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THE INFLUENCE OF VEHICLE AERODYNAMIC AND CONTROL RESPONSE CHARACTERISTICS ON DRIVER-VEHICLE PERFORMANCE

by

Alexander A. Alexandridis
Brian S. Repa
Engineering Mechanics Department
General Motors Research Laboratories
Warren, Michigan 48090

Walter W. Wierwille
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

SUMMARY

The effects of changes in understeer, control sensitivity, and location of the lateral aerodynamic center of pressure (c.p.) of a typical passenger car on the driver's opinion and on the performance of the driver-vehicle system were studied in the moving-base driving simulator at Virginia Polytechnic Institute and State University. Twelve subjects with no prior experience on the simulator and no special driving skills performed regulation tasks in the presence of both random and step wind gusts.

INTRODUCTION

The performance of the driver-vehicle system in the presence of cross-wind disturbances is influenced by the location of the lateral aerodynamic center of pressure (c.p.) of the vehicle.

The extent to which changes in c.p. location are discernible and/or objectionable to ordinary drivers has up to this time been unknown. Most of the previous studies on wind gust disturbance regulation tasks have concentrated on a single c.p. location with the c.p. most frequently placed at the front wheels (references 1-5). Also, although the influence of changes in design parameters, such as understeer and control sensitivity, have been studied previously (references 3, 4), the interaction of these parameters with the location of the c.p. in a closed-loop task is unknown.

The present study examines the influence of various combinations of understeer, control sensitivity, and c.p. location on the performance of twelve ordinary drivers in the presence of wind gust disturbances.

The Virginia Polytechnic Institute and State University (VPI&SU) moving-base driving simulator was chosen for the tests because of the control it offers over the parameters of interest and because of the success of previous research performed with the facility (reference 1). The following sections describe the simulation facility, the experimental design and procedure employed, the performance measures utilized, and the results obtained.

THE VPI&SU DRIVING SIMULATOR

This experimental facility provides the subject with an on-line, computer-generated, television-type display of the roadway in coordination with the motion cues of yaw and roll, as well as lateral and longitudinal translation. In addition, four channels of sound along with vibration are provided for the enhancement of the simulation realism.

Three separate inputs were provided to the vehicle model used for the simulation; namely, steering wheel displacement, accelerator/brake displacement, and aerodynamic force (wind gust). The model consisted of a set of transfer functions relating the three inputs to the vehicle motion components.

References 1, 6, and 7 contain a detailed description of the driving simulator and related equipment; figure 1 shows the simulator motion platform.

DEFINITIONS AND EXPERIMENTAL PROCEDURE

Definitions

The three experimental variables are defined briefly as follows:

1. C.p. location, x_a : The distance between the front-wheel axis and the point of action of the lateral aerodynamic force F_a (see figure 2).

This variable is expressed as a percentage of the vehicle wheelbase (x_a = 0.0% corresponds to a c.p. location at the front wheels).

2. Understeer, K : The numerical difference between the sideslip angles developed at the front and rear wheels during a 1-g lateral acceleration.

Understeer is conventionally measured in deg/g. A more detailed description of this concept is given in reference 8. Figure 2 shows the paths that vehicles with understeer ($K > 0$), neutral steer ($K = 0$), and oversteer ($K < 0$) would follow under the influence of an external side force acting at the center of gravity.

3. Control sensitivity, C.S. : The steady-state lateral acceleration (in g's) developed by a vehicle following a steering wheel displacement of 1.75 rad (100.0 deg).

Experimental Design

A mixed between-subjects and within-subjects factorial design was used, containing two levels of understeer (K = 3.0, 5.0 deg/g), two levels of control sensitivity (C.S. = 0.8, 1.2 g/100 deg), and three c.p. locations (x_a = 0%, 19%, 37% of wheelbase) for a total of twelve vehicle configurations. Six male and six female college students without any previous simulator experience were used as subjects. Three male and three female subjects were randomly assigned to each of the two understeer conditions (understeer was a between-subjects variable). The other two variables were factorially complete and equally likely for all subjects. The subjects were given a 1.5 min period of practice following which they were required to maintain a constant speed of 97 km/h (60 mph) while keeping their normal lane position in the presence of random wind disturbances. Data were collected for a period of 2.0 min. Following the random wind disturbances, a series of step gusts were presented for an additional 2.0 min period. At the end of each run, the subjects rated the disturbances they encountered, taking into account the vehicle path deviations and the amount of steering activity needed to maintain course.

Data Collection

The time histories of the vehicle lateral position and yaw heading deviations, as well as the driver's steering wheel inputs were recorded on an F.M. tape recorder. The objective measures of performance were the root-mean-square (rms) values of these time histories, together with the peak lane overshoots during the step gusts.

RESULTS

Subjective Ratings

Figure 3 shows that the subjective ratings improve as the c.p. moves rearward. The other two variables had no significant effect on the ratings.

Random Disturbance Performance

Significant differences in lane-keeping performance occurred as a result of changes in C.S. and x_a . There is a strong indication of an effect on lateral position deviation due to an interaction between understeer and c.p. location and a significant effect from this interaction on yaw deviations.

