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AN EXPERIMENTAL STUDY OF AUTOMOBILE DRIVER  
CHARACTERISTICS AND CAPABILITIES

R. S. Rice, et al

Calspan Corporation  
Buffalo, New York

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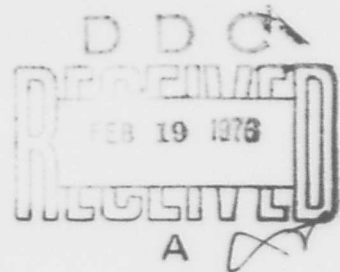
# Calspan

## Technical Report



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# Calspan

*AN EXPERIMENTAL STUDY OF  
AUTOMOBILE DRIVER CHARACTERISTICS  
AND CAPABILITIES*

R.S. Rice and F. Dell'Amico

Calspan Report No. ZS-5208-K-1

Prepared For:

GENERAL MOTORS CORPORATION  
GENERAL MOTORS PROVING GROUND  
MILFORD, MICHIGAN 48042

MARCH 1974  
CONTRACT NO. CC-222  
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## PREFACE

The General Motors Corporation has had a long-term interest in driver characteristics and capabilities and how these are affected by driver training. The Corporation has performed numerous in-house projects and experiments in these areas. One set of findings, based on a limited exploratory effort, suggested that ordinary drivers seldom utilize the maneuvering capability of automobiles even in emergency situations. Additionally, in these experiments drivers did not always react in the most appropriate manner.

A basic objective of the present program was to acquire additional information on driver behavior in maneuvers at accelerations higher than those normally used in vehicle operation on the highway. This allowed the acquisition of driver error data in an amount permitting statistical analysis. The program was conceived as a logical engineering follow-on to the earlier work.

Like the earlier work, the present program was performed in a proving ground environment utilizing cone courses and artificial markers to create driving tasks of various types. The driver sample was chosen to cover a substantial range of probable driver behavior and all of the subjects involved were volunteers. The instructions given to the drivers were intended to induce rapid maneuvers by providing an incentive, and a competitive environment, to drive the course as fast as they were willing. Additionally, some subjects were exposed to a definite emergency situation. In short, the program was framed to produce the desired engineering information.

The results of the program should be viewed in the context of the above plan and limitations. It was intended that these tasks have some relationship to those encountered in actual highway operation but, of course, the experiment was set up to safeguard the participants and all of the subjects were aware of the fact that they were not being exposed to the risks attendant to actual highway conditions. The area was cleared of hostile objects and other traffic commonly found in real life and errors were established on the basis of striking course markers. The drivers were provided test vehicles and did not drive their own cars. There was no restriction, and hence no penalty, on speed.

While the program results accurately represent the drivers' behavior under these test conditions, they do not necessarily represent the behavior of the driving public in real-life highway conditions. The next step in obtaining a more complete understanding of driver behavior is the acquisition of data from actual highway experience as, for example, some form of accident analysis. Such a step may provide sufficient understanding of real-life driver behavior to permit development of proving ground experimentation techniques which correlate well with the real-life situation.

## FOREWORD

This report describes the work performed by Calspan Corporation under Contract No. CC-222 for the General Motors Corporation during the period from August 1, 1972 to March, 1974. Mr. R. S. Rice, Jr., Principal Research Engineer, Transportation Safety Department, was the project engineer.

This report has been reviewed and is approved.

*Edwin A. Kidd*

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Edwin A. Kidd, Head  
Transportation Safety Department

*Arthur M. Hill*

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## ACKNOWLEDGEMENTS

The authors are indebted to a large number of people whose time, effort, comments, and encouragement were of vital importance to the program. Without their contributions, the acquisition of the large amount of raw data and the often laborious reduction of these data into meaningful terms could not have been accomplished. We are particularly grateful to Mr. John E. Schifferle who, in addition to his role as test observer in the experiments, managed the details of scheduling and data collection, to Mr. Donald W. Hess, who kept all the equipment operating, as well as functioning as a test observer, to Mr. Dennis T. Kunkel, who reviewed, compiled, and edited several thousand feet of motion picture film to produce the documentary film which complements this report, and to Dr. E. A. Kidd and Mr. Sanborn W. Chesley for their guidance in the statistical treatment of the data.

We wish also to acknowledge the dedicated support of the project technical monitor, Mr. Keith McKenna of the General Motors Proving Ground, for sound advice and continued encouragement during the course of the program. Finally, we want to thank our willing driver-subjects - all 108 of them - who participated in some way toward developing the methods used in the program and acquiring the data on which the project results stand.

## ABSTRACT

An experimental program to obtain quantitative data on how drivers utilize the performance and handling properties of their vehicles has been performed. Over one hundred drivers participated in the experiment, which consisted of self-paced driving through a specially-constructed proving ground handling course several times. Continuous measurements of primary input variables (steering wheel motions and brake pedal activity) and the principal vehicle responses (speed and lateral and longitudinal accelerations) were made throughout each trial. Total time in the course and incidents of failure to maintain path were also measured. Driving techniques (e.g., hand position on the steering wheel, foot used for braking) of the subjects, who were selected to provide an appropriate representation of the driving population with respect to age, sex, and years of driving experience, were subjectively observed.

The subject sample was separated into four groups according to which of two vehicles (having somewhat different handling characteristics) was driven and to whether the subject was familiar or unfamiliar with the type (size and operational characteristics) of car being used.

Experimental results are analyzed primarily in terms of the application of the maneuvering potential of the vehicle (i. e., lateral acceleration) used by the subjects in negotiating the various driving tasks which they encountered in the course. The results are given in terms of mean values and standard deviations for various groupings within the total sample and, in some cases, have been evaluated for the statistical significance of different factors. It is particularly interesting to note that the subjects, even when encouraged to drive at their limit of willingness, did not normally attempt to operate near the limiting capabilities of the automobiles. It is concluded that in addition to the analyses given in this report the extensive data accumulated in this program can also be applied to many other investigations of driver behavior.

## SUMMARY OF CONCLUSIONS

A large body of information has been accumulated on driver characteristics and capabilities in the baseline experiments performed in this program. Results and conclusions are given throughout the discussions of these data but, since these sections also contain detailed information on individual maneuvers and driver operations, the major conclusions of the study may not be readily apparent. To cover several broad topics of interest, the conclusions are collected here under the following headings:

- Driver Description
- Acceleration-Velocity Performance
- Speed and Accuracy
- Familiarity With the Test Vehicle
- Vehicle Characteristics
- Surprise Intrusion
- Age and Sex
- Steering and Braking  
and, finally,
- The Average Driver

Our conclusions will, of course, be based on the results observed in this program; they will be presented in the context of trends and likelihoods. In many cases, however, comparisons have been made using the Student's *t* as the measure of significance. In this summary, those statements and numerical values that were associated with levels of significance between .001 and 0.1 will simply be marked with an asterisk (\*).

The comments which follow contain a number of specialized terms and references which relate to particular details of the program. So that these remarks may be understood in context, a very brief background on the study is provided here.

Approximately 100 drivers drove one of two test vehicles in five trials through a continuous course consisting of several incidents requiring driver action for successful negotiation. The total subject sample was separated into several groupings (having similar makeup with respect to sex, age, and driving experience).

Familiarity with a vehicle-type (Groups A, B and C using a standard production automobile) as a factor in performance was studied with a portion of the subjects. Vehicle characteristics as a factor was investigated with two groups, D using a modified configuration of the standard vehicle and Cs (a subgroup of C) using the standard vehicle. The major differences in the modified vehicle were larger tires, quicker steering, and reduced understeer.

The driving incidents were given descriptive names which identify some major characteristic of the maneuver.

Geometrical details are given in the body of the report. Individual performance in these incidents was measured in terms of lateral acceleration, speed, success/failure, etc. and then combined for the various groups to give means and standard deviations for these various factors.

### Driver Description

- About 8 in 10 of the female subjects rated themselves as average drivers; the other 2 as above average. Among the male subjects a majority, about 54%, considered themselves above average - the remainder as average. Only one subject in 108 declared himself to be a below average driver.
- The test observers rated most of the subjects as average but also rated more subjects as above average than as below average; their rating distribution was "biased" towards the high side.
- When driver self-ratings are compared with test observer ratings the female subjects agreed with the observers 67% of the time; the male subjects 45% of the time. A little less than 3 in 10 females and a little more than 4 in 10 males rated themselves higher than the test observers rated them.
- 75% of the subjects used right-foot braking; only 20% chose to use the shoulder harness available in the test vehicles.
- About 75% of the subjects declared that they had never in their driving experience driven a car harder than in their test runs.

### Acceleration-Velocity Performance

- For all subjects, in almost all of the tasks, an increase in mean lateral acceleration occurred between the first run and the fastest run (usually the 5th); this increase amounted, on the average, to 0.1g. Similarly, average speed through the course increased from about 28 mph to 36 mph.
- In the two dry surface maneuvers in which peak lateral acceleration used by the subjects was the metric of interest - the Avoidance Maneuver and the Ess turn - the drivers of the Standard car averaged a maximum lateral g of about 0.45g. In contrast, the expert drivers in the study consistently used values at or near the limit-of-performance of the vehicle - i.e. - 0.60g to 0.65g.
- In those maneuvers in which the primary metric was a steady-state acceleration-velocity pair (i.e.  $\bar{A}_y - \bar{V}$ ) the drivers of the Standard vehicle averaged about .4g over a speed range of about 25-40 mph. The drivers of the Modified car averaged somewhat higher lateral accelerations - roughly .45g over the speed range of 25-40 mph.

### Speed and Accuracy

- All drivers averaged a reduction in time-in-course (without regard to failures) from the first run to the fastest run of about 20%.
- 98% of all fastest runs (without regard to failure) occurred in the 4th and 5th runs. The frequency distribution of time-in-course was nearly the same for the Standard car drivers (Groups AB and C); this was not the case, however, with the Cs and D groups (i. e. Std. vs. Mod. car).
- For the Standard car drivers the difference between the fastest run with failures and without failures was about 5 seconds, on the average - i. e. - 125 sec. vs. 130 sec. For the expert drivers the fastest run without failure was about 106 sec.
- Maximum instantaneous speed at any point in the course averaged about 55 mph for all drivers.
- The overall failure rate, all drivers, all runs averaged about 8%; the failure rate increased between the first run and fastest run from about 5% to about 11%.
- The Wet Surface maneuver produced the highest failure rate (not counting the Surprise Intrusion). About 22% of the subjects had at least one failure in this maneuver. The Avoidance Maneuver and Ess turn ranked behind the Wet Surface in difficulty; the Large Radius Arcs and Gravel Turn gave the drivers the least difficulty.

### Familiarity With the Test Vehicle

- Although the familiarity criteria used (for the Standard test car) were relatively crude no large differences attributable to familiarity were detectable in most of the course tasks. However, in the Wet Surface maneuver the unfamiliar drivers (Group C) did not perform as well as the familiar drivers (Group AB); they had a higher failure rate, more failures at lower speeds and a higher frequency of loss-of-control failures.
- Based on the mean time-in-course for fast runs (runs 4 and 5) no statistically significant difference was found between Groups AB (familiar) and C (unfamiliar) drivers of the Standard car. However, the familiar drivers (Group AB) did have a much lower standard deviation indicating, possibly, a greater consistency in performance.
- The difference between Group AB (familiar) and Group C (unfamiliar) time-in-course without failure was 1 second, on the average - i.e. - 129 sec. vs 130 sec. The difference is not significant.

### Standard vs Modified Vehicle

- In a number of the individual tasks (Best Successful Run) the drivers of the Modified car (Group D) were willing to push the car harder than the Standard car drivers (Group Cs); their Off Road Recovery entry velocity was a little higher, their Large Radius Arcs  $\bar{A}_y$  was 0.05g higher, their peak  $A_y$  in the Avoidance Maneuver and the Ess turn were from .06g to .10g higher,\* their Gravel Turn  $\bar{A}_y$  was .06g higher, and their Small Radius Arc  $\bar{A}_y$  was .09g higher.\* In the Wet Surface maneuver the Group D drivers tended to be more aggressive but, at the same time, they had fewer losses of control, than the Group Cs drivers.
- Based on the fast runs (runs 4 and 5) data the Modified car drivers used a lower mean time-in-course, by 7 seconds,\* than the Standard car drivers; a slightly larger difference (i. e. about 9 seconds)\* existed in the fastest run without failure data. However, the Modified car drivers had a slightly larger fastest run failure rate.
- For roughly equal failure rates the Group D drivers tended to go through the course faster than the Group Cs drivers.

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\* Statistically significant,  $p < .10$ .

### Surprise Intrusion

A portion of the subject sample was exposed to a surprise situation in which a large but lightweight plastic object was hurled into the path of the vehicle on the last run of a set.

- In 34 cases in which the plastic barrel was satisfactorily ejected and quantitative performance data are available, only one subject successfully avoided the object.
- Mean reaction time (time between ejection of the object and first evidence of driver avoidance action - braking or steering) was .65 seconds.
- In 75 % of the cases, first reaction was pure braking or combined steering and braking.
- Mean approach speed was 54 mph. In the one successful avoidance of collision, approach speed was only 44 mph.

## Age and Sex

- The mean fastest run without failure for all drivers of the Standard car was about 129 seconds. For the males this figure was 123 seconds; for the females it was 137 seconds - i.e. - the males drove the course much faster.\*
- On the other hand, the fast run (runs 4 and 5) failure rates for all Standard car female drivers was less than 1/2 that for all male drivers.
- If fast run (runs 4 and 5) failure rate is plotted against time-in-course for all Standard car drivers (Groups AB and C) the highest failure rate (23.2%) is associated with males in the 16-24 yr. age bracket; this group had the second lowest time-in-course. The lowest failure rate (<3%) and the highest time-in-course (148 sec.) is associated with females 45 yrs. and older. If two "extreme value" subjects are removed from the 75 subject sample an inverse relationship between failure rate and time-in-course results. In this case the ranking on a scale of "boldness" - i.e. - achieving low time-in-course (TIC) but taking failures in the process is:
  - 25-44 yr. males (highest failure rate,  
lowest TIC)
  - 16-24 yr. males
  - 45 and older males
  - 16-24 yr. females
  - 25-45 yr. females
  - 45 and older females (lowest failure rate,  
highest TIC)

### Steering and Braking

- No significant correlation of steering rates employed in transient maneuvers with the primary test variables (familiarity, vehicle type) were found in a limited analysis. Subjects were able to employ steering rates of over 500 deg/sec with success.
- Steering rates of more than 800 deg/sec were employed in collision-avoidance efforts but the vehicle was frequently not under driver control in these conditions.
- Brake usage patterns varied widely over the subject groups. Frequency, pedal force level, constancy of application, rate of application - all were quite individualistic (but often consistent within one subject) for both slowing the vehicle and stopping.
- Average deceleration in the hard stop required at the end of each trial for all subjects was .60g. This value was achieved in a large portion of the stops ( $\cong 75\%$ ) without lockup.

### Average Driver

The principal conclusions to be drawn from the experimental results with respect to developing a characterization of the average driver are as follows:

- Under unfamiliar route conditions, the average driver utilizes maximum lateral accelerations of about .3g in the speed range of 25 - 40 mph.
- Under near-optimum operating conditions, (route familiarity, no other moving vehicles in the area, no solid roadside obstacles), the average driver is willing to utilize maximum lateral accelerations of about .4g in the speed range of 25 - 40 mph.
- Assuming normal distributions, less than 20% of all drivers will exceed the above values by as much as .1g.
- The average driver is willing to utilize full tractive acceleration capabilities of a vehicle and full braking capabilities of his vehicle in straight line paths.
- A substantial percentage of drivers cannot satisfactorily control their vehicle under relatively mild skid - inducing situations.

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## 1.0 INTRODUCTION

How much of an automobile's performance and handling capabilities will drivers utilize when they are in-a-hurry? What do they do with the controls when confronted with a skid-inducing situation on a wet pavement? Can they routinely recover control in this situation? How do they handle a need for a quick lane change, or react to a sudden intrusion into the car's path? What is the relationship between speed and lateral acceleration willingly employed by drivers?

These are some of the questions faced by automobile designers who are concerned about providing their products with adequate safe-handling characteristics. To obtain answers to these questions, with particular emphasis on accumulating a firm quantitative data base, the experimental program described in this report was performed.

The principal objective of the study was the acquisition of meaningful measurements of the driving characteristics of the average driver in a sufficiently large sample to permit statistically significant conclusions to be drawn about how drivers utilize their vehicles. A secondary objective of evaluating training methods has not been addressed in this program.

Following this introduction, the details of the experimental method - design and layout of the driving course, selection of the vehicles and drivers, test vehicle instrumentation - are described in Section 2.0, Method of Approach. Section 3.0, Discussion of Results, provides analyses of the principal outputs of the experiment, with particular emphasis on evaluating those data which relate to cornering and braking characteristics and capabilities. These results are combined in an effort to produce a profile of the average driver at the end of that Section. Section 4.0 provides a set of recommendations.

This section also includes a discussion of other analyses of driver behavior which are practical with the extensive data bank accumulated from these experiments.

Several appendices to the main report are included. Appendix I provides background data on the driver subjects. Appendix II contains a compilation of all the questionnaires and reporting forms utilized in the program. Appendix III is a copy of a typical transcribed data record with appropriate notations and comments on various aspects of the run.

In addition to this report, a motion picture film demonstrating many different driving patterns in various sections of the course has been prepared and delivered to General Motors Proving Ground.

## 2.0 METHOD OF APPROACH

The various factors and preparations upon which the experimental program are based are discussed in this section. These include development of the details of the driving course, selection of the vehicles to be used in the experiment and the instrumentation to be installed in them, definition of the subject groups and the solicitation and selection of participants, and special considerations regarding experimental operations and data handling. This foundation work involved considerable effort devoted to devising and revising the geometry of the test course to obtain a realistic but challenging arrangement and to putting together and evaluating several combinations of data measurement and recording equipment before selecting the final combination (which proved to be quite reliable).

In addition, two pilot groups of subjects were put through different versions of the program to develop experimental techniques and evaluate results. Since these efforts do not contribute significantly to the data base however, they will not be discussed in detail here.

As initially planned, the factors to be considered in developing the experimental program were arranged in the matrix which is shown in Figure 2.1. Four groups of 25 subjects each (for a total of 100 subjects) were to be formed such that they were as nearly alike as possible relative to age, sex, and driving experience and in reasonable conformance with the distribution of the age and sex factors reflected by the 1971 driver license data of New York state (See Table 2.1).

On the basis of these data, each 25 subject group consisted of 10 females and 15 males distributed in age as shown in the figure. Driving experience information on the general driving population was not available but this factor (in the form of number of years of driving experience - as supplied by the volunteers) was used as an independent check on similarity of the groups. Consideration was also given to the use of "total number-of-miles driven" as an experience factor but we found this to be a relatively unreliable measure as supplied by the subjects themselves.

<u>Background</u>	<u>Vehicle</u>	<u>Number</u>	<u>Remarks</u>	<u>Group</u>
Familiar	Std.	25	To undergo driver training and be retested.	A
Familiar	Std.	25	To be retested without additional training	B
Unfamiliar	Std.	25		C
Unfamiliar	Modified	25		D

Distribution in each group by age and sex

<u>Age</u>	<u>Sex</u>	
	<u>Males</u>	<u>Females</u>
16 - 19	1	1
20 - 24	2	1
25 - 44	6	4
45 - 59	5	3
60 & over	1	1

FIGURE 2.1 PLANNED TEST MATRIX

	<u>New York Licensee Data (1971)</u>	<u>Subjects of This Experiment</u>
Percentage of Male Drivers	58	60
Percentage of Female Drivers	42	40
Average Age of All Drivers, yrs.	41	37
Average Age of Female Drivers, yrs.	39	37
Average Age of Male Drivers, yrs.	42	37

TABLE 2.1 AGE DISTRIBUTIONS

The four subject groups were differentiated on the basis of familiarity with the general characteristics of the test vehicles. Familiarity was determined according to information supplied by the volunteers regarding cars they were currently driving. A subject was judged "familiar" with the test vehicle if he now drove or had recently driven a vehicle of similar wheel-base and model type. For example, the test cars were intermediate sedans (Chevelles) and a subject who currently drove a Chevelle or other manufacturer's intermediate sedan was judged familiar. A subject who drove a sports car, for example, was judged unfamiliar. Subjects were further separated with respect to vehicle assignment and training plans. As will be indicated later, this basic arrangement was later modified by reducing the number of subjects who drove the modified vehicle and postponing the evaluation of training.

It is essential that the limitations and restrictions of the program be thoroughly understood so that the results can be appreciated in the proper framework. We are confident that these results are fully valid in this context but we do not believe that they can necessarily be applied to any and all situations. The principal points to be made in this regard are:

1. All subjects were volunteers. This suggests possible bias of the sample in the direction of having subjects who like to drive and are confident in their ability. If this is accepted, then the results would likely indicate higher speeds and maneuvering accelerations than would be found for the driving population as a whole.
2. The experimental vehicle was the only moving vehicle in the area during performance of the experiment. In addition, no barriers or emplaced objects were within ten feet of the marked path. Thus, the subjects did not have

to be concerned about collisions. We believe that these conditions satisfactorily simulate a real world situation of rural driving in flat terrain. To this extent, the results can conceivably be biased toward higher speeds and maneuvering accelerations.

3. Although much of the driving course was laid out over roadways, most of the driving situations (incidents) were delineated by traffic cones or other artificial markers. The extent to which this loss of fidelity with respect to on-road driving affected results is not known. Few, if any, of the subjects were familiar with driving cone-marked courses. It is clear, however, that different subjects reacted in different ways to this artificiality. In this regard, the comments made by the subjects on how hard they thought they were driving (which are discussed in Section 3) may shed some light.
4. The subjects were aware that their performance was being measured. Again, we have no direct way of assessing this effect on the subject's behavior. While it should have been clear that "good" was getting through the course quickly with minimum error, they had no reference for judging "bad" by tradeoffs between "slow" and "erratic".

In the next several subsections, the general background of the experiment will be described in some detail to provide the reader with a firm foundation for judging the results.

## 2.1 Driving Course

The driving course over which the experiment was performed was set up on Calspan's Vehicle Experimental Research Facility (VERF). A general layout of this facility is shown to scale in Figure 2.1-1a and the course arrangement (not to scale) is shown in Figure 2.1-1b. The principal incidents or driving tasks are identified in this latter figure with the exception of the First Chute (which occurs between the Avoidance Maneuver and Gravel Turn) and the Surprise Intrusion (which was located in the long straight following the Small Radius Arc).

Every effort was made to achieve full use of the available surfaced area with minimum ambiguity in the intended path and with sufficient spacing between incidents to avoid cascading effects. The geometry of each of the incidents, which were conceived of as simulations of situations which are encountered on the road, were determined by trial and error driving checks during development of the course. These incidents (or driving tasks) are described in detail below.

The policy which was followed in arranging the driving course was to provide a sequence of challenging yet realistic driving tasks which could be performed at moderate speeds while emphasizing the maneuvering capabilities of car and driver. We attempted to avoid trick situations in the basic layout recognizing, of course, that the subjects would be unfamiliar with driving a course delineated by traffic cones and that this would pose some degree of artificiality to the experiment.

The course is approximately 1.2 miles in length, and is comprised of ten discrete elements requiring driver inputs exceeding normal highway path-following levels. In sequence from, but not including 'start' as a maneuver, they are:

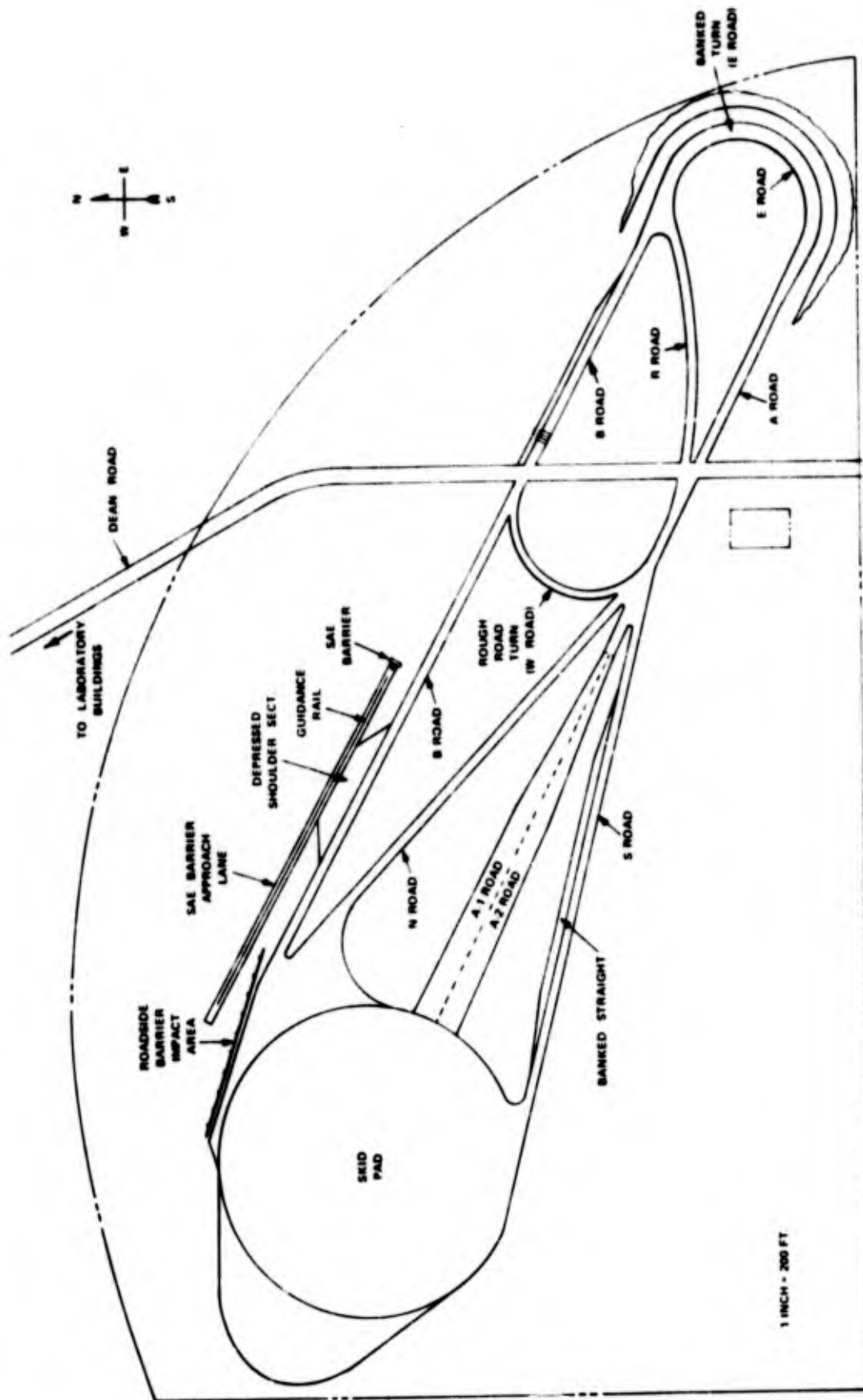


FIGURE 2.1-1a VEHICLE EXPERIMENTAL RESEARCH FACILITY

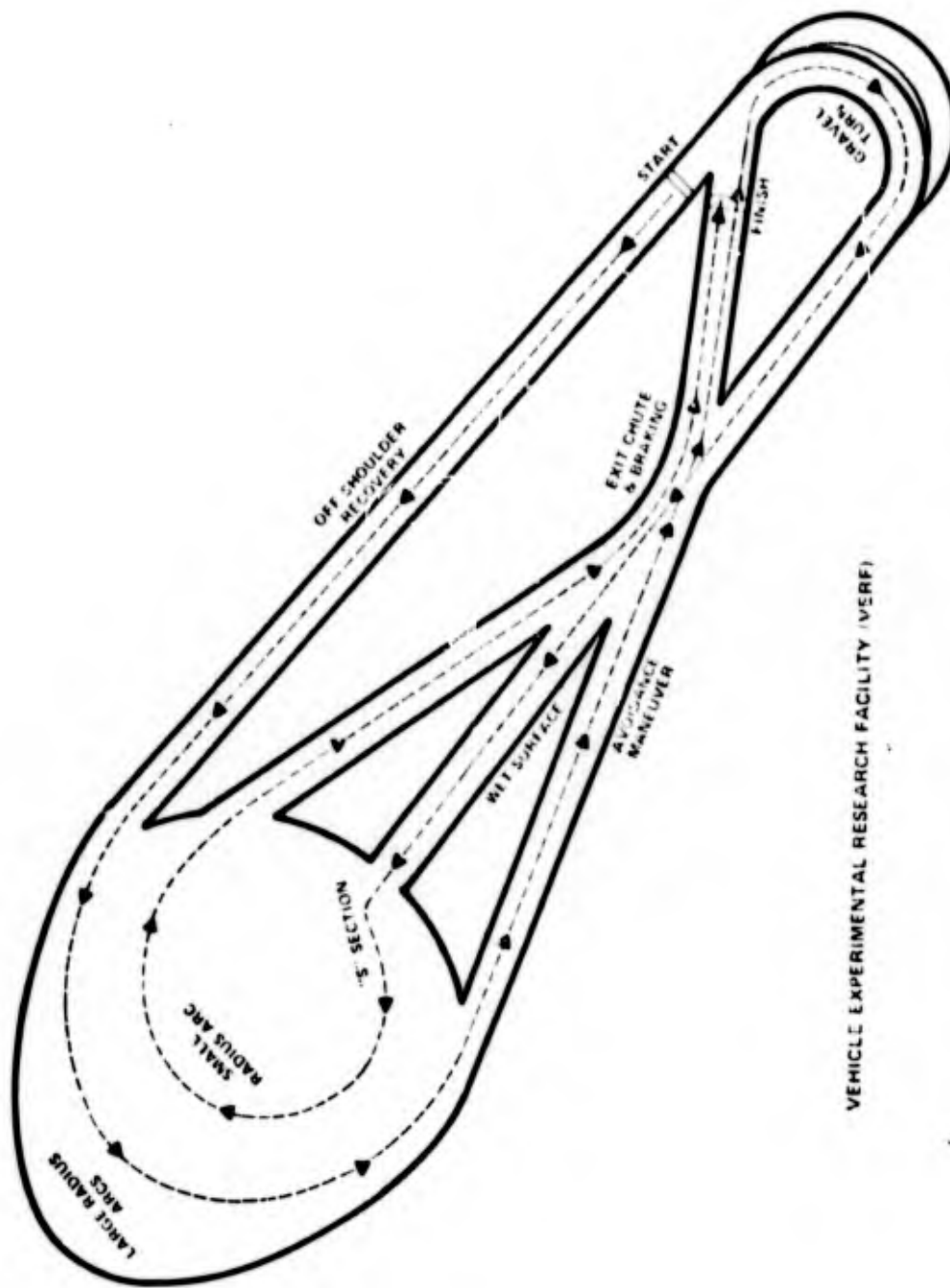


FIGURE 2.1-1b EXPERIMENTAL DRIVING COURSE

1. Off-Road Recovery
2. Large Radius Arcs
3. Avoidance Maneuver
4. First Chute
5. Gravel Turn
6. Wet Surface
7. Ess Turn
8. Small Radius Arc
9. Surprise Intrusion
10. Exit Chute and Braking

All except the Surprise Intrusion were encountered by every subject; this latter maneuver was reserved for selected driver groups which were not to be retested.

1. Off-Road Recovery

This maneuver begins approximately 725 feet from the start line of the course to provide ample opportunity to reach a speed of 50 mph if desired. The path (see Figure 2.1-2) is directed gently off the right edge of the roadway to a gravel surface at the same elevation. At the barrier (shown in Figure 2.1-1a) the shoulder has dropped to a level approximately 4 inches lower than the paved surface. For a length of about 100 feet, the right side of the path is marked by delineators to assure that the vehicle will straddle the curb. At any point along this length, the subject may choose to drive back up over the curb and regain the initial path. The left side of the path is marked by cones for a distance of 80 feet beyond the point at which recovery must be made to avoid violating the course markers. Striking any of these cones provides measurement of faulty recovery.

This incident was designed to simulate a situation in which the vehicle must be returned to the roadway from a depressed shoulder. The challenge of the situation lies in applying the correct amount of steering control to climb over the curb without overcontrolling and moving too far to the left.

The curbing consisted of steel plates butted together to give smooth longitudinal joints and radiused along the top edge to produce a 4 inch curb. A sketch of the cross-section is shown below.

OFF-ROAD RECOVERY  
CURB



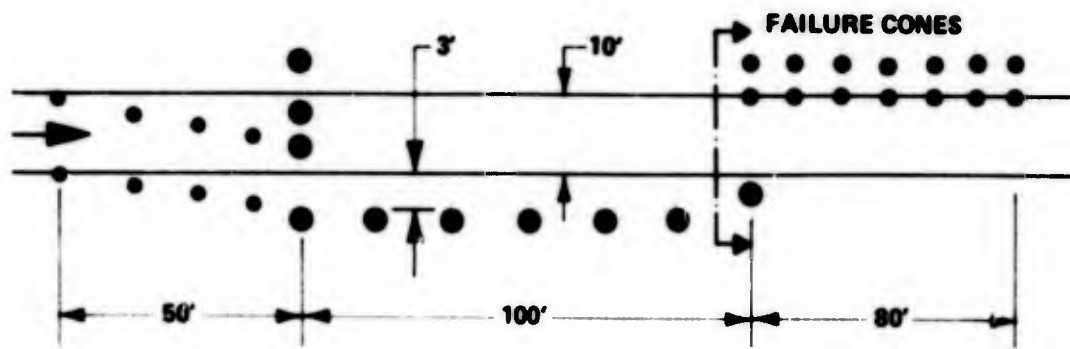
The relatively short riser section together with the rounded top edge of the curb did not produce as demanding a task as had been hoped for. This, coupled with an obligation to provide sufficient right side clearance to avoid penalizing drivers who were capable of performing the maneuver properly (i. e. , avoiding right wheel scrubbing on the curb) did not produce the number of errors in this maneuver that had been anticipated.

