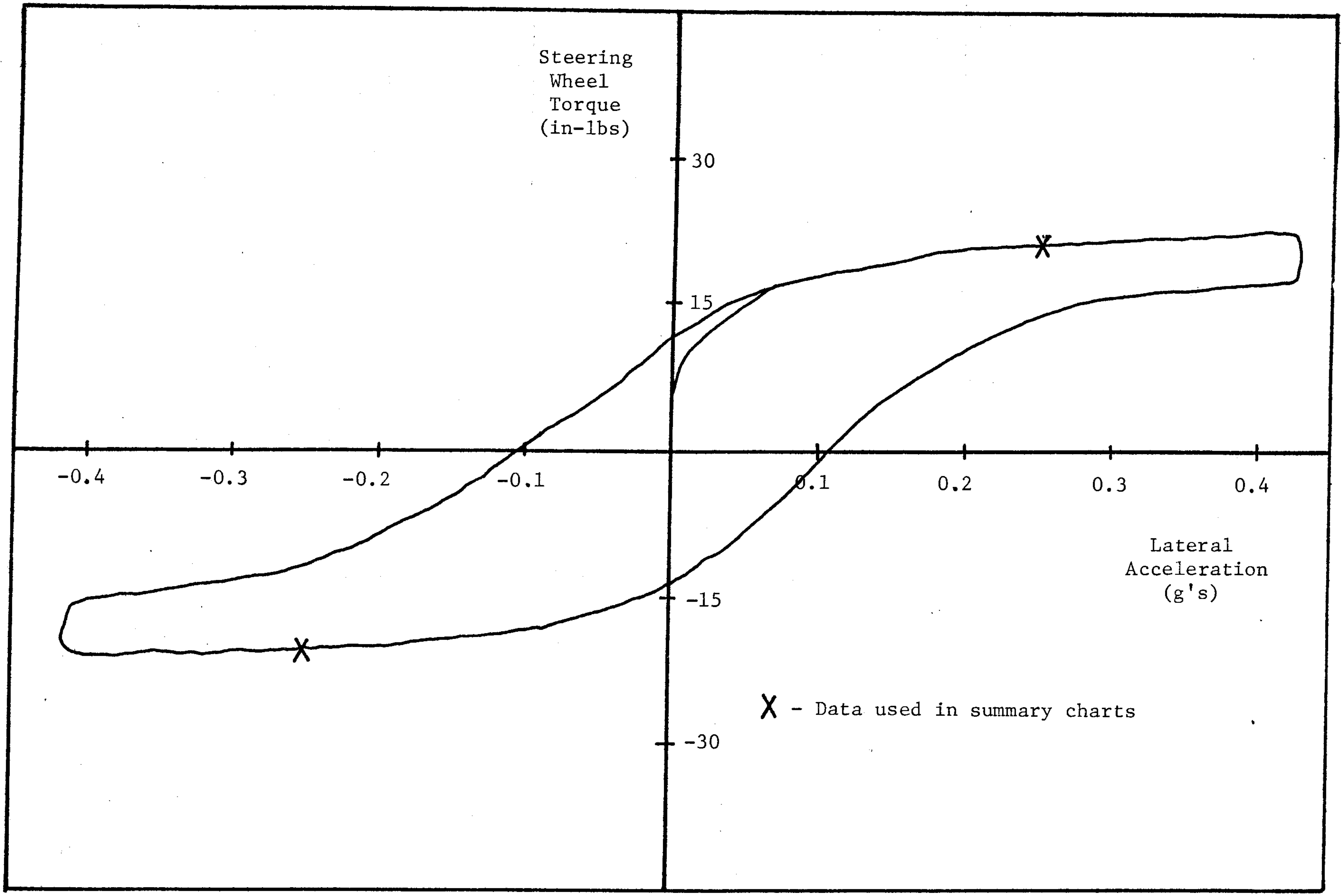


FIGURE 3

DYNAMIC POWER ON STEERING TORQUE VS. LATERAL ACCELERATION

30 MPH POWER STEERING VEHICLE

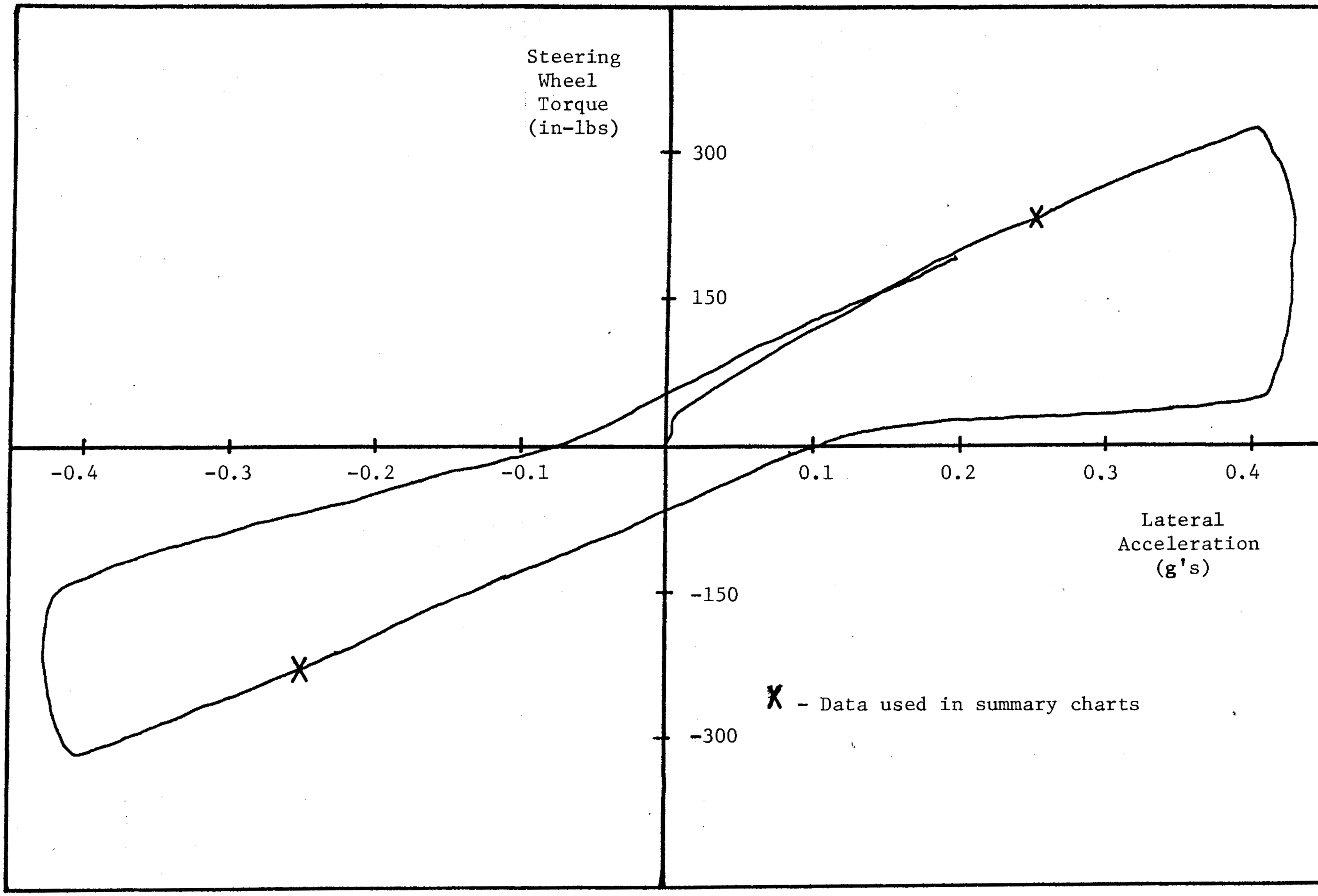


FIGURE 4

DYNAMIC POWER-OFF STEERING TORQUE VS. LATERAL ACCELERATION

30 MPH POWER STEERING VEHICLE

FIGURE 5

RIM FORCE FOR MANUAL STEERING VEHICLES VS.
TOTAL VEHICLE FRONT WEIGHT
STATIONARY ON
3M MEDIUM GRIT SURFACE

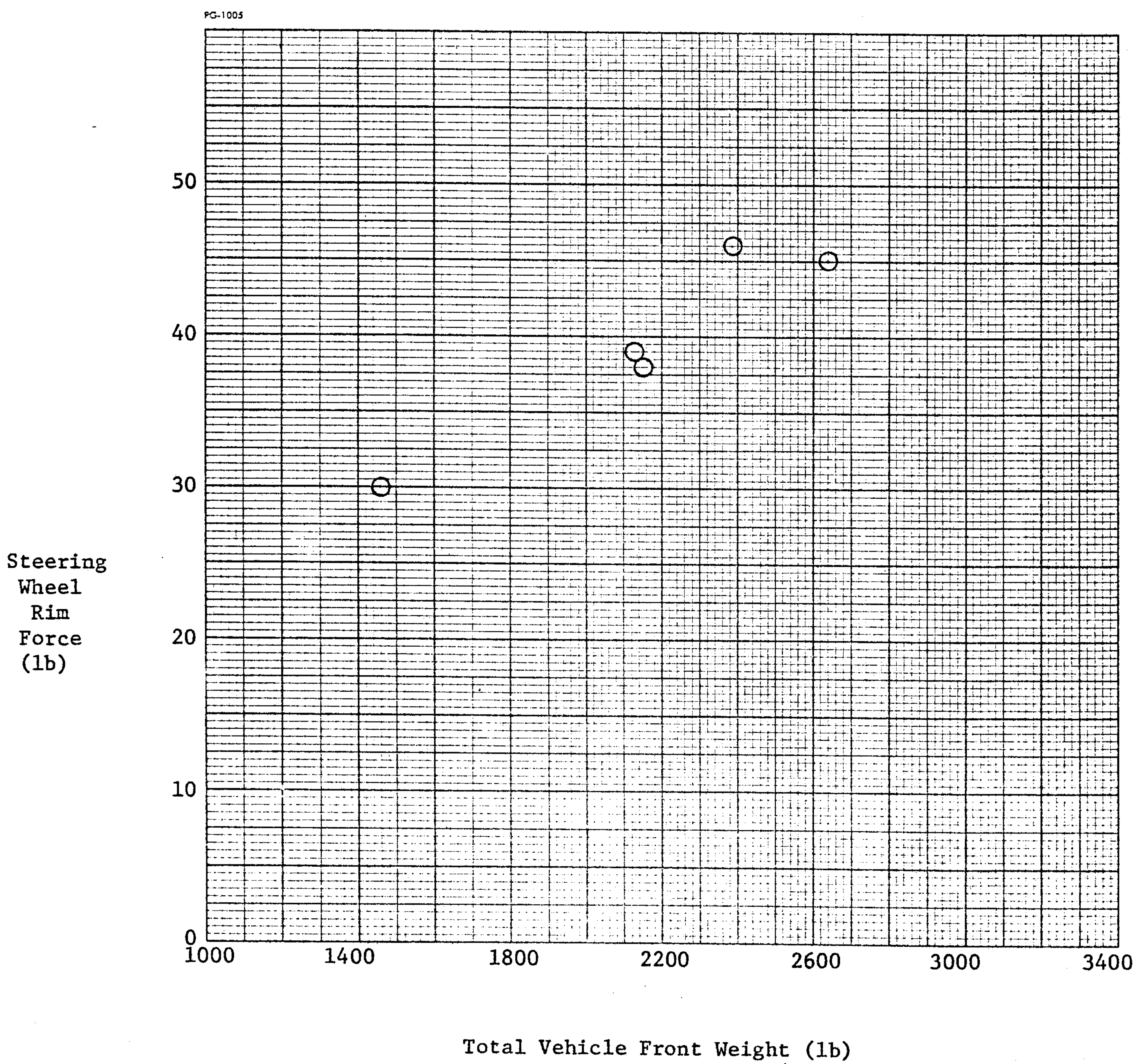


FIGURE 6

RIM FORCE FOR MANUAL STEERING VEHICLES VS.
TOTAL VEHICLE FRONT WEIGHT
30 MPH
0.25g STEADY STATE LATERAL ACCELERATION

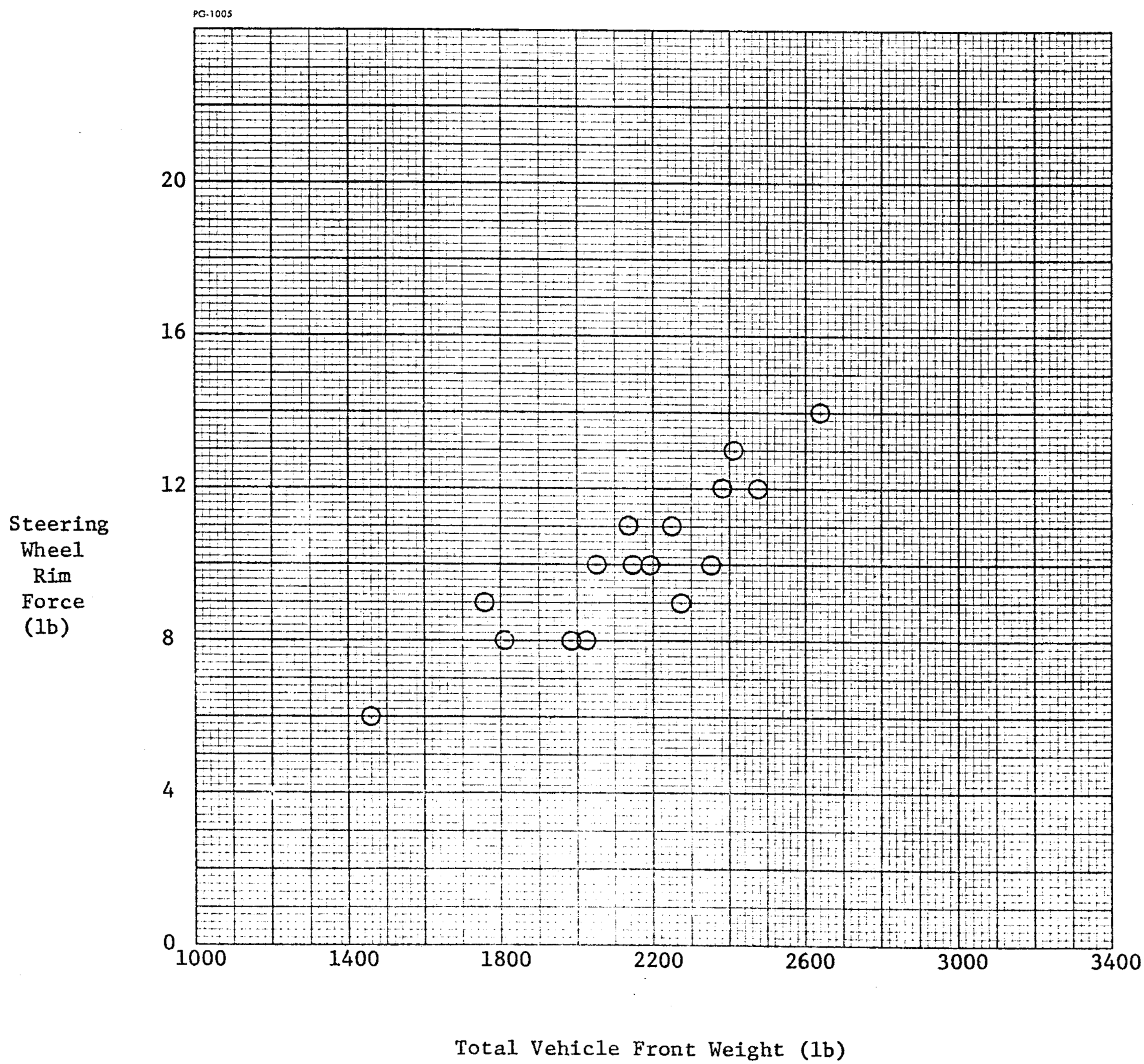


FIGURE 7

POWER ON RIM FORCE VS.

TOTAL VEHICLE FRONT WEIGHT

30 MPH

0.25g STEADY STATE LATERAL ACCELERATION

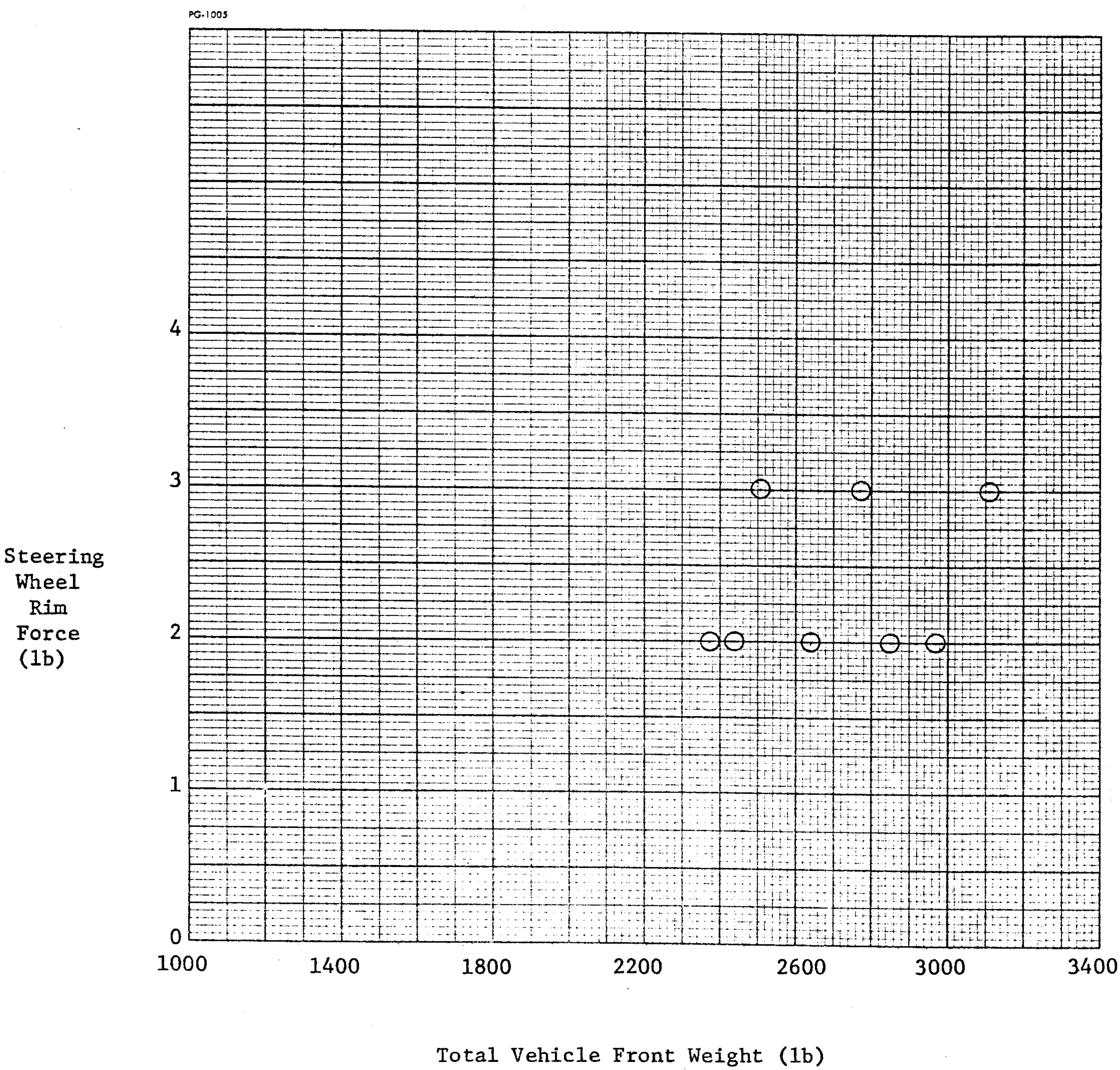


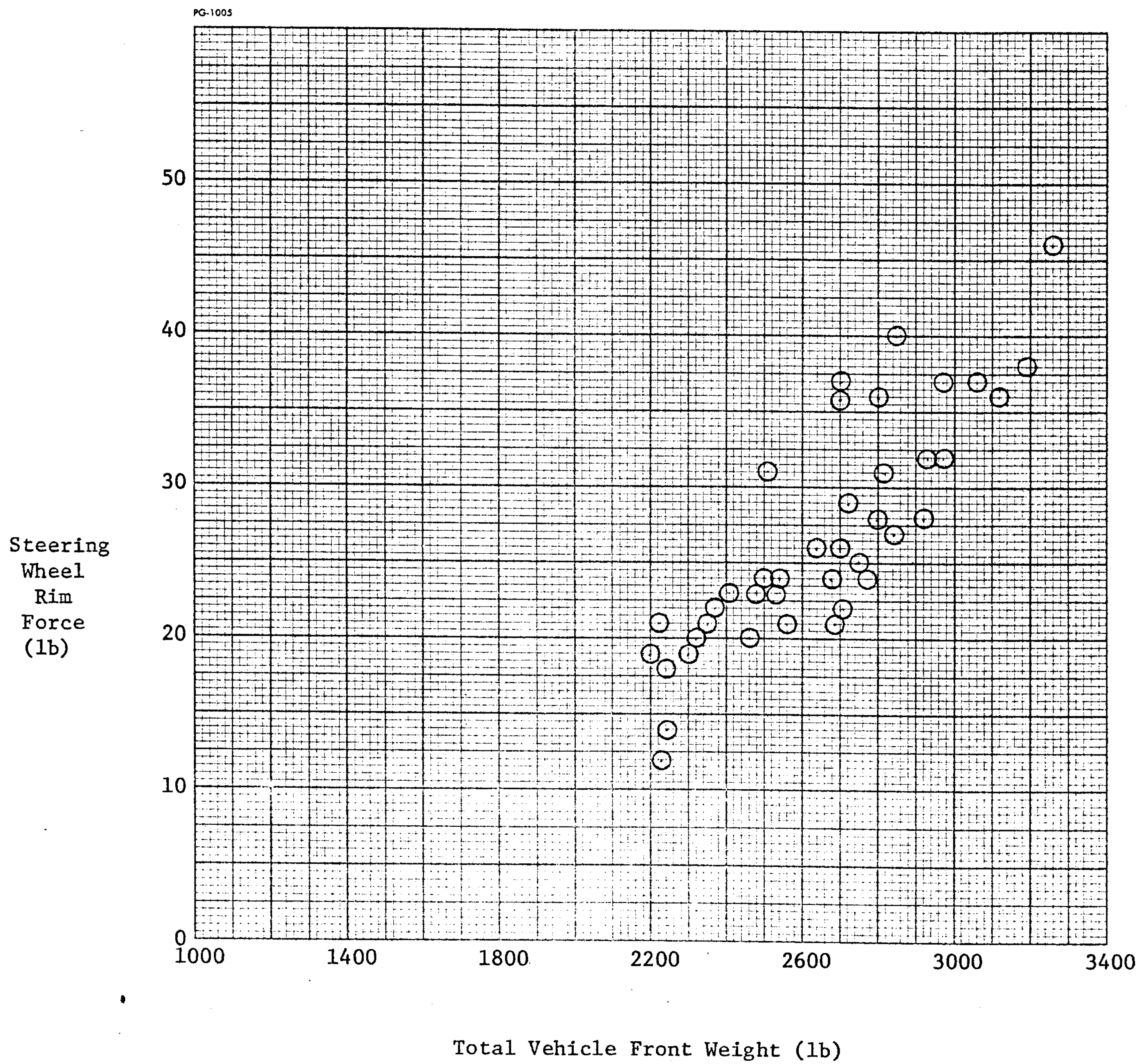
FIGURE 8

POWER OFF RIM FORCE VS.

TOTAL VEHICLE FRONT WEIGHT

30 MPH

0.25g STEADY STATE LATERAL ACCELERATION



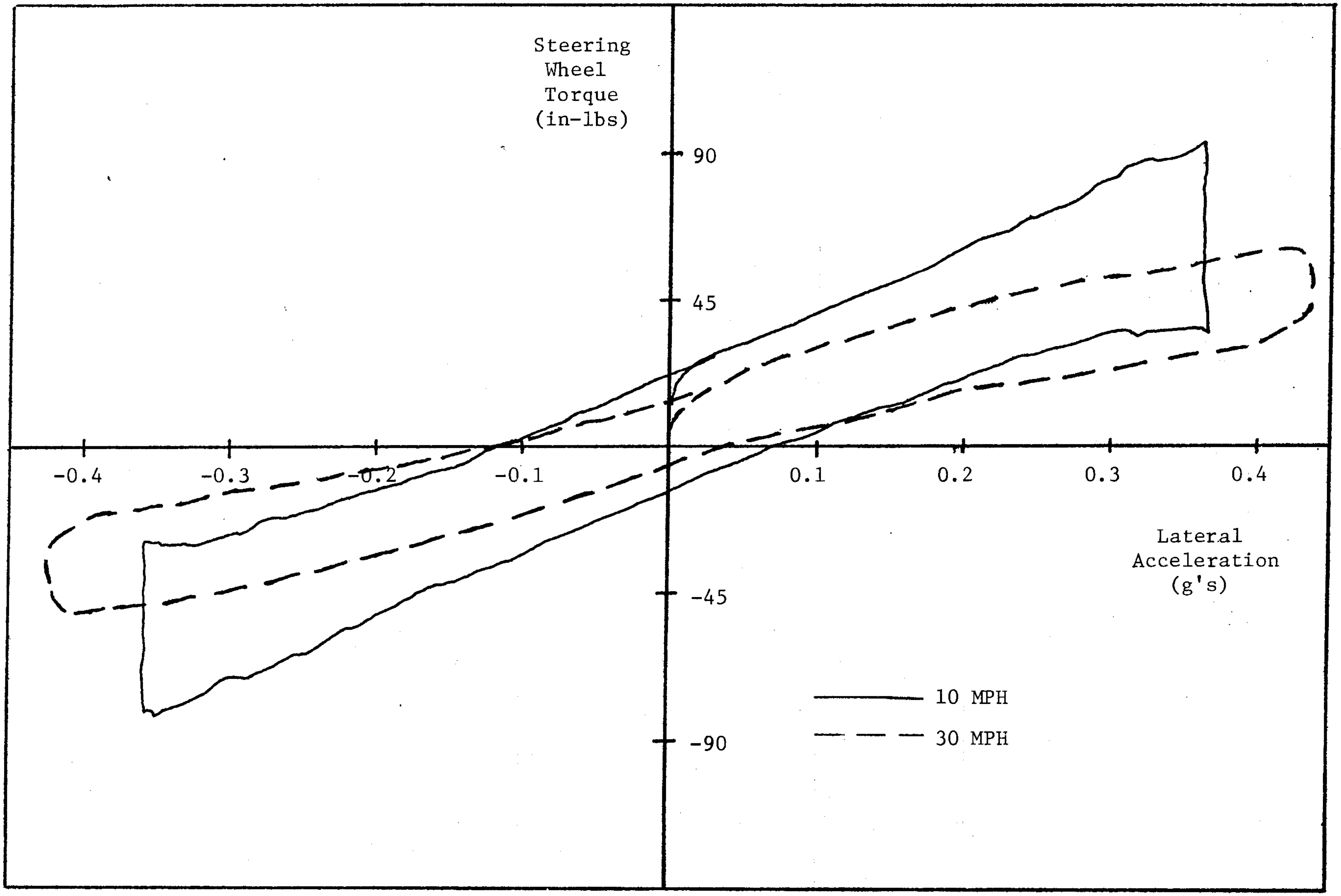


FIGURE 9

COMPARISON OF DYNAMIC STEERING TORQUE AT 10 AND 30 MPH

MANUAL STEERING VEHICLE

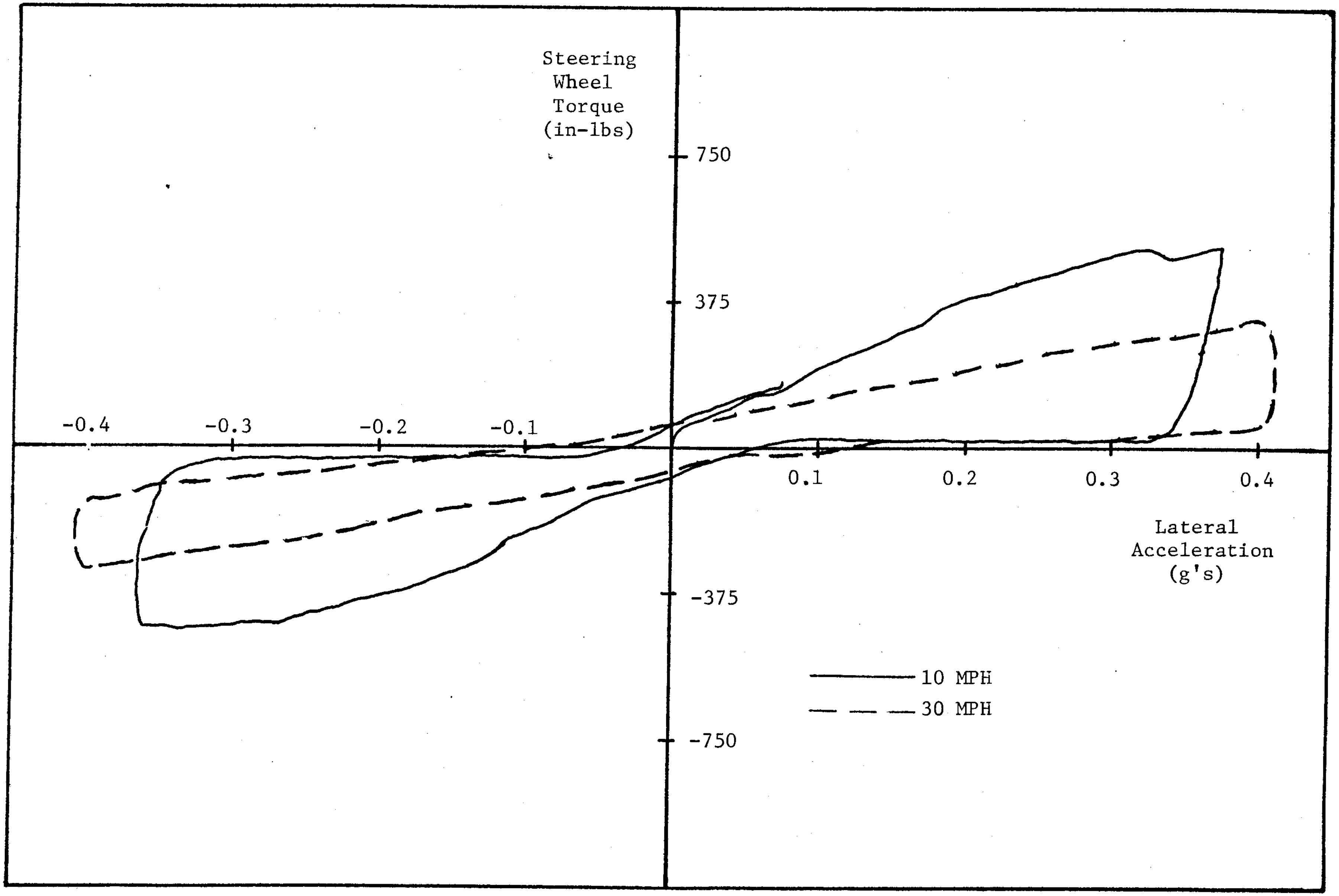


FIGURE 10

COMPARISON OF POWER-OFF DYNAMIC STEERING TORQUE 10 AND 30 MPH

POWER STEERING VEHICLE

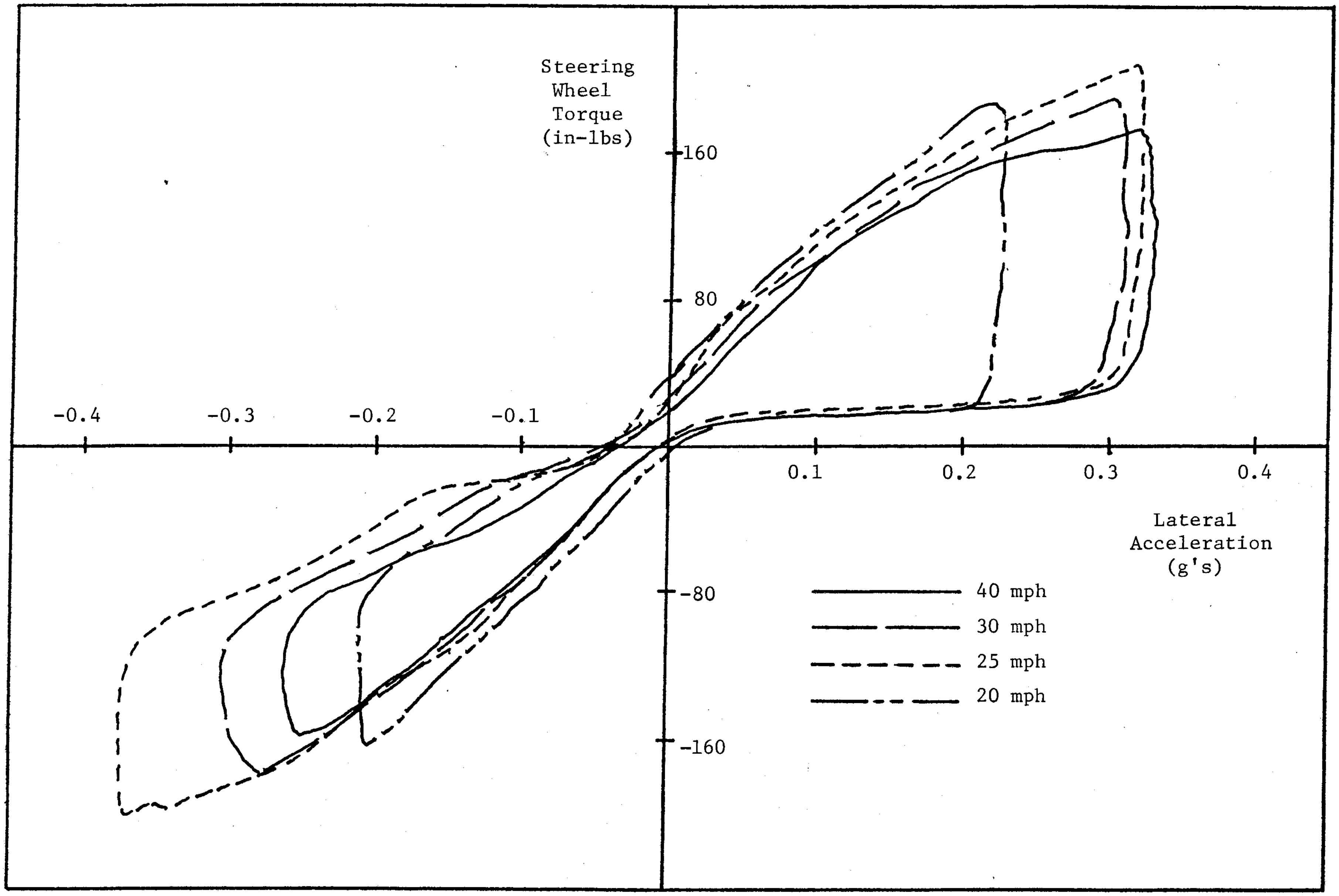


FIGURE 11

COMPARISON OF POWER-OFF DYNAMIC STEERING TORQUE VS. SPEED

POWER STEERING VEHICLE

APPENDIX A

STEERING EFFORT TEST PROCEDURE

STEERING WHEEL RIM FORCE TEST PROCEDURE USED

1.0. Equipment

1.1 Torque sensitive steering wheel (0 - ±50 lb ft) with signal conditioning equipment that will supply an output voltage to operate one channel of an X-Y-Y recorder.

1.2 Steering wheel angular displacement device (0 - ±900°) with signal conditioning equipment that will supply a voltage to operate another channel of an X-Y-Y recorder.

NOTE#1 The angular displacement device should be equipped with a slip-clutch in the potentiometer drive portion. When testing manual steer vehicles the total steering wheel angle displacement may be greater than the range of the steering wheel angle transducer.

1.3 Uniaxial accelerometer (0-1 g) with mounting adapter so that it can be mounted laterally on the rear axle of the test vehicle and with signal conditioning equipment that will supply a voltage to operate the X channel of an X-Y-Y recorder. (Characteristic speed test instrument may be used as an alternative.)

1.4 X-Y-Y Recorder.

1.5 Inverter: 12 VDC to 120 VAC @ 60 cps.

1.6 Fifth wheel with speed readout (resolution of 0.5 mph).

1.7 Graph paper with 20 divisions per inch and a grid area of 9 inches by 6 inches (PG-1004 or equivalent).

1.8 3M adhesive backed grit surface (medium) firmly cemented to the pavement so that the test vehicle front wheels can be easily driven onto and off the test surface.

1.9 Chalk or marking crayon for marking tire.

1.10 Hydraulic jack for lifting front end of the test vehicle.

1.11 Vacuum cleaner for cleaning static test grit surface.

2.0 Procedure

2.1 Test Preparation

2.1.1 Calibrate steering wheel torque transducer per paragraph 2.2.2.2 and lateral accelerometer per paragraph 2.3.1.3

2.1.2 Install instrumentation in test vehicle. (Items 1.1, 1.2, 1.4, 1.5, 1.6)

2.1.3 Install the accelerometer (Item 1.3) on the rear axle of the test vehicle with its sensitive axis parallel to the axle. (Characteristic speed instrument can be installed as an alternative.)

2.1.4 Adjust tire pressure according to test request specifications.

2.1.5 Fill vehicle fuel tank.

2.1.6 Weigh vehicle and record weight. Add weight if necessary to conform to test request, and reweigh.

NOTE#2 Fifth wheel should be lowered when weighing vehicle.

2.2 Static Test

2.2.1 Turn on Instrumentation using an external power source rather than the inverter (Item 1.5).

2.2.2 Install the graph paper on the X-Y-Y recorder and calibrate as follows:

2.2.2.1 Steering wheel angle so that 1 inch along the X-axis is equal to 200° of steering wheel rotation.

2.2.2.2 Steering wheel torque so that:

A) 1 inch along the Y, axis equals 2 lb rim force for vehicles equipped with power steering gear.

B) 1 inch along the Y, axis equals 20 lb rim force for vehicles equipped with manual steering gear.

2.2.3 Remove all foreign particles from the grit pads with the vacuum cleaner. Tires should also be clean.

2.2.4 Push or allow the vehicle to coast onto the grit pads with the front wheels straight ahead.

2.2.5 Mark tire to indicate where it is resting on the grit pad.

NOTE#3 This marking is for reference only so that the same portion of the tire is not reused.

2.2.6 Adjust the pens for zero position on the graph paper. Caution should be used not to touch the steering wheel.

2.2.7 Start the vehicle if it is equipped with power steering.

2.2.8 Lower the pens.

2.2.9 Rotate the steering wheel slowly (approximately 30 deg/sec) and smoothly from the center position to clockwise lock, back through the center to counterclockwise lock, and back to the center.

NOTE#4 Rotate the steering wheel in vehicles equipped with manual steering to ±900° in place of the lock position.

NOTE#5 Starting direction, whether clockwise or counterclockwise, is a choice of the operator. However once committed the convention must be adhered to for the remainder of the test.

2.2.10 Raise the pens.

2.2.11 Back the vehicle off the grit pads.

2.2.12 Shut off the engine if it is running.

2.2.13 Raise the front of the vehicle under test with the hydraulic jack and rotate the tires approximately 120°.

2.2.14 Complete step 2.2.2 through step 2.2.13 a total of three times. A new sheet of graph paper must be placed on the recorder before each successive run.

2.3 Dynamic Test

2.3.1 Install the graph paper in X-Y-Y recorder and calibrate as follows:

2.3.1.1 Steering wheel torque on the Y, axis so that:

A) 1 inch along the Y, axis equals 2 lb rim force for vehicles equipped with power steering gears.

B) 1 inch along the Y, axis equals 20 lb rim force for vehicles equipped with manual steering gears.

2.3.1.3 Vehicle lateral acceleration on the X axis so that 1 inch equals 0.1 g.

2.3.2 Proceed to the V.D.T.A. and adjust the pens of the X-Y-Y plotter to the zero position with:

A) The wheels straight ahead.

B) The vehicle on a level surface (±1% slope).

C) The operator not making contact with the steering wheel.

2.3.3 Accelerate to 10 mph (±1/2 mph) using speed as indicated by the 5th wheel and allow speed to stabilize. Maintain velocity throughout the test run.

2.3.4 With the vehicle headed straight ahead and the driver's hands off of the steering wheel, lower the pens.

2.3.5 Rotate the steering wheel at 10°/sec from the center position to clockwise lock back through the center to lock in the counterclockwise direction and back to zero. (See Note #5).

2.3.6 Raise pens.

2.3.7 Complete step 2.3.3 through step 2.3.6 a total of three times. A new sheet of graph paper must be placed on the recorder before each successive test run.

2.3.8 Complete step 2.3.3 through step 2.3.6 three times with a vehicle velocity of 30 mph (±1/2 mph), a steering wheel angular rate of 30°/sec. The steering wheel should be turned in either direction only until 0.45 g lateral acceleration is generated.

2.4 Power Failure Test

2.4.1 If the vehicle has power steering, remove the power steering belt.

2.4.2 Change the scale on the Y_1 axis (rim force) of the recorder so that 1 inch equals 20 lb rim force.

2.4.3 Repeat step 2.3.2 through step 2.3.7 for the conditions established in step 2.3.8 only.

NOTE: It is suggested that the inexperienced operator monitor steering wheel angle versus time on a Brush Recorder so that steering velocities may be checked. Tape may be placed on the steering wheel at 20 degree increments to aid the operator in establishing a constant input rate.

PE10-005

GM

4/14/2010

ATTACHMENT Q

15 C

1974_03_12_kjm_letter

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Inter-Organizational Letters Only

General Motors GM Proving Grounds

Milford, Michigan 48042

Date: March 12, 1974

Subject: Data for NHTSA Steering Effort Response

To: Robert A. Rogers
Environmental Activities Staff
GM Technical Center
Warren, MI

Enclosed are the steering effort data you requested for the NHTSA steering effort response document. A table listing the data is included.

NHTSA requested steering effort data for standard size passenger cars, standard size station wagons, intermediate passenger cars, compact passenger cars and subcompact passenger cars. They also requested information on steering effort for each of the steering systems available on the above cars. The data included with this letter is the latest data available for each of the car-steering type categories. As we discussed on Monday, the data is available primarily as a function of lateral acceleration. Static data was taken on the manual steering cars. I have given you only raw data as it exists in our files or in reports.

One additional NHTSA request was for steering effort vs. speed and a number of other vehicle parameters. The only data which we have available was included with the draft of steering effort response dated February 25, 1974. Figures 10 and 11 of the draft show the effects of speed on steering effort. Vehicle Dynamics has no other data which consistently shows the effects of other vehicle parameters.

Dick Rasmussen and myself are most anxious to assist you in any way we can on this particular response. Please do not hesitate to give us a call if there are questions with respect to the enclosed data.

Keith J McKenna

Keith J. McKenna
Staff Project Engineer
Vehicle Dynamics Laboratory

/car

cc: R. T. Bundorf
R. R. Gannon
R. E. Rasmussen

Enclosure
F-866

Engineering Staff/General Motors Corporation

VEHICLE TEST DATA FOR NHTSA

STEERING EFFORT RESPONSE

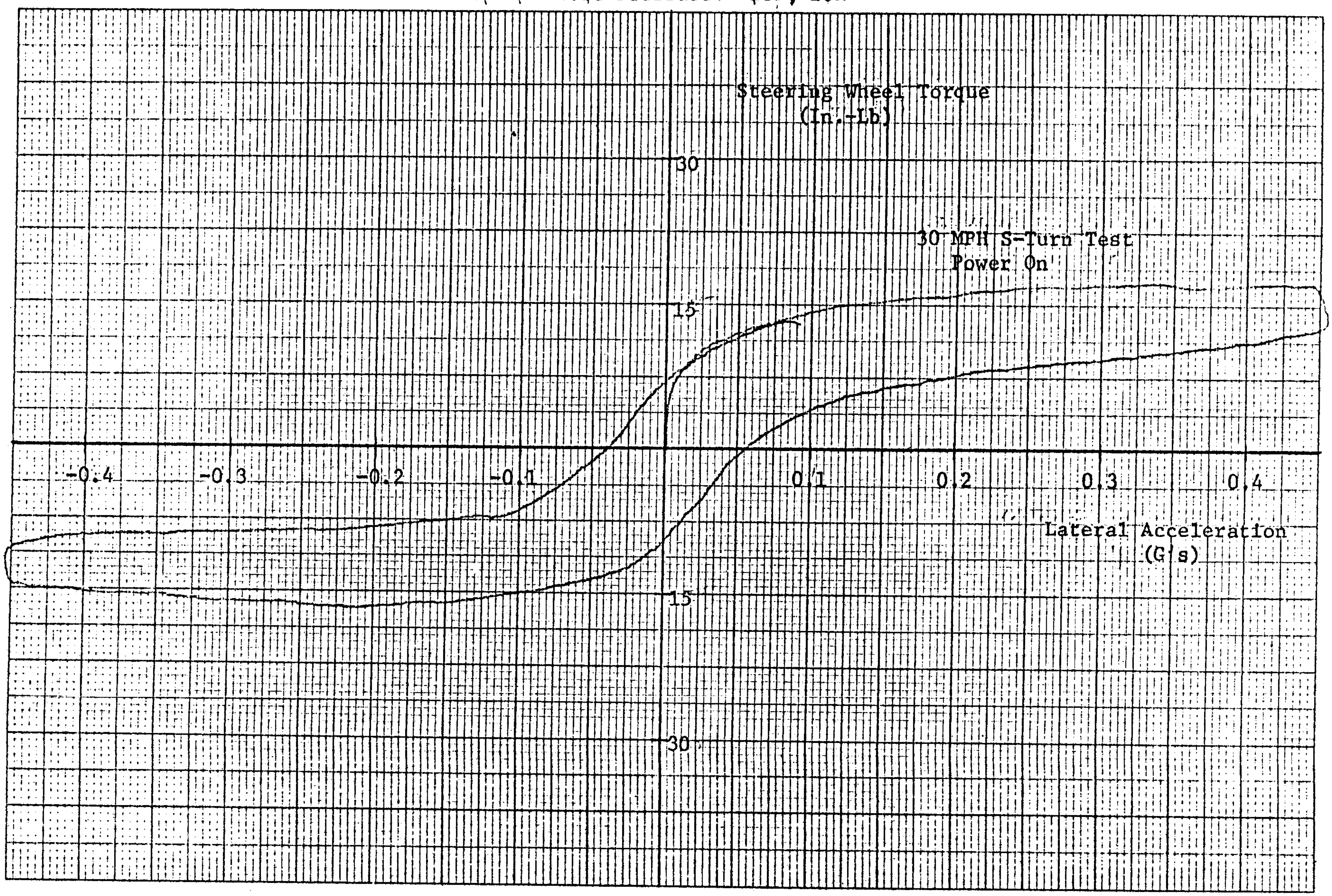
Vehicle	Steering Type	Model Year	Data Enclosed
Standard Size Passenger Car Oldsmobile "B" Body	Power	1972	30 MPH Power On 30 MPH Power Off
Standard Size Station Wagon Chevrolet Kingswood	Power	1970	30 MPH Power Off
Intermediate Size Passenger Car Chevrolet Chevelle	Manual	1973	Static 30 MPH
Intermediate Size Passenger Car Oldsmobile "A" Body	Power	1972	30 MPH Power On 30 MPH Power Off
Compact Passenger Car Buick Apollo	Manual	1973	Static 30 MPH
Compact Passenger Car Chevrolet Nova	Power	1970	30 MPH Power Off
Subcompact Passenger Car Chevrolet Vega	Manual	1973	Static 30 MPH

STEERING EFFORT

Make: Oldsmobile
Model: "B" Body
Year: 1972

No.: 2523
Test Weight: F-2636, R-2022
Plus 2 Passenger
Tires: Firestone
H78-15
Test Pressure: 28F, 28R

Date: January 1972
Operator: T.C.W.
Steering: Power



STEERING EFFORT DATA SHEET

DATE: 10 - 27 - 69

RECORDED BY: TZS & J. V.

VEHICLE INFORMATION:

MAKE: Chevy Kingswood CAR NO. 70028

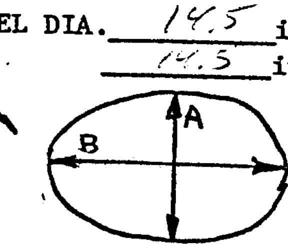
MODEL: 4 Door Wagon ENGINE SIZE 400 cu-in
Group #6

YEAR: 1970

STEERING ✓ POWER

_____ MANUAL

OE WHEEL DIA. 14.5 inches (A)
14.5 inches (B)



BRAKE TYPE: Drum FRONT

Drum REAR

TIRE SIZE: H 78 x 15 FRONT

H78 x 15 REAR

General MAKE

TIRE PRESSURE (COLD, LIGHT LOAD)

FRONT 24 psi

REAR 36 psi

FRONT WHEEL ALIGNMENT:

CASTER LF +0.5 DEGREES RF -0.3 DEGREES

CAMBER LF +0.3 DEGREES RF -0.25 DEGREES

TOE-IN 3/16 INCHES

ODOMETER: 2018 MILES

TEST INFORMATION:

~~'A' curve peak effort = 23 lbs.~~

Revised 12/10/69
'A' curve = 29 lbs

CAR WEIGHT (FULL TANK GAS)
(includes 2-Pass. +Equip.)

RF 1106 LBS.

LF 1210 LBS.

RR 1454 LBS.

LR 1522 LBS.

EQUIPMENT NUMBERS:

PLOTTER Model #3

FIFTH WHEEL VD 206

TORQUE TRANSDUCER #3

BRIDGE VD002

POWER SUPPLY ✓

PLOTTER SETTINGS:

POWER ON
X 1 VOLTS/IN
Y_1 1.5 VOLTS/IN
Y_2 .5 VOLTS/IN

POWER OFF (manual)
X 1 VOLTS/IN
Y_1 .5 VOLTS/IN
Y_2 .5 VOLTS/IN

"A" LOOP (power off manual)
X 1 VOLTS/IN
Y_1 1 VOLTS/IN
Y_2 1 VOLTS/IN

F = [illegible] LBS

PG-2044 REV. 5-72

VEHICLE DESCRIPTION

Make: Chevrolet

Model: Chevelle

Car No.: Chev 36050

Year: 1973

Test Weight: F 2131 R 1798

Tire Make: Uniroyal

Tire Press: F 24 R 24

Tire Size: G78-14

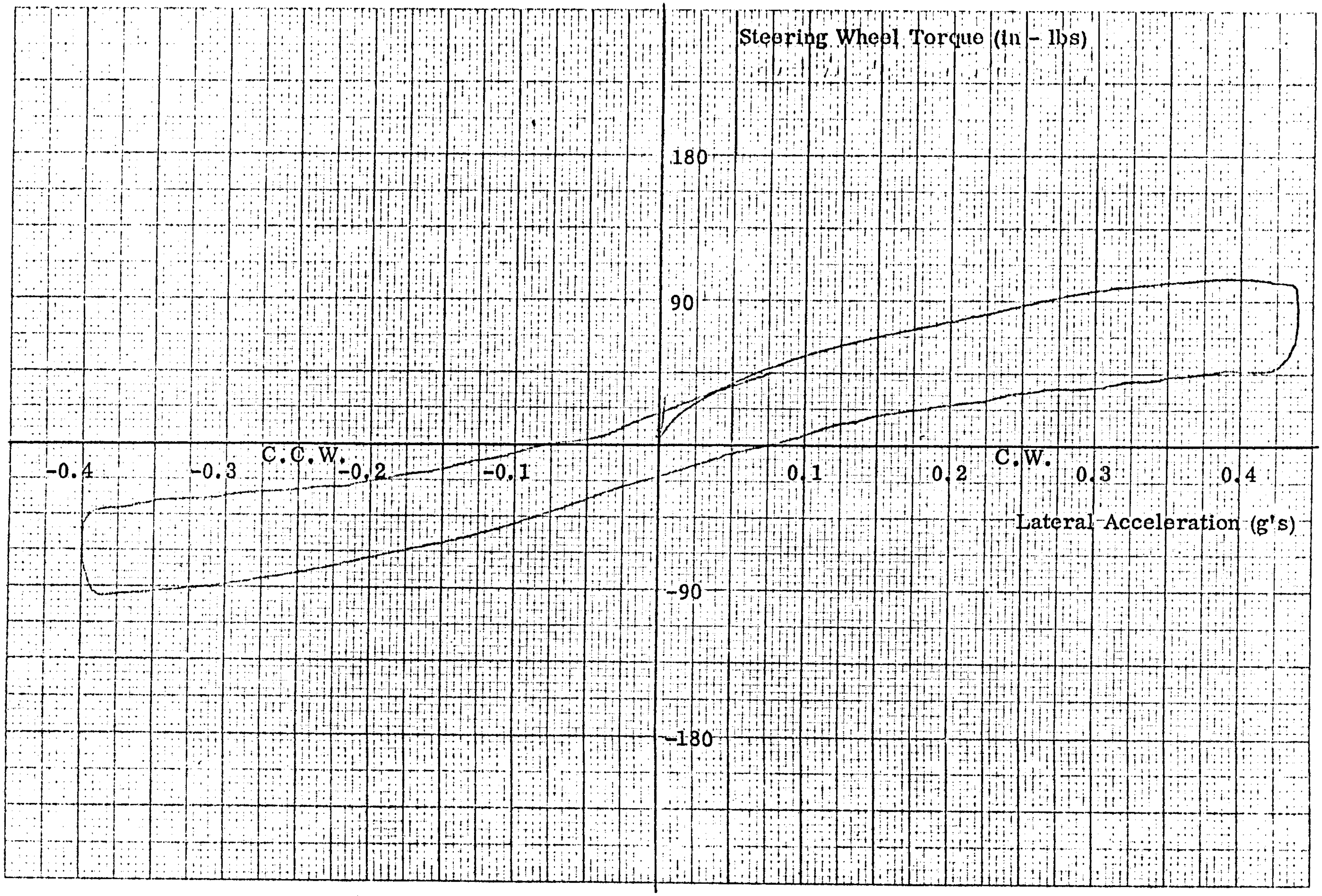
Date: 7-6-73

Operator: D. Salewsky

Steering: Manual

Speed: 30 mph

Steering Wheel Dia.: 15 in.

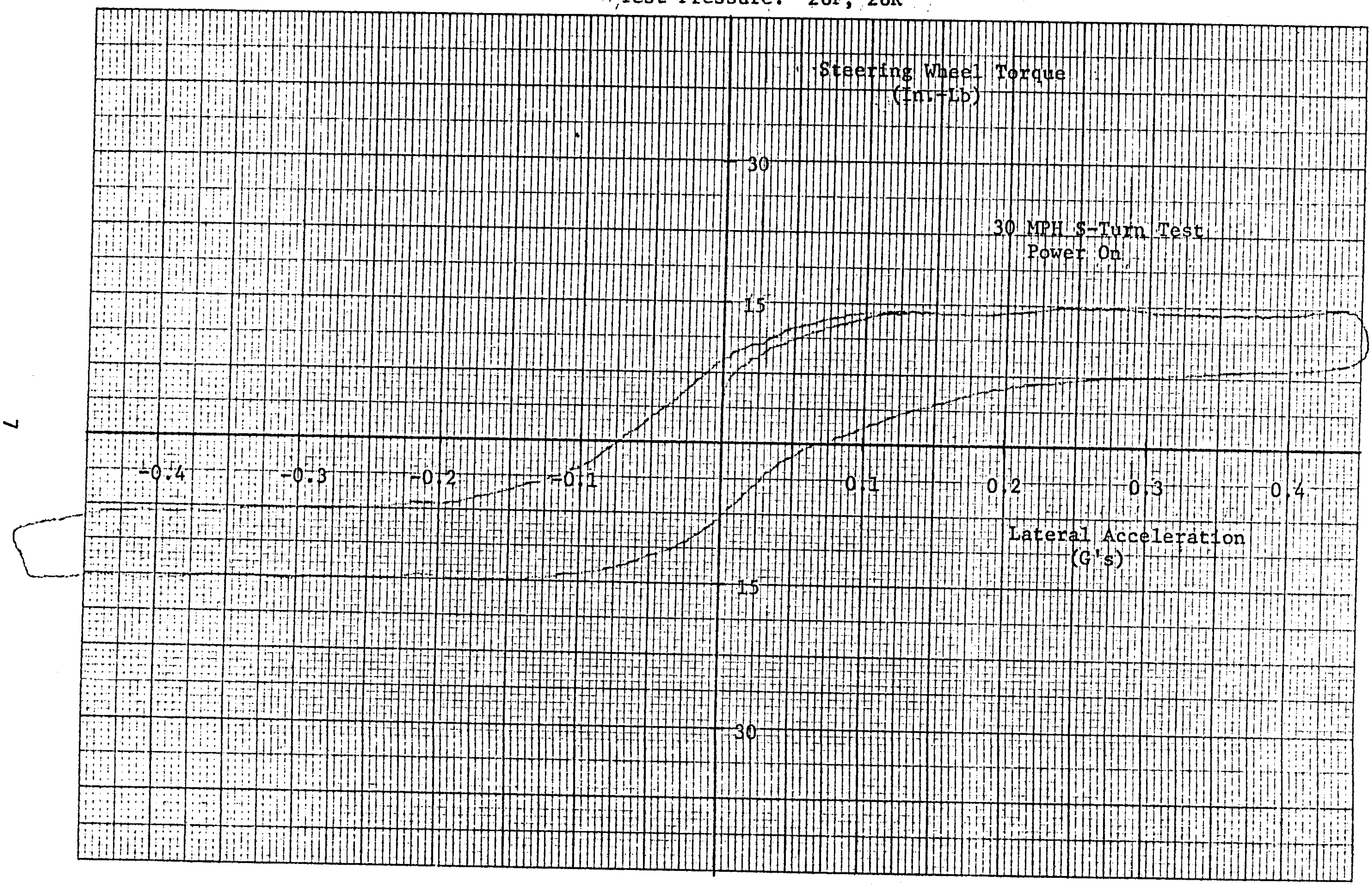


STEERING EFFORT

Make: Oldsmobile
Model: "A" Body
Year: 1972

No.: 2208
Test Weight: F-2370, R-1805
Plus 2 Passenger
Tires: B.F. Goodrich
G78-14
Test Pressure: 28F, 28R

Date: January 1972
Operator: T.C.W.
Steering: Power



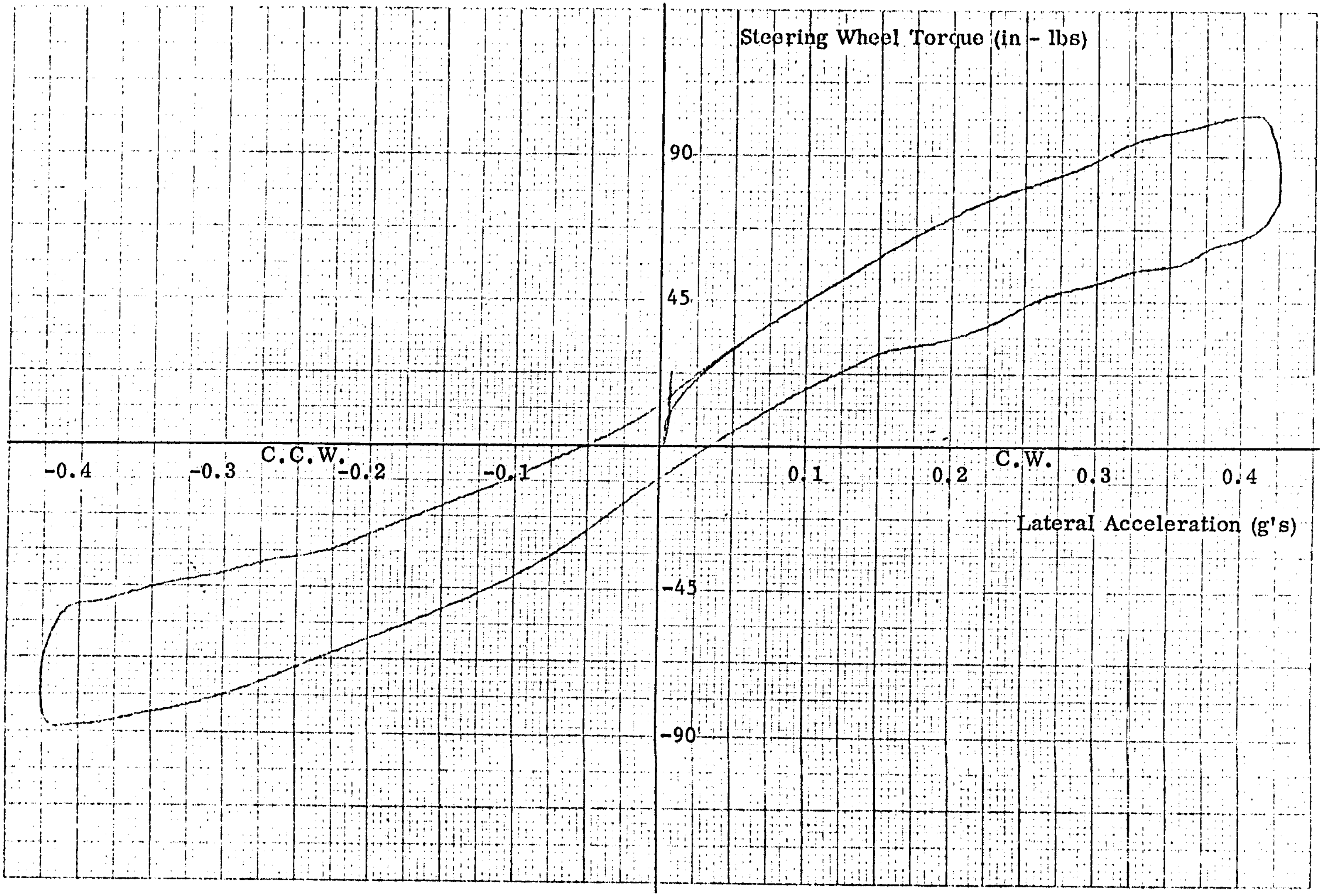
7

Report No. PG-31123

PG-2044 REV. 5-72

VEHICLE DESCRIPTION

Make: Buick	Test Weight: F 2146 R 1883	Date: 8-1-73
Model: Apollo	Tire Make: Firestone	Operator: D. Salewsky
Car No.: 1338	Tire Press: F 24 R 24	Steering: Manual
Year: 1973	Tire Size: E78-14	Speed 30 mph
		Steering Wheel Dia.: 15 in.



STEERING EFFORT DATA SHEET

DATE: Oct. 9, 1969

RECORDED BY: J. Lutz

VEHICLE INFORMATION:

MAKE: Chevy Nova   CAR NO. PG 70002

MODEL: SS-350-2D   ENGINE SIZE 350-4B.

YEAR: 1970   GROUP 5

STEERING ✓ POWER   OE WHEEL DIA. ~~15.5~~ 14.5 inches

_____ MANUAL   GEAR RATIO 16-1

BRAKE TYPE: DISC FRONT

DRUM REAR

TIRE SIZE: E70-14 FRONT   TIRE PRESSURE (COLD, LIGHT LOAD)

E70-14 REAR   FRONT 24 psi

GOODYEAR MAKE   REAR 26 psi

FRONT WHEEL ALIGNMENT:

CASTER LF +0.75 DEGREES   RF +0.5 DEGREES

CAMBER LF -0.25 DEGREES   RF 0 DEGREES

TOE-IN 1/32" out INCHES

ODOMETER: 483 MILES

TEST INFORMATION:

CAR WEIGHT (FULL TANK GAS)
2 PASS + EQUIP.

RF 1140 LBS.

LF 1090 LBS. 2230

RR 970 LBS.

LR 955 LBS.

EQUIPMENT NUMBERS:

PLOTTER XY-model 2

FIFTH WHEEL #43

TORQUE TRANSDUCER #2

BRIDGE 25-350

POWER SUPPLY 182

RESULTS:
AVG. PEAK RIM FORCE - ~~[illegible]~~ LBS
21 LBS

PLOTTER SETTINGS:

POWER ON X ~~[illegible]~~ 1.0 VOLTS/IN
Y 0.1 VOLTS/IN

POWER OFF X 1.0 VOLTS/IN
Y 0.2 VOLTS/IN

"A" LOOP (without power) X 1.0 VOLTS/IN
Y 0.5 VOLTS/IN

CSC
0.8 volts/in = 8.0 in-lbs/in. for torque (true for all tests on & after Oct 9, 1969)

Driver - Irv Hill - G.P.E.S.D.

PG-2044 REV. 5-72

VEHICLE DESCRIPTION

Make: Chevrolet
Model: Vega
Car No.: PG 73001
Year: 1973

Test Weight: F 1455 R 1303
Tire Make: Firestone
Tire Press: F 24 R 24
Tire Size: A70-13

Date: 7-18-73
Operator: D. C. Salewsky
Steering: Manual
Speed: 30 mph
Steering Wheel Dia.: 14 in.

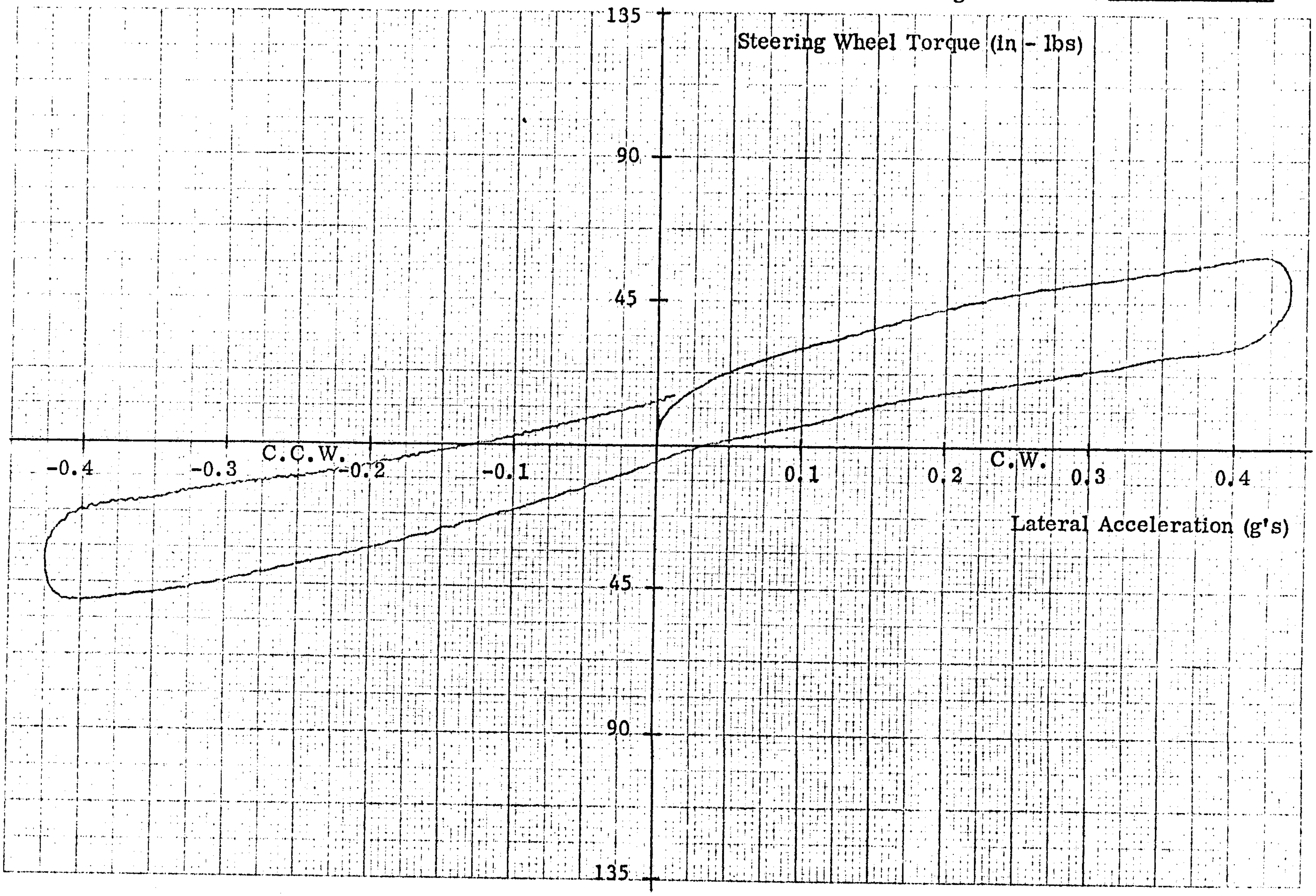


Figure 6

VEHICLE DESCRIPTION

Make	Chevrolet	Test Weight:	F 1455 R 1303	Date:	7-18-73
Model:	Vega	Tire Make:	Firestone	Operator:	D. C. Salewsky
Car No.:	PG 73001	Tire Press:	F 24 R 24	Steering:	Manual
Year:	1973	Tire Size:	A70-13	Speed	Static
				Steering Wheel Dia.:	14 in.

