A Comparison of Real and Simulated Automobile Suspension Systems

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I

INTRODUCTION AND SUMMARY

The extensive and increasing use of simulation in research and development during the past decade has been based to a very large degree on faith. In not more than a very few instances has there been a real opportunity to compare experimental results with simulated results in order to demonstrate conclusively that the simulation was indeed a valid one. In the great majority of cases, the situation was so complex or the experimental results were so difficult to achieve or the simulation was done on such a small part of the whole that the validity of the simulation was an assumption rather than a demonstrable fact.

The present report contains an example of a particularly fortuitous case of simulation in which the situation was complex enough to make hand computations impractical, and yet simple enough so that experimental measurements could be made and compared with the simulation. The results of the simulation coincided with the results of the experimental determination within the limits of the experimental error. Figures 8, 9, and 10 show these results. It can be seen that the simulated curves could be used for prediction of the magnitude of the acceleration which was to be measured and its variation with time.

The experiment reported herein concerned the suspension system of an automobile. It was desired to predict the ride performance of a given automobile with a given set of suspension components and, in particular, to predict the exact motion and acceleration of the body when the automobile drives over a given set of discontinuities and road bumps. Well-instrumented experimental data in the form of accelerometer records of the car traveling over a particular stretch of road were available, as were all of the necessary constants both of the suspension system of the car and of the road itself. The simulation was performed on a conventional electromechanical analog computer. It was concluded that the simulation technique yields test data which are at least as good as the present experimental methods. This study was undertaken as part of a contract between the Willow Run Research Center of the University of Michigan and the Detroit Tank Arsenal for the study of military vehicle suspension systems, and for the study and design of various components of military vehicles and associated equipment. The primary interest under this contract is tanks, and it is intended in the near future to apply these simulation techniques to the suspension of track-laying vehicles.

II

EXPERIMENTAL METHOD

In order to determine the validity of suspension system simulation, comparisons were made between the results of testing an actual suspension with the results obtained by simulating this suspension. The simulation was performed on an analog computer consisting principally of Reeves electronic and electromechanical components. Part of the computer is shown in Figure 1. Because of the high cost of testing an actual military vehicle to determine its suspension characteristics, an automobile, for which experimental data were available, was simulated instead. Accelerometer records were obtained for a Chrysler Corporation car through the courtesy of Mr. R. A. Janeway of the Chrysler Corporation. The necessary engineering constants for use in the simulation, such as moment of inertia and spring and shock-absorber constants, were also supplied for this vehicle. All data were for a car speed of 25 mph.

One additional input for the simulation was necessary: a "road function", to represent the irregularities of the road as seen by the wheels of the automobile. The accelerometer records had been made on Victoria Street in Detroit, Michigan, and therefore a road function for this street had to be obtained. Victoria Street is straight and level between intersections, where it has recently been repaved, and very rough at intersections. Hence the region of interest for comparison of the accelerometer and simulation records was these intersections.

The road function was obtained photographically. A wheel, having the same diameter as the rolling diameter of the car's tires at 25 mph, and having a light bulb attached at its center, was rolled along Victoria Street at night in order to take a time exposure of the light path. This light path is the road function used in the simulation. The wheel used is shown in Figure 2. Figure 3 is a photograph of the light path. The two vertical lines in Figure 3 are from lights held five feet apart for a distance scale.