## 2. Large Radius Arcs

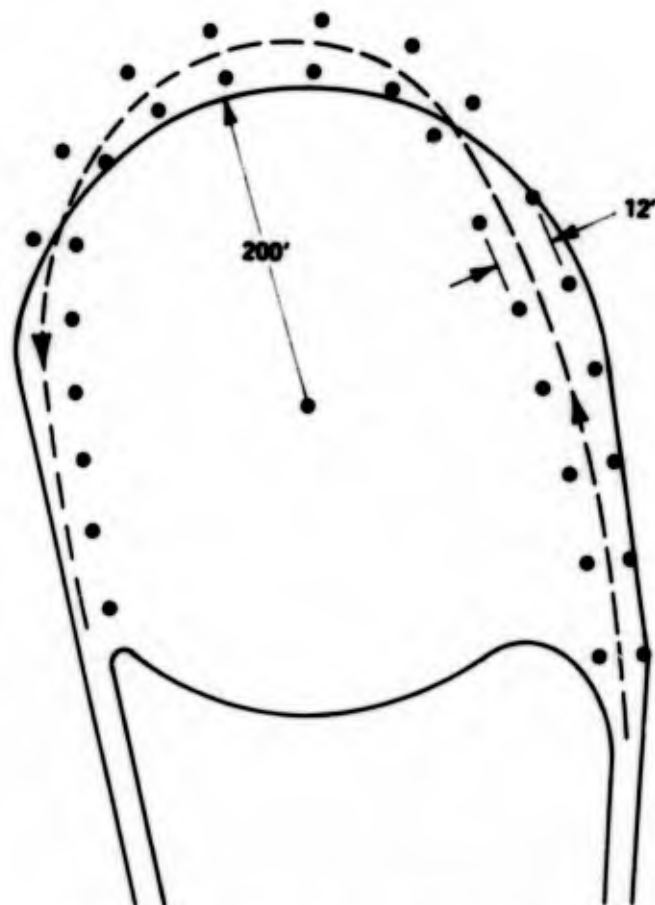
Approximately 400 feet beyond the exit of the off-shoulder incident, the course curves through a long compound arc which first tightens and then spirals out to a near-constant radius. Figure 2.1-3 shows this maneuver. The geometry through the arcs is not precisely defined (it was determined by trial and error) and the figure therefore only loosely defines the path. It simulates an off-ramp from a high-speed roadway and provides a means for measuring lateral accelerations utilized by drivers at moderate speeds. The length of the arc is approximately 600 feet and is marked by cones delineating a 12 ft. wide lane. Over the final 200 feet of the path, a steel roadside barrier runs along the right side of the lane and running wide will bring the vehicle through loose gravel. The arc exits into a straight road section.

## 3. Avoidance Maneuver

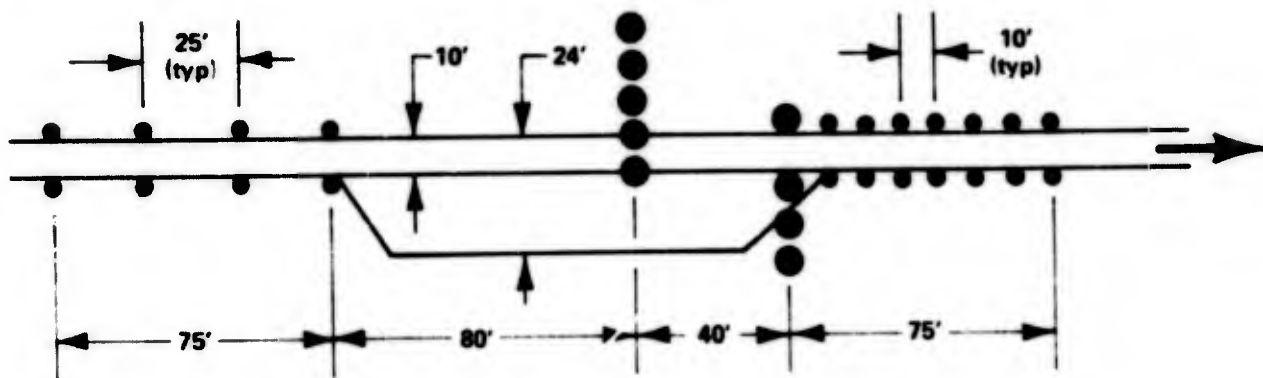
Approximately 400 feet into the aforementioned straight, the driver encounters a series of delineators which constrain him to run a ten foot wide straight path. As shown in Figure 2.1-4, the lane is blocked at a point 80' downstream of the last lane delineator in the entry chute. The driver is thus forced to execute a turn to the right around the blockage followed immediately by an abrupt left turn and right turn to return his vehicle to straight-ahead before entering the First Chute.



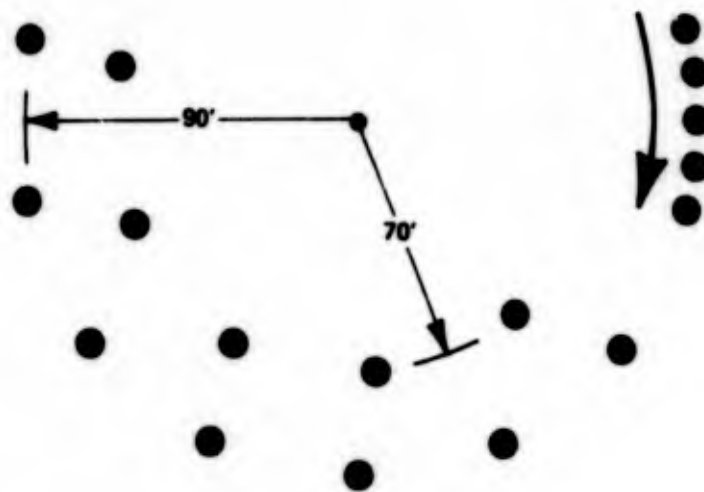
**Figure 2.1-2 OFF-ROAD RECOVERY**



**Figure 2.1-3 LARGE RADIUS ARCS**



**Figure 2.1-4 AVOIDANCE MANEUVER**



**Figure 2.1-5 GRAVEL TURN**

This maneuver was designed to impose a series of quick steering movement requirements on the driver to obtain measures of the transient lateral accelerations used and to study steering rate input capabilities. The geometry was deliberately made non-symmetrical in order to emphasize this latter effect. It also provided opportunity to measure combined steering-braking operations, but only under dynamic conditions.

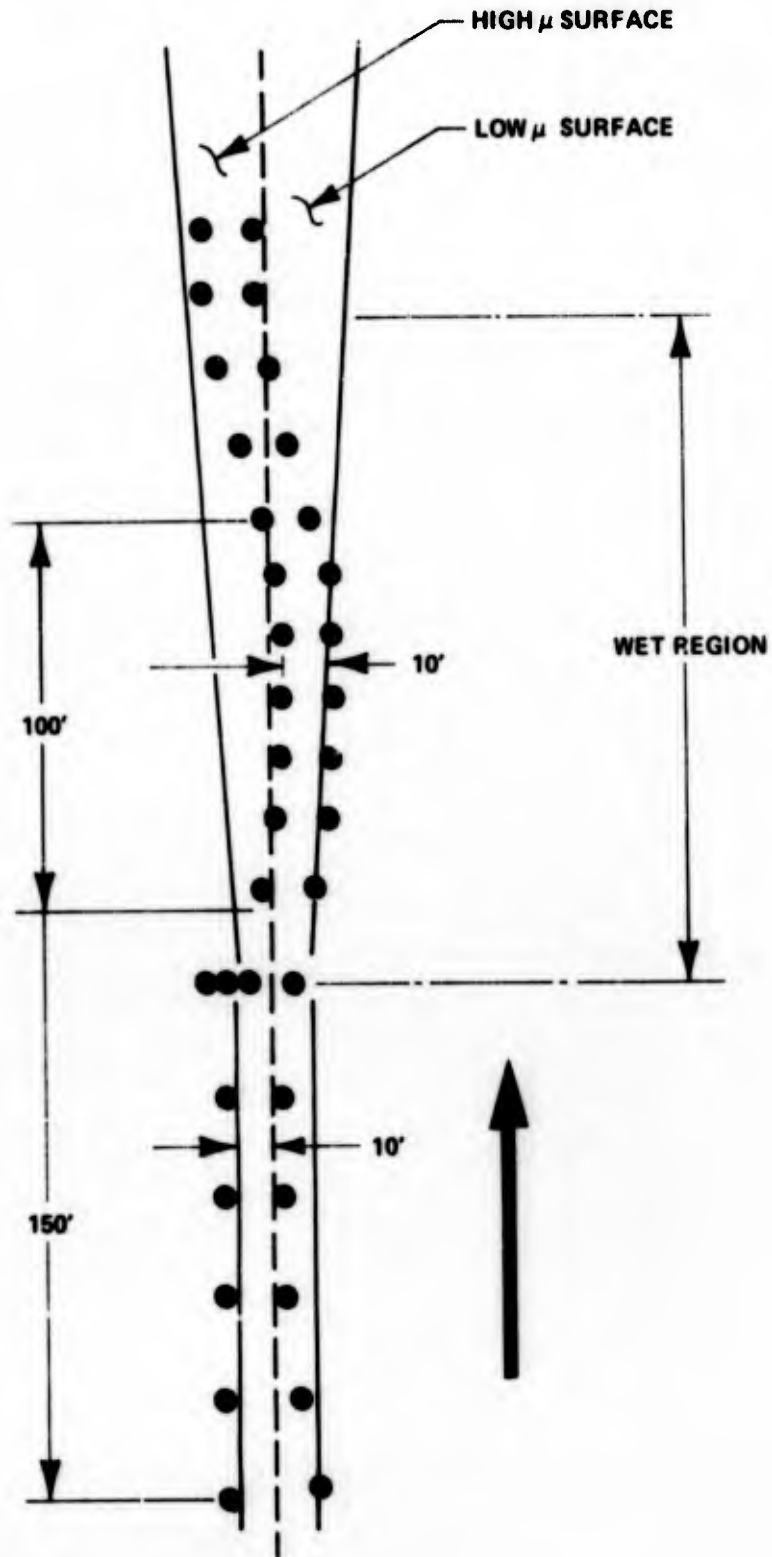
4. Gravel Turn

This maneuver (Figure 2.1-5) is a right hand turn in loose dirt and gravel having a radius to the outside delineators of 90 feet. The overall arc includes approximately 220° with about 180° of this being gravel surfaced. As the driver leaves the Gravel Turn he enters onto a straight 1100 feet in length. About 600 feet into this section of the course, the driver is forced by lane delineators to enter a closely defined path-following maneuver on the Wet Surface.

5. Wet Surface

In this test section, shown in Figure 2.1-6, the driver enters the test surface on high friction asphalt and is directed by lane markers into a right turn onto a wet section of pavement which is coated with a bituminous sealer. This section has a wet coefficient of about 0.3. The marked path then curves left, then right, directing the vehicle back onto the higher friction surface leading to the next element, the Ess section.

The purpose of this maneuver was to study skid recovery methods used by the subjects should skidding occur. By incorporating curvature into the layout, skidding could result from excessive entry speed, application of brakes during the turn, or attempting to regain speed while the driving wheels were still on the wet surface. This incident proved to cause problems for almost half of the total number of subjects with a wide variety of failures including plowing, spinning, and drifting off course, or complete loss of control.



**Figure 2.1-6 WET SURFACE MANEUVER**

6. Ess Turn

Approximately 100' past the point where the vehicle has been restored to the high friction surface following the Wet Surface test, it enters a lane defining the Ess Turn. As shown in Figure 2.1-7, a left hand turn of 75' radius joins a right hand arc of 150' radius. The 150' radius arc comprises a separate test element, called the Small Radius Arc, which is contiguous to the Ess Turn.

7. Small Radius Arc

Shown in Figure 2.1-8, the entire test section is comprised of about 180° of arc on a 150' radius circular path. It is delineated by cones and terminates for test purposes where the radius of curvature increases from 150' to merge with the straight leading to the Surprise Intrusion.

8. Surprise Intrusion

This test is located about 600 feet from the entry to a straight approximately 760 feet in length. The "surprise" is comprised of a light-weight plastic 20 gallon container ejected from an inconspicuous wooden lean-to structure. A trip switch located 100 feet up-track from the test point causes a solenoid to unlatch the launcher which is powered by bungee cords. The device is used selectively on the last of five runs - for certain subjects only and is unarmed for all other runs.

The final test element, Exit Chute and Braking, occurs approximately 550 feet past the Surprise Intrusion on a curved section of roadway having a mean radius of about 640 feet.

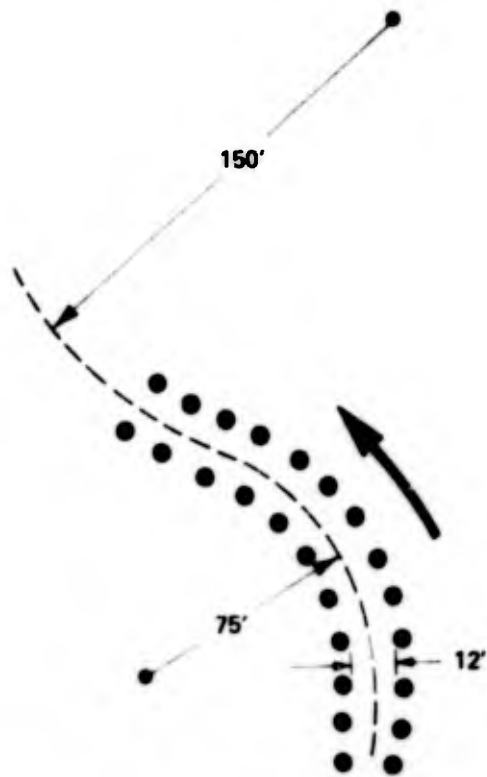


Figure 2.1-7 ESS TURN

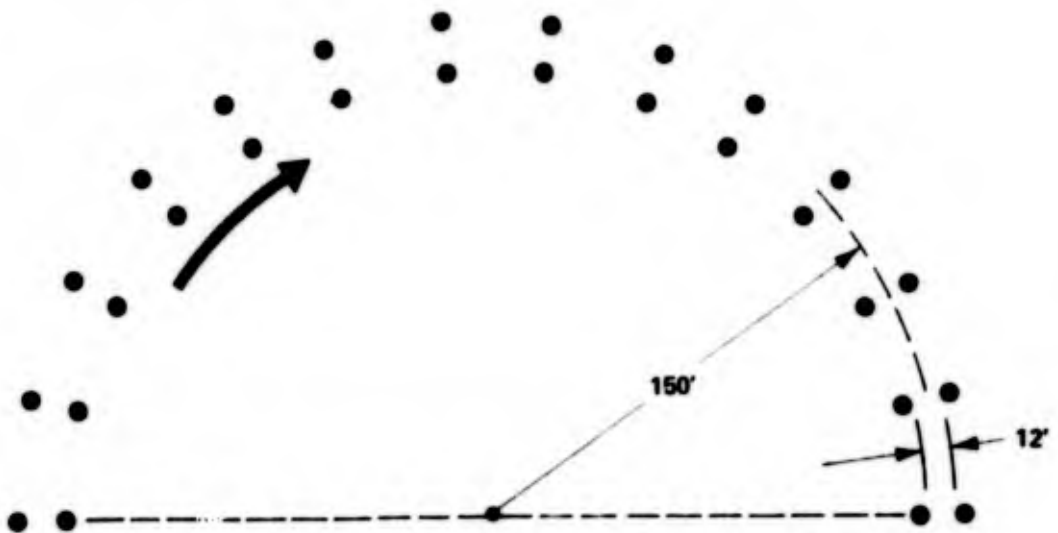


Figure 2.1-8 SMALL RADIUS ARC

9. Exit Chute and Braking

This test includes the long radius turn briefly described in the last section and a short delineated zone, shown in Figure 2.1-9, within the confines of which the driver is expected to stop. This maneuver provides for measurement of lateral acceleration used at reasonable speed (40 mph) and of braking activity in making a hard stop.

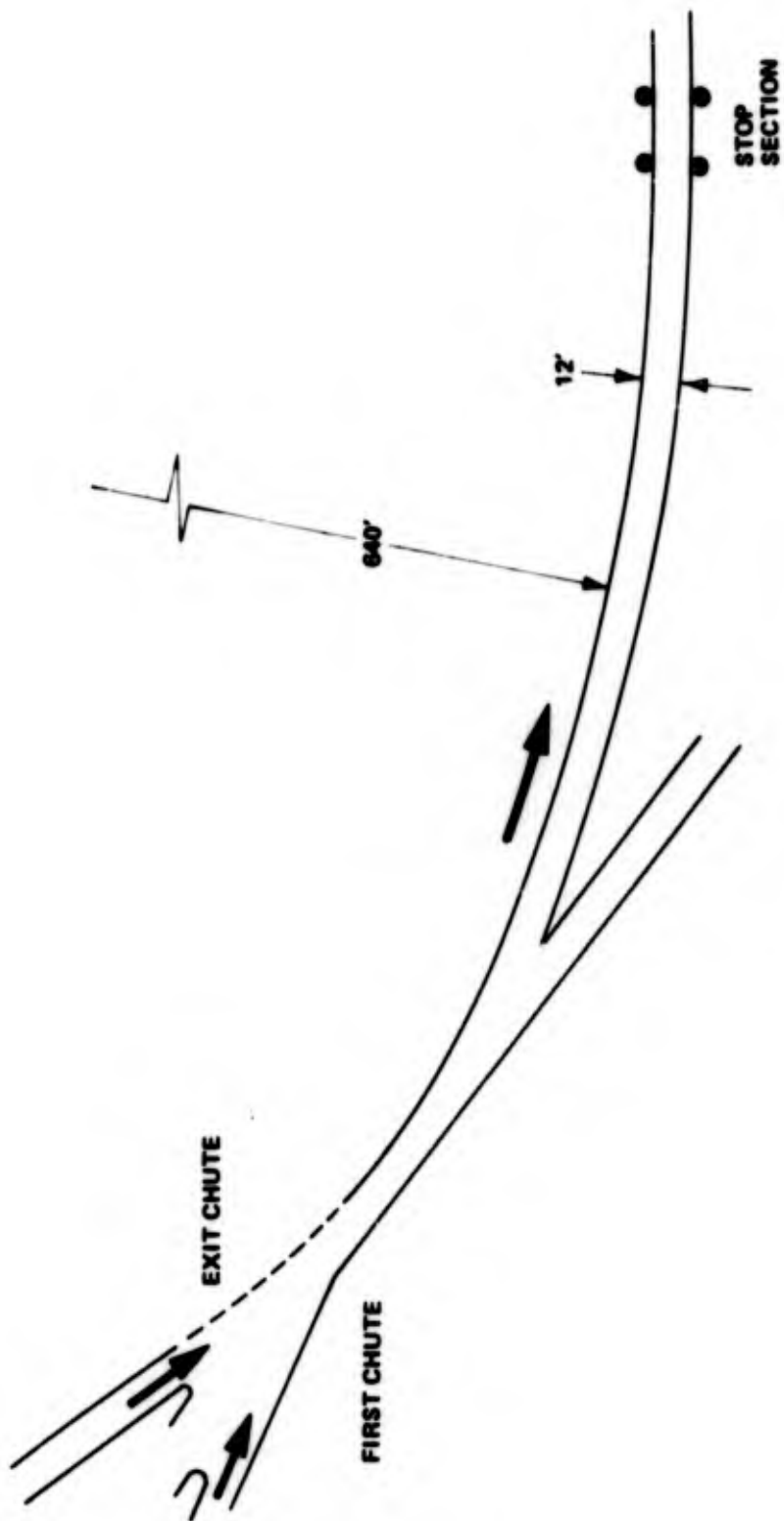


Figure 2.1-9 EXIT CHUTE AND BRAKING

## 2.2 Test Vehicle Descriptions

Two four-door intermediate sedans were used in the experimental driving program. They are described in the listing of Table 2.2-1, provided by GMPG. Except for color, they were similar in both external and internal appearance and driver subjects were not apprised of any differences in operational characteristics. In fact, most of the subjects were unaware that two vehicles were being used in the program since each subject drove only the unit to which he had been assigned.

As shown in Table 2.2-1, the Standard vehicle (or Blue Car, as it was referred to during the program) was a stock Chevelle with automatic transmission, power steering, and power-assisted brakes. It was equipped with E78x14 bias-belted tires inflated to recommended pressures of 24 psi on all wheels. At the conditions imposed for the experiment, it carried a heavy trunk load (due to the data recorder) which produced a weight distribution of about 51/49.

The Modified vehicle (or Brown Car) was also a Chevelle and was equipped with automatic transmission, power steering, and power-assisted brakes. It was outfitted with special radial tires - HR70-15 which were inflated to 24 psi all around. As utilized in the experiments, its test weight distribution was 52/48 exclusive of driver and observer loading.

The instrumentation and loading used in the tests may alter somewhat the vehicle response properties outlined in Table 2.2-1. However, the differences in loading between these tests and the vehicle response tests were the same for both vehicles.

**TABLE 2.2-1**  
**COMPARISON OF STANDARD AND MODIFIED**  
**CHEVELLES TO BE USED IN THE CALSPAN**  
**TEST PROGRAM**

	<u>Standard Vehicle</u>	<u>Modified Vehicle</u>
<b>Tires</b>	E78-14 Uniroyal	HR70-15 Goodyear ESV Tires
<b>Tire Pressure</b>	24 psi F & R	24 psi F & R
<b>Wheel Size</b>	14 x 5	15 x 7
<b>Front Roll Bar and Linkage</b>	15/16" dia. with standard rubber bushings in linkage	1-1/8" dia. with GTO plastic bushings in linkage
<b>Rear Roll Bar</b>	None	1-1/8" dia.
<b>Steer Gear</b>	16:1 to 13:1 standard variable ratio with a .165T bar	11:1 ratio with a high effort .195T bar
<b>Power Steering Pump</b>	Standard A-car pump	Cadillac pump
<b>Shock Absorbers</b>	Standard	Front shocks (Chevrolet optional handling package)
<b>Rear Suspension Control Arms</b>	Standard	Optional lower arms with boxed section - Optional right upper arm (parts of Chevrolet optional handling package)
<b>Front Wheel Alignment</b>	Standard	Left Camber 1.2° + Right Camber 1.05° + Left Caster 4.4° + Right Caster 4.2° + Toe-in 3/16" Total
<b>Measured Understeer</b>	9.3 deg/g	4.8 deg/g
<b>Maximum Lateral Acceleration, Constant Radius Test</b>	.64 g	.72 g
<b>Average Best Maneuvering Distance at 45 mph on Evasive Test</b>	78.5 ft.	66.1 ft.
<b>Roll Compliance</b>	9.8°/g	5.3 deg/g

**TABLE 2.2-1 (cont.)**  
**COMPARISON OF STANDARD AND MODIFIED**  
**CHEVELLES TO BE USED IN THE CALSPAN**  
**TEST PROGRAM**

	<u>Standard Vehicle</u>	<u>Modified Vehicle</u>
Lateral Acceleration Response* Time to Step Steering Input (time to 90% of steady state)	0.46 sec.	0.40 sec.
Yaw Velocity Response Time to Step Steering Input*	0.18 sec.	0.20 sec.
Steering Sensitivity* g's/100 deg. Steering Wheel Angle	0.47	0.97

\* Data taken at 60 mph

<u>Tires</u>	<u>Uniroyal E78-14</u>		<u>Goodyear HR70-15</u>	
<b>Tire Performance</b>				
Pressure (cold)	24		24	
Normal Force, lb.	1125	900	1138	900
Cornering Stiffness (lb/deg)	160	155	217	194
Aligning Torque (ft.-lb/deg)	21.5	15	16	11
Camber Stiffness (lb/deg)	23.3	20	11.4	9
Peak Cornering Force Coefficient	.76		.87	

From a maneuvering capability standpoint, the major differences between the two test vehicles were:

1. steering ratio - the steering system on the Standard vehicle has a variable ratio, changing from 16:1 on-center to 13:1 at large displacement angles. The Modified vehicle, on the other hand, has a fixed ratio 11:1 gear.
2. understeer factor - the Modified vehicle has a significantly lower value of understeer factor than the Standard vehicle. In combination with the lower steering ratio, this imposes the need for much smaller steering wheel displacements in performing maneuvers with the Modified vehicle.
3. peak lateral acceleration - as indicated in Table 2.2-1, the Modified vehicle is capable of sustaining lateral acceleration to a higher value than can the Standard vehicle (according to tests performed at General Motors Proving Ground prior to delivery of the vehicles to Calspan for these experiments). This is a particularly interesting difference between the two vehicles since it permits examination of the question of whether drivers can sense cornering limit capabilities and whether they will attempt to take advantage of increased performance envelopes.
4. roll compliance - the heavier duty suspension on the Modified vehicle resulted in a roll/lateral acceleration ratio (deg/g) about half that of the Standard vehicle. This effect was accounted for in data reduction operations.

### 2.3 Instrumentation

One of the key elements in the pre-experiment preparations was the identification and selection of the variables to be measured, the sensors to be used, and methods of data recording and information keeping. A number of approaches to this multi-faceted problem were tested and discarded before settling on the method which was finally adopted and, although they will not be described in detail, it is pertinent to point out that much useful information on the requirements for conducting a program such as this was acquired during the evaluation of these techniques in pilot studies and pre-test checkouts.

The performance characteristics of the sensors used in the test vehicles are listed in Table 2.3-1.

Total time-in-course for each run was measured by the test observers with a stop watch in addition to the time kept by the recorder. Specific locations along the course were detected by a car-mounted light-sensitive device responding to light sources stationed at the locations of interest.

The velocity measurement was made with a permanent magnet D.C. tachometer teed off the speedometer drive. The unit was calibrated with a fifth wheel and the recording channel was equipped with means for applying a calibration signal to the recorder.

A pair of accelerometers was mounted on the drive line tunnel just behind the front seat to provide measurements of lateral and longitudinal acceleration. Each channel was equipped with suitable signal conditioning and calibration circuits. The lateral acceleration signal was corrected for vehicle roll angle by performing a separate test of the vehicle over a constant radius circular course and comparing the accelerometer output with the acceleration computed from  $V^2/R$ . This steady-state correction was applied to all measurement of  $A_y$ . The vehicle roll sensitivity parameter,

<u>Parameter</u>	<u>Instr. Range</u>	<u>Recorder Range</u>	<u>Instrument Accuracy</u>	<u>Record/Readout Accuracy</u>	<u>Comments</u>
Speed	--	60 mph	.5 mph	1 mph	
Lateral Acceleration	$\pm 3$ g	$\pm .8$	.5% FS	.02 g	Trace corrected for steady-state roll sensitivity.
Longitudinal Acceleration	$\pm 3$ g	$\pm 1.0$ g	.5% FS	.02 g	Trace not corrected for hard stops.
Brake Pressure	--	200 lbs.	--	$\pm 2$ lbs.	Given in terms of equivalent steady-state pedal force.
Steering Angle	Lock-to-lock	$\pm 500^\circ$	--	10°	
Time	--	--	--	.1 sec	

TABLE 2.3-1 TEST VEHICLE INSTRUMENTATION

$\phi/A_y$ , determined in this test agreed very well with the value supplied by GM for both vehicles. As a further check, the corrected lateral accelerometer readings as measured in the small radius arc maneuver agreed with the average values as computed from  $V^2/R$  throughout the whole of the experimental program. No correction was applied to the longitudinal accelerometer output.

Steering activity was measured with a spring-loaded string potentiometer connected to the steering column through a pulley-drive linkage. Full freedom of steering wheel motion was measurable, but a range of only  $\pm 500$  degrees was recorded. The output of the potentiometer was fed through signal conditioning and calibration circuits to the recorder.

Braking activity was monitored by a pressure transducer installed in the braking system. The transducer was calibrated against steady-state brake pedal force to give a recordable indication of the force applied. Because of reservations about the accuracy of the instrumentation under transient conditions, the braking data have been used only for measuring the final stop in a run and for evidence of braking activity throughout the course.

All instrumentation channels were recorded on-board using a Sangamo magnetic tape recorder. Calibration signals were applied at regular intervals on all data channels. The magnetic tape was then processed off-board during periods when experiments were not being run and re-recorded in analog form on a 6-channel Brush recorder. A typical set of data traces are shown in Appendix III. All recorded data in both magnetic and analog trace form have been retained for review.

## 2.4 Descriptive Statistics of Driver Subjects

As noted earlier the original program plan was to run 100 subjects through the driving course - each having five complete runs, from beginning to end. The 100 subject sample was divided into four groups of 25 each - designated A, B, C and D. In actuality some 108 subjects were tested but because of the requirement to achieve a similar distribution, in each of the four groups, by age, sex, and driving experience, 18 of the subjects were, in effect, residual; they were excess in the light of the above need to achieve proper balance in each group.

Further, the onset of winter towards the end of the program forced cancellation of testing. The result was that the final group, group D, contains 15 subjects instead of 25. By the end of the program the subject distribution was:

Group A	25	(15 male, 10 female)
Group B	25	(15 male, 10 female)
Group C	25	(15 male, 10 female)
Group D	15	(11 male, 4 female)
Residuals	<u>18</u>	(9 male, 9 female)
Total	108	

The majority of volunteer subjects were recruited from among company employees; however, some were brought in from outside the company.

Appendix II contains copies of the various questionnaires and forms used in the program and a brief description of the purposes of each. All of the data on driver subject characteristics, i. e., the demographic data and some of the performance data (cone violations in going through the course) were obtained through this paperwork.

The demographic data on the subjects are tabulated, by group, in Appendix I. Some of those data will be summarized here.

#### 2.4.1 Distribution by Age and Sex

Distribution by age and sex is shown in Table 2.4-1. Note that the mean ages for groups A, B and C are quite close, being 37 years, 38 years, and 38 years, respectively. The mean age for the D group is somewhat lower (33 years) owing to the fact that it was not possible to fill that group completely.

The oldest subject tested was a 77 year old male; the youngest male subject (three in number) was 17 years old while the youngest female subject (two in number) was 18 years old.

The percent distribution by age bracket, without regard to sex, for all subjects, is shown in Table 2.4-2.

TABLE 2.4-2  
PERCENT DISTRIBUTION OF SUBJECTS BY AGE BRACKET

<u>Age Bracket</u>	<u>% of Total (90 Subjects)</u>
16-19 years	8
20-24 "	12
25-44 "	45
45-59 "	31
60 years & older	<u>4</u>
	100

TABLE 2.4-1  
DISTRIBUTION OF DRIVER SUBJECTS BY AGE AND SEX

Age Bracket	A		B		C		D		All		All (%)		M&F
	M	F	M	F	M	F	M	F	M	F	M	F	
	15		10		11		4		56		100		
16-19	1	1	1	1	1	1	0	4	2	7	9	8	
20-24	2	1	1	1	1	1	2	6	5	11	15	12	
25-44	6	5	7	4	7	3	1	27	13	48	38	45	
45-59	5	3	5	4	4	5	1	15	13	27	38	31	
60 & over	<u>1</u>	<u>0</u>	<u>1</u>	<u>0</u>	<u>1</u>	<u>0</u>	<u>0</u>	<u>4</u>	<u>0</u>	<u>7</u>	<u>0</u>	<u>4</u>	
	15	10	15	10	11	10	4	56	34	100	100	100	
Mean	38	35	39	36	37	40	34	37	37	37	37	37	
Oldest	67	60	77	58	63	57	52	77	60	77	60	60	
Youngest	17	18	17	18	17	17	24	17	17	17	17	17	
Group Mean	37		38		38		33		37		37		

The age distribution data of Table 2.4-1 are presented in the histogram of Figure 2.4-1, where the subject sample is compared, by sex, with New York State licensees for the year 1971 (a population of about 4.8 million males and 3.5 million females that includes those holding chauffeur licenses).

The data for both populations, without regard to sex, are spotted in as X for this sample and O for the New York State licensee population.

As can be seen in Figure 2.4-1 there is a better age distribution match for those under 25 than for those over 25. The match is poorest for those over 60 years of age; finding qualified volunteer subjects in the 60 and over age bracket was difficult. We suspect that the number of licensees in the 60 and over bracket may not be representative of the number of drivers in that bracket on the road but we have no evidence to confirm or deny the suspicion.

In any event, the age distribution of the subject sample, taken as a whole, is thought to be a fairly good representation of the on-the-road driving population of New York State.

The symbol N is used in Figure 2.4-1, and throughout this report, to indicate the number of subjects; the symbol n is used to designate events.

#### 2.4.2 Driving Experience

Another subject statistic of interest is driving experience. Table 2.4-3, assembled from data given in Appendix I, shows the subject driving experience, in years, as a function of group and sex.