Figure 4 shows that increases in both C.S. and x_a result in decreases in lateral position deviations. The nature of the interaction between K and x_a that approached significance in shown in figure 5. The higher value of understeer has a beneficial effect on lateral position deviations only when the c.p. is located close to the front wheels. Figures 6 and 7 show similar effects for yaw angle deviations.

Steering wheel deviations were significantly affected by all three vehicle parameters. Furthermore, there were significant effects due to interactions between c.p. location and understeer and between c.p. location and control sensitivity.

Figure 8 shows that increases in K, C.S., and x_a all have a similar effect; namely, to decrease steering deviations. Figure 9 reveals that increases in both K and C.S. result in greater decreases in steering deviations the closer the center of pressure is to the front wheels.

Step Disturbance Performance

The peak lane position overshoot was measured from the actual vehicle position prior to the gust onset and not from the center of the lane.

Figure 10 shows that increases in x_a and in C.S. reduce peak lane position overshoot. The effects of understeer were accentuated as the c.p. location moved forward, with the lower level of understeer resulting in the largest lane position overshoot.

DISCUSSION

The subjective and objective measures used in the present study indicate that c.p. location is an extremely important parameter for wind gust regulation performance. Scores on the 0-10 Rating Scale, maximum lane deviations following a step wind gust, and steering wheel deviations during presentation of the random wind gust were all highly significantly affected by changes in c.p. location. Actual lane position deviations during the random wind gust task were only slightly less sensitive to changes in c.p. location than these other measures.

In spite of its great importance, however, c.p. location is difficult to control in practice (reference 9). For this reason, other means for improving disturbance responses of the closed-loop driver-vehicle system were explored; namely, through changes in understeer and control sensitivity. Both parameters were found to have a significant effect on wind gust regulation performance, although subjective opinion data failed to detect this effect. Increased levels of understeer (K = 5.0 deg/g vs 3.0 deg/g) and control sensitivity (C.S. = 1.2 g/100 deg vs 0.8 g/100 deg) both had a beneficial effect on measures of path control and driver steering wheel deviations. These beneficial effects were accentuated where they were needed the most; namely, at forward c.p. locations.

CONCLUSIONS

The following conclusions were reached:

- Driver opinion ratings were significantly influenced by c.p. location only, with rearward locations rated the most favorable.
- Lane-keeping accuracy improved as the c.p. moved rearward and as control sensitivity increased.
- For the forward c.p. locations, lane-keeping performance improved with increased understeer.
- Steering wheel activity required for control was reduced by increased understeer and control sensitivity and by rearward movement of the c.p., with the effects of understeer and control sensitivity accentuated at forward c.p. locations.

Overall, the location of the aerodynamic center of pressure was the predominant vehicle characteristic with an influence that could only partially be offset by changes in understeer and control sensitivity.

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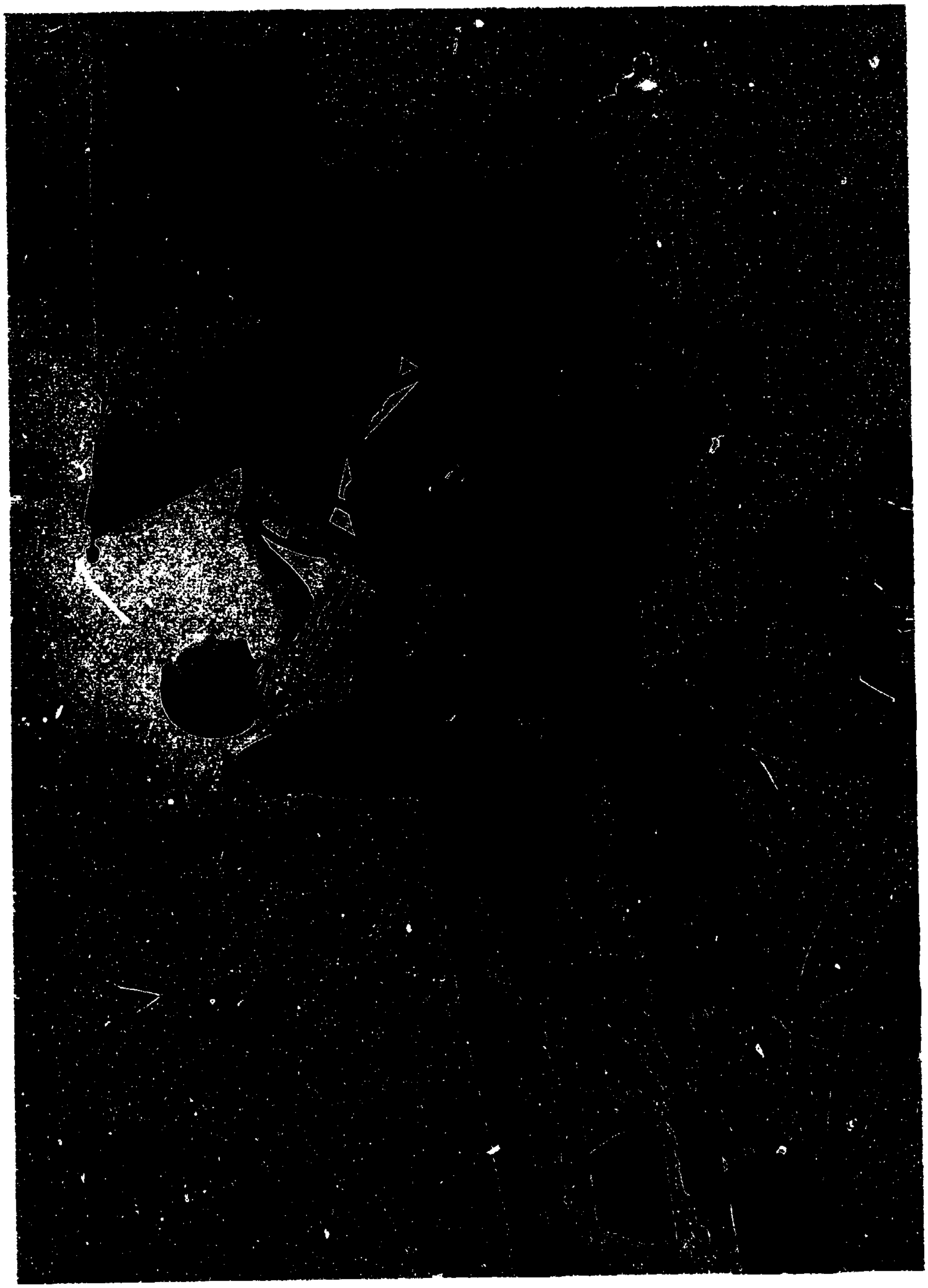