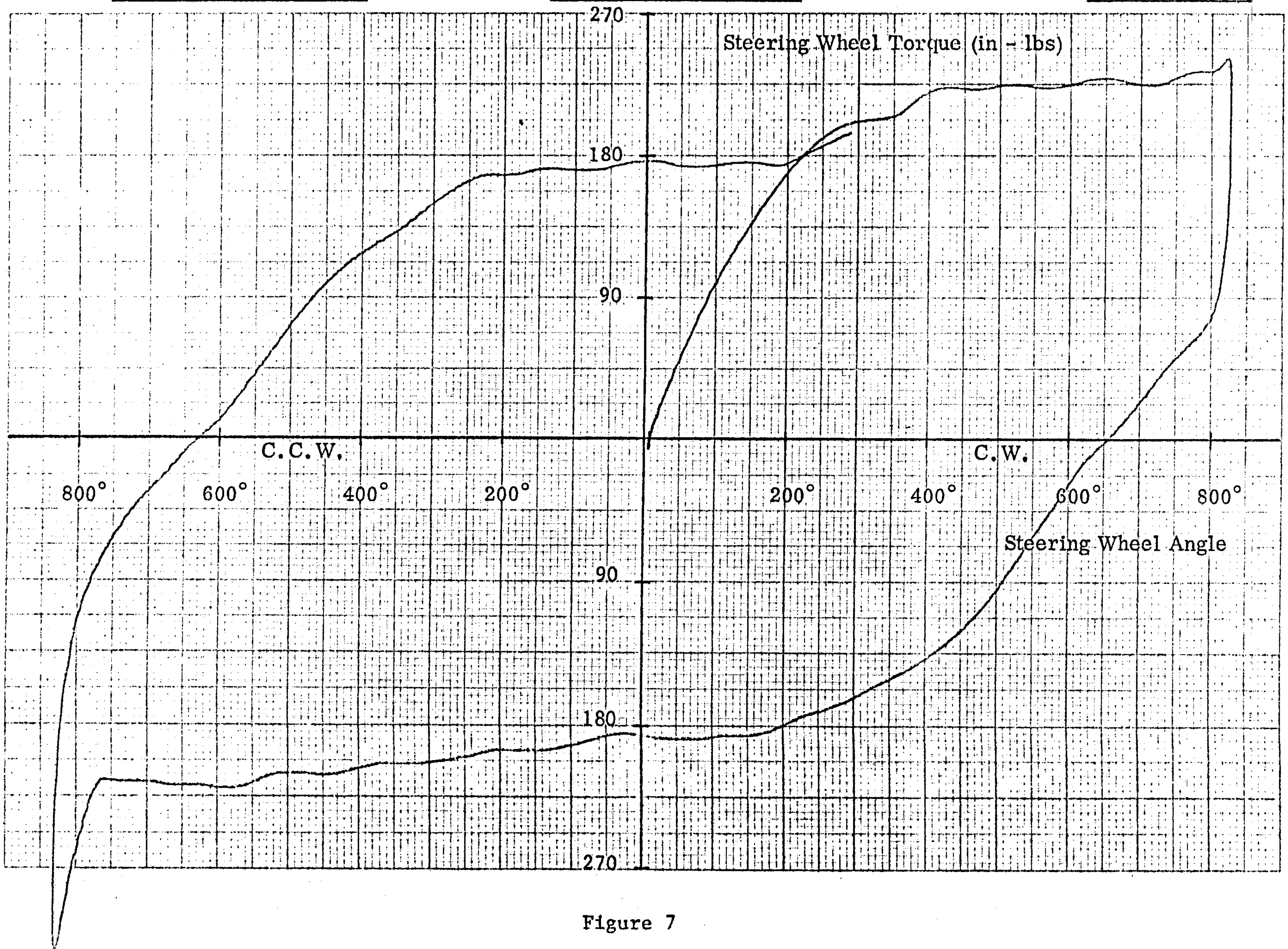
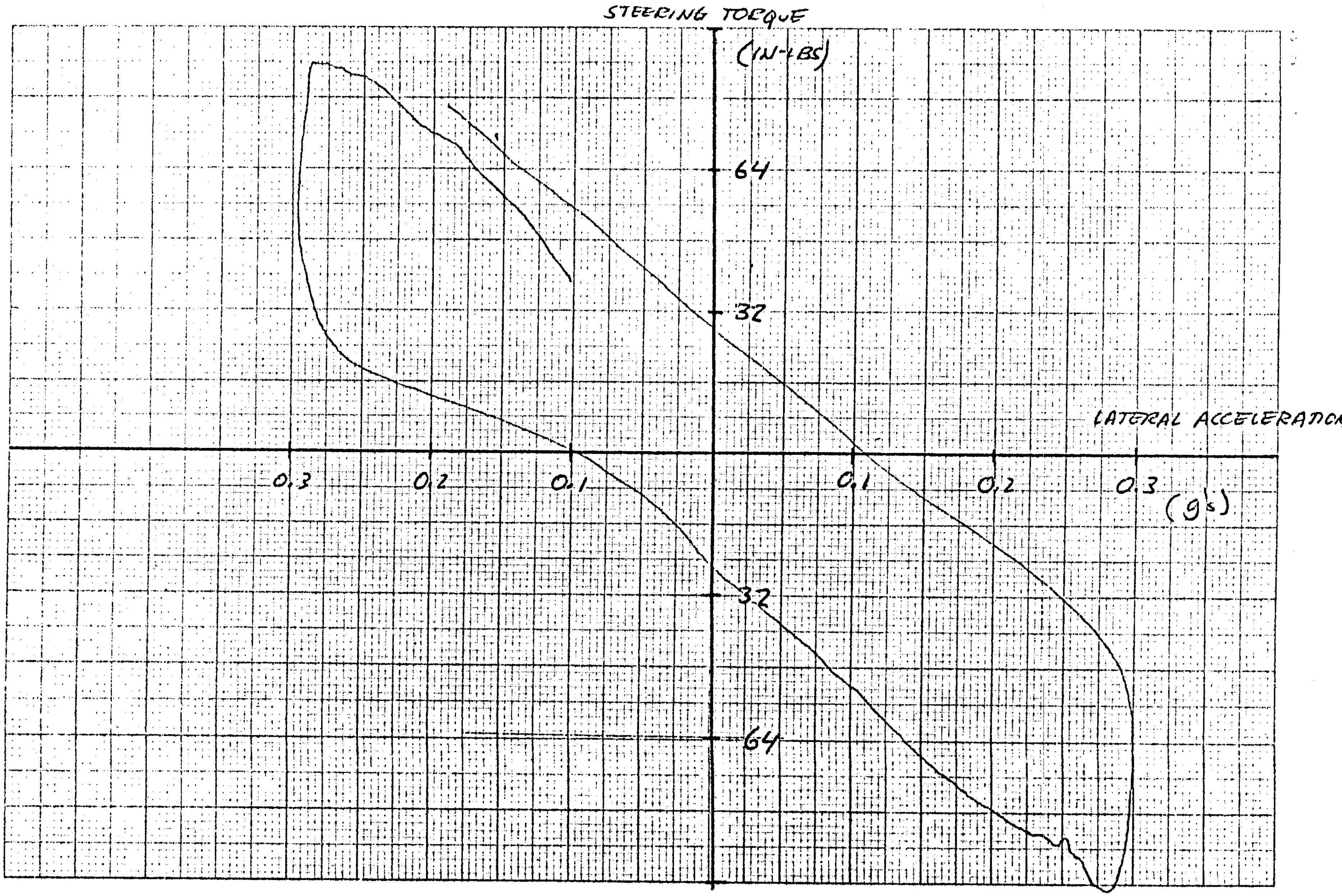


Figure 7

Report No. PG- 33485

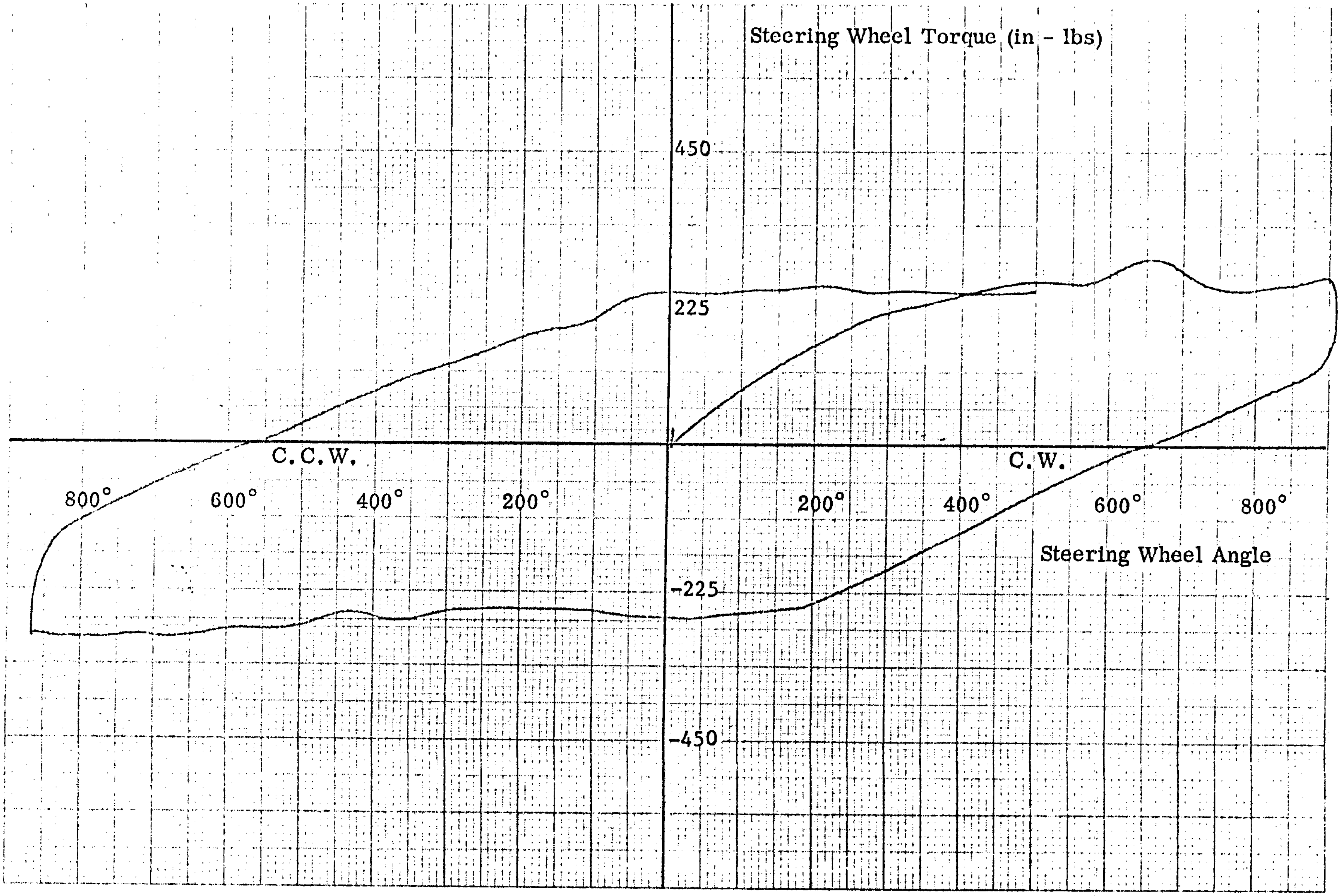
70002

P/S OFF


STEERING TORQUE
(IN-LBS)
64
32
32
64
LATERAL ACCELERATION
0.3
0.2
0.1
0.1
0.2
0.3
(g's)

VEHICLE DESCRIPTION

Make	Buick	Test Weight:	F 2146 R 1883	Date:	8-1-73
Model:	Apollo	Tire Make:	Firestone	Operator:	D. Salewsky
Car No.:	1338	Tire Press:	F 24 R 24	Steering:	Manual
Year:	1973	Tire Size:	E78-14	Speed	Static
				Steering Wheel Dia.:	15 in.

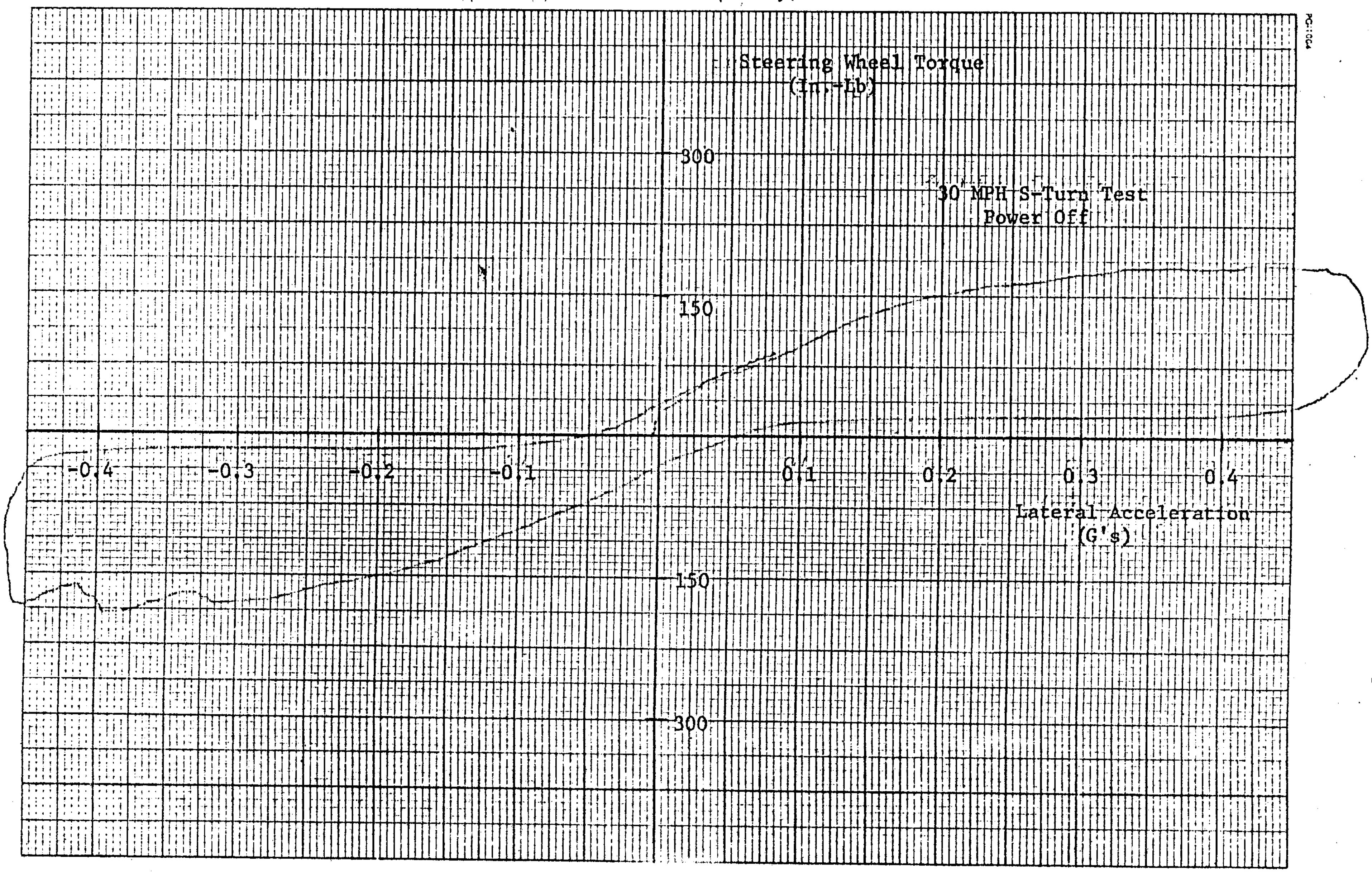


STEERING EFFORT

Make: Oldsmobile
Model: "A" Body
Year: 1972

No. 2208
Test Weight: F-1370, R1805
Plus 2 Passenger
Tires: B.F. Goodrich
G78-14
Test Pressure: 28F, 28R

Date: January 1972
Operator: T.C.W.
Steering: Power



Report No. PG-31123

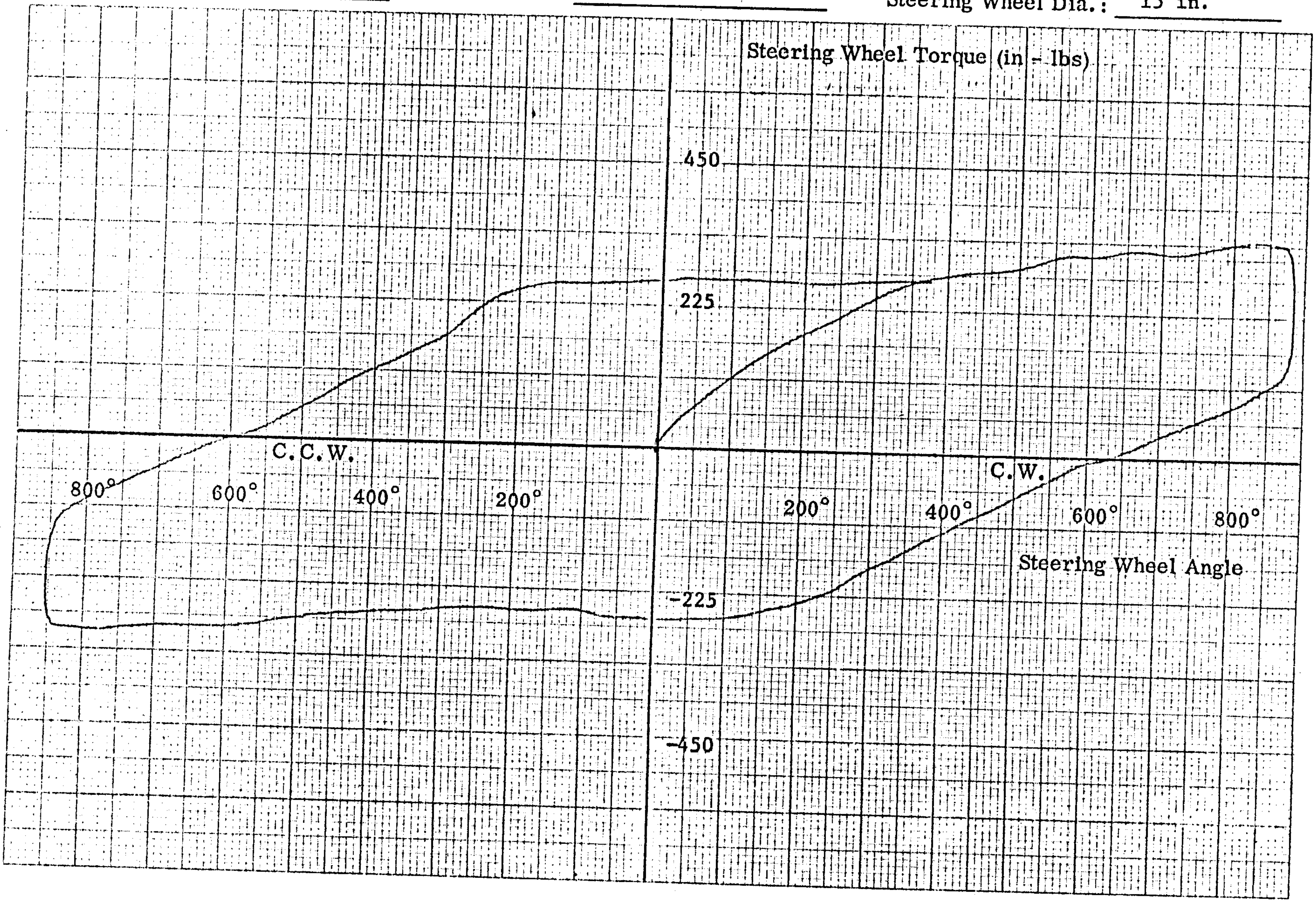
PG-2483

VEHICLE DESCRIPTION

Make: Chevrolet
Model: Chevelle
Car No.: Chev 36050
Year: 1973

Test Weight: F 2131 R 1798
Tire Make: Uniroyal
Tire Press: F 24 R 24
Tire Size: G78-14

Date: 7-5-73
Operator: D. Salewsky
Steering: Manual
Speed: Static
Steering Wheel Dia.: 15 in.



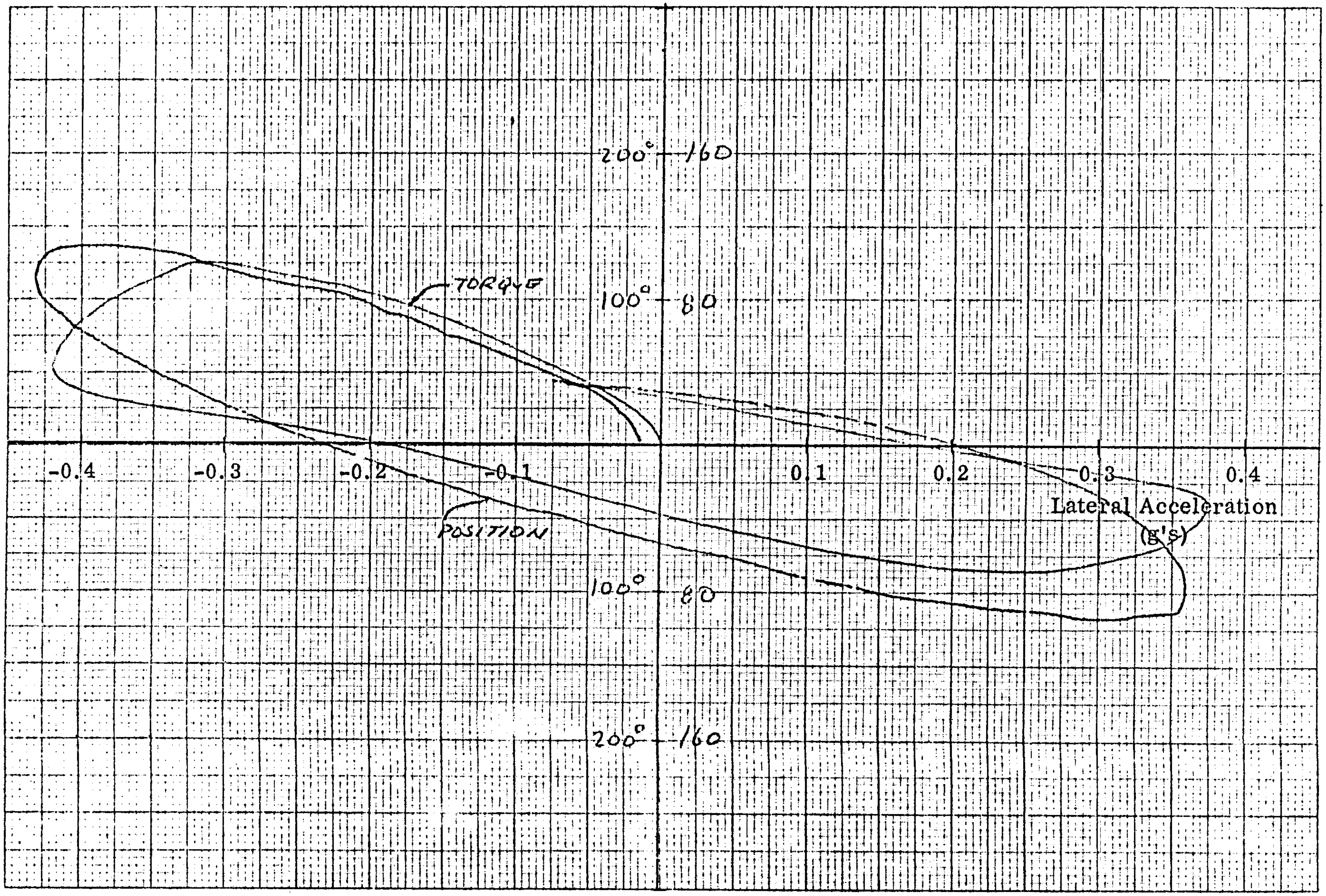
VEHICLE DESCRIPTION

Make: CHEVY No. 70028 Date: 10-27-69

Model: KINGSWOOD Test Weight ______ Operator: ______

Year: 1970 Steering: P/S OFF 30 MPH

Steering Wheel Angle (Degrees) Steering Wheel Torque (in-lbs)

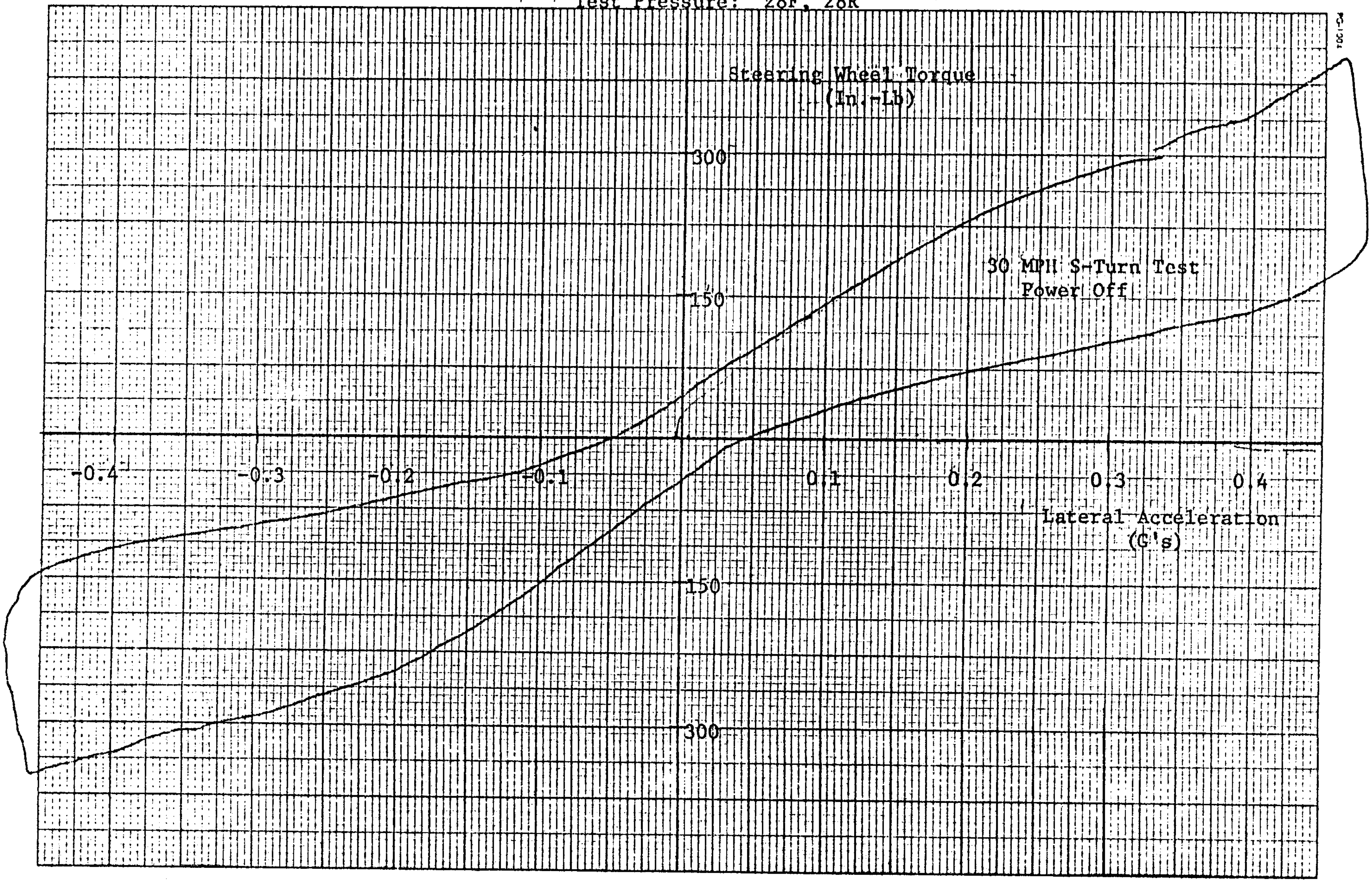


STEERING EFFORT

Make: Oldsmobile
Model: "B" Body
Year: 1972

No. 2523
Test Weight: F-2636, R-2022
Plus 2 Passenger
Tires: Firestone
H78-15
Test Pressure: 28F, 28R

Date: January 1972
Operator: T.C.W.
Steering: Power



Report No. PG-31123

PE10-005

GM

4/14/2010

ATTACHMENT Q

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1974_04_19_rar_memo

F-866

Inter-Organization

Environmental Activities Staff
General Motors Corporation
General Motors Technical Center
Warren, Michigan 48090

FILE COPY DO NOT REMOVE

Date: April 19, 1974

Subject: NHTSA IR on Steering Effort

To: Messrs: J. B. Ridenour - Oldsmobile
W. J. Owen - Cadillac
R. Rasmussen - Vehicle Dynamic Lab (PG)
T. C. McCann - Legal Staff
R. T. Bundorf - Engineering Analysis

Attached is the final draft of a proposed response to the subject information request. This submission has been reviewed by Engineering Analysis, Vehicle Dynamics Laboratory and Legal Staff and is being forwarded for any final comment that you might have.

Inasmuch as ASE plans to submit this material on April 25, 1974, it is requested that any comments you might have be in this office no later than noon of April 24, 1974. Your cooperation is appreciated.

R. A. Rogers
R. A. Rogers
Automotive Safety Engineering

jmp
cc: L. C. Lundstrom
D. E. Martin

Environmental Activities Staff
General Motors Corporation
General Motors Technical Center
Warren, Michigan 48090

Mr. Robert L. Carter
Associate Administrator
Motor Vehicle Programs
National Highway Traffic Safety Administration
Washington, DC 20590

Re: N40-30
KLK

Dear Mr. Carter:

This is being submitted in response to your letter of February 4, 1974, requesting "performance data and other technical data" related to the steering effort of GM vehicles.

Comments

It is noted in your letter that the information requested will be used to formulate rulemaking actions. General Motors wishes to again express its concern (as previously expressed in its August 15, 1973 comments to the NHTSA on Advance Notice of Proposed Rule Making, Docket No. 73-10, Notice 1 - Rollover Resistance and its October 26, 1973 comments to the NHTSA on Advance Notice of Proposed Rule Making, Docket No. 73-17, Notice 1 - Directional Control) about the NHTSA overall program plan for vehicle handling. The subject request and both of the rulemaking actions noted above fall within the vehicle handling area. General Motors wishes to reiterate its previously stated position that the NHTSA should refrain from a fragmented approach to the subject of vehicle handling which may lead to unrealistic and uneconomical compromises in the design of vehicles. It is therefore proposed that the rulemaking suggested relative to this subject be incorporated into one docket in order to promulgate an overall vehicle handling rule in lieu of rules on specific topics such as rollover, braking-in-a-turn and steering effort.

Discussion

Data were requested with regard to all available steering systems and specific test conditions for 1974 passenger cars ranging from standard-sized station wagons to subcompacts.

Because of the minimal model changes for 1974, General Motors relied upon certain data generated during the development of prior model year vehicles and components which in its judgment remained applicable to the 1974 models. It would have served no useful engineering purpose to repeat many of these tests and evaluations for 1974 models. Accordingly, General Motors will, in most instances, respond to the specific NHTSA questions with appropriate data from prior model years.

Item 1 -- Stationary Vehicle Steering

Request: The NHTSA requested information on steering effort required to turn the wheels of standing vehicles plotted versus steering wheel angle. When power assist is available, additional information was requested on the steering effort after loss of pump driving power and after loss of hydraulic fluid.

Response: General Motors conducts stationary vehicle steering effort tests on manual steer vehicles, only. Thus, for stationary vehicles, the only data (equally applicable to the 1974 model cars) is steering effort (torque) vs. steering wheel angle for intermediate (Chevrolet Chevelle -- as representative of the Pontiac LeMans and Buick Century), compact (Buick Apollo -- as representative of the Chevrolet Nova, Pontiac Ventura, and Oldsmobile Omega), and subcompact (Chevrolet Vega and Opel ~~Ascona~~ Manta) passenger cars (figures 1 through 4).

Figure 5 presents data which responds to the NHTSA request for additional information on static steering effort after loss of pump driving power and after loss of hydraulic fluid, in a power assist system.

Note: All steering data presented (figures 1 through 33) were taken at two passenger load with new tires (except Opel data where load distribution per axle and tire profile are noted). All steering gear adjustments, wheel alignments (except where noted otherwise) and tire pressures were set to nominal specifications for the particular vehicle tested. Stationary vehicle tests were conducted on a 3M grit surface so that tire-road interface effects were standardized.

Item 2 -- Steering Effort Design Guidelines

Request: The NHTSA requested information on design guidelines used to determine steering effort upon failure of power assisted units, including the results of any tests conducted in the development of these guidelines.

Response: Steering effort performance for both manual steering and power steering General Motors' vehicles is established through subjective evaluation and judgment by engineering and other experienced personnel.

Critical conditions under which power steering failures might necessitate a design guide are extremely difficult to define. General Motors does not believe the state-of-the-art in this area is sufficiently well advanced to permit such definitions.

In addition, steering effort studies of driver force capability have failed to yield conclusive results. Human effort research is complicated by many experimental and measurement problems. These include motivation, learning, anthropometry, task requirements, the nature of the performance metric, and statistical problems inherent with defining the performance of extremes in the driver population distribution. When all attempts to measure driver force capability are compared, it is clear that these numerous factors have a major influence on the results observed and experiments truly representative of the field situation are not currently feasible. As a result, GM has not reasonably been able to establish guidelines for steering effort performance more definite than the subjective evaluation by engineering and other experienced personnel, noted above.

Item 3 -- Vehicle Parameter Effects on Steering Effort

Request: The NHTSA requested all data which relate to the relationship of steering effort to vehicle speed, tire inflation, misalignment conditions, overloaded vehicles, tilt angle of the steering column, braking pressure, and road roughness.

Response: Vehicle Speed -- General Motors' domestic, dynamic tests for steering effort, performed during the vehicle design development and validation process, are conducted on a large paved surface where a driver can slowly apply steering wheel angle at constant vehicle speed through the range of ± 0.45G lateral acceleration. These steering effort tests are generally conducted at two speeds -- 10 and 30 mph. Therefore, with the exception of Figures 28 through 33 -- which present the results of a special test series (i.e. effect of caster angle change on steering effort) run at 10, 20 and 30 mph -- data developed during the design process, presented herein for domestic vehicles, is necessarily limited to that obtained at 10 and 30 mph.

Dynamic tests for steering effort, performed by General Motors Overseas Operations (importers of the Opel Manta), are conducted by driving the vehicle through both a large and small radii figure ∞ (see Figure 34 for course dimensions), at a constant vehicle speed. Steering effort moment (Newton - centimeter) vs. steering wheel angle (degrees) data for a 1974 Opel Manta are presented in figures 23 through 27.

Data submitted (Figures 6 through 33 attached) in response to this request is summarized below and is the latest available, applicable to 1974 models, for each of the car-steering type categories requested.

Figure	Vehicle	Steering Type	Model Year	Data Attached
6	Standard Size Passenger Car Oldsmobile "B" Body	Power	1972	10 mph Power On
7	"	"	"	10 mph Power Off
8	"	"	"	30 mph Power On
9	"	"	"	30 mph Power Off
10	Standard Size Station Wagon Chevrolet Kingswood	Power	1970	30 mph Power Off
11	Intermediate Size Passenger Car Chevrolet Chevelle	Manual	1973	10 mph
12	"	"	"	30 mph
13	Intermediate Size Passenger Car Oldsmobile "A" Body	Power	1972	10 mph Power On
14	"	"	"	10 mph Power Off
15	"	"	"	30 mph Power On
16	"	"	"	30 mph Power Off
17	Compact Passenger Car - Buick Apollo	Manual	1973	10 mph
18	"	"	"	30 mph
19	Compact Passenger Car Chevrolet Nova	Power	1970	30 mph Power On
20	"	"	"	30 mph Power Off
21	Subcompact Passenger Car Chevrolet Vega	Manual	1973	10 mph
22	"	"	"	30 mph

Figure	Vehicle	Steering Type	Model Year	Data Attached
23	Subcompact Passenger Car Opel Ascona/Manta	Manual	1974	6.2 mph Small Figure ∞
24	"	"	"	12.4 mph Small Figure ∞
25	"	"	"	6.2 mph Large Figure ∞
26	"	"	"	12.4 mph Large Figure ∞
27	"	"	"	18.6 mph Large Figure ∞
28	Intermediate Size Passenger Car Oldsmobile "A" Body at zero Degree Caster Setting	Manual	1973 Proto.	10 mph
29	"	"	"	20 mph
30	"	"	"	30 mph
31	Intermediate Size Passenger Car Oldsmobile "A" Body at -2 Degree Caster Setting	"	"	10 mph
32	"	"	"	20 mph
33	"	"	"	30 mph

With regard to steering effort testing that is applicable to the design and development of 1974 model General Motors passenger cars under the certain specific conditions you enumerate (tire inflation, suspension alignment, overloaded vehicles, tilt angle of the steering column, braking pressure and road roughness), test data of this nature is rarely obtained (See however, Figures 28 through 33 attached, which present data on one car regarding the effect of a 2 degree caster difference at 10, 20 and 30 mph). Instead, General Motors relies upon the subjective evaluation of experienced engineers, as explained above.

In view of the broad nature of this request and the vast complexity of vehicle handling in general, General Motors proposes that a meeting be held with you and members of your staff to permit a complete and thorough review of this topic. Mr. D. P. Reed of our Washington Office will be in contact with you to discuss this proposal.

Very truly yours,

David E. Martin, Manager
Automotive Safety Engineering

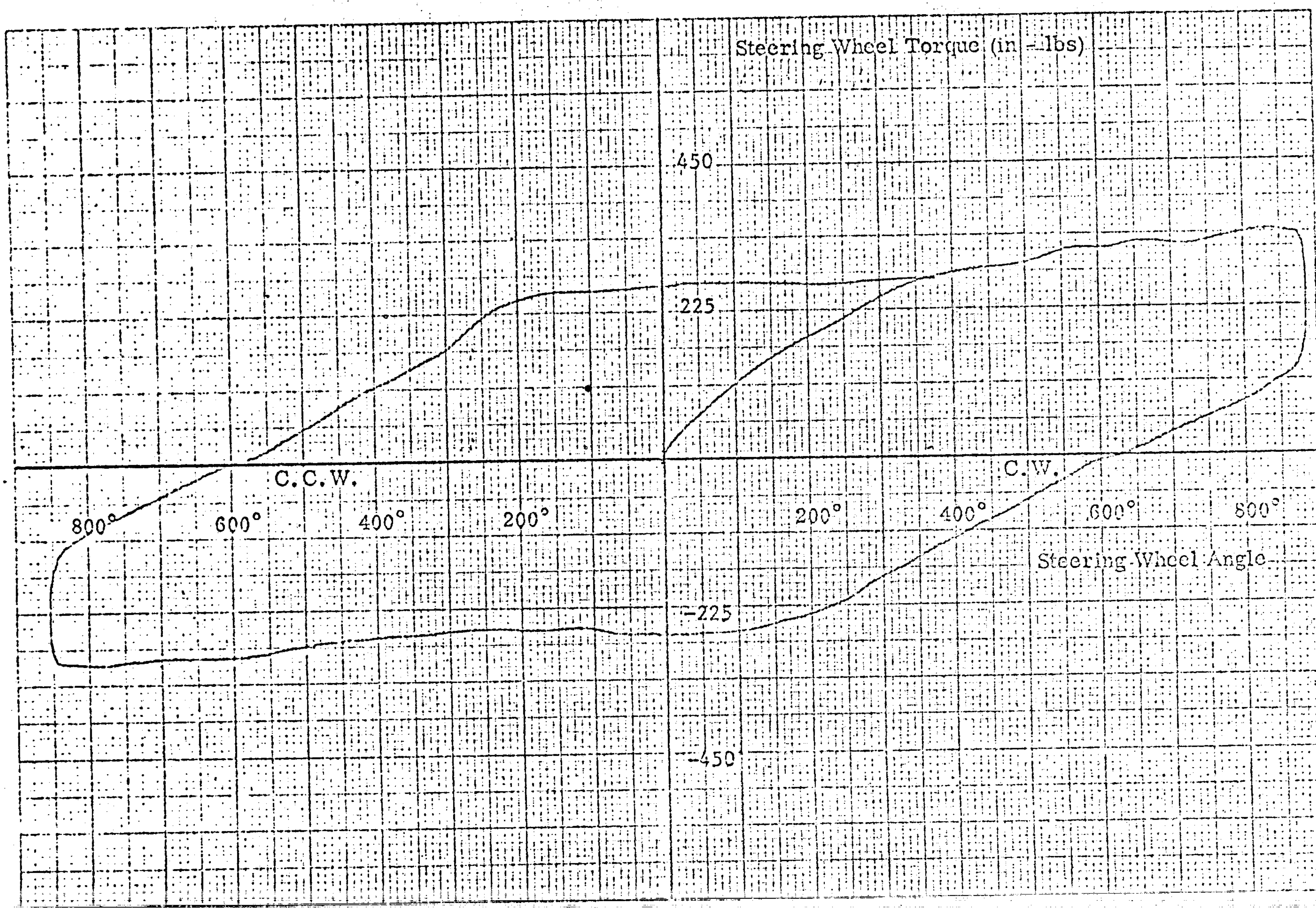
ld

VEHICLE DESCRIPTION

Make: Chevrolet
Model: Chevelle
Car No.: 36050
Year: 1973

Test Weight: F 2131 R 1798
Tire Make: Uniroyal
Tire Press: F 24 R 24
Tire Size: G 78-14

Date: 7-5-73
Steering: Manual
Speed: Static
Steering Wheel Dia: 15 in.



VEHICLE DESCRIPTION

Make: Buick

Model: Apollo

Car No.: 1338

Year: 1973

Test Weight: F 2146 R 1883

Tire Make: Firestone

Tire Press: F 24 R 24

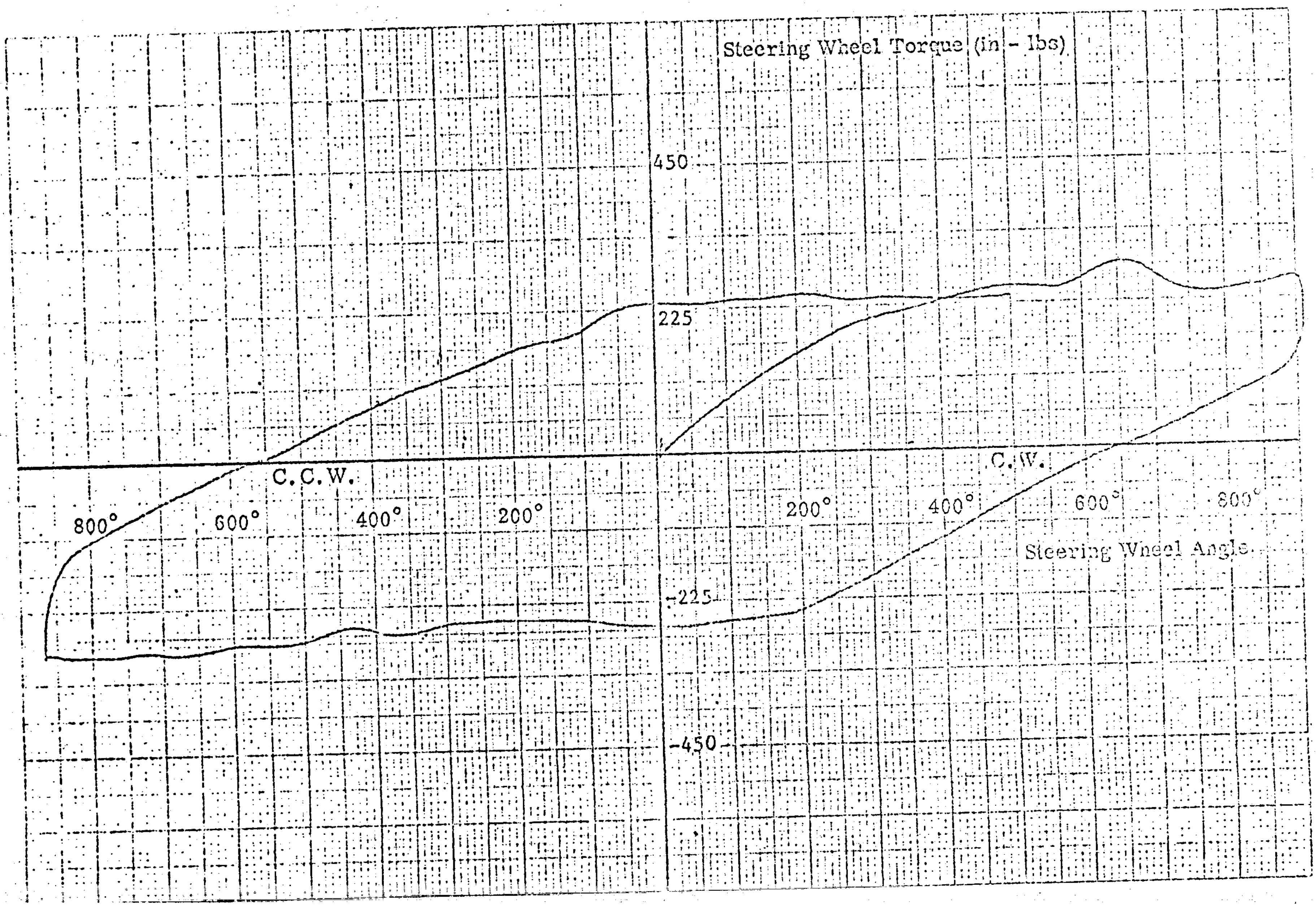
Tire Size: E78-14

Date: 8-1-73

Steering: Manual

Speed: Static

Steering Wheel Dia: 15 in.

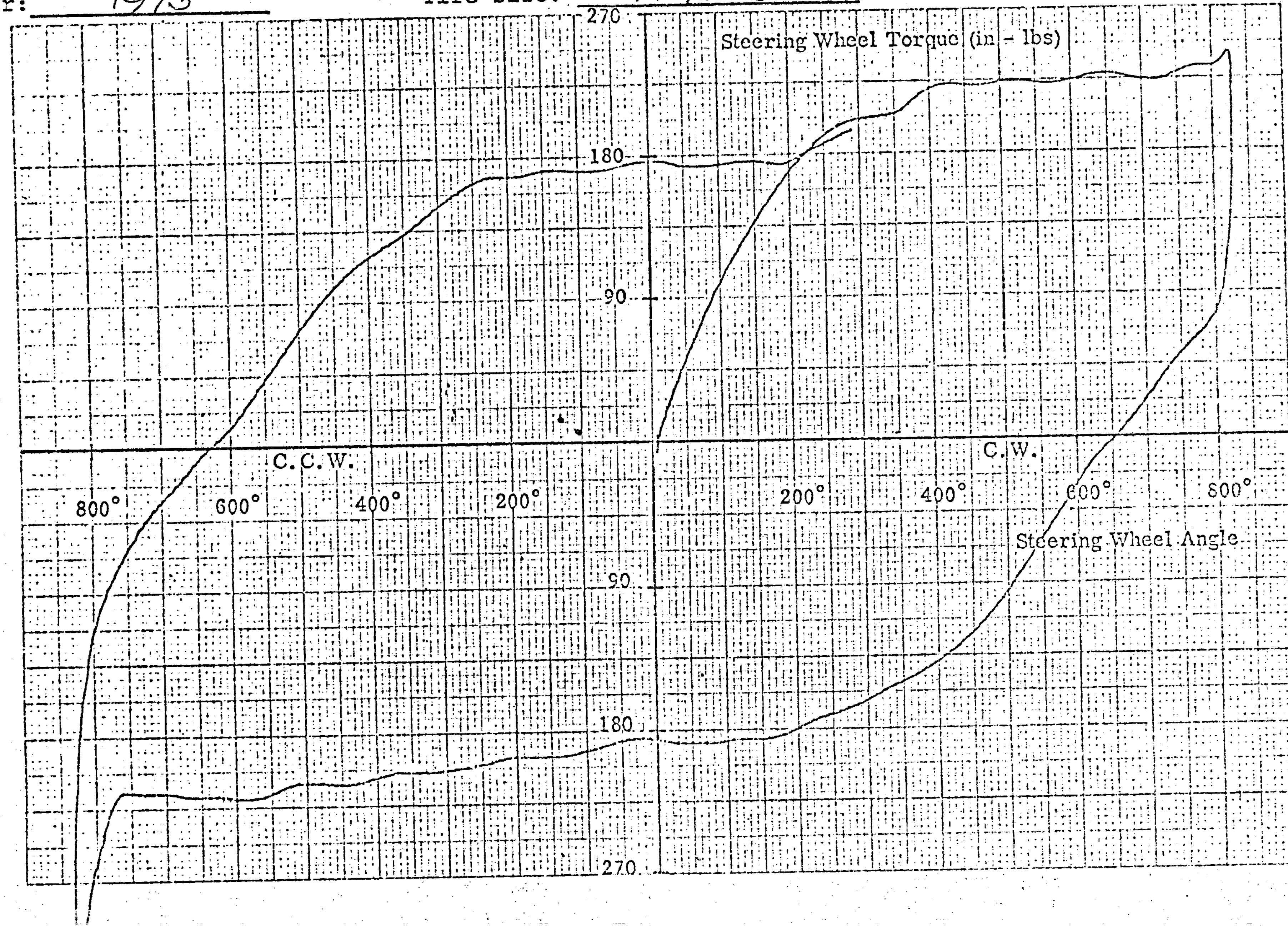


VEHICLE DESCRIPTION

Make: Chevrolet
Model: Vega
Car No.: 73001
Year: 1973

Test Weight: F 1455 R 1303
Tire Make: Firestone
Tire Press: F 24 R 24
Tire Size: A 70-13

Date: 7-18-73
Steering: Manual
Speed: Static
Steering Wheel Dia: 14 in.



VEHICLE DESCRIPTION

Make: Opel

Model: Manta

Car No.: 1840-91

Year: 1974

Test Weight: F 1390 R 1630

Tire Make: Michelin

Tire Press: F 23 R 28

Tire Size: 165 SR 13 (80% profile)

Date: 2-2-74

Steering: Manual

Speed: Static

Steering Wheel Dia: 15 in.

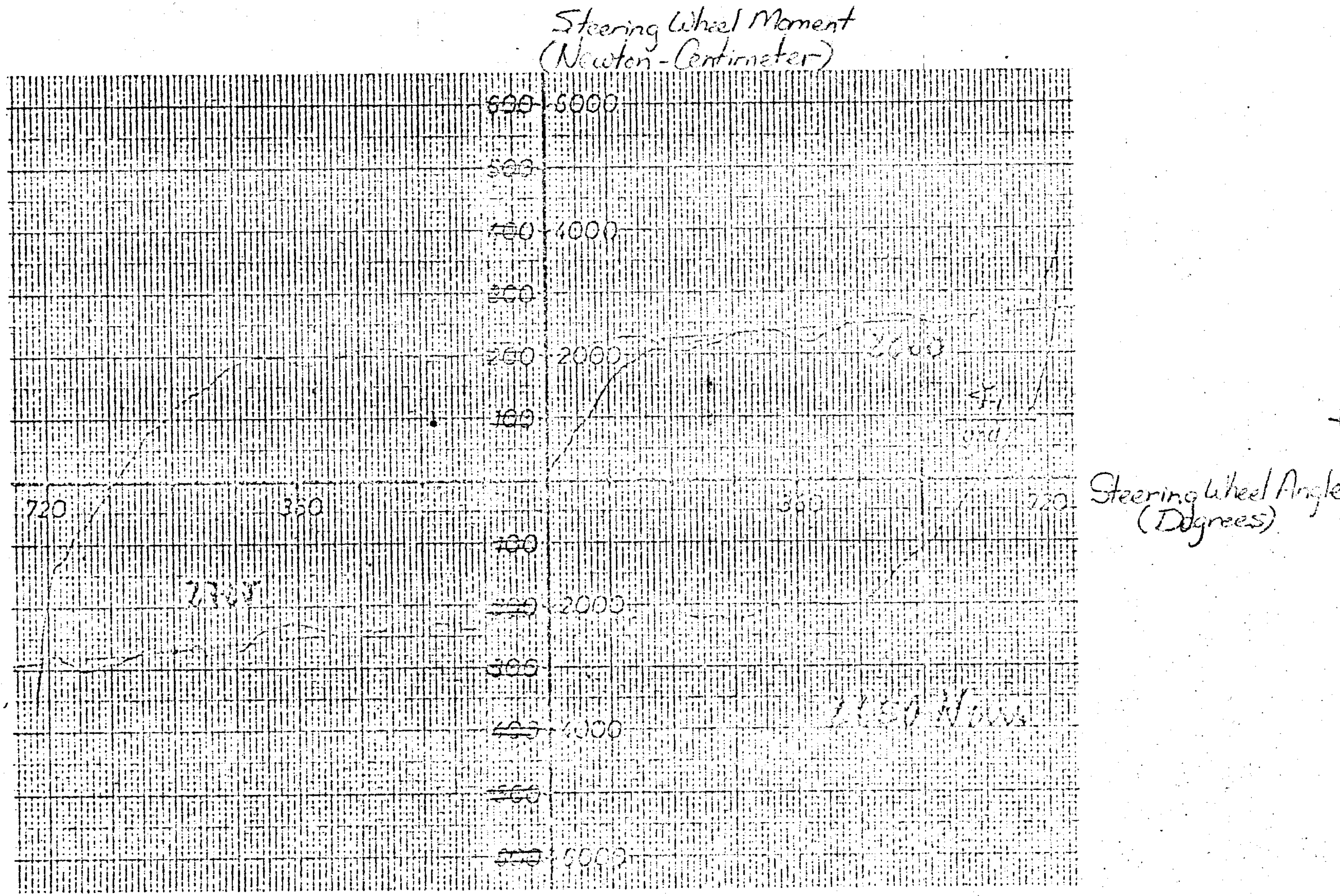


FIGURE ~~4~~5

EFFECT OF HYDRAULIC FLUID IN A NON-POWERED POWER STEERING SYSTEM

Test Vehicle:	1974 Oldsmobile "A"
Car Specifications:	Total Weight - 4535 lbs. Front Wheel Weight - 2645 lbs. H78 x 14 Belted Tires Standard Power Steering System

Test Results

		Maximum Effort (Ft. Lbs.)			
		With Oil		Without Oil	
		L	R	L	R
Static Turning on "3M" Surface					
	90°	26	27	37	25
Steering	180°	46	43	53	46
Wheel	270°	62	62	55	58
Rotation	360°	72	68	72	65
	Lock	73	70	74	67

VEHICLE DESCRIPTION

Make: Oldsmobile

Model: "B" Body

Car No.: 2523

Year: 1972

Test Weight: F 2636 R 2022

Tire Make: Firestone

Tire Press: F 28 R 28

Tire Size: H78-15

Date: January 1972

Steering: Power on

Speed: 10 mph

Steering Wheel Dia: 15 in.

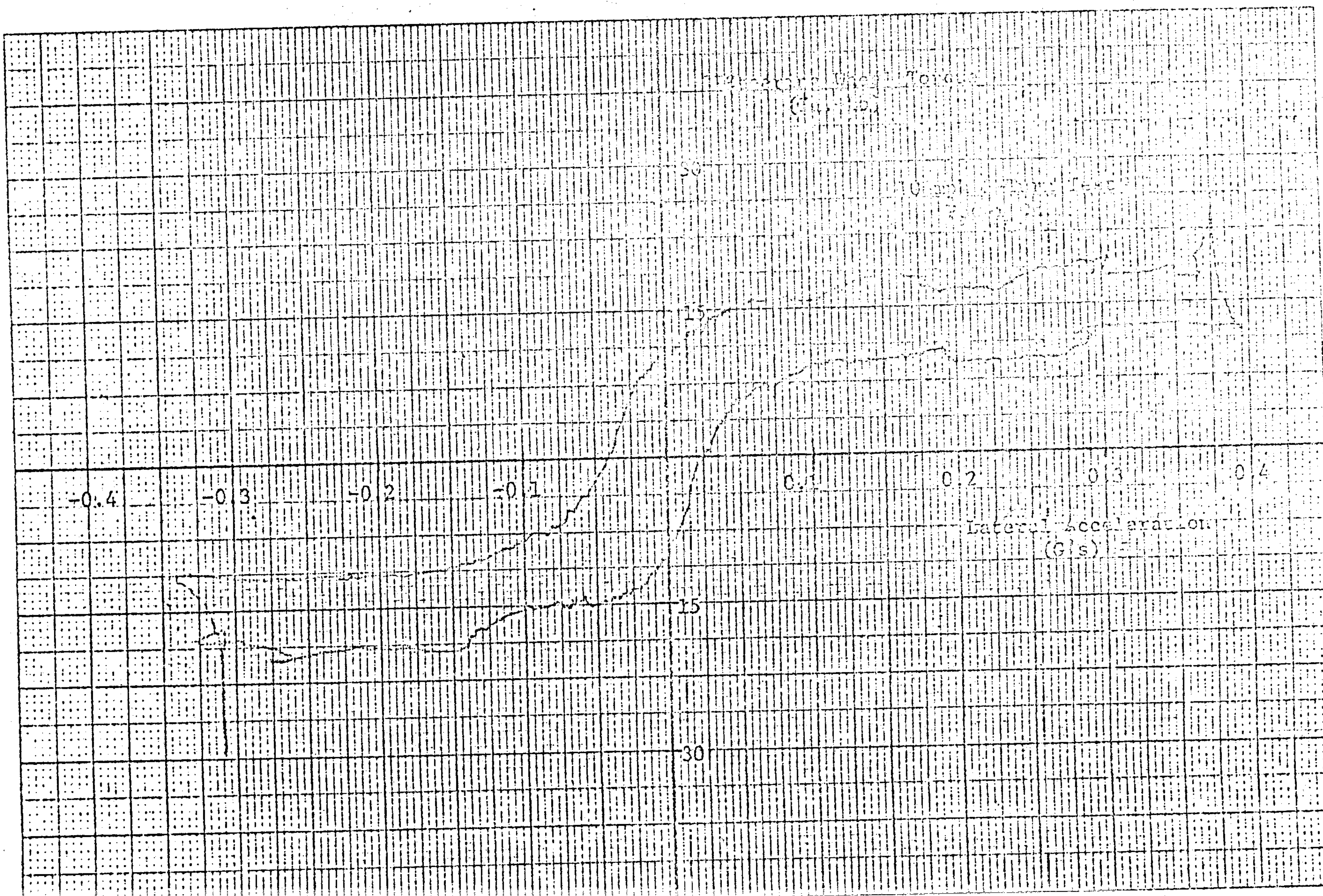


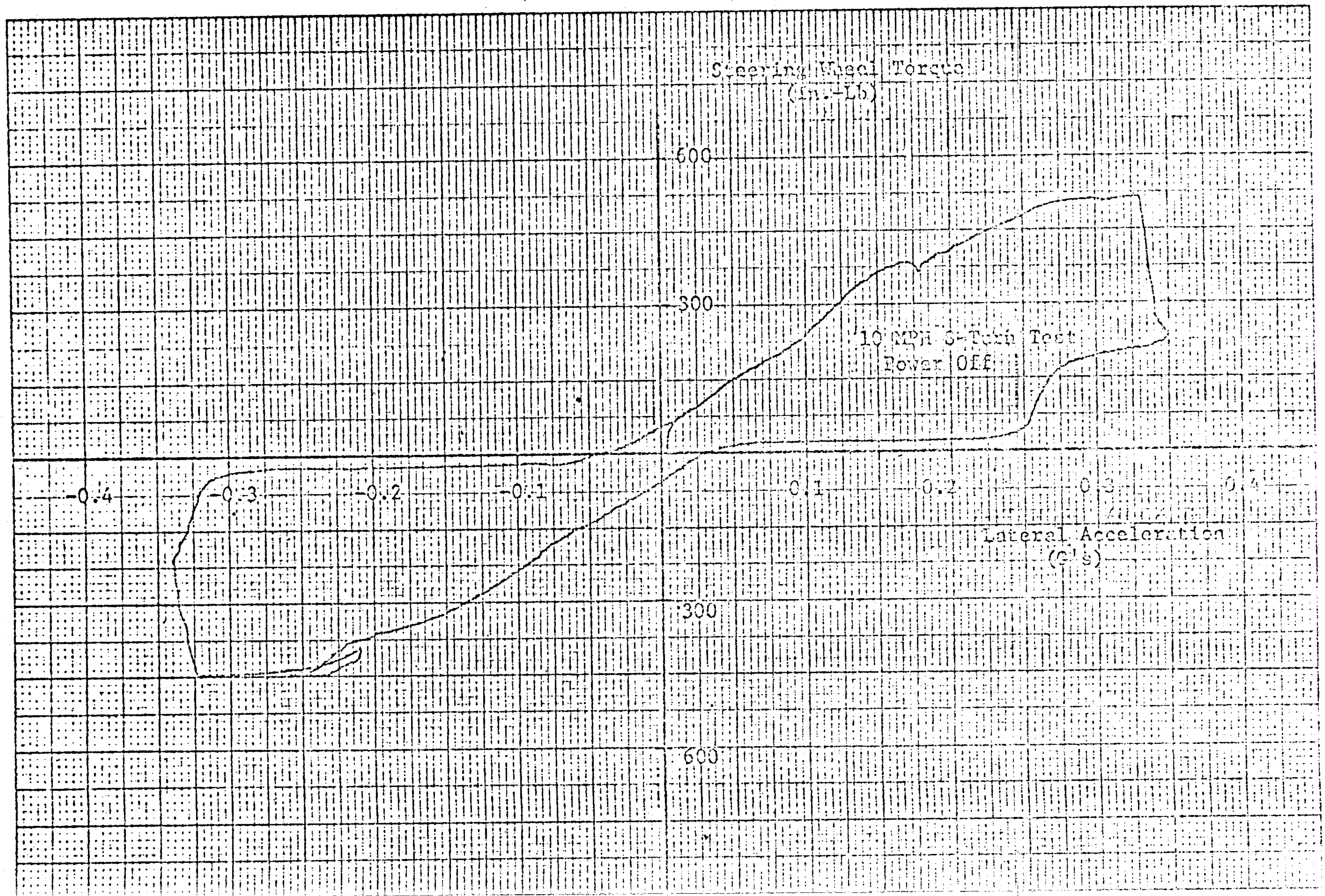
FIGURE 6

VEHICLE DESCRIPTION

Make: Oldsmobile
Model: "B" Body
Car No.: 2523
Year: 1972

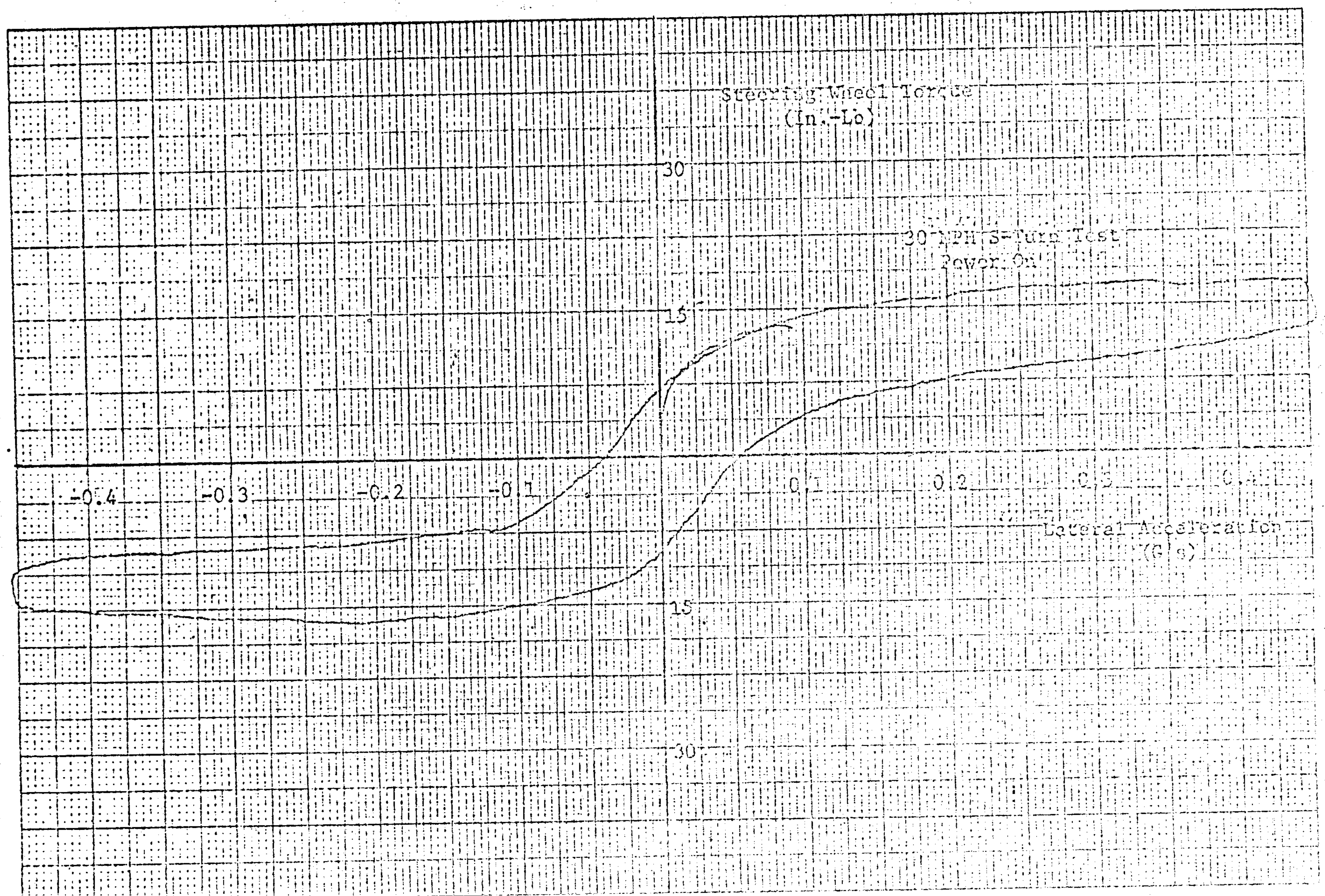
Test Weight: F 2636 R 2202
Tire Make: Firestone
Tire Press: F 28 R 28
Tire Size: H 78-15

Date: January 1972
Steering: Power off
Speed: 10 mph
Steering Wheel Dia: 15 in.