As can be seen in that table the group average of driving experience ranges from 16 to 20 years for all four groups. Over the entire sample the driving experience ranged from a month or two to 50 years; the sample mean was 18 years. It is not known whether data are available on this statistic for on-the-road drivers.

X = COMBINED M & F, THIS SAMPLE  
 O = COMBINED M & F, NY STATE LICENSEES

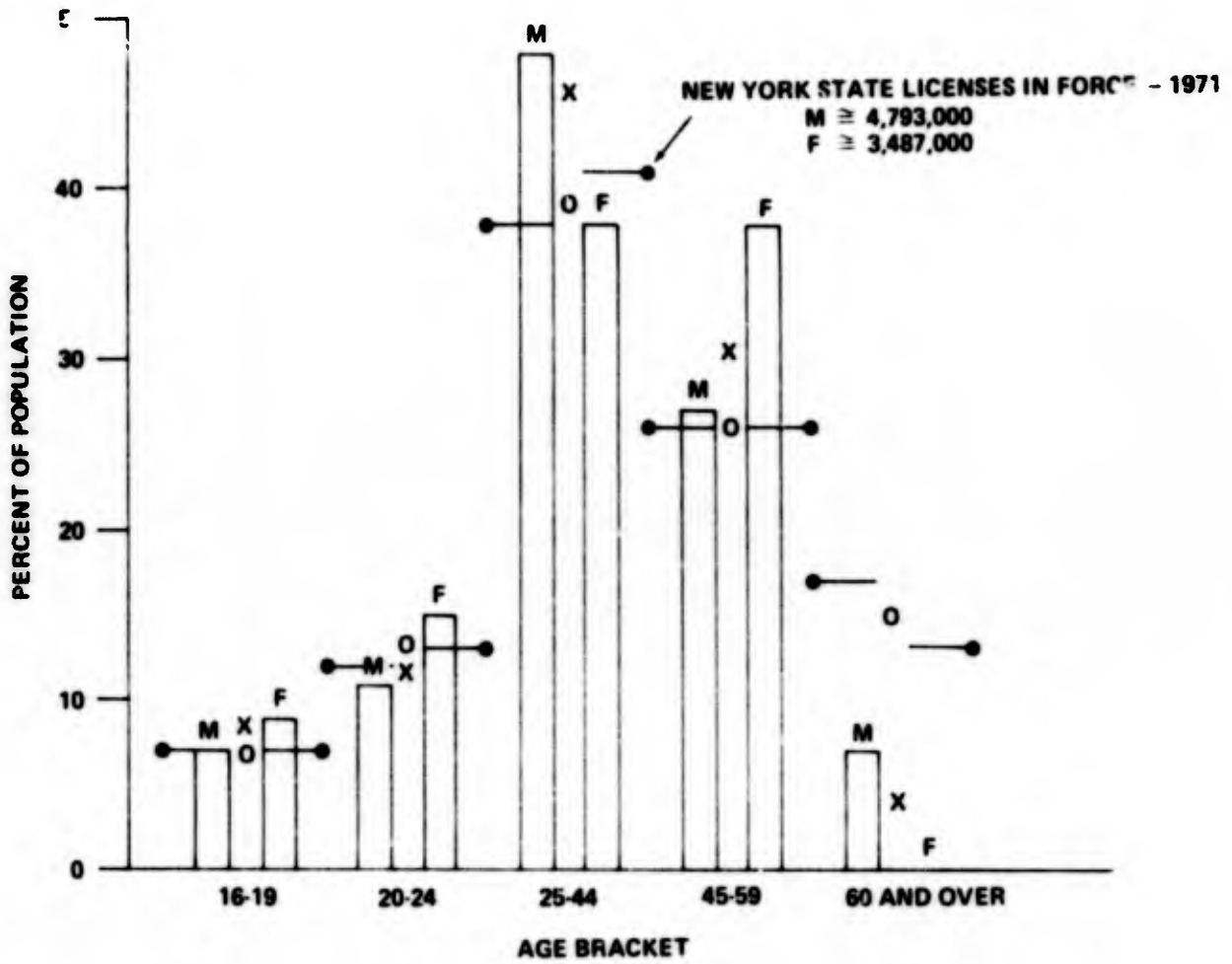


Figure 2.4-1 AGE DISTRIBUTION OF DRIVER SUBJECTS  
 N = 90

TABLE 2.4-3

DISTRIBUTION OF DRIVING EXPERIENCE  
By Age and Sex

Years Driving	A		B		C		D		All		All (%)	
	M	F	M	F	M	F	M	F	M	F	M	F
0 - 5	1	2	1	2	2	2	2	2	5	8	9	24
6 - 10	4	3	4	3	3	2	3	0	14	8	25	24
11 - 20	4	2	3	2	6	3	3	1	16	8	28	23
21 - 30	1	3	1	0	2	1	2	0	6	4	11	12
> 30	<u>5</u>	<u>0</u>	<u>6</u>	<u>3</u>	<u>3</u>	<u>7</u>	<u>1</u>	<u>1</u>	<u>15</u>	<u>6</u>	<u>27</u>	<u>17</u>
	15	10	15	10	15	10	11	4	56	34	100	100
Average	21	14	22	16	19	17	16	15	20	16		
Max.	41	30	50	40	44	40	46	37	50	40		
Min.	0.1	0.5	1	0.5	1	3	1	4	0.1	0.5		
Group Average	18		20		18		16		18			

### 2.4.3 Expert Drivers

At approximately the mid-point of the test program, both vehicles were driven through the course by a group of three expert test drivers in an effort to establish reference "best performance" values. These drivers were not restricted in the number of trials they were permitted nor were they given pre-experiment instructions in the same way as the experimental subjects. In effect, they were merely told to get through the course as quickly as they could without error.

Only the Standard vehicle was completely equipped with instrumentation for these trials, however, both time-in-course and cone violation information was taken with the Modified vehicle. None of the drivers attempted more than 7 trials with either vehicle - concluding, in their own judgment, that they could not significantly improve their performance with more trials. For the most part, the measured performance values achieved by these experts were very nearly equal in their "best success" runs and the data from these tests have therefore been averaged to give reference values for each of maneuvers. These values are shown in the appropriate sections in the discussion of results presented later and are compiled in Appendix V where they are discussed in more detail.

### 3.0 DISCUSSION OF RESULTS

Most of the quantitative performance data are derived from the direct-writing recorder traces taken of each of the five runs for each subject. The exceptions to this are time through the course (taken by the observer in the test vehicle) and success/failure data (taken from the cone-count data sheet of Appendix II). A sample recorder record is given in Appendix III.

In this section we will tabulate the quantitative performance data by group. In general, two types of data will be given: (1) Successful first run and (2) Best successful run (BSR) for a particular task or incident - regardless of run number. It should be noted however that the BSR was almost always run 4 or run 5.

The above data will be given for each task or incident as it occurred through the course - starting with the Off-Road Recovery task. All of the data treated in this manner are acceleration or velocity data. Because of the special nature of the Surprise Intrusion incident it is treated somewhat differently.

After the basic acceleration-velocity data are given, the sections that follow treat other data of importance - i. e. - success/failure, time in course, etc.

Before proceeding two points must be noted.

When it became apparent that it was not going to be possible to use the group A and group B subjects in a training experiment (training one group, holding the other as a control group, and retesting both) there was little point in retaining the group A/group B breakdown - they were theoretically identical sets, according to the grouping criteria used. Hence, while it was convenient to retain the group A/group B breakdown for certain kinds of data

as in Section 2.4) it was deemed more appropriate to combine groups A and B for the purpose of analyzing performance data.

On the other hand, some of the performance data (i. e. means and standard deviations) had already been computed for groups A and B separately. Hence, they had to be combined properly; the method of combining them is given in Appendix IV.

Thus, the combined data from groups A and B, called group AB data, consists of all of the data of the 50 subjects who were judged to be familiar with and who were tested in the Standard vehicle.

The 25 subject data of group C comprised all of the subjects who were judged to be unfamiliar with and who were tested in the Standard vehicle. Thus, the question of the influence of familiarity with the Standard test vehicle could be examined through comparison between group AB and group C data.

Since the group D subjects were deemed to be unfamiliar with the vehicle that they were tested in - the Modified vehicle - any comparison between groups C and D (both unfamiliar; with the difference being Standard vs. Modified vehicle) was considered to be inappropriate because of the differences between the make-ups of these two groups. It was therefore decided that a sub-sample of group C, called group Cs, that was closely matched to group D in number, age and sex distribution, etc. would be useful for comparison with group D.

The subjects drawn from group C for this purpose were (see Table I-3 Appendix I): Subjects number 01, 02, 03, 05, 13, 16, 21, 22, 63, 64, 66, 68, 70, 95 and 98. How the Cs group compares with the D group is shown in Table 3-1.

TABLE 3.1  
COMPARISON BETWEEN GROUPS C<sub>s</sub> AND D

Age Bracket	Age and Sex				Years Exp.	Driving Experience			
	Group C <sub>s</sub>		Group D			Group C <sub>s</sub>		Group D	
	<u>M</u>	<u>F</u>	<u>M</u>	<u>F</u>		<u>M</u>	<u>F</u>	<u>M</u>	<u>F</u>
16-19	1	0	1	0	0 - 5	1	1	2	2
20-24	2	1	1	2	6 - 10	3	1	3	0
25-44	6	2	7	1	11 - 20	5	1	3	1
45-59	1	1	1	1	21 - 30	1	0	2	0
60 and over	<u>1</u>	<u>0</u>	<u>1</u>	<u>0</u>	> 30	<u>1</u>	<u>1</u>	<u>1</u>	<u>1</u>
	11	4	11	4		11	4	11	4
Mean	33	34	33	34	Mean	15	16	16	15
Oldest	63	53	61	52	Max.	44	37	46	37
Youngest	17	23	18	24	Min.	1	4	1	4
Group Mean	33	33	33	33	Group Mean	15	15	16	16

The match between the two groups by age, sex, and driving experience is quite good.

In the acceleration-velocity data to be given first the metrics of interest will be the mean value, the standard deviation about the mean,  $S$ , the maximum and minimum value recorded, and the number of pieces of data used,  $n$ .  $n$  will sometimes differ from the group size,  $N$ ; in these cases it simply means that data were lost or, in the case of first runs, there were failures that were excluded from the tabulated results.

### Statistical Treatment

For most of the variables measured in this study there are two comparisons of primary interest: (1) subjects familiar with and tested in the Standard car (Group AB) versus those unfamiliar with and tested in the Standard car (Group C); this comparison should reveal any influence of familiarity on performance, (2) subjects unfamiliar with and tested on the Standard car (Group Cs) versus those unfamiliar with and tested in the Modified car (Group D); this comparison should reveal any influence of the type of test vehicle on performance.

Where statistical treatment of the data is given, the statistic used is the Student's  $t$  (two-tailed). Use of this analytical tool assumes that each sample of observations is a random one from a normally distributed population and that variances of the populations are equal. Specific tests of these assumptions have not been made for these data. However, the validity of such use of the  $t$ -test has been demonstrated for rather extreme violations of these assumptions. \*

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\* Boneau, C. Alan, "The Effects of Violations of Assumptions Underlying the 't' Test". Psychological Bulletin, Volume 97, No. 1, 1960.

The student's  $t$  is given by the relationship:

$$t = \frac{\bar{y}_1 - \bar{y}_2}{s_p^2 \left( \frac{1}{n_1} + \frac{1}{n_2} \right)}$$

where  $\bar{y}_1$  and  $\bar{y}_2$  are the group means of the two groups being compared,  $n_1$  and  $n_2$  are the number of observations in each group ( $n_1 + n_2 - 2$  degrees of freedom), and  $s_p^2$  is the pooled estimate of the common population variance and is calculated from:

$$s_p^2 = \frac{SS_1 + SS_2}{n_1 + n_2 - 2}$$

where:

$$SS_i = \sum_{j=1}^{n_i} (y_{ij} - \bar{y}_i)^2, \text{ the group sum-of-squares.}$$

The results of each set of  $t$  tests will be presented in the following form:

Comparison	df	$s \bar{y}_1 - \bar{y}_2$	t-value	Significance
Group AB vs C				
Group Cs vs D				

where  $df$  = degrees of freedom

$s_{\bar{y}_1 - \bar{y}_2}$  = the standard deviation of the difference of two means; the denominator of the  $t$  statistic,

$t$  = the numerical value of the statistic, and

Significance = the probability of obtaining a value of the  $t$  statistic as large as or larger than that actually obtained if the two population means are, in fact, equal. This will generally be given as a range of values - e.g. -  $.01 < p < .1$ .

### 3.1 Off-Road Recovery

The performance metric for the Off-Road Recovery task was the entry velocity for a successful pass through the off-road section of the course. In all of the tasks of the course, failure was defined as a violation of any cone-marker delineating the path in question. However, in this task failure was defined as violation of any of the exit cones - those marked off in Figure 2.1-2. Entry cone violations were not used to indicate failure; they only served the function of forcing the drivers to straddle the curb. The task of interest - curb recovery - occurred in the exit region of the layout. Data for the four groups - AB, C, Cs, and D are given in Table 3.1-1.

#### Discussion

Qualitatively, the data show that for first run performance there is little difference of means among groups - all drivers approached the task rather cautiously on the first pass. On the other hand the BSR data show a consistent trend of higher entry speed relative to first runs.

The t-test data for this maneuver are:

	<u>Comparison</u>	<u>df</u>	<u><math>\bar{y}_1 - \bar{y}_2</math></u>	<u>t-value</u>	<u>Significance</u>
1st Run:	AB vs C	67	1.838	1.034	.30 < p < .40
	Cs vs D	27	2.935	.648	.50 < p < .60
BSR:	AB vs C	68	1.668	.540	.50 < p < .60
	Cs vs D	28	2.434	1.561	.10 < p < .20

TABLE 3.1-1  
OFF-ROAD RECOVERY - ENTRY VELOCITY

<u>Entry Velocity, MPH</u>	<u>Group</u>			
	<u>AB</u>	<u>C</u>	<u>Cs</u>	<u>D</u>
<u>1st Run</u>				
Mean	27.9	29.8	31.4	29.5
S	6.6	8.3	8.0	7.8
Max.	44	48	48	47
Min.	12	12	17	9
n	45	24	14	15
 <u>BSR</u>				
Mean	39.5	40.4	41.5	45.3
S	6.6	6.8	7.3	5.9
Max.	51	51	51	52
Min.	24	27	28	29
n	45	25	15	15

None of the group comparisons are highly significant but the higher Modified car (Group D) mean entry velocity, over the Standard car (Group Cs) in the BSR, is significant at a level between .10 and .20 (i. e. the probability that the difference is due to chance alone lies between 10 and 20%).

The BSR mean entry velocity for groups AB and C (Standard Car) is about 40 mph. The comparable figure for the three expert drivers was about 51 mph. In this and subsequent citations of expert driver performance the number of runs involved was eleven; all were without failure and all were driven in the Standard car.

### 3.2 Large Radius Arcs

In the Large Radius Arcs section of the course the measures of performance were the mean lateral acceleration ( $\bar{A}_y$ ), over a given time interval, and the corresponding mean velocity,  $\bar{V}$ ; the two pieces of data constitute an  $\bar{A}_y - \bar{V}$  pair. These means, and all others in the data interpretation phase of the diagram, were read from the strip chart records. To minimize the judgmental aspects of the reading process only two data readers were used for all of the recorded data.

The performance metrics  $\bar{A}_y$  and  $\bar{V}$  for the Large Radius Arcs portion of the course are given in Table 3.2-1; all lateral accelerations are in g units and all velocities in mph.

The t-test data for this maneuver are:

	<u>Comparison</u>	<u>df</u>	<u><math>s \bar{y}_1 - \bar{y}_2</math></u>	<u>t-value</u>	<u>Significance</u>
1st Run	AB vs C	72	.024	.420	.6 < p < .7
$\bar{A}_y$	Cs vs D	27	.034	.1	.9 < p < 1.0
1st Run	AB vs C	72	1.156	.346	.7 < p < .8
$\bar{V}$	Cs vs D	27	1.737	.691	.5 < p < .6
BSR	AB vs C	72	.024	.845	.4 < p < .5
$\bar{A}_y$	Cs vs D	27	.037	1.357	.1 < p < .2
BSR	AB vs C	72	1.061	.188	.8 < p < .9
$\bar{V}$	Cs vs D	27	1.443	2.357	.02 < p < .05

TABLE 3.2-1  
LARGE RADIUS ARCS -  $\bar{A}_y$  and  $\bar{V}$

<u>1st Run</u>	<u>AB</u>	<u>C</u>	<u>Group</u>	<u>Cs</u>	<u>D</u>
$\bar{A}_y$ :					
Mean	.28	.29		.30	.30
S	.09	.10		.10	.10
Max.	.48	.50		.45	.45
Min.	.10	.11		.12	.11
n	50.	24.		14.	15.
$\bar{V}$ :					
Mean	25.5	25.1		26.1	27.3
S	4.7	4.5		4.5	4.8
Max.	35.	36.		34.	35.
Min.	17.	17.		17.	16.
n	50.	24.		14.	15.
<u>BSR</u>					
$\bar{A}_y$ :					
Mean	.39	.41		.43	.48
S	.09	.11		.10	.11
Max.	.55	.59		.59	.65
Min.	.22	.20		.26	.31
n	50.	24.		14.	15.
$\bar{V}$ :					
Mean	31.0	30.8		31.5	34.9
S	4.2	4.4		2.0	5.0
Max.	41.	38.		38.	42.
Min.	21.	22.		26.	23.
n	50.	24.		14.	15.

For the most part the differences between g group means are not highly significant. However, in the BSR runs the  $\bar{A}_y$  difference and the  $\bar{V}$  difference - the higher levels of the Modified car vs the Standard Car (group D vs Cs) - are significant at levels between .1 and .2 and .02 and .05, respectively. This certainly suggests that drivers were willing to drive the Modified car harder through the Large Radius Arcs than the Standard car.

### 3.3 Avoidance Maneuver

The measure of performance for this maneuver was taken as the peak negative lateral acceleration ( $A_{yp}$ ) achieved in the course of the maneuver; the data are given in Table 3.3-1.

#### Discussion

The raw data show a higher  $A_{yp}$  for both first runs and best successful runs of Group C means over Group AB and Group D means over Group Cs. One is tempted to conclude, in the former case, that unfamiliarity is advantageous in this metric!

The t-test data for this maneuver are:

	<u>Comparison</u>	<u>df</u>	<u><math>s_y^2</math></u>	<u>t-value</u>	<u>Significance</u>
1st Run	AB vs C	69	.022	1.371	.1 < p < .2
	Cs vs D	27	.040	1.011	.3 < p < .4
BSR	AB vs C	69	.021	1.910	.05 < p < .1
	Cs vs D	26	.042	1.436	.1 < p < .2

In the first runs the C mean (unfamiliar) vs AB mean difference is significant at the .1 to .2 level - again tempting one to conclude an advantage in unfamiliarity. The BSR results seem to reinforce this conclusion - the significance in this case being at the .05 to .1 level. The larger peak  $A_y$  for the Modified car over the Standard car in the BSR is significant at the .1 to .2 level.

The Group AB and C peak  $A_y$ , BSR, ranged from .43 to .47g; the comparable figure for the expert drivers was about .60g (these data ranged from .55g to .68g).

TABLE 3.3-1  
 AVOIDANCE MANEUVER - PEAK Ay

<u>Ay p(g)</u>	<u>Group</u>			
	<u>AB</u>	<u>C</u>	<u>Cs</u>	<u>D</u>
<u>1st Run:</u>				
Mean	.34	.37	.38	.42
S	.10	.12	.11	.12
Max.	.56	.60	.56	.62
Min.	.13	.16	.23	.24
n	47.	24.	14.	15.
 <u>BSR:</u>				
Mean	.43	.47	.49	.55
S	.09	.12	.10	.13
Max.	.60	.65	.65	.76
Min.	.26	.25	.35	.36
n	48.	23.	13.	15.

### 3.4 First Chute

In this section of the course the measures of performance were the acceleration-velocity pair  $\bar{A}_y - \bar{V}$ , taken over a given time interval. This chute and the exit chute were not delineated by cone markers. The data are shown in Table 3.4-1.

#### Discussion

The group differences in this task are not large, especially in the BSR. The roadway in the first chute area is 12 ft. wide and has 8 ft. wide paved shoulders on either side. Thus, it is possible to trace short-duration paths, that are more-or-less steady-state, that do not correspond to the radius of curvature of the main roadway.

The Group AB and C  $\bar{A}_y - \bar{V}$  pairs, BSR, ranged from .27/43 to .29/44; the corresponding pair for the expert drivers was .38/53. It is interesting that the only vehicle damage incident suffered during the program occurred at the exit from this maneuver when the driver locked the brakes from an initial speed of 54 mph. A description of this accident is given in Appendix VI.

The t-data for this maneuver are of little interest - all but one difference was only significant at levels ranging from .3 to .4 to as high as .7 to .8. The most significant difference (.2 < p < .3) showed up in first run  $A_y$  between Cs and D (i. e. Cs = .22g, D = .19g).

TABLE 3.4-1  
FIRST CHUTE -  $\bar{A}_y$  &  $\bar{V}$

<u>1st Run</u>	<u>Group</u>			
	<u>AB</u>	<u>C</u>	<u>Cs</u>	<u>D</u>
$\bar{A}_y$ :				
Mean	.19	.20	.22	.19
S	.06	.07	.07	.06
Max.	.32	.35	.33	.31
Min.	.06	.10	.13	.07
n	45.	20.	11.	14.
$\bar{V}$ :				
Mean	33.5	35.2	37.3	35.1
S	7.3	7.3	10.4	9.8
Max.	46.	47.	47.	44.
Min.	13.	22.	27.	12.
n	45.	20.	11.	14.
<u>BSR</u>				
$\bar{A}_y$ :				
Mean	.27	.29	.29	.29
S	.07	.09	.12	.07
Max.	.45	.43	.38	.43
Min.	.13	.15	.16	.16
n	48.	21.	12.	15.
$\bar{V}$ :				
Mean	42.9	44.1	45.5	46.3
S	5.9	6.8	7.0	6.3
Max.	55.	54.	54.	52.
Min.	30.	30.	32.	28.
n	48.	21.	12.	15.

### 3.5 Gravel Turn

The performance metrics for the Gravel Turn were mean lateral acceleration-velocity pairs;  $\bar{A}_y$ - $\bar{V}$ .

The data for this section of the course are shown in Table 3.5-1.

#### Discussion

The first run data show no appreciable difference among the four groups; here, as in most of the other tasks or incidents the drivers are exposing themselves to the course for the first time and are understandably cautious.

The BSR raw data show no difference between Group AB and C means (familiar and unfamiliar); the increase in  $\bar{A}_y$  over the first run is, again, about .1g. The Group Cs-D data are interesting - the Modified car group (D) show a .06g increase over the Standard car (Cs group), i.e. .45g compared to .39g.

The statistics for this maneuver are:

	<u>Comparison</u>	<u>df</u>	<u><math>\bar{y}_1 - \bar{y}_2</math></u>	<u>t-value</u>	<u>Significance</u>
1st Run	AB vs C	71	.027	.375	.7 < p < .8
$\bar{A}_y$	Cs vs D	27	.040	.499	.6 < p < .7
1st Run	AB vs C	71	.918	.109	.9 < p < 1.0
$\bar{V}$	Cs vs D	27	1.471	.952	.3 < p < .4
BSR	AB vs C	69	.025	0.1	.9 < p < 1.0
$A_y$	Cs vs D	26	.042	1.414	.1 < p < .2
BSR	AB vs C	69	.884	.113	.9 < p < 1.0
$\bar{V}$	Cs vs D	26	1.252	2.475	.02 < p < .05

TABLE 3.5-1  
GRAVEL TURN -  $\bar{A}_y$  and  $\bar{V}$

<u>1st Run</u>	<u>Group</u>			
	<u>AB</u>	<u>C</u>	<u>Cs</u>	<u>D</u>
$\bar{A}_y$ :				
Mean	.25	.26	.29	.27
S	.11	.10	.10	.12
Max.	.62	.43	.40	.42
Min.	.06	.08	.10	.03
n	48.	25.	15.	14.
$\bar{V}$ :				
Mean	18.0	18.1	18.6	20.0
S	3.7	3.8	3.2	4.6
Max.	24.	24.	23.	26.
Min.	10.	11.	10.	8
n	48.	25.	15.	14.
<u>BSR</u>				
$\bar{A}_y$ :				
Mean	.37	.37	.39	.45
S	.10	.09	.09	.13
Max.	.62	.52	.52	.59
Min.	.17	.18	.21	.19
n	48.	23.	13.	15.
$\bar{V}$ :				
Mean	22.6	22.7	22.9	25.2
S	3.4	3.6	2.6	3.8
Max.	30.	30.	28.	29.
Min.	16.	17.	18.	16.
n	48.	23.	13.	15.

Most of the significance levels confirm the qualitative conclusions prompted by the raw data. However, the differences between BSR  $\bar{A}_y$  and  $\bar{V}$  for the Modified car over the Standard car are significant at the .1 to .2 and .02 to .05 levels, respectively. It is apparent that the drivers of the Modified car were willing to take the Gravel Turn at higher  $\bar{A}_y$  and at significantly higher  $\bar{V}$  than those in the Standard car.

The Group AB and C BSR  $\bar{A}_y - \bar{V}$  pairs were .37/24; the comparable pair for the expert drivers was .55/25 - not much difference in velocity but a large difference in  $\bar{A}_y$ . In other words, the expert drivers were willing to take the Gravel Turn at much tighter radii than the Subject drivers.

### 3.6 Wet Surface

The primary measure of performance for this maneuver was the speed at which the drivers approached the wet pavement section. This speed was measured at the same point in the course for all drivers by utilizing an event marking mechanism located in the straight just prior to the entrance to the wet section. This speed is correlated with success or failure to negotiate the maneuver and is used as a measure of performance. The results for all runs for the primary groups are shown in Figures 3.6-1 through 3.6-6.

#### Discussion

The major observation to be made from the results of this maneuver is that almost half of the subjects (47%) failed at least once to perform the task successfully. In addition over one-half of the attempts made at approach speeds of 40 mph (a reasonable roadway speed) and higher resulted in loss-of-control of the vehicle. Since the expert drivers were invariably successful at this (and slightly higher) speed, the results suggest that driver limitations were the principal cause of failure in this maneuver.

No analyses of statistical significance were made from these data. Interaction of speed effects with success/failure patterns prohibits the meaningful use of simple t-test methods with these results. Some trends are apparent (and these are pointed out below) but it is believed that detailed study of the many factors involved in this maneuver would be required in order to avoid the possibility of inappropriate conclusions. It is therefore recommended that consideration be given to reviewing these data in greater depth in a separate study.

The results given in the previous figures are summarized and extended in Table 3.6-1. With regard to the basic variables of familiarity and vehicle characteristics, the table indicates the following:

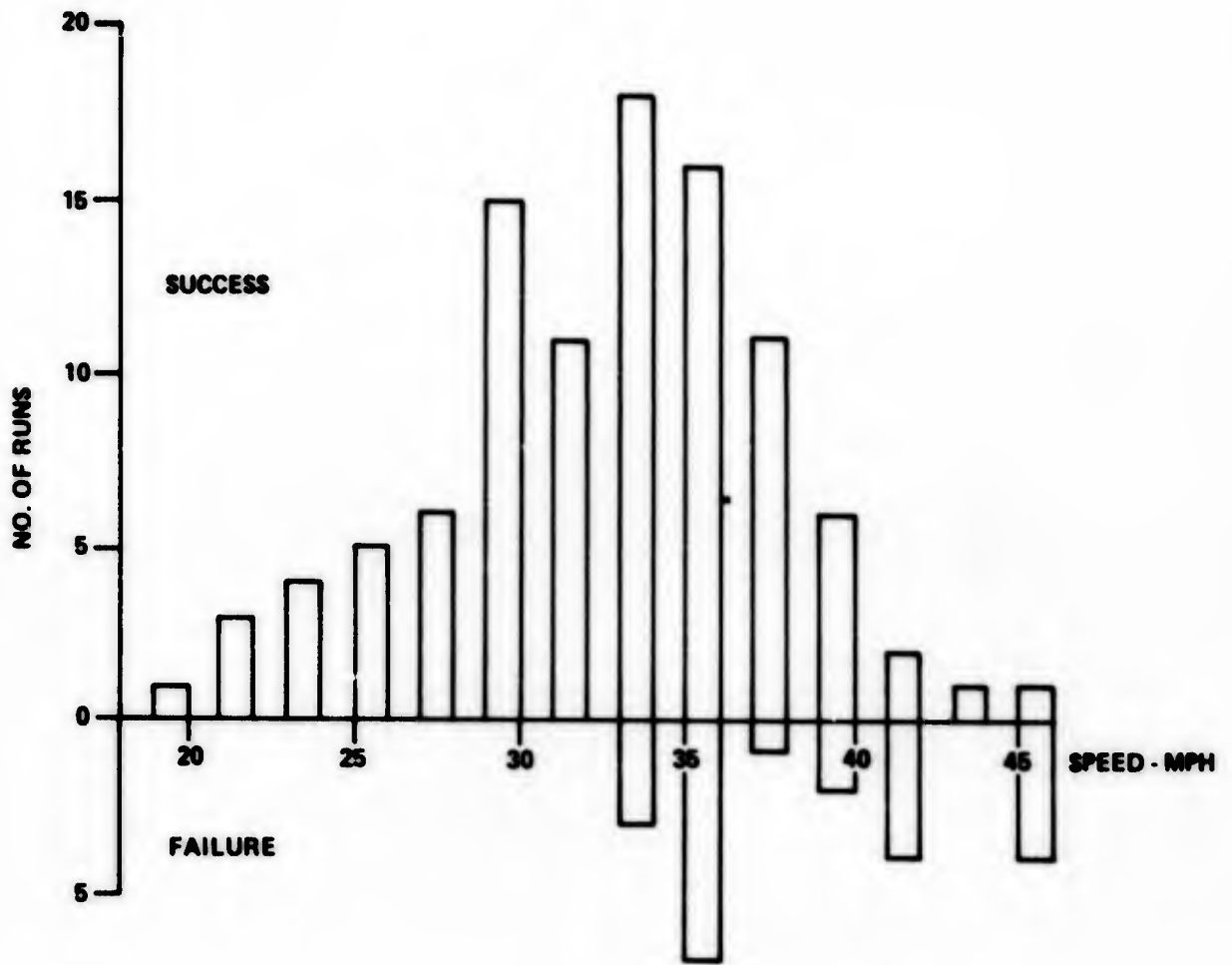
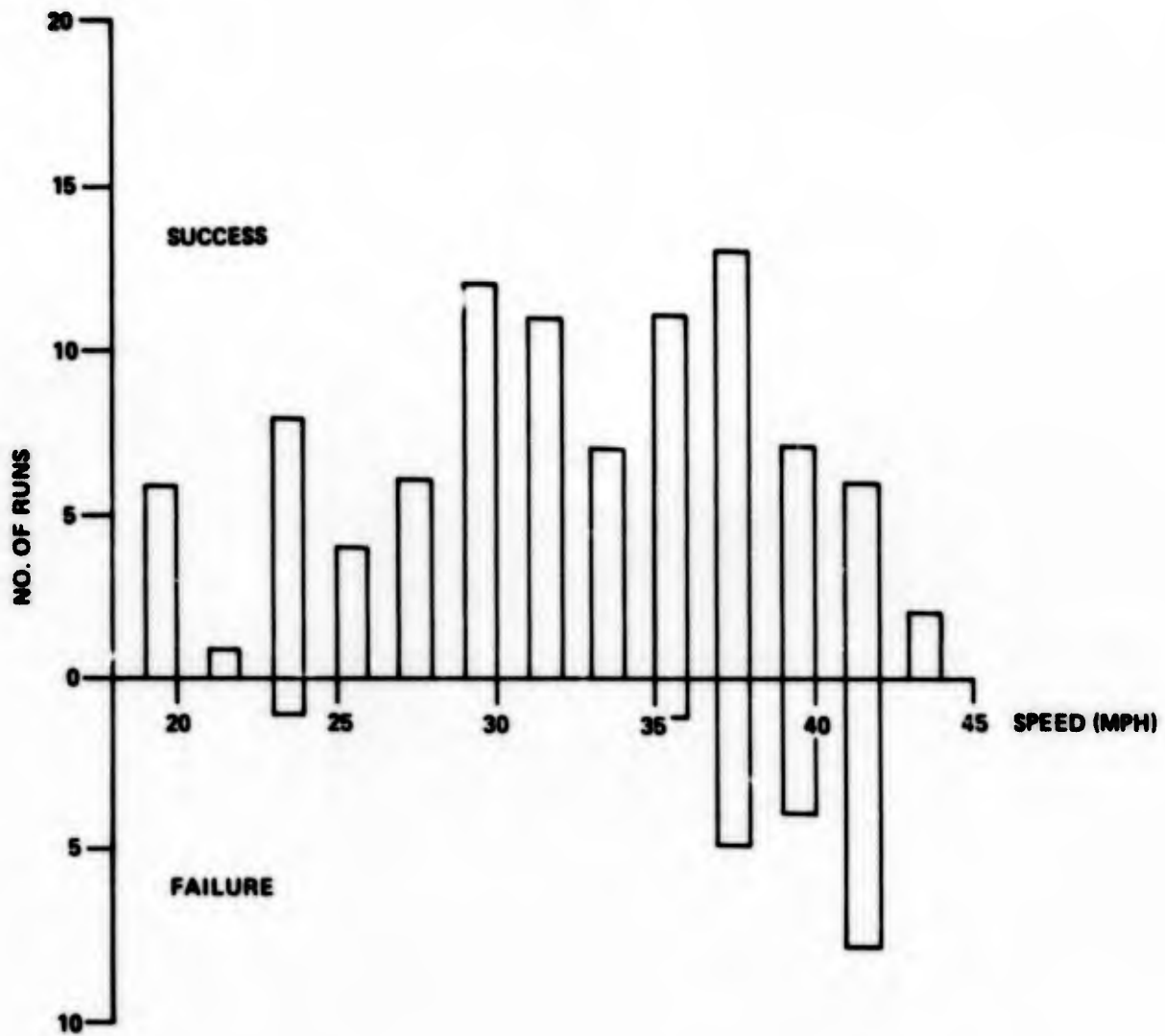
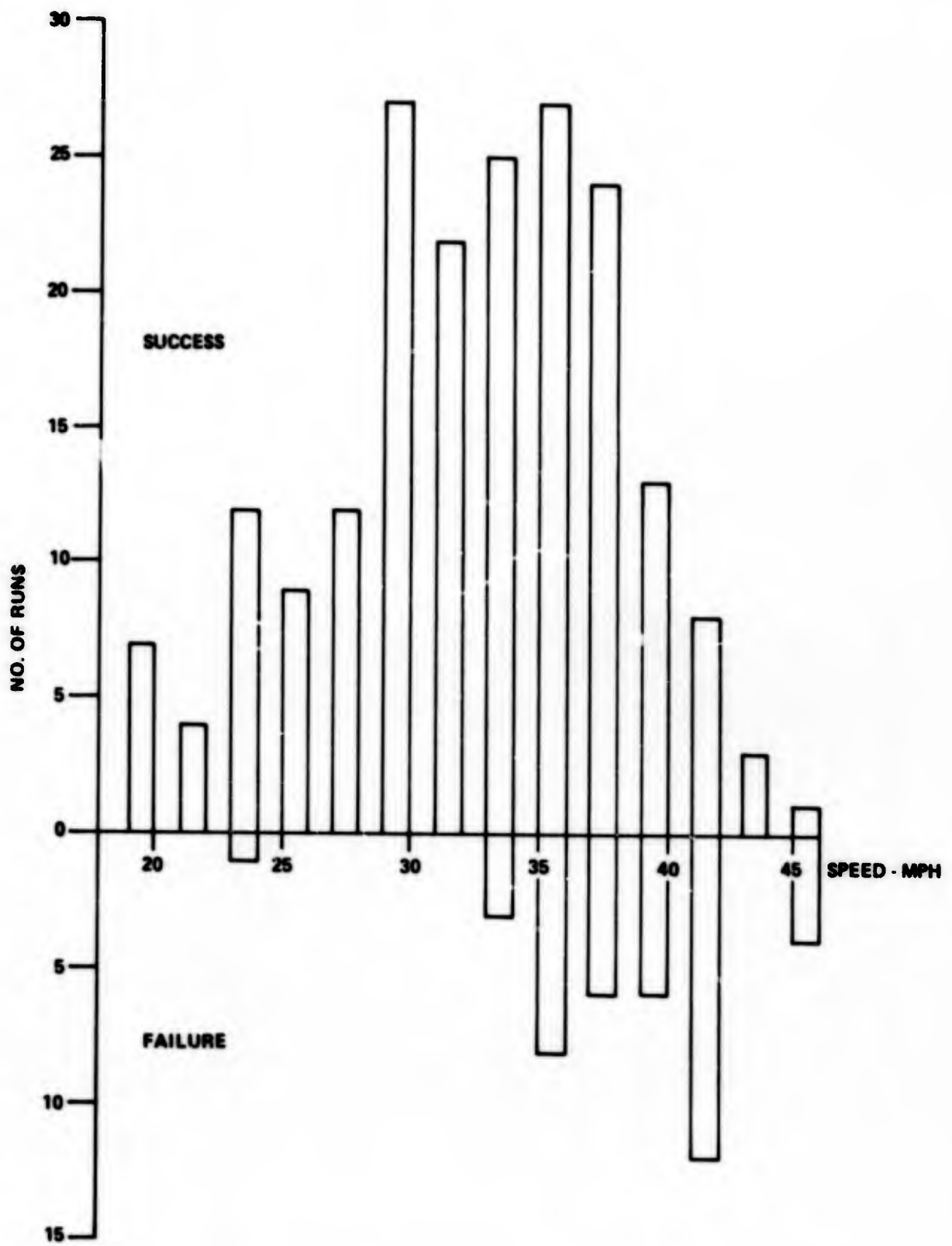