FIG. 1 DRIVING SIMULATOR MOTION PLATFORM

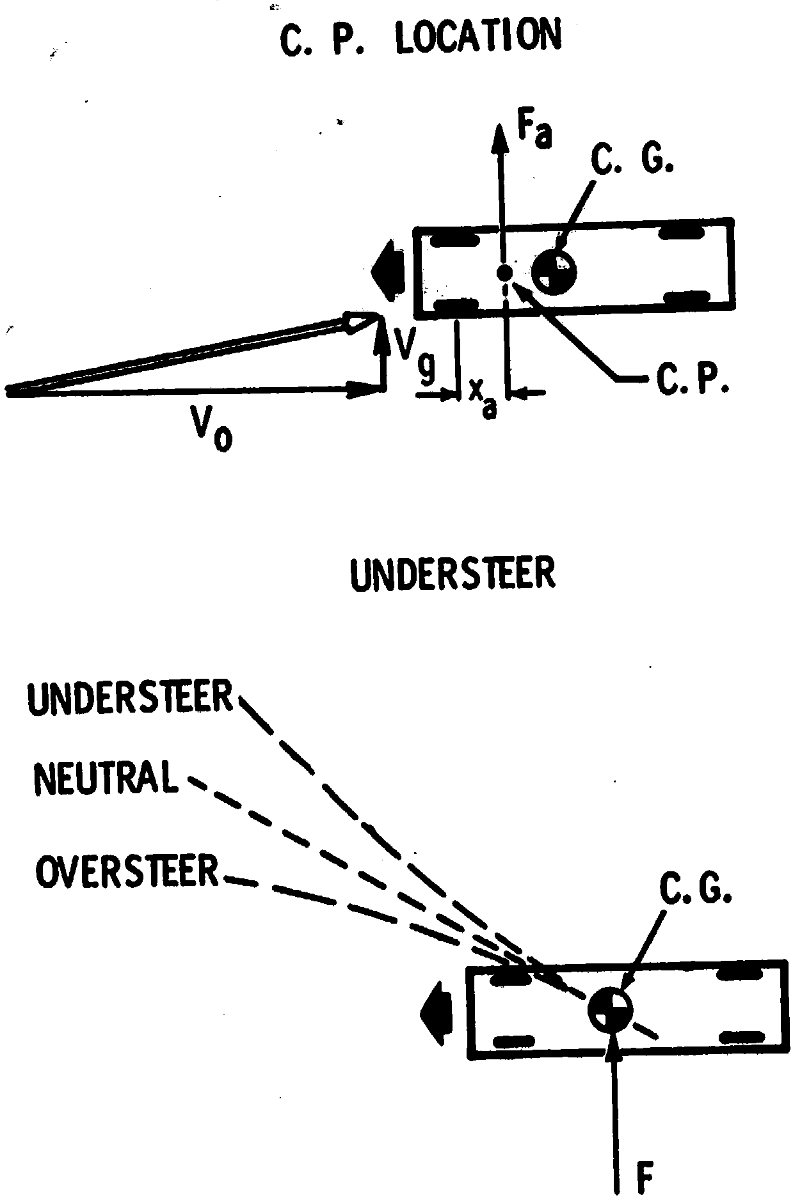

FIG. 2 DEFINITIONS

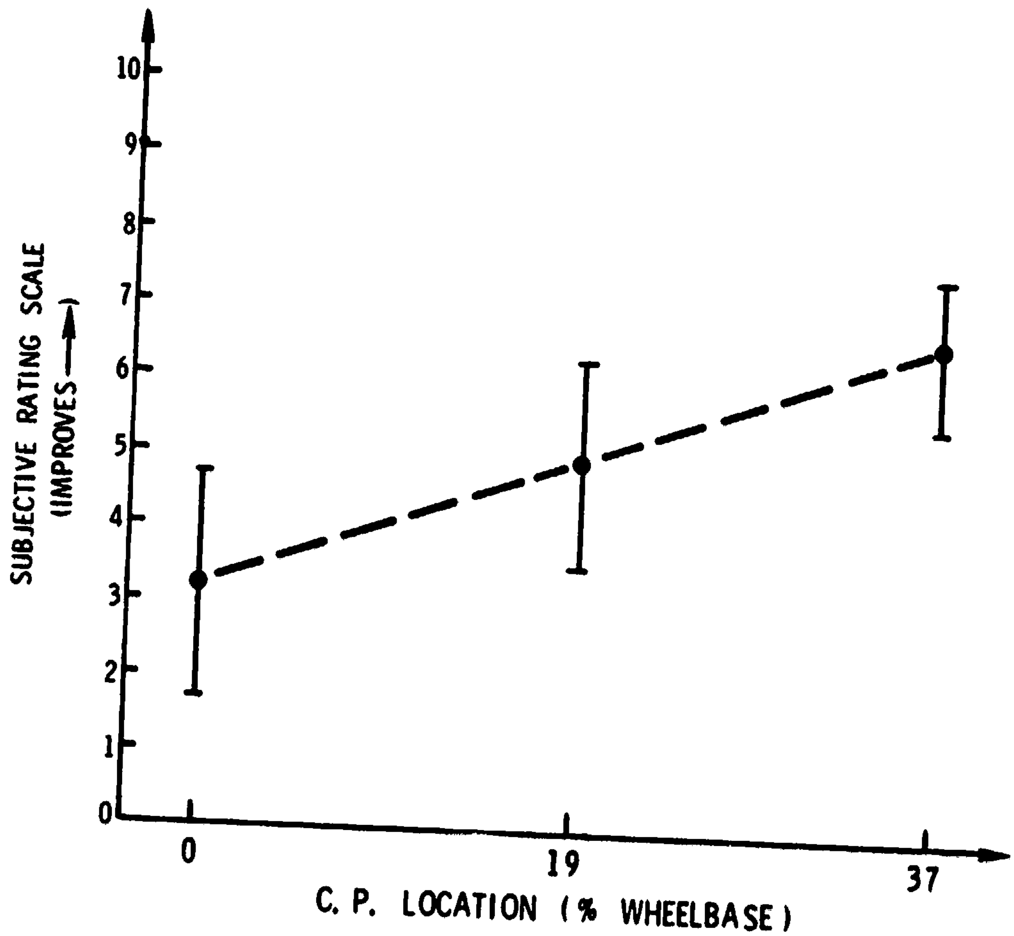

FIG. 3 DEPENDENCE OF SUBJECTIVE