VEHICLE DESCRIPTION

Make: Oldsmobile	Test Weight: F 2636 R 2022	Date: January 1972
Model: "B" Body	Tire Make: Firestone	Steering: Power on
Car No.: 2523	Tire Press: F 28 R 28	Speed: 30 mph
Year: 1972	Tire Size: H78-15	Steering Wheel Dia: 15 in.



VEHICLE DESCRIPTION

Make: Oldsmobile

Model: "B" Body

Car No.: 2523

Year: 1972

Test Weight: F 2636 R 2022

Tire Make: Firestone

Tire Press: F 28 R 28

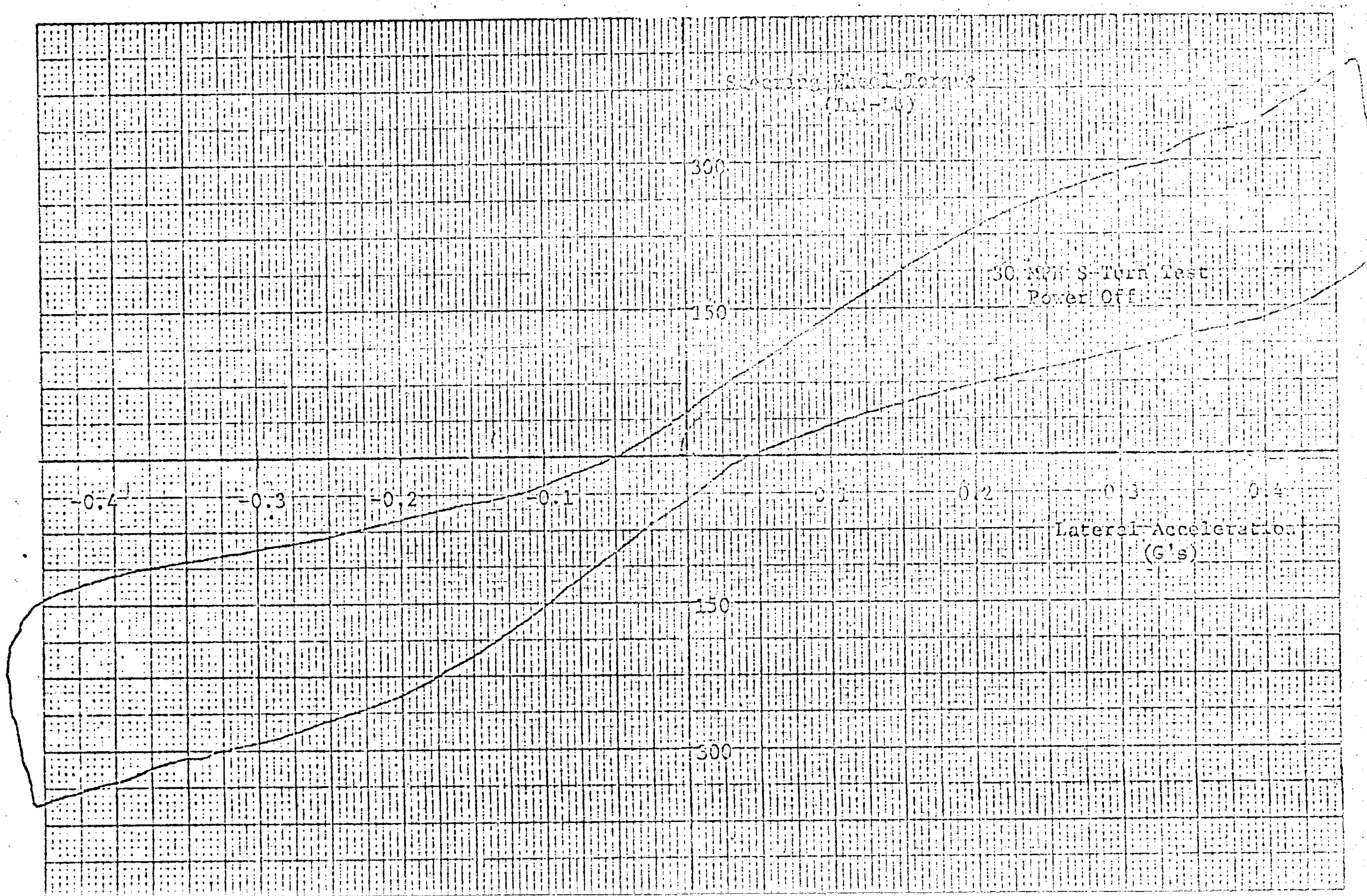
Tire Size: H78-15

Date: January 1972

Steering: Power off

Speed: 30 mph

Steering Wheel Dia: 15 in

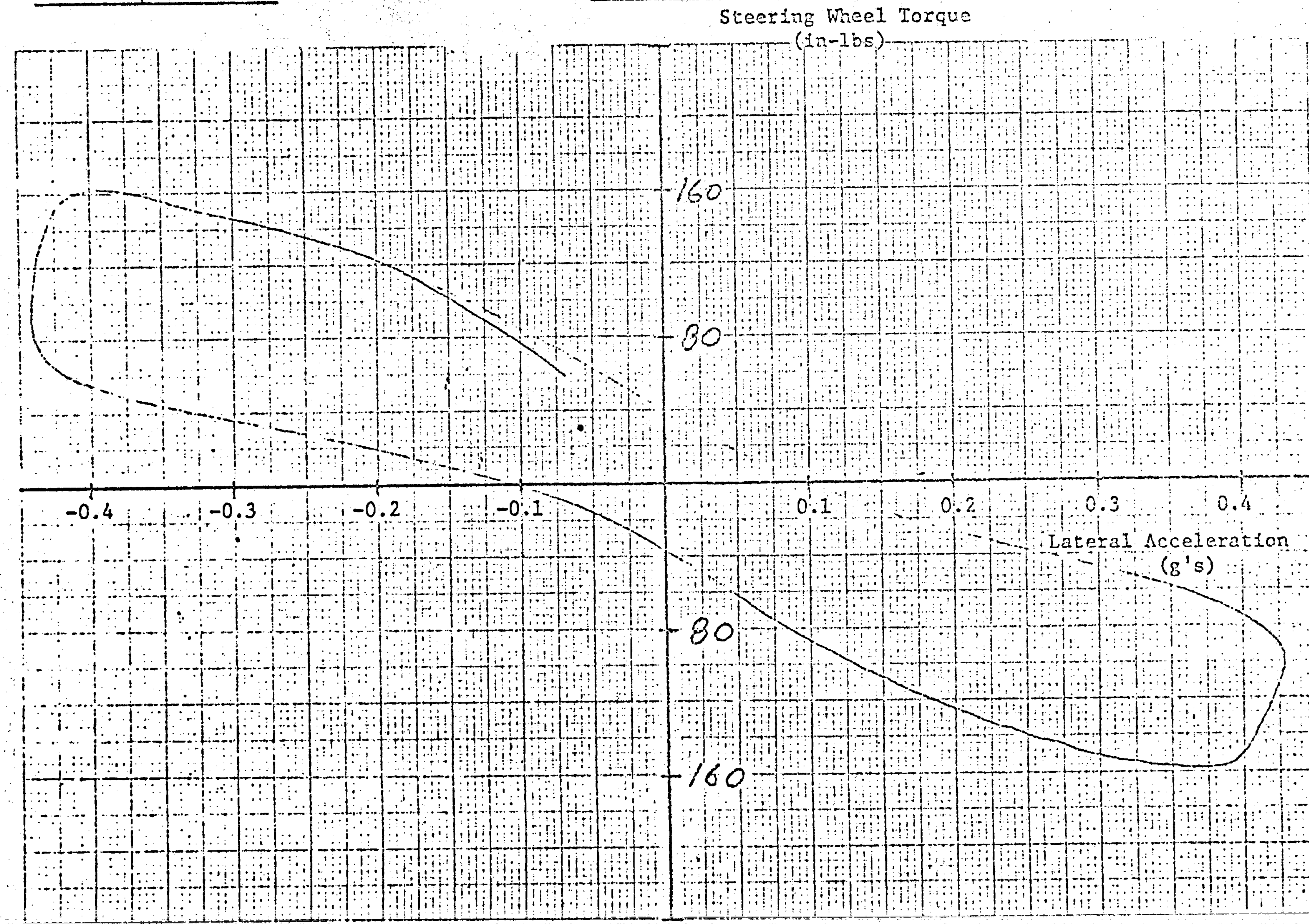


VEHICLE DESCRIPTION

Make: Chevrolet
Model: "B" Station Wagon
Car No.: 70028
Year: 1970

Test Weight: F 2316 R 2976
Tire Make: General
Tire Press: F 24 R 36
Tire Size: H78-15

Date: 10-27-69
Steering: Power off
Speed: 30 mph
Steering Wheel Dia: 14.5 in.



VEHICLE DESCRIPTION

Make: Chevrolet

Model: Chevelle

Car No.: 36050

Year: 1973

Test Weight: F 2131 R 1798

Tire Make: Uniroyal

Tire Press: F 24 R 24

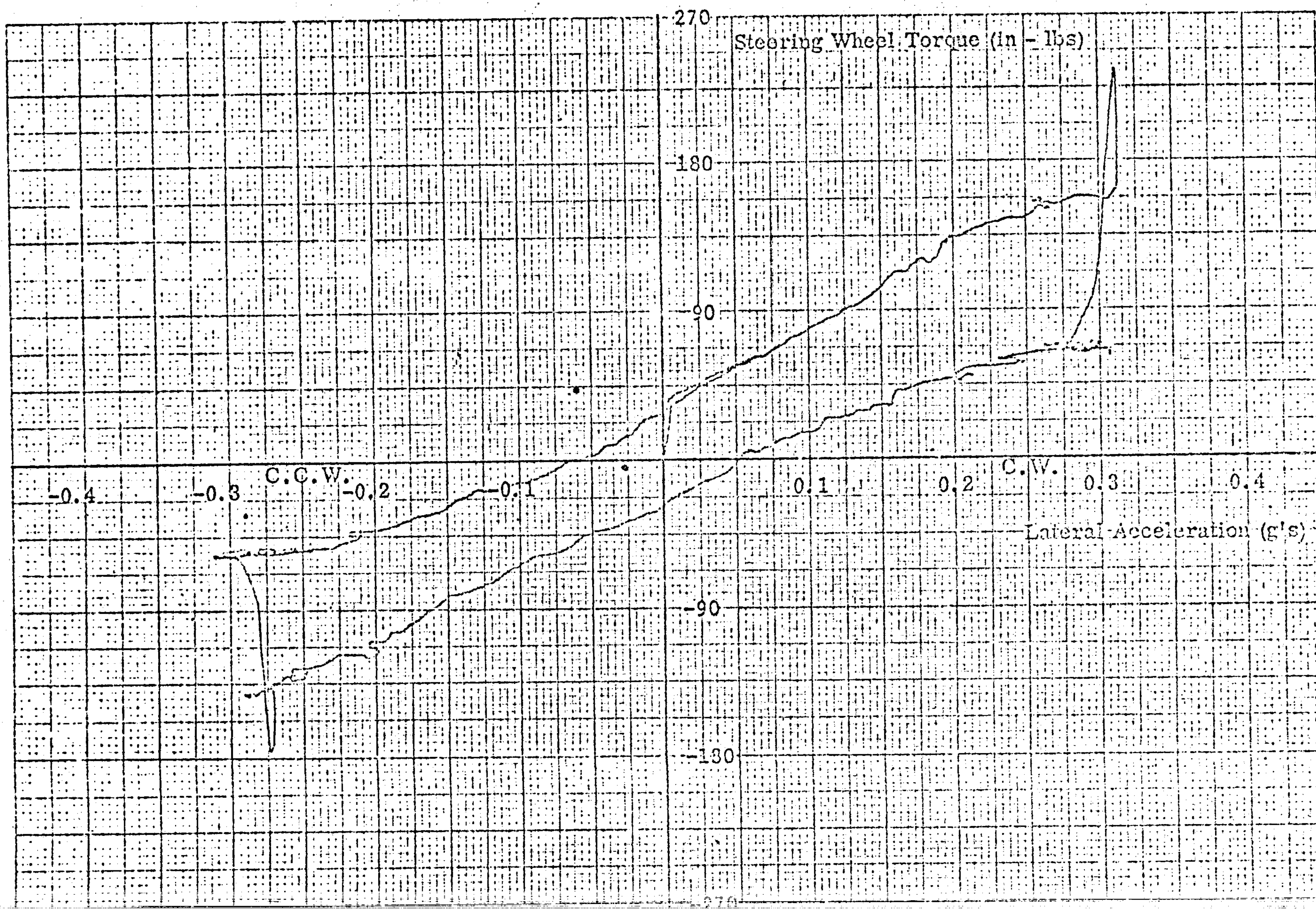
Tire Size: G 78-14

Date: 7-6-73

Steering: Manual

Speed: 10 mph

Steering Wheel Dia: 15 in.

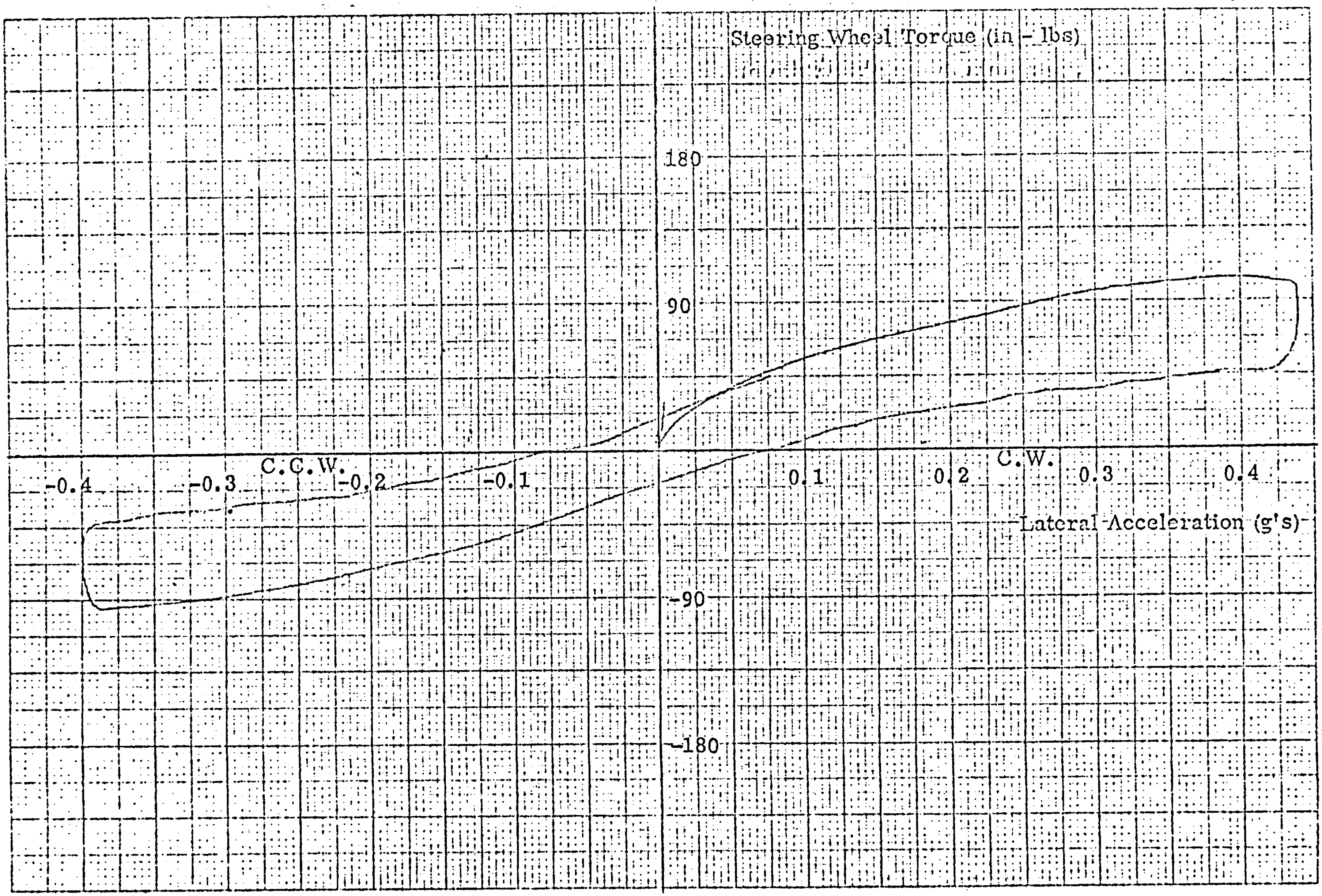


VEHICLE DESCRIPTION

Make: Chevrolet
Model: Chevelle
Car No.: 36050
Year: 1973

Test Weight: F 2131 R 1798
Tire Make: Uniroyal
Tire Press: F 24 R 24
Tire Size: G78-14

Date: 7-6-73
Steering: Manual
Speed: 30 mph
Steering Wheel Dia: 15 in.



VEHICLE DESCRIPTION

Make: Oldsmobile

Model: "A" Body

Car No.: 2208

Year: 1972

Test Weight: F 2370 R 1805

Tire Make: B F Goodrich

Tire Press: F 28 R 28

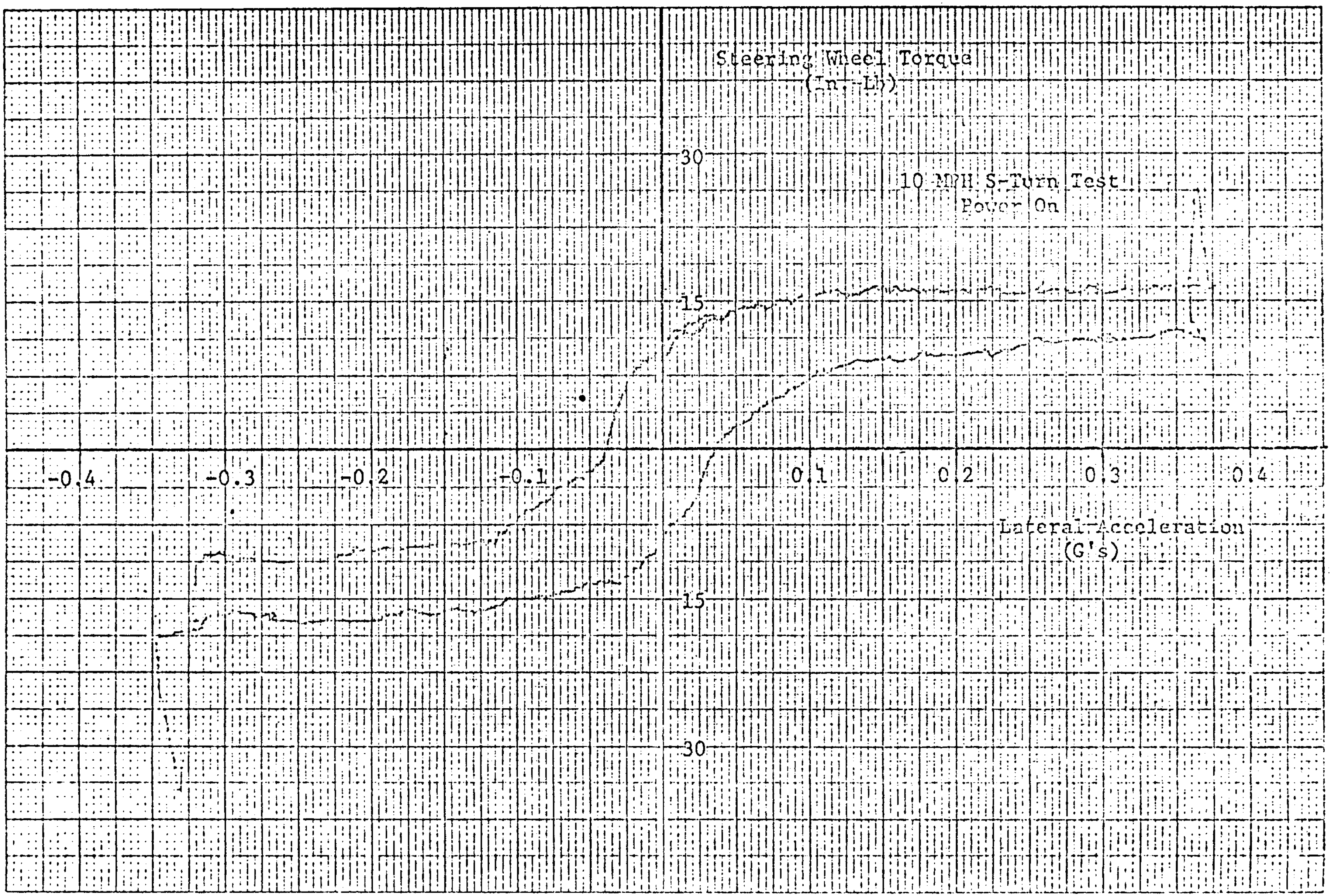
Tire Size: G 78-14

Date: January 1972

Steering: Power on

Speed: 10 mph

Steering Wheel Dia: 15 in.

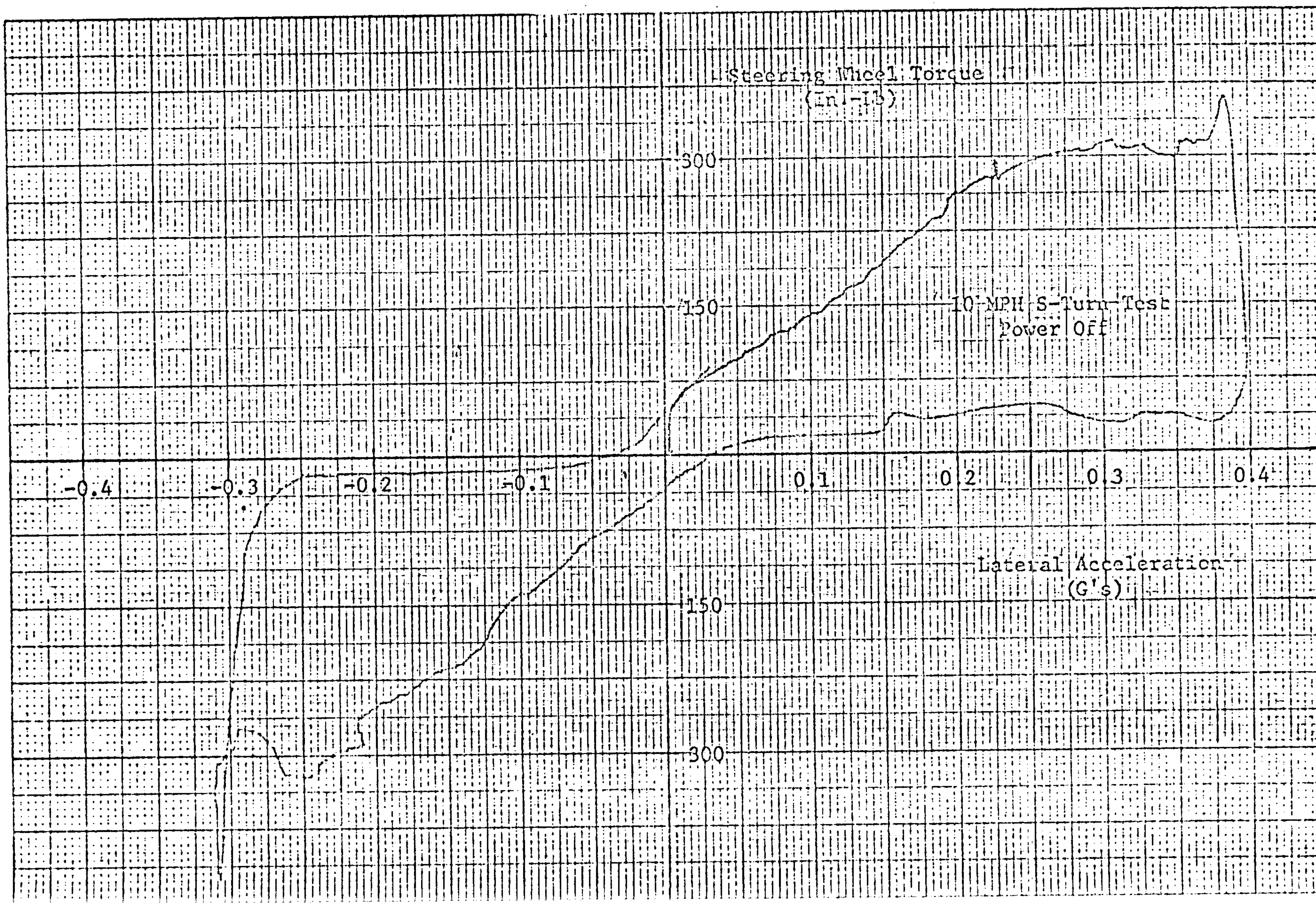


VEHICLE DESCRIPTION

Make: Oldsmobile
Model: "A" Body
Car No.: 2208
Year: 1972

Test Weight: F 2370 R 1805
Tire Make: B.F. Goodrich
Tire Press: F 28 R 28
Tire Size: G78-14

Date: January 1972
Steering: Power off
Speed: 10 mph
Steering Wheel Dia: 15 in.

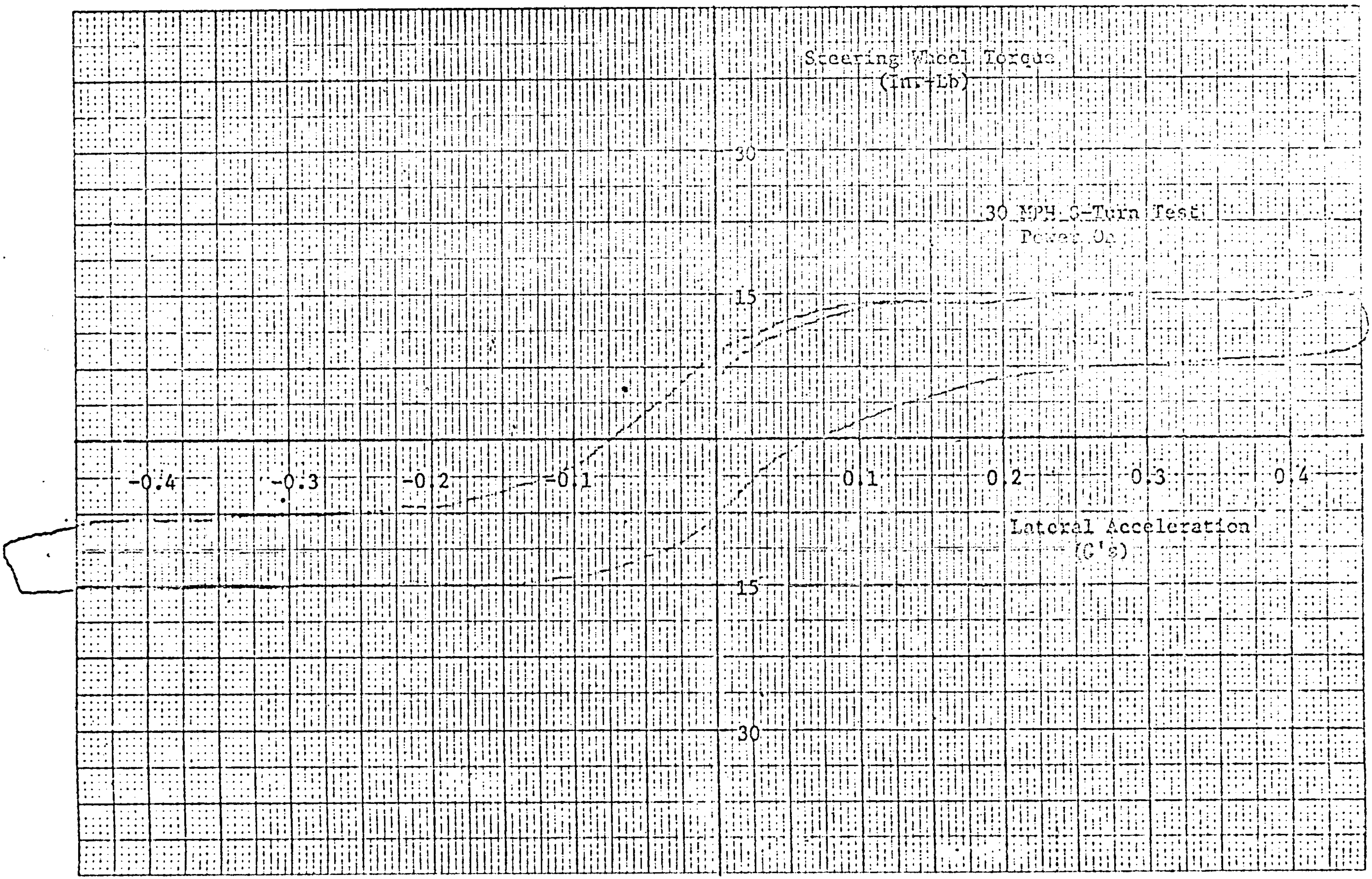


VEHICLE DESCRIPTION

Make: Oldsmobile
Model: "A" Body
Car No.: 2208
Year: 1972

Test Weight: F 2370 R 1805
Tire Make: B.F. Goodrich
Tire Press: F 28 R 28
Tire Size: G78-14

Date: January 1972
Steering: Power on
Speed: 30 mph
Steering Wheel Dia: 15 in.

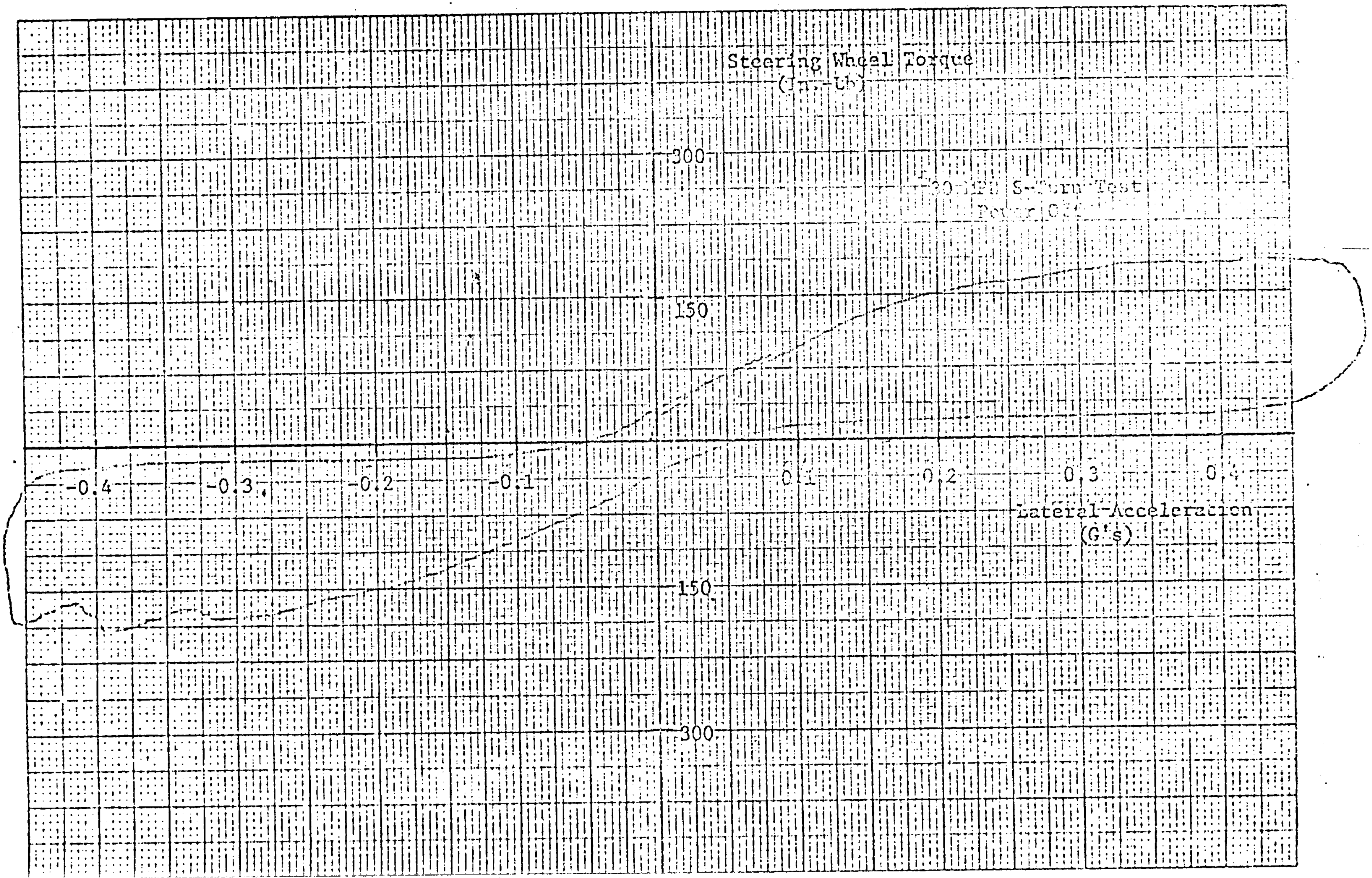


VEHICLE DESCRIPTION

Make: Oldsmobile
Model: "A" Body
Car No.: 2208
Year: 1972

Test Weight: F ~~28~~ 2370 R ~~28~~ 1805
Tire Make: B F Goodrich
Tire Press: F 28 R 28
Tire Size: G78-14

Date: January 1972
Steering: Power off
Speed: 30 mph
Steering Wheel Dia: 15 in.

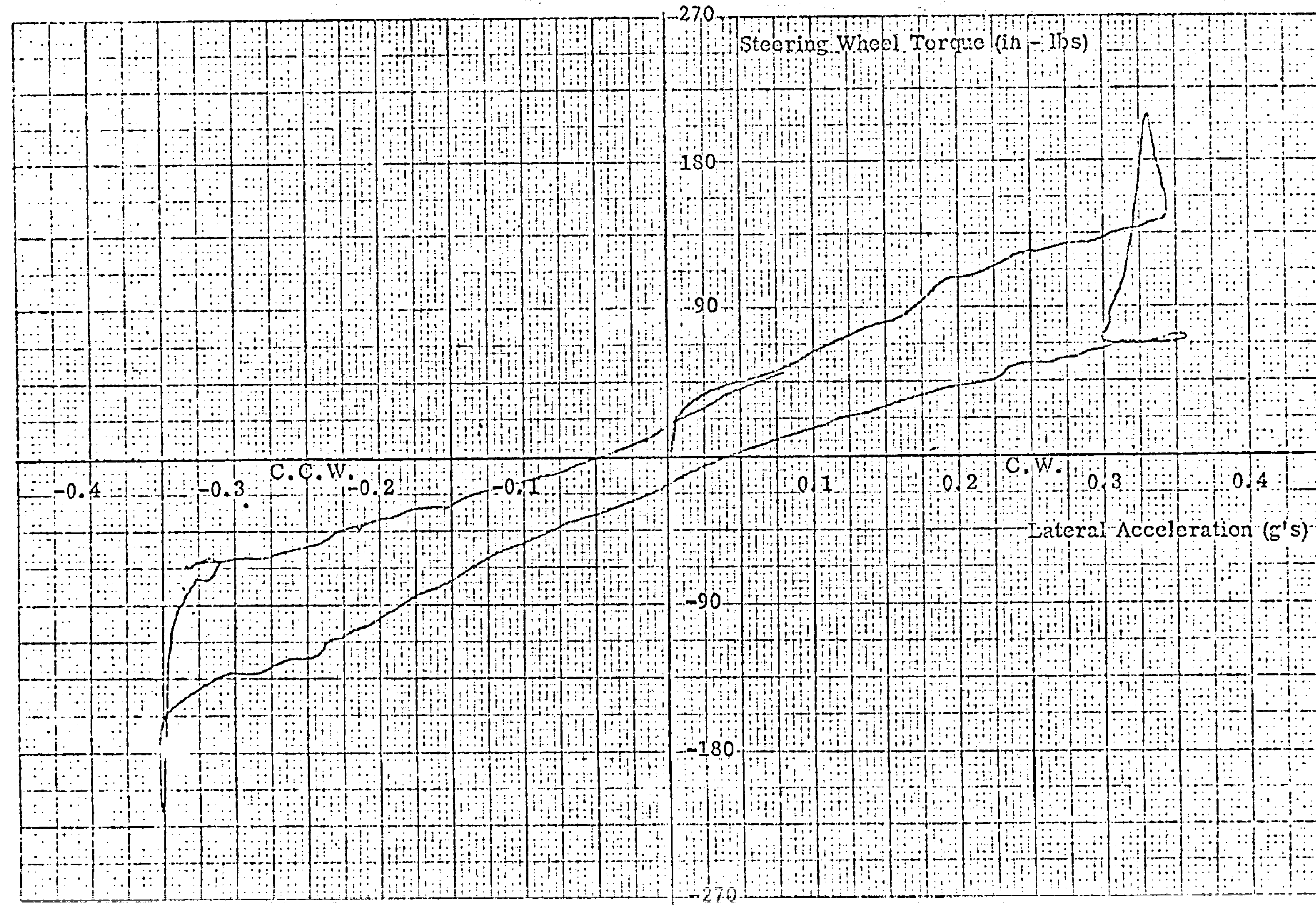


VEHICLE DESCRIPTION

Make: ~~Chevrolet~~ Buick
Model: ~~Nova~~ Apollo
Car No.: ~~7~~ 1338
Year: 1973

Test Weight: F 2146 R 1883
Tire Make: Firestone
Tire Press: F 24 R 24
Tire Size: E78-14

Date: 8-1-73
Steering: Manual
Speed: 10 mph
Steering Wheel Dia: 15 in.



VEHICLE DESCRIPTION

Make: Buick
Model: Apollo
Car No.: 1338
Year: 1973

Test Weight: F 24 R 24
Tire Make: Firestone
Tire Press: F 24 R 24
Tire Size: E78-14

Date: 8-1-73
Steering: Manual
Speed: 30mph
Steering Wheel Dia: 15in.

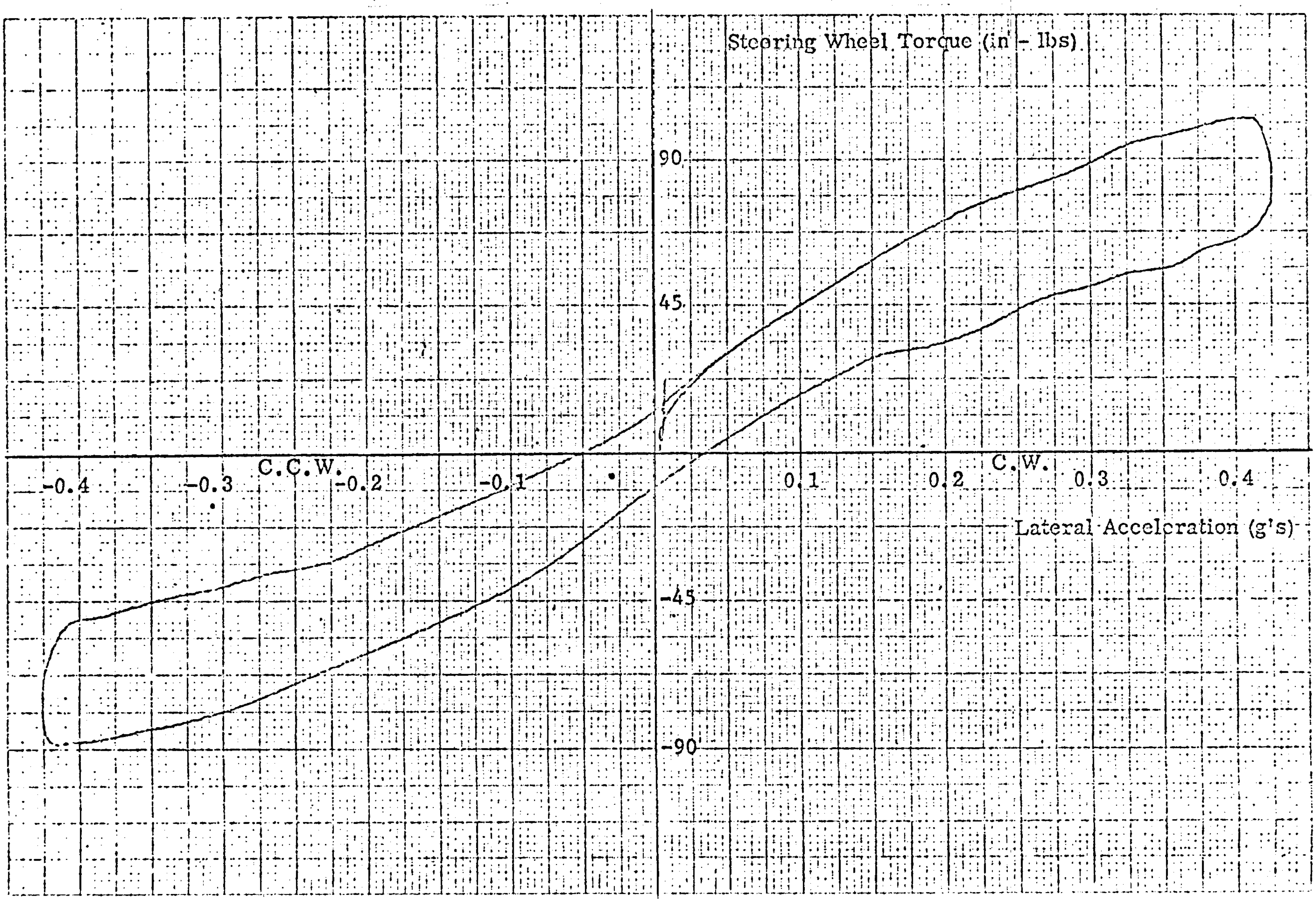


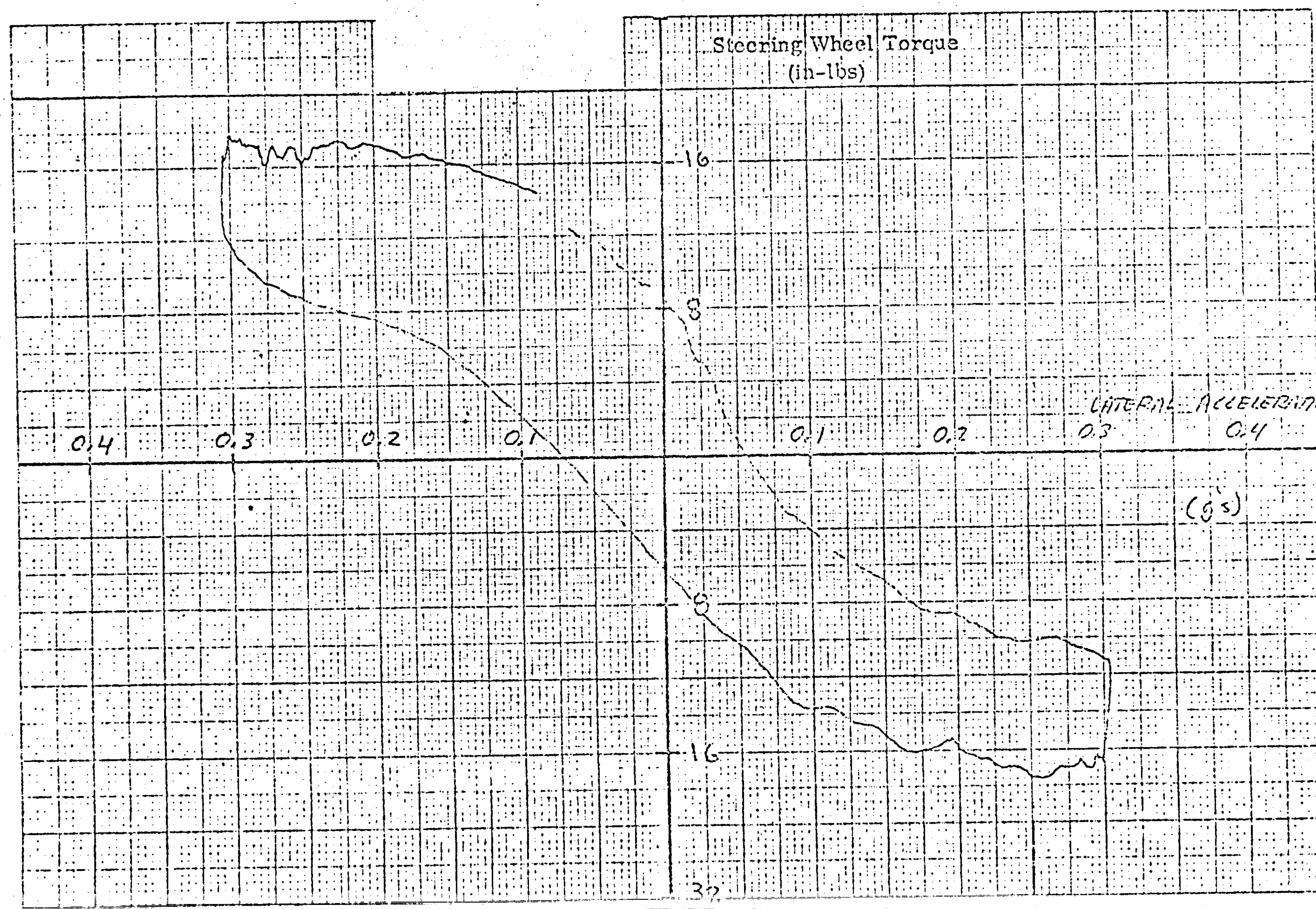
FIGURE 78

VEHICLE DESCRIPTION

Make: Chevrolet
Model: Nova
Car No.: 70002
Year: 1970

Test Weight: F 2230 R 1965
Tire Make: Goodyear
Tire Press: F 24 R 26
Tire Size: E70-14

Date: 10-8-69
Steering: Power on
Speed: 30 mph
Steering Wheel Dia: 15 in.

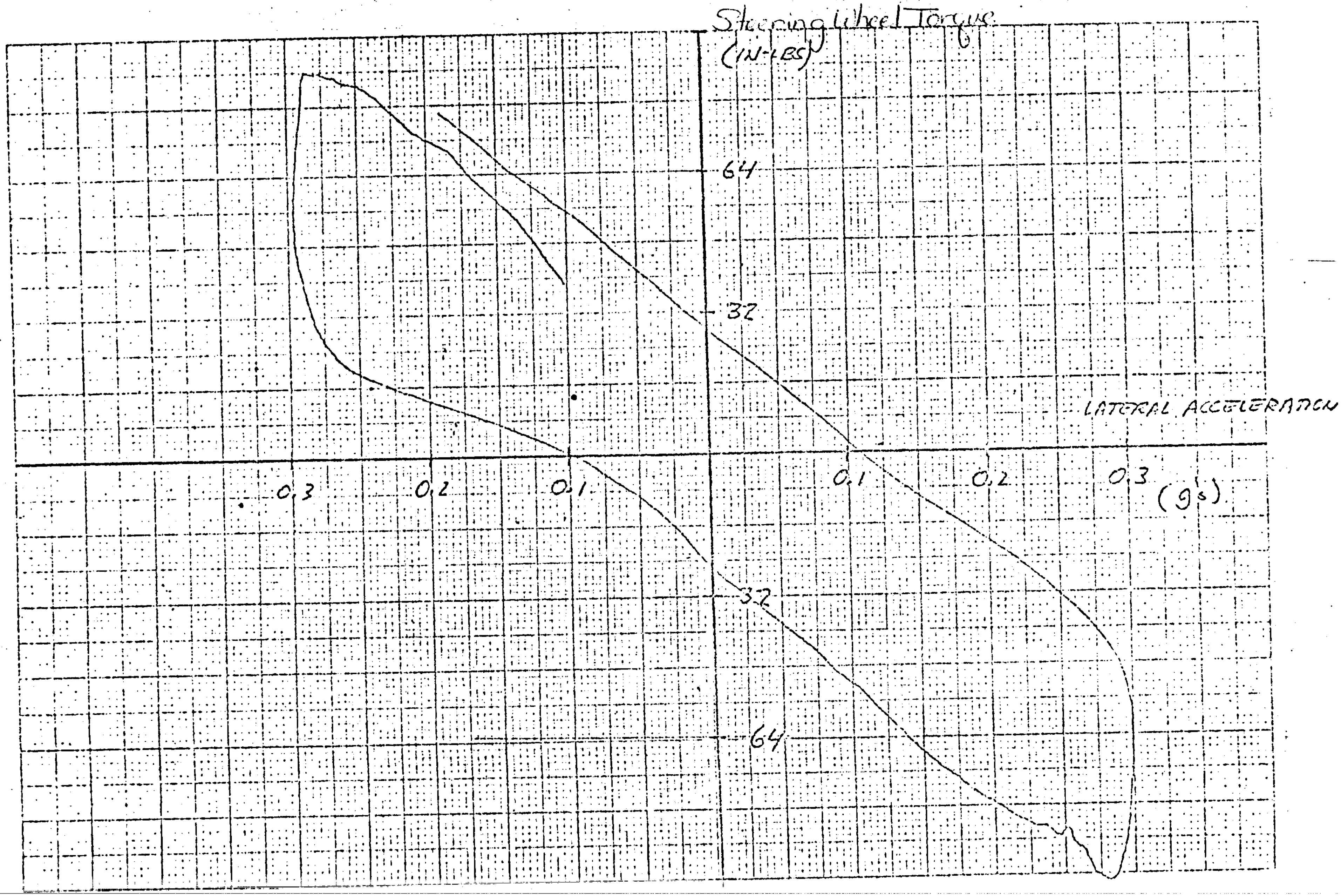


VEHICLE DESCRIPTION

Make: Chevrolet
Model: Nova
Car No.: 70002
Year: 1970

Test Weight: F 2330 R 1955
Tire Make: Goodyear
Tire Press: F 29 R 26
Tire Size: E 70-14

Date: 10-8-69
Steering: Power off
Speed: 30 mph
Steering Wheel Dia: 15 in.



VEHICLE DESCRIPTION

Make: Chevrolet
Model: Vega
Car No.: J73CC1
Year: 1973

Test Weight: F 1455 R 1303
Tire Make: Firestone
Tire Press: F 24 R 24
Tire Size: A 70-13

Date: 7-18-73
Steering: Manual
Speed: 10 mph
Steering Wheel Dia: 14 in.

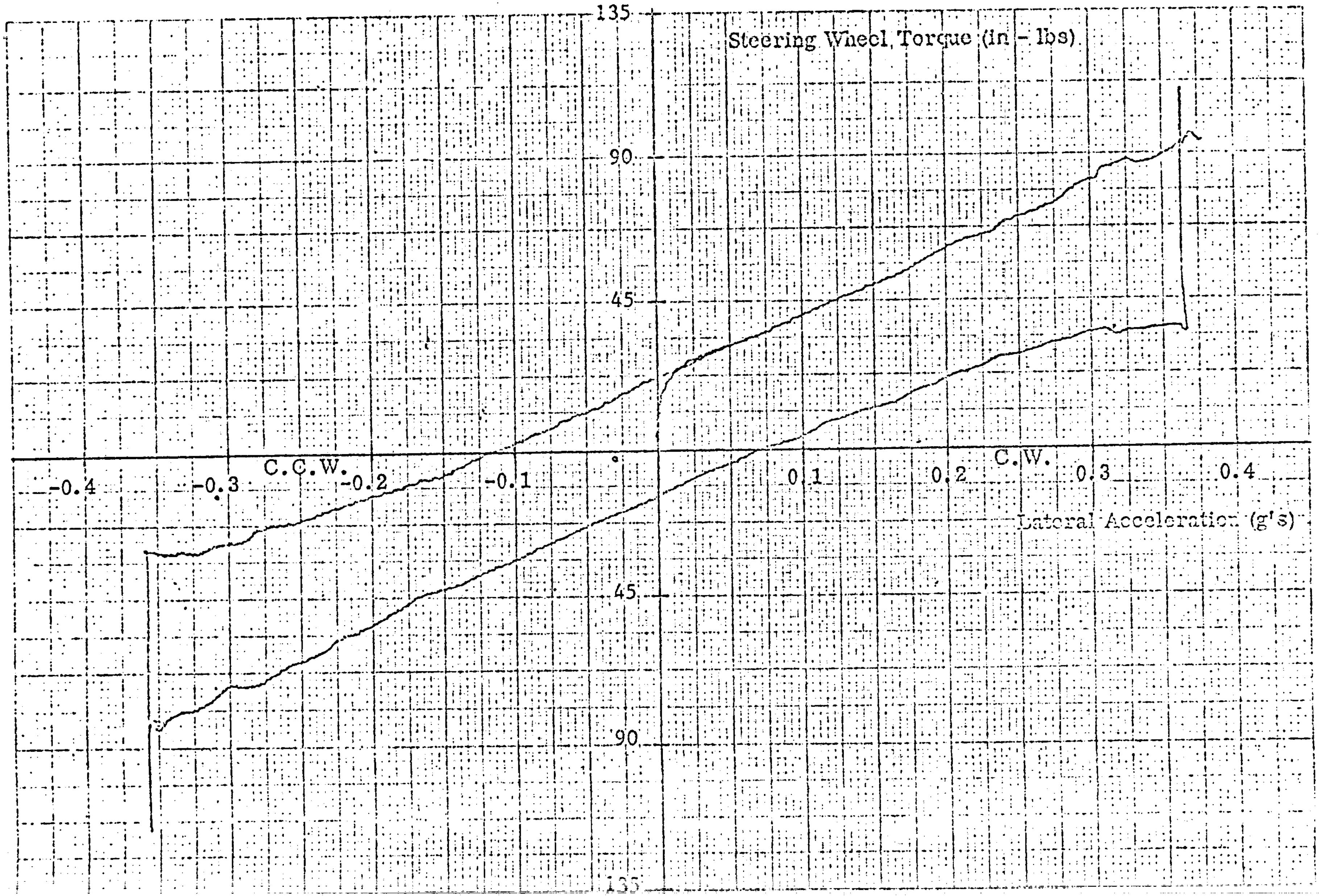


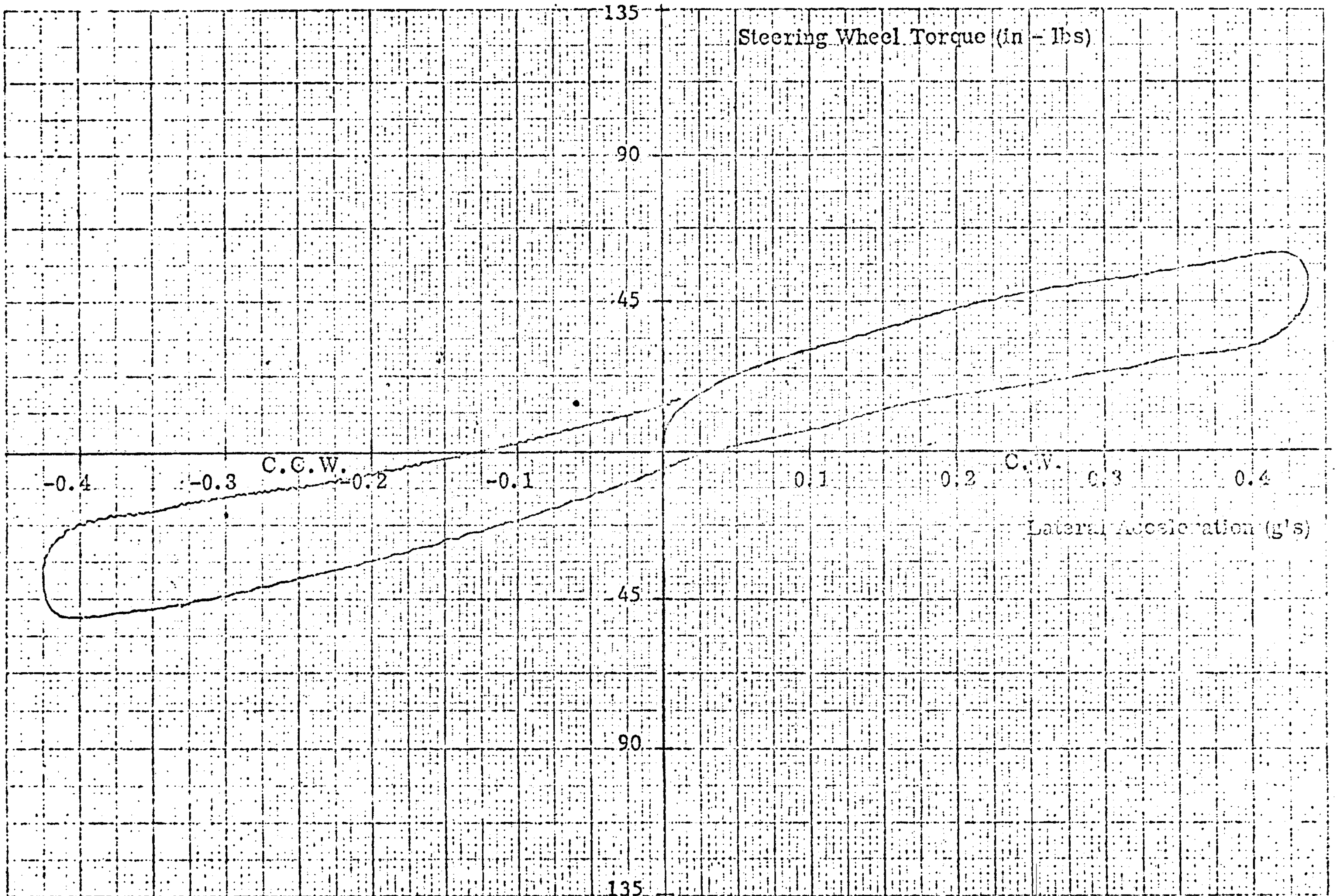
FIGURE 27

VEHICLE DESCRIPTION

Make: Chevrolet
Model: Vega
Car No.: 73001
Year: 1973

Test Weight: F 1455 R 1303
Tire Make: Firestone
Tire Press: F 24 R 24
Tire Size: A70-13

Date: 7-18-73
Steering: Manual
Speed: 30 mph
Steering Wheel Dia: 14 in.

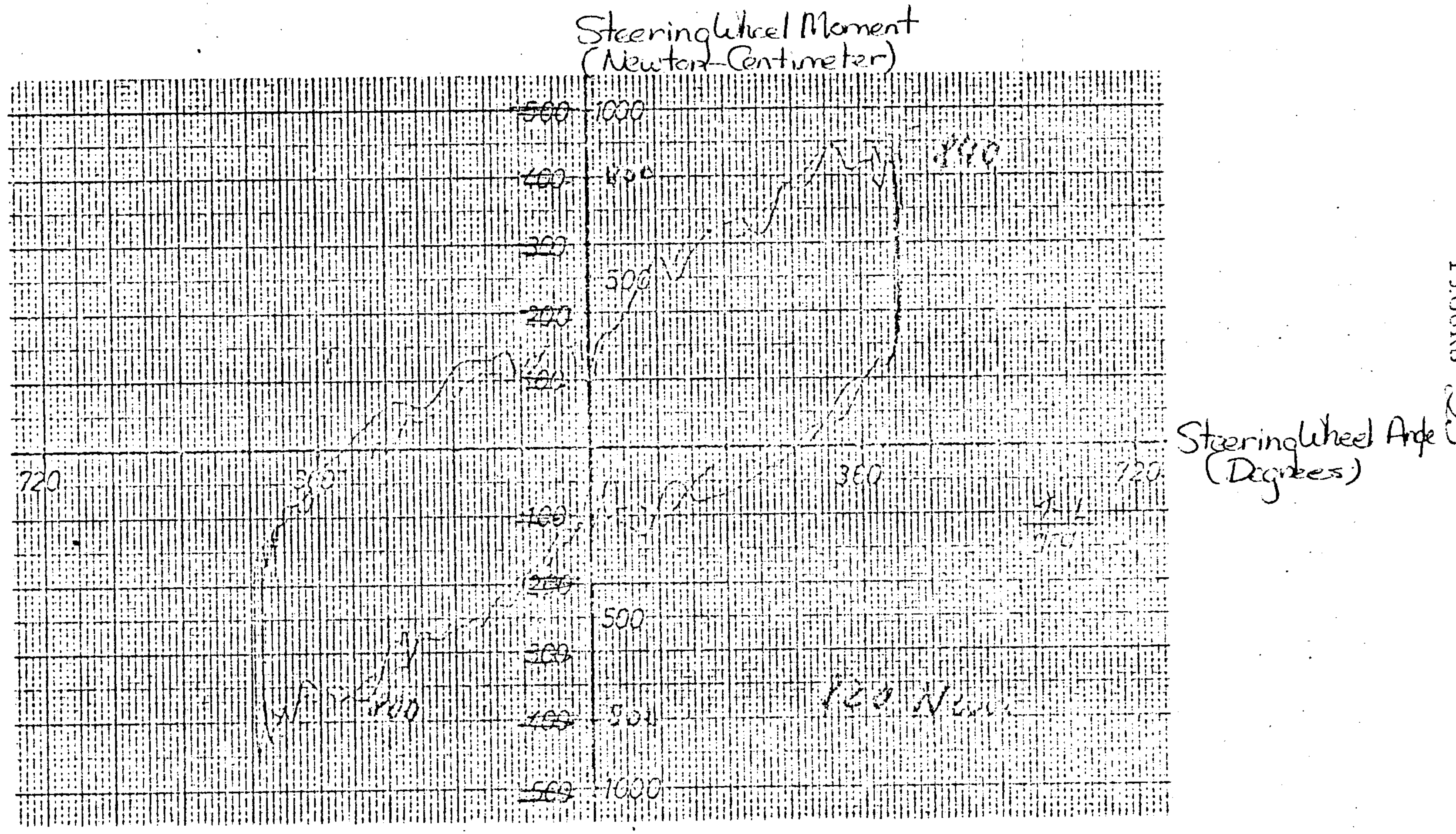


VEHICLE DESCRIPTION

Make: Opel
Model: Manta
Car No.: 1890-91
Year: 1974

Test Weight: F 1390 R 1630
Tire Make: Michelin
Tire Press: F 23 R 28
Tire Size: 165 SR 13 (80% profile)

Date: 2-2-74
Steering: Manual
Speed: 6.2 mph
Steering Wheel Dia: 15 in.