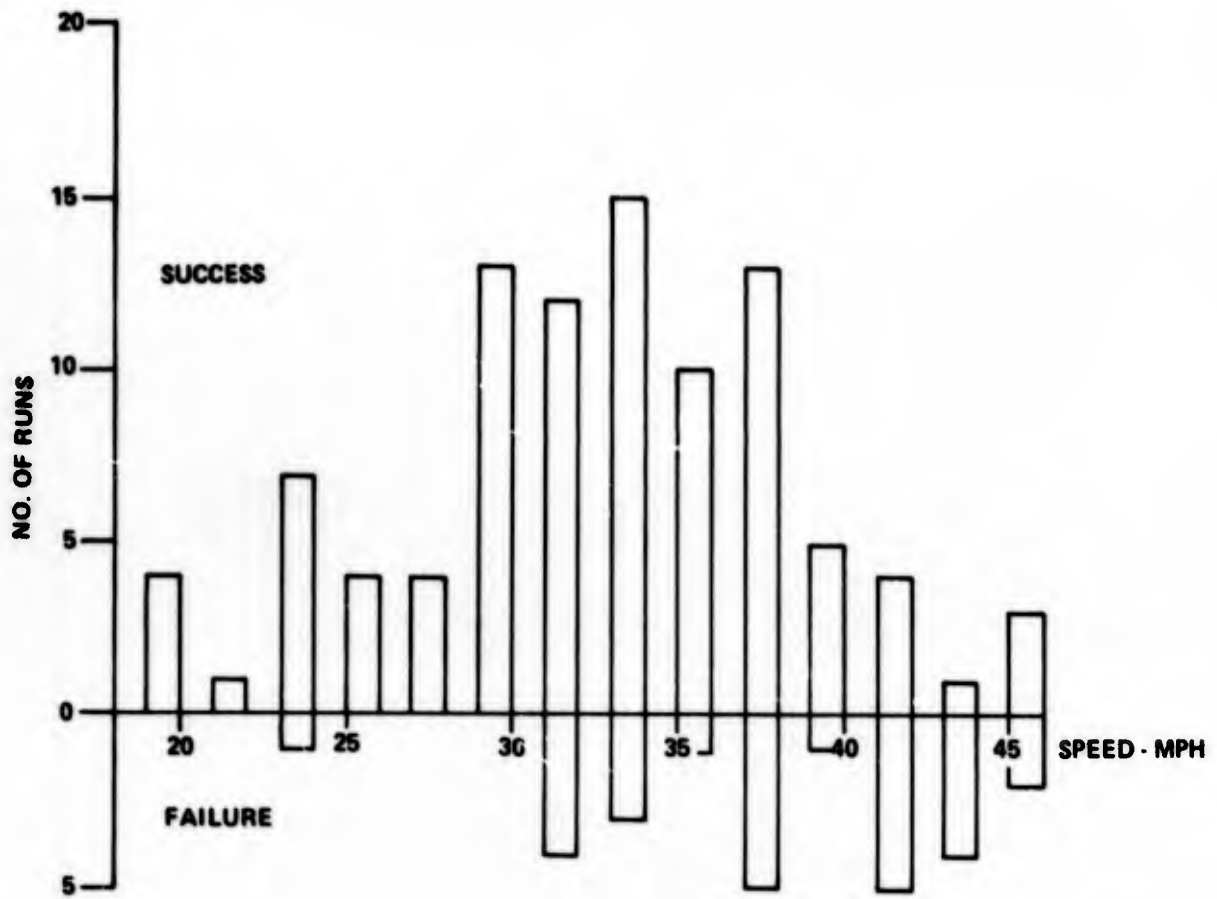
Figure 3.6-1 WET SURFACE TRAVERSAL RESULTS – GROUP A



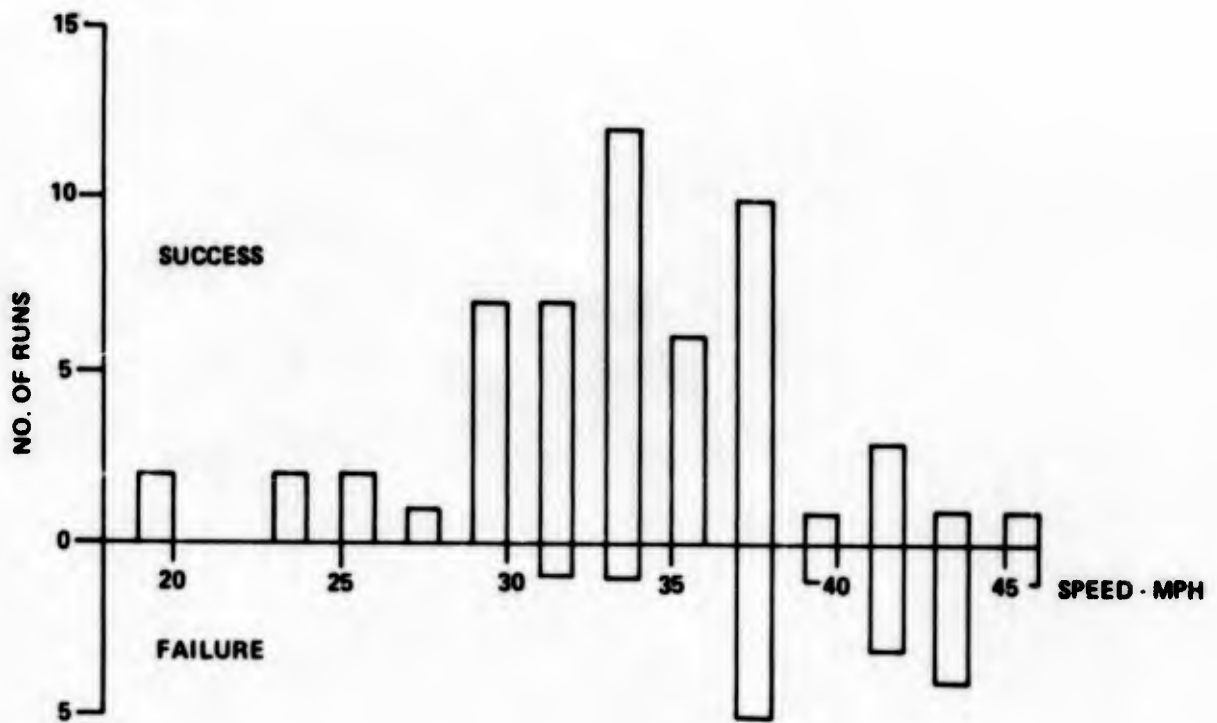
**Figure 3.6-2 WET SURFACE TRAVERSAL RESULTS – GROUP B**



**Figure 3.6-3 WET SURFACE TRAVERSAL RESULTS – GROUP AB**



**Figure 3.6-4 WET SURFACE TRAVERSAL RESULTS – GROUP C**



**Figure 3.6-5 WET SURFACE TRAVERSAL RESULTS – GROUP C3**

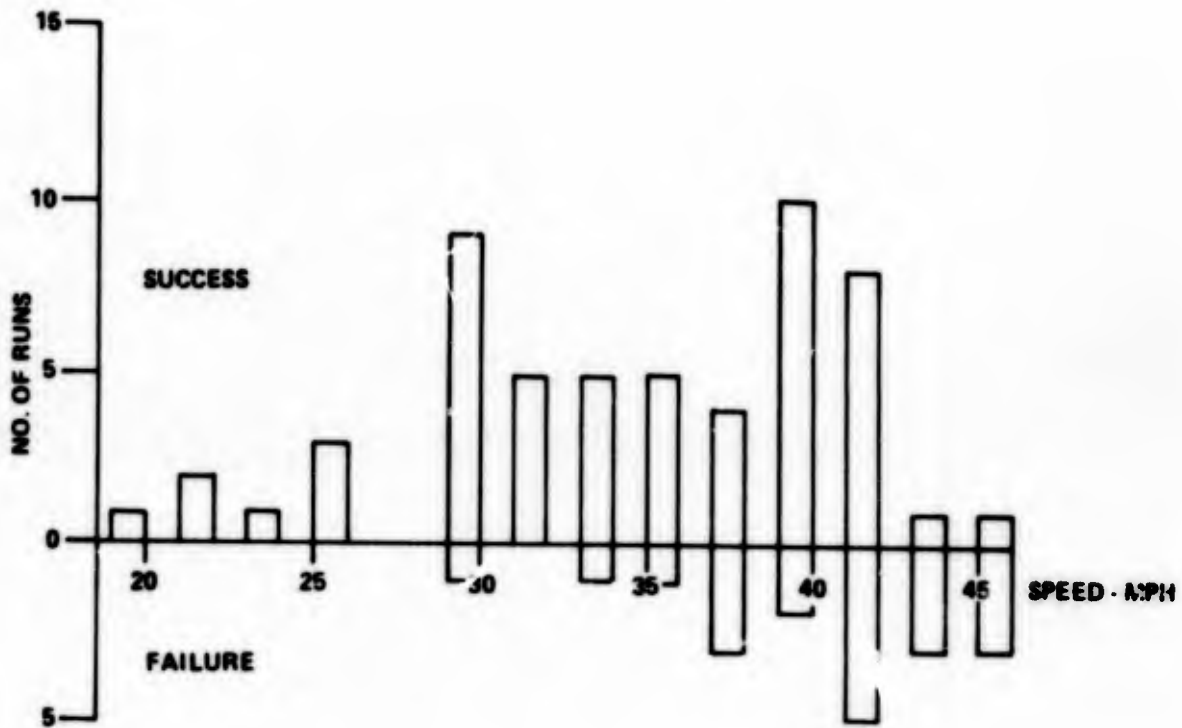


Figure 3.6-6 WET SURFACE TRAVERSAL RESULTS - GROUP D

TABLE 3.6-1  
SUMMARY OF GROUP DATA - WET SURFACE TRAVERSAL

	<u>Group</u>				
	<u>A</u>	<u>B</u>	<u>AB</u>	<u>C</u>	<u>D</u>
Percentage of subjects who failed on at least one attempt	44	40	42	56	53
Total number of failures	21	19	40	26	19
Percentage of failures (referenced to total number of attempts)	17 (124)	17 (113)	17 (237)	21 (122)	26 (74)
Percentage of failures resulting in loss of control	6	4	5	10.5	4
Average speed for all attempts (mph)	33.7	35	34.3	33.4	37.5
Speed above which one-half the attempts resulted in failure (mph)	39	41	40	39	41

- 1) The unfamiliar drivers (Group C) did not perform as well as the familiar drivers (Groups A and B). The C group shows a greater percentage of failures, more failures at lower speeds, and a larger percentage of loss-of-control type of failure.
- 2) Drivers of the Modified vehicle (Group D) tended to be more aggressive (i. e. , attempted to perform the maneuver at higher average speed) than the drivers of the Standard vehicle (Group Cs). They had far fewer losses of control - indicating that they were able to utilize the additional wet-hold capabilities of the Modified vehicle to some extent.
- 3) In general, all subjects were able to perform the maneuver successfully at approach speeds up to 30 mph (approximately .25g lateral acceleration in the wet area). The few failures which occurred at this speed or below are attributed to driver error.
- 4) Most subjects applied braking well into the wet area. The important observation here is that they did not bring their speed down sufficiently low in the preceding straight to have confidence in being able to drive through the wet section without further braking. In many cases, this action resulted in exceeding the limit of adhesion ( $\mu \approx .35$ ).
- 5) Viewed in terms of the distribution of failures by run number, the results show:

Run No.	1	2	3	4	5
No. of Failures	14	17	16	18	20

This relatively even distribution (except for the difference between first and fifth trials) indicates no specific learning effect during the course of the experiment.

On the basis of these results, we conclude that the subjects were not able to handle wet skid-inducing situations (which were self-imposed) with high probability of success. Clearly, more training under these conditions is very desirable.

This maneuver offers a large store of additional information with more detailed analysis. This includes

- data on steering rates employed in trying to recover from the skid
- data on braking levels used in slowing the vehicle under both wet and dry conditions
- data on types of failure (plow, spin) and techniques used in attempt to control
- combined braking and cornering accelerations (g-g diagrams).

### 3.7 Ess Turn

The performance metric in the Ess turn was taken as the peak lateral acceleration (A<sub>yp</sub>) achieved during the maneuver.

Table 3.7-1 gives the results for the Ess turn.

#### Discussion

Again, the first-runs raw data show no appreciable difference between Groups AB and C or between Cs and D. The improvement, shown in the BSR, is a little lower than in most of the other tasks for Groups AB, C, and Cs - being about .08 or .09g. But, notice that the improvement in Group D is .18g and that the Group D mean is also .1g higher than the Group Cs mean (both "unfamiliar" but the former is the Modified car while the latter is the Standard car). The physical characteristics of the Modified car are such that it would be expected to be more responsive and this .1g difference appears to reinforce the car-to-car difference for transient maneuvers that was first demonstrated in the Avoidance Maneuver.

The peak lateral acceleration used in this maneuver by two expert drivers was .65g, i. e., .18g higher than the average of Groups AB and C but only .06g higher than the Group D mean.

The t-statistics for this maneuver are:

	<u>Comparisons</u>	<u>df</u>	<u><math>\bar{y}_1 - \bar{y}_2</math></u>	<u>t-value</u>	<u>Significance</u>
1st Run	AB vs C	68	.029	.343	.7 < p < .8
	Cs vs D	27	.040	.0	.9 < p < 1.0
BSR	AB vs C	71	.025	.809	.4 < p < .5
	Cs vs D	26	.035	2.845	.001 < p < .01

The higher mean A<sub>yp</sub> of the Modified car drivers (Group D) over the Standard car drivers (Groups Cs), in the BSR, is quite significant (.001 < p < .01).

TABLE 3.7-1  
ESS TURN - PEAK LATERAL ACCELERATION

<u>Ayp</u>	<u>Group</u>			
	<u>AB</u>	<u>C</u>	<u>Cs</u>	<u>D</u>
<u>1st Run</u>				
Mean	.38	.39	.41	.41
S	.10	.13	.10	.12
Max.	.57	.62	.55	.57
Min.	.15	.10	.26	.17
n	47.	23.	14.	15.
<u>BSR</u>				
Mean	.46	.48	.49	.59
S	.09	.11	.08	.11
Max.	.66	.65	.62	.78
Min.	.26	.23	.32	.36
n	50.	23.	13.	15.

### 3.8 Small Radius Arc

In the Small Radius Arc (a constant radius turn of 150 ft radius) the performance measures were taken as the average lateral acceleration through the turn and the corresponding average velocity - i. e. - the  $\bar{A}_y$  -  $\bar{V}$  pairs.

The data for this section of the course are given in Table 3.8-1.

#### Discussion

The first-run data show no appreciable difference in mean  $\bar{A}_y$  between Groups AB and C; the difference between Groups Cs and D is only slightly larger. The improvement from first-run to the BSR is a little larger than usual, being about .11g for Groups AB and C and ranging from .12g to .17g for Groups Cs and D.

For the BSR data the Group AB/C difference (in mean  $\bar{A}_y$ ) is, again, small. The Group D mean is, however, .09g higher than the Group Cs mean. Thus - even in a non-transient situation (a steady turn) the Modified car shows up "better" - in the sense that drivers are willing to push it harder.

The t-test comparisons for all first runs and Group AB vs C BSRs show low levels of significance - i. e. -  $.4 < p < .8$  but the Group Cs vs D BSR comparison is interesting:

<u>Comparison</u>	<u>df</u>	<u><math>s \bar{y}_1 - \bar{y}_2</math></u>	<u>t-value</u>	<u>Significance</u>
BSR $\bar{A}_y$	28	.039	2.283	.02 < p < .05
Cs vs D $\bar{V}$	28	1.855	1.455	.1 < p < .2

Thus the .09g higher  $\bar{A}_y$  of Group D over Group Cs is significant at the .02 to .05 level. This, combined with the relatively high value of the increase in  $\bar{A}_y$ , first run to BSR, would appear to indicate that the Modified car drivers were willing to corner harder in a steady turn.

TABLE 3.8-1  
SMALL RADIUS ARC -  $\bar{A}_y$  and  $\bar{V}$

<u>1st Run</u>	<u>Group</u>			
	<u>AB</u>	<u>C</u>	<u>Cs</u>	<u>D</u>
$\bar{A}_y$ :				
Mean	.29	.31	.32	.36
S	.11	.10	.10	.15
Max.	.49	.53	.53	.62
Min.	.10	.13	.13	.06
n	47.	25.	15.	14.
$\bar{V}$ :				
Mean	25.5	26.1	27.0	27.6
S	4.5	4.7	4.6	6.3
Max.	33.	37.	37.	38.
Min.	16.	18.	18.	15.
n	47	25	15	14
<u>BSR</u>				
$\bar{A}_y$ :				
Mean	.40	.42	.44	.53
S	.10	.10	.09	.13
Max.	.61	.59	.59	.68
Min.	.18	.22	.26	.21
n	49.	25.	15.	15.
$\bar{V}$ :				
Mean	30.5	31.2	32.0	34.7
S	4.3	4.7	4.8	5.4
Max.	41.	42.	42.	41.
Min.	22.	23.	25.	23.
n	49.	25.	15.	15.

A measure of the "accuracy" of the data can be obtained by computing the  $\bar{A}_y$  error for the constant radius turn (150 ft) - i. e. - the computed  $A_y$  for the given  $V$  minus the actual  $A_y$ . This is done below for the four groups (BSR):

<u>Group</u>	<u><math>\bar{A}_y</math></u>	<u><math>\bar{V}</math></u>	<u><math>A_y</math> (theoretical)</u>	<u><math>A_y</math> "error"</u>
AB	.40	31	.42	.02g
C	.42	31	.42	0
Cs	.44	32	.46	.02g
D	.53	35	.54	.01g
				<u>Average = .013g</u>

The average  $\bar{A}_y$ - $\bar{V}$  pair for the two expert drivers was .60g/37 mph; they took the constant radius turn at very nearly the limit lateral acceleration of the Standard vehicle.

### 3.9 Exit Chute

The Exit Chute like the First Chute was not a delineated path (i. e. , it was not marked off with traffic cones). The measure of performance, as in the First Chute was an  $\bar{A}_y$ - $\bar{V}$  pair. In this case an attempt was made, in reading the  $\bar{A}_y$  data traces, to average over at least two seconds of time if it could be considered that the lateral acceleration was quasi-steady-state. In a number of cases the  $A_y$  trace was considered to be a transient and was not included in the results.

It should be noted that the  $\bar{A}_y$  in this maneuver were subject to interpretation differences more than perhaps any other maneuver in the course.

The raw data are given in Table 3.9-1.

#### Discussion

The spread in  $\bar{V}$  for BSRs is a little more than in most of the other maneuvers in which the metric was  $A_y - \bar{V}$  pairs. This is probably due to the wide latitude in path curvature that the drivers could take (12 ft roadway plus 8 ft shoulders) together with the question of interpretation of a steady-state time interval, mentioned above.

The results of the t-test comparisons are:

	<u>Comparison</u>	<u>df</u>	<u><math>s \bar{y}_1 - \bar{y}_2</math></u>	<u>t-value</u>	<u>Significance</u>
1st Run	AB vs C	61	.027	1.129	.2 < p < .3
$\bar{A}_y$	Cs vs D	24	.035	1.707	.1 < p < .2
1st Run	AB vs C	61	2.018	.347	.7 < p < .8
$\bar{V}$	Cs vs D	24	3.076	.780	.4 < p < .5
BSR	AB vs C	61	.028	.726	.4 < p < .5
$\bar{A}_y$	Cs vs D	25	.036	1.102	.2 < p < .3
BSR	AB vs C	61	1.453	1.170	.2 < p < .3
$\bar{V}$	Cs vs D	25	2.557	1.251	.2 < p < .3

TABLE 3.9-1  
EXIT CHUTE -  $\bar{A}_y$  and  $\bar{V}$

<u>1st Run</u>	<u>Group</u>			
	<u>AB</u>	<u>C</u>	<u>Cs</u>	<u>D</u>
$\bar{A}_y$ :				
Mean	.30	.33	.35	.29
S	.09	.11	.10	.07
Max.	.48	.49	.49	.48
Min.	.07	.13	.13	.13
n	41.	22.	13.	13.
$\bar{V}$ :				
Mean	35.5	34.8	36.5	34.1
S	8.1	6.7	6.8	8.8
Max.	46.	46.	46.	46.
Min.	20.	23.	23.	17.
n	41.	22.	13.	13.
<u>BSR</u>				
$\bar{A}_y$ :				
Mean	.40	.38	.40	.44
S	.10	.10	.09	.10
Max.	.60	.60	.60	.65
Min.	.18	.15	.25	.26
n	43.	20.	12.	15.
$\bar{V}$ :				
Mean	41.0	39.3	41.3	44.5
S	4.5	6.9	7.1	6.2
Max.	54.	56.	56.	52.
Min.	31.	25.	31.	28.
n	43.	20.	12.	15.

As in the case of most of the other maneuvers familiarity with the test vehicle did not show up as a strong factor; the lowest p-level range evident is  $.1 < p < .2$ . The same can be said of the Standard car vs Modified car results.

The  $\bar{A}_y - \bar{V}$  pair (average) for the expert drivers was .65 and  $> 60$  mph; the experts were willing to take the exit turn much faster than the subjects of program.

### 3.10 Braking

In the final braking portion of the course the subject drivers came to a hard stop at the end of the test. The performance measure of interest was the mean level of longitudinal deceleration used by the driver - including those cases where wheel lock occurred. The results are given in Table 3.10-1.

#### Discussion

One of the problems with the braking data in this maneuver was that of interpreting the recorded time histories. The data readers generally attempted to strike an average during the end portion of the longitudinal deceleration trace over a time interval in which  $A_x$  was "substantially" constant; this time period was usually about 2 seconds. (See Figure 3.11-1, for example.) There was, of course, some uncertainty in this process.

The t-test data for this maneuver are:

	<u>Comparison</u>	<u>df</u>	<u><math>s_{y_1 - y_2}</math></u>	<u>t-value</u>	<u>Significance</u>
1st Run $\bar{A}_x$	AB vs C	73	.040	1.508	.1 < p < .2
	Cs vs D	28	.050	1.209	.2 < p < .3
BSR $\bar{A}_x$	AB vs C	73	.029	2.042	.02 < p < .05
	Cs vs D	28	.047	.211	.8 < p < .9

The AB vs C comparisons are interesting. In both first-runs and BSRs the unfamiliar drivers braked harder (.06g higher) with p being .02 - .05 in the second case; we have no ready explanation for this. Insofar as the Cs vs D comparisons are concerned we note that there was no difference between the braking systems of the two test cars.

TABLE 3.10-1  
FINAL BRAKING - MEAN DECELERATION

$\bar{A}_x$	<u>Group</u>			
	<u>AB</u>	<u>C</u>	<u>Cs</u>	<u>D</u>
<u>1st Run</u>				
Mean	.49	.55	.57	.51
S	.16	.16	.14	.13
Max.	.75	.75	.75	.68
Min.	.16	.20	.20	.18
n	50.	25.	15.	15.
n <sub>1</sub> <sup>*</sup>	3.	2.	0	0
 <u>BSR</u>				
Mean	.56	.62	.62	.61
S	.11	.14	.14	.12
Max.	.72	.84	.84	.70
Min.	.35	.35	.20	.32
n	50.	25.	15.	15.
n <sub>1</sub> <sup>*</sup>	12.	10.	7.	1.

---

\* n<sub>1</sub> = number of cases of wheel lock

The values for Groups AB, C and D (leaving out the sub-set of C) will give some indication of how hard the "average" driver is willing to decelerate. The mean of the means of these three groups is:

1st Run	.52g
BSR	.60g

In other words the subjects were willing to brake harder by .08g after becoming familiar with the course.

The average braking deceleration for the expert drivers was .67g.

### 3.11 Surprise Intrusion

As a means of introducing a simulated accident situation into the experiment, a portion of the subject sample was exposed to the injection of an obstacle into the driving path during the fifth trial. The incident was located in the long straight following the Small Radius Arc. It was set up at a point in the course at which most drivers were operating near the maximum speed which they attained (usually well over 50 mph) and so arranged that pure braking would not be adequate for avoiding the obstacle. The subjects were exposed to the situation in the last of the five-trial set so that their performance would not otherwise be affected. Great care was taken to avoid prior knowledge of the event and, to the best of our knowledge, the subjects were truly "surprised" by the intrusion.

Most of the subjects in the C and D groups were exposed to the incident. In several cases, faulty operation of the barrel launching mechanism caused the barrel to under - or overshoot the center of the path and these runs have been discarded from the analyses. The principal measures used to evaluate performance were:

- success/failure of avoidance
- approach speed
- type of control applied
- reaction time (the measured time interval between passing over the tape switch which triggered the launching mechanism and the first evidence of control activity - braking or steering).

#### Discussion

The results for 34 subjects are shown in Table 3.11-1. In addition to the primary metrics of performance listed above, auxiliary information related to control efforts and subsequent activity are also given. The results may be summarized as follows:

TABLE 3.11-1  
SURPRISE INTRUSIONS DATA

Subject	Success-Fail	Approach Speed	Reaction Time	First Control	Second Control	Control Loss	Remarks
201	F	-	-	B	N		
202	F	62	.4	B	X		
203	F	58	.35	B	X	X	
205	F	54	.6	S	N		continued to accelerate
208	F	52	.7	B	X		
209	F	60	.7	S	N		gave up trying
210	F	37	.75	B	N		
212	F	43	.8	B	N		
213	F	50	.6	B	X	X	
214	F	50	-	S	-		faulty data traces
215	S	44	1.0	S	X		
216	F	60	.6	B	X	X	
218	F	53	.4	B	X		
221	F	52	.5	B	X		
222	F	53	1.7	B	N		reaction time not used in determining average
223	F	60	-	S	-		almost avoided (observer comment)
217	F	60	.8	B	X		small steer input but gave up

B = Braking  
 S = Steering  
 N = None  
 X = applied both steering and braking  
 - = Uncertain data

TABLE 3. 11-1 (cont.)

## SURPRISE INTRUSIONS DATA

Subject	Success - Fail	Approach Speed	Reaction Time	First Control	Second Control	Control Loss	
257	F	54	.5	B	N		
262	F	36	.9	B	X		
263	F	60	.8	B	N	X	
264	F	60	.6	B	X	X	
266	F	60	.75	S	X	X	
268	F	58	-	B	N		
269	F	54	.4	B	X	X	severe loss of control
270	F	60	N	B	N	X	
277	F	60	.6	B	X		
278	F	60	.5	S	X	X	
280	F	60	.5	S	X		
282	F	60	.6	B	X		
283	F	58	.7	B	N		
286	F	60	N	N	N		no reaction
287	F	55	.7	S/B	X		
307	F	55	.6	B	N		
308	F	40	.9	B	X		

1. Thirty-three (33) of the 34 subjects failed to avoid the barrel. In the one successful case, approach speed was relatively low and the driver steered around the obstacle easily.
2. In 25 cases out of the total of 33, (75%) the first reaction of the subjects was to apply braking (or simultaneously brake and steer). In one case, there was no apparent reaction at all.
3. Approximately 57% of the subjects applied both steering and braking in the maneuver. In most of the cases in which steering was employed after braking, it was only weakly applied and cannot be identified as either part of the avoidance procedure or a reaction to the braking operation.
4. Mean values for the quantitative metrics from the table are:  

Mean approach velocity:	55 mph
Mean reaction time:	.65 seconds
5. The subjects lost control of the vehicle during or as a result of the maneuver in 27% of the runs. Control loss is defined as a spin or completely leaving the intended path.

As an example of the type of additional information available in the data traces of this maneuver, a typical run is shown below.

Figures 3.11-1 and 3.11-2 show the data traces for two successive runs by one of the subjects who was exposed to the surprise intrusion.