RATINGS OF VEHICLE CONFIGURATIONS ON C.P. LOCATION

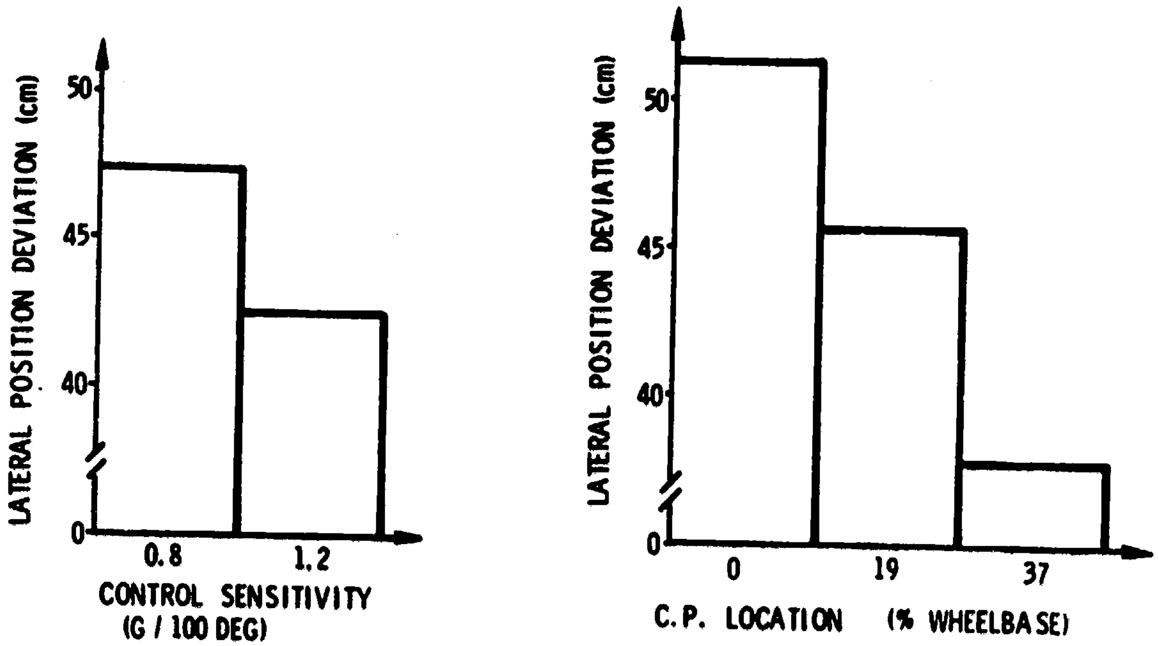

FIG. 4 EFFECTS OF CONTROL SENSITIVITY AND C.P. LOCATION ON LATERAL POSITION