VEHICLE DESCRIPTION

Make: Opel
Model: Manta
Car No.: 1840-91
Year: 1974

Test Weight: F 1390 R 1630
Tire Make: Michelin
Tire Press: F 23 R 28
Tire Size: 165 SR 13 (80% profile)

Date: 2-2-74
Steering: Manual
Speed: 12.4 mph
Steering Wheel Dia: 15 in

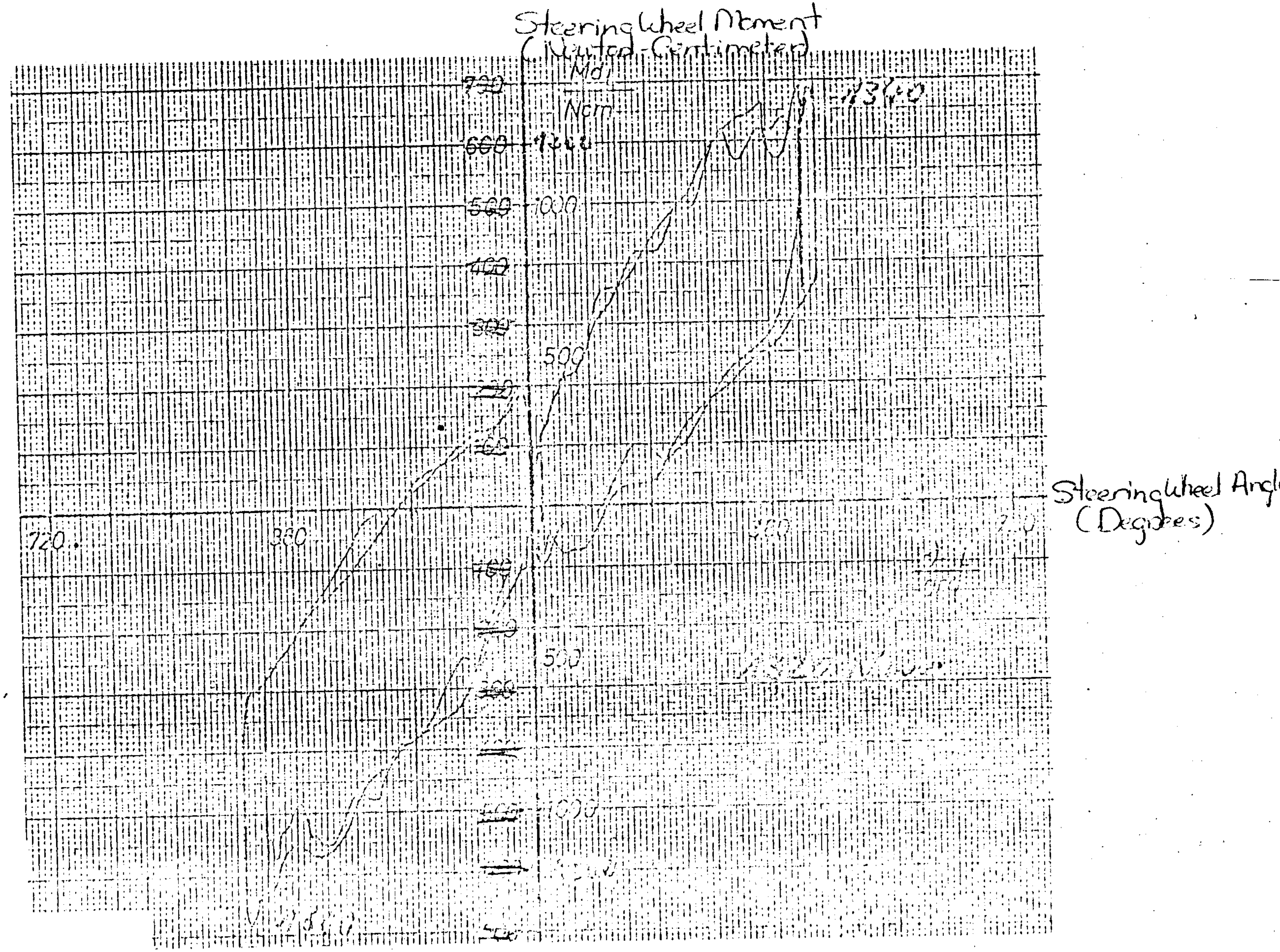


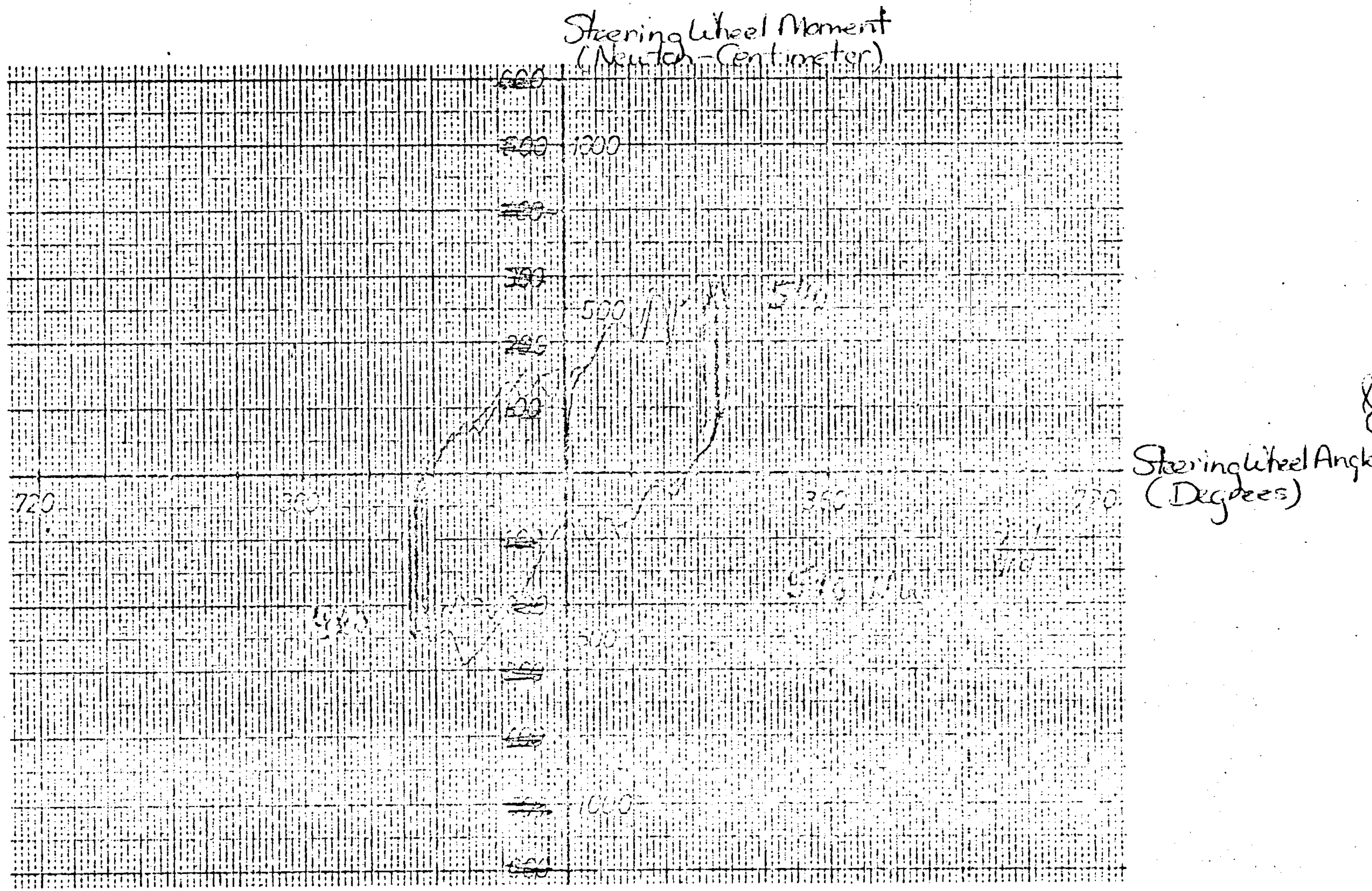
FIGURE 24

VEHICLE DESCRIPTION

Make: Opel
Model: Manta
Car No.: 1840-91
Year: 1974

Test Weight: F 1390 R 1630
Tire Make: Michelin
Tire Press: F 23 R 28
Tire Size: 165 SR 13 (80% profile)

Date: 2-2-74
Steering: Manual
Speed: 6.2 mph
Steering Wheel Dia: 15 in.

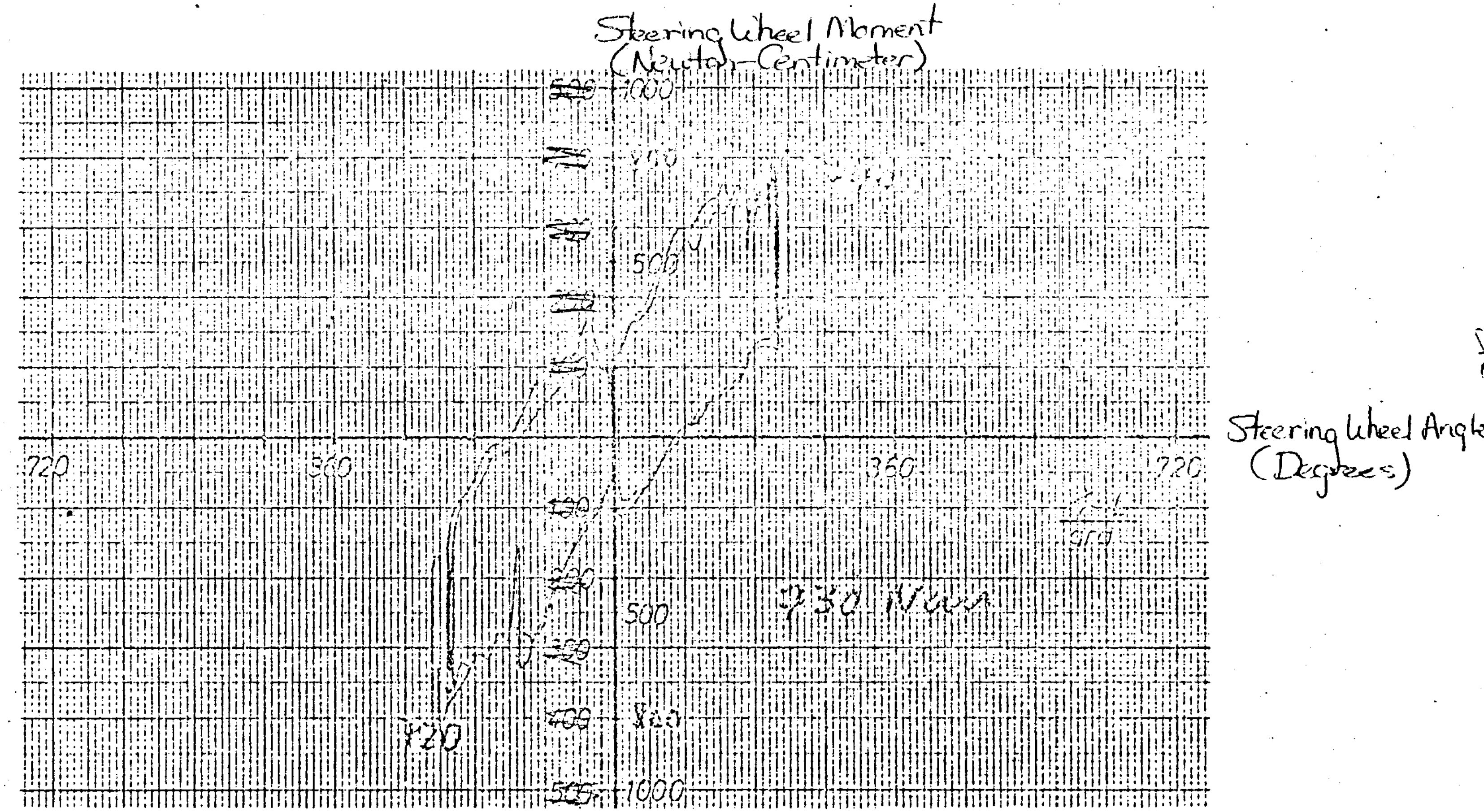


VEHICLE DESCRIPTION

Make: Opel
Model: Manta
Car No.: 1840-91
Year: 1974

Test Weight: F 1390 R 1630
Tire Make: Michelin
Tire Press: F 23 R 25
Tire Size: 165 SR 13 (80% profile)

Date: 2-2-74
Steering: Manual
Speed: 12.4 mph
Steering Wheel Dia: 15 in



VEHICLE DESCRIPTION

Make: Opel
Model: Manta
Car No.: 1840-91
Year: 1974

Test Weight: F 1390 R 1630
Tire Make: Michelin
Tire Press: F 23 R 28
Tire Size: 165 SR 13 (80% profile)

Date: 2-2-74
Steering: Manual
Speed: 18.6 mph
Steering Wheel Dia: 15 in

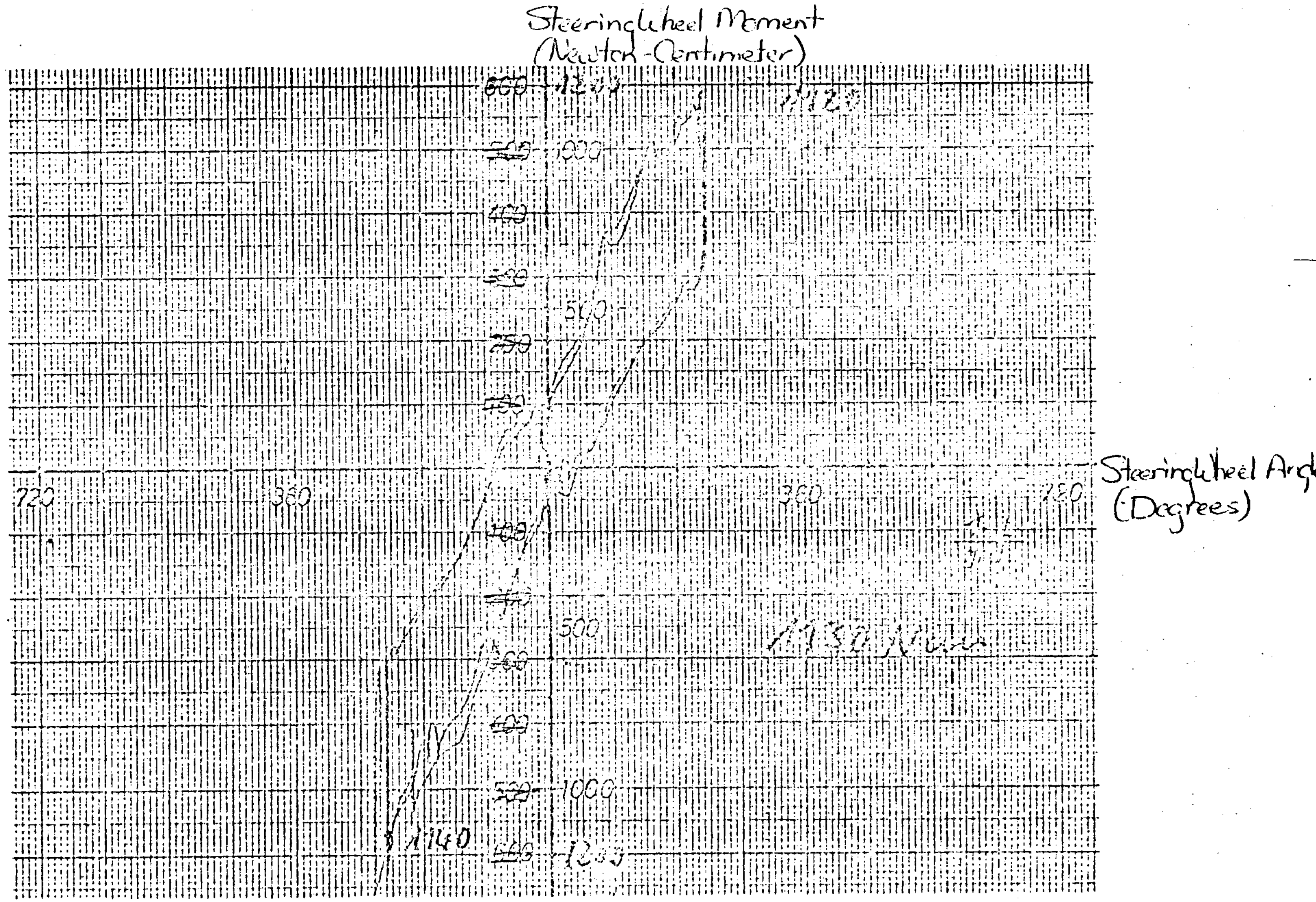


FIGURE 2

VEHICLE DESCRIPTION

Make: Oldsmobile

Model: "A" Body

Car No.: 3102

Year: 1973 Proto.

Test Weight: F ~~2330~~ 2637 R 2003

Tire Make: Uniroyal

Tire Press: F 25 R 26

Tire Size: G78-14

Date: 8-21-71

Steering: Manual

Speed: 10 mph

Steering Wheel Dia: 15 in.

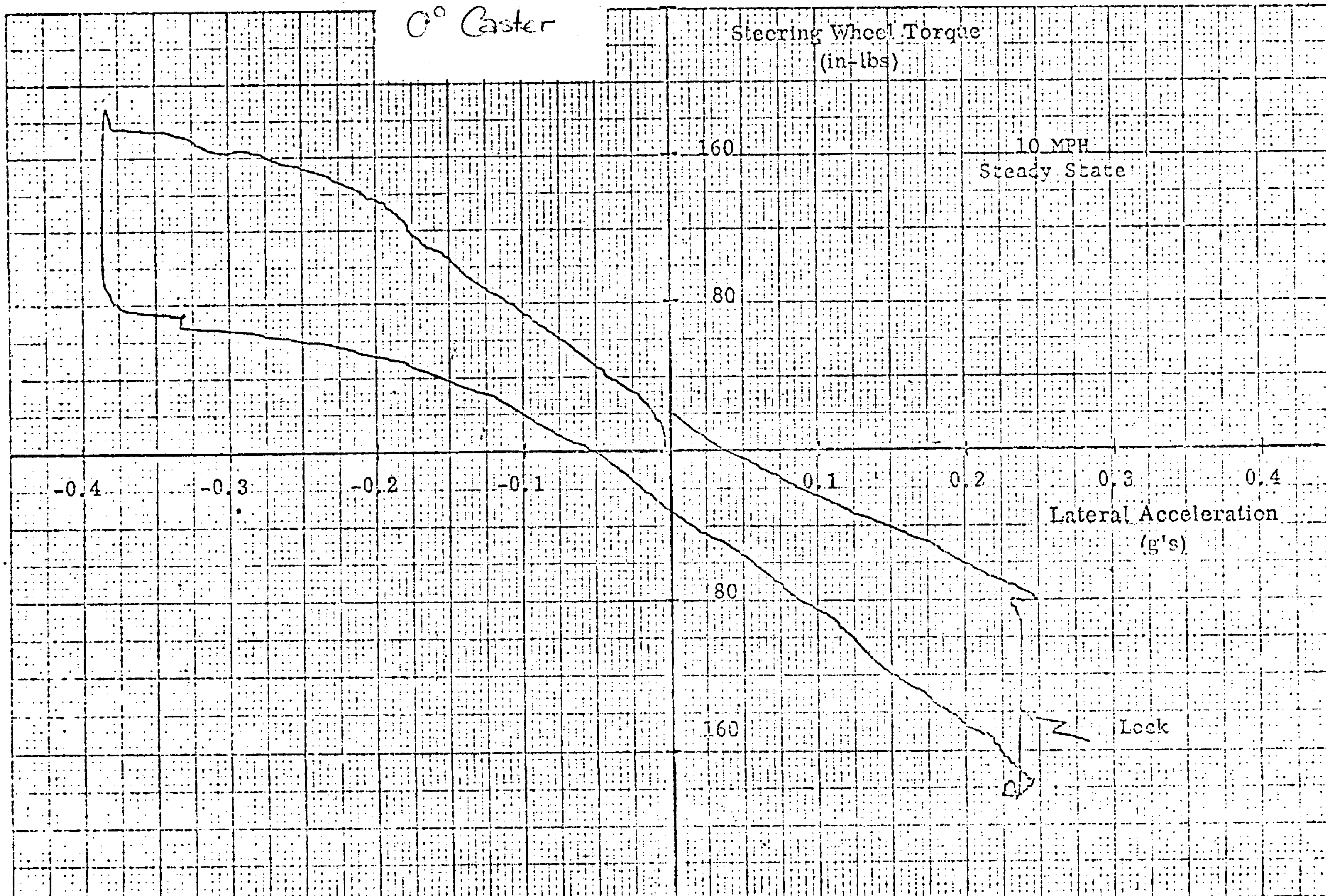


FIGURE 28

VEHICLE DESCRIPTION

Make: Oldsmobile
Model: "A" Body
Car No.: 310-2
Year: 1973 Proto

Test Weight: F 2637 R 2003
Tire Make: Uniroyal
Tire Press: F 25 R 26
Tire Size: G78-14

Date: 8-21-71
Steering: Manual
Speed: 20 mph
Steering Wheel Dia: 15 in.

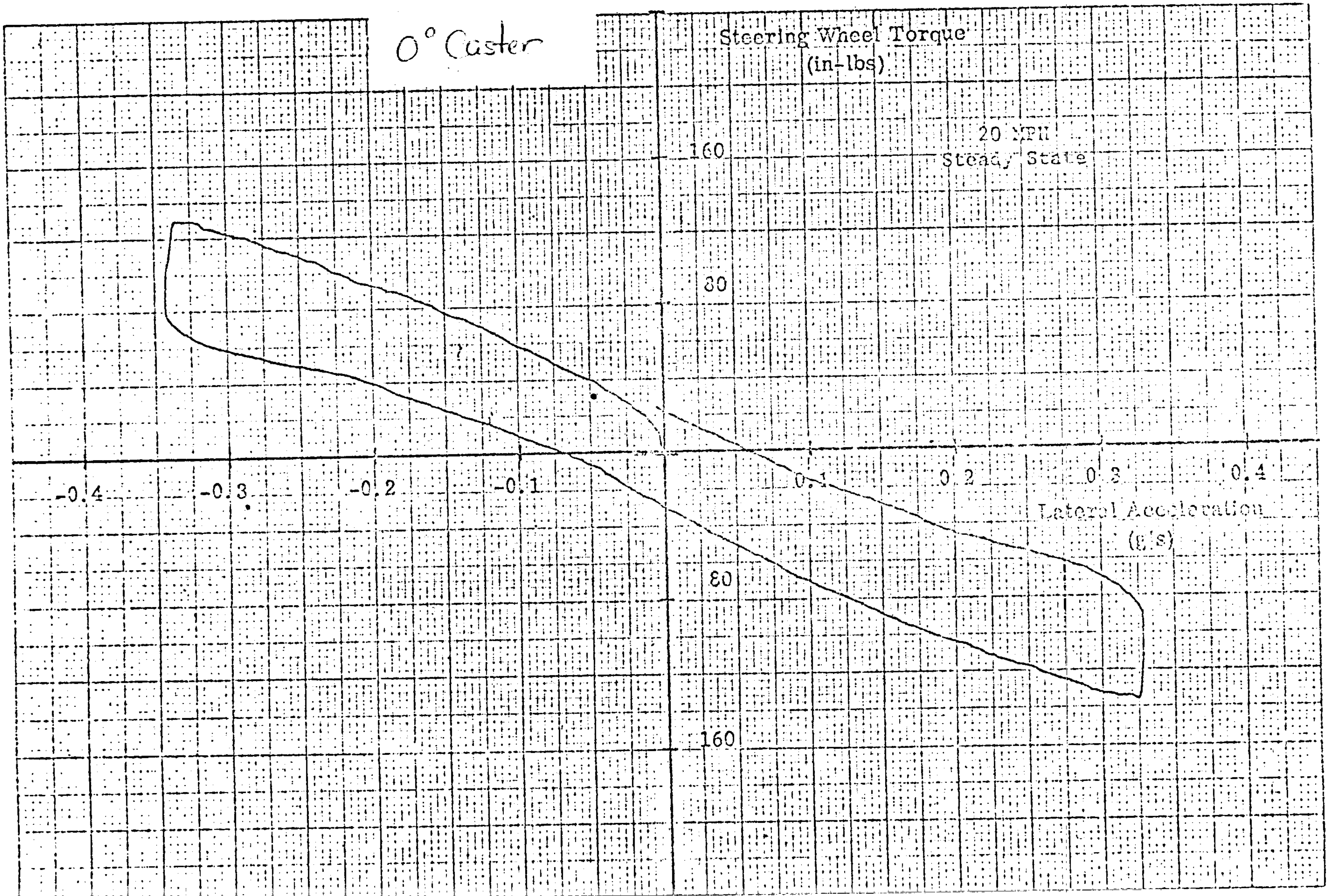


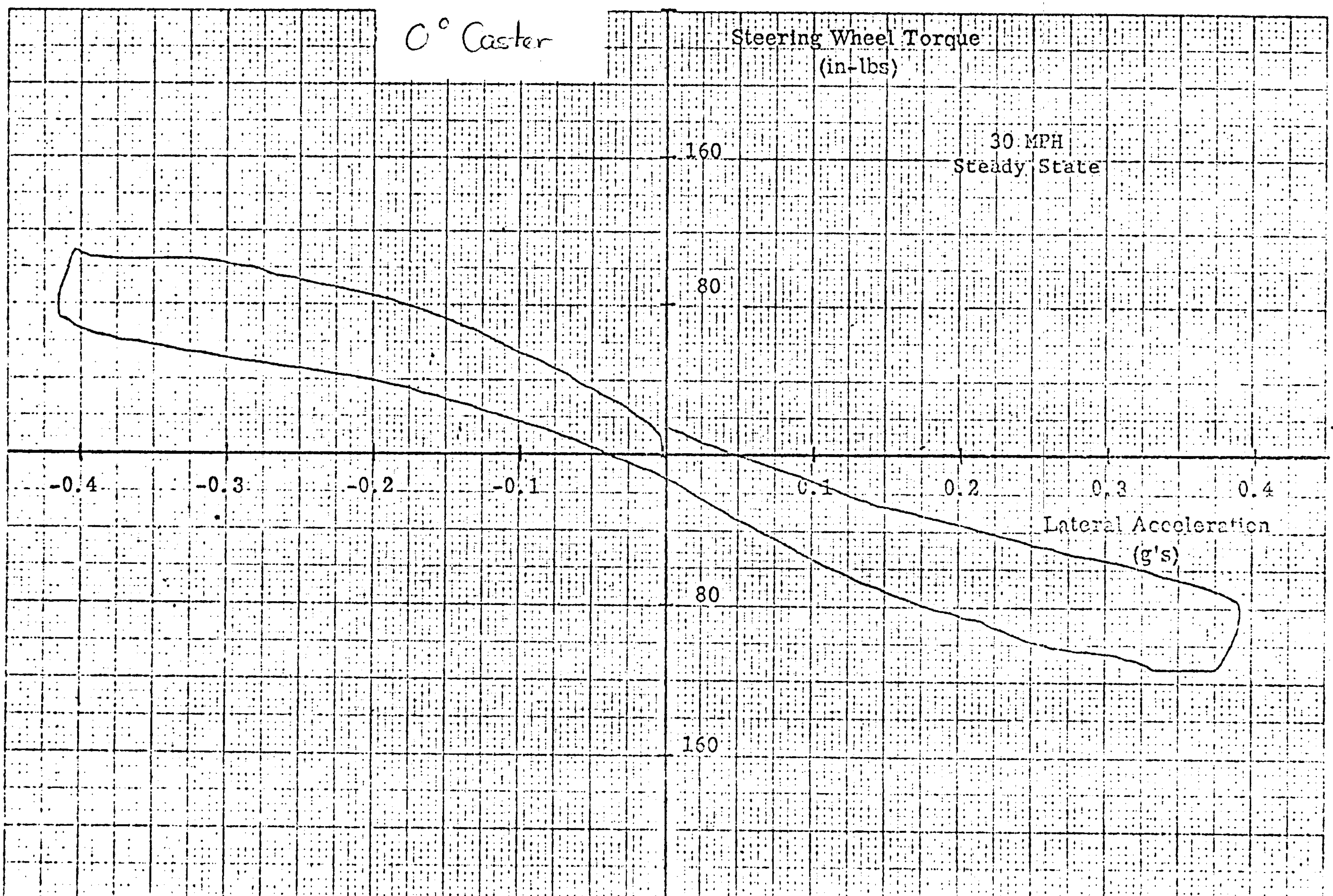
FIGURE 29

VEHICLE DESCRIPTION

Make: Oldsmobile
Model: "A" Body
Car No.: 3102
Year: 1973 Proto.

Test Weight: F 2637 R 2003
Tire Make: Uniroyal
Tire Press: F 25 R 26
Tire Size: G78-14

Date: 8-21-71
Steering: Manual
Speed: 30 mph
Steering Wheel Dia: 15 in.

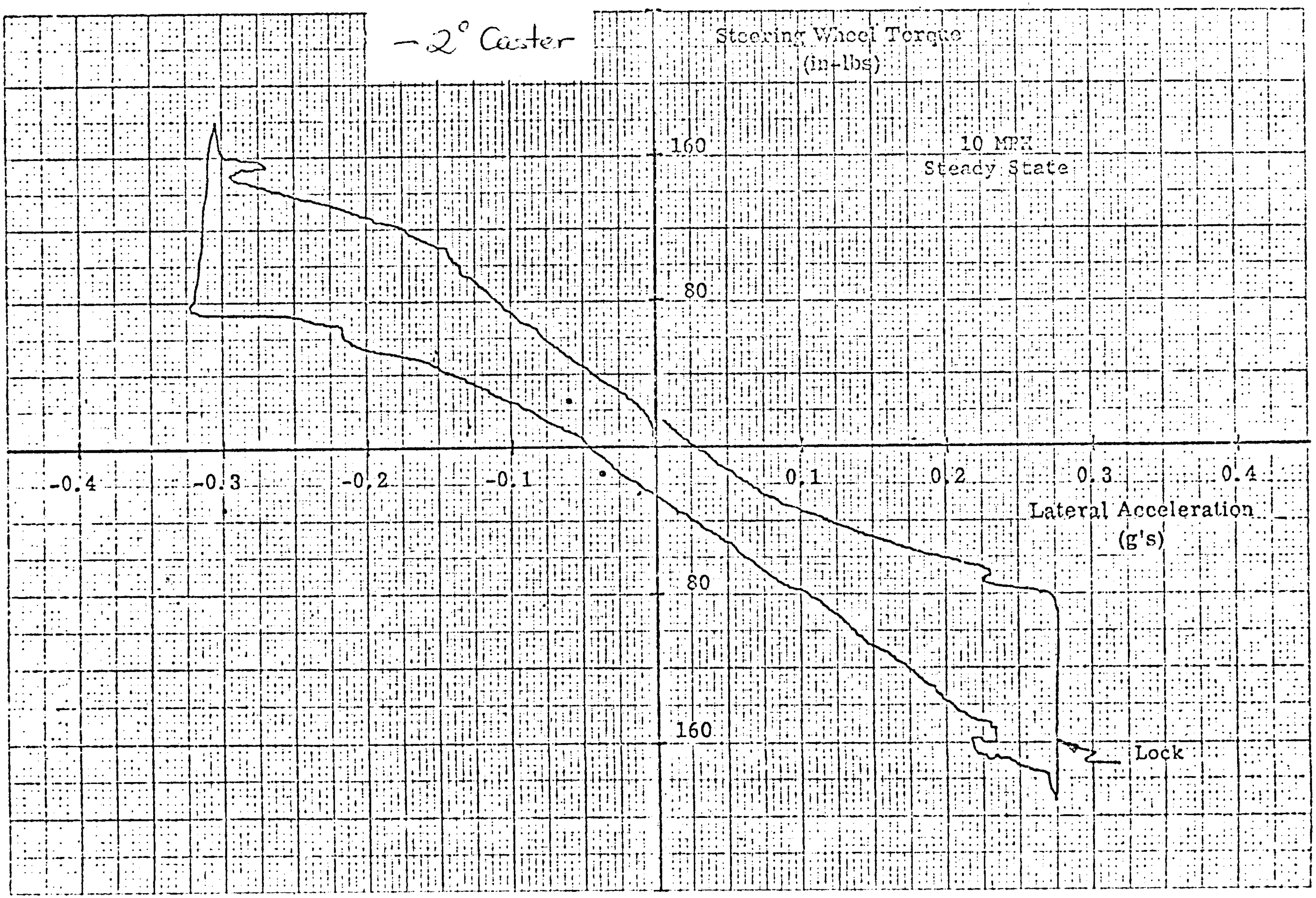


VEHICLE DESCRIPTION

Make: Oldsmobile
Model: 'A' Body
Car No.: 3102
Year: 1973 Proto

Test Weight: F 2637 R 2003
Tire Make: Uniroyal
Tire Press: F 25 R 26
Tire Size: G78-14

Date: 8-21-71
Steering: Manual
Speed: 10 mph
Steering Wheel Dia: 15 in

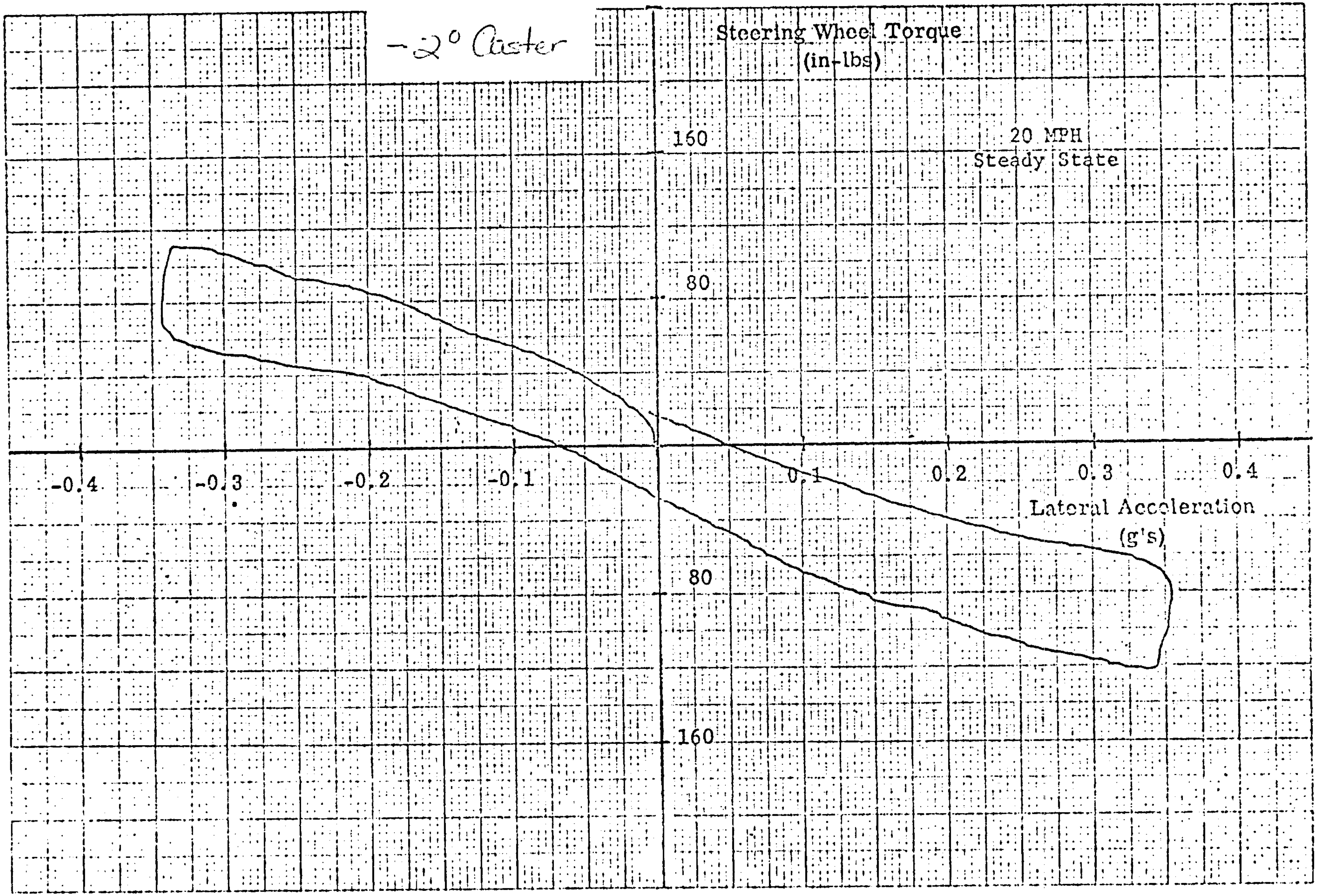


VEHICLE DESCRIPTION

Make: Oldsmobile
Model: "A" Body
Car No.: 3102
Year: 1973 Proto

Test Weight: F 2637 R 2003
Tire Make: Uniroyal
Tire Press: F 25 R 26
Tire Size: G78-14

Date: 8-21-71
Steering: Manual
Speed: 20 mph
Steering Wheel Dia: 15 in



FIGURE

VEHICLE DESCRIPTION

Make: Oldsmobile
Model: "A" Body
Car No.: 3103
Year: 1973 Proto

Test Weight: F 2637 R 2003
Tire Make: Uniroyal
Tire Press: F 25 R 26
Tire Size: G 78-14

Date: 8-21-71
Steering: Manual
Speed: 30 mph
Steering Wheel Dia: 15 in.

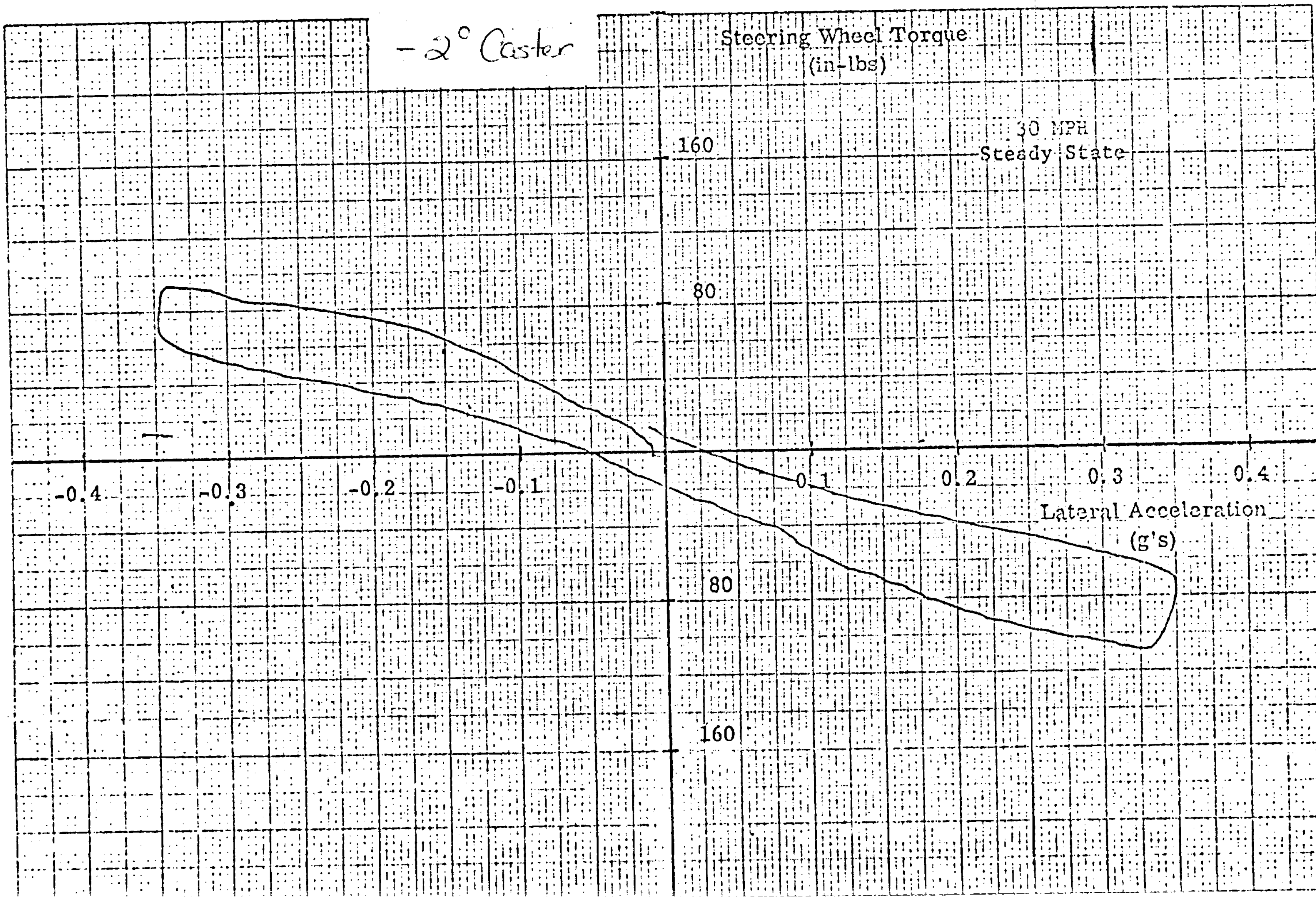
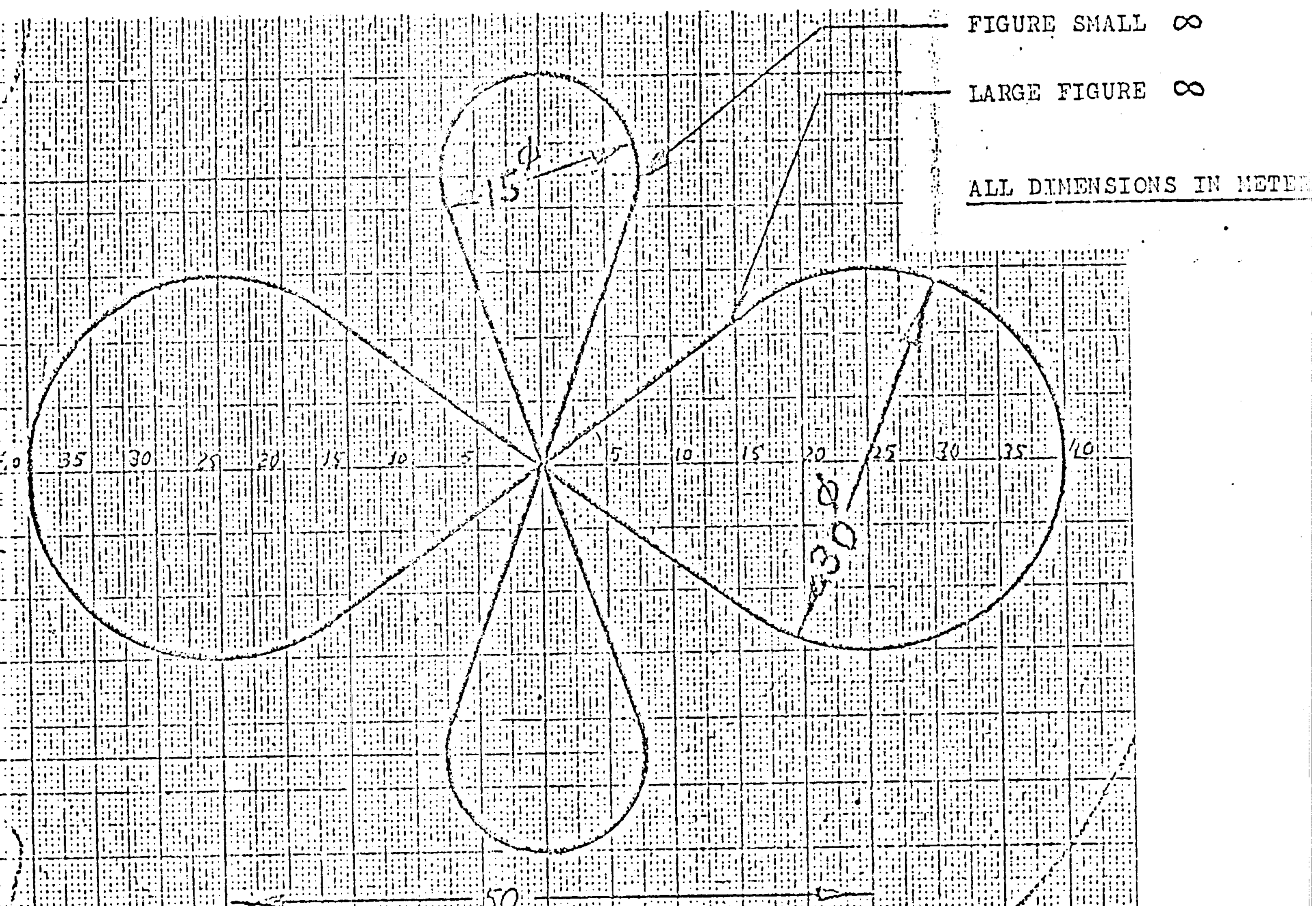


FIGURE 55

Figure ~~33~~ 34

Opel Steering Effort Course



PE10-005

GM

4/14/2010

ATTACHMENT Q

15 C

1974_04_30_rer_memo

F-866

General Motors **GM** Proving Grounds

from the desk of...

R. E. Rasmussen

To: R. T. Bundorf

K. McKenna informs me that the copy of the Mueller memo on steering effort data that I sent you was an old one. The mistake in the classification code had been recognized and corrected. This is a current copy and should replace the initial page on the one you have.

April 30 1974

File F-866

The attached data sheets contain summaries from a review of GM 1241 forms and MIC accident data involving alledged power steering system failures on GM vehicles. Individual cases were reviewed to determine if a loss in power steering assist was a causal factor in the accident. Based on available information, each ease was classified as follows:

I. Power steering failure probable
II. Indeterminate power steering involvement
III. Power steering not involved

Cases where a power steering failure was associated with the accident were placed in Category I. Information regarding the operating condition of the power steering system at the time of the accident was generally provided by a GM zone office representative investigating the case. Cases were classified in Category I when, in the opinion of the investigator, a malfunction of the steering system was a causal factor in the accident. No cases were classified in this category solely on driver allegation. Category II cases are those where driver allegation of a loss in power assist were not confirmed by investigation or other supporting evidence. Cases were placed in Category III when the causal factors of the accident were determined and were not related to the power steering system.

GM Proving Ground

ENGINEERING SUMMARY

REPORT NO. PG- 28985
PROJECT NO. 15-502-000
DATE June 24, 1970

SURVEY OF INFORMATION ON POWER STEERING SYSTEM FAILURES

Objective

To place the problem of power-off steering effort performance in a practical perspective by examining customer service and accident information on steering system failures.

Procedure

Attention was directed to the SRDL-MIC accident report files, PH&H Quality Research Report, Customer Service 1241 Forms, and Legal Staff Litigation files.

Results

None of the above mentioned sources contain a statistically definitive quantity of data, however, the information that is available is summarized below.

1. SRDL-MIC Files - Data on 1968 and 1969 model year accident reports have been combined to yield a total distribution.

Total Cases	4685	(100%)
Alleged Mechanical Failures (of all types)	127	(2.7%)
Alleged Steering Failures	28	(0.6%)
Power Steering Not Involved or Probably Not Involved	15	
Indeterminate Power Steering Involvement	12	
Power Steering Failure Probable	1	

There were 37 alleged brake and 18 alleged tire failures reported which accounted for 43% of all mechanical failures. The 28 alleged steering failures represented 22% of all mechanical failures.

2. PH&H Report - Data collected from 2800 1968 and 1969 Chevrolets indicated a steering system repair and replacement rate of 0.12%/1000 miles for the first 30,000 miles. Components related to power assist (pump, belt, reservoir, etc.) accounted for about 60% of all steering system repairs and replacements.

DISTRIBUTION: PG FILE (3)
VDL File (10)
Surplus (20)

AUTHOR: Fredrick W. Hill
Fredrick W. Hill

APPROVED: R. Thomas Bundorf
R. Thomas Bundorf
Engineer-in-Charge
Vehicle Dynamics Laboratory

PRODUCT ASSURANCE TESTING, GENERAL MOTORS PROVING GROUND, MILFORD MICHIGAN 48042

RESTRICTED

3. 1241 Forms - A survey of about 600 reports indicated that approximately 10% involved steering system malfunctions. Of these, 62% were related to linkage, 15% were related to power assist, and 23% were of indeterminate nature.

4. Litigation Files - Legal Staff provided information on 22 cases that related to steering systems. The nature of the alleged malfunction was obscure in many cases. The identifiable allegations were rather evenly distributed among valve blockage, broken pulleys, loss of fluid, jamming, engine stall, and belt failure. Over half the cars were driven by males and all but 2 cases were related to medium or small size vehicles having less than median power-off effort levels.

Conclusions

1. There are many kinds of steering system failures. System improvement should involve all areas.

2. Steering system failures appear to constitute a significant percentage of vehicle mechanical failures. An excessive failure rate on a failure per mile basis has not been determined.

3. Litigation can result from many types of alleged malfunctions, and is not restricted to "high power-off effort" vehicles. Reduction of power-off effort on relatively high effort vehicles to lower levels will not necessarily eliminate litigation, but could conceivably aid in defense of such cases.

General Motors **GM** Proving Grounds

from the desk of . . .

R. E. Rasmussen

To: Tom Bundorf

Here is the supporting data that you asked for on the subject of power steering failures. This is an analysis of 1241 forms done in February by one of our engineers.

2-17-74

File F-866

The attached data sheets contain summaries from a review of GM 1241 forms and MIC accident data involving alledged power steering system failures on GM vehicles. Individual cases were reviewed to determine if a loss in power steering assist was a causal factor in the accident. Based on available information, each case was classified as follows:

I. Power steering not involved

II. Indeterminate power steering involvement

III. Power steering failure probable

Category I cases are self explanatory. Driver allegation of a loss in power assist where no supporting evidence was available comprise Category II. Accidents where some type of malfunction in the steering system was identified by an investigator after the accident were placed in Category III.

H. K. Mueller

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Summary of [illegible]

2-20-7[illegible]

		Vehicle Speed				Male Drivers				Female Drivers			
	No. of Cases	Slow	10-30 MPH	>30 MPH	Indet.	<20	20-60	>60	Indet.	<20	20-60	>60	Indet.
Chevrolet													
I	41	8	12	13	8	1	21	2	4	2	5	1	5
II	49	3	18	15	13								
III	11	-	-	-	-	-	-	-	-	-	-	-	-
Buick													
I	15	5	2	4	4	-	5	-	5	-	4	-	-
III	25	2	7	6	10								
III	4	-	-	-	-	-	-	-	-	-	-	-	-
Oldsmobile													
I	12	2	4	3	3	-	4	2	2	-	2	1	1
II	21	-	6	8	7								
III	4	-	-	-	-	-	-	-	-	-	-	-	-

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	No. of Cases	Vehicle Speed: Slow	10-30 MPH	>30 MPH	Indet.	Male Drivers: <20	20-60	>60	Indet.	Female Drivers: <20	20-60	>60	Indf
Pontiac													
I	6	1	1	4	-	-	3	1	-	-	1	-	1
II	16	2	1	3	10								
III	3	+	-	-	-	-	-	-	-	-	-	-	-
Cadillac													
I	8	-	3	-	5	-	5	-	2	-	-	-	1
II	17	1	4	3	9								
III	2	-	-	-	-	-	-	-	-	-	-	-	-
Summary													
I	82	16	22	24	20	1	38	5	13	2	12	2	8
II	128												
III	24	-	-	-	-	-	-	-	-	-	-	-	-

* One case driver age & sex unknown

529 LITHO. IN U.S.A

GM 1241 FORM SURVEY

2-A-74

III II I CHEVROLET

Case #	P/S Not Involved	Indeter P/S Involvement	P/S Failure Probable	Vehicle Body Style	Driver Age - Sex	Slow Intersect.	Vehicle Speed Mod 10 - 30	High > 30 MPH	Indet.
31745			✓	74 - B	65 - M		✓		
26218			✓	73 - A	23 - M		✓		
26816		✓		73 - H	43 - F		✓		
27321			✓	73 - X	19 - F	✓			
27596		✓		TRUCK 1/2 T BLAZER 73 4WD	41 - M			✓	
27658		✓		73 - Z	99 - M			✓	
27820	✓								
28041	✓								
28567	✓								
29296			✓	73 - B	18 - M		✓		
29308			✓	73 - X	22 - M				✓
29421		✓		73 - B	39 - M		✓		
29923		✓		TRUCK 73 - C20	26 - M		✓		
29924	✓								
30192		✓		TRUCK 73 - K10	21 - M		✓		
30325			✓	TRUCK 73 - K10	22 - M		✓		
30346	✓								
30393			✓	73 - A	21 - M		✓		
30589		✓		TRUCK 73 - C10	40 - M			✓	
30629		✓		73 - F	20 - M		✓		
30671			✓	73 - Z	99 - M			✓	
30732		✓		73 - H	16 - F			✓	
30582	✓								
31139		✓		73 - B	37 - M			✓	
4741			✓	72 - B	99 - M			✓	
7710			✓	72 - B	39 - M			✓	
9507			✓	TRUCK 72 - K10	38 - M			✓	
9551			✓	72 - X	60 - M			✓	
11657			✓	72 - B	44 - M				✓
21168			✓	72 - A	61 - M	✓			
21420		✓		72 - A	27 - M				✓
21881			✓	72 - F	20 - M		✓		
25756		✓		72 - A	21 - F		✓		
25804			✓	72 - B	52 - M	✓			
25612			✓	TRUCK 72 - K10	19 - M			✓	
26438		✓		72 - B	16 - M				✓

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III I II CHEVROLET

Case #	P/S Not Involved	Indeter P/S Involvement	P/S Failure Probable	Vehicle Body Style	Driver Age - Sex	Slow Intersect.	Vehicle Speed Mod 10-30	Vehicle Speed High > 30 MPH	Indet.
26557			✓	72-A	99-M			✓	
27612			✓	72-X	50-M	✓			
27614		✓		72-A	24-M		✓		
27791			✓	72-A	20-M			✓	
27878			✓	72-B	99-F				✓
28401		✓		72-A	99-F		✓		
28415			✓	72-X	36-F				✓
28417		✓		72-A	19-M		✓		
28754		✓		72-A	99-M	✓			
28911		✓		72-B	99-F				✓
29512		✓		72-B	65-M		✓		
30734		✓		TRUCK 72 C10	37-M			✓	
31559		✓		72-X	99-M				✓
3092		✓		71-A	45-M				✓
3944		✓		71-B	99-M				✓
5065		✓		71-A	20-F			✓	
5543			✓	71-B	23-M				✓
5545			✓	71-A	42-F		✓		
5609			✓	71-A	16-F		✓		
5613		✓		71-A	27-M			✓	
5760	✓								
6046			✓	TRUCK 71 SERIES 40	99-M				✓
6318		✓		71-A	19-M		✓		
7434			✓	71-A	23-M	✓			
9571		✓		71-B	36-M				✓
9691			✓	71-F	99-M			✓	
11996		✓		71-A	30-F			✓	
26237		✓		71-B	44-F				✓
26919		✓		TRUCK 71 60 SERIES	57-M			✓	
28200		✓		71-B	64-M		✓		
29124		✓		TRUCK 71 C20	73-F				✓
31510			✓	71-B	63-F			✓	
31584		✓		71-B	25-M				✓
734			✓	70-X	35-F			✓	
1602			✓	70-A	43-F				✓
1695		✓		70-F	21-F		✓		

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III II I CHEVROLET

Case #	P/S Not Involved	Indeter P/S Involvement	P/S Failure Probable	Vehicle Body Style	Driver Age-Sex	Slow Intersect.	Vehicle Speed Mod 10-30	Vehicle Speed High > 30 MPH	Indet.
3112			✓	70-A	99-F			✓	
3208		✓		70-A	19-M		✓		
3233			✓	70-X	33-M	✓			
3281			✓	70-B	29-M		✓		
3349			✓	70-F	20-M		✓		
5659		✓		1970-Conv. Cab CE 53	17-M			✓	
9655		✓		1970-CE 14 Pickup	99-M			✓	
11879		✓		70-B	32-M			✓	
~~600~~			~~✓~~	~~69-B~~	~~26-F~~	~~✓~~			
697			✓	69-B	23-M			✓	
1689		✓		69-A	27-M			✓	
2442		✓		69 ME 639 TRK	41-M			✓	
2482			✓	69 TRK CE 24	36-M	✓			
3015		✓		69-B	19-M			✓	
3227		✓		69-B	51-F			✓	
5709		✓		69-Z	36-M			✓	
8264	✓								
13023	✓								
13528	✓								
13620		✓		69-F	21-M				✓
14048			✓	69 SteelVan OE 35	30-M	✓			
14189			✓	69-X	55-M		✓		
14928			✓	69-B	37-M			✓	
15033	Same as case 600 (will keep the higher no. - ie. This one)								
15355			✓	69-F	22-M		✓		
16882			✓	69-B	55-M			✓	
19151		✓		69-B	82-M	✓			
28760		✓		69-B	18-M		✓		
30758		✓		69-A	56-F		✓		
31042		✓		69-B	41-M				✓
1308			✓	68-B	48-M	✓			
8150		✓		68-F	99-M		✓		
8158			✓	68-A	99-F				✓
8310		✓		68-B	99-M				✓
11309		✓		68-B	40-F		✓		
14707			✓	68-X	99-F		✓		

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III II I CHEVROLET

Case #	P/S Not Involved	Indeter P/S Involvement	P/S Failure Probable	Vehicle Body Style	Driver Age-Sex	Slow Intersect.	Vehicle Speed Mod 10-30	Vehicle Speed High > 30 MPH	Indet.
14762		✓		68-B	58-M			✓	
16076		✓		68-Z	17-M		✓		
18153		✓		68-B	17-M			✓	
19410		✓		68-B	99-M				✓
19931		✓		68-B	80-M		✓		
24755			✓	68-B	99-F				✓
711		✓		67-B	60-F			✓	
19002		✓		67-B	58-M			✓	
28848	✓								
7645		✓		66-A	22-F	✓			
117	11	59	47			13	33	37	23

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CAT. I - CHEVROLET

	MALE <20	20-60	>60	INDET		FEMALE <20	20-60	>60	INDET				Total
Body A		4	1	1		1	2		2	A			11
B	1	9	1	1			1	1	2	B			16
F		3		1						F			4
H										H			0
X		5				1	2		1	X			9
Z				1						Z			1
	1	21	2	4		2	5	1	5				41
Total		28					13						

CAT. II - CHEVROLET

	<20	20-30	>60	INDET.		<20	20-60	>60	INDET.				
A										A			
B										B			
F										F			
H										H			
X										X			
Z										Z			
TRUCK										TRUCK			

GM 1241 LOAN SURVEY

2-19-74

[illegible] <10

Case #	III P/S Not Involved	II Indeter P/S Involvement	I P/S Failure Probable	Buick Vehicle Body Style	Driver Age - Sex	Slow Intersect.	Vehicle Speed Mod 10-30	Vehicle Speed High > 30 MPH	Indet.
31620			✓	74-A	99-M	✓			
28178		✓		73C	99-F	✓			
29139			✓	73-E	38-F			✓	
29235			✓	73-A	50-M			✓	
30854		✓		73-A	37-M		✓		
31395		✓		73-A	43-F		✓		
31848	✓								
11726			✓	72-A	43-F	✓			
25772		✓		72-C	99-F				✓
26256		✓		72-C	69-M			✓	
28683		✓		72-C	40-M			✓	
29137	✓								
31618		✓		72-C	99-M			✓	
2194		✓		71-A	34-M			✓	
2386	✓								
3229			✓	71-B	99-M*				✓
4555			✓	71-C	99-M	✓			
4558			✓	71-B	39-M	✓			
5984		✓		71-A	70-F			✓	
28078			✓	71-E	38-M				✓
2015	1 (see 9753)		✓	70-C	51-M			✓	
2223		✓		70-A	99-M				✓
2226		✓		70-B	45-M				✓
2242		✓		70-A	99-M*				✓
2262		✓		70-A	99-F			✓	
2270		✓		70-A	99-F				✓
2299		✓		70-A	24-M		✓		
3528		✓		70-C	99-M		✓		
5946		✓		70-B	99-M				✓
~~3153~~	~~[illegible] 2015 [illegible]~~								
2325		✓		69-B	22-F		✓		
6232		✓		69-E	99-M*				✓
13800			✓	69-A	99-M*	✓			
15311		✓		69-A	99-M*				✓
15354			✓	69-C	99-99**				✓
15626	—	—							

** - ISD Initial only

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III II I BUICK

Case #	P/S Not Involved	Indeter P/S Involvement	P/S Failure Probable	Vehicle Body Style	Driver Age-Sex	Slow Intersect.	Vehicle Speed Mod 10-30	High > 30 MPH	Indet.
16051		✓		69-B	99-F		✓		
20443			✓	69-A	55-F				✓
21280			✓	69-A	55-F			✓	
22628		✓		69-B	99-M				✓
2014	↗	✓		68-A	99-M		✓		
8592			✓	68-B	44-M		✓		
14244	✓								
~~18550~~		~~Same as~~		~~Case #~~	~~2014~~	~~([illegible]~~	~~[illegible])~~		
19118			✓	68-B	99-M		✓		
28080		✓		68-E	54-F				✓
20096		✓		67-C	99-F	✓			

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CAT. I - BUICK

		MALE					FEMALES						
	<20	20-60	>60	INDET.			<20	20-60	>60	INDET			Total
BODY A		1		2				3					6
B		2		2									4
C		1		1									2
E		1						1					2
		5		5		*		4					14

* ONE SAMPLE NO AGE OR SEX

CAT II - BUICK

	<20	20-60	>60	INDET.			<20	20-60	>60	INDET
A										
B										
C										
E										

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GM 1241 Form Survey

GM 529 LITHO. IN U.S.A

Pontiac

	Case #	III P/S Not Involved	II Indicates P/S Functioned	I P/S Failure Probable	Vehicle Body Style	Driver Age Sex	Slow Intersect.	Vehicle Speed Mod 10-30	Vehicle Speed High >30 mph	Indet
✓ 73	26787			✓	73-A	32-M			✓	
✓	26999			✓	73-B	52-M	✓			
✓	28501	✓								
✓	28769			✓	73-A	32-M			✓	
✓	30537		✓		73 A	19-M			✓	
✓	31177		✓		73 F	99-M				✓
✓	31348		✓		73 A	24-F				✓
✓	31705		✓		73 B	54-M		✓		
✓ 72	27282			✓	72 B	99-F			✓	
✓	30536			ENG. STALLED ✓	72 B	67-M			✓	
✓ 71	6993		✓		71 B	57-F	✓			
✓	9353		✓		71 B	99-M				✓
✓	18887		✓		71 B	99-F				✓
✓	28485		✓		71 B	99-M				✓
✓ 70	162		✓		70 F	36-M	✓			
✓	7199	✓								
✓ 69	1884		✓		69 A	22-F				✓
✓	4298		✓		69-F	20-M				✓
✓	7101		✓		69-A	20-M			✓	
✓	7157		✓		69-B	99-F				✓
✓	8164		✓		69 B	99-M				✓
✓	13504		✓		69 A	99-M				✓
✓	13610			✓	69 A	22-F		✓		
✓	25365		✓		69 B	26-M			✓	
✓	26789	✓								
25										

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Pontiac - Cat. 1

	Male <20	Male 20-60	Male >60	Male Indet.			Female <20	Female 20-60	Female >60	Female Indet.			
Body A		II 2						I 1					3
B		I 1	I 1							I 1			3
F													
		3	1					1		1			6

GM 529 LITHO. IN U.S.A.

GM 1241 FORM SURVEY

III II I OLDSMOBILE

	Case #	P/S Not Involved (III)	Indicator P/S Involved (II)	P/S Failed Probable (I)	Vehicle Body Style	Driver Age Sex	Slow Intersect.	Vehicle Speed Mod 10-30	Vehicle Speed High >30 mph	Inde
✓ 73	26776			✓	73-A	22-M			✓	
✓	27256		✓		73-C	37-M			✓	
✓	29085		✓		73-A	99-M		✓		
✓	29503			✓	73-A	99-F				✓
✓	30257			✓	73-X	30-M		✓		
✓	30426		✓		73-B	24-M		✓		
✓	30632		✓		73-E	27-M			✓	
✓	31338			✓	73-C	58-F	✓			
✓	31439		✓		73-C	49-F			✓	
✓	31763	✓								
✓	31810			✓	73-C	47-M	✓			
✓ 72	11462			✓	73-E	27-F		✓		
✓	27539	✓								
✓	29086		✓		72-A	38-M				✓
✓	29805		✓		72-B	34-M		✓		
✓ 71	4658			✓	71-C	66-M			✓	
✓	4788		✓		71-B	99-M				✓
✓	6136		✓		71-E	31-F				✓
✓	29212		✓		71-C	38-M			✓	
✓ 70	379		✓		70-A	19-M				✓
✓	2698		✓		70-E	99-M				✓
✓	2743			✓	70-E	99-M		✓		
✓	4186		✓		70-B	38-F		✓		
✓	27057			✓	70-C	99-M				✓
✓ 69	1016		✓		69-C	42-M			✓	
✓	2762		✓		69-B	64-M			✓	
✓	16852		✓		69-A	21-M		✓		
✓	21091			ENG. STALLED ✓	69-B	66-F			✓	
✓	~~23249~~	~~SAME AS 1016 ABOVE~~								
✓	23476			✓	69-E	50-M				✓
✓	24690		✓		69-A	50-F		✓		
✓ 68	1		✓		68-C	82-M				✓
✓	4322	✓								
✓	8423		✓		68-A	20-M			✓	
✓	19508		✓		68-B	42-F			✓	
✓ 67	4192		✓		67-E	99-F				✓

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G.M 529 LITHO. IN U.S.A

III II I OLDSMOBILE

	Case #	P/S Not Involved	Indeter P/S Involvement	P/S Failure Probable	Vehicle Body Style	Driver Age Sex	Slow Intersect.	Vehicle Speed Mod 10-30	Vehicle Speed High > 30 MPH	Inde[illegible]
✓ 63	2626			✓	63-B	76-M		✓		
62	2791	✓								
2										

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OLDSMOBILE - CAT. I

	MALES						FEMALES						
	<20	20-60	>60	INDET			<20	20-60	>60	INDET			
BODY A		1								1			2
B			1						1				2
C		1	1	1				1					4
E		1		1				1					3
X		1											1
		4	2	2				2	1	1			12

GM 1241 Form Survey

III II I Cadillac

Case #	P/S Not Involved	Indeter P/S Involvement	P/S Failure Probable	Vehicle Body Style	Driver Age-Sex	Slow Intersect.	Vehicle Speed Mod 10-30	Vehicle Speed High > 30 MPH	Indet.
31615		✓		74-C	43-F		✓		
27838			✓	73-C	50-M				✓
29152		✓		73-C	55 M				✓
29483		✓		73-E	38-F			✓	
29830		✓		73-C	50-F		✓		
30270		✓		73-C	99-M			✓	
30449			✓	73-E	99-F	/			✓
30480	✓								
30487			✓	73-C	49-M		✓		
30665			✓	73-C	99-M				✓
31084		✓		73-C	35-M		✓		
31614		✓		73-C	60-M				✓
4997		✓		72-C	99-M				✓
26170		✓		72-C	53-F				✓
28523		✓		72-C	99-M				✓
30506		✓		72-C	99-M				✓
30560			✓	72-C	59-M				✓
21674		✓		71-C	99-M				✓
1956			✓	70-C	99-M		✓		
2855	✓								
19693			✓	69-E	40-M				✓
23010		✓		69-C	50-M			✓	
16282			✓	68-E	49-M		✓		
18120		✓		68-C	42-M	✓			
16702		✓		67-C	99-F				✓
23850		✓		66-C	99-M				✓
4637		✓		64-C	32-M		✓		

CP 153 Rev.
Prtd. U.S.A.