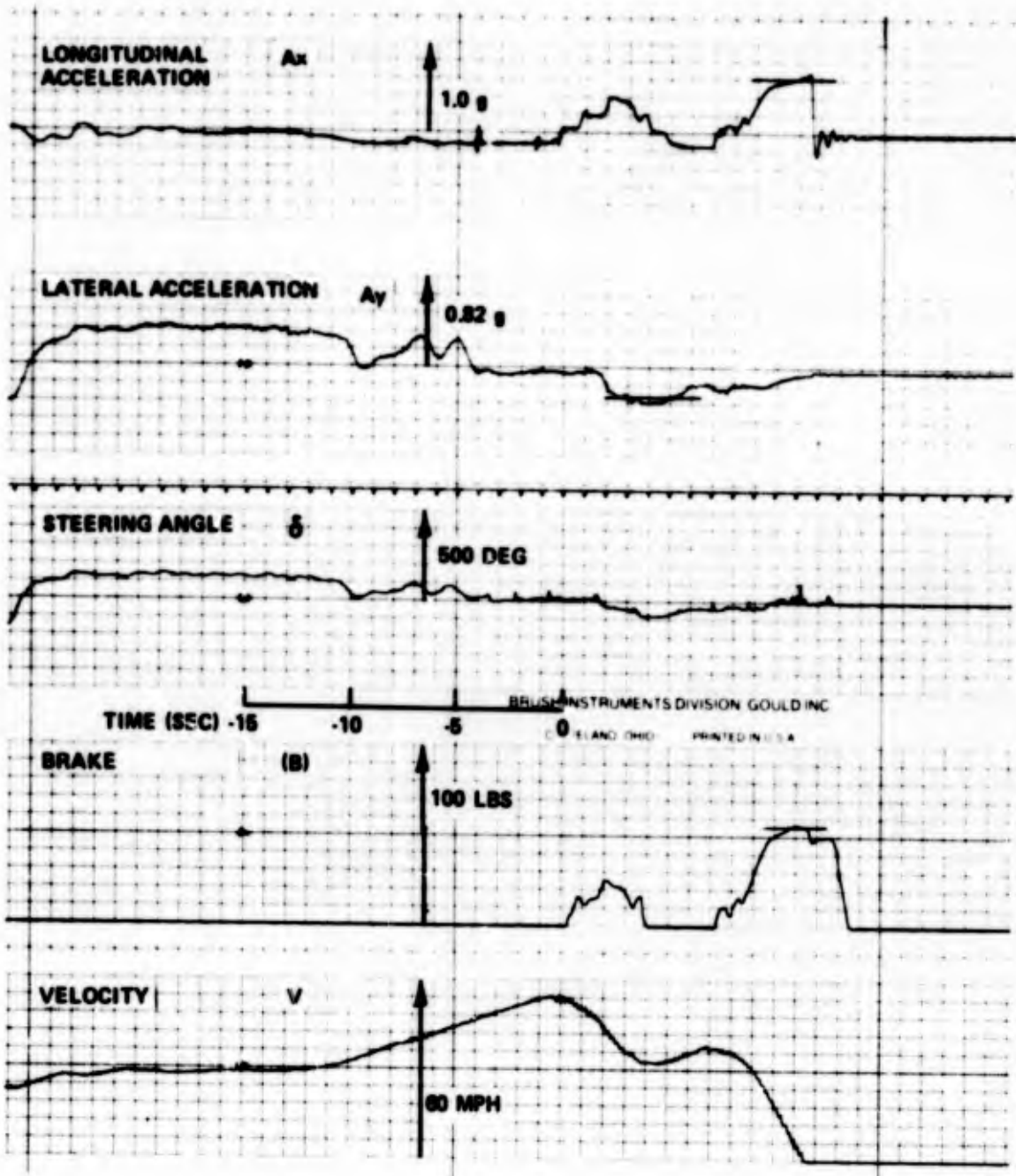


Figure 3.11-1 SAMPLE RUN WITHOUT SURPRISE INTRUSION

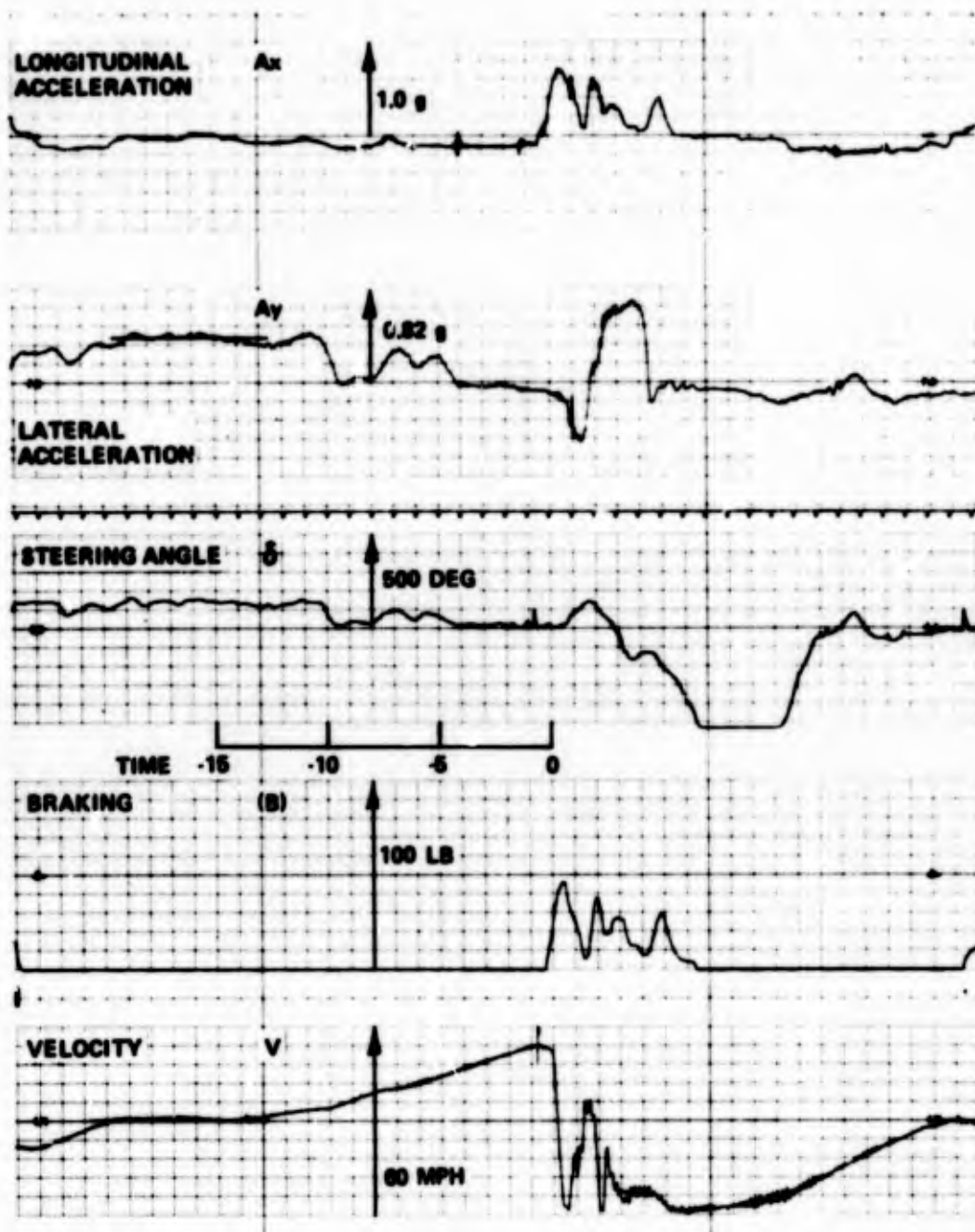


Figure 3.11-2 SAMPLE RUNS WITH SURPRISE INTRUSION

The differences in the two runs demonstrate this subject's reaction to the situation. For convenience, the traces have been marked at five second intervals; zero time indicates the obstacle ejection point.

Figure 3.11-1 shows this subject's fourth run in the sequence. At 15 seconds, the driver is proceeding smoothly through the small radius arc at a near constant speed of less than 30 mph and at a lateral acceleration of about .32g. At 10 seconds, the driver is accelerating out of the constant radius portion of the turn and this continues for the next several seconds. By about 4 seconds, the driver is in the straight section ( $A_y \approx 0$ ) and still accelerating (reaching a speed of 54 mph). Shortly after zero seconds, the subject applies reasonable braking to slow the vehicle preparatory to entering the chute turn. The vehicle then proceeds smoothly into and through the turn ( $t > +2$  seconds).

In Figure 3.11-2, almost precisely the same pattern exists through the period from 15 seconds to 1 second (when the obstacle trigger switch is encountered). About .4 seconds later, the subject responds to the intruding element by applying the brakes. In rapid succession from  $t = 0$ , the brakes lock; the car starts to spin in a CCW direction, the driver relieves the brakes and applies CW steering, and the vehicle begins to come around in a CW direction. At  $t = +2$  seconds, the driver has relocked the brakes and the vehicle continues in a CW direction even though CCW steering is applied shortly thereafter. The braking and steering of the driver are of no avail for heading control beyond this point as the vehicle speed is reduced to near zero. The driver then applies large CCW steering to return the vehicle to the course and proceeds through to the end.\*

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\* This sequence is shown in the motion picture film describing this study which has been submitted as part of the final report.

This incident has been chosen as a good example of the "loss-of-control" situation. By applying the brakes in a way that produced lockup, the driver precipitated a sequence of events with which his own control activity was soon out of phase. Two points stand out - the subject's driving habits were such that his first reaction was to use the brakes for avoidance and he did not have sufficient training to be able to recover from a dry-surface skid.

The important observation summarizing the results of this maneuver is that most of the subjects attempted to use braking as the primary means of avoidance. Although steering was also applied in many cases, it was often delayed until it was ineffective. Given the average reaction time (.65 seconds) at the average speed (54 mph), approximately one-half of the distance to the obstacle was covered before control action was applied. Under these conditions, steering avoidance, if used, could have been effective.

### 3.12 Time-in-Course

In the written instructions given each subject before the test, speed through the course and accuracy (as measured by cone violations) were given equal emphasis\*. The measure of average speed through the course is time-in-course, as recorded by the test observer for each run.

The total sample for these data will be the 90 subjects of the test group - not including the 18 residual subjects. We will examine first time-in-course without regard to failure (TIC).

It will be remembered that a failure is defined as the violation of one or more cones in any task or incident. In other words, no attempt was made to differentiate between a failure in which one cone was knocked down or one in which many may have been knocked down.

In this section and in Section 3.14, Success-Failure Data, seven tasks were considered: Off-Road Recovery (ORR), Large Radius Arcs (LRA), Avoidance Maneuver (AM), Gravel Turn (GT), Wet Surface (WS), Ess Turn (ET), and Small Radius Arc (SRA); the Surprise Intrusion task was handled separately in Section 3.11.

Thus, in any one run a subject could have committed seven failures (i. e. failed all of the above seven tasks) at most.

#### Time-In-Course Without Regard to Failure (TIC)

We examine first the First-Run/Fastest Run data; fastest run is equivalent to lowest TIC. Table 3.12-1 gives the raw data comparisons by group.

---

\* See Appendix II, Item 3 "Driving Experiment Information"

TABLE 3.12-1  
 TIME-IN-COURSE:  
 FIRST RUN AND FASTEST RUN

TIC (seconds)	<u>Group</u>			
	<u>AB</u>	<u>C</u>	<u>Cs</u>	<u>D</u>
<b><u>1st Run</u></b>				
Mean	159.	155.	150.	149.
S	33.8	30.4	29.0	40.9
Max.	259.	235.	180.	284.
Min.	117.	115.	122.	109.
n	50.	25.	15.	14.
 <b><u>Fastest Run</u></b>				
Mean	124.	125.	122.	114.
S	13.8	15.3	11.8	14.2
Max.	161.	172.	153.	161.
Min.	107.	105.	105.	100.
n	50.	25.	15.	15.

It is worth pointing out, first, that the fastest run occurred 78% of the time in the fifth run, 20% of the time in the fourth run, and 2% of the time in the third run. In other words a distinct majority of the fastest runs (again, without regard to failure) occurred in the last run; the subjects tended to feel the course out in the early runs and to become bolder in the later runs.

The first-run data show that all drivers went through the course relatively slowly and that there was little difference in TIC magnitudes. The latter is borne out by the t-test results.

	<u>Comparison</u>	<u>df</u>	<u><math>s \bar{y}_1 - \bar{y}_2</math></u>	<u>t-value</u>	<u>Significance</u>
1st Run TIC	AB vs C	73	8.012	.499	.6 < p < .7
	Cs vs D	27	13.094	.076	.9 < p < 1.0
Fastest Run TIC	AB vs C	73	3.497	.286	.7 < p < .8
	Cs vs D	28	4.767	1.678	.1 < p < .2

The Fastest Run difference between Groups AB and C is negligible - again borne out by the p-level. One might have expected that if there is a difference due to familiarity it would have shown up in TIC. The eight second difference between the Cs and D Groups (D faster) stands out in the table; as can be seen above, it is significant at the .1 to .2 level. Reduction of time-in-course from First Run to Fastest Run is of interest. The raw data are given in Table 3.12-2.

TABLE 3.12-2  
AVERAGE REDUCTION IN TIME-IN-COURSE  
FIRST RUN TO FASTEST RUN

ΔTIC, sec	<u>Group</u>			
	AB	C	Cs	D
Mean	34.7	30.0	28.1	34.9
S	23.0	20.1	18.9	28.7
Max.	101	82	82	123
Min.	9	9	9	9
n	50	25	15	14

The table shows a slightly greater "improvement" for the AB Group (Standard car, familiar subjects) and the D Group (Modified car) over the C and Cs Groups (Standard car, unfamiliar subjects) but the significance levels for these differences are relatively low - for AB vs C,  $.3 < p < .4$ , and for Cs vs D,  $.4 < p < .5$ .

In examining "fast run" data more closely it is appropriate to increase the data base by pooling data for runs 4 and 5 since 98% of all fastest runs occurred in these two runs. The results, using the pooled data, are given in Table 3.12-3.

TABLE 3.12-3  
TIME-IN-COURSE: RUNS 4 & 5

TIC: Seconds	<u>Group</u>			
	AB	C	Cs	D
Mean	126	127	123	116
S	7.1	16.7	14.3	15.3
Max.	165	177	175	169
Min.	106	105	105	100
n	99	49	30	29

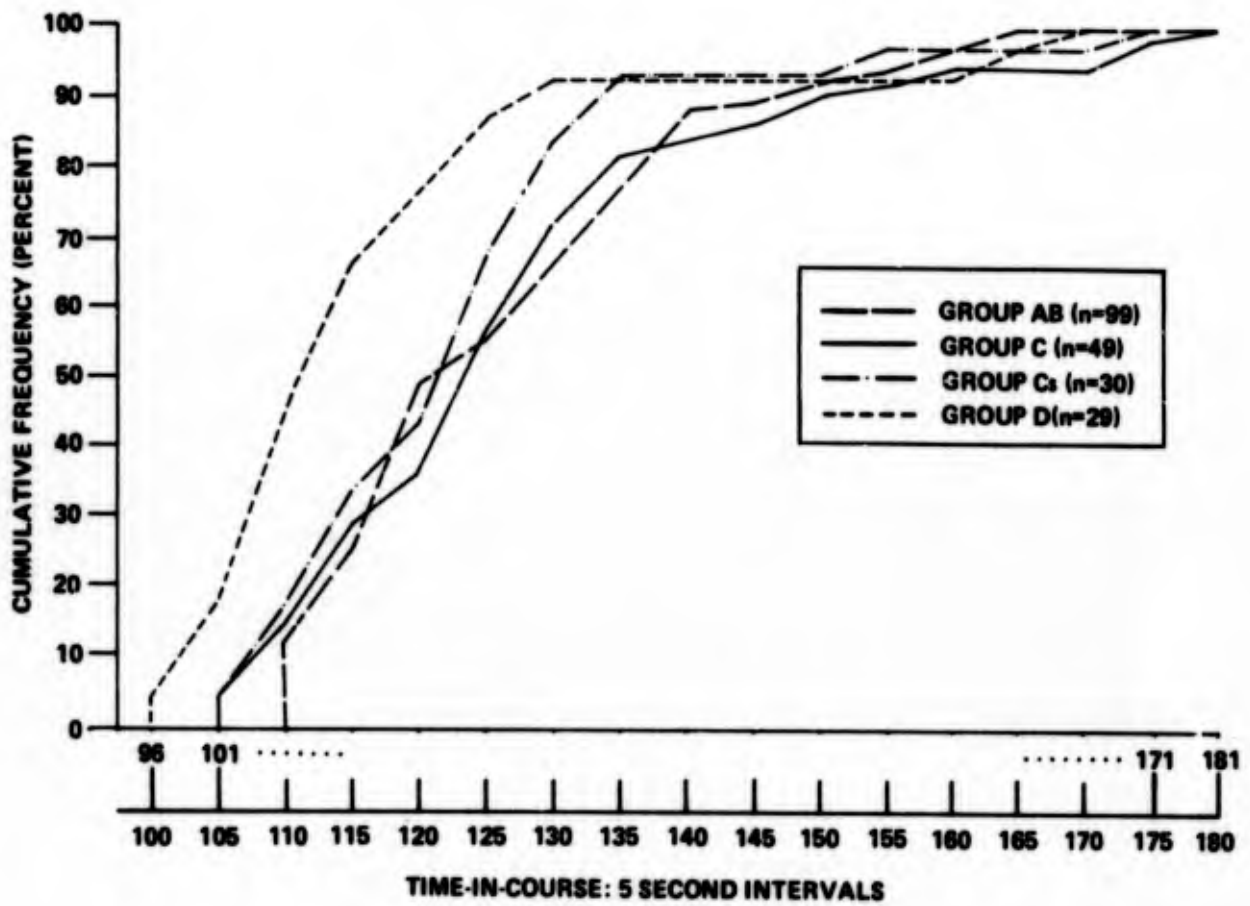
Aside from differences in mean values, which will be discussed later, the lower standard deviation of the AB group (familiar subjects) is of interest; it might say something about the consistency of the familiar drivers.

The distribution of TIC (runs 4 and 5) is shown in Figure 3.12-1. In this figure 5 second intervals of TIC were chosen - i.e. - 96 to 100 seconds, 101 to 105 seconds, etc. The figure shows that groups AB and C are very much alike. The difference between the means of these two groups is one second. The t-test data, given below, show that the difference is not significant, however. In other words even when the "fast run" data are pooled to increase the data base, familiarity (Group AB vs C) does not appear to be of significance in determining how fast the subjects were willing to drive the Standard car through the course. This is borne out by the t-test results:

<u>Comparison</u>	<u>df</u>	<u><math>\bar{y}_1 - \bar{y}_2</math></u>	<u>t-value</u>	<u>Significance</u>
Fast Run TIC (sec)				
AB vs C	146	1.957	.511	.6 < p < .7
Cs vs D	57	3.854	1.816	.05 < p < .10

Turning next to the Cs and D Groups the difference between the means, in Table 3.12-3 is 7 seconds; the frequency distributions of Figure 3.12-1 show a more pronounced difference than in the AB/C case.

The t-test data indicate that the Cs vs D difference of 7 seconds is significant at a p-level of .05 to .10 (earlier, with fastest runs only, the difference was 8 seconds and .1 < p < .2). Thus, it is likely that the Modified car in Group D was an important factor in the lower TIC relative to the Standard car of Group Cs; this correlates, in a general way, with the tendency of the Group D drivers to use higher lateral accelerations (see Sections 3.3 and 3.8, for example).



**Figure 3.12-1 FREQUENCY DISTRIBUTION-TIME IN COURSE  
4th AND 5th RUNS (POOLED)**

Finally, it is of interest to compare the fastest time data of Table 3.12-1 with the time-in-course used by the expert drivers. The spread in TIC of the expert drivers was small - of the order of perhaps 2 or 3 seconds. The figures for these drivers, given in Table 3.12-4, are for runs without failure.

TABLE 3.12-4  
FASTEST RUN - COMPARISON WITH EXPERT DRIVERS

Group	Mean TIC (seconds)	n
AB (Standard car)	124	50
C (Standard car)	125	25
Cs (Standard car)	122	15
D (Modified car)	114	15
Experts (Standard car)	104	11
Experts (Modified car)	98	2

In either car, Standard or Modified, the test subjects drove about 16% or 17% slower than the experts.

Time-In-Course Without Failure

The lowest time-in-course achieved without failure (symbol TICnf) will be examined next. For the 90 test subjects of Groups AB, C and D the distribution of TICnf with run number is shown in Table 3.12-5.

**TABLE 3. 12-5**  
**DISTRIBUTION OF LOWEST TIC**  
**WITHOUT FAILURE BY RUN NO.**  
**GROUPS AB, C AND D**

<u>Run Number</u>	<u>Percent</u>	
1	7.1	} 22.6
2	6.0	
3	9.5	
4	25.0	} 77.4
5	<u>52.4</u>	
	<u>100</u>	

Note that whereas for the fastest TIC without regard to failure 98% occurred in runs 4 and 5, the comparable figure for TICnf is down to 77.4%.

The means of TICnf are given in Table 3. 12-6.

**TABLE 3. 12-6**  
**FASTEST RUN WITHOUT FAILURE**

Group	Mean TICnf (sec.)	n
AB	129	47
C	130	23
Cs	127	14
D	118	14
Experts (Std. car)	106	7
Experts (Mod. car)	98	2

Comparing the data of Tables 3.12-6 and 3.12-3 on a same-group and different-group basis we have:

Group	TIC (sec)		Same Group Difference (sec)
	TIC Fast Runs* (4 & 5) Table 3.12-3	TICnf Fastest Run Without Failure Table 3.12-6	
AB	126	129	-3
C	127	130	-3
Cs	123	127	-4
D	116	118	-2

For all groups the price paid in TIC for perfection (over that without regard to failure) was not high, being only a few seconds. The difference ranges from 2 seconds in Group D ( $\approx 2\%$ ) to 4 seconds in Group Cs ( $\approx 3\%$ ). The AB vs C comparison shows little difference between TIC and TICnf. In the Cs vs D comparison the Modified car advantage increases from 7 to 9 seconds. The 9 second difference is significant at the .01 to .05 level (p for the 7 second difference was .05 to .10). Thus, it would appear that the Modified car has the advantage over the Standard car both in TIC and TIC without failure.

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\* Without regard to failure.

### 3.13 Maximum Speed

One of the pieces of data taken was the instantaneous top speed anywhere in the course on any run. This speed almost always occurred towards the end of the course as the driver proceeded down the Exit Chute before applying the brakes.

The data, which were tabulated only for Groups A, C and D, show little difference between groups. The group means were:

<u>Group</u>	<u>Mean of Max. V</u>
A	55
C	55
D	57

Combining all data for the three groups (n = 64) results in:

Mean:	55.4 mph
Max:	62 mph
Min:	38 mph
S:	5.7 mph

### 3.14 Success-Failure Data

In Section 3.12 we examined the Time-in-Course data - in both the "without regard to failure" and the "without failure" cases. It was noted that in any one run seven failures were possible at most - corresponding to seven of the eight maneuvers for which cone violations were recorded. Thus, in all 5 runs 35 possible failures existed per subject. The maximum number of failures per group is  $35n$ , where  $n$  is the number of data points (for no lost data this is  $35N$ , where  $N$  is the number of subjects in the group).

Failure rate, in percent, is defined as the total number of failures divided by the total possible failures times 100. The overall failure rates by group are shown in Table 3.14-1.

TABLE 3.14-1  
OVERALL FAILURE RATES (ALL RUNS)

	AB	C	Cs	D
Overall Failure Rate (%)	7	8	10	9

The failure rates in Table 3.14-1 are for all runs - without regard to Time-in-Course; as can be seen, there is no marked difference among the groups.

Table 3.14-2 gives the First Run/Fastest Run failure rates, by group.

TABLE 3.14-2  
FAILURE RATES - FIRST RUN/FASTEST RUN

<u>Failure Rate (%)</u>	<u>Group</u>			
	<u>AB</u>	<u>C</u>	<u>Cs</u>	<u>D</u>
<u>1st Run:</u>				
Mean	6.0	4.0	5.7	2.9
Max.	42.9	42.9	42.9	14.3
Min.	0	0	0	0
S	10.4	10.5	13.0	5.9
n	50.	25.	15.	15.
 <u>Fastest Run</u>				
Mean	10.0	9.1	11.4	14.3
Max.	71.4	57.1	57.1	42.9
Min.	0	0	0	0
S	17.9	13.6	15.5	14.3
n	50.	25.	15.	15.

The t-test data for Table 3.14-2 are:

	<u>Comparison</u>	<u>df</u>	<u><math>\bar{y}_1 - \bar{y}_2</math></u>	<u>t-value</u>	<u>Significance</u>
1st Run	AB vs C	73	2.564	0.780	.4 < p < .5
	Cs vs D	28	3.691	0.774	.4 < p < .5
Fastest Run	AB vs C	73	4.076	0.211	.8 < p < .9
	Cs vs D	28	5.437	0.526	.6 < p < .7

As the t-test data show, the differences between the group means for either the first run or the fastest run are not particularly significant. In the case of the first runs the raw data differences are appreciable but they are due to failures of a minority of subjects - 15 of 50 in Group AB and 4 of 25 in Group C, for example.

The fastest run failure rates are appreciably higher than the first run failure rates - showing the price paid for increased speed (i. e., lower TIC). However, since the levels of significance are very low this cannot be attributed to either familiarity or car type (Standard or Modified).

Another way to look at the overall data is failure rate by task. The results are shown in Table 3.14-3.

TABLE 3.14-3  
FAILURE RATES BY TASK - ALL RUNS

<u>Task</u>	<u>Percent Failures</u>			
	<u>AB</u>	<u>C</u>	<u>Cs</u>	<u>D</u>
Off-Road Recovery	6.4	8.0	8.0	4.0
Large Radius Arcs	2.0	2.4	5.3	1.3
Avoidance Maneuver	10.4	8.8	10.7	8.0
Gravel Turn	0.4	0.8	1.3	0
Wet Surface	16	22	25	28
Ess	7.2	7.2	10.7	9.3
Small Radius Arc	6.8	6.4	8.0	5.3

As might be expected the Wet Surface task gave the subjects the most trouble. The Avoidance Maneuver and Ess turn rank next in "difficulty", followed by the Small Radius Arc and Off-Road Recovery tasks. The Large Radius Arcs and the Gravel Turn apparently gave the subjects the least trouble.

It is difficult to come to any firm conclusions based on the overall failure rates - without regard to Time-in-Course. For example, in the Avoidance Maneuver and the Small Radius Arc the Group AB failure rates are higher than the Group C failure rates but in all other tasks Group C is higher (they are equal in the Ess turn).

As for the Cs and D groups all of the failure rates are higher in Group Cs than in D except for the Wet Surface task.

In order to deal with the overall failure rate data (i. e. all five runs) in a satisfying way one would probably have to go into a detailed statistical analysis - taking Time-in-Task and Time-in-Course into account. This is one of many ways in which the data of this program might be analysed in the future to extract more information than will be gained in the limited effort of this program.

For the present, however, we can concentrate on the "fast run" data - runs four and five.

We have already seen that insofar as TIC is concerned there is little difference between Groups AB and C (see, for example, Figure 3.12-1 in Section 3.12). It should be of interest, then, to compare the failure rates of these two groups as a function of time-in-course. This is shown in Figure 3.14-1. The fraction yielding the failure rate in this figure is the total number of task failures divided by the total number of task exposures. For example, the grand total of task exposures (assuming no data loss) in Group AB is 50 subjects times 2 runs per subject times 7 tasks per run, or 700. Note that for either group if no runs were made in a given time bracket the failure rate is not zero - there is simply no entry.

The mean value of the fastest run without failure for both groups (AB and C) falls within the 126-130 second bracket; it is shown in the figure for reference.

The total number of runs, for both groups, in Figure 3.14-1, is 148 (representing  $148 \times 7 = 1036$  exposures to tasks). Of these runs 31 fell outside of the 136-140 second time bracket. If the one run in the 141-145 second time bracket is ignored it is seen that no significant failure rate occurs beyond a time-in-course of 136 seconds.

The data to the left of the line marking the 106-110 second (or lower) time bracket contains 19 runs. In this region the C group shows up better than the AB group but it should be noted that the high failure rate of the AB group in the 106-110 second time bracket was primarily due to two subjects (out of 7) who, together, contributed more than half the failures.

In the middle region (111 to 135 seconds) where the bulk of the runs occur it is difficult to decide which group is "better" - the numbers next to the symbols in this region are the number of runs in the given time interval. In the region from 121 to 135 seconds - near the mean value of the fastest run for both groups - the C group subjects had 68% of their middle region runs (i. e. 23 out of 34) whereas the AB group subjects had only 44% of their middle region runs. In other words, the C group occupied the slower part of the middle region more frequently but had higher failure rates in that region.

In the faster part of the middle region, from 111 to 120 seconds, the C group subjects took 32% of their middle region runs (i. e. 11 out of 34) whereas the AB group subjects took 56% of theirs (i. e. 36 out of 64). But, here, the AB group has the higher failure rates.

From these data we are unable to conclude anything decisive about the influence of familiarity with the test vehicle on failure rates.

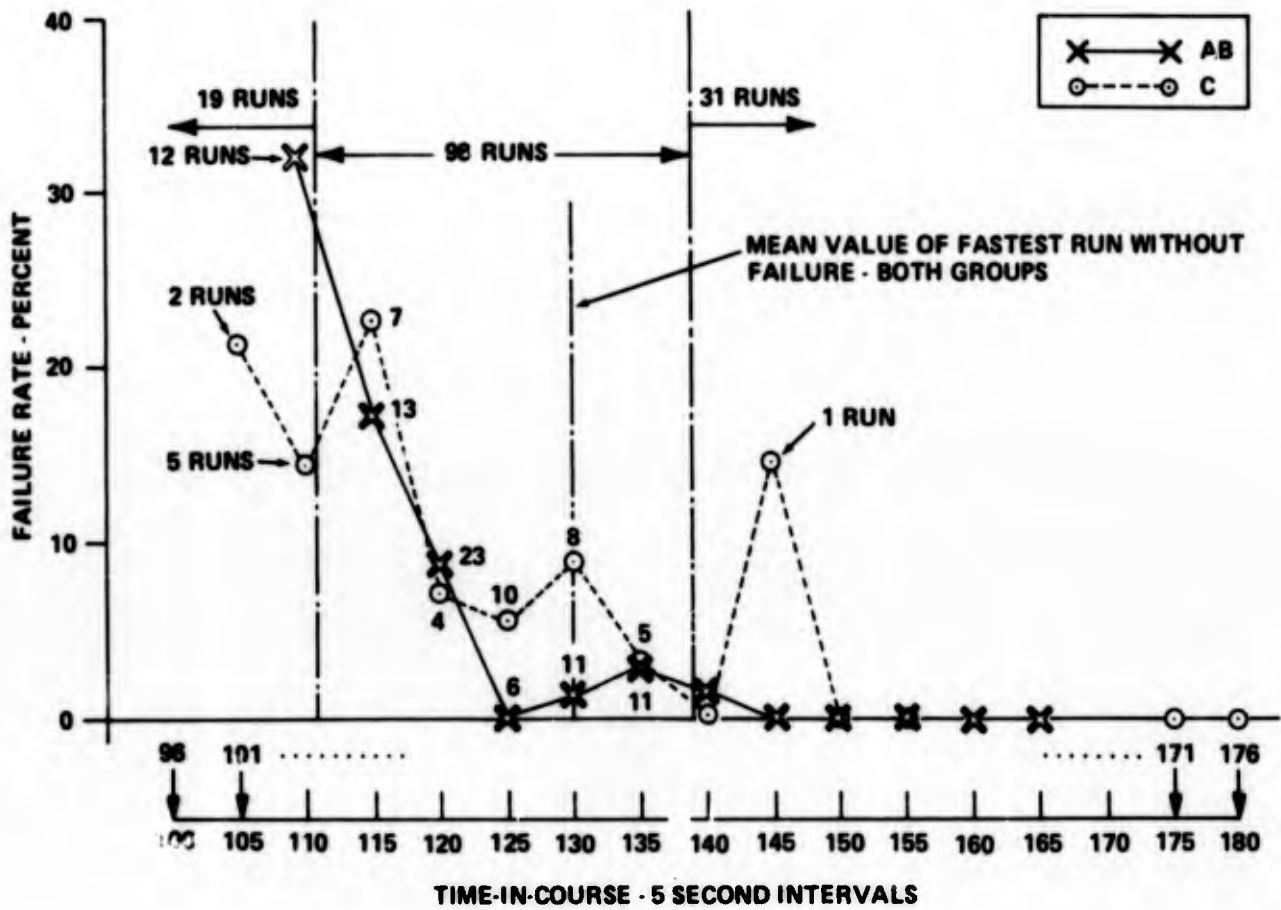


Figure 3.14-1 FAILURE RATE VS TIME-IN-COURSE (RUNS 4 AND 5) GROUPS AB AND C

Failure rate as a function of time-in-course for the Group Cs and D "fast" runs (runs 4 and 5) are plotted in Figure 3.14-2. For the 30 subjects in these two groups there were 59 usable runs, yielding  $59 \times 7 = 413$  task exposures.

As can be seen in the figure the failure rate for both groups is zero at or above a TIC of 131 seconds - however there were only 7 runs taken at or above that time.

At the low end of the scale there were only 6 runs taken in the 101 - 105 second bracket (or lower); one of these runs produced the entire Group D 28.5% failure rate and can be discarded. Again, the numbers next to the symbols are the number of runs taken in a given time interval.

The bulk of the runs were taken between 111 and 130 seconds; in this region there appears to be a marked difference in failure rates but the Group Cs 29% rate in the 111-115 time bracket is produced largely by 1 subject (out of 3) who committed 80% of the total failures; without this subject the failure rate would be under 10%. It will be recalled that the frequency distribution (Figure 1, Section 3.12) for the Cs and D groups were not alike - as was the case with the AB and C groups. Hence, a direct comparison between failure rates for a given TIC is complicated by the fact that the frequency of occurrence at that TIC is quite different for the two groups (i. e. , Cs and D).

Setting aside this difficulty, the figure does show that the D group subjects (Modified Car) tended to frequent the faster side of the middle region more than the slower side (17 runs to the left of the 121-125 second interval, 5 to the right). The Cs groups - Standard Car is balanced (12 to the left, 12 to the right).