The maximum change in amplitude between successive maxima and

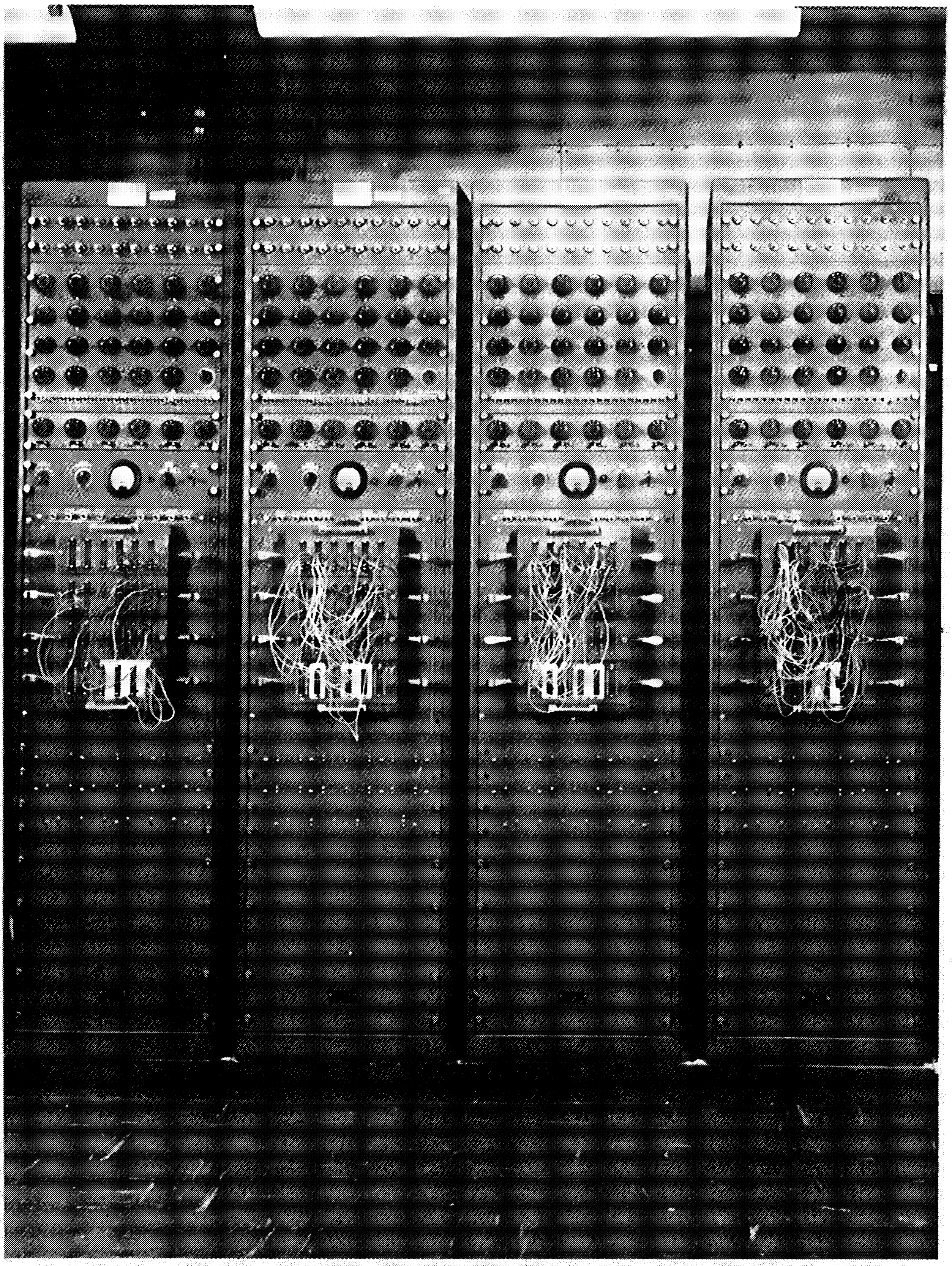


FIG. 1 FOUR RACKS OF THE ANALOG COMPUTING EQUIPMENT

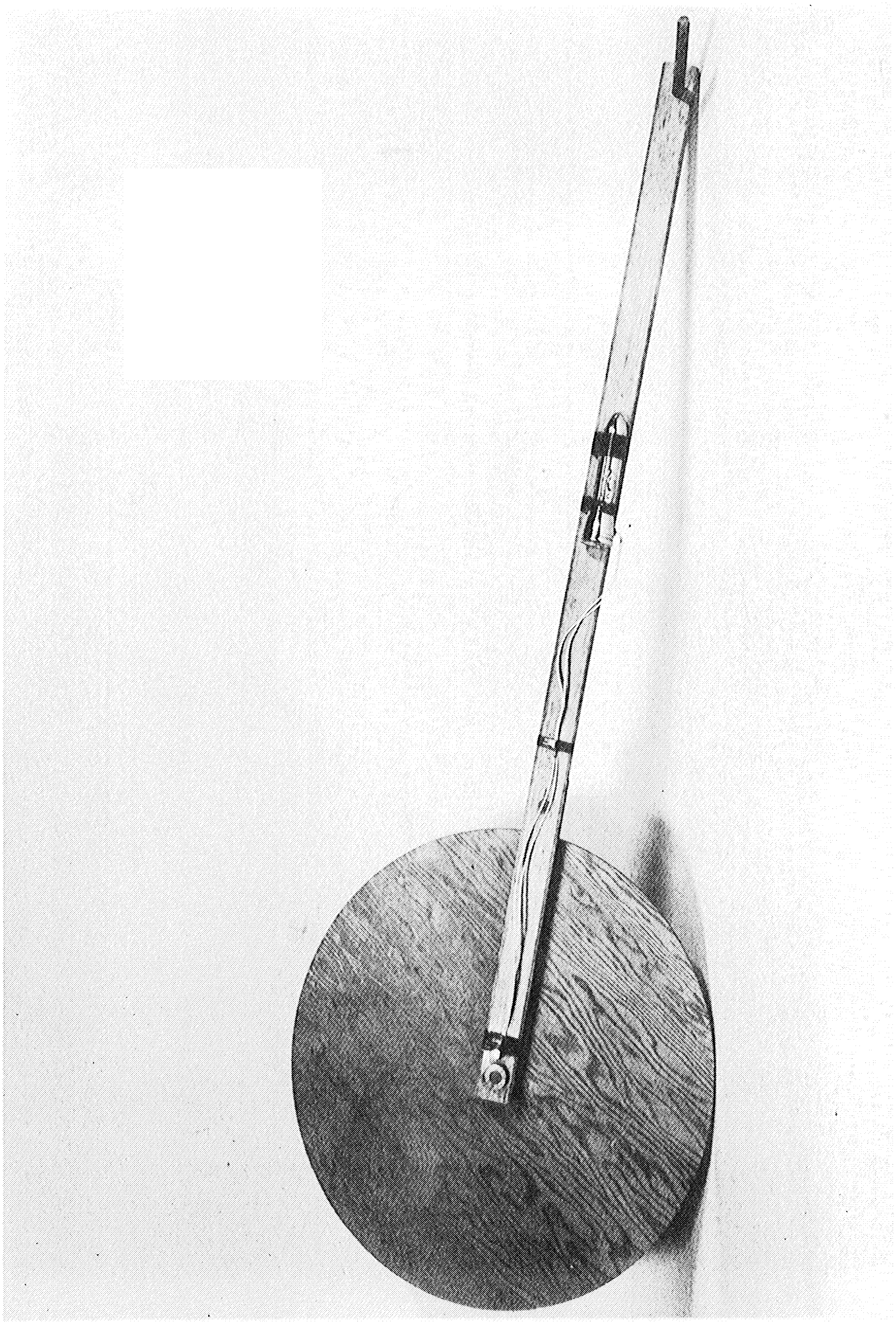


FIG. 2 WOODEN WHEEL WITH ATTACHED LIGHT USED TO DETERMINE ROAD FUNCTION

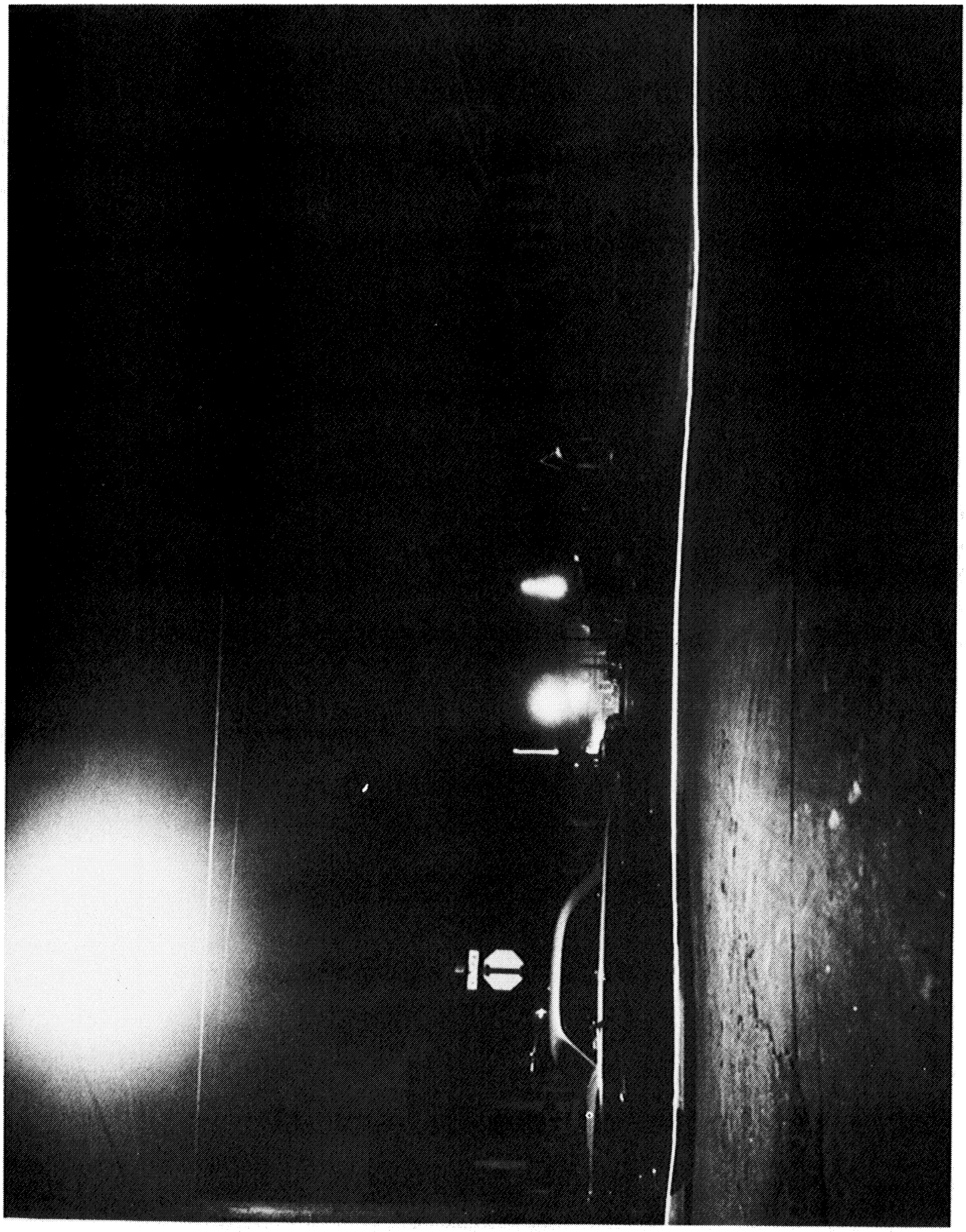


FIG. 3 LIGHT PATH TRACED OUT BY THE WHEEL TO REPRESENT THE ROAD FUNCTION

minima of the road function is only four inches. For this reason, it was concluded that the violent pitch and bounce observed at the intersections is caused mainly by the spacing of the bumps in relation to the wheel base.

In order to simulate the effect of the spacing between the wheels, two identical functions for use on the simulator's function table were constructed from the light path. The function tables were driven by integrators at a simulated speed of 25 mph, with the integrator for the rear wheels 120 inches behind the integrator for the front wheels. It was possible to "drive" the car across the intersection in either direction. Figure 4 is a schematic drawing of the input function generators; Figure 5 shows this equipment in operation.

A conventional coupled mass simulation was made, using linearized spring constants and shock absorber coefficients. The outputs from the road function were used as inputs to the tires and wheel masses in the simulations. The tire and wheel masses were coupled to the body mass. The arrangement of the circuitry for this simulation is shown in Figure 6. The physical situation being simulated and the equations of motion of the systems are shown in Figure 7 A table of constants typical of suspension systems is given in Table I.

The outputs obtained for this comparison were the rotational and vertical accelerations of the suspension system.