Cadillac – Cat. I

	Male <20	Male 20-60	Male >60	Male Indet.			Female <20	Female 20-60	Female >60	Female Indet.			
Body C		3		2									5
E		2								1			3
	–	5	–	2			–	–	–	1			8
Totals all Divisions		57				*		24					

GM 1241 Form Survey

2-19-74

GMC (Trucks)

Case #	III P/S Not Involved	II Indeter P/S Involvement	I P/S Failure Probable	Vehicle Body Style	Driver Age-Sex	Slow Intersect.	Vehicle Speed Mod 10-30	Vehicle Speed High > 30 MPH	Indet.
29394		✓		73 TRUCK TCE66203	40-M				✓
31422		✓		73 TRUCK ASTRO	35-M			✓	
6111			✓	73 TRUCK DH92A ASTRO	40-M			✓	
21106		✓		72 TRUCK TCM53W	18-M	✓			
26615		✓		72 TRUCK CE56703	33-M			✓	
27289		✓		72 ASTRO TDH9500	23-M			✓	
7469			✓	71 BUS SM502	99-F				✓
9402		✓		71 TRUCK DH92A	27-M				✓
9412			✓	72 TRUCK TDH92A	24-M			✓	
21944			✓	71 1/2T TRUCK CE134	53-M		✓		
21949			✓	'71 TRK CM63 (mod)	42-M		✓		
5269		✓		1970 TRK CE [illegible]	67-M			✓	
7675		✓		1970 JJ70A	32-M		✓		
9416		✓		1970 TRK J190A	41-M			✓	
25995			✓	1970 DH92A (mod)	36-M		✓		
26288		✓		1969 ASTRO 95	32-M				✓
30377			✓	1970 ASTRO 95	30-M			✓	
5328			✓	1969 DH90A	59-M	✓			
20052		✓		1969 DI92A	38-M				✓
12384		✓ *		1967-BUS SM5810Y	53-M				✓
19675	✓								
2583			✓	1964 BUS DD4106	52-M			✓	
5293		✓		1954 PD4104	99-M				✓

[illegible]

MIC Accidents Where Possible P/S Failure Occurred

Case #	P/S Not Involved	Indeter P/S Functioning	P/S Failure Probable	Vehicle Body Style	Driver Age - Sex	Vehicle Speed: Slow Intersect.	Mod 10 - 30	High > 30 MPH	Indet
D-140		✓		1971 CHEV-X	17-M			✓	
D-129	✓ DWI								
D-426		✓		1971 CHEV-A	53-M			✓	
D-542		✓		1971 Chev-B	61-F		✓		
D-734		✓		71 Chev-B	31-M			✓	
D-797			(✓)*	71 Pont-A	66-F			✓	
D-980	✓ DWI								
D-932		✓		71 CHEV-A	36-F			✓	
D-1013		✓		71 Buick-A	58-F		✓		
D-1246		✓		71 Cadillac-C	41-M			✓	
D-1315		✓		71 Chev-A	18-M			✓	
D-1406	✓								
D-1478		✓		71 CHEV-A	47-F			✓	
D-1523		✓		71 CHEV-A	23-M			✓	
D-1571		✓		71 Pont-F	33-F			✓	
D-1937		✓		71 Chev-A	20-M			✓	
D-2057		✓		71 CHEV-X	30-M		✓		
K-0096	(Drinking)	✓		73 Olds-A	22-F			✓	
K-129		✓		73 Pont-A	31-M			✓	
K-134	✓								
K-141	✓								
K-418	✓ Dr.								
K-595		✓		73 Buick-A	61-F		✓		
K-842			(✓)*	73 CHEV-X	65-F			✓	
K-1103		✓		73 CHEV-X	21-M			✓	
K-1180		✓		73 Pont-F	35-M			✓	
K-1352		✓		73 Olds-A	27-M		✓		
K-1413	(This is ? is the Driver	Specifically Steering Dev?)	Str. wheel weld ✓ broke	73 Buick-C	59-F			✓	
K-1534		✓		73 Pont-A	99-M				✓
K-1563		✓		73 Buick-A	50-F			✓	
K-1600		✓		73 CHEV-A	19-M			✓	
K-1743		✓		73 CHEV-A	21-F			✓	
K-1976		✓		73 OLDS-A	20-F		✓		
K-1955		✓		73 CHEV-A	19-F			✓	
K-1992		✓		73 CHEV-A	26-M			✓	
		26							

[illegible]

GM 529 LITHO. IN U.S.A

MIC P/S Failure Cases

	Case #	P/S Not Involved	Indeter. P/S Involvement	P/S Failure Probable	Vehicle Body Style	Driver Age - Sex	Slow Intersect.	Vehicle Speed Mod 10 - 30	Vehicle Speed High > 30 mph	Indet.
	K-2075	✓ (M)								
	K-2086	✓ (M)								
m	K-2013	✓ (M)								
	K-2277		✓		73 CHEV - A	23 - F			✓	
	K-2840		✓		73 PONT - A	30 - M			✓	
	K-2859		✓		73 CAD - C	34 - F		✓		
	J-77		✓		72 OLDS - A	42 - M			✓	
	J-149		✓		72 PONT - X	33 - F		✓		
	J-205	✓								
	J-235		✓		72 CHEV - A	23 - M		✓		
	J-530	✓ (M)								
	J-620	✓ DRINKING, RECKLESS								
	J-704			ENG. STALLED ✓	72 CHEV - A	37 - M		✓		
	J-793		✓		72 CHEV - B	29 - M		✓		
1972	J-859		✓		72 BUICK - A	22 - M			✓	
	J-920	✓ DRINKING								
	J-976	✓								
	J-991	✓								
	J-996		✓		72 PONT - A	44 - M			✓	
	J-1276		✓		72 CHEV - B	52 - F			✓	
	J-1360		✓		72 CHEV - A	21 - M			✓	
	J-1506		✓		72 CHEV - A	24 - F		✓		
	J-2054		✓		72 CHEV - A	22 - M			✓	
	J-2219		✓		72 CHEV - X	39 - M			✓	
	J-2486		✓		72 CHEV - B	38 - F			✓	
	J-2638	✓								
	J-2706		✓		72 CHEV - A	21 - F			✓	

Total # of cases

71	2295
72	2867
73	1850
	7012

16

(M) MANUAL STEER

PE10-005

GM

4/14/2010

ATTACHMENT Q

15 C

1974_06_27_rer_pres

SLIDE 1 - BLANK

SLIDE 2 - TITLE

WITHIN GM THERE HAVE BEEN A NUMBER OF ATTEMPTS TO DEFINE DRIVER BRAKE AND STEER FORCE CAPABILITY. DIFFERENT APPROACHES HAVE YIELDED DIFFERENT RESULTS, PARTICULARLY WHEN COMPARED WITH THE WORK OF OTHERS. WE THINK THIS EXPERIENCE GIVES SOME USEFUL INSIGHT TO THE PROBLEM OF DEFINING EFFORT CAPABILITY. WE FEEL, HOWEVER, THAT HIGHLY MOTIVATED 5th PERCENTILE CAPABILITY PROBABLY HAS NOT BEEN ESTABLISHED BY OUR WORK OR ANY OTHER THAT HAS BEEN REVEALED.

THE EARLIEST MODERN GM STUDY WAS DONE BY THOMPSON IN 1966. AN INSTRUMENTED CAR WAS DRIVEN AT LOW SPEED (10 MPH) THROUGH A 90° INTERSECTION TURN. THE ENGINE WAS STALLED BY GROUNDING THE COIL. ALL DRIVERS BRAKED TO A STOP WITH MOST APPLYING MODERATE FORCE LEVELS.

MEAN - 15.9 LB.
RANGE - 4-25 LB.
20% < 7.5 LB.

19 FEMALES
MODIFIED 1966 CHEVROLET

EXPERIMENT CONSIDERED UNSUCCESSFUL AND RESULTS FILED WITHOUT FINAL PROCESSING OR REPORT.

SLIDE 3 - IMPORTANT FACTORS

IN REVIEWING OUR INITIAL WORK AND SIMILAR BRAKING EXPERIMENTS, IT APPEARED THAT MOTIVATION, TASK REQUIREMENTS AND DATA INTERPRETATION INFLUENCE THE RESULTS OF THESE EXPERIMENTS.

SLIDE 4 - MOTIVATION

SLIDE 5 - OVERALL COURSE

PROCEDURE - 1969 OLDS 98
30 MPH
0.3 G
TWO FAILURES
PUMP CLUTCH
PHASE I - 16 MALES
16 FEMALES

SLIDE 6 - PHASE I CONDITION - 10 FT SPACING.

SLIDE 7 - PHASE II CONDITION - 5 FT SPACING

11:1 STEERING RATIO
20 PSI FRONT TIRE INFLATION

SLIDE 8 - TASK REQUIREMENTS

PHASE I SUBJECTS TRACKED TASK REQUIREMENTS. PHASE II SUBJECTS GAVE HIGHER NUMBERS. LEAST VALUE FOR PHASE II 30 LB. STATISTICAL 5th PERCENTILE 29.5 LB. DATA MEETS TEST FOR NORMALITY.

STATIC DATA SIMILAR TO HARVARD

SCORE 9 - INTERSECTION

13 OF 16 FEMALE TRIALS STOPPED

MEAN 28.8 dB

STANDARD DEVIATION 10.9

LOWEST EFFECT -15 dB.

QUESTIONS ON MAN FACTORS STEERING EFFORT CAPABILITY TEST

1. What was the effort level required to perform the task, namely steering through the 60 foot radius curves at 15 mph?

2. Was the needle valve in the power steering pump-gear by-pass valve adjusted during the test or was it kept at a constant level?

3. What percentage of the subjects completed the turn and/or brake to a stop? That is, did the subjects turn the car through the maneuver or did they simply brake to a stop?

4. What was the variation in vehicle speed at the time of power steering failures?

5. The comment was made in the report that the brake failure was not as obvious as the steering failure. Was this due to some mechanical "clunk" obvious to the subject or other radical change in the car?

6. What was the resolution of the recording equipment?

7. Were the order effects randomized among age and stature characteristics of the sample population?

8. I would question the representativeness of the sample in that friends and relatives of previous subjects were used, test subjects from previous Man Factor studies, etc. What was percentage of these individuals?

9. Was the data tested for normality?

	(BLANK)	
74-121	Steering Effort (Title)	
74-122	GM Subjective Rating Scale	
74-123	Steering Effort - list of subjects covered	
74-124	General Motors Steering Torque Test Techniques	
74-125	Steering Laboratory Facility (circa 1950's)	
74-126	" " " " "	
74-127	" " " " " - (not used in presentation)	
	(70-86)	A-Curve - drawing
	(D 39)	Steering torque test wheel (Instrumentation Eng. Slide)
74-128	Static Test - text	
	BLANK - Movie of Static Test - M-52	
74-129	Stationary Manual Steer Torque Data	
74-130	Dynamic Test - text	
	BLANK - Movie of Static Test - M-52	
74-131	Dynamic Manual Steer Torque Data	
74-132	Test Conditions - text	
74-133	Why Dynamic Test - text	
74-134	Data Evaluation (subtitle)	
	(74-139)	Stationary Manual Steer Torque Data
74-135	Dynamic Power On Steer Torque Data	
74-136	Dynamic Power Off Steer Torque Data	
74-137	Effects of Vehicle Parameters (subtitle)	
74-138	Comparison of Static and Dynamic Steer Torques	
74-139	Comparison of Dynamic Steer Torques	
74-140	Manual Steer Stationary Effort vs. Front Weight	
74-141	Manual Steer 30 MPH 0.25 g Lateral Acceleration Steer Force vs. Front Weight	
74-142	Manual and Power Off Steer Torque vs. Front Weight 10 MPH, 0.25 g Lateral Acceleration (not used in presentation)	

74-143	Same as above 30 MPH (not used in presentation)
74-144	Power Off Rim Pull (data)
74-145	Caster Comparison 30 MPH
74-146	Human Steering Effort Capabilities
74-147	Four Studies - text
74-148	Important Factors - text
74-149	Motivation Text
74-150	Failed Power Steering Study - Serpentine Course
74-151	Failed Power Steering Study - 1st Serpentine Course
74-152	Failed Power Steering Study - 2nd Serpentine Course
	(BLANK) Movie - Failed Power Steering Study - M-52
74-153 - 158	Misc. Slides - Failed Power Steering Study Course (not used in presentation)
74-159	Task Requirements - Effort (text)
74-160	Task Requirements - Speed (text)
74-161	Data Reduction (text)
74-162	Fifth Percentile Female Maximum Steering Effort Levels (bar graph)
74-163	Accident Data (text)
	"A Variable Response Vehicle - Description and Applications", JACC paper presentation - June 1974 - S-2510
	(BLANK) Movie - M-53
74-164	The General Motors Variable Response Vehicle, etc. (title)
	(70-3) Calspan VRV
	(69-177) VRV (title)
	(69-179) VRV Objective
	(69-178) VRV Objective
	(69-180) VRV Side View
	(69-182) Manual Steering Control
	(69-183) Servo Steer Control
	(BLANK) Movie - M-53

STEERING EFFORT

GM

SUBJECTIVE RATING SCALE

	PERFORMANCE	DISTURBANCE
10	EXCELLENT	NONE
9		
8	GOOD	TRACE
7		
6	FAIR	MODERATE
5		
4	POOR	ANNOYING
3		
2	BAD	SEVERE
1		
0	NOT APPLICABLE	

STEERING EFFORT

GM Measurement Techniques

Vehicle Parameter Effects

Human Effort Capabilities

Accident Data

GENERAL MOTORS
STEERING TORQUE
TEST TECHNIQUES

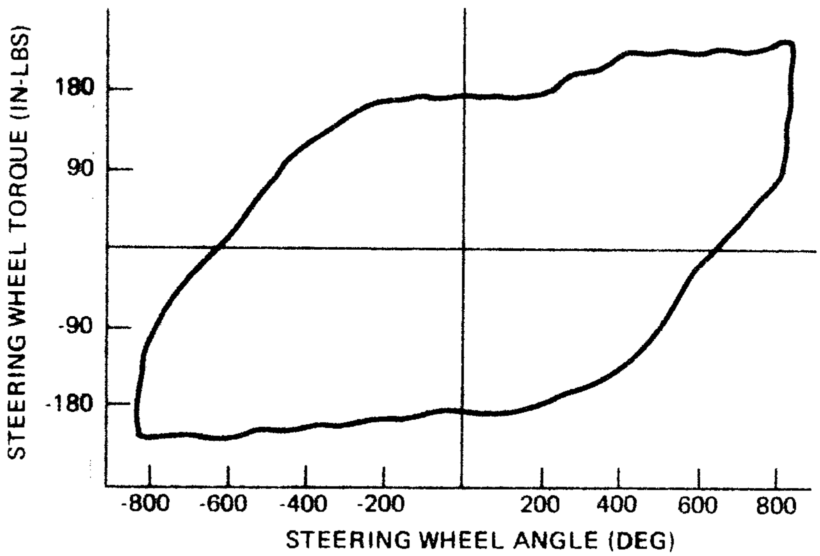
STATIC TEST

Manual Steer Vehicles Only

Performed on 3M Grit Pads

Torque vs Steering Wheel Angle

STATIONARY MANUAL



DYNAMIC TEST

Performed on Handling Pad

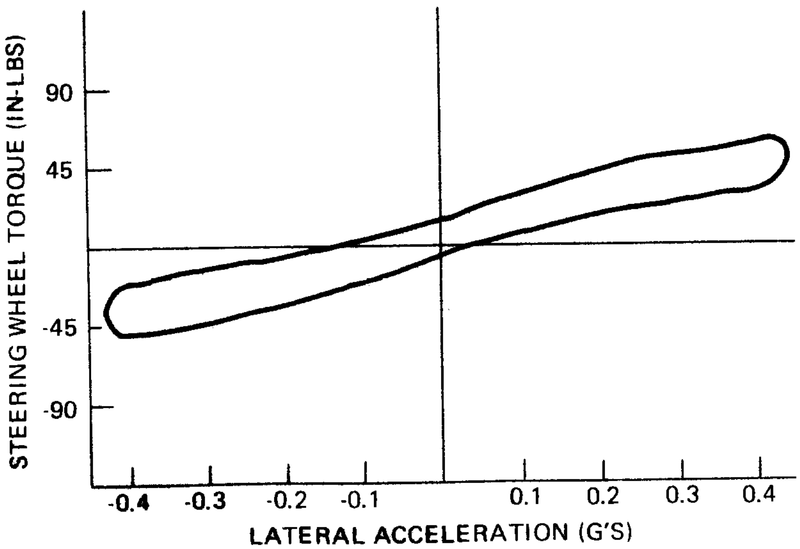
Torque vs. Lateral Acceleration

Constant Speed - 10 and 30 mph

Slow Turning Rate

Manual and Power Off Vehicles

MANUAL STEER 30 MPH



TEST CONDITIONS

Two Passenger Load

New Tires at Recommended Pressure

Speeds:

- Stationary - Manual Steer Only
- 10 mph - Parking and Intersection
- 30 mph - Moderate

Repeated Three Times

WHY DYNAMIC TEST

Power Off Stationary Rim Force

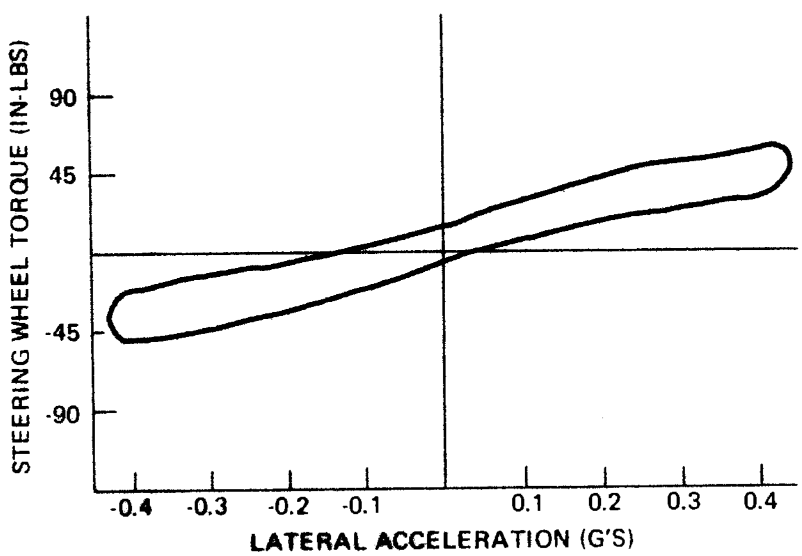
- Not Normal Usage
- Not Safety Related

Dynamic Rim Force

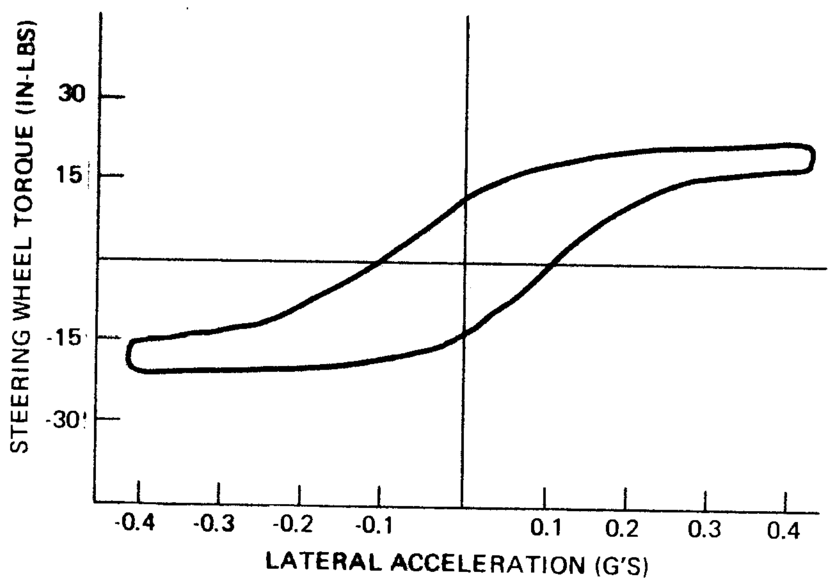
- Different Parameters
- Ratio Effects Removed

DATA EVALUATION

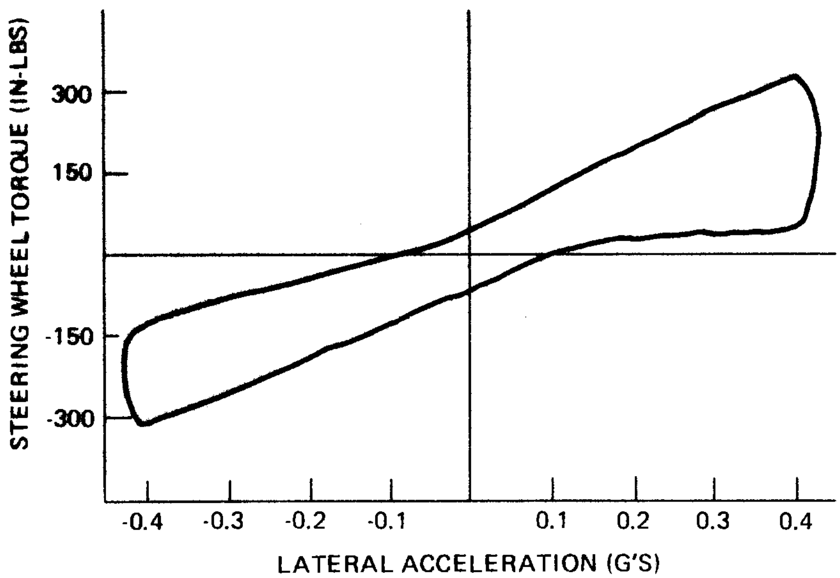
MANUAL STEER 30 MPH



POWER ON 30 MPH

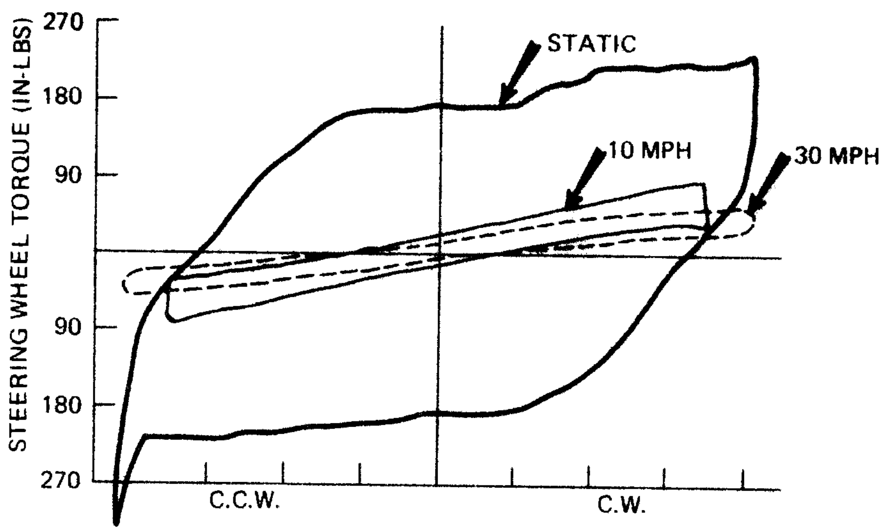


POWER-OFF 30 MPH

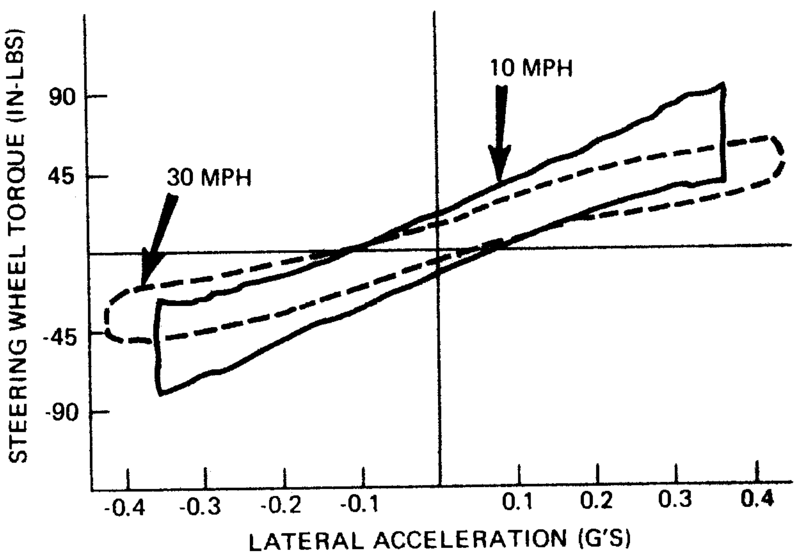


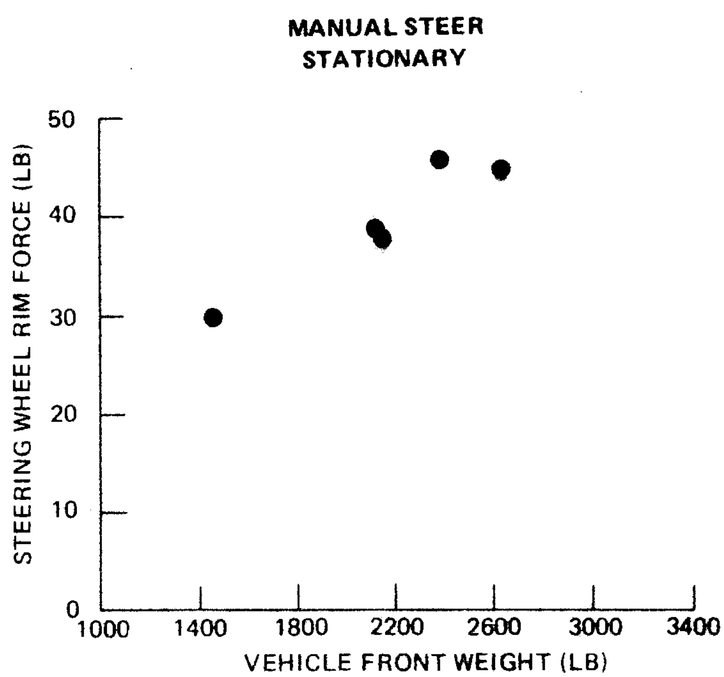
EFFECTS OF VEHICLE PARAMETERS

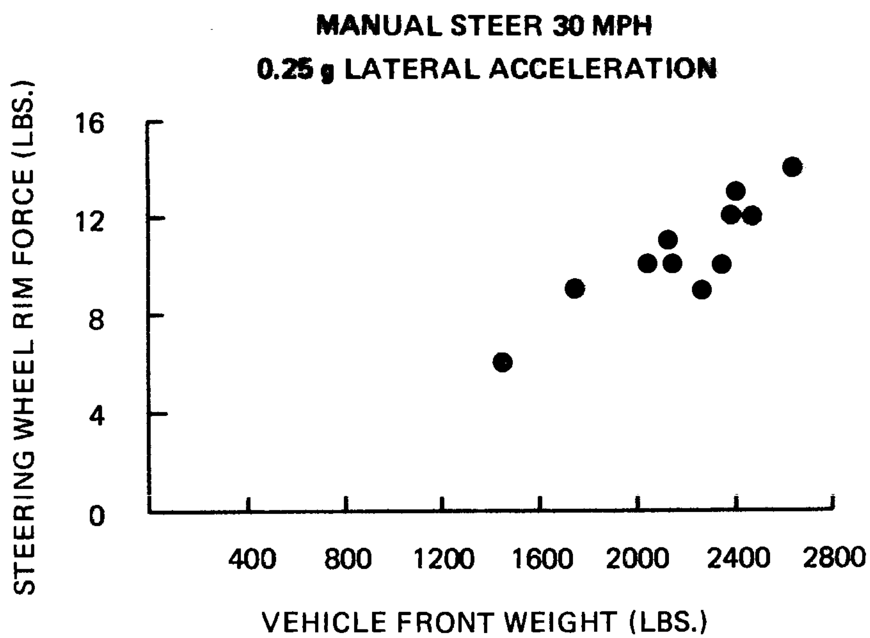
COMPARISON STATIC AND DYNAMIC



COMPARISON OF DYNAMIC STEERING TORQUE



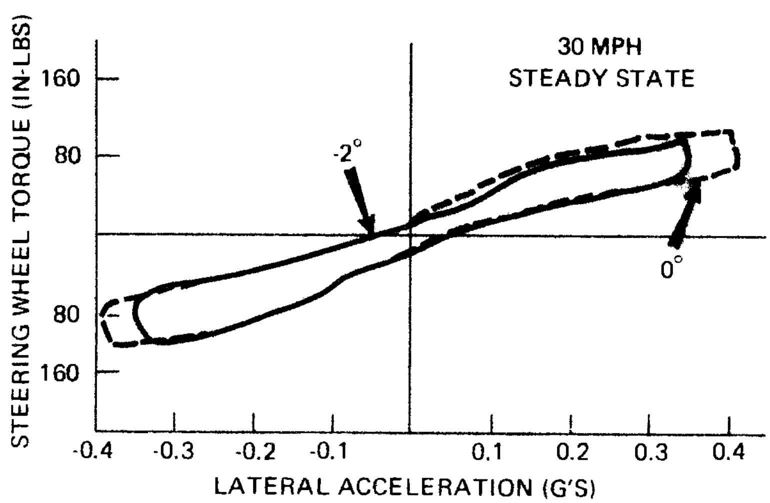

MANUAL STEER
STATIONARY
STEERING WHEEL RIM FORCE (LB)
50
40
30
20
10
0
1000
1400
1800
2200
2600
3000
3400
VEHICLE FRONT WEIGHT (LB)


MANUAL STEER 30 MPH
0.25 g LATERAL ACCELERATION
STEERING WHEEL RIM FORCE (LBS.)
16
12
8
4
0
400
800
1200
1600
2000
2400
2800
VEHICLE FRONT WEIGHT (LBS.)

POWER OFF RIM PULL

Vehicle	10 MPH 0.1g	10 MPH 0.25g	30 MPH 0.1g	30 MPH 0.25g
Compact	–	–	7	11
Intermediate	22	46	12	25
Full Sized	32	61	20	36

CASTER COMPARISON



FOUR STUDIES

Harvard

Ford

General Motors

Man Factors

TASK REQUIREMENTS - SPEED

Moderate Speed

- GM - 30 mph
- Ford - 35 mph

Intersection Speed

- GM - 0 to 10 mph
- Man Factors - 15 mph

DATA REDUCTION

Measurement Technique

- Peak or Average
- Time for Averaging

Horsepower Not Accurate Measure

Need to Completely Report Statistics

- Mean, Standard Deviation
- Normal?
- 5th % tile @ 90% Confidence

ACCIDENT DATA

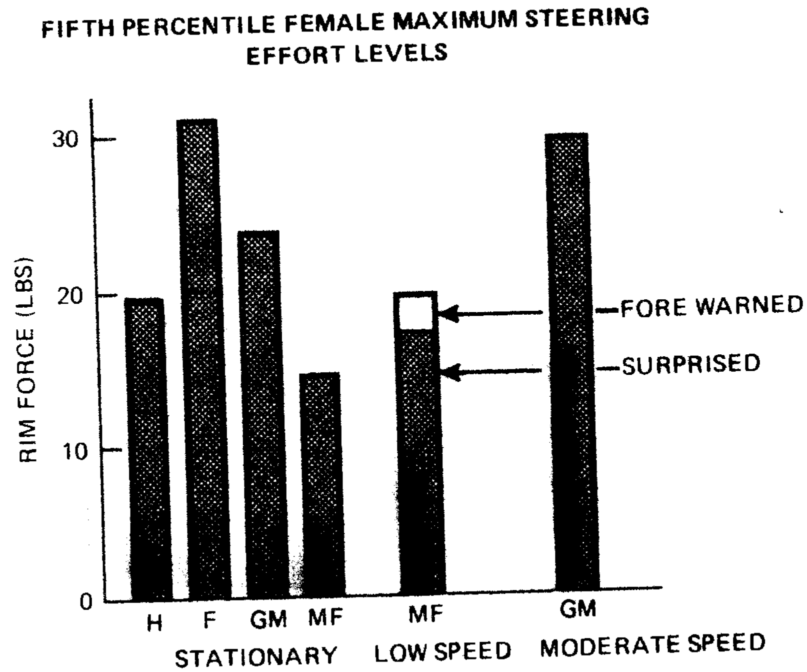
Indiana University — Zero/1000

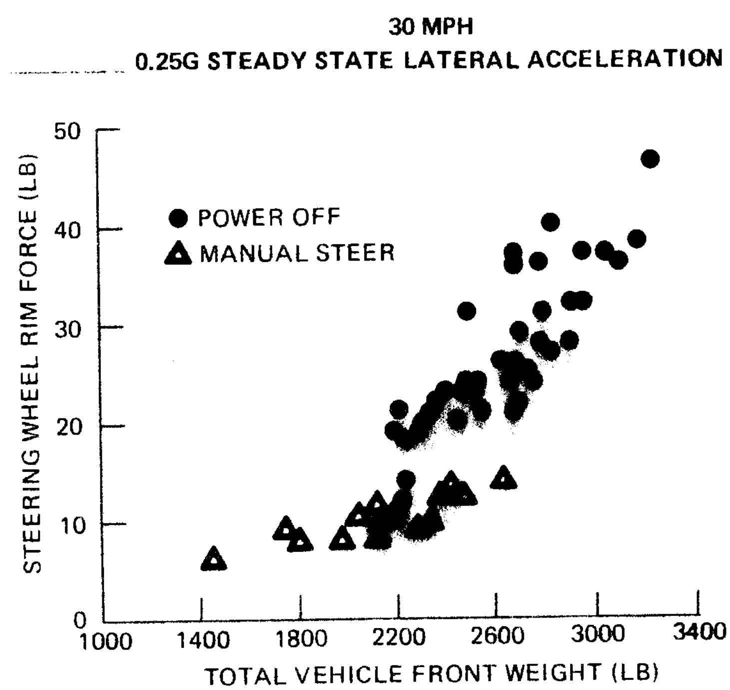
GM - MIC

- 0.7%
- Only Allegations

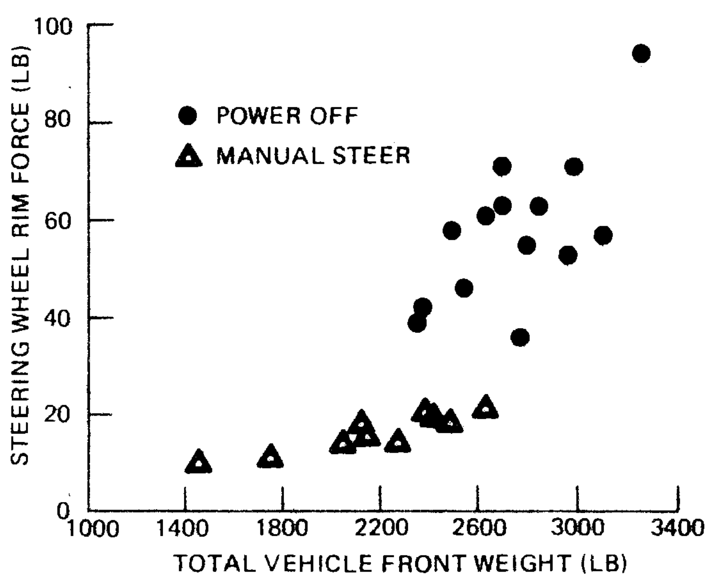
GM Field Reports

- 70% Male Drivers
- Standard or Smaller Cars


FIFTH PERCENTILE FEMALE MAXIMUM STEERING
EFFORT LEVELS
RIM FORCE (LBS)
30
20
10
0
H
F
GM
MF
MF
GM
STATIONARY
LOW SPEED
MODERATE SPEED
FORE WARNED
SURPRISED


30 MPH
0.25G STEADY STATE LATERAL ACCELERATION
STEERING WHEEL RIM FORCE (LB)
POWER OFF
MANUAL STEER
0
10
20
30
40
50
1000
1400
1800
2200
2600
3000
3400
TOTAL VEHICLE FRONT WEIGHT (LB)

10 MPH
0.25G STEADY STATE LATERAL ACCELERATION



HUMAN STEERING
EFFORT CAPABILITIES

IMPORTANT FACTORS

- Motivation
- Task Requirements
- Data Reduction

MOTIVATION

Instructions

Feedback to Subject

Task Environment

TASK REQUIREMENTS - EFFORT

GM Study:

	Required	Mean Value
Study 1	27 lbs	26.4 lbs
Study 2	36 lbs	40.3 lbs

Ford Study - Most Subjects Failed

Man Factors - No Information

PE10-005

GM

4/14/2010

ATTACHMENT Q

15 C

1974_07_18_rer_memo

F-866

JUL 19 1974

General Motors **GM** Proving Grounds

from the desk of ...

July 18, 1974

R. E. Rasmussen

To: Dick Humphrey

Here is a report that we hope is suitable for submission to Mr. Driver on the steering effort issue. It is very similar to the internal publication except for references to internal reports and a few statements that appeared somewhat speculative. Please make sure that Bundorf gets to review this before it goes out. If there are questions or changes that we have to implement, please call K. McKenna. I will be gone from July 24 until August 12. Keith can handle anything that comes up.

GMPG 357
REV. 5-66

MISCELLANEOUS SHIPPER

GENERAL MOTORS CORPORATION
PROVING GROUND

MILFORD, MICHIGAN 48042

№ 33093

DATE 7/18/74
YOUR ORDER NO. ______ OUR JOB NO. ______
OUR ORDER NO. ______
SHIPPER PREPARED BY C. Fetterman
SHIPMENT AUTHORIZED BY Rich K. [signature]
SHIPPED VIA PG Courier Mail
PREPAID ☐ COLLECT ☐ VALUE

SHIP TO

Richard Humphrey
Environmental Activities Staff
Engineering Staff
GM TECHNICAL CENTER

ATTENTION OF

QUANTITY	IDENTIFYING NO.	DESCRIPTION AND REASON SHIPPED	AMOUNT
10 copies		Report "A Review of Measurements of Maximum Steering Efforts for Drivers"	
		Material not to be returned to the Proving Grounds.	

COPIES: WHITE—ACCOUNTING
CANARY—PACKING SLIP
PINK—GATEHOUSE
CANARY—MATERIAL HANDLING
GREEN—DEPARTMENT
GOLDENROD—MATERIAL HANDLING

RECEIVED BY ______

A REVIEW OF MEASUREMENTS OF MAXIMUM STEERING EFFORTS FOR DRIVERS

July 15, 1974

VEHICLE DYNAMICS LABORATORY

GENERAL MOTORS PROVING GROUND

A REVIEW OF MEASUREMENTS OF MAXIMUM

STEERING EFFORTS FOR DRIVERS

PREFACE

During 1973, the Vehicle Dynamics Laboratory at the General Motors Proving Ground began a review of all studies relevant to the determination of the maximum steering force capability of the driver population. This review included work available in the published literature and unpublished work done over a considerable period by various GM staff organizations. The totality of the available data was thought to be more definitive than data from the individual studies.

The majority of this material was written by G. L. Rupp. Other members of the VDL staff contributed to the editing. Much of the previously unpublished information was drawn from the work of F. W. Hill, A. P. Lawrence and R. R. Thompson.

add to preface the request for confidential treatment

which constitutes a trade secret, commercial or financial information. The engineering test data and reports have value to GM and could be of value to our domestic and foreign competitors. Substantial expense was incurred by GM in sponsoring these engineering tests.

ABSTRACT

Studies of maximum steering effort are important because there is some probability, however small, that power assistance can fail. The power-off steering control will require an increased muscular exertion from the driver. Human effort research is complicated by several experimental and measurement problems. These problems are reviewed so that the reader will have some background for interpreting the experimental data.

Seven studies of maximum driver steering effort are summarized. Two of these experiments involved static efforts. The other studies examined dynamic efforts in both surprise and forewarned power steering failures. Dynamic task maneuvers included lane changes, intersections, and serpentines. The serpentine maneuvers had the lowest variability in maximum efforts. From these experiments, the ~~most reasonable~~ estimates of the lower one-sided tolerance limit for a 95th percentile female at 90% confidence level ~~were seen to be~~ 19.6 lb rim force for static efforts (Stoudt), 18.6 lb for intersection maneuvers, (Man Factors, Inc.), and 29.4 lb for highly motivated dynamic efforts (~~Hill and Lawrence~~).

Some standardization of experimental methodology is required before a steering effort design specification can be written. It was suggested that statistical analyses of the data should report a lower one-sided tolerance limit, preferably for a 95th percentile female with a confidence level of 90%.

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INTRODUCTION

Power-assisted control devices are intended to improve human performance by reducing the task workload. Should the power assistance fail, an operator will have to perform the task under manual control. It is important to understand a human operator's control capabilities under these conditions. Keeping the muscular effort within the capability of an operator, even after the power assistance has failed, is a desirable attribute of powered control devices.

The purpose of this paper is to discuss and compare the previous research regarding the maximum steering effort capabilities of drivers, with the hope of clarifying the differences which exist among the experiments, and possibly suggesting future experiments. Because maximum efforts are so difficult to define experimentally, some of the experimental and measurement difficulties will also be reviewed. Only seven experiments concerned with maximum steering effort were found in the literature. These experiments principally involved female drivers. Steering efforts were measured [redacted] in isometric and in sudden power steering failure situations. Detailed summaries of the data are presented in this report.

CONCLUSIONS AND RECOMMENDATIONS

1. Seven studies of maximum driver steering effort were reviewed. Stoudt (1)* investigated static efforts. The other studies examined dynamic efforts in surprise power steering failures. Dynamic task maneuvers included lane changes, intersections and serpentines. The serpentine maneuvers had the lowest variability in maximum efforts. Fifth percentile female tolerance limits at 90% confidence greatly depend on experimental and measurement variables. The three studies which seemed to provide the most valid estimates of these tolerance limits were Stoudt - 19.6 lb rim force for static efforts, Man Factors (2) - 18.6 for low speed turns, and Hill and Lawrence - 29.4 lb for highly motivated dynamic efforts.

2. Many experimental and measurement problems complicate human effort research. The experimental instructions can introduce variability into the data. Motivational variables such as rewards, knowledge of results, exhortations, and environmental stresses can significantly influence performance scores. Because of these variables, human effort output seldom approaches physiological capacity.

3. Dynamic and static efforts are not significantly correlated.

4. Vehicle variables can influence maximal effort measurements. In addition, the exertion levels required to successfully perform a dynamic task will influence the distribution of maximum effort data for that task. For these reasons, efforts measured in dynamic tasks may not be maximal efforts.

*Numbers in ( ) denote reports listed in the references.

5. It was recommended that statistical analyses of data should report a lower one-sided tolerance limit, preferably for a 95th percentile female with a confidence level of 90%.

6. Some standardization of experimental methodology is needed in maximal effort research.

7. There ~~seems to be meager~~ evidence which would implicate failures of power steering assistance as ~~an important~~ causative factor in accidents.

8. Potential areas for further research include investigations of driver decision-making, kinesthetic feedback, and learning and retention at high effort levels.

EXPERIMENTAL AND MEASUREMENT DIFFICULTIES

Several difficulties are encountered in the measurement of maximal driver steering efforts, or in fact in the measurement of any maximal muscular exertion. An excellent checklist for human strength experimentation has been compiled by Kroemer (3) and is reproduced as Appendix A in this report. It is generally self-explanatory, although some items will be discussed further in succeeding paragraphs. Special emphasis will be placed on the experimental instructions, task selection, data analysis, motivational factors, and performance scores. This discussion is intended to give the reader some background for interpreting the results of maximum effort experimentation.

Instructions: The instructions an experimenter gives his subjects can determine in large part the type of performance that will ensue. The less the subject knows about the purpose of the experiment, and what is expected from him, the more variable will be his performance. For example, if a subject were exerting a maximal static effort on a locked steering wheel, the magnitude of the force exerted may vary according to the rate at which the subjects develop force. Subjects could adopt a gradual increase-to-maximum strategy as opposed to a rapid, jerky exertion (3). Most probably the subjects would try several different strategies. The maximal forces so measured will be confounded with strategy, practice and perhaps fatigue effects. The experimenter could reduce this variability by instructing the subjects about the manner in which they should exert the force. If different driver strategies are allowed, then sample sizes should be increased. Within the constraints of the experimental design, the driver should also understand how his performance is being scored. It is important that the experimenter instruct the subjects as clearly and in as much detail as possible about the experiment, and then report the instructions sufficiently well so that others may reproduce the experiment.

Dynamic vs Static Efforts: Effort tests can be classified as either static or dynamic (3). Static efforts refer to muscular exertions which produce no mechanical work. Dynamic efforts do produce work because motion accompanies

the muscular exertion. There are important differences, both physiologically and mechanically, between static and dynamic efforts. Physiologically, maximal static efforts retard blood flow through the muscle, whereas dynamic efforts may facilitate blood flow. Insufficient blood flow will hasten muscle fatigue (3). Furthermore, in a dynamic effort, different muscle groups may be used, with the tension and phase relationships between the muscle groups changing as steering wheel angle changes. Changes in the spatial orientation and velocity of the limbs relative to the steering wheel will alter the driver's mechanical advantage.

Past research confirms that static efforts are not reliable predictors of dynamic efforts. There is little correlation between forces exerted statically and forces exerted dynamically (see Figure 9).

If the driver were an ideal system, then his inherent mechanical advantages together with his muscular strength would determine the maximum force which he could apply to the steering wheel. However, the driver does not behave ideally so that any measurement of intrinsic muscular strength does not correlate well with experimental measurements of human effort.

There are several factors which can contribute to the lack of correlation between intrinsic strength, static effort, and dynamic effort. Some physiological factors have already been mentioned. Psychological factors are probably more important. It is difficult to motivate drivers to exert themselves maximally. Motivation can vary between drivers, between tasks and between trials of the same task for the same driver. Some techniques for motivating drivers will be discussed later. Dynamic task variables can also influence the maximal driver effort. For example, drivers often reduce their muscular output when the duration of the exertion is long, as might be the case if their task demanded large steering wheel angles and slow rotation rates.

It has not been resolved whether the factors which limit a maximal human muscular exertion originate within the central nervous system or within the muscle. Some scientists claim that the brain ultimately limits muscular output, whereas others say that muscular fatigue is the cause. Regardless of which side one supports, it must be recognized that "maximal" efforts seldom represent maximal muscular capacity, and that both physiological and psychological factors influence muscular exertions.

Vehicle: The automobile itself is not a simple system. Its directional control response characteristics change with speed and become nonlinear during high lateral forces. Any measure of human effort in a dynamic test will depend in part on the characteristics of the vehicle. One vehicle characteristic which can influence effort measurements is the amount of steering force required to achieve a specified lateral acceleration. If steering wheel torque is plotted as a function of lateral acceleration as a vehicle is driven through an approximately sinusoidal path at constant speed, a steady-state steering effort plot can be made (Figure 1). Steering wheel inputs are applied slowly so that the vehicle is nearly always at a steady state lateral acceleration. The arrows indicate the torque levels as lateral acceleration is increased

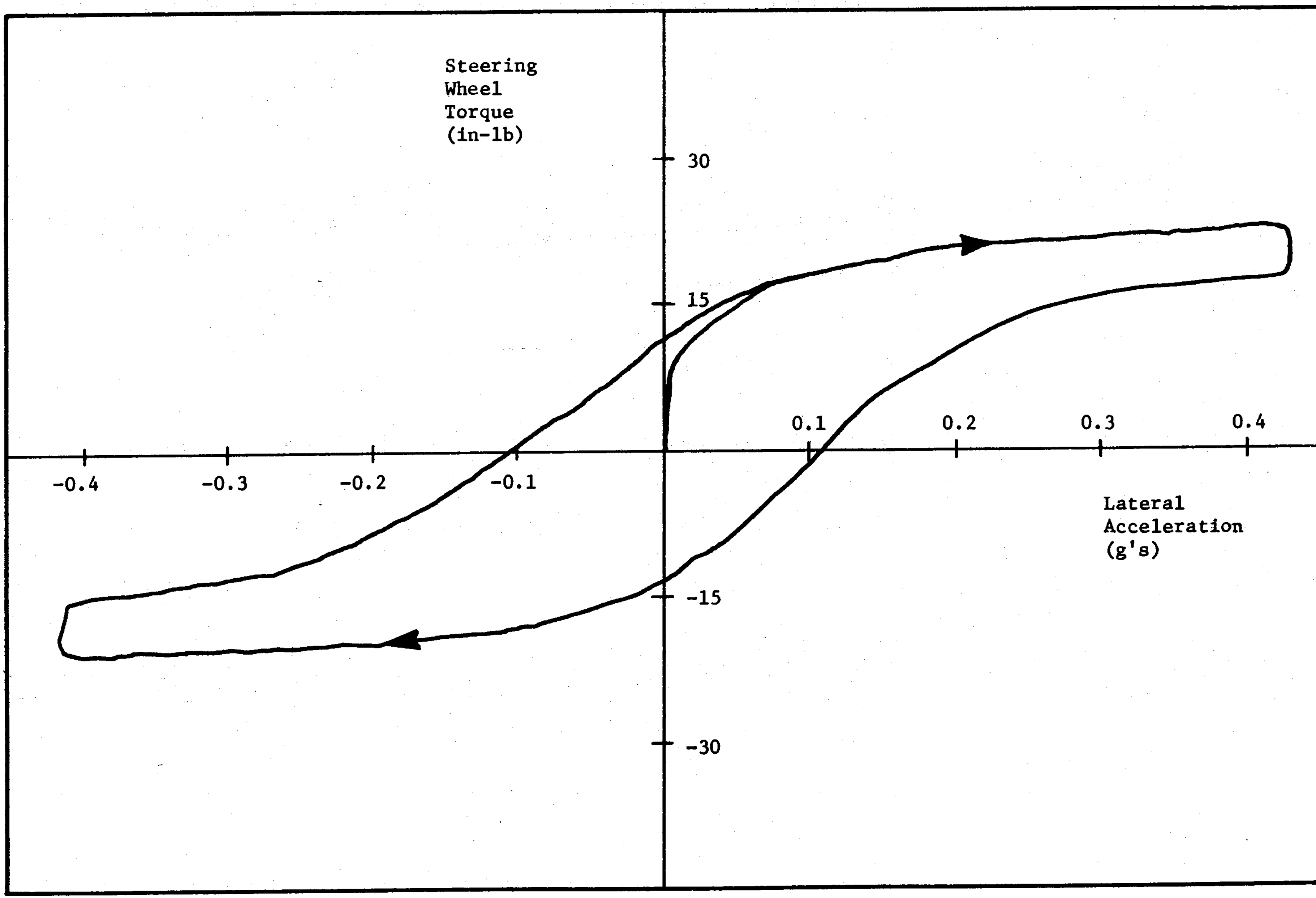

Figure 1. Typical Steady State Steering Hysteresis with Power Steering Operative.

or decreased. Though not specifically shown, the effort level required to maintain a given lateral acceleration will be somewhat less than the effort level required to reach that lateral acceleration. Also the power-off steering system hysteresis is different from power-assisted steering hysteresis (Figure 2).

Another measurement problem introduced by vehicle characteristics is that steering wheel torque is speed-dependent (Figure 3). Steering forces for a specified level of lateral acceleration will decrease as vehicle speed increases. For the data shown in Figure 3 steering rim force decreased by about 3 lb at 0.3 g for a speed increase from 25 to 40 mph. The effect of vehicle speed on steering force is related to steering angle. More angle is required for 0.3 g lateral acceleration at 10 mph than at 30 mph.

Performance Test: The selection of an appropriate test in which the true maximum steering efforts can be measured is always a problem. There are disagreements regarding the importance of static and dynamic performance tests. Static tests are said to be unrealistic. Dynamic tests, on the other hand, can cause many vehicle variables to interact with the effort measurements. Even in dynamic tasks the degree of realism is questionable.

In fact, any experimental effort test can only be regarded as a simulation of the real world. There is no general agreement about the type of driving maneuver which provides the most accurate assessment of driver effort. Severe emergency maneuvers, such as lane changes under power assistance failure, may not be especially meaningful since the probability of occurrence is minute. Power failure in a straightaway does not provide a fair test of effort, although it might be interesting to measure the failure recognition time. Parking maneuvers will require the greatest expenditures of effort but are not dangerous from a safety viewpoint. Between these extremes are maneuvers such as low speed intersection turns and moderate speed serpentine driving tasks.

If one attempts to define maximal efforts by having drivers maneuver through a test course, then the steering efforts so measured will depend on the maneuver. The driver must be capable of exerting a certain amount of effort in order to accomplish the maneuver. Since steering efforts can be quite variable among drivers, the task-defined effort level may not be attainable by all drivers. If the task effort level is so high that few drivers can successfully perform the maneuver, the remaining drivers may content themselves with a submaximal exertion or even give up entirely. As a result, the mean effort for all drivers is reduced and the variability is increased. If the task-defined effort is reduced so that nearly all drivers can perform the task, then the mean effort is not an accurate estimate of the maximal steering effort.

Anthropomorphic variables such as location of controls, seat position, hand position, etc., will also affect both static and dynamic efforts. The usual practice has been to permit drivers to adjust themselves to nominally comfortable positions.

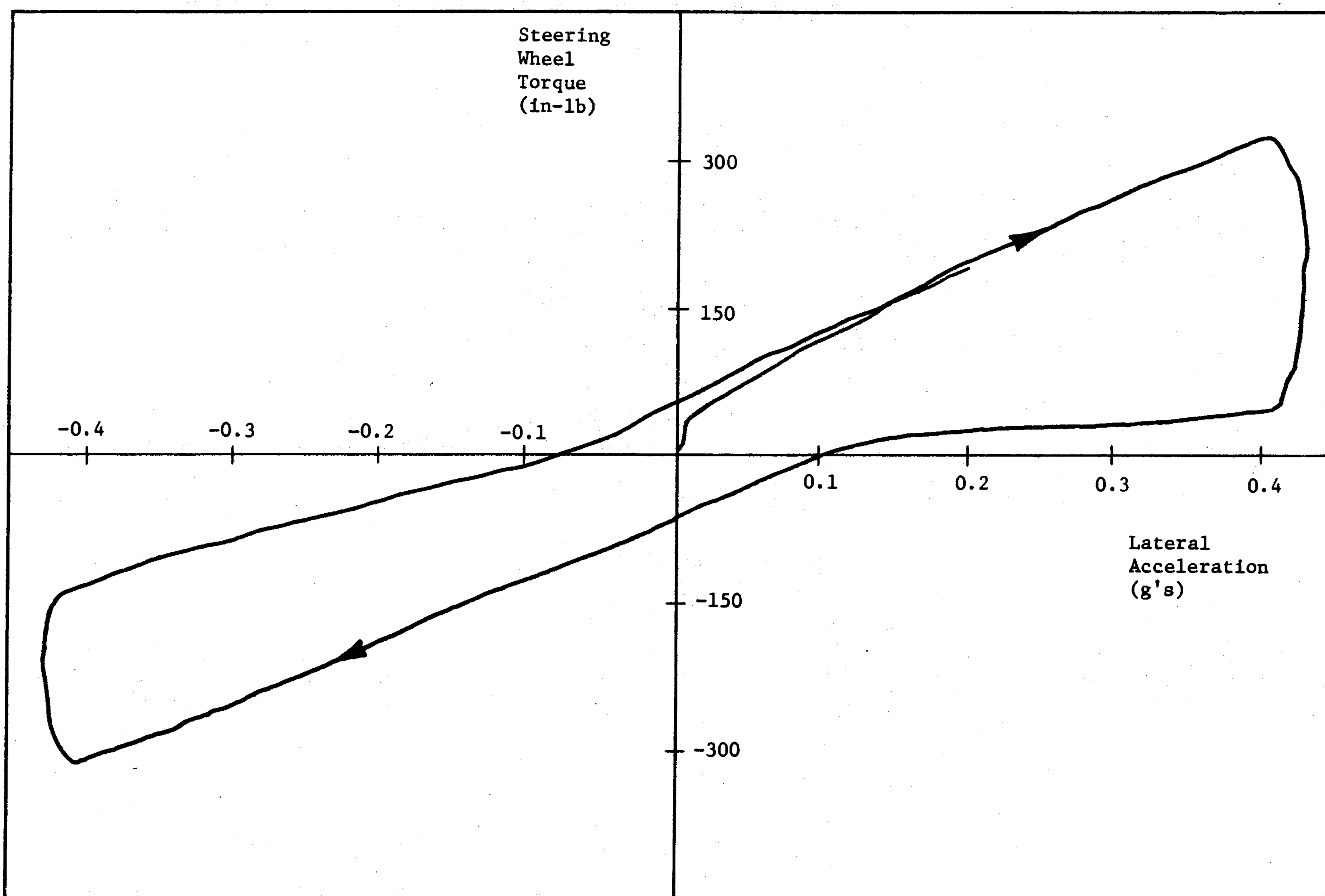

Figure 2. Steering Hysteresis with
Power Steering Inoperative.

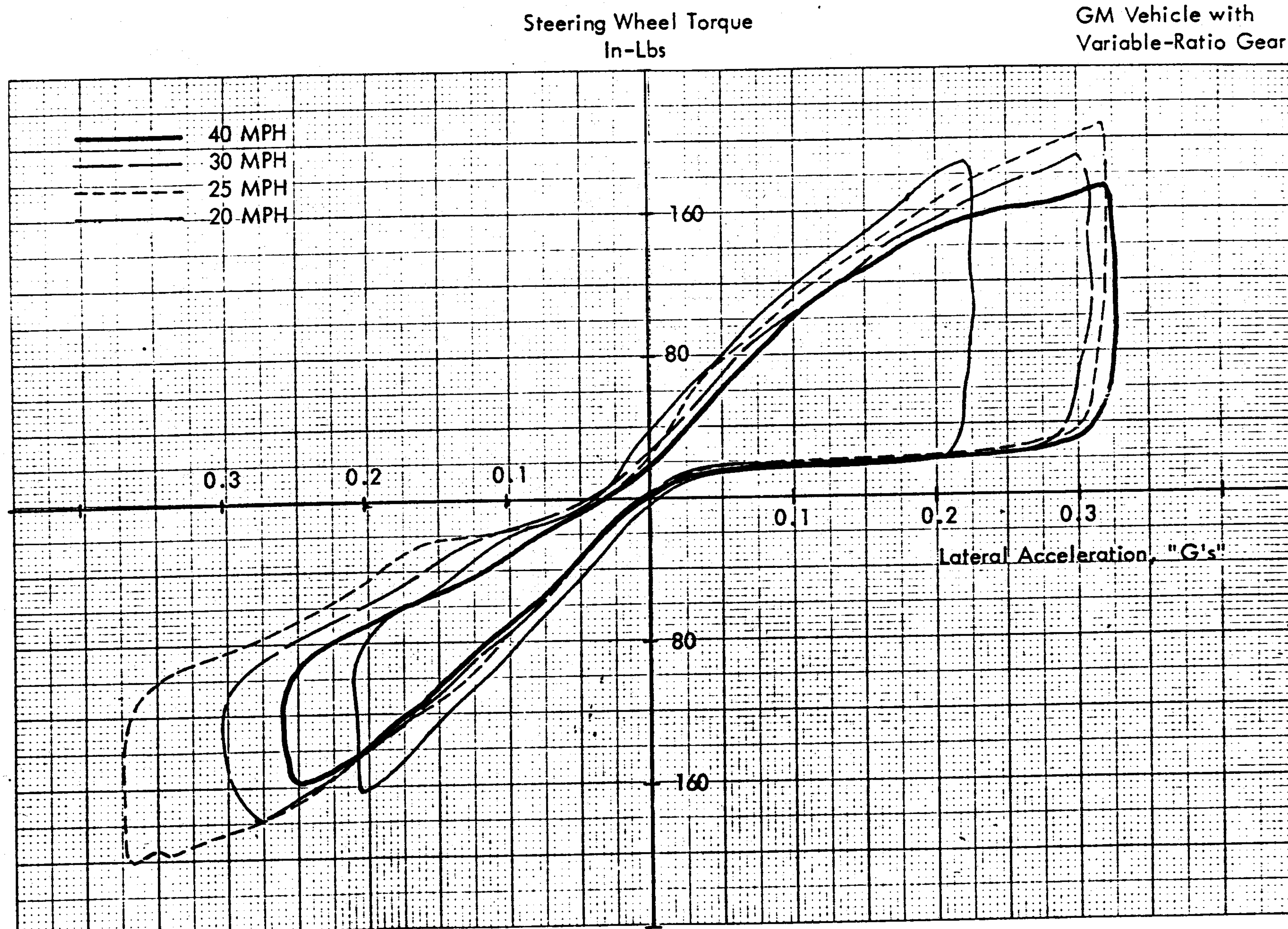

Figure 3. Effect of Vehicle Speed on Power Steering Inoperative Hysteresis Plot

Motivation: The problem of adequately motivating subjects must always be dealt with in any human research. It is an especially difficult problem in measuring maximal efforts. The effort scores can dramatically change as a function of a driver's motivational state. Consequently, it is very important to motivate subjects in a reliable and uniform manner. If the experimenter ignores the issue of motivation, then subjects will provide their own motivation, thereby introducing unwanted variability into the experiment. Some of the techniques used to manipulate motivation include the offering of payoff schedules, the feedback of knowledge of results (KR), the use of verbal exhortations, and the choice of driving environments.

Payoff schedules are constructed to reward subjects contingent on their attaining a specified criterion performance score. It may be necessary to conduct a pilot experiment in order to determine an appropriate criterion score. One possible experimental method is to establish a fixed criterion level below which no reward is given and above which the rewards are given according to a payoff curve (linear, logarithmic, etc.). Many other payoff techniques can also be conceived.

Knowledge of results can be manifested in several ways. It can be a smile or nod from an experimenter or a complex computer-generated display. It can be a quantitative score or qualitative judgment of the subjects' performance. KR can be given during or after a performance trial. It can be intrinsically derived by the subject from his task or extrinsically provided by the experimenter. An extensive discussion of KR is given by Annett (4).

Verbal exhortation is another means to motivate subjects to better their performance. The experimenter should keep the verbalizations approximately similar for all subjects. It is often a good idea to rehearse the exhortation before beginning the experiment.

The driving environment can also be an important motivational variable. The presence of stress-inducing stimuli in the environment can influence the driver's assessment of his risk level in a maneuver. Increased risk levels during a power steering failure can significantly increase the driver's muscular exertion. However, data variability can also increase because some drivers may freeze or make the wrong decision when overstressed. The risks versus benefits of the experiment must be carefully considered.

Practice: One of the ironies of maximal strength experimentation is that the maximal human efforts exhibit a strong learning effect. Maximum efforts increase rapidly during the first few practice trials. The data variability is also greatest on these trials. The maximum efforts reported by an experimenter will depend on the trial or trials for which they were computed. There is no standardized practice schedule to be used in effort experimentation.

Performance Metric: The choice of a performance metric is especially perplexing in tests of human effort. Several measures have been tried, such as peak force, average force exerted over some time interval (usually $t = 1,2,\ldots, 10$ sec), mean force neglecting any transient peaks, etc. Even root mean square (rms) force is a potential measure since the tension often randomly fluctuates about some mean value. It is disconcerting that these metrics may score the same performance quite differently. For example, a performance trial can exhibit a low peak but high mean force compared to other performances. Therefore, drivers will be graded differently relative to one another because of the choice of performance metric. The peak force is the least conservative estimate of the driver effort.

Maneuvers which require a maximal exertion for more than a one second duration seldom occur in normal automobile driving. Also, since power-off steering control usually requires more effort to reach a given lateral acceleration than to maintain the lateral acceleration, peak effort (or peak effort for about one second duration) may be a reasonable performance metric for power-failed tasks.

It is important that all force measuring instrumentation be reported. Reports should also include an estimate of the measurement resolution. Scale changes on the recording device when measuring different effort levels should also be noted. If the measurement is made from chart paper, the experimenter should describe how he judged the performance. Human interpretation of peaks or averages does introduce variability.

Statistics: It is frequently suggested that the maximum effort capabilities of a 5th percentile female be used to establish design limits for brake or steering controls without power assistance. Measurement of 5th percentile female effort should include a lower tolerance limit. Lower one-sided tolerance limits specify, with some probability γ, that a fixed proportion $(1 - \alpha)$ of the driver population will be capable of exerting efforts greater than that limit. For a sample of size N this limit is computed from the relation, $\bar{x} - Ks$, where $\bar{x}$ is the sample mean, s is the standard deviation, and K is found from tables once N, γ, α and the sample distribution are known. The coefficient K will be smallest; i.e. the lower tolerance limit will be largest, if the sample data can be shown to be normally distributed.

For example, if $\gamma = .90$, $\alpha = .05$, and if a second sample of N efforts is to be measured, one can be 90% certain that 95% of these effort levels will be greater than the tolerance limit $(\bar{x} - Ks)$ computed from the first sample statistics. A tolerance limit will produce a more conservative estimate of the 5th percentile effort than will the 5th percentile computed from any single sample population statistics. It is important to recognize that small sample sizes do not provide much useful information about the 5th percentile performance level unless the variability of the data is very low.

APPLICABLE STUDIES

The four experiments to be reviewed include the Harvard study by Stoudt, et. al., the Ford study by Eaton and Dittmeier (5), three GM studies, one by Thompson and the other two by Hill and Lawrence, and two government sponsored studies by

Man Factors, Inc. (2, 6). Each experiment will be summarized separately. A detailed chart comparing the experiments is given in Appendix B.

Stoudt, et al (1)

Fifty female volunteers were employed as subjects. These subjects as a group were generally representative of the female driving population in terms of age, weight, height and possibly handgrip strength. Their task was to exert a static effort, both clockwise and counterclockwise, against a locked 18-inch steering wheel. A seating buck was used with the steering column angle at 27° from the horizontal. They were given one familiarization trial followed by ten more trials, one trial in each direction at each of five different diametric hand positions. A maximal effort was required for five seconds after which a one minute rest was granted. It is not clear if knowledge of results was provided after each trial. Verbal exhortations were given prior to and during each trial. All but one subject were believed to be sufficiently motivated. Presentations of hand position were systematically ordered in an attempt to balance any practice or fatigue effects across hand positions. Data were recorded on chart paper and average torque to the nearest 5 inch-pounds was computed over the five-second trial.

Note from Table 1 that the "9-3" hand position (C) yielded a high mean torque in both directions, although the variability was also comparatively large. The 5th percentile score, computed from the mean and standard deviation of the data, was 25.4 lb rim force. The lower one-sided tolerance limit was 21.8 lb for the 5th percentile female with 90% confidence ($\alpha = .05$ and $\gamma = .9$). The data ranged from a low of 21.1 lb to a high of 75 lb rim pull for position C. One 76 year old had a low of 18.9 lb in position D with the remainder of her efforts ranging between 22.8 and 37.8 lb. All subjects averaged more than 22 lb for the ten exertions. The lowest rim force for any hand position was 12.8 lb, and the highest 76.7 lb. Age, sex and weight have not correlated with maximum steering wheel rim forces. Handgrip strength correlations were significant but could account for only 10% of the variance in efforts. Other variables were apparently more important in determining a driver's effort capabilities.

check for specific statement

The authors suggest that the efforts determined in their isometric laboratory tests probably underestimate the forces exertable in actual emergencies under ideal conditions, but overestimate efforts in sub-optimal conditions.

Eaton and Dittmeier (5)

Twenty age-representative female drivers performed a lane change maneuver under the guise that they were rating handling qualities of a 1968 full-sized sedan having a 16-inch diameter steering wheel. The maneuver required a 12-foot lateral lane change within a variable (40'-50') longitudinal gap into a 12-foot wide recovery lane (Figure 4). Drivers were permitted to familiarize themselves with the vehicle's handling properties, following which they were given one familiarization trial at 5 mph through the maneuver. On the last four trials,

TABLE 1

Torques Exerted on a Steering Wheel
(in Inch-Pounds) by 50 Female Subjects. Values
are Average Torques Maintained Over 5 Seconds. Stoudt Study (1)

Hand Position[1]	Direction of Movement	Mean ± S.E.[2]	S.D.[3]	Approximate Percentiles 1st	5th
A	Right	364 ± 15.9	112.2	103	179
A	Left	268 ± 11.3	80.0	82	136
B	Right	396 ± 15.6	110.5	139	214
B	Left	320 ± 11.4	80.5	133	188
C	Right	395 ± 14.3	100.9	160	229
C	Left	388 ± 14.5	102.5	150	219
D	Right	308 ± 11.9	84.1	112	170
D	Left	390 ± 15.6	110.1	134	209
E	Right	265 ± 11.0	77.9	84	137
E	Left	343 ± 13.6	95.9	120	185
Average of all 5	Right	364 ± 11.8	83.3	152	209
Average of all 5	Left	342 ± 11.5	81.2	153	208
Average of all Positions	Both Directions	344 ± 11.4	81.0	156	211

[1]The hand positions are as follows - with reference to a clock face:
- A - Right Hand at 12, Left at 6
- B - Right 1:30, Left 7:30
- C - Right 3, Left 9
- D - Right 4:30, Left 10:30
- E - Right 6, Left 12

[2]S.E. refers to Standard Error

[3]S.D. refers to Standard Deviation

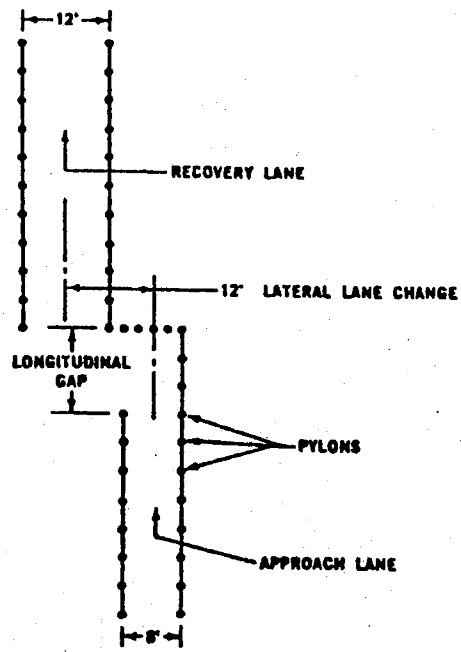

Figure 4. Lane Change Task Maneuver
Eaton and Dittmeier Study (5)

unknown to the drivers, the longitudinal gap size was adjusted trial-by-trial as follows: 50, 45, 40, 40 feet. Speed for each of these trials was fixed at 35 mph. Also unknown to the drivers the power assist was disabled on the last trial.