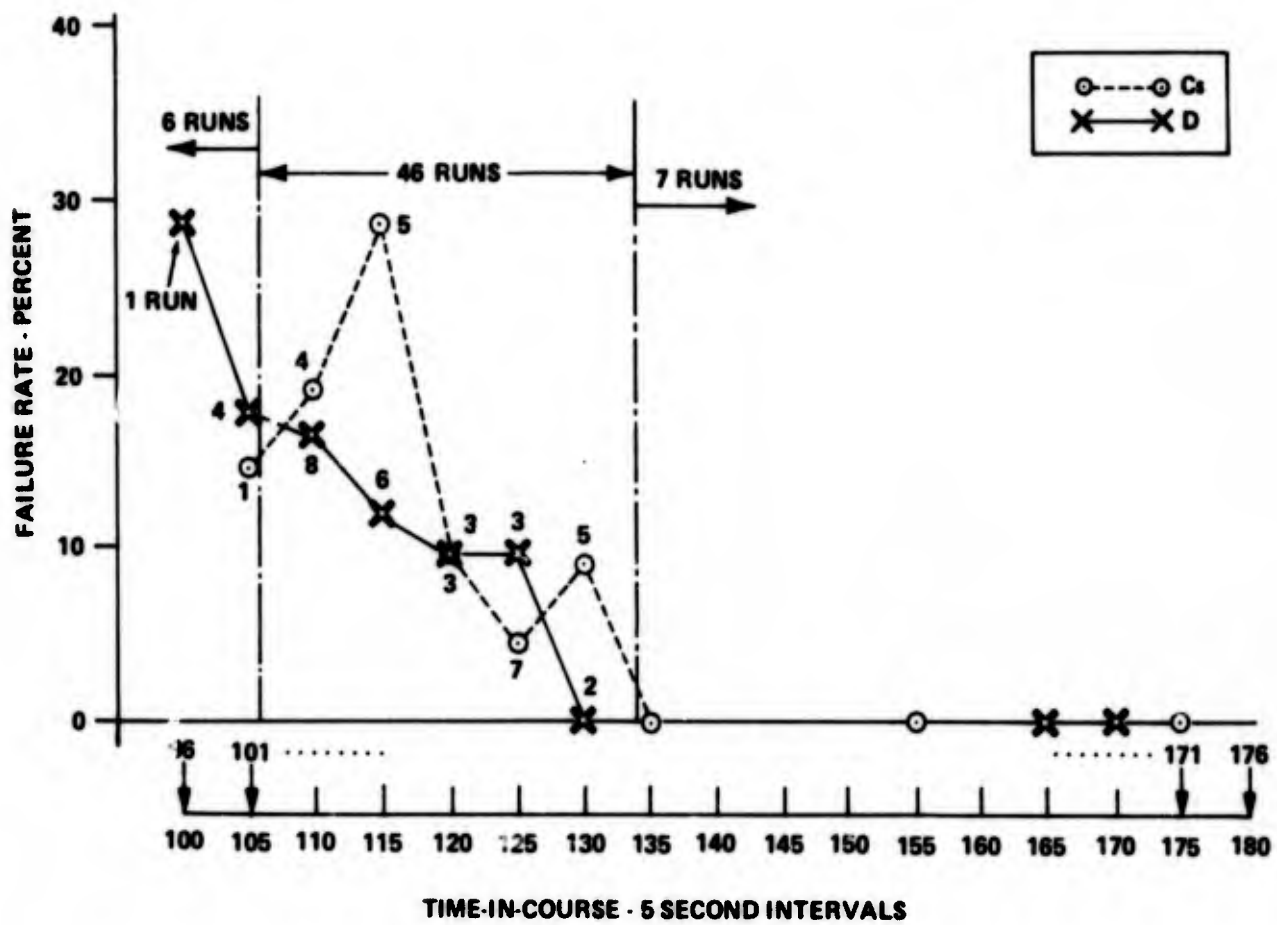


Figure 3.14-2 FAILURE RATE VS TIME-IN-COURSE (RUNS 4 AND 5)  
GROUPS Cs AND D

If one is willing to concede that the failure rates in the middle region are about the same for the two groups it follows that the Group D subjects tended to go through the course faster than the Groups Cs subjects for "equal" failure rates; this tendency is in the same direction as the fastest run without failure data of Table 3. 12-6, Section 3. 12 - where the mean TIC nf for Group Cs was 127 and that for Group D was 118 sec.

### 3.15 Selected Comparisons by Age and Sex

Given the wealth of data accumulated during the program there are a large number of comparisons that could be made of performance as a function of some driver characteristic. In this section we will examine a few of the performance parameters treated earlier as a function of age and sex of the subjects.

For these comparisons we will use the pooled data for Groups AB and C since these groups were structured in the beginning to be as nearly alike as possible with regard to the age, sex, and driving experience factors.

#### Fastest Run Without Failure

The fastest run without failure for Groups AB and C, broken down by sex and by age bracket is shown in Table 3.15-1.

The comparison by sex only shows a large (14 second) difference between means of males and females. The comparison by age only indicates that the young group is not the "boldest"; the more experienced group (25 - 44) drove the course 5 seconds faster. The least young group, while more experienced, was apparently more cautious than the other two.

The t-test data for Table 3.15-1 are:

<u>Comparisons</u>	<u>df</u>	<u><math>s \bar{y}_1 - \bar{y}_2</math></u>	<u>t-value</u>	<u>Significance</u>
Males vs Females	68	2.792	5.015	$0 < p < .001$
Young vs Less Young	39	3.487	1.147	$.2 < p < .3$
Less Young vs Least Young	54	3.738	2.140	$.02 < p < .05$

The male-female difference is highly significant. Also, an F-test comparing the difference among means of the three age-bracket groups shows significance at the .05 level.

TABLE 3.15-1

FASTEST RUN WITHOUT FAILURE  
(SEC) - BY SEX AND AGE  
Groups AB and C (pooled)

	<u>By Sex</u>		<u>By Age</u>		
	Males	Females	16-24 yrs. (young)	25-44 yrs. (less young)	45 and over (least young)
Mean	123	137	130	125	133
Max.	165	172	165	158	172
Min.	107	110	107	110	112
S	10.3	13.4	13.8	11.5	15.2
n	4J.	30.	14.	27.	29.

If the fastest run without failure data are ranked with respect to age and sex Table 3.15-2 results (n = number of runs)\*.

TABLE 3.15-2  
FASTEST RUN WITHOUT FAILURE  
GROUPS AB AND C (POOLED)

<u>Group</u>	<u>Mean TIC (seconds)</u>	<u>n</u>
Female - 45 and over	145	12
Female - 25 - 45 yrs.	132	12
Female - 16 - 24 yrs.	131	6
Male - 16 - 24 yrs.	129	8
Male - 45 and over	124	17
Male - 25 - 44 yrs.	119	15
Experts (Standard car)	106	7

If, in spite of the small sample size, we accept the data for the young female and young male groups they show little difference - and both are "slower" than the two older male groups. The largest group difference is at the top of the table - 13 seconds between the females over 45 and the next ranking group.

#### Failure Rates

For these comparisons we will use the "fast run" data - the fourth and fifth runs. The overall comparison by sex and age is shown in Table 3.15-3; n is the number of exposures to the seven tasks previously enumerated.

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\* In this and the remaining comparisons t-tests were not made owing to the small sample size of some of the sub-groups.

TABLE 3.15-3  
FAILURE RATES BY SEX AND AGE (RUNS 4 & 5)  
GROUPS AB AND C (POOLED)

	<u>Failure Rate (percent)</u>	n
Females	4.1	420
Males	12.3	616
Difference	8.2	
16-24 yrs.	16.8	196
25-44 yrs.	9.8	441
45 and over	4.0	399

As can be seen from the table the TIC "advantage" of the male subjects over the female subjects is compensated for by a much lower failure rate for the females.

In the next table these failure rates are ranked by sex and age group and compared with TIC for runs 4 and 5.

TABLE 3.15-4  
FAILURE RATES AND TIC BY AGE AND SEX  
GROUPS AB AND C (POOLED)-RUNS 4 AND 5

	<u>Failure Rate (Percent)</u>	<u>n<sub>1</sub></u> <sup>*</sup>	<u>Mean TIC (Seconds)</u>	<u>n<sub>2</sub></u> <sup>*</sup>
Male: 16-24 yrs.	23.2	112	117	16
Male: 25-44 yrs.	13.9	273	115	39
Female: 16-24 yrs.	8.3	84	129	12
Male: 45 and older	5.2	231	124	33
Female: 25-44 yrs.	3.6	168	132	24
Female: 45 and older	2.4	168	148	24

\* n<sub>1</sub> = number of exposures to tasks

n<sub>2</sub> = number of runs

Note that there is a pronounced inverse ranking between failure rate and TIC. The very high failure rate of the 16-24 yr. males is due primarily to one subject (out of 8) who committed 30% of the group's failures and whose mean TIC ( for the 4th and 5th runs) was 108 sec. - i. e. - 4 sec. faster than the group mean and not far from "expert" driver TIC. In other words, this one subject paid the price of a 50% failure rate to achieve the low TIC. Without this one subject the group's failure rate goes down to about 10.2%.

Similarly, if one subject (out of 6) in the 16-24 yr. female group, who committed 4 failures out of a total of 7 for the group, is removed the group failure rate goes down to about 5%.

The data of Table 3.15-4 are shown graphically in Figure 3.15-1. The problem of "extreme value" subjects (the two mentioned above) and how they greatly influence results for small sample sizes is seen by the shifts produced by their removal. If one were to remove these two subjects from the 75 subject sample the ranking by group on a scale of "boldness" - i. e. - achieving low TIC and taking failures would be:

25-44 yr males  
16-24 yr males  
45 and older males  
16-24 yr females  
25-44 yr females  
45 and older females

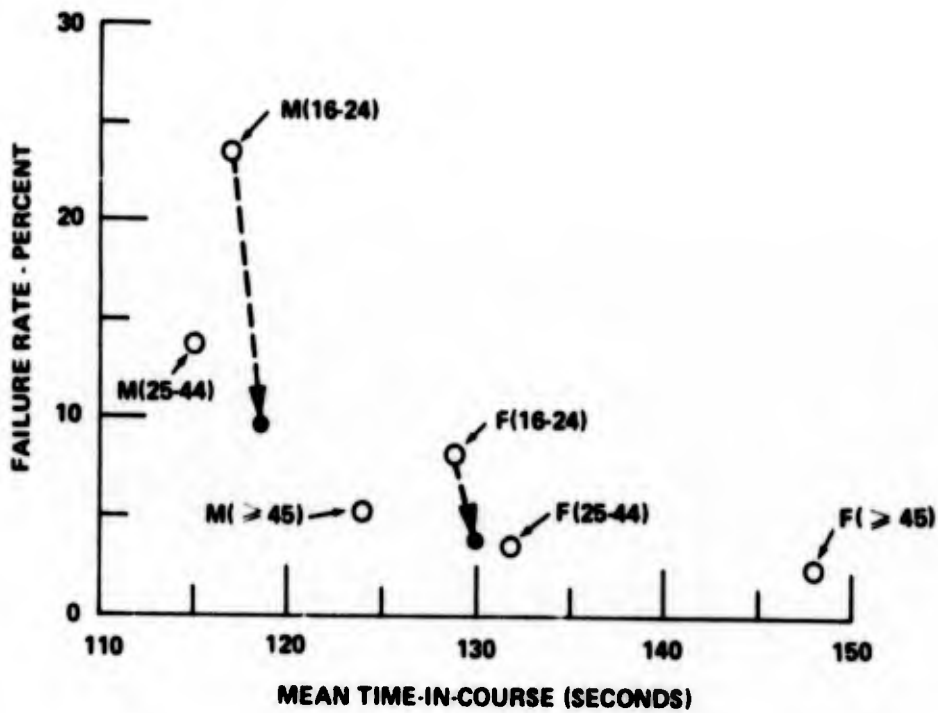


Figure 3.15-1 FAILURE RATE VS TIME-IN-COURSE BY AGE & SEX - GROUPS AB AND C (POOLED) RUNS 4 AND 5

### 3.16 Subjective Driver Data

One of the statistics of interest that was collected was driver self-rating. Each subject rated himself before going through the course; the data were collected from Item 2 of Appendix II - "CAL Driver Measurement - Information Form" - and are tabulated by subject in Appendix I.

Self-rating results are summarized in Table 3.16-1.

The data show that among women drivers in the 90 subject test sample about 79% considered themselves average drivers and 21% considered themselves above average. Among the males in the sample about 45% considered themselves average while a majority, 54%, considered themselves above average.

When the 18 residual subjects are thrown in with the test sample, making for 108 subjects in all, the percentages are about the same. It is interesting to note that in the 108 subject sample only one considered himself below average.

Of equal interest is how the two test observers rated the subjects; this information is given in Table 3.16-2.

The observers were given a 5-number rating scale - number one being the highest rating and number five the lowest. They rated the subjects immediately after the test without any knowledge of quantitative performance, except for time-in-course (which they measured and recorded) and any cone violations that they might have noted. Their rating was entirely subjective and was based, in part, on success or failure in the various incidents and maneuvers but also on their assessment of the subject's driving skill and on the degree of improvement in performance as the subject progressed from Run 1 through Run 5.

TABLE 3.16-1

DRIVER SELF-RATING BY SEX

Self-Rating	A		B		C		Group D		All		All (%)		All (%)*	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F
	7	0	9	3	8	4	6	0	30	7	54	21	54	19
Better than Average	7	0	9	3	8	4	6	0	30	7	54	21	54	19
Average	7	10	6	7	7	6	5	4	25	27	45	79	45	81
Less than Average	1	0	0	0	0	0	0	0	1	0	1	0	1	0
	15	10	15	10	15	10	11	4	56	34	100	100	100	100

\* With 18 residual subjects included (65 males, 43 females)

TABLE 3. 16-2  
OBSERVER RATING OF SUBJECTS

<u>Rating</u>	<u>Group</u>					<u>All (%)</u>	<u>All (%)</u> *
	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>All</u>		
1	1	0	0	1	2	2	2
2	6	7	6	5	24	27	25
3	16	13	16	9	54	61	62
4	2	5	2	0	9	10	10
5	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>1</u>
n =	25	25	24 <sup>(1)</sup>	15	89	100	100

\* Including 18 residual subjects

(1) Observer rating was lacking in one instance

As the program progressed the two test observers found themselves shading the 5-point scale - i. e. - using in-between ratings. In order to keep matters as uncomplicated as possible we have not shown the expanded scale but, instead, have compressed it back to a 5-point scale - on a linear basis. In words, the 5-point scale can be read as: 1 = very good, 2 = good, 3 = average, 4 = poor, 5 = very poor.

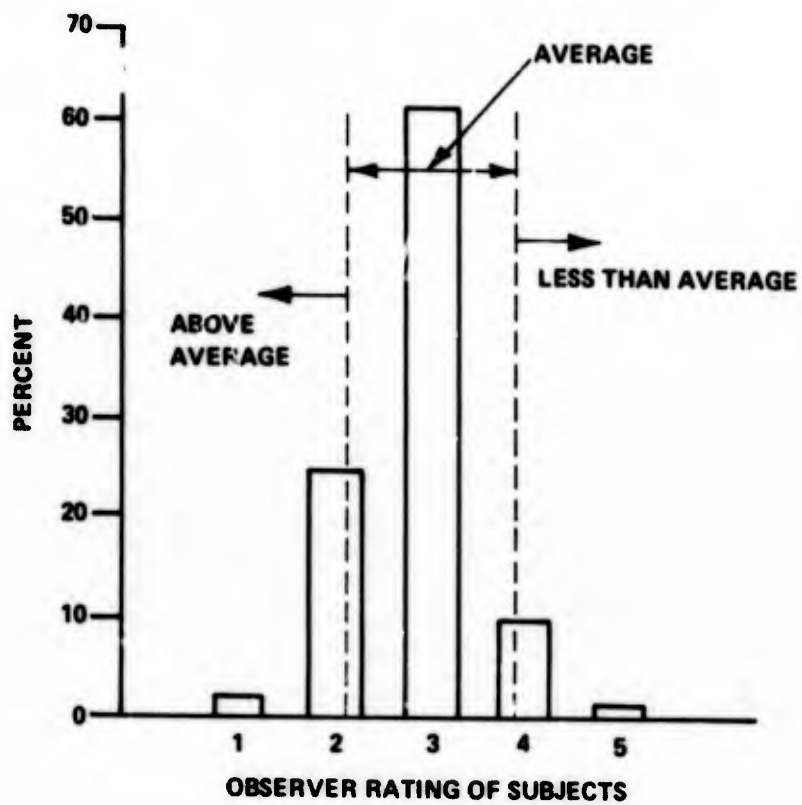
The authors are well aware of the pitfalls in the use of subjective rating scales. For one thing, one might question the "qualifications" of the two test observers to rate the subjects. The following information may be of help to the reader in answering this question himself.

Both observers were experienced automobile test technicians and highly skilled drivers - their ability to traverse the test course, in terms of time-in-course without failure, approached that of the two expert drivers used in the program (see Section 2.4.3). In other words, they were able to take maximum advantage of the capabilities of the test vehicles.

In addition, the observers and the project engineer had had several discussion sessions in which they attempted to get agreement among themselves on what to look for in rating the subjects. Finally, the test observers did have the advantage of having gone through the testing and rating process before testing the first subject of the 90-subject sample; prior to that, 5 subjects were tested in a procedures shakedown program and an additional 12 were tested before the course was changed slightly and the program started over again.

Returning to Table 3.16-2 it is seen that there is not much difference in observer ratings between the 90-subject test sample and the same sample with the 18 residual subjects added.

The histogram of Figure 3.16-1 shows the distribution of observer ratings pictorially. The figure suggests that the observer ratings may be biased toward the high side. On the other hand, we cannot conclude that it is a true bias since we do not know what this distribution looks like in the driving population.



**Figure 3.16-1 OBSERVER RATING OF 107 SUBJECTS**

The dotted lines in Figure 3.16-1 show the approximate relationship between the 5-point rating scale used by the test observers and the 3-point scale used by the subjects in rating themselves.

In Table 3.16-3 a comparison between subject self-rating and observer rating is given. In the 89 subjects (out of the 90-subject test sample) for which information was available the observer and subject were in agreement 54% of the time. Drivers rated themselves lower than the observers only 11% of the time and higher than the observers 35% of the time. If the 18 residual subjects are thrown in with the test sample the percentages change very little - being 54%, 9% and 37%, in the order given above.

If the test observer ratings are taken as "true", the fact that the drivers rated themselves lower than the observers rated them only 9% of the time but, in contrast, rated themselves higher than the observers rated them 37% of the time would indicate that the self-ratings of Table 3.16-1 are biased towards the self-serving side. The data are not broken down by sex in Table 3.16-3 but if this is done the results are - for the sample that includes the 18 residual subjects:

TABLE 3.16-4  
COMPARATIVE RATINGS BY SEX

	<u>Male</u>	<u>Female</u>
Self-Rating Higher than Observer Rating	42	28
Self-Rating Lower than Observer Rating	13	5
Self-Rating Same as Observer Rating	<u>45</u>	<u>67</u>
	100	100

It would appear then that the female self ratings tended to agree more closely with the observer ratings.

Other subjective data of interest in Table 3.16-3 include:

TABLE 3.16-3  
OTHER DRIVER SUBJECTIVE DATA

	Group							All* All (%)	All* All	All* All (%)
	A	B	C	D	All	All (%)	All			
Self-Rating Higher than Obs. Rating	6	12	9	4	31	35	39	37	37	
Self-Rating Lower than Obs. Rating	5	2	2	1	10	11	10	9	9	
Self-Rating Same as Obs. Rating	14	11	13	10	48	54	58	54	54	
Right Foot Braking	17	20	19	10	66	75	80	75	75	
Left Foot Braking	8	5	5	4	22	25	26	25	25	
Wore Shoulder Harness	5	2	8	3	18(1)	20	24(2)	22	22	
Answer to Question:										
Yes	6	11	3	1	21	23	27	25	25	
No	19	14	22	14	69	77	81	75	75	

The course emphasized handling at moderate speeds. At these speeds have you ever driven a car harder?

\* 18 residual subjects added to All column of groups

(1) n = 90

(2) n = 108

### Braking

This information was recorded by the test observers. As can be seen in the table a clear majority - 75% - used right-foot braking. It was not possible to pursue further the question of braking activity - for example - to seek out a possible correlation between performance and left/right foot braking.

### Shoulder Harness

Although the subjects were asked to use the test vehicle lap belt they were given the option of using or not using the shoulder harness available in each test vehicle. As can be seen in Table 3.16-3 only 20% of the 90 subjects in the test sample chose to use the shoulder harness; this figure is not much different - 22% - if the 18 residual subjects are added to the test sample.

Finally, the first question asked of each subject in the Post- Experiment Questionnaire\* was: "The course emphasized handling at moderate speeds. At these speeds have you ever driven a car harder?" The question was designed to provide some indication on whether the subjects had pushed themselves to their limit of willingness in the test course. As shown in Table 3.16-3 77% of the test sample of 90 and 75% of the total sample, including the 18 residual subjects, responded in the negative. Thus, for most of the subjects their test course driving represented their "hardest" driving experience.

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\* See Appendix II.

### 3.17 Lateral Acceleration vs Speed

One of the goals of the experimental program was to obtain data on the lateral accelerations utilized by the subjects in cornering maneuvers. The driving course incorporated five incidents of somewhat different character calling for cornering at quasi-steady state conditions - (1) the Large Radius Arcs, (2) the First Chute turn, (3) the Small Radius Arc, (4) the Exit Chute turn, and (5) the Gravel Turn.

Unfortunately, it was not possible to arrange a course over the existing facilities which permitted a wide range of operating speeds for the average driver and also included a reasonable number of challenging driving situations. Although speeds ranged from about 25 mph to 50 mph in these maneuvers, operating constraints imposed by the sequence of the events did not permit full freedom of the subjects to employ any speed they chose to attempt.

In examining the test data from this program in this light, it is apparent that more stylized test procedures than used here would be helpful in order to obtain data on lateral acceleration - velocity interaction over a wide speed range. One approach might be to have each driver turn the tightest corner which he is willing to try at several speed levels without any constraint. <sup>(1)</sup> Nevertheless, results from this work produced a solid basis for evaluating limit-of-willingness behavior in the moderate speed range (from 25 to 45 mph).

In the following figures, the raw  $\bar{A}_y - \bar{V}$  data for the Best Successful Run were fitted with a linear least squares curve for each of the above five tasks. A quadratic fit would have been more in consonance with the nature

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(1) Another would be to have the drivers go through a series of delineated constant radius arcs, of progressively increasing radius, at maximum willing speed.

of the maneuver paths (roughly circular) but since the speed ranges of interest were not large, except for extremes, a linear fit was felt to be adequate for showing  $\bar{A}_y - \bar{V}$  trends. Figure 3.17-1 is for the pooled data of Groups AB and C (75 subjects in the Standard car); Figure 3.17-2 is for the 15 subjects of Group D (Modified car).

The figures provide a graphic representation of the information given earlier in tabular form. It is seen that although the speed ranges, minimum to maximum, of the AB + C vs D groups are about the same the mean  $\bar{A}_y$  and  $\bar{V}$  are higher for the Modified car drivers - as was indicated previously in the tabulated data.

Concentrating on the larger sample (Figure 3.17-1) it is apparent that on the average the drivers were willing to use lateral accelerations of about 0.4g over a speed range of 25 - 40 mph. The small group (Figure 3.17-2) used somewhat higher lateral accelerations - roughly .45g over the range of 25 - 45 mph. In making these observations the curves for the First Chute have been neglected because of suspected influence of the preceding task (the Avoidance Maneuver) and the following task (the Gravel Turn) on behavior in this maneuver. This supposition is supported by the data of the expert drivers who operated at about .6g in the other maneuvers but at only .4g in the First Chute. Nevertheless, it is interesting to note that at the higher speeds used in this task, the mean lateral acceleration value of all groups is lower than it is for the other maneuvers.

The linear regression lines fit the data reasonably well. Correlation coefficients for the Small and Large Radius Arc maneuvers were somewhat higher than those for the other tasks, reflecting the reduced spread of speed used in these maneuvers as well as their more tightly constrained paths. (It will be remembered that 12 ft. wide cone-delineated lanes were used in these maneuvers whereas the chute turns were unmarked except by the paved surface; the Gravel Turn was loosely defined by a 20 ft. wide lane.)

MANUEVER	LINE CODE	$\bar{V}$	$\bar{A}_y$
GRAVEL TURN	—————	22.7	.37
SMALL RADIUS ARC	- - - - -	30.6	.41
LARGE RADIUS ARCS	—————	30.9	.40
EXIT CHUTE	- - - - -	40.0	.39
FIRST CHUTE	· · · · ·	43.0	.28

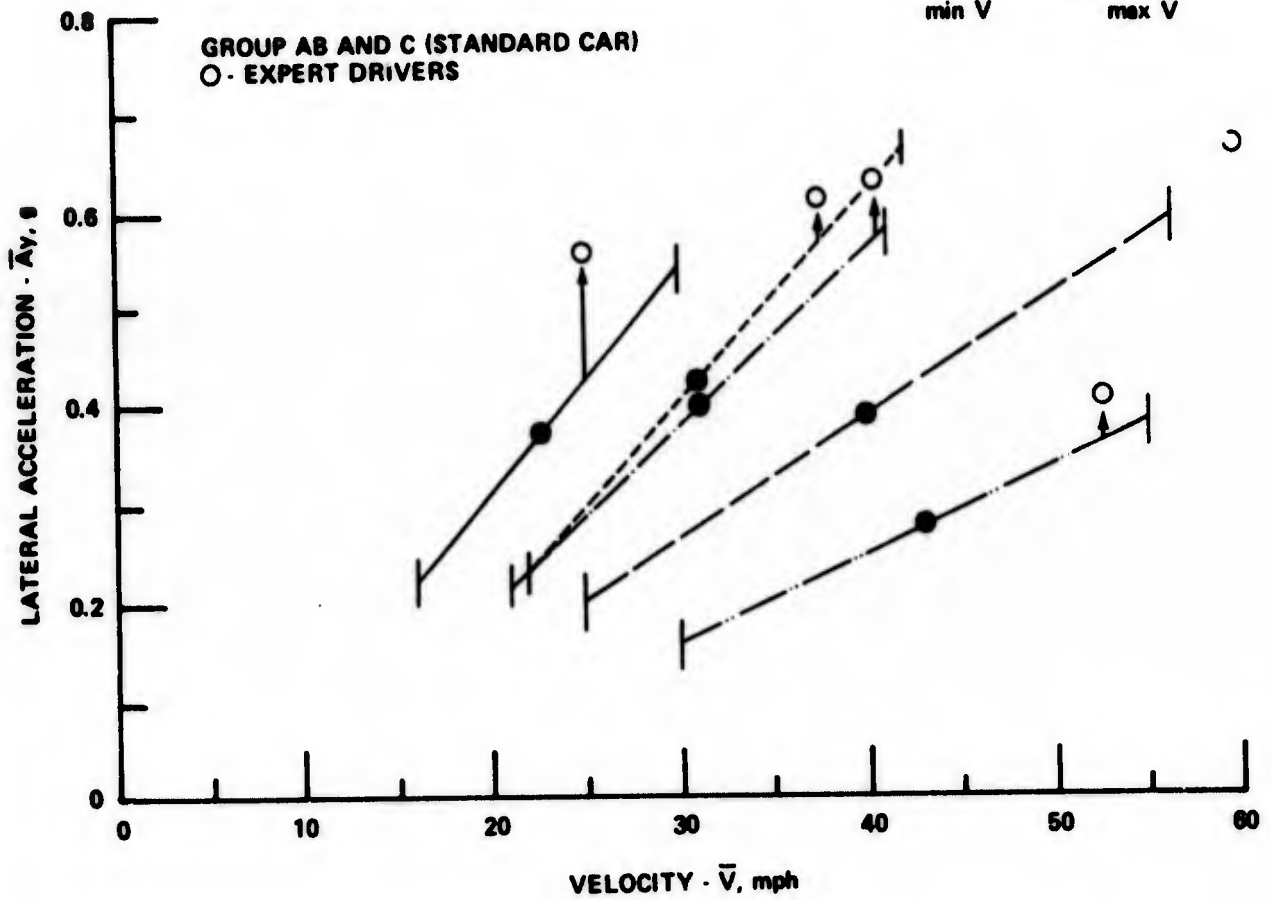
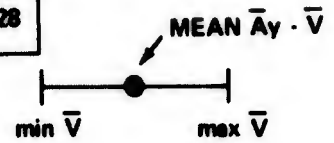


Figure 3.17-1 LATERAL ACCELERATION vs SPEED

MANUEVER	LINE CODE	$\bar{V}$	$\bar{A}_y$
GRAVEL TURN	—————	25.2	.45
SMALL RADIUS ARC	- - - - -	34.7	.52
LARGE RADIUS ARCS	- · - · - ·	34.9	.48
EXIT CHUTE	—————	44.5	.44
FIRST CHUTE	- · - · - ·	46.3	.28

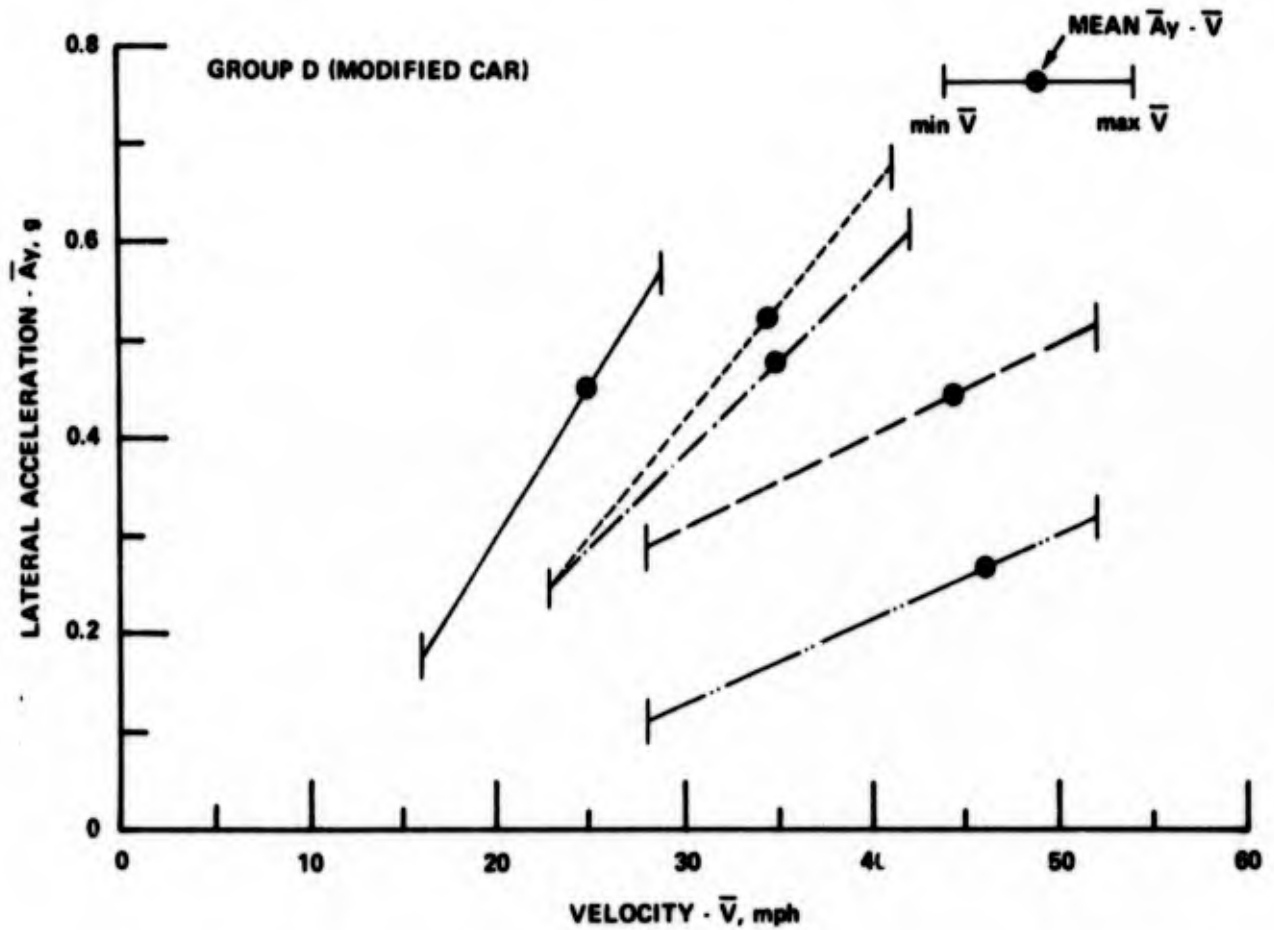


Figure 3.17-2 LATERAL ACCELERATION vs SPEED

In Figure 3.17-1, the mean values of the performances by the "Expert" drivers have also been shown. The points fall near the maximum values achieved by the test sample drivers. The large departure of the expert's point from the regression line for the Gravel Turn suggests that these drivers ran a much tighter arc through this maneuver. They also were traveling at higher speeds in the Exit Chute, indicating that they delayed braking to stop at the finish line until somewhat later in the maneuver.