DEVIATION (RANDOM WIND GUST)

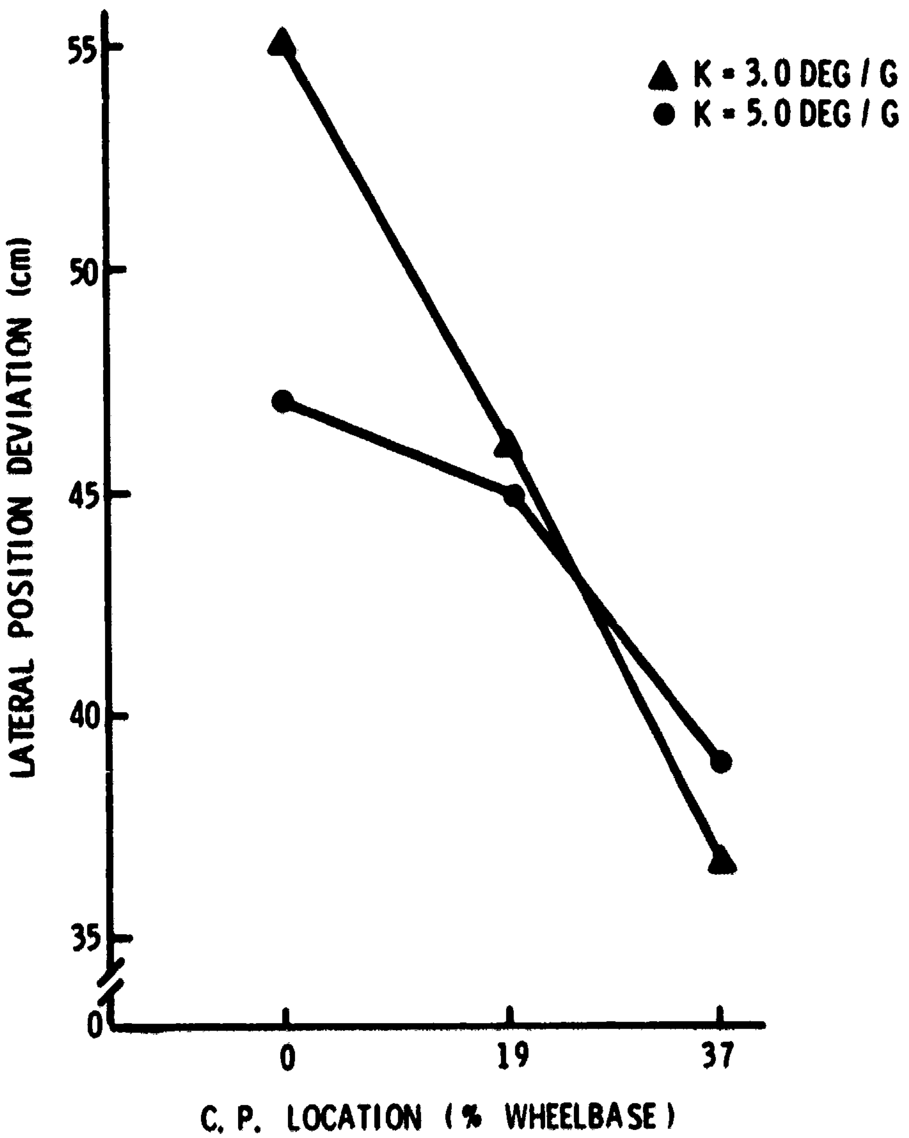

FIG. 5 COMBINED EFFECTS OF UNDERSTEER AND C.P. LOCATION ON LATERAL POSITION DEVIATION (RANDOM WIND GUST)