Data were recorded for the last two trials only. Steering effort performance was scored as the maximum horsepower (which is proportional to the instantaneous product of steering wheel angular velocity and torque) maintained for one-half second. All transducers and recording equipment were concealed. The mean maximum power for all subjects was 0.103 horsepower, with a standard deviation of 0.041 hp. The data ranged from 0.045 - 0.20 hp, and were "nearly" normal on probability paper. The lower one-sided tolerance limit for the 95th percentile female is 0.013 hp with 90% confidence (Figure 5).

The task difficulty was such that, under power assist failure, the "majority of subjects could not successfully negotiate the course." Performance accuracy before and after power failure was not reported so it is not possible to interpret a "successful" performance. Furthermore, no report was given regarding the amount of effort required to successfully traverse the course with power failed. Since the task itself establishes a ceiling effect on maximal efforts, the effort requirements of the task should have been reported. No mention is made of the drivers' brake, usage or motivation state with power failure.

Perhaps the most interesting feature of this experiment is the use of horsepower as the performance metric. This score represents an attempt to remove the variability in rim forces that is attributable to steering wheel velocities. The rate of steering wheel rotation is known to inversely affect the driver's maximum effort capability. It has not been substantiated that the two variables satisfy the multiplicative relationship which the horsepower measure would indicate. The horsepower metric is justifiable if drivers are power-limited rather than force or velocity limited.

It is difficult to compare the horsepower data with other experimental data because rim forces and steering velocities were not reported. If a 5th percentile steering wheel velocity of 60 deg/sec is reasonable for the lane change maneuver with the power steering failed, then the steering force at the 0.013 hp tolerance limit would be 10.2 lb rim pull for the 16-inch steering wheel. However, a steering velocity of 60 deg/sec would require a rather large distance to complete a lane change. Most lane change maneuvers require steering wheel velocities of more than 600 deg/sec. In this case the steering wheel force at the 0.013 hp tolerance limit would be about 1 lb which is an unreasonably small number.

The authors also refer to another Ford study which found a 5th percentile effort tolerance limit (at γ = .90) of 31 lb rim force using an isometric wheel, and a steering velocity tolerance limit (at γ = .90) of 165 deg/sec for zero steering wheel force. Based on this data, it is ~~apparent~~ likely that less than 95% of the female drivers could successfully execute the maneuver even with normal power steering.

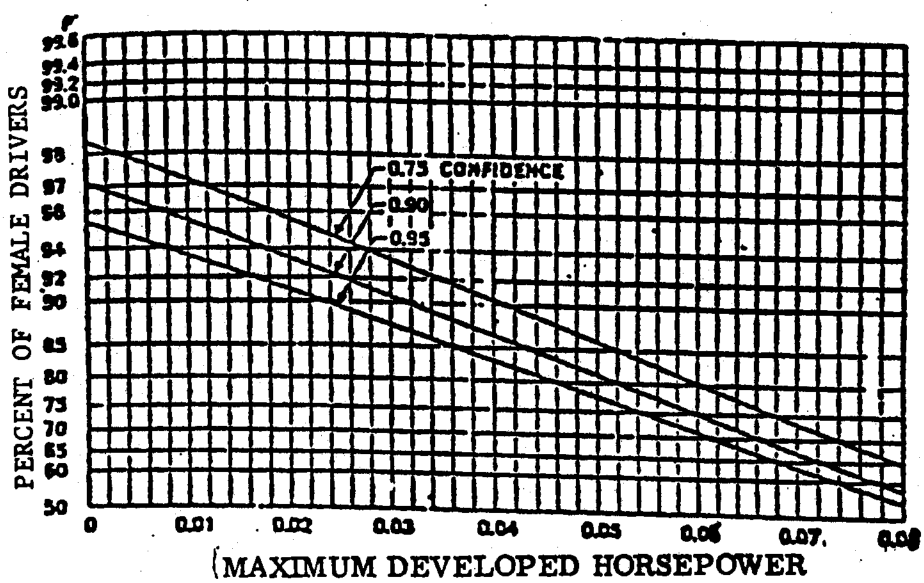

Figure 5. Percent of the Female Driving Population which can Generate at Least the Indicated Steering Wheel Horsepower. Eaton and Dittmeier Study (5)

Thompson General Motors - 19XX

Nineteen female subjects drove a 1966 Buick LaSabre equipped with 11:1 ratio steering gear through an intersection maneuver at speeds of 10 mph or less. Subjects were informed only that their performance was being monitored. After two practice trials the engine was failed at 30 feet from several large rubber oil drums. Subjects had the option to stop or to make a 90° turn, either left or right. After convincing drivers that the first failure was unplanned, the drivers performed another intersection maneuver in which a surprise power failure occurred. They were then informed that the failures were planned, and they were instructed to turn as hard as possible for three more intersection maneuvers. Finally, with the vehicle stationary, dynamic efforts were read from chart recordings.

The mean peak force for all subjects, regardless of turn direction, was 15.9 lb rim pull on the first intersection trial. The mean peak force with the vehicle motionless was 38.4 lb, with about 29% of the forces falling below 26.3 lb. Data ranged from 8.75 - 50 lb. Data were plotted as cumulative percentiles (Figure 6). No standard deviations were reported and apparently the data were not tested for normality. With a surprise failure the range of the data was about 3.8 - 25 lb, and with foreknowledge of failure the range was about 3.8 - 31.2 lb. Approximately 20% of the forces on the surprise trials were less than 7.5 lb.

No estimate of the torque required to successfully complete the maneuver was given. (~~Hill has~~ Subsequent studies estimated the task difficulty at 52 lb rim pull.) No subjects successfully completed the turn in the surprise failure condition. All braked before reaching the barrels. One female driver did complete the turn when forewarned about the power steering failure. All subjects exerted more force with the vehicle stationary than with the vehicle moving, indicating that they were capable of greater exertions in the intersection maneuver.

The steering torques in the intersection maneuver were quite low. They were approximately similar to the torque levels of a manual steering vehicle. It is very difficult to interpret these results, particularly since the nature of the subjects' instructions is not clear. If the drivers were only informed that their performance was being measured, they could easily misinterpret the purpose of the experiment. For example, it could be an experiment about reaction time or minimum stopping distance, in which case driver strategy would be to brake hard as soon as she detected an unusual steering effort. Since no premium is placed on negotiating the corner, the drivers' optimum strategy in terms of minimum effort was simply to stop the vehicle. This was the easier course of action, it had no adverse consequences, and it would not stress the drivers very much. In addition, unless adequately encouraged, there may be a greater reluctance among females than males to apply their maximum force to any failed device, because females are usually less knowledgeable about mechanical systems and may have a greater fear of breaking something.

Discuss earlier motivation

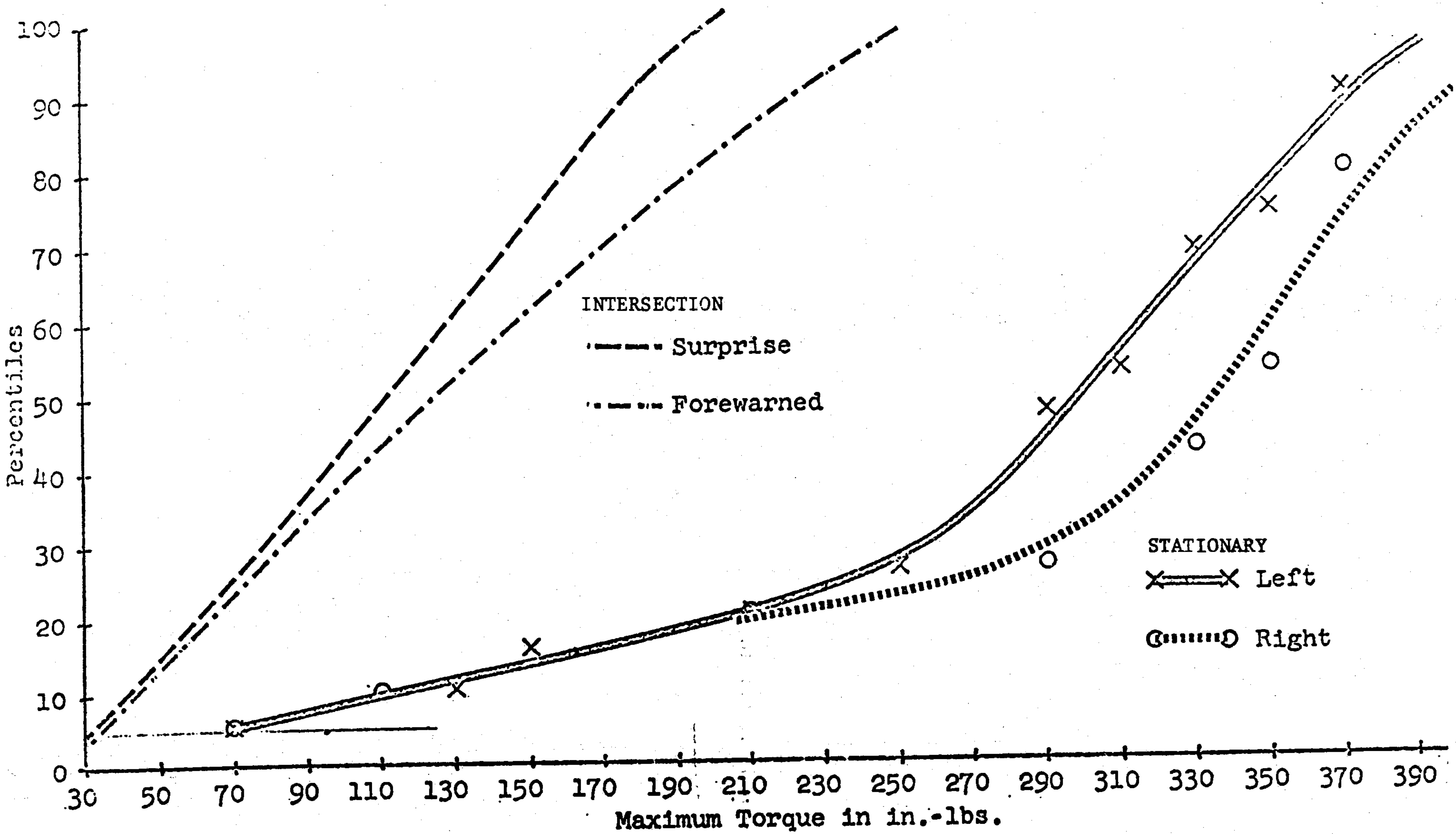

Figure 6. Distribution Showing the Percent of the Test Population Exerting up to the Indicated Torque Under Various Conditions. ~~Thompson~~ Study.

GM 19XX

General Motors

Hill and Lawrence

This study comprised two related experiments. Each will be reported separately.

1970

Part 1 - Sixteen male and sixteen (clerical and secretarial) female subjects drove a standard 1969 Oldsmobile 98 with 16-inch steering wheel diameter through intersection and serpentine maneuvers. They were told they were participating in a speed holding and steering smoothness test. Their task was to traverse at 30 mph a cone course which began with a serpentine maneuver consisting of four 200-foot radius curves (Figure 7). The middle two curves were outlined with a guard rail placed 10 feet outside the course and mounted on a moveable platform. The course continued to a stop sign prior to entering an intersection maneuver at about 7-10 mph. Left and right turn radii were 40 feet and 25 feet respectively. Turn direction was always to the left. Turns were negotiated into a 12-foot lane bounded on the far side with guard rail.

Subjects were driven through the course at 20 mph prior to the experiment. Drivers were given a total of four trials. Following the first trial, the power steering was unexpectedly disabled using a silent switch which disengaged an electric clutch. Power was reinstated at the conclusion of the maneuver in which the failure occurred. After one more dummy trial the power assistance was again failed. Half of the drivers of each sex experienced power failures only in the intersection maneuver, while the remaining subjects encountered failures only in the serpentine. No driver had power assistance disabled in both maneuvers. Power failures in the serpentine course always occurred midway between two curves at transition points where steering wheel angle magnitude and velocity were nearly zero. Power was only failed prior to entering the curves bordered by guard rail. Half the drivers had the power failed first in a left turn and then in a right turn of the serpentine. Order of failure was reversed for the other drivers.

At the conclusion of the experiment, steering efforts were measured for each driver with the vehicle motionless (so-called stationary steering torque). Drivers were instructed to turn the wheel as hard as possible and to hold the force for about four seconds. Initial hand position was diametrically placed at ±45 degrees from horizontal with the movement proceeding clockwise or counterclockwise respectively. Usually wheel motion stopped after about 180° of rotation and the wheel was held there for the duration of a trial. Each driver was given one trial in a clockwise direction and one trial in a counterclockwise direction. The order of presenting the turn directions was balanced across drivers. No knowledge of results was given.

Data were recorded with the on-board instrumentation typically used in control response experiments. Peak torques sustained for at least 0.5 seconds were read to the nearest ft-lb from chart recordings. Rim forces for the serpentine were measured in the curve where the failure occurred. The serpentine maneuver required about 27 lb and the intersection about 42 lb rim force for successful

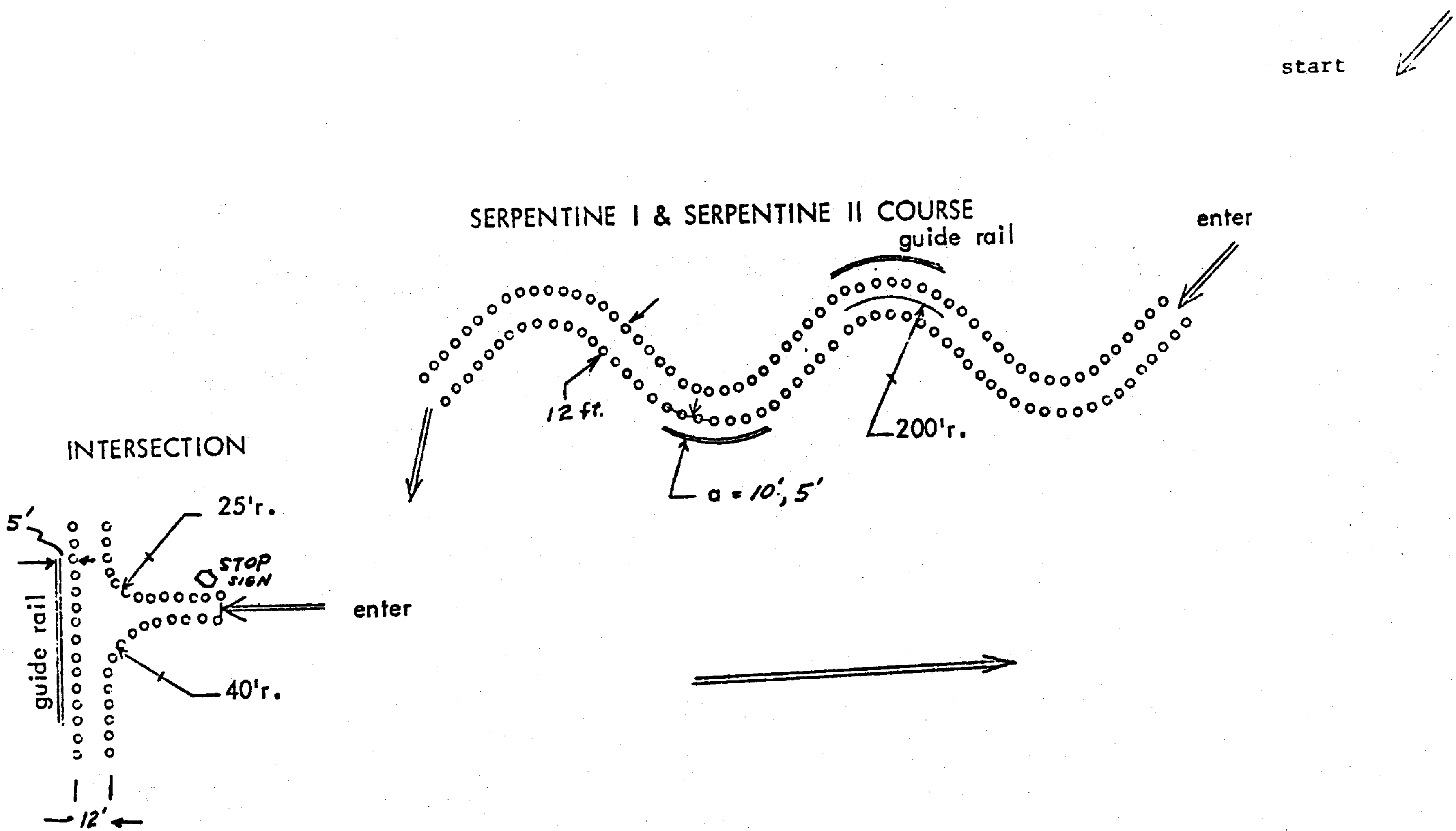

Figure 7. Diagram of Courses Used in Surprise Power Steering Failure Study.
~~Hill and Lawrence~~ Study

completion of the task. Both peak forces and forces sustained for three-five seconds (hold force) were measured in the stationary effort tests.

All males successfully completed the intersection maneuver. Mean peak force for the males was 53.2 lb. On the other hand, female drivers successfully continued through the intersection on only 3 of 16 trials. There were 12 stops in the intersection and one guard rail contact. Mean peak effort was 28.8 lb with a standard deviation of 10.9 lb. The high variability reflects the alternative courses of action taken by the eight female drivers. The lowest effort was 15 lb. All women exerted less effort in the intersection test than in the stationary vehicle test. In other words, they usually chose to stop even though they were capable of greater effort. All drivers successfully maneuvered through the serpentine course. The mean force for the females was 26.4 lb with a standard deviation of 3.13 lb. Some of the women exceeded their stationary steering force in this maneuver.

Part 2 - Sixteen different clerical and secretarial female subjects drove the same serpentine course with the test vehicle modified to include an 11:1 steering gear ratio. Front tire pressures were also reduced from 26 to 20 psi cold. Guard rails were moved to within five feet of the cone course. A steering wheel force of about 36 lb was now required to negotiate the serpentine with the modified vehicle. No intersection maneuvers were tested, but stationary steering forces were measured.

Results are tabulated in Table 2. The mean peak force sustained for 0.5 seconds was 40.3 lb with a standard deviation of 4.7 lb. A lower one-sided tolerance limit at 90% confidence for a 95th percentile female was 29.4 lb. Data for all power failures ranged from 30 to 51 lb rim force. Data for the first failure ranged from 30 lb (for the driver who stopped) to 46.5 lb. Mean rim forces for the first and second failures were 39.5 lb and 40.6 lb, respectively. Two subjects failed to complete the course on the first power steering failure - one subject stopped in the course, and the other brushed the guard rail and subsequently left the course. Another driver slowed down considerably, and two more drivers struck a few traffic cones. All drivers were successful when power was failed the second time, although one subject did give up in the final curve.

Maximum steering wheel angles on the power failed trials ranged from 72° to 190°. On the immediately preceding trial these ranges were 90° to 151°. Vehicle speeds when the power assist was disabled ranged from 27 to 24 mph. Speed on the first power-failed turn ranged from 0 to 37 mph (for the driver who hit the guard rail); speeds in the second power-failed turn ranged from 25-33 mph. Mean speed reduction was 5.7 mph in the first failure. There were 10 brake pedal applications in the first failure and one in the second failure. Mean peak lateral accelerations were 0.31 g and 0.32 g respectively.

A sample time history showing the force requirements for one serpentine curve is shown in Figure 8. Each curve required about four seconds to complete. Note that a peak force is perhaps necessary for about one second, following which a nearly constant force must be exerted for about two seconds before

TABLE 2

Summary of Steering Effort Data Including Tolerance Limits. ~~Hill and Lawrence~~

Maneuver	Subjects	Mean Rim Force (lb)	Standard Deviation (lb)	Tolerance Limit $\alpha = .05, \gamma = .90$
Intersection	8 Males	53.2	7.6	<0
	8 Females	28.8	10.9	
Serpentine - Part 1	8 Males	27.1	2.0	
	8 Females	26.4	3.1	17.8
Serpentine - Part 2	16 Females	40.3	4.7	29.4
Stationary Steering Torque				
Part 1:	16 Females	Peak = 45.1	9.8	22.5
		Hold = 30.2	6.7	14.9
Part 2:	16 Females	Peak = 61.9	7.2	45.4
		Hold = 44.4	9.0	23.8
Parts 1 and 2:	32 Females	Peak = 53.5	12.2	28.2
		Hold = 37.3	11.2	14.1

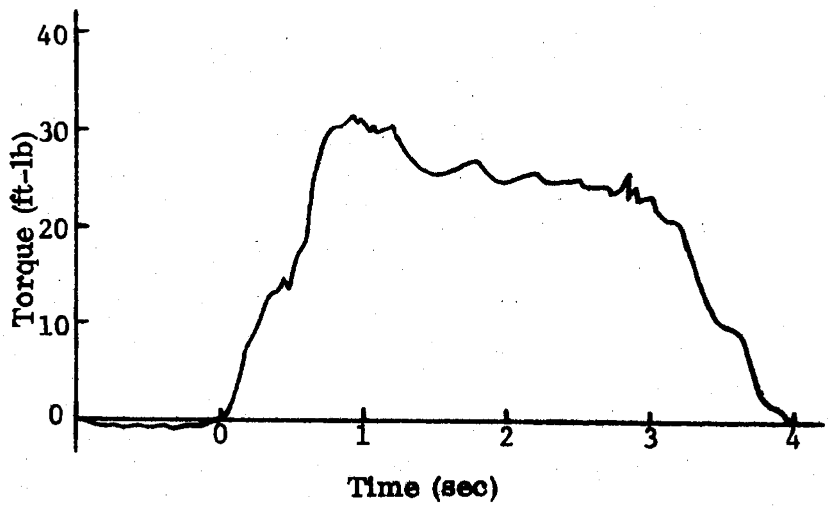

Figure 8. Typical Record of Torque versus Time Through One Curve of the Serpentine. Power Failure Occurred at t = 0. ~~Hill and Lawrence~~ Study.

exiting from the curve. However, rapid, jerky steering movements could cause transient peaks to be greater for less period of time. Fortunately only one driver adopted a jerky strategy, so judgment of peak efforts was not very difficult. No measures of steering smoothness were reported.

Stationary steering torques were measured using both peak force sustained for one-half second and mean torque held for three seconds as performance scores. The hold torque was difficult to determine because the torques did not remain constant. The peak stationary hold force for all thirty-two females was 37.3 lb. The second group of sixteen females had mean peak rim forces of 61.9 lb with a standard deviation of 7.2 lb; their three second hold forces were 44.4 lb with a standard deviation of 9 lb. This group of subjects produced a lower one-sided tolerance limit of 45.5 lb peak rim force but only 23.8 lb sustained force.

The rim force required to negotiate the serpentine with power steering failed was at least 12 lb lower than the peak force which any subject exerted with the stationary vehicle. No subject exerted as much peak rim force in the maneuver as in the stationary vehicle (Figure 9). There was no significant correlation ($r = 0.143$) between peak maneuver effort and peak stationary effort. There also was no significant correlation ($r = 0.019$) between peak maneuver effort and stationary hold effort. Hence, there is no linear relationship between serpentine maneuver efforts and stationary steering efforts even though both are dynamic efforts by definition.

The results demonstrate that female drivers can steer a vehicle without power assistance through a fairly severe dynamic maneuver. The lone exception was the driver who brushed the guard rail. She exerted 36 lb rim force just before contacting the guard rail. However, her vehicle speed increased from 33 to 37 mph and her maximum steering angle input was only 80° after the power failure. She was successful on the second power failure. Her stationary hold steering rim force was 58.5 lb, which ranks second highest among the sixteen drivers. Although apparently physically capable of performing the task, she probably erred in good judgment about her predicament. She had had her drivers license for only one year.

There are some important differences in driver control behavior between the first and second serpentine power failure. Primarily, the number of brake pedal applications was reduced from ten to one. Since the drivers had not previously experienced a power failure such as this, they were apparently more undecided about what action to take. Although the power-off efforts are approximately similar in both failures, the suspicion is that the first loss of power steering was the only true surprise failure.

It is surprising that stationary steering rim forces are considerably greater for the second group of female drivers (30.3 lb vs 44.4 lb). It could be that the second group of subjects were stronger. However, the torque differences are more likely related to the different gear ratios and tire pressures used in each vehicle. The lower gear ratio and tire pressures in the modified vehicle of Part 2 permitted drivers to develop and hold their

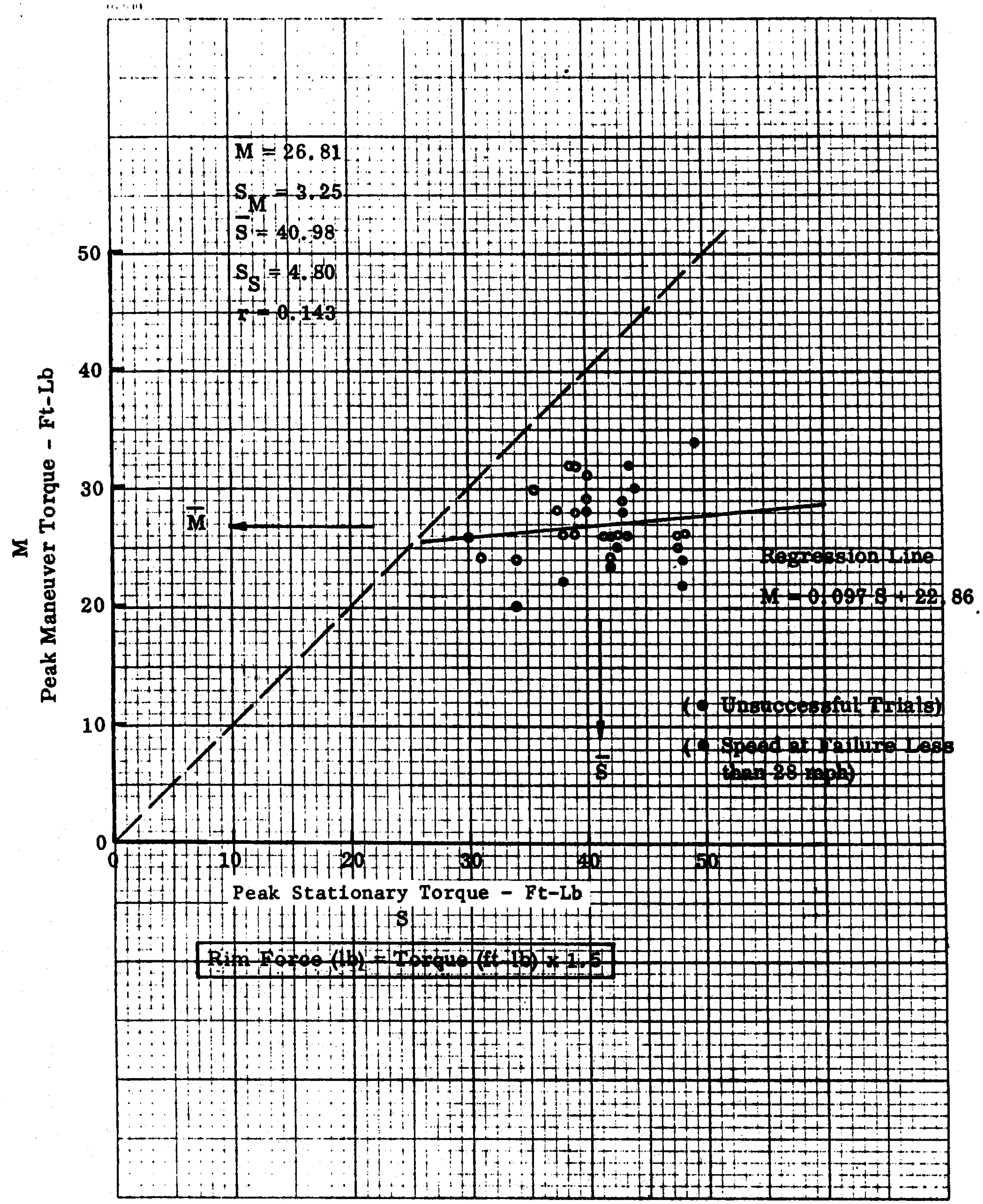

Figure 9. Peak Serpentine Maneuver Power-Off Effort versus Peak Stationary Effort. ~~Hill and Lawrence~~ Study.

maximum rim force at much lower steering angles where their mechanical advantage was greater. A less plausible explanation is that the drivers were more acclimated to the higher torques demanded by the modified vehicle.

The authors do not report the characteristics of their driver sample. However, they do acknowledge the similarity between their mean steering rim forces of 44.4 lb with a standard deviation of 9 lb and the Harvard mean static steering effort, grand mean of 38.2 lb with a standard deviation of 9 lb. Since the Harvard data showed no correlations of age, weight or height with static effort, the representativeness of the GM subjects is less in doubt.

The serpentine maneuver with power steering disabled appears to have been sufficiently taxing to have adequately motivated the drivers. While seldom encountered in real life, loss of power steering in a serpentine bordered with guard rail does place a high priority on negotiating the curve. The maneuver is considered to be moderately severe because 90% of the driving population seldom reach 0.3 g in curves (7). In fact, some subjects needed the initial practice trial in order to maintain the lateral acceleration at 0.3 g through the curves.

With respect to ~~Loss of power assistance probably occurs most frequently in a low speed~~ intersection maneuver, ~~primarily because of engine stalling.~~ The engine was not failed in this experiment so that drivers could choose to complete the maneuver. ~~It could be argued that steering control is not crucial in an intersection because stopping distances are so short.~~ However, if one plans to use the intersection maneuver to establish guidelines for maximum driver efforts, then some priority must be established for completing the turn. Monetary incentives, approaching vehicles, etc., must encourage the driver to execute the turn. Certainly these tests have not established maximum effort levels in intersection failures because the prevailing circumstances did not emphasize completion of the turn.

Man Factors, Inc. (2)

Two government funded research projects involving driver steering efforts were conducted by MFI. The first study was conducted in seating bucks while the second utilized on-the-road vehicles.

MFI-1 - Nine female subjects were selected from a total of forty females who were tested for their handgrip strength. Although it was intended that these nine subjects represent the weakest drivers, only five of the subjects who were selected were below the 50th percentile in grip strength. The subjects were given three trials each in the clockwise and counterclockwise directions at three different hand positions, at three different angular velocities, and in three different buck configurations. In addition, two steering wheel diameters were used in Buck III, and three steering column angles were used in Buck II. Not all subjects were tested in every condition. Each buck was tested at a different period in time, and the subjects also performed braking tasks prior to the steering tasks.

The subjects were given practice trials before taking data but the amount of practice was not reported. Both hands were placed on the wheel about 180° apart. The task itself was somewhat unusual in that the subjects did not rotate the wheel themselves, but instead were required to exert force against either a locked or a rotating wheel. Apparently the wheel maintained the same rotational speed regardless of the subjects' exertions.

Data were recorded on an X-Y recorder as force versus displacement. The total displacement was about 195° of steering wheel rotation. An average trace for the three trials was visually fitted through the data and peak forces were measured at three different displacements representing about 0°, 90° and 180° rotation. Data from five subjects were used in the analysis. Because each subject was not tested in all conditions, the mean force scores for only four subjects were computed for each buck, and each group of four had in it some subjects not represented in the other groups. Taken together, these subjects were shorter and older but weighed nearly the same as the national averages for drivers.

The ~~method of~~ data analysis ~~was obviously determined ex post facto. The analysis itself was~~ questionable because the subjects were confounded among the bucks. The plan of the experiment also permitted some subjects to gain more experience than others in this kind of task. This lack of experimental controls makes it difficult to interpret the results.

In summary, the results indicated the drivers exerted the largest forces when the wheel was locked and the hands were in the "9-3" position, and the least forces when the wheel was rotating fastest (25 rpm) and the hands had been rotated to the "6-12" position (or "12-6", depending on the rotational direction). In making their recommendations for a maximum allowable steering force, the authors selected the lowest mean force for the four subjects from all combinations of conditions within each buck, subtracted a 25% safety factor, and rounded down the result to the nearest half-pound. For the buck which represented the standard sedan, the recommended force was 3.5 lb. By comparison, a typical power steering automobile would require about 2 lb of rim force just to negotiate a turn at a lateral acceleration of 8 ft/sec^2.

There are some problems justifying the use of the fast rotation with the hand position having rotated 195° from the start of the trial as the basis for a force standard. First, the drivers always experienced the fast rotation rate last in their practice schedule. So the drivers may have been fatigued at this point. Second, this hand position occurred only at the end of a trial when the subjects were more likely to be letting up because they knew the trial was about finished. Third, this score weighs only low speed turns involving at least 180° of steering wheel input.

<u>MFI-2</u> - The second experiment employed as subjects one hundred and eight-two females who were representative of the national driver population in terms

of their age, height and weight. They were asked to exert their maximum pedal and wheel force with the power assist failed and the vehicle stationary. They then drove three laps at 15 mph around a short closed course (Figure 10). The subjects were only informed that their steering and braking behavior was being monitored.

The course was delinated with white lines and outlined with cones at certain places. Shortly into the second lap, unknown to the subjects, the brakes were failed. Farther into the lap the power steering was failed. The steering failures occurred equally often in left and right turns. These failures occurred again on the third lap, but this time the subjects were forewarned. It was believed that the first steering failure was a surprise to most subjects even though it followed the brake failure because the brake failure was not very noticeable. The amount of power-off effort required in this task was not specified but was believed to be greater than that of the Ford experiment. The task itself is basically a serpentine maneuver, but because of the low vehicle speed it can also be considered as an intersection-like maneuver.

The peak steering wheel rim force, the steering wheel velocity at the peak force, and the peak horsepower were read from chart recordings. Distributions of the data were plotted and the 5th percentiles were recorded. Chart resolutions were not specified, nor were the variations in vehicle speed.

The results are summarized in Table 3. All individual correlations between these performance measures and the subjects' age, weight, height and driving experience were below 0.4, indicating that subject characteristics had little affect on their performance. The mean force for all trials was 38.6 lb and the standard deviation was 12.2 lb. Assuming a normal distribution the 5th percentile of this mean was 18.6 lb. Except for the overall average scores, the 5th percentiles shown in Table 3 were measured directly from the data. The authors did not believe their sample data were normally distributed. Although the data were somewhat skewed, it was not evident that the assumption of normality would be rejected in a statistical sense. One would expect the steering force data to be normally distributed for a random sample as large as was tested in this experiment.

The mean steering wheel velocity, as measured at the instant of maximum force, was 6.1 rpm or 36.6 deg/sec. Since this rate is quite slow, it appears that either the subjects could perform the task with low steering rates or they could not generate large rates because the power-off steer force was too high.

Their mean horsepower score was 0.038 hp, which is less than the lowest score (0.045 hp) measured in the Ford study. In most trials the horsepower as measured at the maximum steering force was less than the actual maximum horsepower. Because the maximum horsepower almost always occurred after the maximum force, the steering wheel rate was increasing faster than the force was decreasing as the driver turned the wheel. Since the horsepower was not constant throughout the trial, the force-velocity relationship did not satisfy a fixed inverse proportionality.

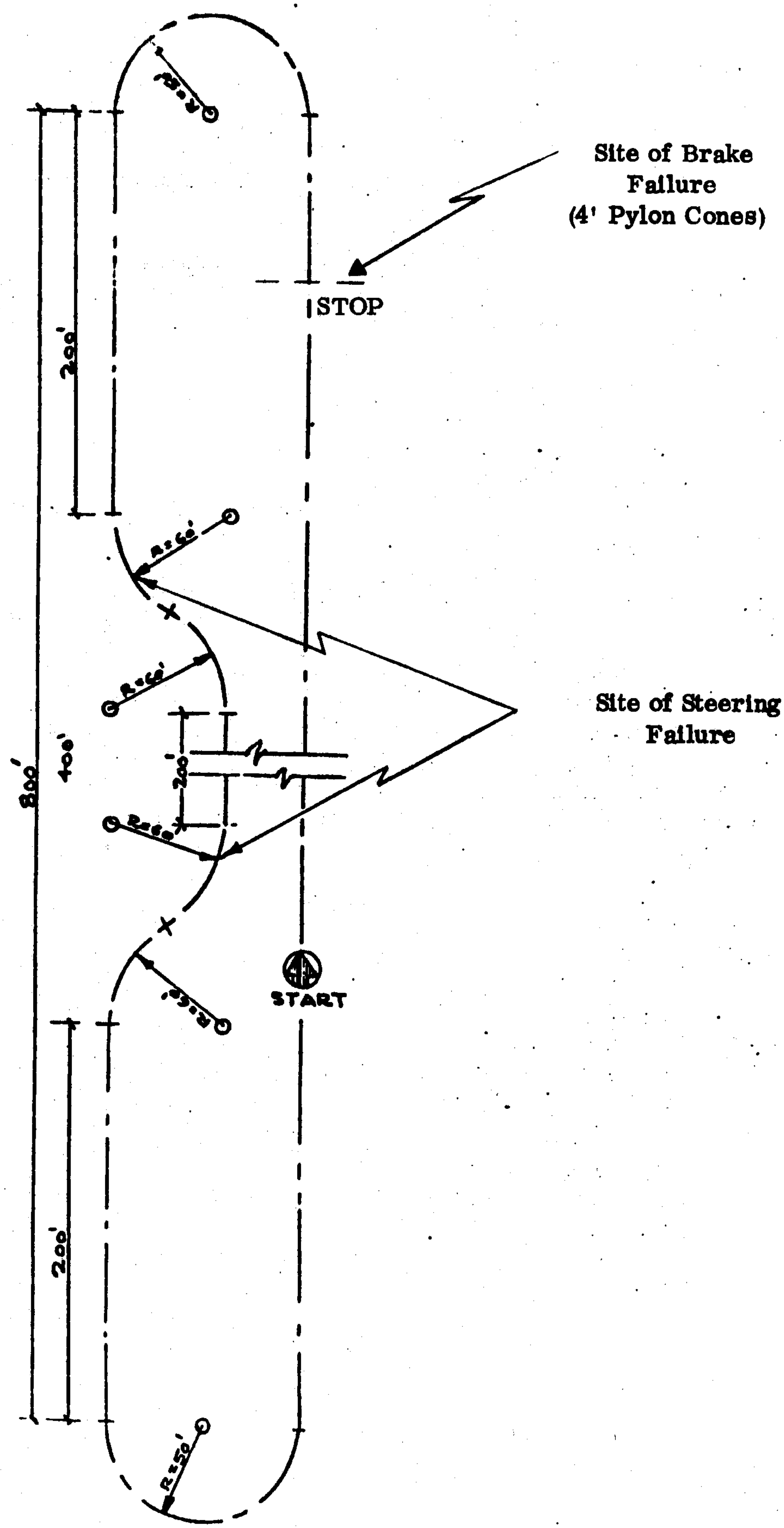

Figure 10. Diagram of the Test Course.
Man Factors Study (2)

TABLE 3

Summary of Data Man Factors Study (2)

N = 182 (91 CW + 91 CCW)	Stationary Trial 1	Surprise Trial 2	Forewarned Trial 3	Grand Average
Mean Force (lb)	41.6	36.2	38.3	38.6
SD	15.3	10.9	9.5	12.15
Range	10-80	0-68	10-65	
5th %	14.4	17.1	19.5	18.6
Mean Rate (rpm)	4.3	6.6	7.3	6.1
SD	2.4	3.2	3.1	2.9
Range	0-13	0-22	1-22	
5th %	0.5	1.8	2.2	1.33
Mean hp	0.031	0.04	0.044	0.038
SD	0.019	0.024	0.023	0.022
Range	0.003-0.1	0-0.13	0.005-0.15	
5th %	0.004	0.008	0.015	0.0018
Mean hp_{f-max}	0.025	0.028	0.036	0.03
SD	0.018	0.02	0.019	0.019
Range	0-0.099	0-0.102	0.005-0.108	
5th %	0.002	0.007	0.009	0.001

It was not reported whether each subject traded force for rate across trials. But on each trial the authors did find a small positive correlation between force and rate across subjects. That is, the subjects who had the larger forces were also more likely to have the faster rates. It was also found that the subjects who were in the 5th percentile for force were usually below the 5th percentile for velocity. Therefore, across subjects the force and velocity were not even inversely related.

However, because this correlation was small, force and velocity are relatively independent measures of performance in this task. Certainly, force is the more important of these two performance scores for maximum effort tests because the wheel cannot be turned if sufficient force cannot be generated. At least for this task, it does not seem that horsepower would be a good performance metric on which to base a steering effort design standard.

It would have been helpful had MFI discussed the various control responses of the drivers, including how successfully the subjects drove through the curves after the power was failed. Based on data in the Appendix of the report, two subjects had zero rim force; i.e., they made no steering response in the surprise failure. Three other subjects exerted less than 11 lb. Apparently, with few exceptions, most subjects made some attempt to steer the car.

<u>Comparison of Data</u>

Table 4 presents a comparison of the lower one-sided tolerance limits for the 95th percentile female with 90% confidence. No tolerance limit can be computed for the Thompson data because standard deviations were not reported. One can speculate that the variability would be high enough so that an unrealistically low tolerance limit would result. Note, for example, that the Hill and Lawrence intersection data predict a lower-one-sided tolerance effort below zero lb. The intersection maneuvers have not provided reasonable estimates of driver effort capabilities.

Because of the low vehicle speed, the driving task used in MFI experiment is analagous to an intersection maneuver. Compared with the GM intersection tests, the MFI data had a higher mean force but a similar standard deviation. Neither organization offered special incentives to encourage the drivers to steer through the maneuver. Because the MFI data is nearly identical to the Harvard data, it appears that 18-20 lb is a reasonable estimate of the force capability of a 5th percentile female in both seating buck and intersection-type effort tests where motivation levels are modest.

Both Stoudt's isometric data and Hill's stationary data have similar mean steering efforts even though one task is static and the other dynamic. The difference between their tolerance limits is a result of the difference between their sample sizes. It is important to remember, however, that Hill has shown that the 5th percentile subjects for the stationary vehicle test are not the same as the 5th percentile subjects in the serpentine test.

TABLE 4

Lower One-Sided Tolerance Limits for Steering Efforts

	Investigator	Mean (x)	Standard Deviation	Sample Size	K for $1 - \alpha = .95$ $\gamma = .90$	Tolerance Limit (x - Ks)
1.	Stoudt	39.1 lb	9.6	50	1.965	19.6 lb
2.	Eaton & Dittmeier	0.103 hp	0.041	20	2.208	0.0125 hp
3.	Thompson (Peak-Intersection)	15.8 lb	?	19	2.208	?
4.	Hill & Lawrence					
	(a) Intersection	28.8 lb	10.9	8	2.755	<0
	(b) Serpentine-1	26.4 lb	3.1	8	2.755	17.8 lb
	(c) Serpentine-2	40.3 lb	4.7	16	2.299	29.4 lb
	(d) Stationary-2	44.4 lb	9	16	2.299	23.8 lb
5.	Man Factors Inc.-2	38.6 lb	12.2	182	1.645	18.6 lb

The serpentine maneuvers demonstrate the task dependency of dynamic efforts. When the effort criterion was increased by 50% (from 26.4 lb) for the second group of subjects in the Hill experiment, the mean effort of the sample population also increased by approximately 50% (to 40.3 lb). However, variability remained low. As a result, this maneuver provided one of the highest steering effort limits (29.4 lb) for the 5th percentile female. The drivers were also highly motivated.

The Ford study is difficult to assess. The predicted tolerance limit seems to be surprisingly low. One would expect much higher efforts because the maneuver was very severe. Apparently, many subjects gave up and crashed through the barrels without ever exerting a maximal effort. The authors indicated that the majority of subjects were not successful in executing the lane change.

Another author has suggested that stationary steering torques for passenger cars should not exceed 15 kp rim effort, although no experimental basis for this value was reported (8). This is equivalent to about 33 lb rim force. It is interesting that this recommended stationary level is very similar to the 5th percentile effort from the serpentine maneuver.

DISCUSSION

Steering effort research has certainly not defined a maximum driver steering force. Each experiment had some limitations. Effort tolerance limits were found to vary according to the performance task and the performance metric which an experimenter used.

The Harvard study employed a large subject sample, but the task was conducted in a seating buck with an isometric wheel. Part of the data collected in the other experiments included the maximum steering forces with the vehicle stationary, and these results correlate well with the Harvard data. Although the isometric and stationary effort data are very important, they should be used in conjunction with dynamic efforts when decisions about effort standards are finally made.

Not unexpectedly, however, there is no recognized standard maneuver to be used for measuring dynamic efforts. The intersection maneuvers used in the GM studies and the lane change maneuver used by Ford did not yield a realistic estimate of the 5th percentile driver effort because of the high variability in the data and the small sample sizes. An intersection-like maneuver, performed by a much larger number of drivers in an MFI experiment, provided a better indication of the force capability of weaker females, although some might question the lack of incentives given to their drivers.

Perhaps the most useful maneuvers have been the serpentines. Data variability is remarkably low, but questions could be raised concerning the representativeness of the sample populations used in the experiment. Also, any dynamic

maneuver raises the problem that the measurement of maximal effort is confounded with the effort requirements inherent in negotiating that maneuver.

It is well known that the rate of turning the steering wheel influences the amount of force that can be generated. The Ford study attempted to define the force-velocity relationship by using horsepower as a performance metric. However, this definition was refuted, albeit in a different task, by the MFI data. Yet rate can be an important consideration ~~for proposed standards, because any indecision~~ by the driver when his power steering fails usually will force him to make more rapid wheel movements to avoid a crisis. The failed system should be forgiving enough to permit reasonable rates of turning by most females.

Hopefully, the data already collected will help to formulate the future research programs. Decisions need to be reached regarding (1) which maneuvers constitute appropriate tests of effort, (2) the importance of surprise rather than forewarned power failures, (3) the motivation to be given, (4) the relative importance of static or dynamic efforts, (5) the most meaningful performance metric, and (6) the acceptable ranges for variables such as vehicle speed, magnitude of steer input, and steering angular velocity. ~~A steering effort standard can be realized once issues such as these are resolved.~~

Although the justification for research on maximal steer efforts is evident, there is very little information which would indicate that loss of power assistance is a factor in accident causation. Hill, in a review of 1968 and 1969 MIC accident files, found only 9 (0.3%) cases in 3000 accidents (1968) for which alleged steering failures could have been steering failures. In 1969 there were 4 potential power steering failures in 1695 accidents (0.24%). These alleged power steering failures represent accident cases for which power failure could have occurred or cases in which power failures could not be ruled out. More recently, an in-depth survey of 530 accidents conducted by the Indiana Institute for Research in Public Safety over a two year period found that steering system problems were at least a probable cause of 2% of these accidents, but in no case did they determine that undue steering effort was a causative factor (9).

In another sample of 21 accidents which allegedly involved power steering failure, twelve male drivers (57%) were involved. (This is about the proportion of males in the driving population). Fifteen (72%) accidents involved B cars. Of the vehicles having higher power-off steering efforts, there were two C cars and no front drive cars. Although this small sample of accident reports is not statistically valid, it does implicate male and female drivers, and vehicles having moderate and high power-off steering efforts, about in proportion to their presence in the total driver/vehicle population. It is interesting to note that high power-off efforts may not be the primary cause of accidents when the power steering fails, because most drivers should be capable of controlling B cars with loss of power assistance. Seemingly these drivers just made erroneous judgments at the time of failure.

delete unless discussed in the context of experimental work

All maneuver tests which have been reviewed included a surprise power failure. The surprise occurrence is more realistic, and also requires rapid decision-making by the driver. Some drivers give up (freeze or stop) because they are not aware that a car can be steered without power assistance or because there is no incentive to continue, and not because they are incapable of exerting the necessary torque. Other experiments have shown that some subjects will crash through cone barriers in an unexpected obstacle avoidance maneuver even with full power available. ~~A very tenuous conclusion might be that it is the surprise element in power steering failures, and not the actual magnitude of power-off steering effort, which is more important in accident causation.~~

The issue of driver decision making under stress, i.e., selection of alternative courses of action in the event of power assist failure, needs clarification. This research might define motivational conditions and force thresholds above which the driver will alter his risk-taking behavior. For example, the intersection maneuvers have shown that certain circumstances, such as 300° steering inputs into 12 foot lanes bordered on one side by guard rail, with no danger of a rear end collision, will cause most female drivers to stop a vehicle rather than complete a turn without power assistance. In addition, variables such as lateral or longitudinal accelerations may also influence driver behavior when the steering rim forces are high.

APPENDIX A (3)

CHECKLIST

A checklist has been prepared as an aid for reporting how force is measured, where force is applied, what body parts are mainly involved and what posture is employed, how the subject is instructed to exert force, what role motivational factors play, and what index is selected to rate the subject's performance. There are interactions between apparatus, subject, experimenter, and environment that cause some redundancies in the list. For example, the subject's body posture as well as the magnitude of exertible force will be affected by the support (reaction force) available to him. Such cross-references are useful since they point out the multiple effects of a single factor.

The following list has been compiled for force measurements. It can easily be adapted to tests of torque and work, etc.

A. Measuring Device
   1. General identification
      a. function
      b. model, manufacturer
      c. last calibration
   2. Attachment of measuring device to the subject
   3. Output-readout (digital, analog) - units read
   4. Other (specify)

B. Location of the Force Vector
   1. Static force exertion (no motion): coordinates of the point of force application and direction of force
   2. Dynamic force exertion (motion):
      a. coordinates of the path of the force application
      b. direction of force along the path
      c. motion of the path (temporary location, speed, acceleration)
      d. masses accelerated or decelerated
   3. Other (specify)

C. Subject
   1. Drawn from what population
   2. Anthropometric data
   3. Other (specify)

D. Posture of the Subject
   1. Coupling of the subject to the measuring device
   2. Body parts and muscles chiefly used
   3. Body posture during force exertion
   4. Body support-reaction force available
   5. Other (specify)

E. Method of Force Exertion
Exact wording of the instructions given to the subject or (especially if no specific instructions given) how force was actually exerted. In particular:

1. Requested magnitude of force (all-out effort or submaximal)
2. Requested manner of force exertion
    a. how to build up force
    b. what to do after requested magnitude has been reached
    c. how long to exert force
    d. whether muscle length is kept constant during exertion (isometric)
    e. whether muscle tension is kept constant during exertion (isotonic)
3. Time interval between subsequent tests
4. How many repetitions
5. Practice/training
6. Other (specify)

F. Motivational Factors

1. Selection of subjects
2. Voluntary/required participation
3. Mode of payment
4. Knowledge of the purpose of the experiment
5. Knowledge of the experimental procedure
6. Feedback of performance
7. Supervision during the experiment
8. Stimulating factors, such as encouragements, rewards, competition, spectators
9. Restraining factors, such as danger, fear of injuries, adverse environmental conditions, fatigue, lack of interest, spectators
10. Other (specify)

G. Selection of Performance Score

1. Amplitude-dependent value (maximum, minimum, etc.)
2. Time-dependent value (at or over a specified time)
3. Other (specify)

APPENDIX B

SUMMARY TABLE

Table 5 itemizes important experimental and measurement variables along with the data from the studies reviewed in this paper. All subjects were permitted to adjust the seat comfortably. Hand positions were specified by Stoudt, and by Hill and Lawrence (for their stationary tests). Subjects were believed to be representative of the normal driving population. Data are given in units of pounds rim force. All tolerance limits, except those followed by a question mark, were computed under the assumption that the data were normally distributed.

All maneuver tests involved unexpected power failures in cone courses. Driver control behavior such as performance accuracy, brake usage, etc., was generally not reported in these experiments. (Hill did report some driver information for the second serpentine experiment).

Author	Vehicle	Type of Effort	Motivation	Task	Task Required Effort (lb force)	Instructions	N_s-Sex	# of Trials Per Subject	Performance Metric	Mean ± S.D.	Range of Data	Lower one-sided Tolerance Limit (# rim pull) (1 - a)= .95, γ=.90, Normal	Author
Stoudt et. al.	Seating buck with 18" S. W. diam.	Static	Exhortation	Isometric wheel; 5 diametric hand positions	-	Hold max. force for 5 sec.	50 F	10	Ave. torque for 5 sec.	44 ± 11.2 lb	23.8 - 84.4 lb	22 lb	Stoudt
Eaton and Dittmeier	1968 Full-size sedan S. W. diam = ?	Dyn.	?	35 mph lane change	?	Evaluate handling qual.	20 F	4	?	0.103 ± 0.041 hp	0.045 - 0.20 hp	1.7 lb	Eaton & Dittmeier
	?	Static	?	Isometric steering wheel	-	?	?	?	?	?	?	31 lb (?)	Another Ford Study
Thompson	1966 LeSabre 11:1 gear 16" S. W. diam	Dyn.	Large rubber drums	Intersection Surprise	52 lb	Drive normally; monitoring vehicle motions T-turn; L or R	19 F	2-norm (N) 2-fail (F)	Peak torque	15.8 ± ? lb	3.4 - 25 lb	?	Thompson-Surprise
		Dyn.		Intersection Foreknowledge				3		34.5 ± ?	3.4 - 31.3 lb	?	-Foreknowledge
			None	Stationary	-	Turn as hard as possible		2		38.3 ± ?	8.8 - 50 lb	?	-Stationary
Hill and Lawrence -1	1969 Olds 98 26 psi cold(F, R) 16:1 gear 16" S. W. diam	Dyn.	Guard rail	Intersection	42 lb	Drive normally; 40' radius turn;L/R	8 M	4 N-F-N-F	Peak torque 1/2 sec.	53.1 ± 7.6 lb	?	-	Hill & Lawrence-Inter.-Males
							8 F			28.8 ± 11 lb	?	< 0	Intersection-Female
				Serpentine-1	27 lb	Maintain 30 mph speed and steer smoothly	8 M			27.1 ± 2 lb	?	-	Serpentine-1-Male
							8 F			26.4 ± 3.1 lb	?	17.8 lb	Serpentine-1-Female
-2	20 psi cold F 26 psi cold R 11:1 gear	Dyn.	Guard rail	Serpentine-2	36 lb		16 F	4 N-F-N-F		40.5 ± 4.8 lb	30 - 51 lb	29.3 lb	Serpentine-2
		Dyn.	None	Stationary-2	?	Turn as hard as possible and hold for 3-4 sec.	all 33 F	2	Peak torque	61.9 ± 7.2 lb	?	45.4 lb	Stationary Peak 2
									3 sec. hold	44.4 ± 8.9 lb	?	25.8 lb	Stationary Hold 2
				Stationary with Veh. 1&2 combined					Peak	53.5 ± 12.3 lb	?	28.2 lb	Stationary Peak (1&2)
									3 sec. hold	37.3 ± 11.3 lb	?	14.1 lb	Stationary Hold (1&2)
Man Factors, Inc.	1966 Mercury Montclaire	Dyn.	None	Stationary	?	Turn as hard as possible	182 F	1	Peak torque	41.0 ± 15.3 lb	10 - 80 lb	16.4 lb	Man Factors-Stationary
				15 mph S-turn Surprise	?	Maintain 15 mph speed through course		1		36.3 ± 10.9 lb	0 - 66 lb	18.3 lb	-Surprise
				15 mph Foreknowledge	?			1		26.3 ± 9.5 lb	10 - 66 lb	22.7 lb	-Forewarned

TABLE 5

Summary of Experiments

REFERENCES

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ATTACHMENT Q

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Inter-Organization F-866

GM

DO NOT [illegible]

Engineering Staff
General Motors Corporation
General Motors Technical Center
Warren, Michigan 48090

Date: August 12, 1974

Subject: Supplemental Material to the NHTSA Relating to Their Information Request on Steering Effort

To: Messrs: R. A. Rogers & R. E. Rasmussen

Pages from the draft document with modified language are enclosed. I would be pleased to discuss these changes further with you if you desire.

This is a good supplementary document and should more than adequately fulfill the NHTSA request. Since we have not released it publicly at this time, it might be best to ask the NHTSA to treat it as proprietary, consistent with the previous material produced.

R. Thomas Bundorf
Assistant to Director
Engineering Analysis

/jlm
Enclosures (Pages ii, 1, 2, 31, 32 & 33)

Inter-Organization

GM

Environmental Activities Staff
General Motors Corporation
General Motors Technical Center
Warren, Michigan 48090

Date: July 29, 1974

Subject: Draft of Supplemental Material for Submittal to the NHTSA with Regard to IR on Steering Effort

To: Messrs: ~~R. T. Bundorf - Engineering Analysis~~
F. W. Allen - Legal Staff
T. Rasmussen - Oldsmobile Division

The addressees are requested to review and comment on the attached report regarding suitability for submittal to the NHTSA. This material represents supplemental data with respect to the General Motors' response to the NHTSA Information Request (IR) submitted on May 17, 1974 (USG 1111). This IR was with regard to "performance data and other technical data related to the steering effort of GM vehicles." Subsequently, GM representatives met with the NHTSA on June 27, 1974 wherein a verbal presentation was made supplementing our written response. Attendees at this meeting agreed that it would be worthwhile for GM to submit some supplemental material to the NHTSA regarding the GM evaluation of a number of steering effort studies.

A previous analysis of this type had been conducted by Vehicle Dynamics and published as an internal GM report (Report No. PG 33333, dated 2/8/74) - A Review of Measurements of Maximum Steering Efforts for Drivers. Vehicle Dynamics has reviewed this report and prepared the attached version for possible submittal to the NHTSA. Vehicle Dynamics has advised that it is very similar to the Report No. PG33333 except for deletion of GM internal report references and some material which was somewhat speculative.

Please advise Automotive Safety Engineering of your evaluation of this report by August 16, 1974. Thank you for your assistance in this matter.

R. A. Rogers
R. A. Rogers
Automotive Safety Engineering

jmp
attach.
cc: D. E. Martin
R. F. Humphrey
C. R. Sharp
R. E. Rasmussen

ABSTRACT

Studies of maximum steering effort are important because there is some ~~probability, however small~~, that power assistance can fail. The power-off steering control will require an increased muscular exertion from the driver. Human effort research is complicated by several experimental and measurement problems. These problems are reviewed so that the reader will have some background for interpreting the experimental data.

Seven studies of maximum driver steering effort are summarized. Two of these experiments involved static efforts. The other studies examined dynamic efforts in both surprise and forewarned power steering failures. Dynamic task maneuvers included lane changes, intersections, and serpentines. The serpentine maneuvers had the lowest variability in maximum efforts. From these experiments, the more reasonable estimates of the lower one-sided tolerance limit for a 95th percentile female at 90% confidence level were 19.6 lb rim force for static efforts (Stoudt), 18.6 lb for intersection maneuvers, (Man Factors, Inc.), and 29.4 lb for highly motivated dynamic efforts (Hill and Lawrence).

Some standardization of experimental methodology is required before a steering effort design specification can be written. It was suggested that statistical analyses of the data should report a lower one-sided tolerance limit, preferably for a 95th percentile female with a confidence level of 90%.

INTRODUCTION

Power-assisted control devices are intended to improve human performance by reducing the task workload. Should the power assistance fail, an operator will have to perform the task under manual control. It is important to understand a human operator's control capabilities under these conditions. Keeping the muscular effort within the capability of an operator, even after the power assistance has failed, is a desirable attribute of powered control devices.

The purpose of this paper is to discuss and compare the previous research regarding the maximum steering effort capabilities of drivers, with the hope of clarifying the differences which exist among the experiments, and possibly suggesting future experiments. Because maximum efforts are so difficult to define experimentally, some of the experimental and measurement difficulties will also be reviewed. Only seven experiments concerned with maximum steering effort were found in the literature. These experiments principally involved female drivers. Steering efforts were measured both in isometric and in sudden power steering failure situations. Detailed summaries of the data are presented in this report.

CONCLUSIONS AND RECOMMENDATIONS

1. Seven studies of maximum driver steering effort were reviewed. Stoudt (1)* investigated static efforts. The other studies examined dynamic efforts in surprise power steering failures. Dynamic task maneuvers included lane changes, intersections and serpentines. The serpentine maneuvers had the lowest variability in maximum efforts. Fifth percentile female tolerance limits at 90% confidence greatly depend on experimental and measurement variables. The three studies which seemed to provide the most valid estimates of these tolerance limits were Stoudt - 19.6 lb rim force for static efforts, Man Factors (2) - 18.6 for low speed turns, and Hill and Lawrence - 29.4 lb for highly motivated dynamic efforts.

2. Many experimental and measurement problems complicate human effort research. The experimental instructions can introduce variability into the data. Motivational variables such as rewards, knowledge of results, exhortations, and environmental stresses can significantly influence performance scores. Because of these variables human effort output seldom approaches physiological capacity.

3. Dynamic and static efforts are not significantly correlated.

4. Vehicle variables can influence maximal effort measurements. In addition, the exertion levels required to successfully perform a dynamic task will influence the distribution of maximum effort data for that task. For these reasons efforts measured in dynamic tasks may not be maximal efforts.

*Numbers in ( ) denote reports listed in the references.

5. It was recommended that statistical analyses of data should report a lower one-sided tolerance limit, preferably for a 95th percentile female with a confidence level of 90%.

6. Some standardization of experimental methodology is needed in maximal effort research.

7. There ~~seems to be meager~~ evidence ~~which would~~ implicate failures of power steering assistance as an important causative factor in accidents.

8. Potential areas for further research include investigations of driver decision-making, kinesthetic feedback, and learning and retention at high effort levels.

EXPERIMENTAL AND MEASUREMENT DIFFICULTIES

Several difficulties are encountered in the measurement of maximal driver steering efforts, or in fact in the measurement of any maximal muscular exertion. An excellent checklist for human strength experimentation has been compiled by Kroemer (3) and is reproduced as Appendix A in this report. It is generally self-explanatory, although some items will be discussed further in succeeding paragraphs. Special emphasis will be placed on the experimental instructions, task selection, data analysis, motivational factors, and performance scores. This discussion is intended to give the reader some background for interpreting the results of maximum effort experimentation.

Instructions: The instructions an experimenter gives his subjects can determine in large part the type of performance that will ensue. The less the subject knows about the purpose of the experiment, and what is expected from him, the more variable will be his performance. For example, if a subject were exerting a maximal static effort on a locked steering wheel, the magnitude of the force exerted may vary according to the rate at which the subjects develop force. Subjects could adopt a gradual increase-to-maximum strategy as opposed to a rapid, jerky exertion (3). Most probably the subjects would try several different strategies. The maximal forces so measured will be confounded with strategy, practice and perhaps fatigue effects. The experimenter could reduce this variability by instructing the subjects about the manner in which they should exert the force. If different driver strategies are allowed, then sample sizes should be increased. Within the constraints of the experimental design, the driver should also understand how his performance is being scored. It is important that the experimenter instruct the subjects as clearly and in as much detail as possible about the experiment, and then report the instructions sufficiently well so that others may reproduce the experiment.

Dynamic vs Static Efforts: Effort tests can be classified as either static or dynamic (3). Static efforts refer to muscular exertions which produce no mechanical work. Dynamic efforts do produce work because motion accompanies

The serpentine maneuvers demonstrate the task dependency of dynamic efforts. When the effort criterion was increased by 50% (from 26.4 lb) for the second group of subjects in the Hill experiment, the mean effort of the sample population also increased by approximately 50% (to 40.3 lb). However, variability remained low. As a result, this maneuver provided one of the highest steering effort limits (29.4 lb) for the 5th percentile female. The drivers were also highly motivated.

The Ford study is difficult to assess. The predicted tolerance limit seems to be surprisingly low. One would expect much higher efforts because the maneuver was very severe. Apparently, many subjects gave up and crashed through the barrels without ever exerting a maximal effort. The authors indicated that the majority of subjects were not successful in executing the lane change.

Another author has suggested that stationary steering torques for passenger cars should not exceed 15 kp rim effort, although no experimental basis for this value was reported (8). This is equivalent to about 33 lb rim force. It is interesting that this recommended stationary level is very similar to the 5th percentile effort from the serpentine maneuver.

DISCUSSION

Steering effort research has certainly not defined a maximum driver steering force. Each experiment had some limitations. Effort tolerance limits were found to vary according to the performance task and the performance metric which an experimenter used.

The Harvard study employed a large subject sample, but the task was conducted in a seating buck with an isometric wheel. Part of the data collected in the other experiments included the maximum steering forces with the vehicle stationary, and these results correlate well with the Harvard data. Although the isometric and stationary effort data are ~~very~~ important, they should be used in conjunction with dynamic efforts when decisions about effort standards are finally made.

Not unexpectedly, however, there is no recognized standard maneuver to be used for measuring dynamic efforts. The intersection maneuvers used in the GM studies and the lane change maneuver used by Ford did not yield a realistic estimate of the 5th percentile driver effort because of the high variability in the data and the small sample sizes. An intersection-like maneuver, performed by a much larger number of drivers in an MFI experiment, provided a better indication of the force capability of weaker females, although some might question the lack of incentives given to their drivers.

Perhaps the most useful maneuvers have been the serpentines. Data variability is remarkably low, but questions could be raised concerning the representativeness of the sample populations used in the experiment. Also, any dynamic

maneuver raises the problem that the measurement of maximal effort is confounded with the effort requirements inherent in negotiating that maneuver.

It is well known that the rate of turning the steering wheel influences the amount of force that can be generated. The Ford study attempted to define the force-velocity relationship by using horsepower as a performance metric. However, this definition was refuted, albeit in a different task, by the MFI data. Yet rate can be an important consideration for proposed standards, because any indecision by the driver when his power steering fails usually will force him to make more rapid wheel movements to avoid a crisis. The failed system should be forgiving enough to permit reasonable rates of turning by most females.

Hopefully, the data already collected will help to formulate the future research programs. Decisions need to be reached regarding (1) which maneuvers constitute appropriate tests of effort, (2) the importance of surprise rather than forewarned power failures, (3) the motivation to be given, (4) the relative importance of static or dynamic efforts, (5) the most meaningful performance metric, and (6) the acceptable ranges for variables such as vehicle speed, magnitude of steer input, and steering angular velocity. A steering effort standard can be realized once issues such as these are resolved.

Although the justification for research on maximal steer efforts is evident, there is very little information which would indicate that loss of power assistance is a factor in accident causation. Hill, in a review of 1968 and 1969 MIC accident files, found only 9 (0.3%) cases in 3000 accidents (1968) for which alleged steering failures could have been steering failures. In 1969 there were 4 potential power steering failures in 1695 accidents (0.24%). These alleged power steering failures represent accident cases for which power failure could have occurred or cases in which power failures could not be ruled out. More recently, an in-depth survey of 530 accidents conducted by the Indiana Institute for Research in Public Safety over a two year period found that steering system problems were at least a probable cause of 2% of these accidents, but in no case did they determine that undue steering effort was a causative factor (9).