The figures also provide a good check on operation at about 30 mph. The Small Radius Arc was a constant 150 ft. radius circular arc about 500 feet in length. \* The drivers tended to perform this 10-12 second maneuver by holding lateral acceleration nearly constant at whatever value they chose to use. The Large Radius Arcs maneuver, on the other hand, was in reality a tightening spiral (from a straight) followed by an expanding transition to a short stretch of a constant 200 ft. radius arc. This maneuver is also of extended duration and the  $\bar{V}$  and  $\bar{A}_y$  metrics are average values for the whole period. The fact that the mean performance for this maneuver ( $\bar{V} = 30.9$  mph;  $\bar{A}_y = .40g$ ) is so close to that for the Small Radius Arc ( $\bar{V} = 30.6$  mph;  $\bar{A}_y = .41g$ ) as, in fact, are the complete regression lines, Figure 3.17-1, suggests that the constant radius equivalent of the Large Radius Arcs is about the same as for the Small Radius maneuver. This is supported by the data of the expert drivers. Thus, in different but nearly equivalent maneuvers, the subjects reinforced the preference for using about .4g lateral acceleration at about 30 mph.

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\* For this radius, a speed of 30 mph would produce a lateral acceleration of .4g. The linear fit through the data over the range of 25 to 40 mph is an excellent approximation to the parabolic curve for this maneuver. This observation also speaks well for the accuracy of the raw data.

If there is a single trend in these data it would appear to be that in the context of this experiment the drivers were willing to take lateral accelerations of about 0.4g over the tested speed range - from roughly 20 - 45 mph. Put another way - they were willing to go faster as the maneuvers opened up but were not willing to expose themselves, on the average, to lateral accelerations much higher than 0.4g.

### 3.18 Steering Rates

The experimental data provides a rich store of information on the steering wheel rates employed by drivers when operating under conditions similar to those imposed by this driving course. No attempt has been made to analyze these data in detail. Specific observations of the steering rates employed by approximately 30 subjects in the Standard vehicle in the Avoidance Maneuver have been made and, where appropriate, the rates utilized in control recovery attempts (usually associated with the Avoidance Maneuver, Wet Surface, and Surprise Intrusion) have been noted. These latter data are of special interest. The average maximum steering rates used by the subjects in successful transitions through the avoidance maneuver is approximately 520 deg/sec. This value is associated with an average maximum value of lateral acceleration of .46g in the maneuver. The expert drivers successfully performed this maneuver at about .6g, applying average steering rates of 800 deg/sec. In seven unsuccessful attempts, the subjects averaged over 850 deg/sec for steering rate input, indicating a capability to apply high rates but not the ability to utilize them successfully. The lack of correlation between maximum and minimum steering rate values and lateral accelerations is indicative of the variation in the tracks used by the different subjects to get through the maneuver.

In 11 additional observations of failures in various maneuvers, steering rates exceeded 1000 deg/sec on 6 occasions. On the other hand, there is evidence of only feeble attempts to utilize steering to avoid failure in several cases, so it is difficult to obtain firm values to define steering behavior without more detailed analysis of each individual situation. It is safe to say, however, that the average subject utilized steering rates of 500 deg/sec with success when required by the maneuver and that much higher rates (over 800 deg/sec) were applied under some conditions.

### 3.19 The Average Driver

Throughout the discussions of the results of the experimental work, we have attempted to present data in terms of group statistics and to show any trends or significant effects with respect to the influence of vehicle design and familiarity with the vehicle type on performance. The data may also be applied toward a characterization of the average driver - the Man-off-the-Street - and how the car's capabilities are utilized by this driver in performing driving tasks.

Taking the entire experimental sample of 75 subjects who drove the Standard vehicle, \* a profile of the average driver in this study can be developed; it covers three primary categories - demographic description, operating patterns, and performance characteristics. With respect to the first of these, our driver is 38 years old, has 19 years of driving experience, and drives an Intermediate or Full-size sedan. When asked to rate himself as a driver he will more than likely rate himself above average and very rarely below average.

#### Operating Patterns

This term is used to identify a set of habits and behavior patterns that provide a description of the average subject's approach to driving. In this respect, it is generally easier to give percentages of the sample who followed a specific pattern.

- 25% used their left foot for braking.
- 22% used the shoulder restraint for the experimental driving. (They were told that its use was optional.)

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\* The 75 subjects who make up Groups A, B, and C.

- 83% kept both hands on the wheel throughout the exercise. The most widely used patterns were the 10-2 and 11-1 o'clock positions. The one-handed drivers usually had their right hand at 12 o'clock in straight running.
- The average driver builds up confidence in his ability to handle a vehicle quite rapidly. Average speed in the course increased from 28 mph on first trials to 36 mph on fifth trials.

### Performance Characteristics

Combined results yield the following performance profile of the average driver:

- In the speed range of 25-40 mph, he will utilize lateral accelerations as high as .30g in steady state maneuvering in unfamiliar conditions.
- In this same speed range, he will increase the level of lateral acceleration utilized to .40g in steady-state over a familiar route.
- He is capable of effectively utilizing steering input rates of 500 deg/sec in maneuvers requiring rapid steering wheel motion.
- In hard controlled stops, he willingly uses deceleration of about .55g over periods of a few seconds.

- In dynamic driving maneuvers, he will utilize peak transient lateral accelerations about 20% higher than the steady state values.
- Even under the idealized safety conditions of this experiment, he operates his vehicle well below its cornering limit for dry roadway surfaces.
- He does not adapt his driving patterns to low coefficient of friction road surfaces (approximately 1/2 of the subjects failed at least one trial in the wet).
- He does adapt to an unfamiliar vehicle within a very short period for "normal" driving but not for abnormal circumstances (skidding situations).
- He willingly applies full throttle in a straight and in exits from turns.

#### 4.0 RECOMMENDATIONS

An extensive body of information on driver characteristics and capabilities has been collected during this program. Much of it has been discussed in appropriate sections throughout the report. For convenience, the major conclusions have been summarized in an earlier section and therefor will not be repeated here. We believe that the data analyses which have been performed and reported on are consistent with the goals set down initially. We recommend, however, that consideration be given to the additional potential of the data taken during this study.

Without going into extensive detail to describe additional analyses which could be made, the listing given below provides a general outline of other potentially useful studies.

- GMPG personnel have suggested that information on all subjects (background, operational characteristics, and performance capabilities) be cataloged and indexed to serve as a data bank for inquiries on various questions regarding driving habits.
- Performance envelopes (g-g diagrams) should be generated for each subject in the BSR trial and compared with the vehicle's envelope to obtain overall graphics of driver behavior patterns, margins of performance utilized, specific driver idiosyncracies, etc.
- Very little work has been done with the data with respect to learning patterns on a trial-by-trial basis. Results should be reviewed making more extensive use of intermediate trial results.

- We have analyzed only a small portion of the total amount of braking data collected. Some potential results of interest are determination of frequencies when pump-braking is employed, average pedal forces (or deceleration values) used for slowing a vehicle, possible correlation between speed and deceleration levels used at given speeds, general performance evaluations of left-footed brakemen as a group, etc.
  
- The experiments performed in this program were subject self-paced and therefore provide good "limit-of-willingness" data. With these results as background, task performance experiments, setting initial conditions beyond the self-determined willingness limits, could be devised to investigate driver behavior at or near the "limit-of-capability".
  
- The subjective and observational information collected should be examined in greater depth. This would reveal information on such subjects as attitudes on task difficulty and desirability of further training and identify additional groupings of interest (correlation of driving experience, use of shoulder restraint, or hand location on the steering wheel with performance, for example).

## APPENDIX I

### Description of the Driver Sample

A good deal of information about the subject drivers was obtained in the various forms and data sheets used in the program. Some of this information is presented in Tables I-1 through I-4 for the four subject groups. It will be recalled that the group characteristics were:

- Group A - 25 subjects who were judged to be familiar with the Standard test vehicle and who were tested in the Standard test vehicle.
- Group B - Same as Group A.
- Group C - 25 subjects who were judged to be unfamiliar with the Standard test vehicle and who were tested in the Standard test vehicle.
- Group D - Subjects who were tested in the Modified test vehicle. Because of the nature of the Modified test vehicle any subject who drove it was judged to be unfamiliar with it.

The various headings in the columns of Tables I-1 through I-4 are:

**Age:** - Age, rounded off to the nearest year, as stated by the subject or inferred from his operator license.

**Driving Experience:-** The number of years of driving experience as stated by the subject - rounded off to the nearest year except for those with less than one year of experience.

**Vehicle Exposure** - Data obtained from the subject on the vehicle he usually drove at the time of testing.

The size symbols are:

**F** = Full-size, wheelbases of 120" and over.

**I** = Intermediate-size; wheelbases from about 112" to 120".

**C** = Compact; wheelbases from about 103" to 111"

**S** = Sub-compact; wheelbases from about 79" to 103"

The subject's vehicles were categorized under Type into four groups:

**S** - Sedan

**W** - Station wagon

**M** - Multipurpose (e.g. Van, Jeep)

**C** - Convertible

The year and miles columns are the model year of the subject's vehicle and the estimated number of miles, to the nearest thousand, that the subject stated he drove the vehicle.

In the columns headed Steering and Brakes the symbols **P** and **M** stand for power (or power-assisted) and manual. In the Transmission column the symbols **A** and **M** stand for automatic or manual. Finally, in the column headed Driver Self-Rating the symbols **0**, **+**, **-**, stand for Average, Better than Average, and Less than Average; these are the answers given by the test subjects to question 10 in the pre-test information form - see Appendix II, item 2.

**TABLE I-1**  
**Subject Data Obtained From Pre-Test Questionnaire**  
**Group A - Familiar Car (Standard Test Vehicle)**

<u>Subject Identif. Number</u>	<u>Age</u>	<u>Sex</u>	<u>Driving Experience (Years)</u>	<u>Size</u>	<u>Type</u>	<u>Year</u>	<u>Miles</u>	<u>Steering</u>	<u>Brakes</u>	<u>Transm.</u>	<u>Driver Self-Rating</u>
07	31	F	15	/	S	70	35	P	M	A	+
11	46	F	25	C	S	70	8	M	M	M	0
14	60	F	25	F	S	72	4	P	P	A	0
17	34	M	17	I	S	64	50	M	M	M	0
19	23	M	8	S	S	72	5	M	M	M	-
20	25	M	9	C	S	69	35	P	P	M	+
24	21	F	3	I	S	71	1	P	P	A	0
28	32	M	15	I	S	69	56	M	P	M	+
35	18	F	0.5	I	W	65	0.5	M	M	A	0
40	30	M	14	F	S	73	1.5	P	P	A	+
44	26	M	9	I	S	72	/	P	P	A	0
45	67	M	38	I	S	69	55	P	P	A	0
46	25	F	7	I	S	69	45	P	M	A	0
49	52	M	35	C	S	65	25	M	P	A	0
51	23	M	7	I	S	67	60	M	M	M	+
55	57	M	40	C	S	70	10	P	P	A	0
58	34	F	17	I	S	72	3	P	M	A	0
59	45	M	29	I	S	73	2	P	P	A	0
61	32	M	15	C	S	65	40	M	M	A	+
72	25	F	7	I	S	68	47	P	M	A	0
74	25	F	10	I	S	70	20	P	M	A	0
93	57	M	41	F	S	68	40	P	M	A	+
96	53	M	38	F	S	67	30	P	P	A	0
99	17	M	0.1	I	S	64	0.1	P	P	A	+
105	54	F	30	I	S	73	6	P	M	A	0

TABLE I-2  
 Subject Data Obtained From Pre-Test Questionnaire  
 Group B - Familiar Car (Standard Test Vehicle)

<u>Subject Identif. Number</u>	<u>Age</u>	<u>Sex</u>	<u>Driving Experience (Years)</u>	<u>Size</u>	<u>Type</u>	<u>Year</u>	<u>Miles</u>	<u>Vehicle Exposure</u>	<u>Steering</u>	<u>Brakes</u>	<u>Transm.</u>	<u>Driver Self- Rating</u>
25	20	F	2	F	S	66	5	P	P	P	A	0
27	27	M	9	S	S	68	51	M	M	M	M	+
29	27	F	10	C	S	70	27	M	M	M	M	0
30	53	M	37	F	W	72	14	P	P	P	A	+
31	51	F	33	I	S	71	13	P	P	M	A	+
33	31	M	15	I	S	72	35	P	P	P	M	0
34	18	F	0.5	I	W	65	0.5	M	M	M	A	0
36	58	F	40	C	S	68	48	P	P	P	M	+
41	41	M	24	S	S	70	25	P	P	P	M	+
42	30	M	14	I	C	65	30	P	P	P	A	0
43	25	F	8	I	S	71	16	P	P	P	A	0
47	48	M	31	F	W	65	115	M	M	M	A	+
48	26	M	8	C	S	70	25	P	P	M	A	+
50	25	M	8.5	F	M	72	16	P	P	M	A	+
52	22	M	6.5	F	M	72	31	M	M	P	M	+
53	55	M	38	I	W	67	70	P	P	P	A	0
54	48	F	31	I	S	73	3	P	P	P	A	+
57	50	M	33	F	S	68	15	M	M	M	A	+
65	29	M	11	I	S	69	30	P	P	P	A	+
71	25	F	6	I	S	71	16	P	P	M	A	0
75	77	M	50	I	S	72	15	P	P	P	A	0
76	31	F	12	I	S	67	10	P	P	P	A	0
94	57	M	40	F	S	73	20	P	P	M	A	0
101	17	M	1	C	S	72	2	P	P	M	A	0
103	53	F	15	C	S	70	13	P	P	M	A	0

TABLE I-3  
 Subject Data Obtained From Pre-Test Questionnaire  
 Group C - Unfamiliar Car (Standard Test Vehicle)

Subject Identif. Number	Age	Sex	Driving Experience (Years)	Size	Type	Vehicle Exposure			Brakes	Transm.	Driver Self- Rating
						Year	Miles	Steering			
01	33	F	15	F	S	/	15	P	P	A	0
02	28	M	12	S	S	68	60	M	M	M	+
03	32	M	14	C	S	67	50	M	M	M	+
05	23	F	4	C	S	68	23	M	M	M	0
06	31	F	12	F	S	67	25	P	M	A	0
13	25	F	8	I	S	65	100	M	M	A	+
16	26	M	9	C	S	69	38	M	P	M	+
21	37	M	18	I	W	69	28	P	P	A	+
22	30	M	14	S	W	73	2	M	P	M	0
26	47	F	16	S	C	63	40	M	M	M	+
39	31	M	15	I	S	72	12	P	M	M	+
56	19	F	3	C	S	70	8	P	M	A	+
62	55	F	24	C	S	71	6	M	M	A	0
63	48	M	26	S	S	70	28	M	P	M	0
64	17	M	1	S	W	68	1	M	M	A	0
66	35	M	18	F	M	69	43	M	M	A	0
68	53	F	37	F	S	70	20	P	P	A	0
69	60	F	10	C	S	68	40	P	M	A	0
70	24	M	7	S	S	72	17	M	M	M	0
95	23	M	6	S	S	72	12	M	P	M	+
97	55	M	24	S	S	73	3	M	M	A	0
98	63	M	44	F	S	72	26	P	P	A	0
100	47	M	35	F	W	72	20	P	P	A	+
102	59	M	44	C	S	68	82	M	M	M	+
104	57	F	40	C	S	71	4	P	P	A	0

**TABLE I-4**  
**Subject Data Obtained From Pre-Test Questionnaire**  
**Group D - Unfamiliar Car (Modified Test Vehicle)**

<u>Subject Identif. Number</u>	<u>Age</u>	<u>Sex</u>	<u>Driving Experience (Years)</u>	<u>Size</u>	<u>Type</u>	<u>Year</u>	<u>Vehicle Exposure</u>			<u>Brakes</u>	<u>Transm.</u>	<u>Driver Self-Rating</u>
							<u>Miles</u>	<u>Steering</u>				
77	35	M	19	C	S	70	5	P	P	P	M	0
78	23	M	5	I	S	64	35	P	P	M	A	0
79	35	F	15	C	S	67	4	M	M	M	A	0
80	31	M	13	S	S	73	2	M	M	M	M	+
81	25	M	9	C	S	72	15	M	M	M	A	0
82	37	M	21	F	S	68	36	P	M	M	A	+
83	27	M	9	S	S	68	53	M	M	M	M	0
84	24	F	4	C	S	72	13	M	M	M	A	0
85	24	F	4	C	S	70	33	P	M	M	M	0
86	25	M	9	S	S	71	100	M	M	M	M	+
87	18	M	1	S	S	68	1	M	M	M	M	+
88	34	M	16	F	S	64	70	P	M	M	A	+
106	49	M	24	S	S	68	40	M	M	M	M	+
107	61	M	46	F	S	72	22	P	P	M	A	0
108	52	F	37	F	S	72	20	P	P	P	A	0

## APPENDIX II

### Questionnaires and Reporting Forms

In this appendix, we have compiled sample copies of the several forms used in processing information for the driving experiment. These include:

1.     **Driver Training at CAL**

This two-page announcement was used to recruit the volunteer subjects.

2.     **CAL Driver Measurement - Information Form**

This form was distributed with Item 1; interested persons were asked to submit the form with the desired information provided. The form supplied most of the demographic data and was used by the project personnel to determine the question of familiarity with the Standard test vehicle. The criteria used in judging whether a subject could be said to be familiar (or unfamiliar) with the Standard test vehicle were: size, type (i. e. sedan, station wagon, etc.) and type of steering, brakes, and transmission (with emphasis on the latter). In some cases the question of familiarity was judged on the basis of a second car normally driven by the subject other than the primary car used by him.

3.     **Driving Experiment Information**

This four-page form was given to each subject immediately before the start of his 5-run test.

4. **Starting Line Instructions**

The first two pages of this four-page form were used by the test observer at the starting line before run number one. The text was read to each subject by the test observer.

The last two pages of the four were data sheets for use by the test observer. The primary performance data recorded consisted of time through the course for each of the five runs. Note, however, that the observer recorded a good deal of demographic data - such as braking foot used, shoulder belt utilization, driving posture, and so on.

The observer provided his post experiment comments on the bottom of the fourth page of this form. These included the observer's impressions of the subject's attitude, his mental state (e. g. whether calm, excited, etc.), whether he was judged to have shown improvement over the 5 test runs, and, his subjective rating of the subject.

5. **No title**

This is the sheet used to record path violations through the course. An assistant to the observer drove through the course after each run, marked off the cones knocked down, and replaced them in preparation for the next run. The time between the finish of one run and the start of the next - needed for cone replacement - was of the order of 5 minutes.

6. **Post-Experiment Questionnaire**

This two-page questionnaire was filled out by each subject at the conclusion of the test. Its general purpose was to obtain information for use in defining elements of a training course for driver improvement. In the analyses given in this report we have utilized only the responses to the first question.



## DRIVER TRAINING AT CAL

Throughout the past twelve years, Cornell Aeronautical\* Laboratory has been a national leader in the field of automobile safety. It has pioneered in research on automobile performance, in accident causation and occupant injury, in improved crashworthiness, and in accident avoidance. Now we are entering into work on advanced driver training and we are asking for your help in defining the right approach.

In order to obtain essential baseline data for this purpose, we want to put together a group of drivers which is representative of the total driving population. Selected volunteers will be asked to drive an instrumented car around a short course which we have set up on our Vehicle Experimental Research Facility behind the Genesee Street buildings. Details of the course will be given to you when you come to the Lab to do your bit.

Typical problems encountered by the automobile driver are such situations as recovering from a depressed shoulder off the road, transiting through a wet patch or performing a quick passing maneuver. We have simulated these situations on VERF and we will ask you to perform such operations as part of a short driving exercise. In addition to the measurements which we will be making as you drive, we will ask for your opinions of the procedures after you have finished your drive. These will be most helpful in defining how the training exercises should be developed.

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\* In 1972 Cornell Aeronautical Laboratory, Inc. became Calspan Corporation

We sincerely solicit your participation in this program. Automobile safety is a problem for all of us and we believe that the accident which is avoided because of driver alertness and skill represents by far the best approach to this problem. If you would like to help, please fill out the attached form and return to Dee Trippe by Friday, September 29, 1972.

After we have processed the information and determined that your qualifications fit the needs of our sample, you will be contacted to arrange a time and date for your participation. Only about an hour of your time will be required.

# CAL DRIVER MEASUREMENT

## INFORMATION FORM

1. Name \_\_\_\_\_
2. Address \_\_\_\_\_
3. Telephone No. \_\_\_\_\_
4. Driver Registration No. \_\_\_\_\_
5. Number of years you have been driving \_\_\_\_\_
6. Approximate number of miles you have driven \_\_\_\_\_
7. What type of car do you usually drive?

Make \_\_\_\_\_

Model - (Sedan), (Station Wagon), (Compact)

Year \_\_\_\_\_

Type of Steering: Manual \_\_\_\_\_ Power \_\_\_\_\_

Type of Brakes: Manual \_\_\_\_\_ Power \_\_\_\_\_

Type of Transmission: Manual \_\_\_\_\_ Automatic \_\_\_\_\_

Approximate number of miles you have driven this car \_\_\_\_\_

8. What other car(s) do you currently drive?

<u>Type</u>	<u>Steering</u>	<u>Brakes</u>	<u>Transmission</u>
-------------	-----------------	---------------	---------------------

9. Approximately what percentage of your driving is on open road (Thruway or rural roads) \_\_\_\_\_; in-city (Moderate to heavy traffic) \_\_\_\_\_

10. How would you rate yourself as a driver?

Better than average \_\_\_\_\_ Average \_\_\_\_\_ Less than average \_\_\_\_\_

Mon. Tues. Wed. Thurs. Fri.

Preferred Appointment: AM or PM

(Please circle)

## DRIVING EXPERIMENT INFORMATION

You are about to perform a driving exercise on Calspan Corporation's Vehicle Experimental Research Facility in an instrumented automobile which will give us data on your use of the steering wheel, brake, and throttle as you progress through the course. These measures will be used to examine the manner in which people drive a vehicle when they are in a hurry. We have marked the driving lanes of this course with traffic cones and barrels so that it can easily be followed. A map showing the path which you are to follow is attached. Please study it and if you have any questions, ask your instructor for clarification. Upon completion of the driving exercise, we will ask you to fill out a short questionnaire. Your comments, answers, and driving records will be kept confidential.

You were selected for this experiment because we believe you are representative of a certain segment of the population of automobile drivers. You will receive awards based upon how well you perform compared to the other drivers similar to you. We cannot tell you how your performances relate to other drivers until we have examined the scores of all participants.

This is not a test, therefore, you cannot pass or fail it. We wish only to obtain data on the various measures of your ability to drive this course.

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This is not a test, therefore, you cannot pass or fail it. We wish only to obtain data on the various measures of your ability to drive this course.

The general instructions for performing the driving exercises are quite simple:

1. The instructor will ride with you. He will be in the rear seat where he can operate the instrumentation system and answer questions pertaining to the course at the conclusion of each trial. He will neither judge your driving ability nor will he offer directions or assistance once a trial commences. Ignore his presence.

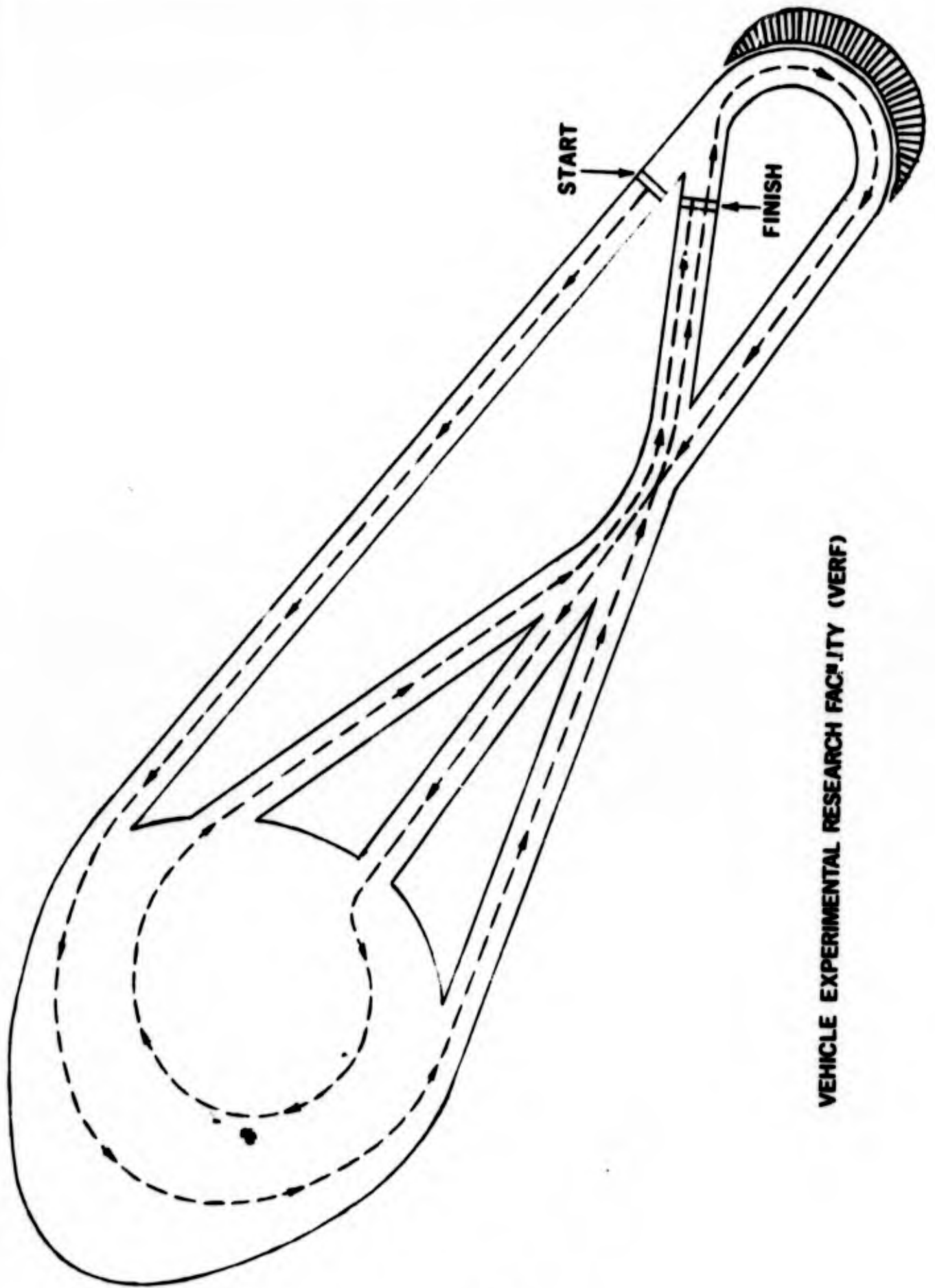
2. You will be asked to drive through the course several times. Each run will require only a few minutes. After each trial, we will provide you with two scores - (1) your total time from start to finish, and (2) an estimate of the number of cones and barrels hit, if any.

3. The course is outlined by markers of traffic cones and barrels. Stay within the lanes marked by the cones and avoid all barrels. However, do not stop if you strike a cone or barrel, it will be replaced before your next run.

4. There are a few operating procedures which we use in all of our driving work here at Calspan Corporation which we ask you to observe:

- Fasten your lap belt. (The use of the shoulder restraint is optional.)
- Close all windows. (The cars are air-conditioned and you may adjust the temperature as you desire.)
- Depress your door latch button.
- Seat and position yourself comfortably in the car just as you do in your own car.

Assume you find yourself in a situation requiring you to drive a strange automobile at the maximum of your ability on a road you have never traveled previously. Time is an extremely critical factor, but just as critical and important is your safe arrival at your destination, requiring you to accurately maneuver this vehicle through various road configurations, conditions and hazards. The cones will tell you where the path may narrow or curve. The barrels represent fixed obstacles (tree, other vehicles, etc.) in your path. Your score will depend upon both your speed and accuracy through the course. To emphasize this, awards will be presented to drivers in various classes who have the best scores for their best driving performance. Your time and accuracy scores will be adjusted and averaged over all trials for your final score. Thus, it is very important that you perform as well as possible on all trials.



**VEHICLE EXPERIMENTAL RESEARCH FACILITY (VERF)**

## STARTING LINE INSTRUCTIONS

(Received by instructor only)

(When positioned at the starting line the instructor will again review the course with the aid of a diagram and will read the following:)

I am now going to give you some simple instructions. Please listen carefully as I will ask you to summarize them for me.

As an instructor my functions are to operate the vehicle instrumentation, record trial times and answer any questions pertaining to the course at the conclusion of a trial. I will neither judge your driving ability nor will I offer instructions or assistance once a trial commences. Ignore my presence and remember this experiment is designed to obtain driving data, not to grade your driving ability. If you strike a cone or barrel do not stop unless I instruct you to do so.

Remember your driving situation. Both speed and accuracy are critically important in every trial. Any questions?

(At the conclusion of each trial the instructor will give the subject his trial time, number of errors and will remind him of his driving situation.)

After the first trial has been completed, the instructor will ask the subject the following questions and record his answers.

- Did you find that any part of the course was not clearly marked or was ambiguous ?
- Did you fully understand the driving instructions I read to you prior to this trial?

(At the completion of the third trial the instructor will ask the following question in a friendly relaxing voice and record the comments. " Well, how do you like it?")

(At the conclusion of the fifth trial the instructor will ask the subject how he feels and record his answer.)

Driver Name \_\_\_\_\_ Driver No. \_\_\_\_\_ Instructor \_\_\_\_\_  
 Vehicle \_\_\_\_\_ Date \_\_\_\_\_ Time \_\_\_\_\_

**TIME SCORE**

Trial No.	Times	Path Following Comments
1	_____	_____
2	_____	_____
3	_____	_____
4	_____	_____
5	_____	_____
6	_____	_____

**ERROR SCORE**

Trial No.	Cones or Barrels Down	Location
1	_____	_____
2	_____	_____
3	_____	_____
4	_____	_____
5	_____	_____
6	_____	_____

**OBSERVATIONS:**

- Braking foot, left \_\_\_\_\_, right \_\_\_\_\_.
- Steering wheel hand positions, left \_\_\_\_\_, right \_\_\_\_\_.
- Hands used on steering wheel in maneuvers, left \_\_\_\_\_, right \_\_\_\_\_, both \_\_\_\_\_.
- Shoulder belt utilization, yes \_\_\_\_\_, no \_\_\_\_\_.
- Seat location, forward \_\_\_\_\_, middle, \_\_\_\_\_, rearward \_\_\_\_\_.

- Driver physical size \_\_\_\_\_.
- Driving posture, leaning forward with arms bent \_\_\_\_\_, upright with arms slightly bent \_\_\_\_\_, positioned against seat back with arms relatively straight \_\_\_\_\_.
- Driver movement, rolled in corners \_\_\_\_\_, shifted in seat seldom \_\_\_\_\_, occasionally \_\_\_\_\_, often \_\_\_\_\_.
- Eye positions through maneuvers, directly straight in front of vehicle \_\_\_\_\_, straight and far ahead \_\_\_\_\_, side to side and directly ahead \_\_\_\_\_, side to side and far ahead \_\_\_\_\_, one of the previous and instruments (speedometer)
- Lowest number visible when seated in vehicle with head straight ahead, right \_\_\_\_\_, left \_\_\_\_\_.
- Answers to questions after trial one.

\_\_\_\_\_

\_\_\_\_\_

- Answer to question after trial three.