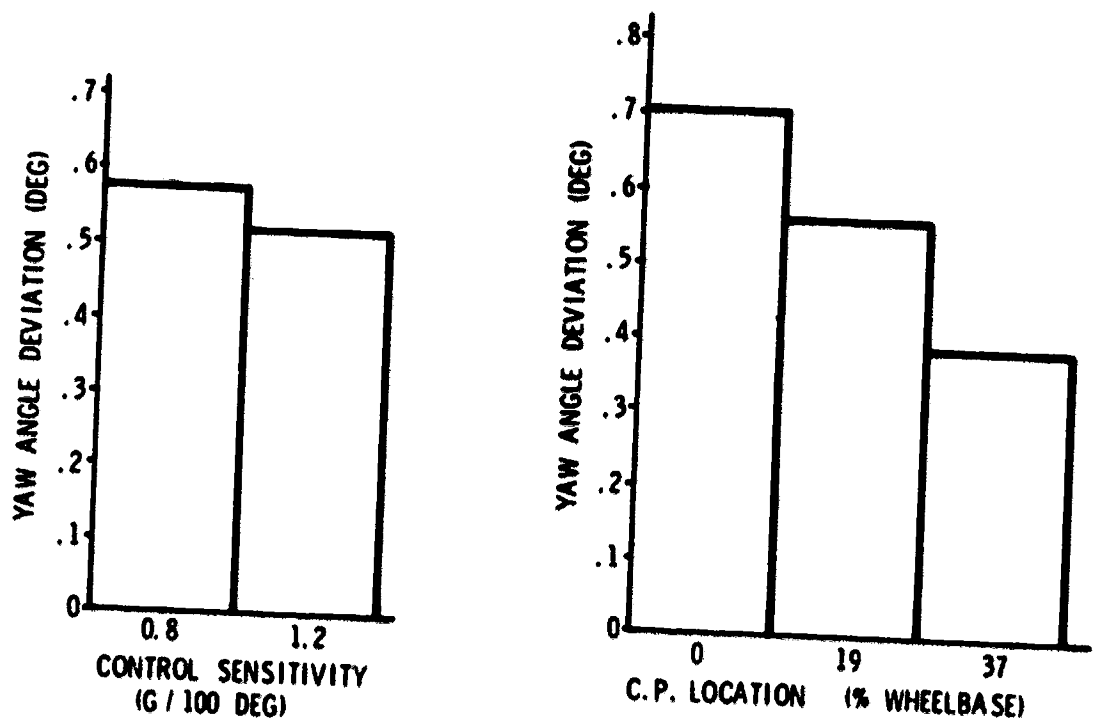

FIG. 6 EFFECTS OF CONTROL SENSITIVITY AND C.P. LOCATION ON YAW ANGLE DEVIATION (RANDOM WIND GUST)

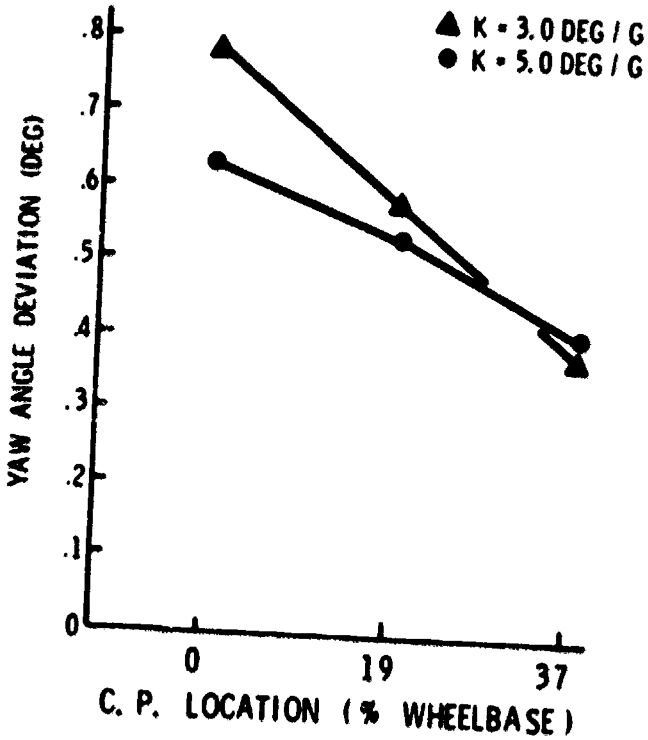

FIG. 7 COMBINED EFFECTS OF UNDERSTEER AND C.P. LOCATION ON YAW ANGLE DEVIATION (RANDOM WIND GUST)