In another sample of 21 accidents which allegedly involved power steering failure, twelve male drivers (57%) were involved. (This is about the proportion of males in the driving population). Fifteen (72%) accidents involved B cars. Of the vehicles having higher power-off steering efforts, there were two C cars and no front drive cars. Although this small sample of accident reports is not statistically valid, it does implicate male and female drivers, and vehicles having moderate and high power-off steering efforts, about in proportion to their presence in the total driver/vehicle population. It is interesting to note that high power-off efforts may not be the primary cause of accidents when the power steering fails, because most drivers should be capable of controlling B cars with loss of power assistance. Seemingly these drivers just made erroneous judgments at the time of failure.

It does not call out the vehicles most likely to have higher power-off steering effort or the weaker drivers as causal factors.

All maneuver tests which have been reviewed included a surprise power failure. The surprise occurrence is more realistic, and also requires rapid decision-making by the driver. Some drivers give up (freeze or stop), because they ~~are~~ not aware that a car can be steered without power assistance or because there ~~is~~ no incentive to continue, and not because they ~~are~~ incapable of exerting the necessary torque. Other experiments have shown that some subjects will crash through cone barriers in an unexpected obstacle avoidance maneuver even with full power available. A very tenuous conclusion might be that it is the surprise element in power steering failures, and not the actual magnitude of power-off steering effort, which is more important in accident causation.

The issue of driver decision making under stress, i.e., selection of alternative courses of action in the event of power assist failure, needs clarification. This research might define motivational conditions and force thresholds above which the driver will alter his risk-taking behavior. For example, the intersection maneuvers have shown that certain circumstances, such as 300° steering inputs into 12 foot lanes bordered on one side by guard rail, with no danger of a rear end collision, will cause most female drivers to stop a vehicle rather than complete a turn without power assistance. In addition, variables such as lateral or longitudinal accelerations may also influence driver behavior when the steering rim forces are high.

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OLDSMOBILE DIVISION

GENERAL MOTORS CORPORATION

F-866

TO	R. A. Rogers	ADDRESS	Automotive Safety Engineering G. M. Technical Center Warren, Michigan
FROM	T. Rasmussen	ADDRESS	Lansing, Michigan
SUBJECT	DRAFT OF SUPPLEMENTAL MATERIAL FOR SUBMITTAL TO THE NHTSA WITH REGARD TO IR ON STEERING EFFORT	DATE	August 20, 1974

Oldsmobile has reviewed the draft copy, "A Review of Measurements of Maximum Steering Efforts for Drivers", dated July 15, 1974.

We are in agreement that it would be worthwhile to submit this type of supplemental material to the NHTSA and feel that this report is satisfactory from a standpoint of the material and data which are included.

We would like to suggest some additional items and ask that you consider them for inclusion in your reply. It is our feeling that the following points would add to the reply and help to put this subject in the proper perspective.

1. Should question the need for a maximum effort requirement for all vehicle operating conditions. Should point out need to determine most common vehicle operating condition at time of failure and what type of maneuver would be required to bring the vehicle to a safe stop adjacent to the road. This is needed to properly define the driver task.

2. Emphasize the differences in effort required for low speed and high speed operation to maintain the same factor of safety. We should include any data or reports which could be used to substantiate this.

3. Recommendation for a study on loss of power steering assist and how many result in an accident and to what degree of accident severity. Study should include data on cause for loss of assist. It is possible that significant reliability improvements in the power steering system could be made with the use of items such as dual drive belts, ultra-high pressure hose, etc. -- if these could be identified and the means of failure established.

4. Some brief discussion on possible means to incorporate a redundant back-up system. Point out need for a cost/benefit relationship study to identify what type of changes or back-up system is most practical.

5. It would also appear in line to draw some conclusions based on the test results listed in the report. It appears that a reasonable conclusion, based on the data presented, would be to suggest no less than a 20 pound maximum effort to satisfy the 95% female at a 90% confidence level. This is significantly above the 10 to 15 pound level suggested in some research studies.

T Rasmussen

T. Rasmussen
Steering Systems Engineer

ch

cc: D. E. Martin - ASE
R. T. Bundorf - Eng. Analysis
R. E. Rasmussen - Veh. Dyn., PG
T. J. Krieg
D. E. Condon

PE10-005

GM

4/14/2010

ATTACHMENT Q

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A REVIEW OF MEASUREMENTS OF MAXIMUM STEERING EFFORTS FOR DRIVERS

September 10, 1974

VEHICLE DYNAMICS LABORATORY

GENERAL MOTORS PROVING GROUND

A REVIEW OF MEASUREMENTS OF MAXIMUM

STEERING EFFORTS FOR DRIVERS

PREFACE

During 1973, the Vehicle Dynamics Laboratory at the General Motors Proving Ground began a review of all studies relevant to the determination of the maximum steering force capability of the driver population. This review included work available in the published literature and unpublished work done over a considerable period by various GM staff organizations. The totality of the available data was thought to be more definitive than data from the individual studies. The majority of this report was written by G. L. Rupp. Other members of the VDL staff contributed to the editing.

Much of the unpublished GM information was drawn from the work of F. W. Hill, A. P. Lawrence and R. R. Thompson. GM treats these test data and this report as confidential with only authorized GM personnel having access to them. This engineering material is not otherwise subject to public disclosure. Therefore, this confidential engineering material should be maintained as confidential by the NHTSA pursuant to Exemption IV of the Freedom of Information Act as implemented by regulations issued by the Department of Transportation (49 C.F.R.S7.59, as amended) and S112(e) of the National Traffic and Motor Vehicle Safety Act of 1966.

ABSTRACT

Studies of maximum steering effort are important because there is some possibility that steering power assistance can fail. The power-off steering control may require increased muscular exertion from the driver. Human effort research is complicated by several experimental and measurement problems. These problems are reviewed so that the reader will have some background for interpreting the experimental data.

Seven studies of maximum driver steering effort are summarized. Two of these experiments involved static efforts. The other studies examined dynamic efforts in both surprise and forewarned power steering failures. Dynamic task maneuvers included lane changes, intersections, and serpentines. The serpentine maneuvers had the lowest variability in maximum efforts. From these experiments, estimates of the lower one-sided tolerance limit for a 95th percentile female at 90% confidence level were 19.6 lb rim force for static efforts (Stoudt), 18.6 lb for intersection maneuvers, (Pierce), and 29.4 lb for highly motivated dynamic effotts (Hill and Lawrence).

In the experimental data cited in the report, significant variations in methodology were used with significant variations in the results. Therefore, it would be extremely difficult to select design guidelines based upon currently available data. Some standardization of experimental methodology is required. For example, it is suggested that statistical analyses of the data should report a lower one-sided tolerance limit, preferably for a 95th percentile female with a confidence level of 90%.

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INTRODUCTION

Power-assisted control devices are intended to improve human performance by reducing the task workload. Should the power assistance fail, an operator will have to temporarily perform or terminate the task under manual control. It is important to understand a human operator's control capabilities under these conditions. Keeping the muscular effort within the capability of an operator, even after the power assistance has failed, is a desirable attribute of powered control devices.

The purpose of this paper is to discuss and compare the previous research regarding the maximum steering effort capabilities of drivers, with the hope of clarifying the differences which exist among the experiments, and possibly suggesting future experiments. Because maximum efforts are difficult to define experimentally, some of the experimental and measurement difficulties will also be reviewed. Seven experiments concerned with maximum steering effort were found in the literature. These experiments principally involved female drivers. Steering efforts were measured both in isometric and in sudden power steering failure situations. Detailed summaries of the data are presented in this report.

CONCLUSIONS AND RECOMMENDATIONS

1. Seven studies of maximum driver steering effort were reviewed. Stoudt (1)* investigated static efforts. The other studies examined dynamic efforts in surprise power steering failures. Dynamic task maneuvers included lane changes, intersections and serpentines. The serpentine maneuvers had the lowest variability in maximum efforts. Fifth percentile female tolerance limits at 90% confidence greatly depend on experimental and measurement variables. The three studies which provide estimates of these tolerance limits were Stoudt - 19.6 lb rim force for static efforts, Pierce (2) - 18.6 for low speed turns, and Hill and Lawrence - 29.4 lb for highly motivated dynamic efforts.

2. Many experimental and measurement problems complicate human effort research. The experimental instructions can introduce variability into the data. Motivational variables such as rewards, knowledge of results, exhortations, and environmental stresses can significantly influence performance scores. Because of these variables human effort output during experimental tests seldom approaches physiological capacity.

3. Dynamic and static efforts are not significantly correlated.

4. Vehicle characteristics can influence maximal effort measurements. For example, the maximum effort level required to perform a particular maneuver used in an experiment will influence the maximum effort level determined. A low required effort level would result in a low measured effort level.

*Numbers in ( ) denote reports listed in the references.

5. It is recommended that statistical analyses of data should report a lower one-sided tolerance limit, preferably for a 95th percentile female with a confidence level of 90%.

6. Some standardization of experimental methodology is needed in maximal effort research.

7. There seems to be meager evidence which would implicate failures of power steering assistance as a causative factor in accidents.

8. Potential areas for further research include investigations of driver decision-making, kinesthetic feedback, and learning and retention at high effort levels.

EXPERIMENTAL AND MEASUREMENT DIFFICULTIES

Several difficulties are encountered in the measurement of maximal driver steering efforts, or in fact in the measurement of any maximal muscular exertion. An excellent checklist for human strength experimentation has been compiled by Kroemer (3) and is reproduced as Appendix A in this report. It is generally self-explanatory, although some items will be discussed further in succeeding paragraphs. Special emphasis will be placed on the experimental instructions, task selection, data analysis, motivational factors, and performance scores. This discussion is intended to give the reader some background for interpreting the results of maximum effort experimentation.

Instructions: The instructions an experimenter gives his subjects can determine in large part the type of performance that will ensue. The less the subject knows about the purpose of the experiment, and what is expected from him, the more variable will be his performance. For example, if a subject were exerting a maximal static effort on a locked steering wheel, the magnitude of the force exerted may vary according to the rate at which the subjects develop force. Subjects could adopt a gradual increase-to-maximum strategy as opposed to a rapid, jerky exertion (3). Most probably the subjects would try several different strategies. The maximal forces so measured will be confounded with strategy, practice and perhaps fatigue effects. The experimenter could reduce this variability by instructing the subjects about the manner in which they should exert the force. If different driver strategies are allowed, then sample sizes should be increased. Within the constraints of the experimental design, the driver should also understand how his performance is being scored. It is important that the experimenter instruct the subjects as clearly and in as much detail as possible about the experiment, and then report the instructions sufficiently well so that others may reproduce the experiment.

Dynamic vs Static Efforts: Effort tests can be classified as either static or dynamic (3). Static efforts refer to muscular exertions which produce no mechanical work. Dynamic efforts do produce work because motion accompanies

the muscular exertion. There are important differences, both physiologically and mechanically, between static and dynamic efforts. Physiologically, maximal static efforts retard blood flow through the muscle, whereas dynamic efforts may facilitate blood flow. Insufficient blood flow will hasten muscle fatigue (3). Furthermore, in a dynamic effort, different muscle groups may be used, with the tension and phase relationships between the muscle groups changing as steering wheel angle changes. Changes in the spatial orientation and velocity of the limbs relative to the steering wheel will alter the driver's mechanical advantage.

Past research confirms that static efforts are not reliable predictors of dynamic efforts. There is little correlation between forces exerted statically and forces exerted dynamically (see Figure 9).

If the driver were an ideal system, then his inherent mechanical advantages together with his muscular strength would determine the maximum force which he could apply to the steering wheel. However, the driver does not behave ideally so that any measurement of intrinsic muscular strength does not correlate well with experimental measurements of human effort.

There are several factors which can contribute to the lack of correlation between intrinsic strength, static effort, and dynamic effort. Some physiological factors have already been mentioned. Psychological factors are probably more important. It is difficult to motivate drivers to exert themselves maximally. Motivation can vary between drivers, between tasks and between trials of the same task for the same driver. Some techniques for motivating drivers will be discussed later. Dynamic task variables can also influence the maximal driver effort. For example, drivers often reduce their muscular output when the duration of the exertion is long, as might be the case if their task demanded large steering wheel angles and slow rotation rates.

It has not been resolved whether the factors which limit a maximal human muscular exertion originate within the central nervous system or within the muscle. Some scientists claim that the brain ultimately limits muscular output, whereas others say that muscular fatigue is the cause. Regardless of which side one supports, it must be recognized that "maximal" efforts seldom represent maximal muscular capacity, and that both physiological and psychological factors influence muscular exertions.

Vehicle: The automobile itself is not a simple system. Its directional control response characteristics change with speed and become nonlinear during high lateral forces. Any measure of human effort in a dynamic test will depend in part on the characteristics of the vehicle. One vehicle characteristic which can influence effort measurements is the amount of steering force required to achieve a specified lateral acceleration. If steering wheel torque is plotted as a function of lateral acceleration as a vehicle is driven through an approximately sinusoidal path at constant speed, a steady-state steering effort plot can be made (Figure 1). Steering wheel inputs are applied slowly so that the vehicle is nearly always at a steady state lateral acceleration. The arrows indicate the torque levels as lateral acceleration is increased

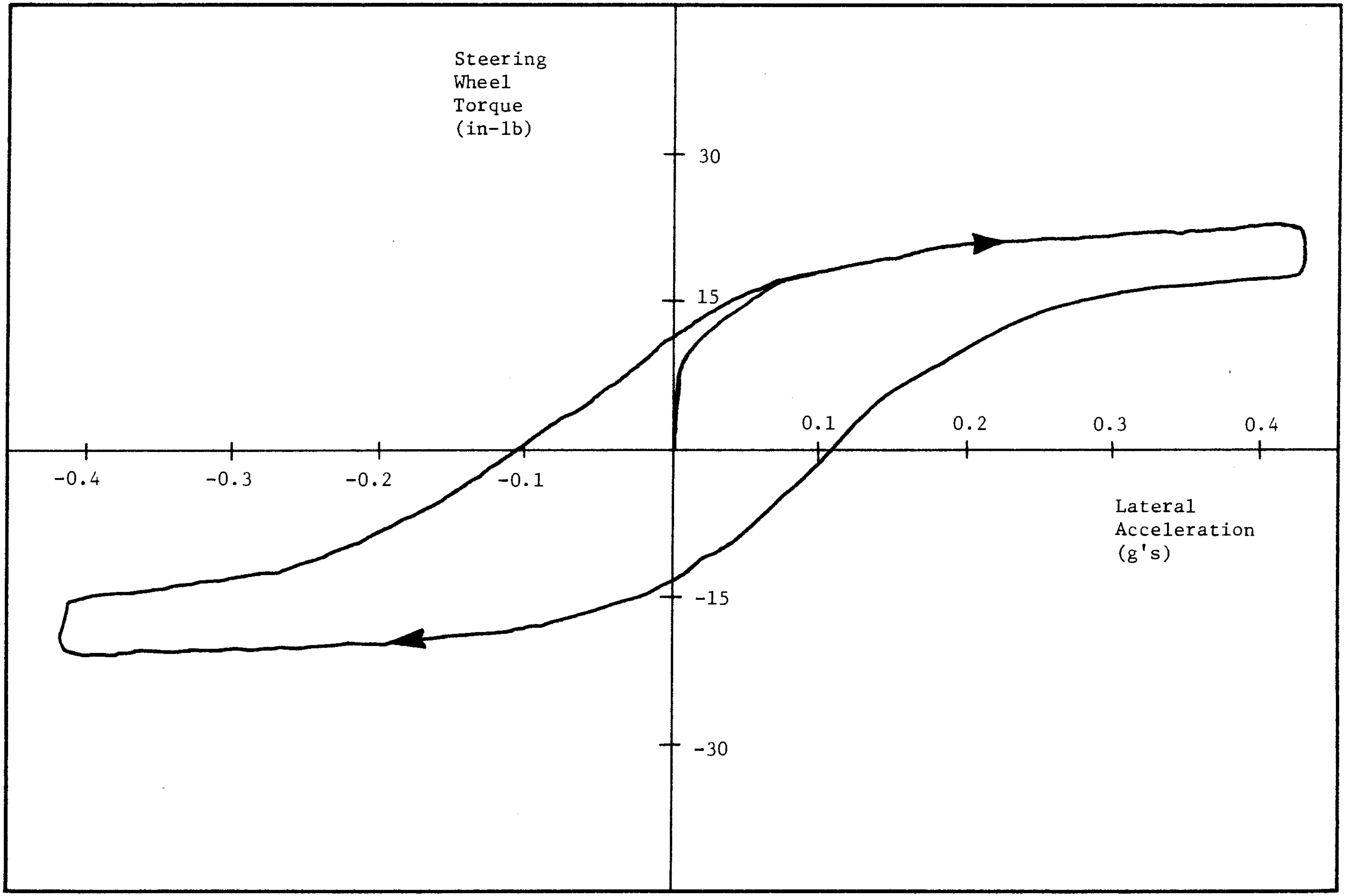

Figure 1. Typical Steady State Steering Hysteresis
with Power Steering Operative.

or decreased. Though not specifically shown, the effort level required to maintain a given lateral acceleration will be somewhat less than the effort level required to reach that lateral acceleration. Also the power-off steering system hysteresis is different from power-assisted steering hysteresis (Figure 2).

Another measurement problem introduced by vehicle characteristics is that steering wheel torque is speed-dependent (Figure 3). Steering forces for a specified level of lateral acceleration will decrease as vehicle speed increases. For the data shown in Figure 3 steering rim force decreased by about 3 lb at 0.3 g for a speed increase from 25 to 40 mph. The effect of vehicle speed on steering force is related to steering angle. More angle is required for 0.3 g lateral acceleration at 10 mph than at 30 mph.

Performance Test: The selection of an appropriate test in which the true maximum steering efforts can be measured is always a problem. There are disagreements regarding the importance of static and dynamic performance tests. Static tests may be unrealistic. Dynamic tests, on the other hand, can cause many vehicle variables to interact with the effort measurements. Even in dynamic tasks the degree of realism is questionable.

In fact, any experimental effort test can only be regarded as a simulation of the real world. There is no general agreement about the type of driving maneuver which provides the most accurate assessment of driver effort. Severe emergency maneuvers, such as lane changes under power assistance failure, may not be especially meaningful since the probability of occurrence is minute. Power failure in a straightaway does not provide a fair test of effort, although it might be interesting to measure the failure recognition time. Parking maneuvers with power off will require the greatest expenditures of effort, but are not related to normal customer usage or safety. Between these extremes are maneuvers such as low speed intersection turns and moderate speed serpentine driving tasks.

If one attempts to define maximal efforts by having drivers maneuver through a test course, then the steering efforts so measured will depend on the maneuver. The driver must be capable of exerting a certain amount of effort in order to accomplish the maneuver. Since steering efforts can be quite variable among drivers, the task-defined effort level may not be attainable by all drivers. If the task effort level is so high that few drivers can successfully perform the maneuver, the remaining drivers may content themselves with a submaximal exertion or even give up entirely. As a result, the mean effort for all drivers is reduced and the variability is increased. If the task-defined effort is reduced so that nearly all drivers can perform the task, then the mean effort is not an accurate estimate of the maximal steering effort.

Anthropomorphic variables such as location of controls, seat position, hand position, etc., will also affect both static and dynamic efforts. The usual practice has been to permit drivers to adjust themselves to nominally comfortable positions.

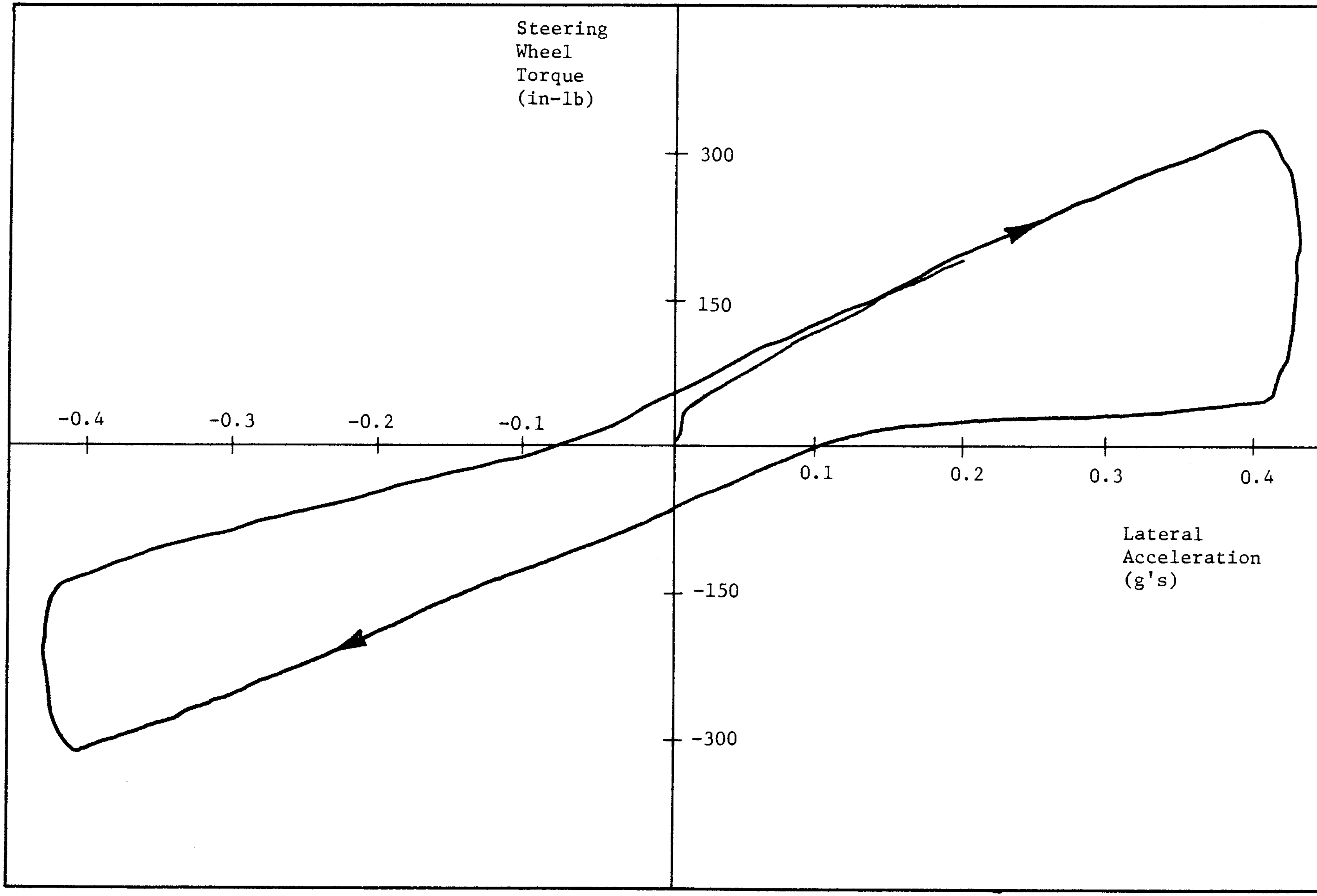

Figure 2. Steering Hysteresis with
Power Steering Inoperative.

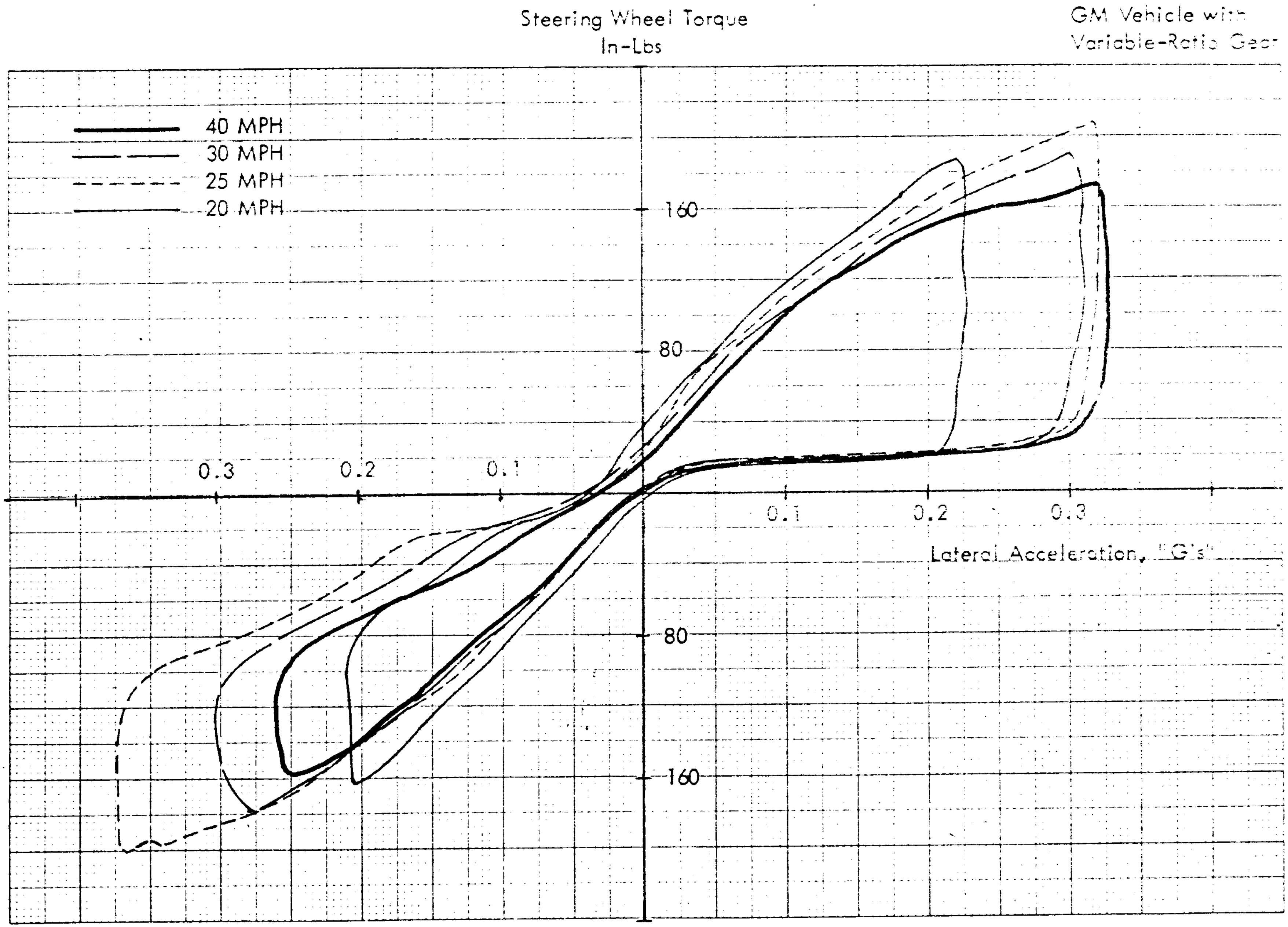

Figure 3. Effect of Vehicle Speed on Power Steering Inoperative Hysteresis Plot

Motivation: The problem of adequately motivating subjects must always be dealt with in any human research. It is an especially difficult problem in measuring maximal efforts. The effort scores can dramatically change as a function of a driver's motivational state. Consequently, it is very important to motivate subjects in a reliable and uniform manner. If the experimenter ignores the issue of motivation, then subjects will provide their own motivation, thereby introducing unwanted variability into the experiment. Some of the techniques used to manipulate motivation include the offering of payoff schedules, the feedback of knowledge of results (KR), the use of verbal exhortations, and the choice of driving environments.

Payoff schedules are constructed to reward subjects contingent on their attaining a specified criterion performance score. It may be necessary to conduct a pilot experiment in order to determine an appropriate criterion score. One possible experimental method is to establish a fixed criterion level below which no reward is given and above which the rewards are given according to a payoff curve (linear, logarithmic, etc.). Many other payoff techniques can also be conceived.

Knowledge of results can be manifested in several ways. It can be a smile or nod from an experimenter or a complex computer-generated display. It can be a quantitative score or qualitative judgment of the subjects' performance. KR can be given during or after a performance trial. It can be intrinsically derived by the subject from his task or extrinsically provided by the experimenter. An extensive discussion of KR is given by Annett (4).

Verbal exhortation is another means to motivate subjects to better their performance. The experimenter should keep the verbalizations approximately similar for all subjects. It is often a good idea to rehearse the exhortation before beginning the experiment.

The driving environment can also be an important motivational variable. The presence of stress-inducing stimuli in the environment can influence the driver's assessment of his risk level in a maneuver. Increased risk levels during a power steering failure can significantly increase the driver's muscular exertion. On the other hand, there may be a greater reluctance among females than males to apply their maximum force to any failed device, because females are usually less knowledgeable about mechanical systems and may have a greater fear of breaking something. Therefore, data variability can also increase because some drivers may freeze or make the wrong decision when overstressed. The risks versus benefits of the experiment must be carefully considered.

Practice: One of the ironies of maximal strength experimentation is that the maximal human efforts exhibit a strong learning effect. Maximum efforts increase rapidly during the first few practice trials. The data variability is also greatest on these trials. The maximum efforts reported by an experimenter will depend on the trial or trials for which they were computed. There is no standardized practice schedule to be used in effort experimentation.

Performance Metric: The choice of a performance metric is especially perplexing in tests of human effort. Several measures have been tried, such as peak force, average force exerted over some time interval (usually $t = 1,2,\ldots, 10$ sec), mean force neglecting any transient peaks, etc. Even root mean square (rms) force is a potential measure since the tension often randomly fluctuates about some mean value. It is disconcerting that these metrics may score the same performance quite differently. For example, a performance trial can exhibit a low peak but high mean force compared to other performances. Therefore, drivers will be graded differently relative to one another because of the choice of performance metric. The peak force is the least conservative estimate of the driver effort.

It is important that all force measuring instrumentation be reported. Reports should also include an estimate of the measurement resolution. Scale changes on the recording device when measuring different effort levels should also be noted. If the measurement is made from chart paper, the experimenter should describe how he judged the performance. Human interpretation of peaks or averages does introduce variability.

Statistics: It is frequently suggested that the maximum effort capabilities of a 5th percentile female be used to establish design limits for brake or steering controls without power assistance. Measurement of 5th percentile female effort should include a lower tolerance limit. Lower one-sided tolerance limits specify, with some probability γ, that a fixed proportion $(1 - \alpha)$ of the driver population will be capable of exerting efforts greater than that limit. For a sample of size N this limit is computed from the relation, $\bar{x} - Ks$, where $\bar{x}$ is the sample mean, s is the standard deviation, and K is found from tables once N, γ, α and the sample distribution are known. The coefficient K will be smallest; i.e. the lower tolerance limit will be largest, if the sample data can be shown to be normally distributed.

For example, if $\gamma = .90$, $\alpha = .05$, and if a second sample of N efforts is to be measured, one can be 90% certain that 95% of these effort levels will be greater than the tolerance limit $(\bar{x} - Ks)$ computed from the first sample statistics. A tolerance limit will produce a more conservative estimate of the 5th percentile effort than will the 5th percentile computed from any single sample population statistics. It is important to recognize that small sample sizes do not provide much useful information about the 5th percentile performance level unless the variability of the data is very low.

APPLICABLE STUDIES

The four experiments to be reviewed include the study by Stoudt, et. al. (1), the study by Eaton and Dittmeier (5), three GM studies, one by Thompson and the other two by Hill and Lawrence, and two government sponsored studies performed by Man Factors, Inc.; Woodson (6) and Pierce (2). Each experiment will be summarized separately. A detailed chart comparing the experiments is given in Appendix B.

Stoudt, et al (1)

Fifty female volunteers were employed as subjects. These subjects as a group were generally representative of the female driving population in terms of age, weight, height and possibly handgrip strength. Their task was to exert a static effort, both clockwise and counterclockwise, against a locked 18-inch steering wheel. A seating buck was used with the steering column angle at 27° from the horizontal. They were given one familiarization trial followed by ten more trials, one trial in each direction at each of five different diametric hand positions. A maximal effort was required for five seconds after which a one minute rest was granted. It is not clear if knowledge of results was provided after each trial. Verbal exhortations were given prior to and during each trial. All but one subject were believed to be sufficiently motivated. Presentations of hand position were systematically ordered in an attempt to balance any practice or fatigue effects across hand positions. Data were recorded on chart paper and average torque to the nearest 5 inch-pounds was computed over the five-second trial.

Note from Table 1 that the "9-3" hand position (C) yielded a high mean torque in both directions, although the variability was also comparatively large. The 5th percentile score, computed from the mean and standard deviation of the data, was 25.4 lb rim force. The lower one-sided tolerance limit was 21.8 lb for the 5th percentile female with 90% confidence (α = .05 and γ = .9). The data ranged from a low of 21.1 lb to a high of 75 lb rim pull for position C. One 76 year old had a low of 18.9 lb in position D with the remainder of her efforts ranging between 22.8 and 37.8 lb. All subjects averaged more than 22 lb for the ten exertions. The lowest rim force for any hand position was 12.8 lb, and the highest 76.7 lb. Age, sex and weight have not correlated with maximum steering wheel rim forces. Handgrip strength correlations were significant but could account for only 10% of the variance in efforts. Other variables were apparently more important in determining a driver's effort capabilities.

The authors suggest that the efforts determined in their isometric laboratory tests probably underestimate the forces exertable in actual emergencies under ideal conditions, but overestimate efforts in sub-optimal conditions.

Eaton and Dittmeier (5)

Twenty age-representative female drivers performed a lane change maneuver under the guise that they were rating handling qualities of a 1968 full-sized sedan having a 16-inch diameter steering wheel. The maneuver required a 12-foot lateral lane change within a variable (40'-50') longitudinal gap into a 12-foot wide recovery lane (Figure 4). Drivers were permitted to familiarize themselves with the vehicle's handling properties, following which they were given one familiarization trial at 5 mph through the maneuver. On the last four trials,

TABLE 1

Torques Exerted on a Steering Wheel (in Inch-Pounds) by 50 Female Subjects. Values are Average Torques Maintained Over 5 Seconds. Stoudt Study (1)

Hand Position[1]	Direction of Movement	Mean ± S.E.[2]	S.D.[3]	Approximate Percentiles	
				1st	5th
A	Right	364 ± 15.9	112.2	103	179
A	Left	268 ± 11.3	80.0	82	136
B	Right	396 ± 15.6	110.5	139	214
B	Left	320 ± 11.4	80.5	133	188
C	Right	395 ± 14.3	100.9	160	229
C	Left	388 ± 14.5	102.5	150	219
D	Right	308 ± 11.9	84.1	112	170
D	Left	390 ± 15.6	110.1	134	209
E	Right	265 ± 11.0	77.9	84	137
E	Left	343 ± 13.6	95.9	120	185
Average of all 5	Right	364 ± 11.8	83.3	152	209
Average of all 5	Left	342 ± 11.5	81.2	153	208
Average of all Positions	Both Directions	344 ± 11.4	81.0	156	211

[1]The hand positions are as follows - with reference to a clock face:

A - Right Hand at 12, Left at 6
B - Right 1:30, Left 7:30
C - Right 3, Left 9
D - Right 4:30, Left 10:30
E - Right 6, Left 12

[2]S.E. refers to Standard Error

[3]S.D. refers to Standard Deviation

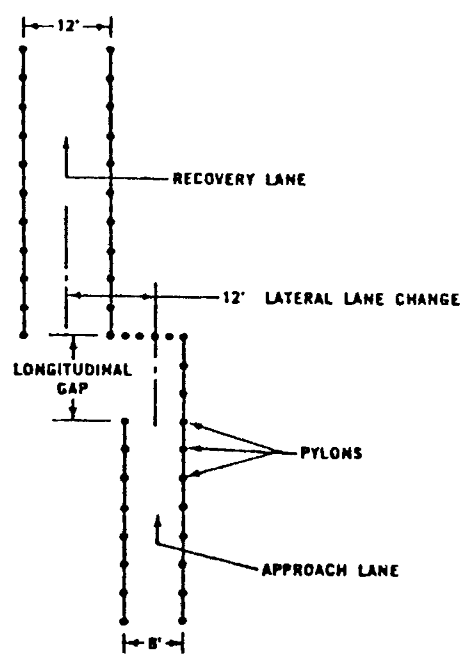

Figure 4. Lane Change Task Maneuver
Eaton and Dittmeier Study (5)

unknown to the drivers, the longitudinal gap size was adjusted trial-by-trial as follows: 50, 45, 40, 40 feet. Speed for each of these trials was fixed at 35 mph. Also unknown to the drivers the power assist was disabled on the last trial.

Data were recorded for the last two trials only. Steering effort performance was scored as the maximum horsepower (which is proportional to the instantaneous product of steering wheel angular velocity and torque) maintained for one-half second. All transducers and recording equipment were concealed. The mean maximum power for all subjects was 0.103 horsepower, with a standard deviation of 0.041 hp. The data ranged from 0.045 - 0.20 hp, and were "nearly" normal on probability paper. The lower one-sided tolerance limit for the 95th percentile female is 0.013 hp with 90% confidence (Figure 5).

The task difficulty was such that, under power assist failure, the "majority of subjects could not successfully negotiate the course." Performance accuracy before and after power failure was not reported so it is not possible to interpret a "successful" performance. Furthermore, no report was given regarding the amount of effort required to successfully traverse the course with power failed. Since the task itself establishes a ceiling effect on maximal efforts, the effort requirements of the task should have been reported. No mention is made of the drivers' brake, usage or motivation state with power failure.

Perhaps the most interesting feature of this experiment is the use of horsepower as the performance metric. This score represents an attempt to remove the variability in rim forces that is attributable to steering wheel velocities. The rate of steering wheel rotation is known to inversely affect the driver's maximum effort capability. It has not been substantiated that the two variables satisfy the multiplicative relationship which the horsepower measure would indicate. The horsepower metric is justifiable if drivers are power-limited rather than force or velocity limited.

It is difficult to compare the horsepower data with other experimental data because rim forces and steering velocities were not reported. If a 5th percentile steering wheel velocity of 60 deg/sec is reasonable for the lane change maneuver with the power steering failed, then the steering force at the 0.013 hp tolerance limit would be 10.2 lb rim pull for the 16-inch steering wheel. However, a steering velocity of 60 deg/sec would require a rather large distance to complete a lane change. Most lane change maneuvers require steering wheel velocities of more than 600 deg/sec. In this case the steering wheel force at the 0.013 hp tolerance limit would be about 1 lb which is an unreasonably small number.

The authors also refer to another Ford study which found a 5th percentile effort tolerance limit (at $\gamma = .90$) of 31 lb rim force using an isometric wheel, and a steering velocity tolerance limit (at $\gamma = .90$) of 165 deg/sec for zero steering wheel force. Based on this data, it appears that less than 95% of the female drivers could successfully execute the maneuver even with normal power steering.

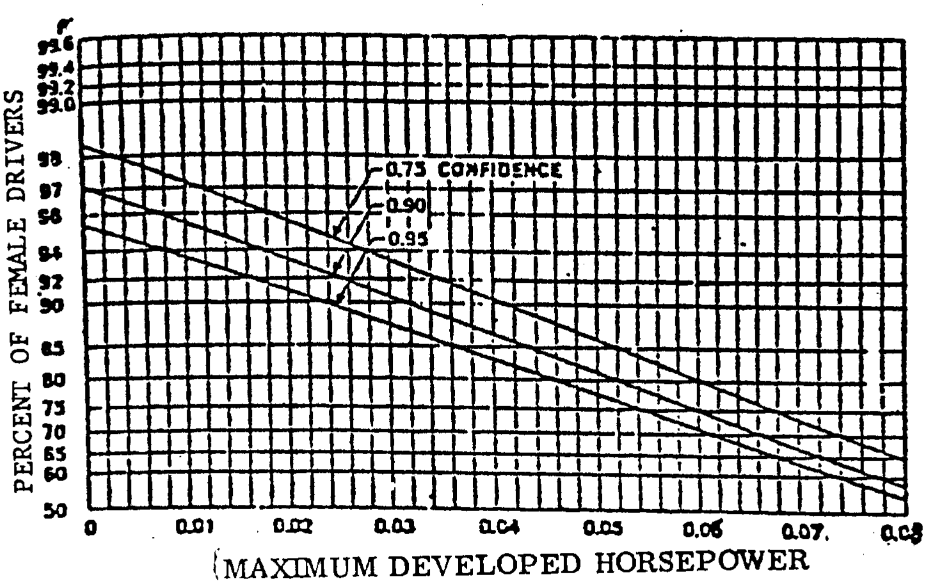

Figure 5. Percent of the Female Driving Population which can Generate at Least the Indicated Steering Wheel Horsepower. Eaton and Dittmeier Study (5)

Thompson

Nineteen female subjects drove a 1966 Buick LaSabre equipped with 11:1 ratio steering gear through an intersection maneuver at speeds of 10 mph or less. Subjects were informed only that their performance was being monitored. After two practice trials the engine was failed at 30 feet from several large rubber oil drums. Subjects had the option to stop or to make a 90° turn, either left or right. After convincing drivers that the first failure was unplanned, the drivers performed another intersection maneuver in which a surprise power failure occurred. They were then informed that the failures were planned, and they were instructed to turn as hard as possible for three more intersection maneuvers. Finally, with the vehicle stationary, dynamic efforts were read from chart recordings.

The mean peak force for all subjects, regardless of turn direction, was 15.9 lb rim pull on the first intersection trial. The mean peak force with the vehicle motionless was 38.4 lb, with about 29% of the forces falling below 26.3 lb. Data ranged from 8.75 - 50 lb. Data were plotted as cumulative percentiles (Figure 6). No standard deviations were reported and apparently the data were not tested for normality. With a surprise failure the range of the data was about 3.8 - 25 lb, and with foreknowledge of failure the range was about 3.8 - 31.2 lb. Approximately 20% of the forces on the surprise trials were less than 7.5 lb.

No estimate of the torque required to successfully complete the maneuver was given. (Hill has estimated the task difficulty at 52 lb rim pull. No subjects successfully completed the turn in the surprise failure condition. All braked before reaching the barrels. One female driver did complete the turn when forewarned about the power steering failure. All subjects exerted more force with the vehicle stationary than with the vehicle moving, indicating that they were capable of greater exertions in the intersection maneuver.

The steering torques in the intersection maneuver were quite low. They were approximately similar to the torque levels of a manual steering vehicle. It is very difficult to interpret these results, particularly since the nature of the subjects' instructions is not clear. If the drivers were only informed that their performance was being measured, they could easily misinterpret the purpose of the experiment. For example, it could be an experiment about reaction time or minimum stopping distance, in which case driver strategy would be to brake hard as soon as she detected an unusual steering effort. Since no premium is placed on negotiating the corner, the drivers' optimum strategy in terms of minimum effort was simply to stop the vehicle. This was the easier course of action, it had no adverse consequences, and it would not stress the drivers very much.

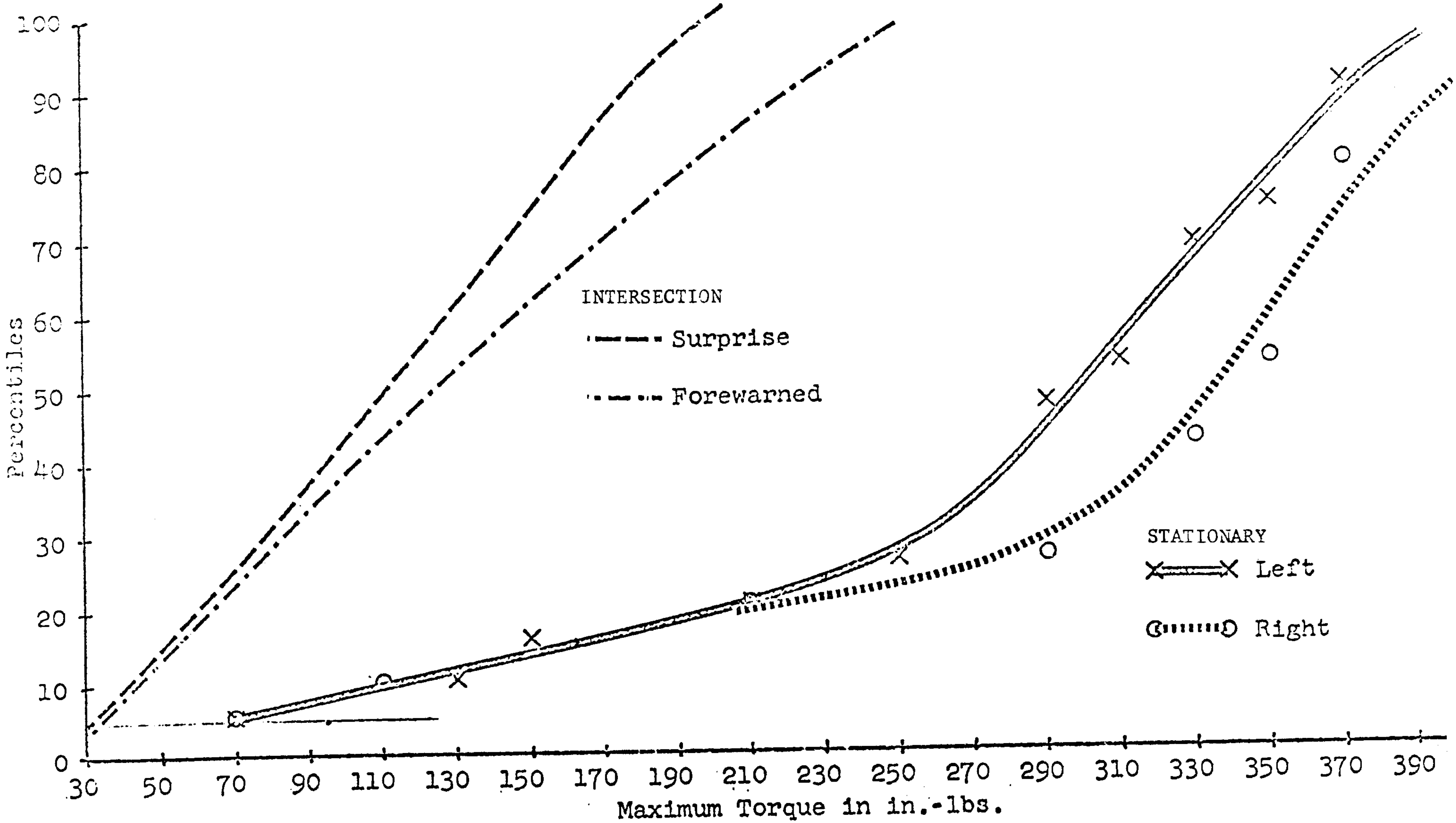

Figure 6. Distribution Showing the Percent of the Test Population Exerting up to the Indicated Torque Under Various Conditions. Thompson Study.

Hill and Lawrence

This study comprised two related experiments. Each will be reported separately.

Part 1 - Sixteen male and sixteen (clerical and secretarial) female subjects drove a standard 1969 Oldsmobile 98 with 16-inch steering wheel diameter through intersection and serpentine maneuvers. They were told they were participating in a speed holding and steering smoothness test. Their task was to traverse at 30 mph a cone course which began with a serpentine maneuver consisting of four 200-foot radius curves (Figure 7). The middle two curves were outlined with a guard rail placed 10 feet outside the course and mounted on a moveable platform. The course continued to a stop sign prior to entering an intersection maneuver at about 7-10 mph. Left and right turn radii were 40 feet and 25 feet respectively. Turn direction was always to the left. Turns were negotiated into a 12-foot lane bounded on the far side with guard rail.

Subjects were driven through the course at 20 mph prior to the experiment. Drivers were given a total of four trials. Following the first trial, the power steering was unexpectedly disabled using a silent switch which disengaged an electric clutch. Power was reinstated at the conclusion of the maneuver in which the failure occurred. After one more dummy trial the power assistance was again failed. Half of the drivers of each sex experienced power failures only in the intersection maneuver, while the remaining subjects encountered failures only in the serpentine. No driver had power assistance disabled in both maneuvers. Power failures in the serpentine course always occurred midway between two curves at transition points where steering wheel angle magnitude and velocity were nearly zero. Power was only failed prior to entering the curves bordered by guard rail. Half the drivers had the power failed first in a left turn and then in a right turn of the serpentine. Order of failure was reversed for the other drivers.

At the conclusion of the experiment, steering efforts were measured for each driver with the vehicle motionless (so-called stationary steering torque). Drivers were instructed to turn the wheel as hard as possible and to hold the force for about four seconds. Initial hand position was diametrically placed at ±45 degrees from horizontal with the movement proceeding clockwise or counterclockwise respectively. Usually wheel motion stopped after about 180° of rotation and the wheel was held there for the duration of a trial. Each driver was given one trial in a clockwise direction and one trial in a counterclockwise direction. The order of presenting the turn directions was balanced across drivers. No knowledge of results was given.

Data were recorded with the on-board instrumentation typically used in control response experiments. Peak torques sustained for at least 0.5 seconds were read to the nearest ft-lb from chart recordings. Rim forces for the serpentine were measured in the curve where the failure occurred. The serpentine maneuver required about 27 lb and the intersection about 42 lb rim force for successful

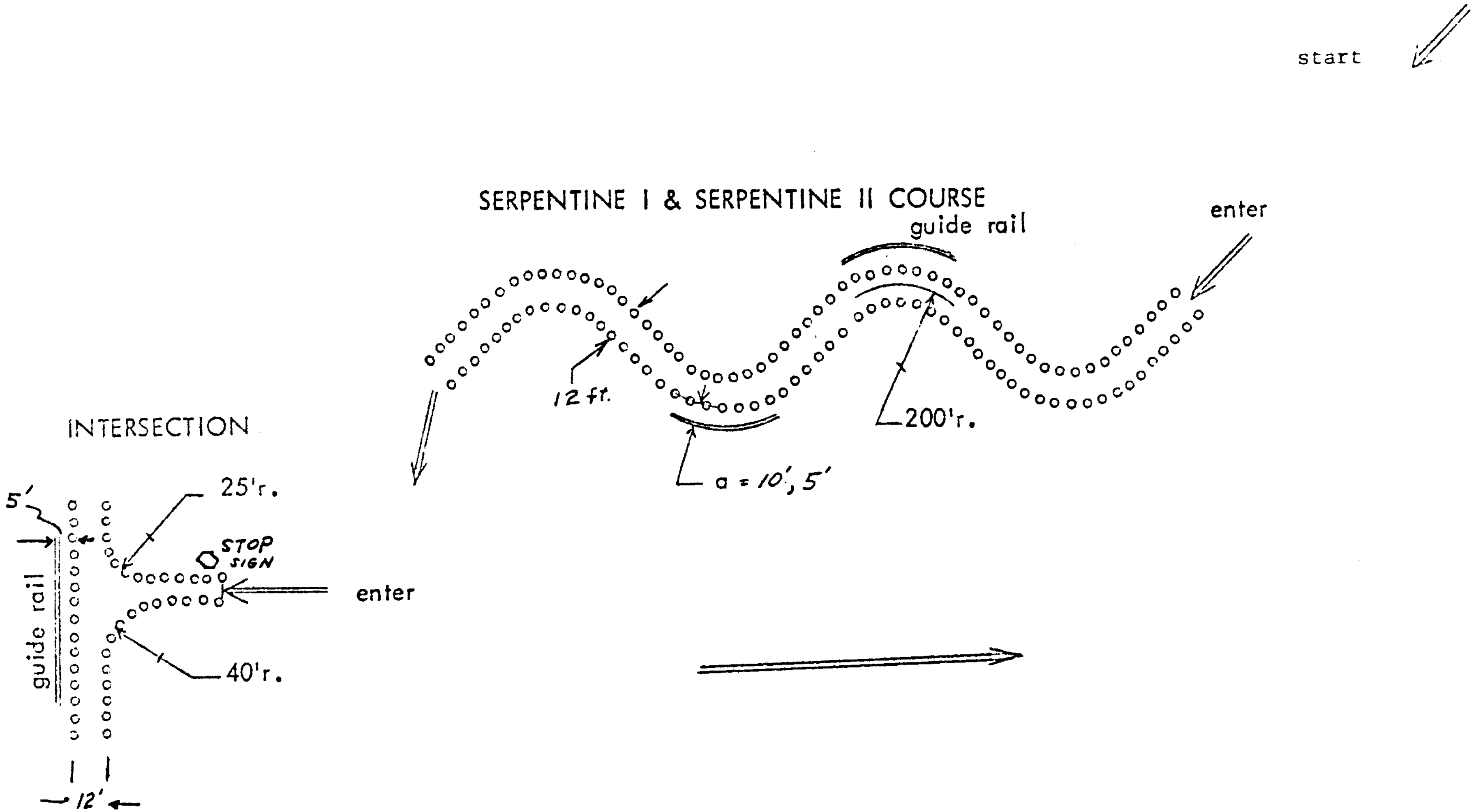

Figure 7. Diagram of Courses Used in Surprise Power Steering Failure Study.
Hill and Lawrence Study

completion of the task. Both peak forces and forces sustained for three-five seconds (hold force) were measured in the stationary effort tests.

All males successfully completed the intersection maneuver. Mean peak force for the males was 53.2 lb. On the other hand, female drivers successfully continued through the intersection on only 3 of 16 trials. There were 12 stops in the intersection and one guard rail contact. Mean peak effort was 28.8 lb with a standard deviation of 10.9 lb. The high variability reflects the alternative courses of action taken by the eight female drivers. The lowest effort was 15 lb. All women exerted less effort in the intersection test than in the stationary vehicle test. In other words, they usually chose to stop even though they were capable of greater effort. All drivers successfully maneuvered through the serpentine course. The mean force for the females was 26.4 lb with a standard deviation of 3.13 lb. Some of the women exceeded their stationary steering force in this maneuver.

Part 2 - Sixteen different clerical and secretarial female subjects drove the same serpentine course with the test vehicle modified to include an 11:1 steering gear ratio. Front tire pressures were also reduced from 26 to 20 psi cold. Guard rails were moved to within five feet of the cone course. A steering wheel force of about 36 lb was now required to negotiate the serpentine with the modified vehicle. No intersection maneuvers were tested, but stationary steering forces were measured.

Results are tabulated in Table 2. The mean peak force sustained for 0.5 seconds was 40.3 lb with a standard deviation of 4.7 lb. A lower one-sided tolerance limit at 90% confidence for a 95th percentile female was 29.4 lb. Data for all power failures ranged from 30 to 51 lb rim force. Data for the first failure ranged from 30 lb (for the driver who stopped) to 46.5 lb. Mean rim forces for the first and second failures were 39.5 lb and 40.6 lb, respectively. Two subjects failed to complete the course on the first power steering failure - one subject stopped in the course, and the other brushed the guard rail and subsequently left the course. Another driver slowed down considerably, and two more drivers struck a few traffic cones. All drivers were successful when power was failed the second time, although one subject did give up in the final curve.

Maximum steering wheel angles on the power failed trials ranged from 72° to 190°. On the immediately preceding trial these ranges were 90° to 151°. Vehicle speeds when the power assist was disabled ranged from 27 to 24 mph. Speed on the first power-failed turn ranged from 0 to 37 mph (for the driver who hit the guard rail); speeds in the second power-failed turn ranged from 25-33 mph. Mean speed reduction was 5.7 mph in the first failure. There were 10 brake pedal applications in the first failure and one in the second failure. Mean peak lateral accelerations were 0.31 g and 0.32 g respectively.

A sample time history showing the force requirements for one serpentine curve is shown in Figure 8. Each curve required about four seconds to complete. Note that a peak force is perhaps necessary for about one second, following which a nearly constant force must be exerted for about two seconds before

TABLE 2

Summary of Steering Effort Data Including Tolerance Limits. Hill and Lawrence

Maneuver	Subjects	Mean Rim Force (lb)	Standard Deviation (lb)	Tolerance Limit $\alpha = .05, \gamma = .90$
Intersection	8 Males	53.2	7.6	<0
	8 Females	28.8	10.9	
Serpentine - Part 1	8 Males	27.1	2.0	
	8 Females	26.4	3.1	17.8
Serpentine - Part 2	16 Females	40.3	4.7	29.4
Stationary Steering Torque				
Part 1:	16 Females	Peak = 45.1	9.8	22.5
		Hold = 30.2	6.7	14.9
Part 2:	16 Females	Peak = 61.9	7.2	45.4
		Hold = 44.4	9.0	23.8
Parts 1 and 2:	32 Females	Peak = 53.5	12.2	28.2
		Hold = 37.3	11.2	14.1

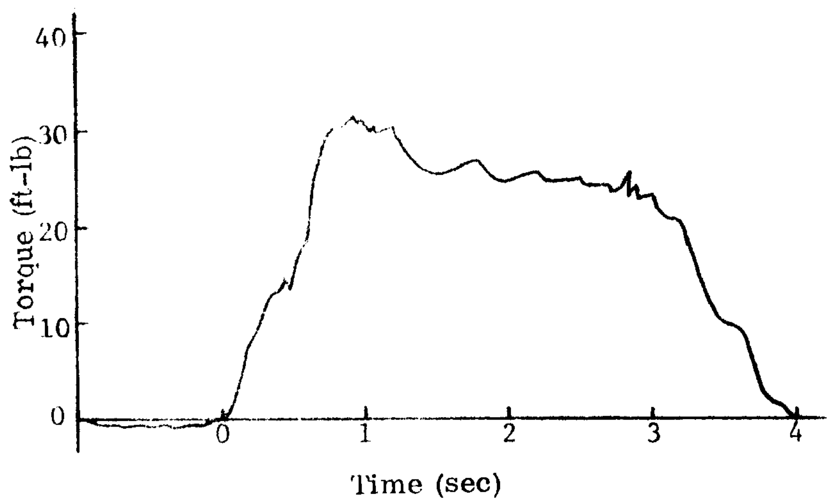

Figure 8. Typical Record of Torque versus Time Through One Curve of the Serpentine. Power Failure Occurred at t = 0. Hill and Lawrence Study.

exiting from the curve. However, rapid, jerky steering movements could cause transient peaks to be greater for less period of time. Fortunately only one driver adopted a jerky strategy, so judgment of peak efforts was not very difficult. No measures of steering smoothness were reported.

Stationary steering torques were measured using both peak force sustained for one-half second and mean torque held for three seconds as performance scores. The hold torque was difficult to determine because the torques did not remain constant. The peak stationary hold force for all thirty-two females was 37.3 lb. The second group of sixteen females had mean peak rim forces of 61.9 lb with a standard deviation of 7.2 lb; their three second hold forces were 44.4 lb with a standard deviation of 9 lb. This group of subjects produced a lower one-sided tolerance limit of 45.5 lb peak rim force but only 23.8 lb sustained force.

The rim force required to negotiate the serpentine with power steering failed was at least 12 lb lower than the peak force which any subject exerted with the stationary vehicle. No subject exerted as much peak rim force in the maneuver as in the stationary vehicle (Figure 9). There was no significant correlation (r = 0.143) between peak maneuver effort and peak stationary effort. There also was no significant correlation (r = 0.019) between peak maneuver effort and stationary hold effort. Hence, there is <u>no</u> linear relationship between serpentine maneuver efforts and stationary steering efforts even though both are dynamic efforts by definition.

The results demonstrate that female drivers can steer a vehicle without power assistance through a fairly severe dynamic maneuver. The lone exception was the driver who brushed the guard rail. She exerted 36 lb rim force just before contacting the guard rail. However, her vehicle speed increased from 33 to 37 mph and her maximum steering angle input was only 80° after the power failure. She was successful on the second power failure. Her stationary hold steering rim force was 58.5 lb, which ranks second highest among the sixteen drivers. Although apparently physically capable of performing the task, she probably erred in good judgment about her predicament. She had had her drivers license for only one year.

There are some important differences in driver control behavior between the first and second serpentine power failure. Primarily, the number of brake pedal applications was reduced from ten to one. Since the drivers had not previously experienced a power failure such as this, they were apparently more undecided about what action to take. Although the power-off efforts are approximately similar in both failures, the suspicion is that the first loss of power steering was the only true surprise failure.

It is surprising that stationary steering rim forces are considerably greater for the second group of female drivers (30.3 lb vs 44.4 lb). It could be that the second group of subjects were stronger. However, the torque differences are more likely related to the different gear ratios and tire pressures used in each vehicle. The lower gear ratio and tire pressures in the modified vehicle of Part 2 permitted drivers to develop and hold their

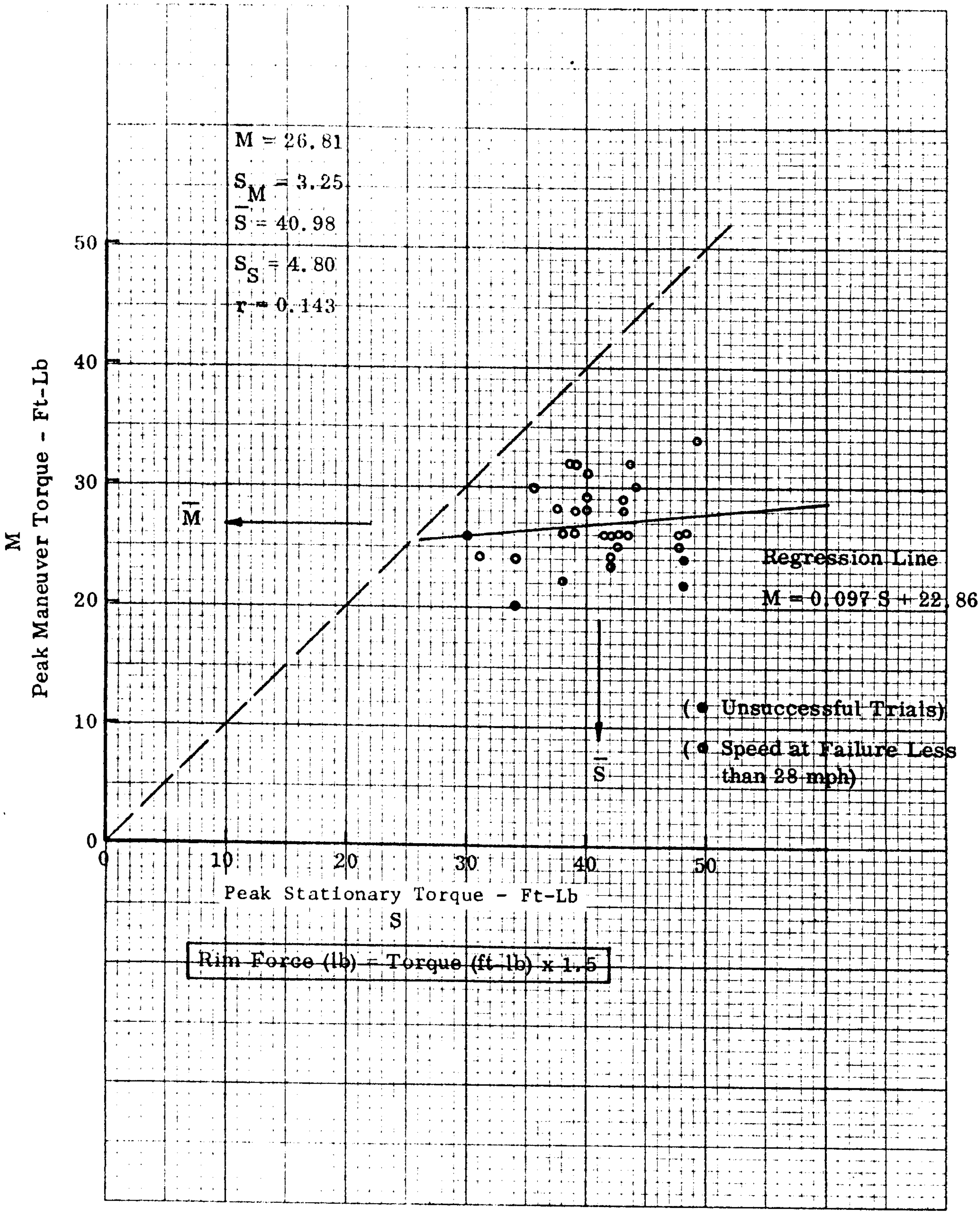

Figure 9. Peak Serpentine Maneuver Power-Off Effort versus Peak Stationary Effort. Hill and Lawrence Study.

maximum rim force at much lower steering angles where their mechanical advantage was greater. A less plausible explanation is that the drivers were more acclimated to the higher torques demanded by the modified vehicle.

The authors do not report the characteristics of their driver sample. However, they do acknowledge the similarity between their mean steering rim forces of 44.4 lb with a standard deviation of 9 lb and the Stoudt mean static steering effort grand mean of 38.2 lb with a standard deviation of 9 lb. Since the Stoudt data showed no correlations of age, weight or height with static effort, the representativeness of the GM subjects is less in doubt.

The serpentine maneuver with power steering disabled appears to have been sufficiently taxing to have adequately motivated the drivers. While seldom encountered in real life, loss of power steering in a serpentine bordered with guard rail does place a high priority on negotiating the curve. The maneuver is considered to be moderately severe because 90% of the driving population seldom reach 0.3 g in curves (7). In fact, some subjects needed the initial practice trial in order to maintain the lateral acceleration at 0.3 g through the curves.

In the intersection maneuver the engine was not failed in this experiment so that drivers could choose to complete the turn. However, if one plans to use the intersection maneuver to establish guidelines for maximum driver efforts, then some priority must be established for completing the turn. Monetary incentives, approaching vehicles, etc., must encourage the driver to execute the turn. Certainly these tests have not established maximum effort levels in intersection failures because the prevailing circumstances did not emphasize completion of the turn.

Man Factors, Inc.

Two government funded research projects involving driver steering efforts were conducted by Man Factors, Inc. The first study was conducted in seating bucks while the second utilized on-the-road vehicles.

Woodson (6) - Nine female subjects were selected from a total of forty females who were tested for their handgrip strength. Although it was intended that these nine subjects represent the weakest drivers, only five of the subjects who were selected were below the 50th percentile in grip strength. The subjects were given three trials each in the clockwise and counterclockwise directions at three different hand positions, at three different angular velocities, and in three different buck configurations. In addition, two steering wheel diameters were used in Buick III, and three steering column angles were used in Buck II. Not all subjects were tested in every condition. Each buck was tested at a different period in time, and the subjects also performed braking tasks prior to the steering tasks.

The subjects were given practice trials before taking data but the amount of practice was not reported. Both hands were placed on the wheel about 180° apart. The task itself was somewhat unusual in that the subjects did not rotate the wheel themselves, but instead were required to exert force against either a locked or a rotating wheel. Apparently the wheel maintained the same rotational speed regardless of the subjects' exertions.

Data were recorded on an X-Y recorder as force versus displacement. The total displacement was about 195° of steering wheel rotation. An average trace for the three trials was visually fitted through the data and peak forces were measured at three different displacements representing about 0°, 90° and 180° rotation. Data from five subjects were used in the analysis. Because each subject was not tested in all conditions, the mean force scores for only four subjects were computed for each buck, and each group of four had in it some subjects not represented in the other groups. Taken together, these subjects were shorter and older but weighed nearly the same as the national averages for drivers.

The data analysis itself is questionable because the subjects were confounded among the bucks. The plan of the experiment also permitted some subjects to gain more experience than others in this kind of task. This lack of experimental controls makes it difficult to interpret the results.