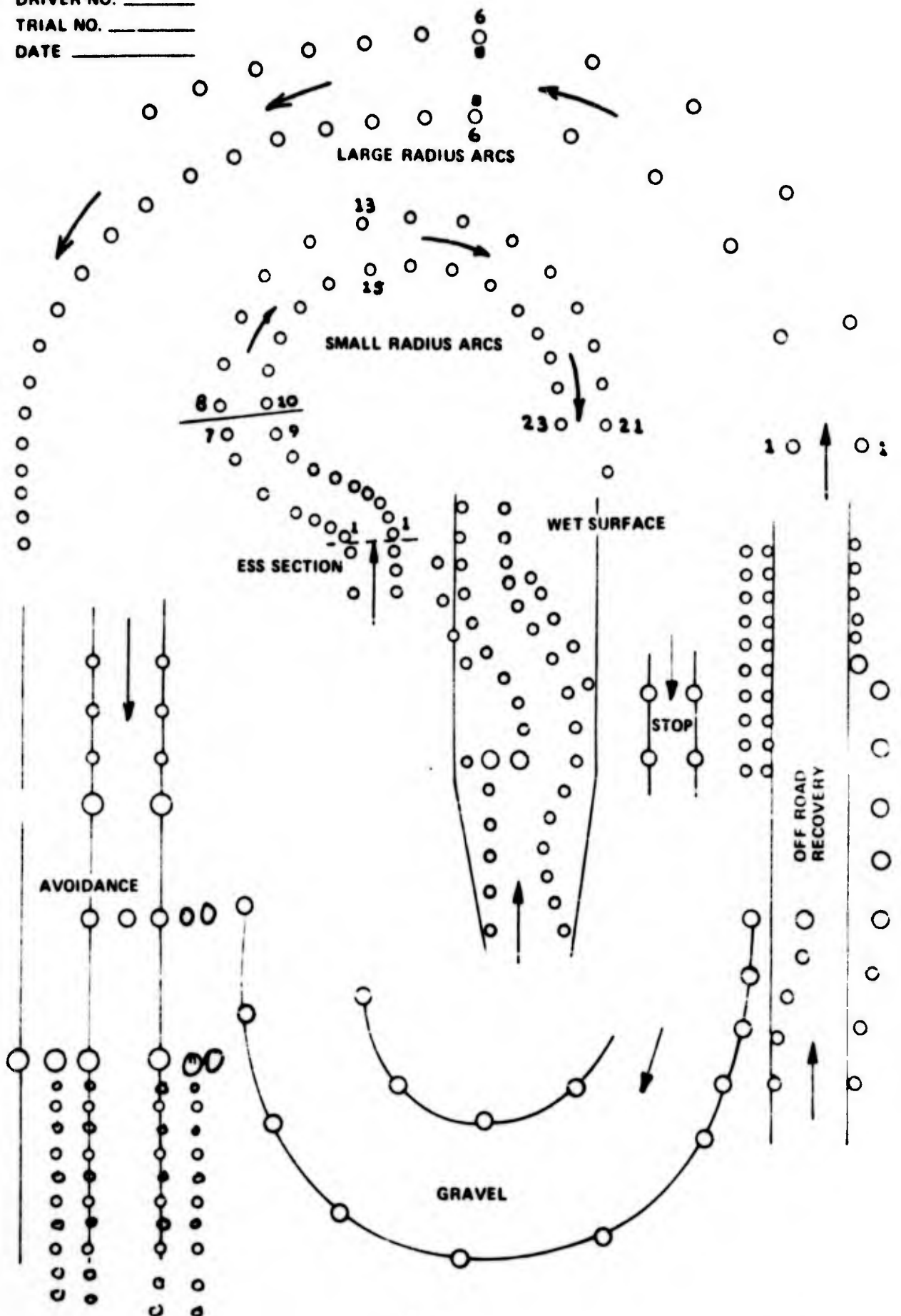
\_\_\_\_\_

- Answer to question after trial five.

\_\_\_\_\_

**POST EXPERIMENT INSTRUCTOR COMMENTS:**

DRIVER NO. \_\_\_\_\_  
TRIAL NO. \_\_\_\_\_  
DATE \_\_\_\_\_





POST EXPERIMENT QUESTIONNAIRE

Driver No. \_\_\_\_\_

Date \_\_\_\_\_

1. The course emphasized handling at moderate speeds. At these speeds, have you ever driven a car harder?

Yes \_\_\_\_\_ No \_\_\_\_\_

2. How would you describe your driving in this experiment?

\_\_\_\_\_ Were confident that you had the car under control in all maneuvers.

\_\_\_\_\_ On occasion, felt you might lose control of the car in a maneuver.

\_\_\_\_\_ Were uncomfortable (with respect to having control of the car) in many of the maneuvers.

\_\_\_\_\_ Believe that you temporarily lost control of the car in at least one maneuver.

3. What part of the course did you find most challenging?

\_\_\_\_\_ Off-shoulder recovery

\_\_\_\_\_ Large radius arcs

\_\_\_\_\_ Avoidance maneuver

\_\_\_\_\_ Gravel turn

\_\_\_\_\_ Wet surface

\_\_\_\_\_ "S" section

3. (continued)

\_\_\_\_\_ Small radius arc  
\_\_\_\_\_ Exit chute and braking

4. Do you feel that you could improve your score?

\_\_\_\_\_ in your own car  
\_\_\_\_\_ with more trials  
\_\_\_\_\_ with advanced driver training  
\_\_\_\_\_ other

5. Would you apply for an advanced driver training course here at CAL?

\_\_\_\_\_ Yes                      \_\_\_\_\_ No

6. How do you rate yourself as a driver?

\_\_\_\_\_ Better than average  
\_\_\_\_\_ Average  
\_\_\_\_\_ Poorer than average

The success of this experiment depends on keeping the experiences of individual drivers on the course confidential until all drivers have completed their runs. Please don't describe the course to others who may be participating later in the schedule.

Thank you very much for your help. We will be announcing the overall results of the work later in the year. If you have any comments to offer on the experiment, please give them to your instructor.

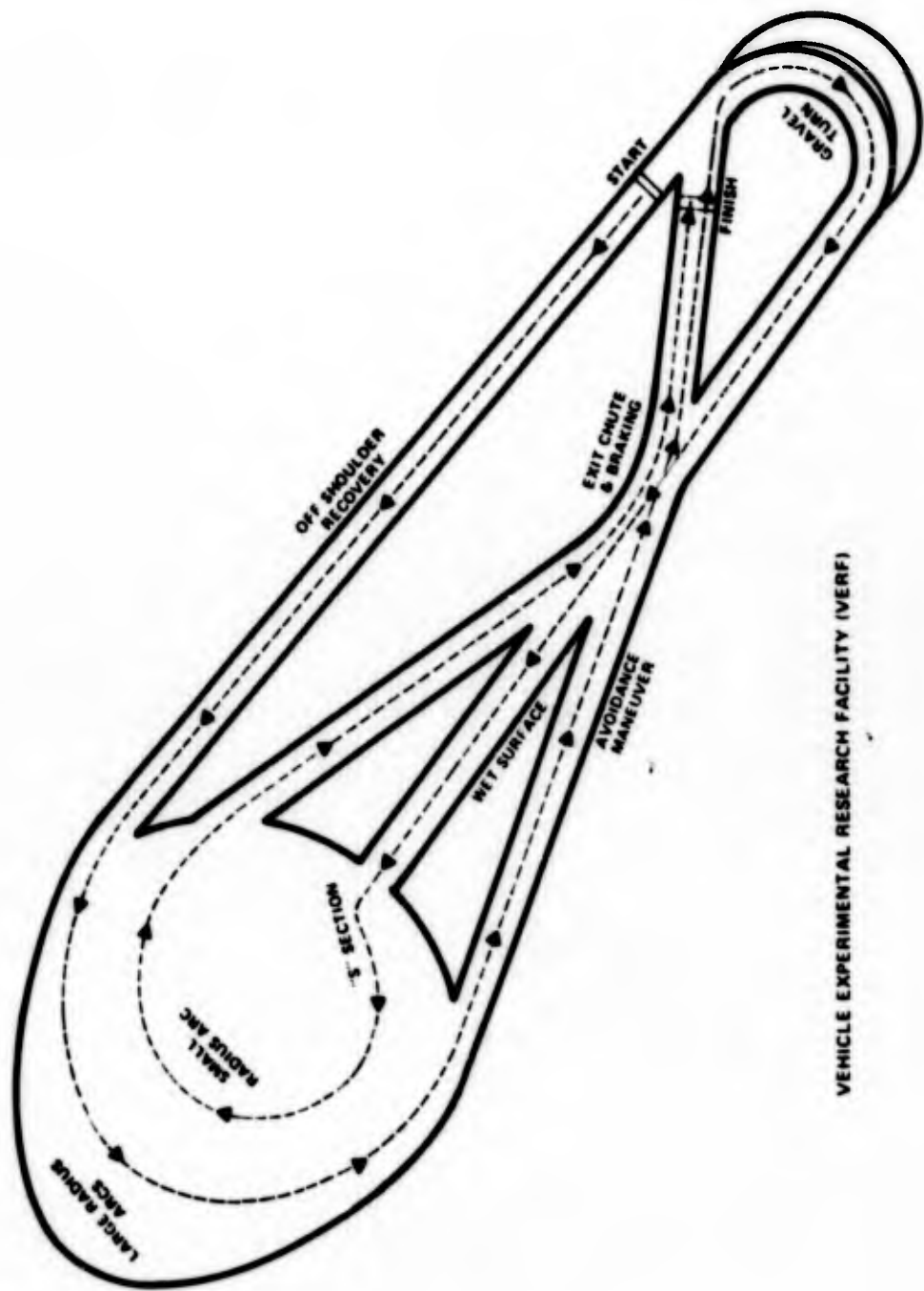
## APPENDIX III

### Sample Recording of Measured Data

This appendix contains an example of a single run through the driving course which has been selected to illustrate the type and amount of information about driver characteristics and capabilities which is available from these experiments. The data record is reproduced as Figure III-1; scale factors, location of the various driving incidents, and comments have been added to aid in interpretation. A copy of the course plan (previously given as Figure 2.1-1) is provided to help in following progress through the data traces. The five analog channels are clearly marked; the sixth channel marks specific locations on the course (four such positions are identified); and true time is marked by the trace between the second and third analog channels (one second intervals very nearly correspond to the markings on the data channels). The process of obtaining average values for some of the metrics is demonstrated by the horizontal lines drawn through the data traces at several points. Two examples of steering rate computations are also shown.

Several observations that may be made from the traces are worth discussing in detail. It should be noted in general that this trial represents an aggressive attempt by a competent driver who appears to be motivated to do well. (He indicated in the post-experiment questionnaire that he had not previously driven harder at these speeds.) Further details on his background (Subject No. 66) may be obtained in Appendix I.

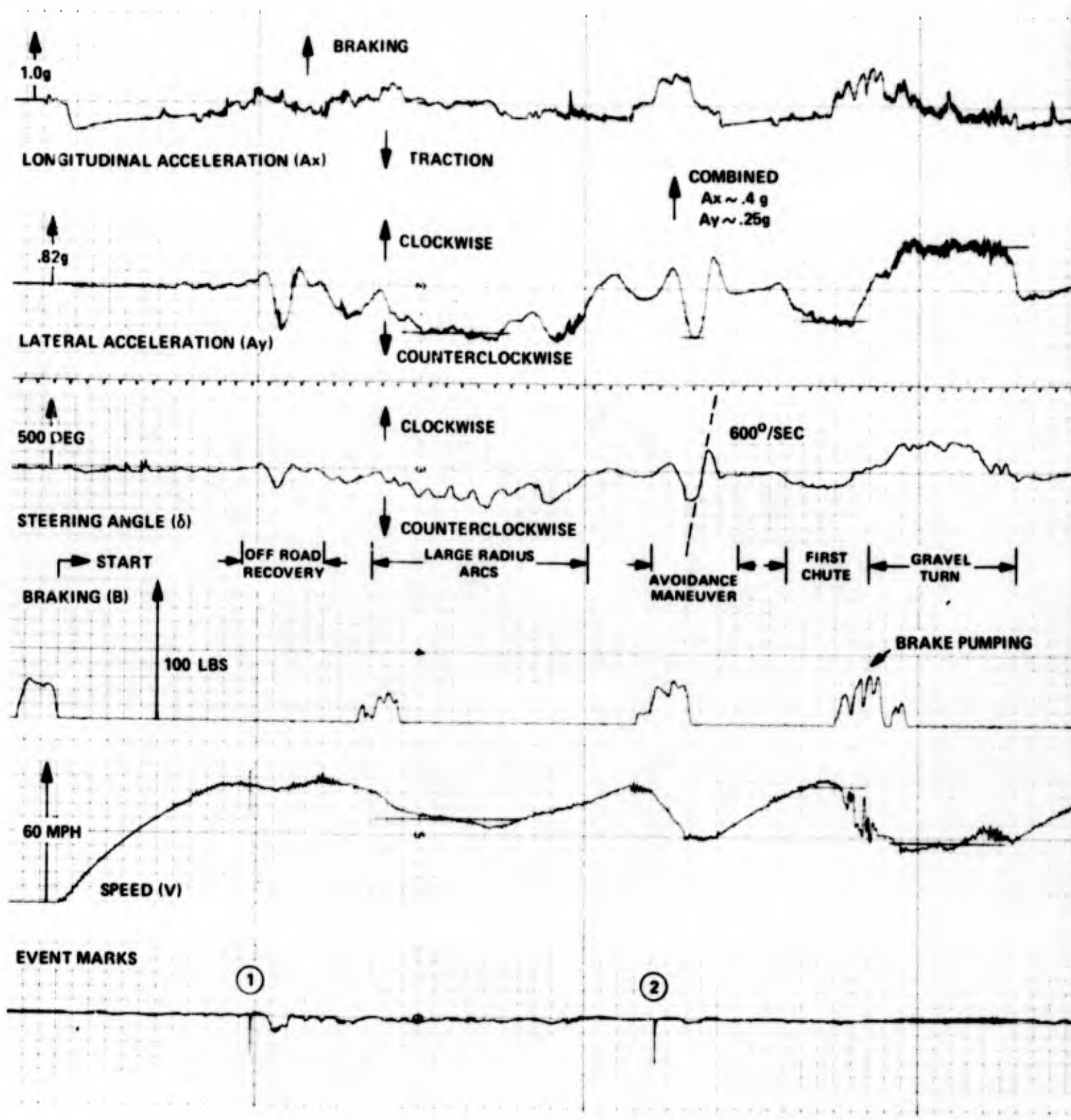
The subject applies full throttle at the start and keeps it in through the Off-Road Recovery maneuver. Note that no braking is applied and his speed in this maneuver is 51 mph. Some small amount of braking is used into the Large Radius Arcs, which are cornered at an average value of .53 g, and considerable oscillatory steering activity is shown. The Avoidance Maneuver is negotiated with one cone violation at the exit, using both brakes and steering, at a maximum transient  $A_y$  of about .55 g. Note that at the peak lateral acceleration in the CCW direction, all braking has been removed.



VEHICLE EXPERIMENTAL RESEARCH FACILITY (VERF)

The driver accelerates well into the First Chute bend (apparently at full throttle) and then slows the vehicle by pumping the brakes (about 1.5 Hz frequency) to go through the Gravel Turn. The irregular speed trace during this period shows some tendency toward wheel lock. The Gravel Turn is negotiated cleanly although steering has to be reduced significantly in the last few seconds of the maneuver (when throttle is applied) to prevent spin. Note that  $A_y$  remains high. Speed is regained in the straight and then wiped off to a reasonable level for getting through the Wet Surface. It is interesting that the subject uses nearly the same maximum brake pressure for each of five principal decelerations made through the course.

The Wet Surface posed no problem at  $A_y = .25g$  (entrance speed of 35 mph) although partial brake locking occurs here and in the ESS maneuver. A very high steering rate is used in the ESS to avoid control loss at the high value of lateral acceleration employed. The Small Radius Arc is negotiated with considerable steering wheel activity at about  $A_y = .58g$ . The vehicle is accelerated out of this turn and into the straight where a speed of over 60 mph is reached. Brake locking starts to occur as the car is slowed for the Exit Chute bend and, in fact, the driver has to countersteer to avoid spinning. The car is brought to a hard stop ( $A_x = .68g$ ) at the end of the record.



155

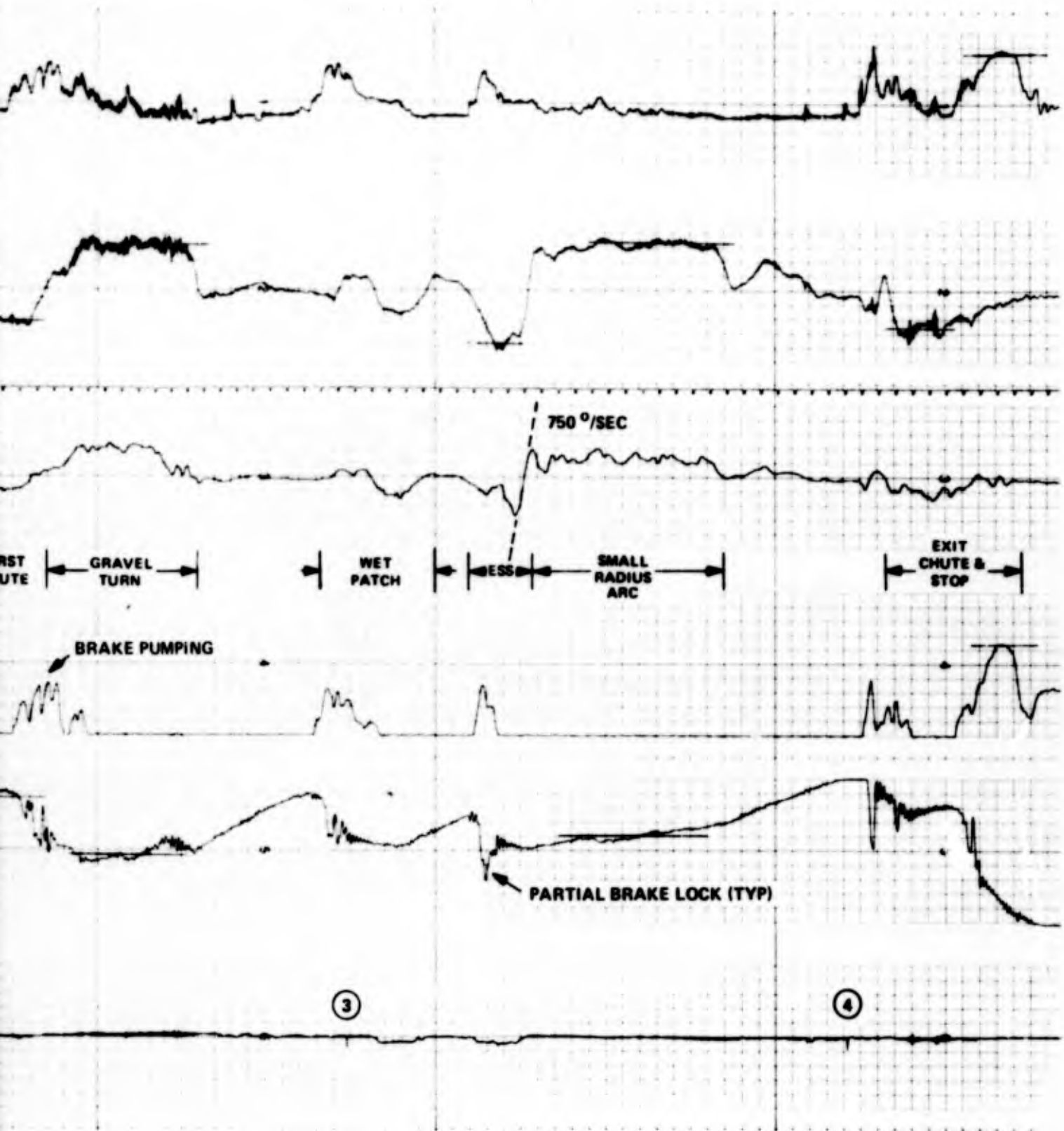


Figure III-2 SAMPLE RECORD

## APPENDIX IV

### Combination of Group A and Group B Data

The method of combining the data for groups A and B into a single group, AB, is indicated below.

- Let: M = The mean value of a sample  
N = The number of elements in a sample  
S = Standard deviation of a sample  
SOS = Sum of squares of the deviations from the mean  
A, B, AB = Subscripts for groups A, B, and their combination, AB

First, the group AB mean is computed from:

$$M_{AB} = \frac{N_A M_A + N_B M_B}{N_A + N_B}$$

Then, the contribution to the group AB sum of squares, defined as  $\gamma$ , due to the deviation of the individual group means from the grand mean is computed:

$$\gamma = N_A [M_{AB} - M_A]^2 + N_B [M_{AB} - M_B]^2$$

The group AB sum of squares is then given by:

$$SOS_{AB} = SOS_A + SOS_B + \gamma$$

Finally, the combined group standard deviation is computed from:

$$S_{AB} = \left[ \frac{SOS_{AB}}{N_A + N_B - 1} \right]^{1/2}$$

**APPENDIX V**  
**Expert Driver Results**

Results of the trials performed by the expert drivers have been inserted in appropriate sections in the main body of this report. They are included in this appendix in order to provide an integrated evaluation of the performance which was achievable. In general the numerical data are in the same form as used in the discussions of the individual maneuvers given previously.

(1) Off Road Recovery

Average approach speed - 51 mph. In most runs, a small amount of braking ( $A_x \approx .2g$ ) was used prior to recovery over the curb. All runs were successful.

(2) Large Radius Arcs

Average velocity was about 40 mph and average lateral acceleration was about .63 g. This latter value is near the limit capabilities of the Standard vehicle and most trials are marked by considerable steering activity by the driver in order to maintain control.

(3) Avoidance Maneuver

Peak transient lateral accelerations varied between .55g and .68g. Presumably the value varies as a function of speed and the line taken through the maneuver. The average value of the maximum steering rates employed was about 800 deg/sec on successful runs. On one unsuccessful trial, a peak steering rate of about 1200 deg/sec was applied. Braking was invariably used during the first phase of the maneuver.

**(4) First Chute**

Average velocity = 53 mph; average lateral acceleration (over a 2-3 second period) = .38g. In this first pass through this turn, the driver must first accelerate away from the Avoidance Maneuver and then prepare to brake before entering the Gravel Turn. This may explain the lower  $A_y$  values employed.

**(5) Gravel Turn**

Average lateral acceleration = .55g at an average velocity of about 25 mph (actual speed varied considerably through the maneuver). This event is effectively one long transient operation as the tires slip and grab so a great deal of steering activity is required to maintain control at these speeds through this maneuver.

**(6) Wet Surface**

Entrance velocity for successful trials averaged about 42 mph. The experts had the most trouble with this incident, failing on 4 occasions in 18 attempts at an average entrance speed of 44 mph.

**(7) ESS Turn**

Average value of peak transient  $A_y$  was about .65g. Only 4 failures out of 34 trials were recorded - all with the modified vehicle.

**(8) Small Radius Arc**

Average velocity: 37 mph; average lateral acceleration: .60g. The value of lateral acceleration was usually maintained quite constant through the maneuver (8-10 seconds) although accompanied by considerable steering activity. No failures occurred.

(9) Exit Chute

In this second pass through this bend,  $A_y$  averaged about .65g. Speed in the preceding straight invariably exceeded 60 mph. With the somewhat easier entry into this turn at this stage in the run than is provided in the first pass, the experts employed near-limit  $A_y$  cornering.

(10) Braking

Average longitudinal deceleration: .67g. Most of the stops involved some degree of lock-up of the wheels. The expert drivers showed the greatest amount of variation among themselves in how they applied the brakes (not only for this stop but when slowing the vehicle throughout the course).

(11) Total Time-in-Course

With the standard vehicle, the best successful trial times for the three drivers were within a few tenths of a second of each other, averaging 103.5 seconds. The variation was greater with the modified vehicle with an absolute best time of 98 seconds. This difference of approximately 5 seconds between the two vehicles is believed to be a reasonable measure of the increased capability of the modified car in this course.

## APPENDIX VI

### Accident Description

It is significant that, with the hard driving that the subjects did and the number of loss-of-control situations which resulted, only one property damage incident occurred over the course of the program. This incident took place at the junction of the First Chute corner and the entrance to the Gravel Turn. (See Figure 2.1-1b for the course layout in this area). The path through the gravel was marked by large plastic barrels but beyond the left side of the path is a banked roadway as shown in Figure 2.1-1a. The subject was unable to negotiate the transition from the large radius CCW chute bend to the much smaller radius CW turn in the gravel and impacted the banked road surface. The front end of the test vehicle was damaged but no injuries were suffered.

The operating conditions leading up to the incident are depicted in Figures VI-1 and VI-2. The former shows data from the run in which the problem occurred; the latter shows data from the immediately previous run in which the maneuver was successfully performed. All data traces are identified and specific course situations are marked. The general patterns are seen to be quite similar for the two attempts. These figures are direct copies of portions of the transcribed recordings of the runs.

The data traces are picked up in the straight which precedes the fixed geometry avoidance maneuver. In both cases the driver is accelerating through this section, reaching a speed of approximately 54 mph before braking for the avoidance maneuver. A precise physical location on the course is identified by the event marker tick on the speed trace (channel 5).

Note that the driver, who brakes with his left foot, continues to accelerate for a few tenths of a second after braking initiation before closing the throttle. This same pattern is again displayed when slowing for the gravel turn.

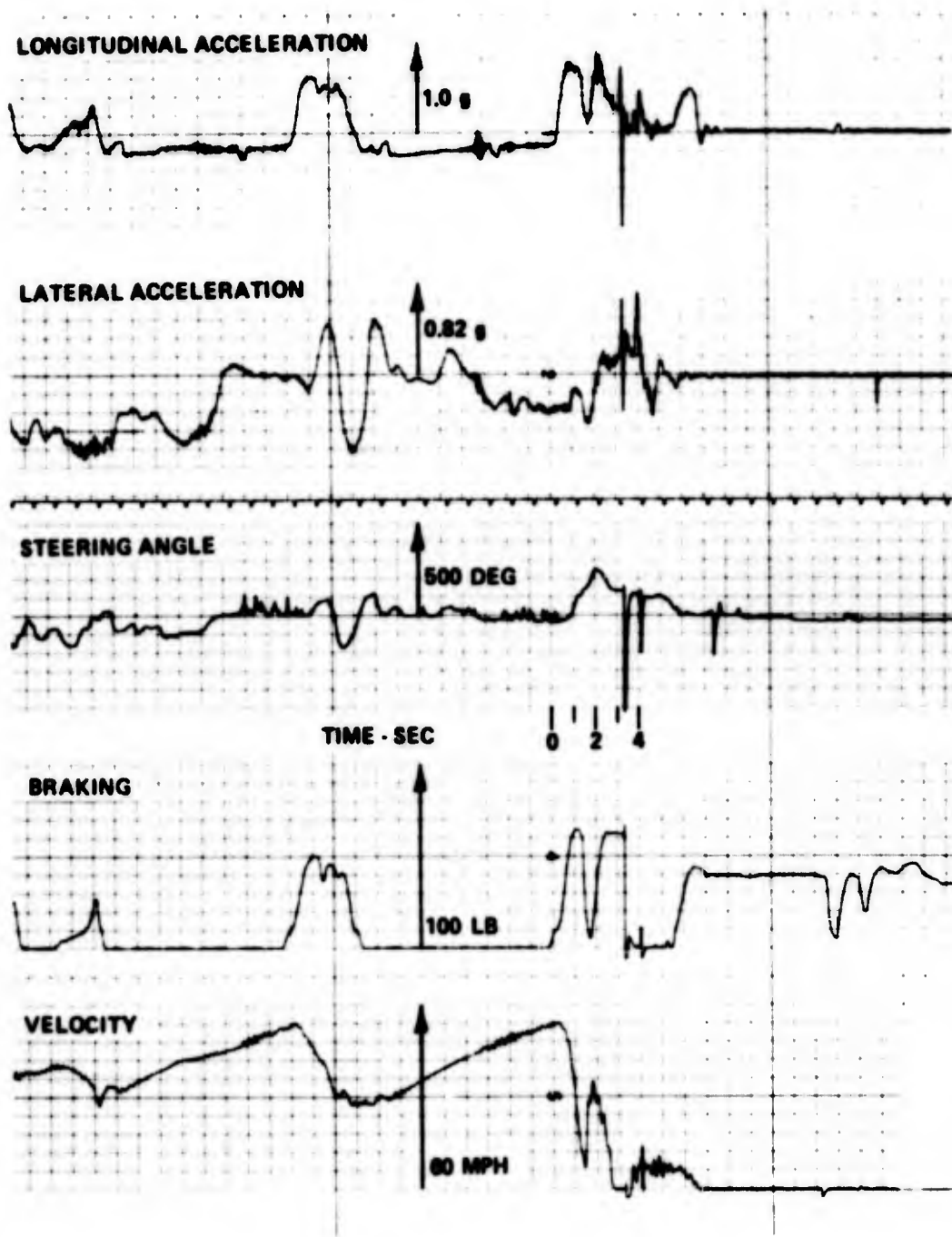


Figure VI-1 TRIAL NO. 5

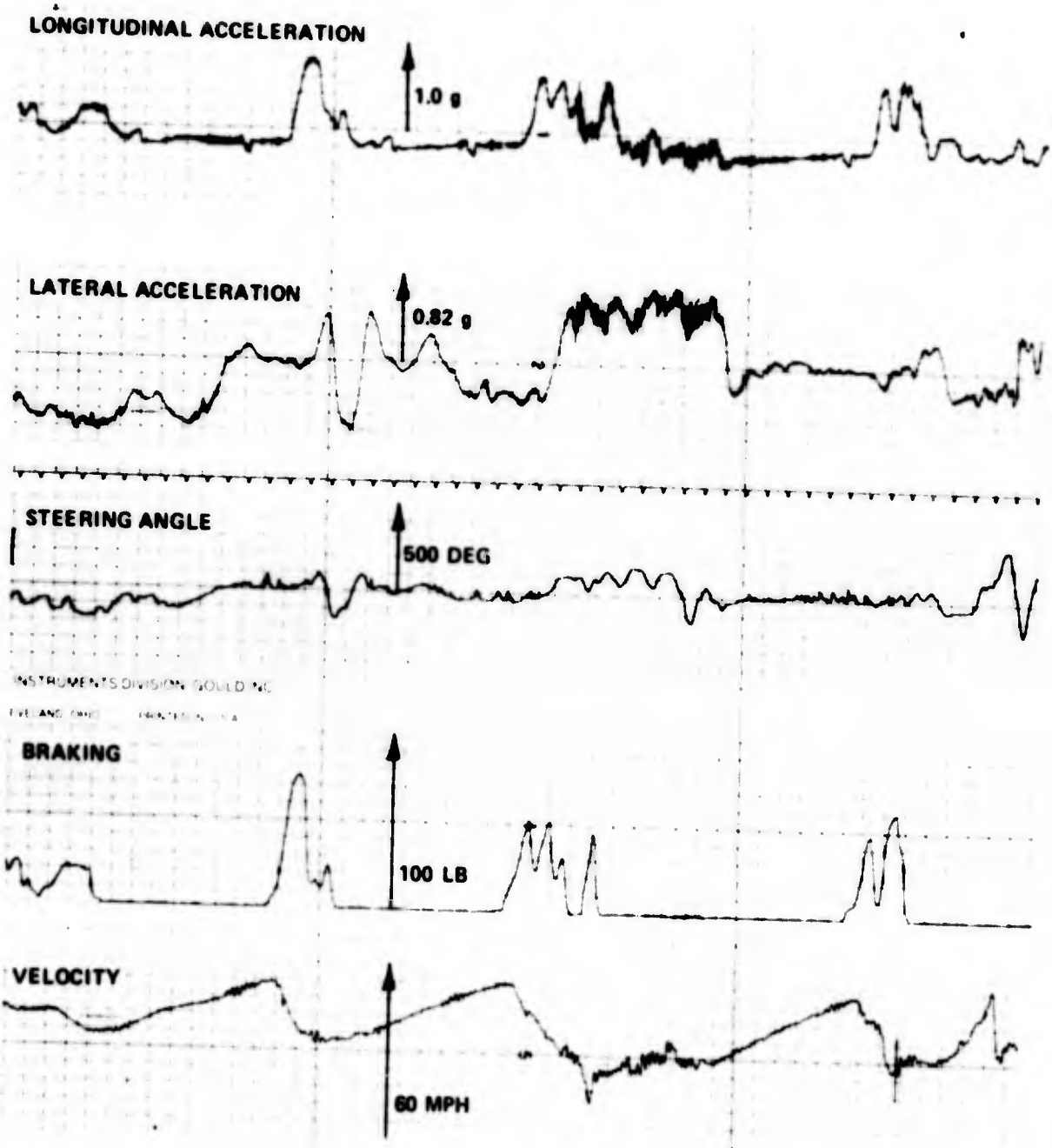


Figure VI-2 TRIAL NO. 4

The greater total braking energy employed in the unsuccessful run resulted in a lower minimum speed through the avoidance maneuver and this differential (of about 3 mph) continued through the next portion of the course consisting of a short straight, a mild CW bend, and the longer CCW chute bend. Throughout this period of about eight seconds, full throttle is apparently used. Accounting for the speed differential, braking preparatory to entering the gravel turn occurs at approximately the same location in the two runs. In both cases, a speed of 54 mph is achieved. Up to this point, conditions are nearly identical for the two runs.

In the successful run, (VI-2), speed is reduced smoothly, using braking modulation at a reasonable force level, and CW steering is applied to bring the vehicle into the gravel turn. Approximately 100 degrees of steering wheel displacement is used. At the high lateral accelerations employed by this subject in the gravel, nearly continuous steering wheel activity is required in order to maintain path. Note that braking is applied for one short period while in the turn, producing a tendency toward locking the rear wheels.

In the unsuccessful run (VI-1), a series of events takes place in short succession that clearly identifies what occurred in the collision. These are probably best described in time sequence -

Time: 0 secs. Braking is initiated although speed continues to increase. Lateral acceleration (CCW) in the chute turn is maintained nearly constant.

Time: .5 secs. Brake pedal force has been increased to a level which is producing significant deceleration but the wheels are developing high slip ratios approaching lockup (as evidenced by the large rate of change of the velocity trace, channel 5).

**Time: .9 secs.** Steering is initiated and the vehicle starts to respond in the proper direction (shown by the decrease in the CCW lateral acceleration value, channel 2). Brake pedal force has continued to increase and longitudinal deceleration has reached a value of over .6g.

**Time: 1.4 secs.** The subject apparently senses the skid and begins to release the brakes. Deceleration remains high (approximately .7g) and the vehicle starts to spin in the CCW direction, additional steering (CW) is applied to correct for the spin.

**Time: 1.9 secs.** The driver has released the brakes almost completely; the road wheels are nearly back up to speed; and deceleration has been significantly reduced. The vehicle CCW spin has been arrested as more CW steering continues to be added. At this point, it appears that path control can still be recovered.

**Time: 2.5 secs.** The driver again applies braking (over the next few tenths of a second) and locks up the road wheels by 2.8 seconds. Impact occurs at about 3.5 seconds.