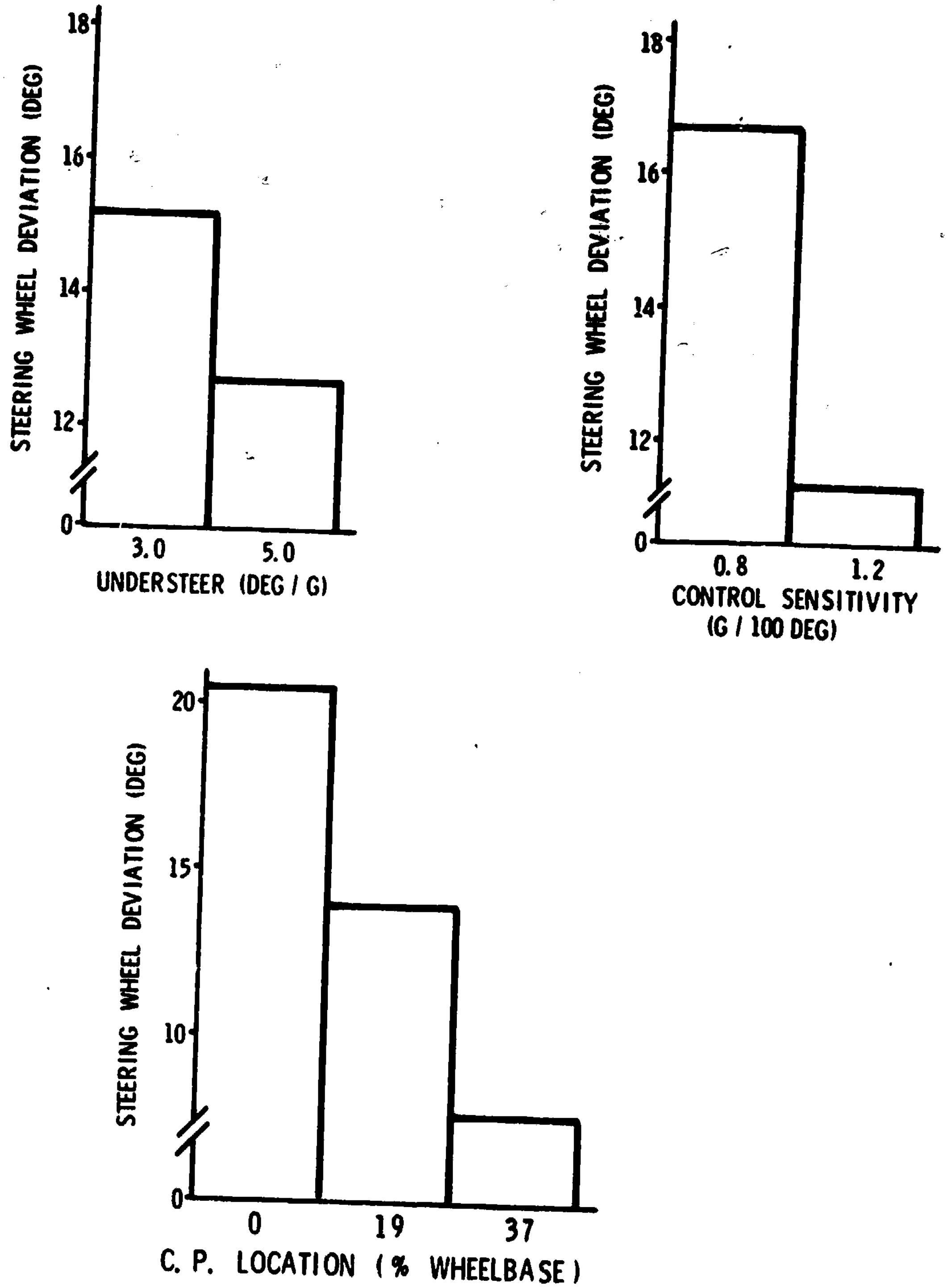

FIG. 8 EFFECTS OF UNDERSTEER, CONTROL SENSITIVITY, AND C.P. LOCATION ON STEERING WHEEL DEVIATION (RANDOM WIND GUST)