In summary, the results indicated the drivers exerted the largest forces when the wheel was locked and the hands were in the "9-3" position, and the least forces when the wheel was rotating fastest (25 rpm) and the hands had been rotated to the "6-12" position (or "12-6", depending on the rotational direction). In making their recommendations for a maximum allowable steering force, the authors selected the lowest mean force for the four subjects from all combinations of conditions within each buck, subtracted a 25% safety factor, and rounded down the result to the nearest half-pound. For the buck which represented the standard sedan, the recommended force was 3.5 lb. By comparison, a typical power steering automobile would require about 2 lb of rim force just to negotiate a turn at a lateral acceleration of 8 ft/sec^2.

There are some problems justifying the use of the fast rotation with the hand position having rotated 195° from the start of the trial as the basis for a force standard. First, the drivers always experienced the fast rotation rate last in their practice schedule. So the drivers may have been fatigued at this point. Second, this hand position occurred only at the end of a trial when the subjects were more likely to be letting up because they knew the trial was about finished. Third, this score weighs only low speed turns involving at least 180° of steering wheel input.

<u>Pierce</u> (2) - The second experiment employed as subjects one hundred and eighty-two females who were representative of the national driver population in terms

of their age, height and weight. They were asked to exert their maximum pedal and wheel force with the power assist failed and the vehicle stationary. They then drove three laps at 15 mph around a short closed course (Figure 10). The subjects were only informed that their steering and braking behavior was being monitored.

The course was delinated with white lines and outlined with cones at certain places. Shortly into the second lap, unknown to the subjects, the brakes were failed. Farther into the lap the power steering was failed. The steering failures occurred equally often in left and right turns. These failures occurred again on the third lap, but this time the subjects were forewarned. It was believed that the first steering failure was a surprise to most subjects even though it followed the brake failure because the brake failure was not very noticeable. The amount of power-off effort required in this task was not specified but was believed to be greater than that of the Eaton and Dittmeier experiment. The task itself is basically a serpentine maneuver, but because of the low vehicle speed it can also be considered as an intersection-like maneuver.

The peak steering wheel rim force, the steering wheel velocity at the peak force, and the peak horsepower were read from chart recordings. Distributions of the data were plotted and the 5th percentiles were recorded. Chart resolutions were not specified, nor were the variations in vehicle speed.

The results are summarized in Table 3. All individual correlations between these performance measures and the subjects' age, weight, height and driving experience were below 0.4, indicating that subject characteristics had little affect on their performance. The mean force for all trials was 38.6 lb and the standard deviation was 12.2 lb. Assuming a normal distribution the 5th percentile of this mean was 18.6 lb. Except for the overall average scores, the 5th percentiles shown in Table 3 were measured directly from the data. The authors did not believe their sample data were normally distributed. Although the data were somewhat skewed, it was not evident that the assumption of normality would be rejected in a statistical sense. One would expect the steering force data to be normally distributed for a random sample as large as was tested in this experiment.

The mean steering wheel velocity, as measured at the instant of maximum force, was 6.1 rpm or 36.6 deg/sec. Since this rate is quite slow, it appears that either the subjects could perform the task with low steering rates or they could not generate large rates because the power-off steer force was too high

Their mean horsepower score was 0.038 hp, which is less than the lowest score (0.045 hp) measured in the Eaton and Dittmeier study. In most trials the horsepower as measured at the maximum steering force was less than the actual maximum horsepower. Because the maximum horsepower almost always occurred after the maximum force, the steering wheel rate was increasing faster than the force was decreasing as the driver turned the wheel. Since the horsepower was not constant throughout the trial, the force-velocity relatioship did not satisfy a fixed inverse proportionality.

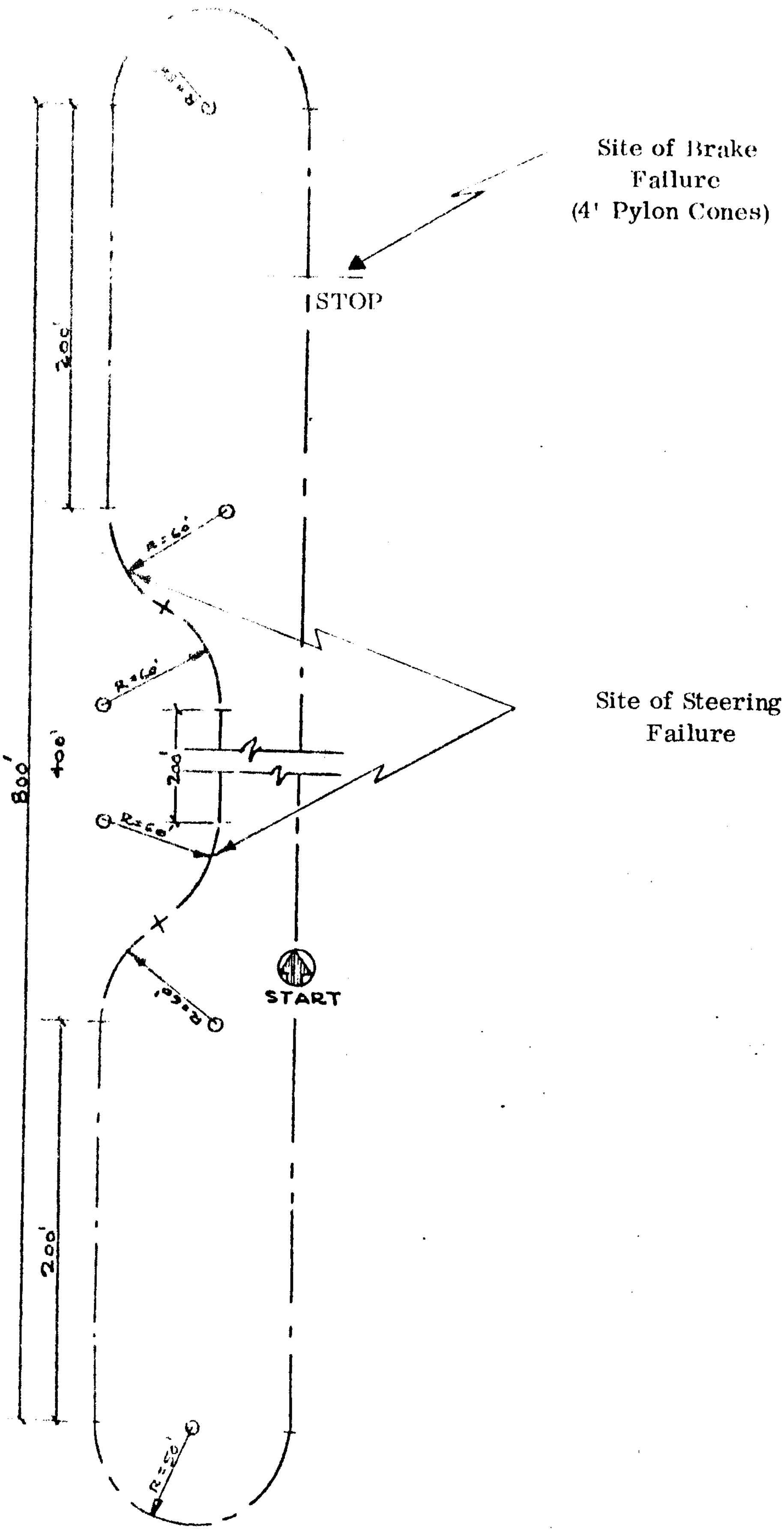

Figure 10. Diagram of the Test Course.

Pierce (2)

TABLE 3

Summary of Data Pierce Study (2)

N = 182 (91 CW + 91 CCW)	Stationary Trial 1	Surprise Trial 2	Forewarned Trial 3	Grand Average
Mean Force (lb)	41.6	36.2	38.3	38.6
SD	15.3	10.9	9.5	12.15
Range	10-80	0-68	10-65	
5th %	14.4	17.1	19.5	18.6
Mean Rate (rpm)	4.3	6.6	7.3	6.1
SD	2.4	3.2	3.1	2.9
Range	0-13	0-22	1-22	
5th %	0.5	1.8	2.2	1.33
Mean hp	0.031	0.04	0.044	0.038
SD	0.019	0.024	0.023	0.022
Range	0.003-0.1	0-0.13	0.005-0.15	
5th %	0.004	0.008	0.015	0.0018
Mean hp_{f-max}	0.025	0.028	0.036	0.03
SD	0.018	0.02	0.019	0.019
Range	0-0.099	0-0.102	0.005-0.108	
5th %	0.002	0.007	0.009	0.001

It was not reported whether each subject traded force for rate across trials. But on each trial the authors did find a small positive correlation between force and rate across subjects. That is, the subjects who had the larger forces were also more likely to have the faster rates. It was also found that the subjects who were in the 5th percentile for force were usually below the 5th percentile for velocity. Therefore, across subjects the force and velocity were not even inversely related.

However, because this correlation was small, force and velocity are relatively independent measures of performance in this task. Certainly, force is the more important of these two performance scores for maximum effort tests because the wheel cannot be turned if sufficient force cannot be generated. At least for this task, it does not seem that horsepower would be a good performance metric on which to base a steering effort design standard.

It would have been helpful had Pierce discussed the various control responses of the drivers, including how successfully the subjects drove through the curves after the power was failed. Based on data in the Appendix of the report, two subjects had zero rim force; i.e., they made no steering response in the surprise failure. Three other subjects exerted less than 11 lb. Apparently, with few exceptions, most subjects made some attempt to steer the car.

Comparison of Data

Table 4 presents a comparison of the lower one-sided tolerance limits for the 95th percentile female with 90% confidence. No tolerance limit can be computed for the Thompson data because standard deviations were not reported. One can speculate that the variability would be high enough so that an unrealistically low tolerance limit would result. Note, for example, that the Hill and Lawrence intersection data predict a lower-one-sided tolerance effort below zero lb. The intersection maneuvers have not provided reasonable estimates of driver effort capabilities.

Because of the low vehicle speed, the driving task used in the Pierce experiment is analagous to an intersection maneuver. Compared with the Hill and Lawrence intersection tests, the Pierce data had a higher mean force but a similar standard deviation. Neither organization offered special incentives to encourage the drivers to steer through the maneuver. Because the Pierce data is nearly identical to the Stoudt data, it appears that 18-20 lb is an estimate of the force capability of a 5th percentile female in both seating buck and intersection-type effort tests where motivation levels are modest.

Both Stoudt's isometric data and Hill's stationary data have similar mean steering efforts even though one task is static and the other dynamic. The difference between their tolerance limits is a result of the difference between their sample sizes. It is important to remember, however, that Hill has shown that the 5th percentile subjects for the stationary vehicle test are not the same as the 5th percentile subjects in the serpentine test.

TABLE 4

Lower One-Sided Tolerance Limits for Steering Efforts

Investigator	Mean (x)	Standard Deviation	Sample Size	K for $1 - \alpha = .95$ $\gamma = .90$	Tolerance Limit (x - Ks)
1. Stoudt	39.1 lb	9.6	50	1.965	19.6 lb
2. Eaton & Dittmeier	0.103 hp	0.041	20	2.208	0.0125 hp
3. Thompson (Peak-Intersection)	15.8 lb	?	19	2.208	?
4. Hill & Lawrence					
(a) Intersection	28.8 lb	10.9	8	2.755	<0
(b) Serpentine-1	26.4 lb	3.1	8	2.755	17.8 lb
(c) Serpentine-2	40.3 lb	4.7	16	2.299	29.4 lb
(d) Stationary-2	44.4 lb	9	16	2.299	23.8 lb
5. Pierce	38.6 lb	12.2	182	1.645	18.6 lb

The serpentine maneuvers demonstrate the task dependency of dynamic efforts. When the effort criterion was increased by 50% (from 26.4 lb) for the second group of subjects in the Hill and Lawrence experiment, the mean effort of the sample population also increased by approximately 50% (to 40.3 lb). However, variability remained low. As a result, this maneuver provided one of the highest steering effort limits (29.4 lb) for the 5th percentile female. The drivers were also highly motivated.

The Eaton and Dittmeier study is difficult to assess. The predicted tolerance limit seems to be surprisingly low. One would expect much higher efforts because the maneuver was very severe. Apparently, many subjects gave up and crashed through the barrels without ever exerting a maximal effort. The authors indicated that the majority of subjects were not successful in executing the lane change.

Another author has suggested that stationary steering torques for passenger cars should not exceed 15 kp rim effort, although no experimental basis for this value was reported (8). This is equivalent to about 33 lb rim force. It is interesting that this recommended stationary level is very similar to the 5th percentile effort from the serpentine maneuver.

DISCUSSION

Steering effort research has certainly not defined a maximum driver steering force. Each experiment had some limitations. Effort tolerance limits were found to vary according to the performance task and the performance metric which an experimenter used.

The Stoudt study employed a large subject sample, but the task was conducted in a seating buck with an isometric wheel. Part of the data collected in the other experiments included the maximum steering forces with the vehicle stationary, and these results correlate well with the Stoudt data. Although the isometric and stationary effort data are important, they should be used in conjunction with dynamic efforts when decisions about effort standards are finally made.

Not unexpectedly, however, there is no recognized standard maneuver to be used for measuring dynamic efforts. The intersection maneuvers used in the Thompson and Hill and Lawrence studies and the lane change maneuver used by Eaton and Dittmeier did not yield a realistic estimate of the 5th percentile driver effort because of the high variability in the data and the small sample sizes. An intersection-like maneuver, performed by a much larger number of drivers in the Pierce experiment, provided a better indication of the force capability of weaker females, although some might question the lack of incentives given to their drivers.

Perhaps the most useful maneuvers have been the serpentines. Data variability is remarkably low, but questions could be raised concerning the representativeness of the sample populations used in the experiment. Also, any dynamic

maneuver raises the problem that the measurement of maximal effort is confounded with the effort requirements inherent in negotiating that maneuver.

It is well known that the rate of turning the steering wheel influences the amount of force that can be generated. The Eaton and Dittmeier study attempted to define the force-velocity relationship by using horsepower as a performance metric. However, this definition was refuted, albeit in a different task, by the Pierce data.

Hopefully, the data already collected will help to formulate the future research programs. Decisions need to be reached regarding (1) which maneuvers constitute appropriate tests of effort, (2) the importance of surprise rather than forewarned power failures, (3) the motivation to be given, (4) the relative importance of static or dynamic efforts, (5) the most meaningful performance metric, and (6) the acceptable ranges for variables such as vehicle speed, magnitude of steer input, and steering angular velocity.

Although the justification for research on maximal steer efforts is evident, there is very little information which would indicate that loss of power assistance is a factor in accident causation. In a review of 1968 and 1969 Motors Insurance Corp. accident files, found only 9 (0.3%) cases in 3000 accidents (1968) for which alleged steering failures could have been steering failures. In 1969 there were 4 potential power steering failures in 1695 accidents (0.24%). These alleged power steering falures represent accident cases for which power failure could have occurred or cases in which power failures could not be ruled out. More recently, an in-depth survey of 530 accidents conducted by the Indiana Institute for Research in Public Safety over a two year period found that steering system problems were at least a probable cause of 2% of these accidents, but in no case did they determine that undue steering effort was a causative factor (9).

In another sample of 21 accidents which allegedly involved power steering failure, twelve male drivers (57%) were involved. (This is about the proportion of males in the driving population). Fifteen (72%) accidents involved standard sized cars. Of the vehicles having higher power-off steering efforts, there were two luxury sedans and no front drive cars. Although this small sample of accident reports is not statistically valid, it does implicate male and female drivers, and vehicles having moderate and high power-off steering efforts, about in proportion to their presence in the total driver/vehicle population.

The issue of driver decision making under stress, i.e., selection of alternative courses of action in the event of power assist failure, needs clarification. This research might define motivational conditions and force thresholds above which the driver will alter his risk-taking behavior. For example, the intersection maneuvers have shown that certain circumstances, such as 300° steering inputs into 12 foot lanes bordered on one side by guard rail, with no danger of a rear end collision, will cause most female drivers to stop a vehicle rather than complete a turn without power assistance. In addition, variables such as lateral or longitudinal accelerations may also influence driver behavior when the steering rim forces are high.

APPENDIX A (3)

CHECKLIST

A checklist has been prepared as an aid for reporting how force is measured, where force is applied, what body parts are mainly involved and what posture is employed, how the subject is instructed to exert force, what role motivational factors play, and what index is selected to rate the subject's performance. There are interactions between apparatus, subject, experimenter, and environment that cause some redundancies in the list. For example, the subject's body posture as well as the magnitude of exertible force will be affected by the support (reaction force) available to him. Such cross-references are useful since they point out the multiple effects of a single factor.

The following list has been compiled for force measurements. It can easily be adapted to tests of torque and work, etc.

A. Measuring Device
   1. General identification
      a. function
      b. model, manufacturer
      c. last calibration
   2. Attachment of measuring device to the subject
   3. Output-readout (digital, analog) - units read
   4. Other (specify)

B. Location of the Force Vector
   1. Static force exertion (no motion): coordinates of the point of force application and direction of force
   2. Dynamic force exertion (motion):
      a. coordinates of the path of the force application
      b. direction of force along the path
      c. motion of the path (temporary location, speed, acceleration)
      d. masses accelerated or decelerated
   3. Other (specify)

C. Subject
   1. Drawn from what population
   2. Anthropometric data
   3. Other (specify)

D. Posture of the Subject
   1. Coupling of the subject to the measuring device
   2. Body parts and muscles chiefly used
   3. Body posture during force exertion
   4. Body support-reaction force available
   5. Other (specify)

E. Method of Force Exertion

Exact wording of the instructions given to the subject or (especially if no specific instructions given) how force was actually exerted. In particular:

1. Requested magnitude of force (all-out effort or submaximal)
2. Requested manner of force exertion
    a. how to build up force
    b. what to do after requested magnitude has been reached
    c. how long to exert force
    d. whether muscle length is kept constant during exertion (isometric)
    e. whether muscle tension is kept constant during exertion (isotonic)
3. Time interval between subsequent tests
4. How many repetitions
5. Practice/training
6. Other (specify)

F. Motivational Factors

1. Selection of subjects
2. Voluntary/required participation
3. Mode of payment
4. Knowledge of the purpose of the experiment
5. Knowledge of the experimental procedure
6. Feedback of performance
7. Supervision during the experiment
8. Stimulating factors, such as encouragements, rewards, competition, spectators
9. Restraining factors, such as danger, fear of injuries, adverse environmental conditions, fatigue, lack of interest, spectators
10. Other (specify)

G. Selection of Performance Score

1. Amplitude-dependent value (maximum, minimum, etc.)
2. Time-dependent value (at or over a specified time)
3. Other (specify)

APPENDIX B

SUMMARY TABLE

Table 5 itemizes important experimental and measurement variables along with the data from the studies reviewed in this paper. All subjects were permitted to adjust the seat comfortably. Hand positions were specified by Stoudt, and by Hill and Lawrence (for their stationary tests). Subjects were believed to be representative of the normal driving population. Data are given in units of pounds rim force. All tolerance limits, except those followed by a question mark, were computed under the assumption that the data were normally distributed.

All maneuver tests involved unexpected power failures in cone courses. Driver control behavior such as performance accuracy, brake usage, etc., was generally not reported in these experiments. (Hill did report some driver information for the second serpentine experiment).

Author	Vehicle	Type of Effort	Motivation	Task	Task Required Effort (lb force)	Instructions	N_s-Sex	# of Trials Per Subject	Performance Metric	Mean ± S.D.	Range of Data	Lower one-sided Tolerance Limit (# rim pull) (1 - a)= .95, γ = .90, Normal	Author
Stoudt et. al.	Seating buck with 18" S. W. diam.	Static	Exhortation	Isometric wheel; 5 diametric hand positions	-	Hold max. force for 5 sec.	50 F	10	Ave. torque for 5 sec.	44 ± 11.2 lb	23.8 - 84.4 lb	22 lb	Stoudt
Eaton and Dittmeier	1968 Full-size sedan S. W. diam = ?	Dyn.	?	35 mph lane change	?	Evaluate handling qual.	20 F	4	?	0.103 ± 0.041 hp	0.045 - 0.20 hp	1.7 lb	Eaton & Dittmeier
	?	Static	?	Isometric steering wheel	-	?	?	?	?	?	?	31 lb (?)	Another Ford Study
Thompson	1966 LeSabre 11:1 gear 16" S.W. diam	Dyn.	Large rubber drums	Intersection Surprise	52 lb	Drive normally; monitoring vehicle motions T-turn; L or R	19 F	2-norm (N) 2-fail (F)	Peak torque	15.8 ± ? lb	3.4 - 25 lb	?	Thompson-Surprise
		Dyn.		Intersection Foreknowledge				3		34.5 ± ?	3.4 - 31.3 lb	?	-Foreknowledge
			None	Stationary	-	Turn as hard as possible		2		36.3 ± ?	8.8 - 50 lb	?	-Stationary
Hill and Lawrence -1	1969 Olds 98 26 psi cold(F,R) 16:1 gear 16" S.W. diam	Dyn.	Guard rail	Intersection	42 lb	Drive normally; 40' radius turn;L/R	8 M	4 N-F-N-F	Peak torque 1/2 sec.	53.1 ± 7.6 lb	?	-	Hill & Lawrence-Inter.-Males
							8 F			28.8 ± 11 lb	?	< 0	Intersection-Female
				Serpentine-1	27 lb	Maintain 30 mph speed and steer smoothly	8 M			27.1 ± 2 lb	?	-	Serpentine-1-Male
							8 F			26.4 ± 3.1 lb	?	17.8 lb	Serpentine-1-Female
-2	20 psi cold F 26 psi cold R 11:1 gear	Dyn.	Guard rail	Serpentine-2	36 lb		16 F	4 N-F-N-F		40.5 ± 4.8 lb	30 - 51 lb	29.3 lb	Serpentine-2
		Dyn.	None	Stationary-2	?	Turn as hard as possible and bold for 3-4 sec.	all 32 F	2	Peak torque	61.9 ± 7.2 lb	?	45.4 lb	Stationary Peak 2
									3 sec. hold	44.4 ± 8.9 lb	?	23.8 lb	Stationary Hold 2
				Stationary with Veh. 1&2 combined					Peak	53.5 ± 12.3 lb	?	28.2 lb	Stationary Peak (1&2)
									3 sec. hold	27.3 ± 11.3 lb	?	14.1 lb	Stationary Hold (1&2)
Pierce	1966 Mercury Montclaire	Dyn.	None	Stationary	?	Turn as hard as possible	182 F	1	Peak torque	41.6 ± 15.3 lb	10 - 80 lb	16.4 lb	Pierce-Stationary
				15 mph S-turn Surprise	?	Maintain 15 mph speed through course		1		36.2 ± 10.9 lb	0 - 68 lb	18.3 lb	-Surprise
				15 mph Foreknowledge	?			1		38.3 ± 9.5 lb	10 - 65 lb	22.7 lb	-Forewarned

TABLE 5

Summary of Experiments

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ATTACHMENT Q

15 C

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GENERAL MOTORS PROVING GROUND

GENERAL MOTORS ENGINEERING STAFF
PROVING GROUND SECTION
CHARLES J. BRADY—DIRECTOR

April 15, 1970

REPORT NO. PG-28547

DRIVER BEHAVIOR UNDER SIMULATED POWER ASSIST FAILURE CONDITIONS

GM RESTRICTED

PG Job No. 15-505-006

File No. F-285

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TABLE OF CONTENTS

ABSTRACT

The purpose of this study was to determine driver strategies and steering efforts exerted when experiencing an unexpected power assist failure during a steering maneuver. Separate groups of male and female subjects drove a car through one of two test courses simulating different vehicle cornering situations. After each subject had made a number of passes through the course, the vehicle's power steering assist was unexpectedly deactivated just before the subject was about to execute a maneuver. Metal guard rails were used to provide suitable motivation to complete the maneuver. The steering torques exerted by each subject were measured in the maneuvers. The maximum torques each subject could exert on the steering wheel under static conditions were measured after the tests were completed.

All of the male subjects exerted sufficient torques to complete both a low speed intersection maneuver and a 30 mph, 0.3g cornering maneuver after the power assist was deactivated.

Only a small proportion (2/16) of the female subjects successfully completed the low speed intersection maneuver, with the remainder stopping in the intersection after exerting something less than their peak static capability.

All of the women subjects who drove a standard sedan as the test vehicle were able to successfully complete the 30 mph, 0.3g cornering maneuver after experiencing an unexpected power assist failure. Only three of thirty-two trials by women subjects using the same car modified to require approximately fifty percent higher efforts were unsuccessful.

There was little correlation between the subjects' peak efforts in the maneuver and their peak static efforts. Consequently, the subjects' peak maneuvering efforts cannot be accurately predicted from their static torque capabilities.

OBJECT

The purpose of this study was to determine typical maneuvering strategies and steering wheel effort levels for normal drivers when confronted with a power steering assist failure in representative driving situations with as realistic motivation as possible.

CONCLUSIONS

1. There was little correlation between the subjects' peak efforts in the maneuvers and their peak efforts under static conditions. Consequently, it does not appear feasible to accurately predict effort levels under dynamic, stressed, motivated conditions from static effort data.

2. All men subjects in the sample were able to successfully complete both a low speed intersection maneuver and a 30 mph, 0.3g lateral acceleration maneuver while experiencing an unexpected power steering assist failure.

3. The strategy of the majority of female drivers in the sample tested was to stop rather than complete the maneuver when experiencing a power assist failure in a low speed intersection maneuver. All of the female subjects exerted peak maneuvering torques that were less than their measured static peak torques. The lowest torque exerted was 10 ft-lb (15 lb rim force).

4. All women subjects used in Phase II successfully completed the 30 mph, 0.3g lateral acceleration maneuver after experiencing an unexpected power steering assist failure with a standard large sedan.

5. Three of 32 trials by a separate group of female subjects on the same course, but using a vehicle modified to require higher efforts, were unsuccessful. The vehicle used in this phase was the same vehicle with an 11:1 steering gear and the front tire pressures reduced to 18 psi. A successful maneuver with the power assist inoperative required a peak torque of approximately 24 ft-lb. The lowest effort exerted by the females on the three unsuccessful trials was 20 ft-lb (30 lb rim force).

6. The distribution of static torque capabilities of the total sample of female subjects used appears to be representative of the female driving population. The mean torque that the female subjects could sustain over approximately 3 seconds was approximately 25 ft-lb with a standard deviation of 7.5 ft-lb.

INTRODUCTION

This study was conducted to provide basic data to better determine the strategies and force levels of a sample of "normal" drivers while experiencing an unexpected power steering failure during the execution of some representative driving maneuvers.

Similar testing has been done which indicated that motivation had a significant effect on the steering effort levels of normal women drivers in stressed, unanticipated driving situations. Consequently, this study attempted to construct driving situations that provided as much motivation as possible while still being safe. The motivation used in this study was provided by outlining the test courses with metal guard rails in critical areas. It was felt that the guard rails provided as much realistic motivation to stay on the course as possible without unduly endangering the subjects (and experimenters).

One driving situation used was a situation in which the loss of power may be relatively frequent, i.e. a low speed intersection maneuver. The other is a situation in which the loss of power assist may be relatively infrequent, but the driving maneuver involved is of at least moderate severity for the driving public, i.e. a 30 mph, 0.3g cornering maneuver. No attempt was made to simulate the simultaneous occurrence of an unexpected loss of power assist and an extreme driving maneuver, as this joint probability is almost sure to be extremely small. Work in driver-vehicle performance in extreme handling situations indicates that the performance of the total driver-vehicle system is very dependent upon driver skill and practice, driver attention, etc., and is extremely variable. Consequently, meaningful, repeatable measurements are difficult to obtain under such stressed, motivated conditions.

METHOD AND EQUIPMENT

The vehicle used for this study was a 1969 Oldsmobile 98, 4-door hardtop, provided by Oldsmobile Division. An electric clutch was attached to the power steering pump pulley to allow the power assist to be deactivated using a switch concealed on the passenger side of the passenger compartment. The rear seat was removed and relevant instrumentation was mounted in the vehicle. A six-channel Brush recorder and transducers were installed to measure and record:

1) Steering wheel torque (16" dia. torque wheel)
2) Steering wheel angle
3) Vehicle lateral acceleration
4) Vehicle forward velocity
5) Vehicle fore-aft acceleration
6) Brake application

The subjects were told that they were taking part in a study to determine how accurately they could track a given speed (30 mph) while going through the maneuvers. They were also told that we were trying to determine whether there were any differences in the smoothness of their steering motions while traversing the areas outlined by guard rails as opposed to those sections of the course outlined by traffic cones only. These supposed test objectives were then justification for the on-board instrumentation and guard rails. A different group of subjects was used for each phase of the study. The subjects used were non-technical employees of the General Motors Proving Ground and Saginaw Steering Gear division. The distribution of maximum static hold torques measured on the total sample of female subjects used in this study had a mean of 25.0 ft-lb and a standard deviation of 7.5 ft-lb. A study done at the Harvard School of public Health by Stoudt, et al [1]* measured maximum static hold torques of female subjects on an isometric wheel for various hand locations reported a distribution with an average left/right turn mean of 25.8 ft-lb and a standard deviation of 6.8 ft-lb for a similar

*[ ] Numbers in brackets refer to references at the end of this report.

task. This "static hold" effort is somewhat meaningless as people did not hold constant torques over a 3-5 second period and an average over this period can be hard to interpret. The maximum static hold levels generated by the subjects certainly depend on motivation. The torque exerted by the subjects in the test maneuvers was irregular and not a smooth, slowly changing effort. None the less, the similarity in static hold capabilities of the female subjects in this study and those given by Harvard data indicate the total sample of females used in this study was representative of the female driving population in terms of their steering torque capabilities.

DISCUSSION OF RESULTS

PHASE I:

The first test configuration simulated a right or left turn at an intersection. The test course was laid out on the Vehicle Dynamics Test Area and is indicated in Figure 1. The subjects were told to stop at a stop sign just before the intersection and then told to make either a right or left turn at whatever speed felt comfortable to them. After a number of trials, the power assist was failed unexpectedly just as they began to initiate a turn. The maximum torque exerted and whether or not the course was completed were recorded. It was usually possible to give a subject some excuse for the initial failure that seemed plausible and proceed with the testing for a period before introducing another failure. There was no statistically significant difference between the distribution of efforts for the first "surprise" trial and the second "surprise" trial.

All sixteen surprise trials for the men subjects resulted in successful completion of the course. It was determined that approximately 28 ft-lb of torque was required to successfully complete the course. This value can vary somewhat, particularly if one put in rapid, jerky inputs, but a smooth completion of the maneuver could be accomplished with a maximum of 28 ft-lb (42 lb rim force).

Figure 2 shows the peak maneuvering torque plotted versus the peak static torque for the men in this study. The mean peak maneuvering torque was 35.3 ft-lb and the mean peak static torque was 33.0 ft-lb. The correlation between maneuvering peak and static peak is very low, $r = 0.214$. This indicates that there is no good linear fit to these data, i.e. no correlation between maneuvering and static peak torques. It can also be interpreted as indicating that only 4% (r^2) of the variance in peak maneuvering torques can be attributed to variance in static torques.

Since the torque required to complete the task was 28 ft-lb, any subject whose static peak cability was greater than 28 ft-lb did not have to exert his total static effort. Consequently, he would only have to be motivated sufficiently to exert the required task torque and not his total static level. This is illustrated by the dashed line on Figure 3. The ratio of maneuvering to static peaks is plotted versus static peaks in this figure. The dashed line represents a "motivation reference line" for the task difficulty. It represents a ratio of 1.0 for static efforts less than that required by the task, and a ratio of the task required torque to the static torque for static torques greater than the task required torque. Figure 3 shows that all subjects whose peak static efforts were less than 28 ft-lb exerted maneuvering torques higher than their measured static level. Those with static capabilities greater than 28 ft-lb exerted some amount more than that required by the task. The correlation between the ratio and static effort was high, -0.79.

The fact that there is a high negative correlation between the maneuvering to static ratio and the static effort is primarily an artifact of the test design and is due in large part to the relative difficulty of the task. For a given task that requires a low effort relative to a group's static effort distribution, we would expect the group to exert something approximating the task required effort. This effort level would be essentially constant across all static efforts. The distribution of ratios would then depend primarily on the distribution of static efforts and very little on the maneuvering efforts. The expected ratios would be reasonably approximated by a straight line with a negative slope through the region of static torques measured. Figure 3 is only presented as another method of viewing the test results and should only be interpreted in the context of this given task.

The group of women subjects used in the intersection test produced only three successful maneuvers out of sixteen "surprise" trials. The other thirteen surprise trials ended with the women choosing the alternative of stopping in the intersection after exerting something less than their peak static efforts. The vehicle's engine was not turned off and the subjects could have completed the turn if they chose to exert the required effort. The statistically significant correlation coefficient (r = .65) indicates that there was a significant non-zero correlation between the maneuvering and static peaks (see Figure 4). However, this still does not mean that we can accurately predict a maneuvering effort corresponding to a given static effort based on these data. As an example, consider the 10th percentile static effort level of 21.2 ft-lb for these subjects. Based on the regression line:

$$M = .517\ S + 3.061$$

and a correlation coefficient of r = .656, the 90 percent confidence limits for the predicted value of maneuvering torque corresponding to this static level are:

$$3.7 < \text{maneuvering torque} < 24.3 \text{ ft-lb.}$$

This is some improvement over an estimate based solely on the distribution of all maneuvering efforts. In this case, the 90 percent confidence limits for the maneuvering torque (i.e. the range between the 5th and 95th percentile levels) are:

$$5.1 < \text{maneuvering torque} < 32.3 \text{ ft-lb}$$

This means that if we were to measure the peak maneuvering efforts on this task of a group of 100 women, all of whom demonstrated a static peak effort of 21.2 ft-lb, we would expect 90 of them to exert between 3.7 and 24.3 ft-lb of peak torque in the maneuver. We would expect 10 of them to exert maneuvering torques outside of this range. The lowest torque exerted was 10 ft-lb (15 lb rim force).

Figure 5 is a plot of the ratio of peak maneuvering to static effort versus static effort for these subjects. There is very little correlation between the ratio and static effort. The previous discussion for a similar plot of the men subjects' data is again pertinent and interpretation of this plot must be constrained to these particular test conditions. This form of data presentation does indicate that only one of the subjects approached her static capability and that a number of the "stronger" subjects did not even approach the task required effort, even though it was less than their measured peak static capability. This indicates that the women subjects chose the alternative of stopping rather than completing the maneuver. The mean ratio for the subjects with less than 28 ft-lb static capability was 0.63, as was the mean ratio for all subjects. However, we can make no inferences about the ratio for a given level of static effort because of the low correlation.

PHASE II:

The second phase of the study involved a task that was considered to represent a power assist failure in a moderate-to-above-moderate cornering maneuver for the driving public. It was decided not to simulate a combined extreme, evasive maneuver together with a loss of power assist, as the joint probability of these two occurrences was considered remote. A speed of 30 mph was used, as back drive produces power assist above that speed with the ignition turned off for all GM cars. At higher speeds, the vehicle lateral acceleration gains increase such that smaller steering motions are required for a given lateral acceleration.

A lateral acceleration level of 0.3g was chosen to represent a somewhat higher than comfortable lateral acceleration at 30 mph. A search of existing literature on driver lateral acceleration behavior [2] has indicated that a "comfortable" lateral acceleration decreases with increasing speed. A number of pertinent articles found in the literature are given in the included bibliography and can be summarized a number of ways. One interpretation is that a maximum "comfortable" lateral acceleration level at 30 mph for a 90th percentile driver is from 0.25 to 0.30g. Consequently, 0.3g was chosen as the lateral acceleration for this study. This appeared to be a reasonable level as not all the women drivers would drive the course at the required speed on the first few passes and had to practice a few times to keep the speed up to 30 mph. The course used for Phase II consisted of four sections of arc (r = 200 ft.) joined by straight segments, and outlined by traffic cones and metal guard rails (see Figure 6).

All of the men and women subjects in Phase II exerted enough torque to successfully complete the 0.3g maneuver at 30 mph after experiencing an unexpected power assist failure in a standard vehicle. There were 14 surprise trials by men subjects and 16 by women. The average torque exerted for a nominal 0.3g maneuver was 18 ft-lb (27 lb rim force). All efforts were below the subjects' static capabilities. The test vehicle for this phase was a standard 1969 C-body, four-door sedan.

PHASE III:

Since all of the male and female subjects were able to successfully complete the 0.3g, 30 mph maneuver in Phase II, it was decided to modify the test vehicle to require more effort to complete the same maneuver. An 11:1 steering gear was installed and the front tire pressures were reduced to 18 psi cold. The vehicle with these modifications required approximately 24 ft-lb steering wheel torque or 36 lb of rim force to successfully execute the maneuver. A separate group of 16 female subjects was used for this phase which used a test procedure identical to Phase II except for the vehicle modifications.

Three of thirty-two trial runs were unsuccessful in that the females either hit cones and stopped the car before the end of the course, or in one case, actually struck the guard rail. The peak maneuvering efforts were plotted versus static efforts in Figure 7. This shows that none of the female subjects exerted as much of their static effort (45 degree line through origin) and the lowest effort exerted in the maneuver was 20 ft-lb (30 lb rim force). The correlation for these two variables is not significantly different than zero, r = 0.143.

This low correlation indicates that the derived regression line provides estimates of the maneuvering torque associated with a given static level that are no more accurate than an estimate based merely on the measured mean and standard deviation of the distribution of maneuvering torques. The 10th percentile static level for these data was 34.8 ft-lb. The regression line evaluated at this level and a correlation of 0.143 result in a 90 percent confidence range for the estimated value of the maneuvering torque corresponding to a 34.8 ft-lb static torque of:

$$19.95 < M < 32.55$$

The 90 percent confidence range for the maneuvering effort data based merely on a mean of 26.81 and standard deviation of 3.25 is:

$$20.45 < M < 33.17$$

These ranges are essentially equivalent.

Figure 8 is a plot of the ratio of maneuvering peak to static peak versus the static peak for the women subjects in Phase III. This plot provides an alternative way of viewing the results, but again, it should only be interpreted based on the particular conditions of this test. The task required effort was approximately 24 ft-lb and the "motivation reference line" based on this required effort level is the dotted line on Figure 3. The cloud of data points indicate that all subjects had static capabilities higher than the task required effort and that all but three exerted maneuvering torques somewhat above that required to complete the task. There is a significant correlation of -0.667, as could be expected. The three subjects who did not successfully complete the course are indicated by the three points below the dotted line.

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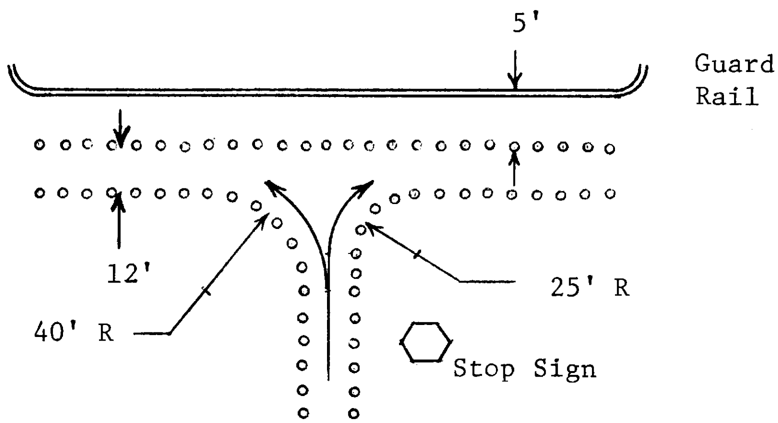
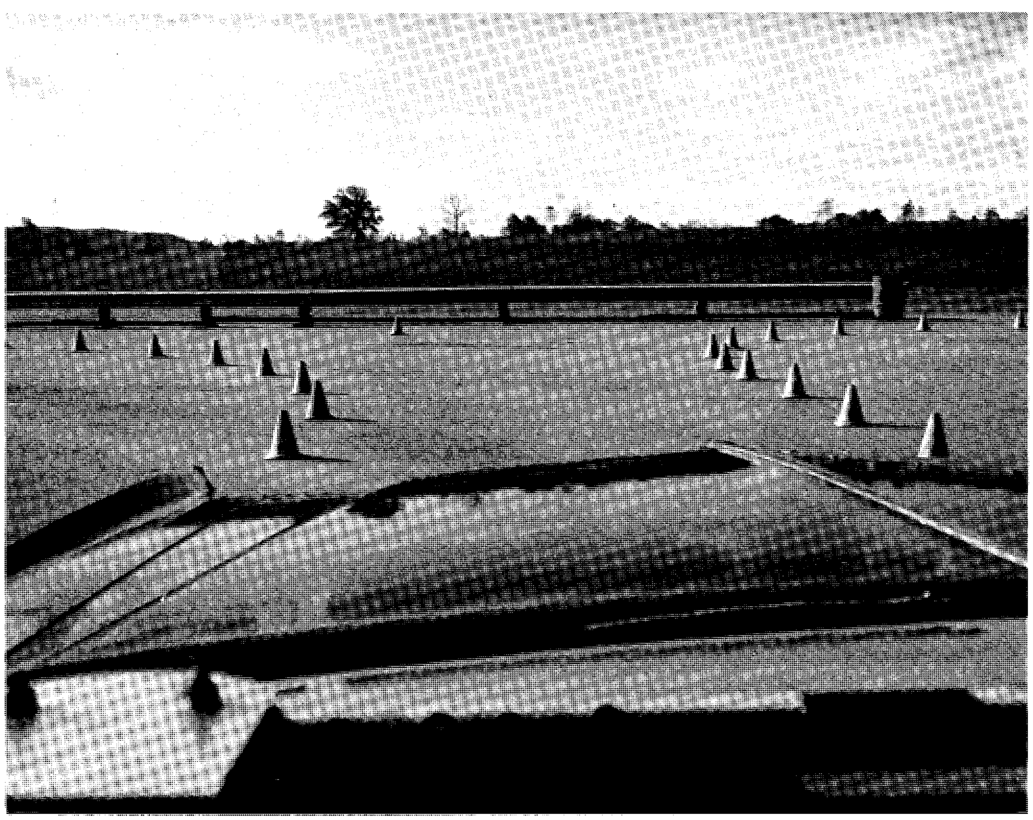
FIGURE 1

Low Speed Intersection Course



COURSE DIAGRAM



Neg. 0969.077

SUBJECT'S VIEW FROM INSIDE CAR


0969.677

FIGURE 2

INTERSECTION - MEN

PEAK MANEUVER TORQUE VS PEAK STATIC TORQUE

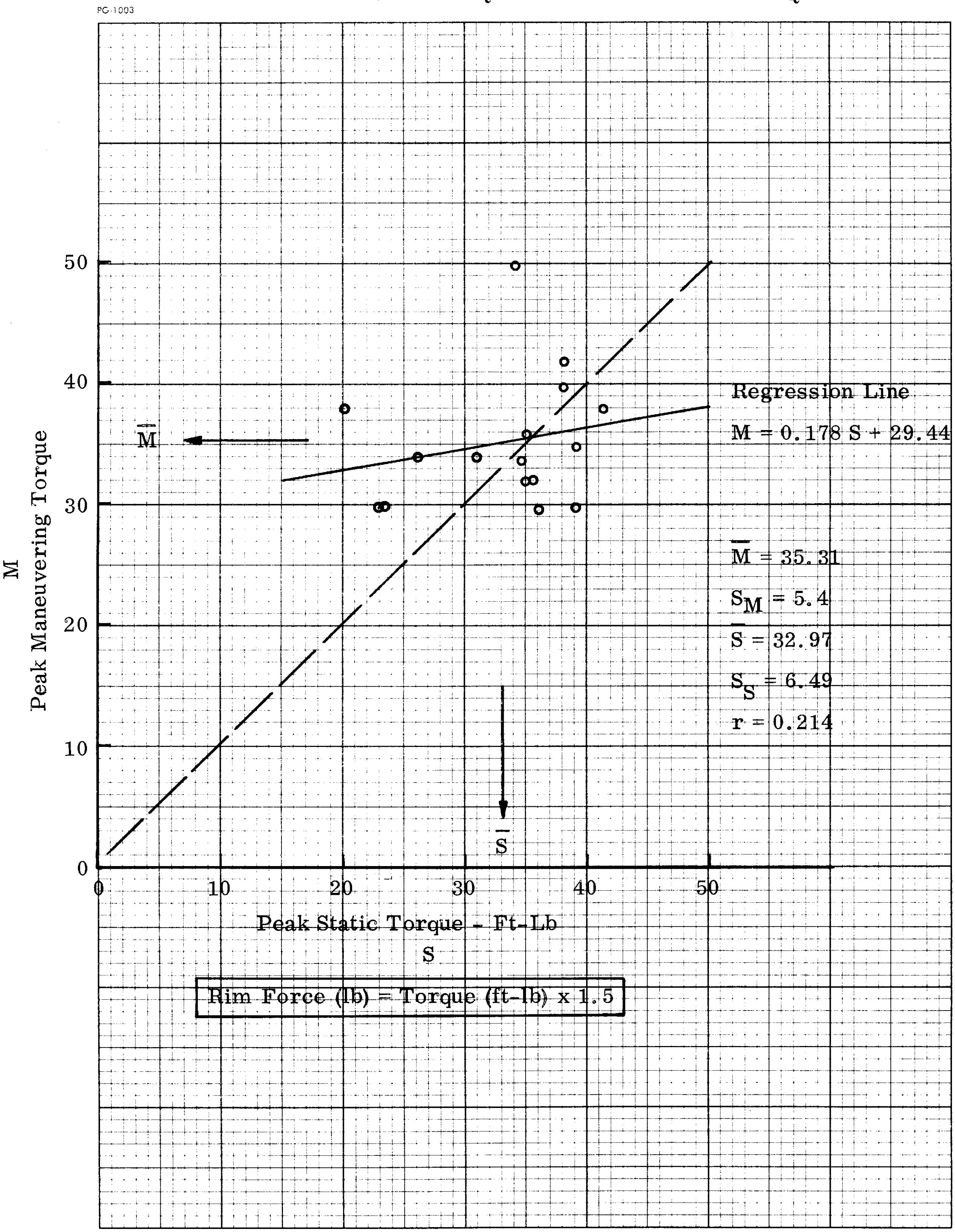


FIGURE 3

INTERSECTION - MEN

RATIO OF PEAK MANEUVER / PEAK STATIC VS PEAK STATIC TORQUE

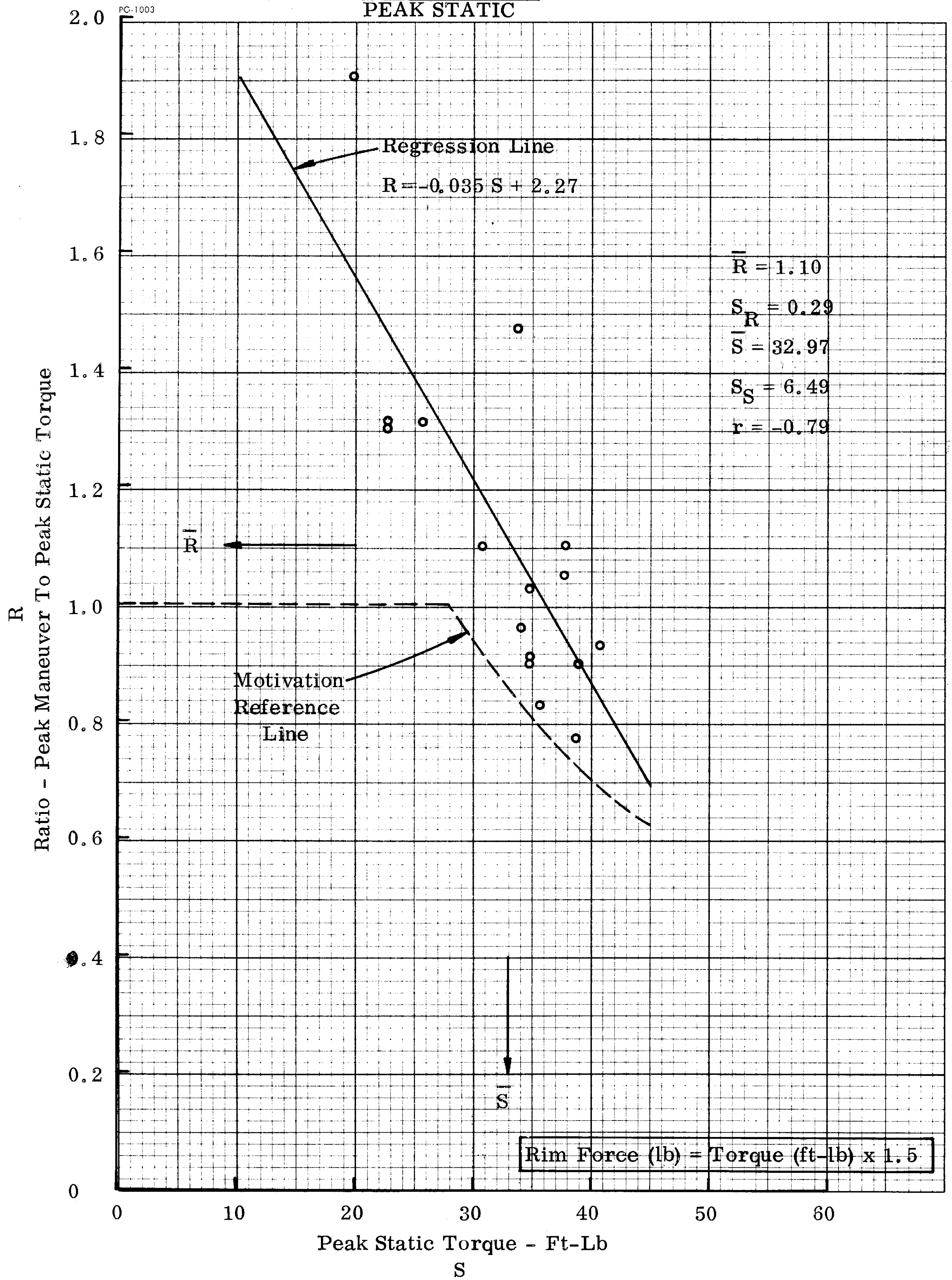


FIGURE 4

INTERSECTION - WOMEN

PEAK MANEUVER TORQUE VS PEAK STATIC TORQUE

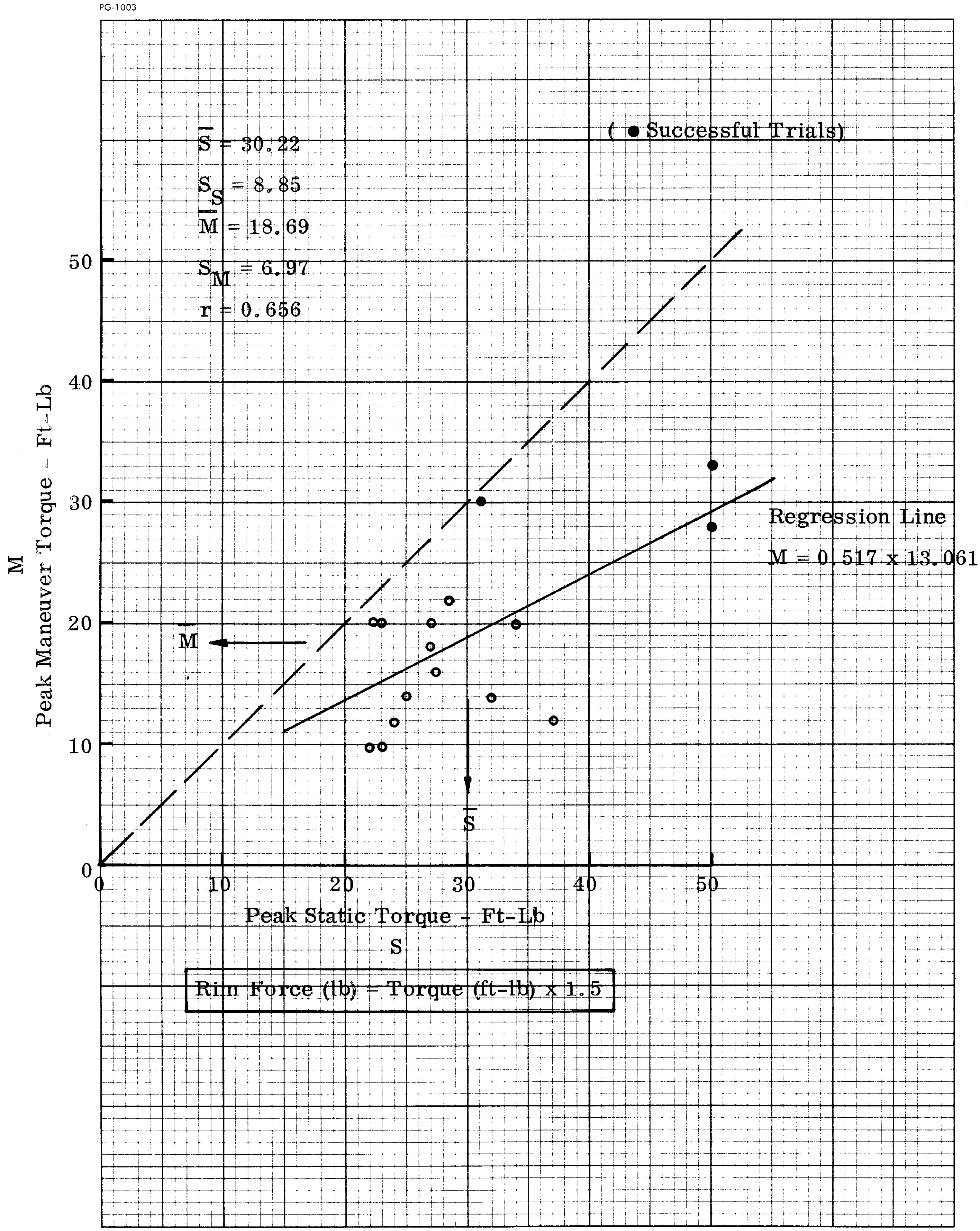


FIGURE 5

INTERSECTION - WOMEN

RATIO OF $\frac{\text{PEAK MANEUVER}}{\text{PEAK STATIC}}$ VS PEAK STATIC TORQUE

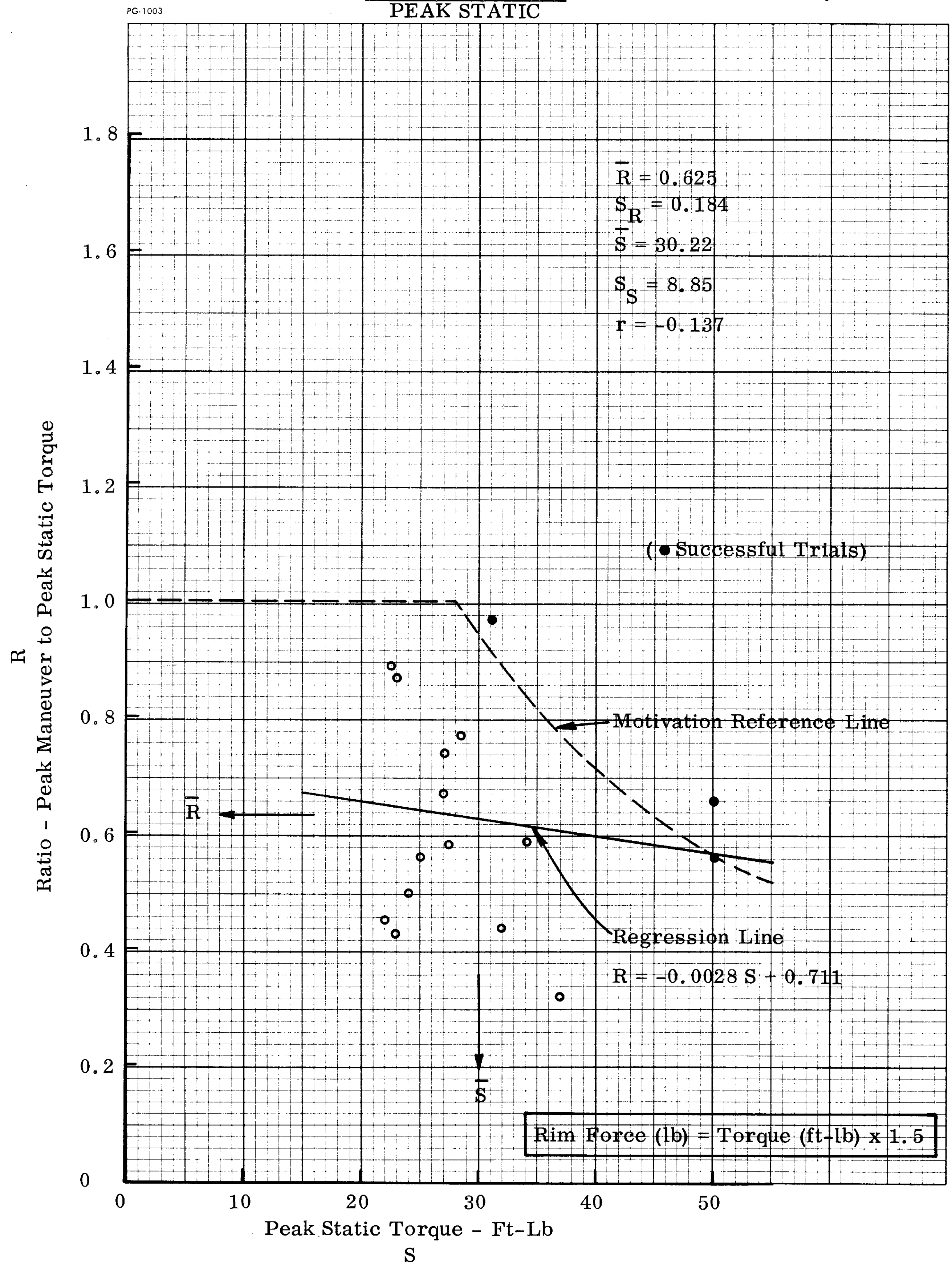
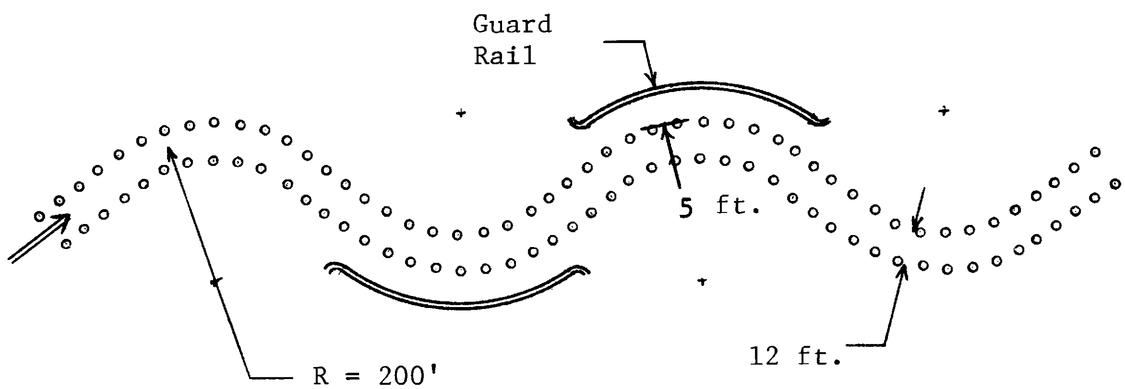


FIGURE 6

30 MPH, 0.3g CORNERING COURSE



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SUBJECT'S VIEW FROM INSIDE CAR

FIGURE 7

30 mph, 0.3g CORNERING-MODIFIED VEHICLE - WOMEN

PEAK MANEUVER TORQUE VS PEAK STATIC TORQUE

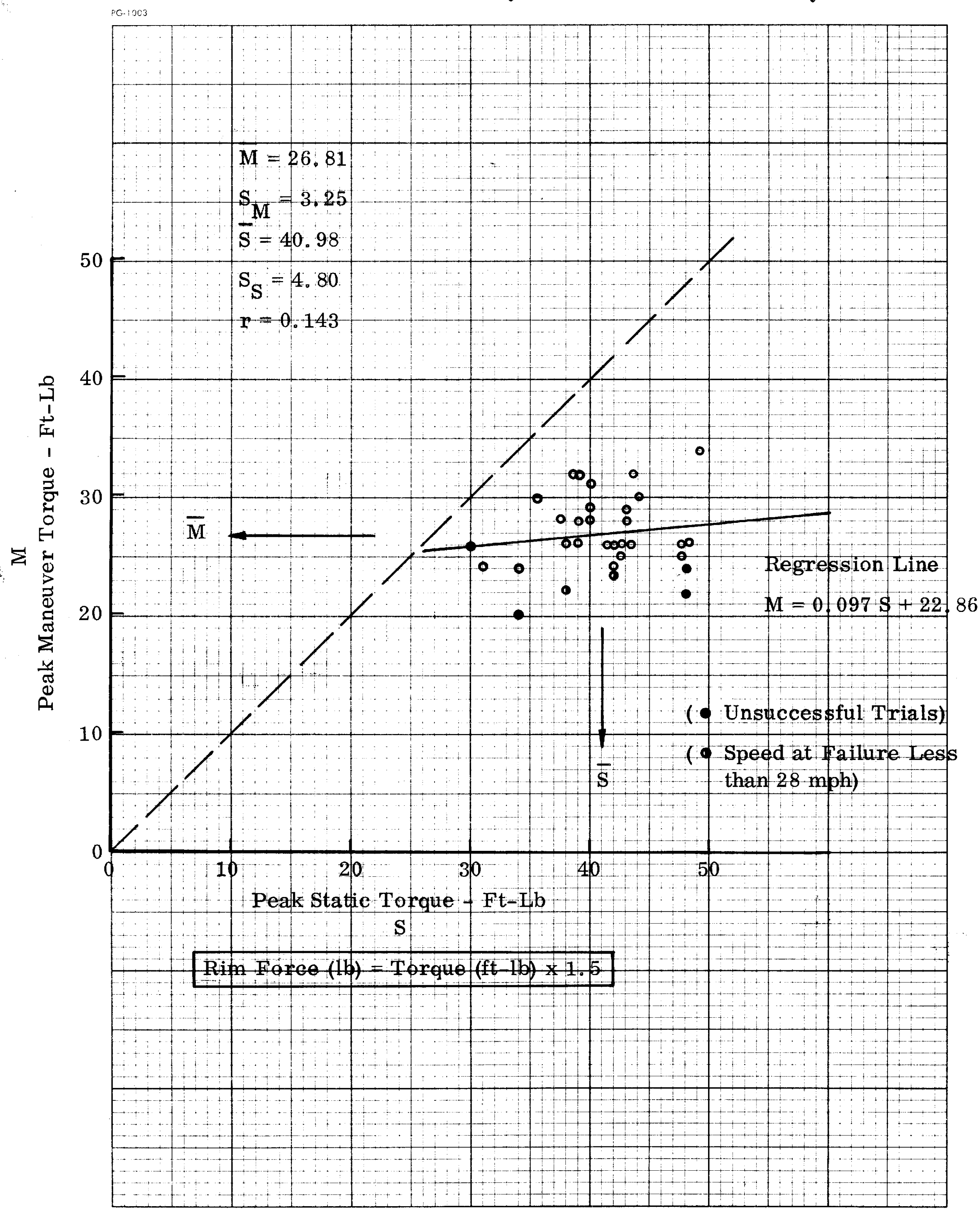
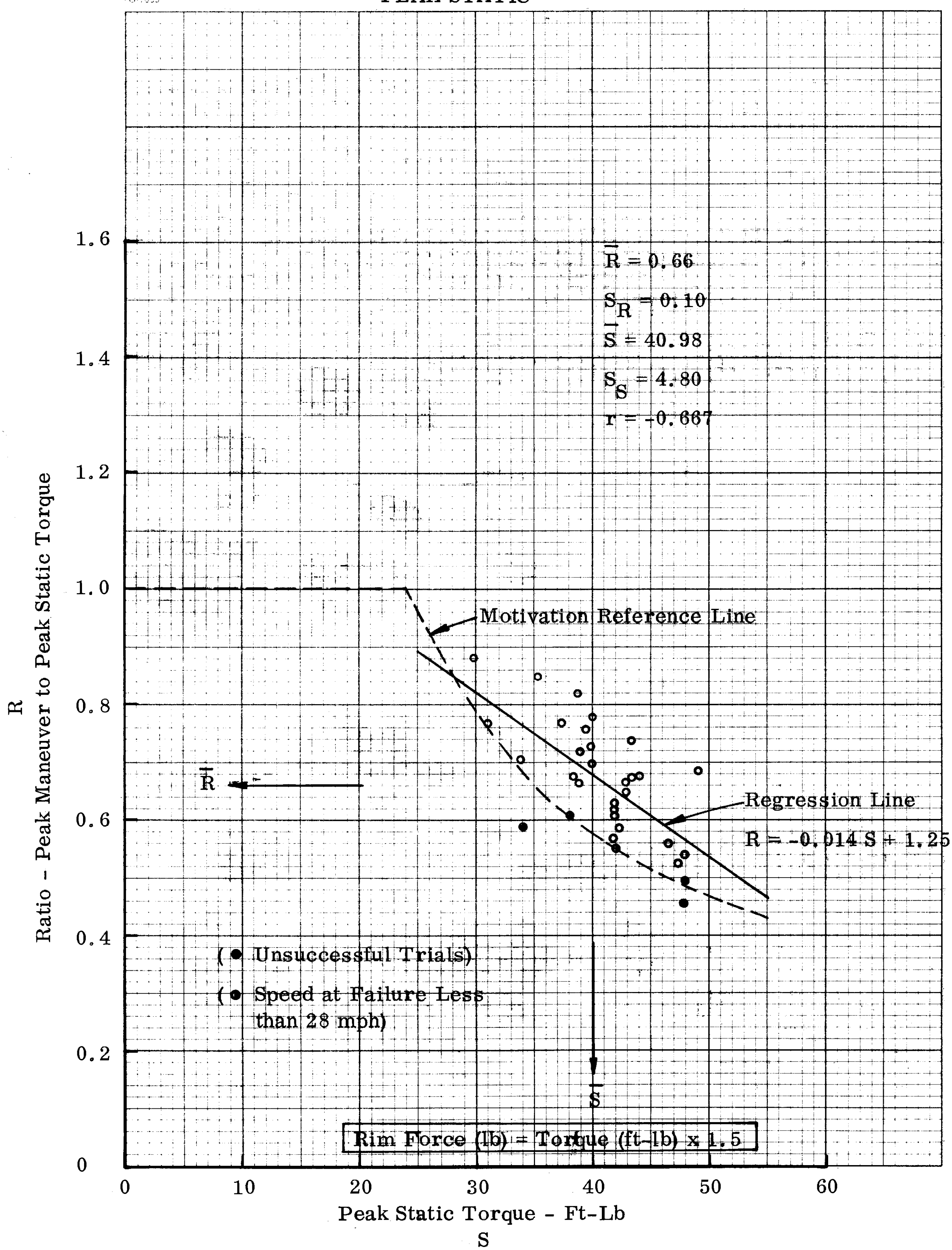


FIGURE 8

30 mph, 0.3g CORNERING - MODIFIED VEHICLE - WOMEN

RATIO OF PEAK MANEUVER / PEAK STATIC VS PEAK STATIC TORQUE



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