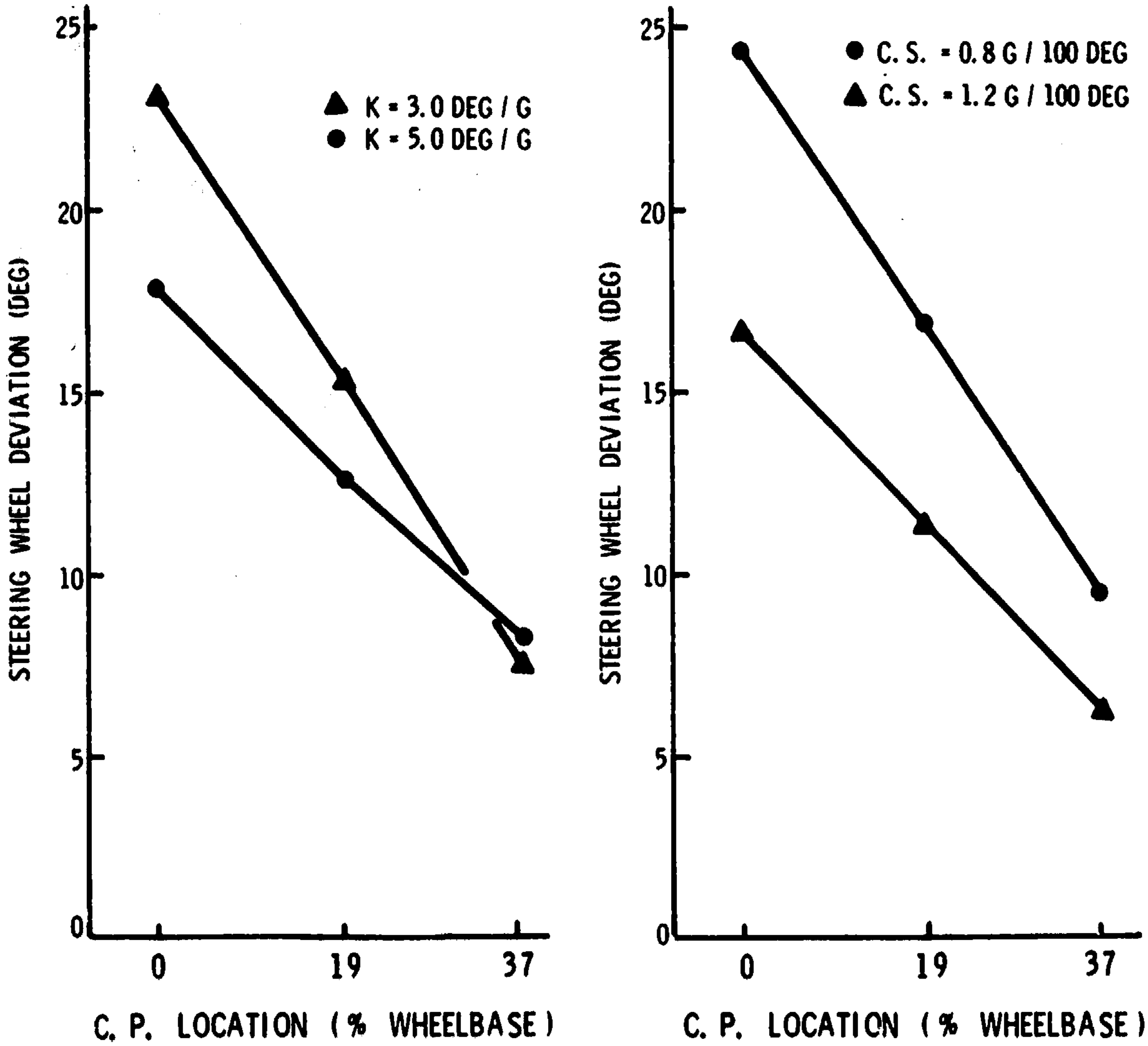

FIG. 9 COMBINED EFFECTS OF UNDERSTEER AND C.P. LOCATION AND OF CONTROL SENSITIVITY AND C.P. LOCATION ON STEERING WHEEL DEVIATION (RANDOM WIND GUST)

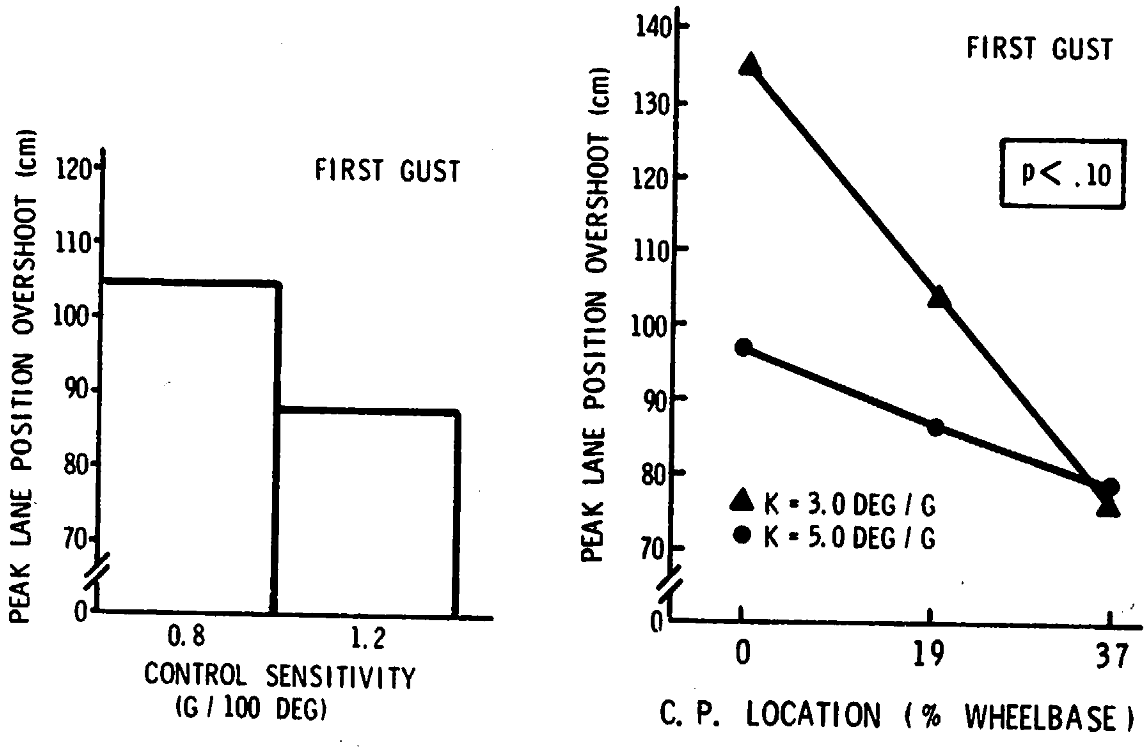

FIG. 10 EFFECTS OF C.P. LOCATION, CONTROL SENSITIVITY, AND UNDERSTEER ON PEAK LANE POSITION OVERSHOOT (STEP WIND GUST)