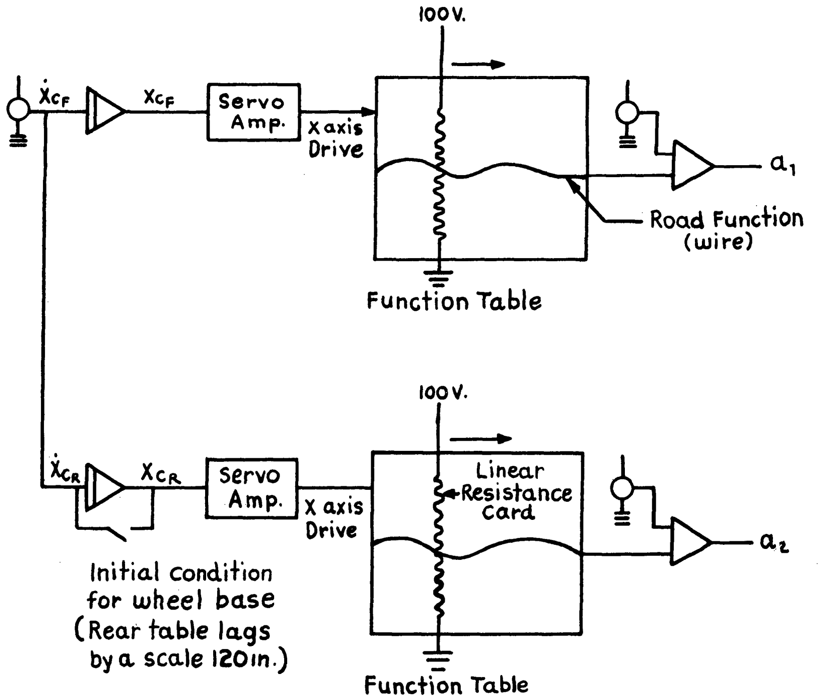


FIG. 4 SCHEMATIC DIAGRAM OF THE INPUT FUNCTION GENERATORS

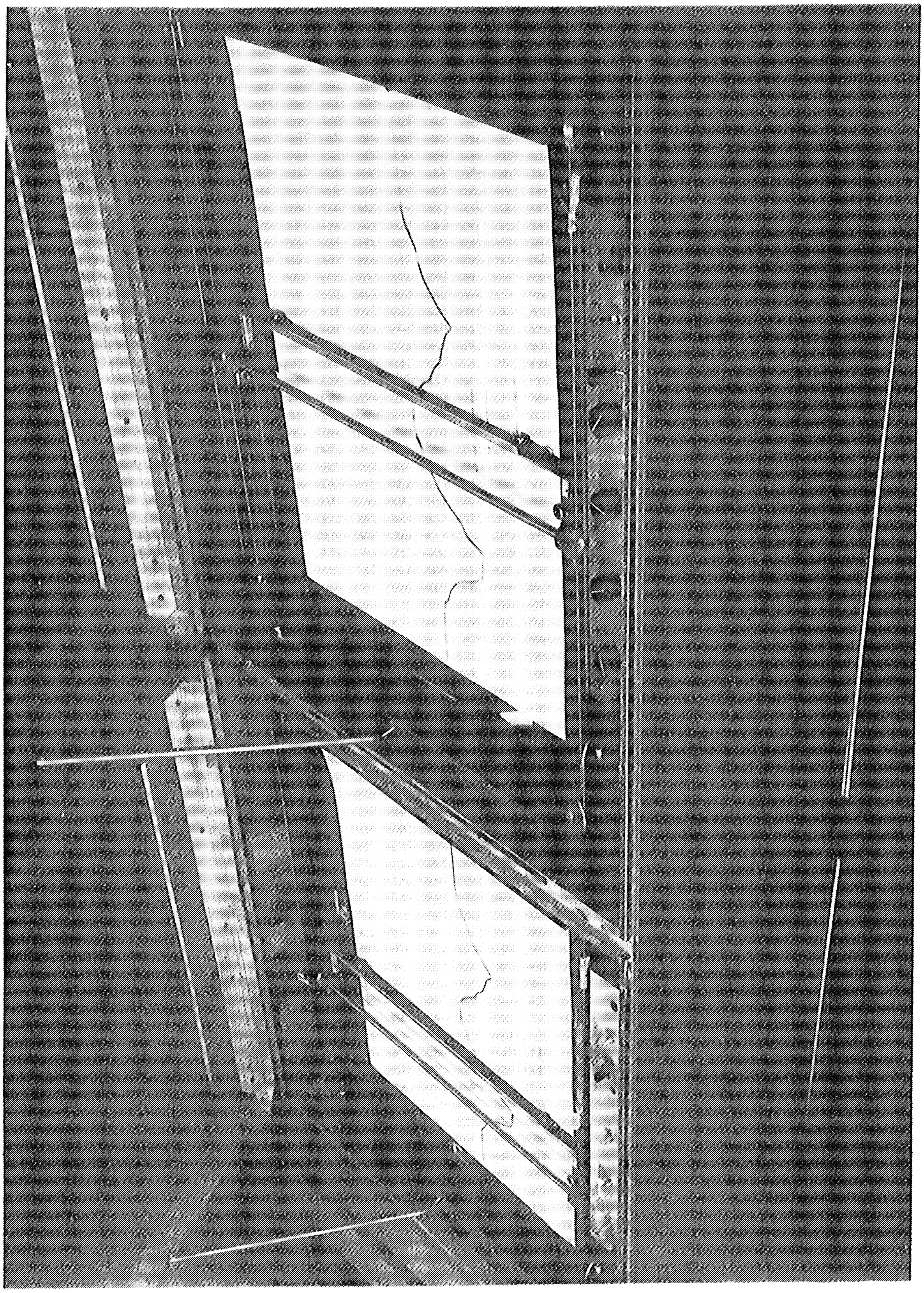


FIG. 5 THE INPUT FUNCTION GENERATORS

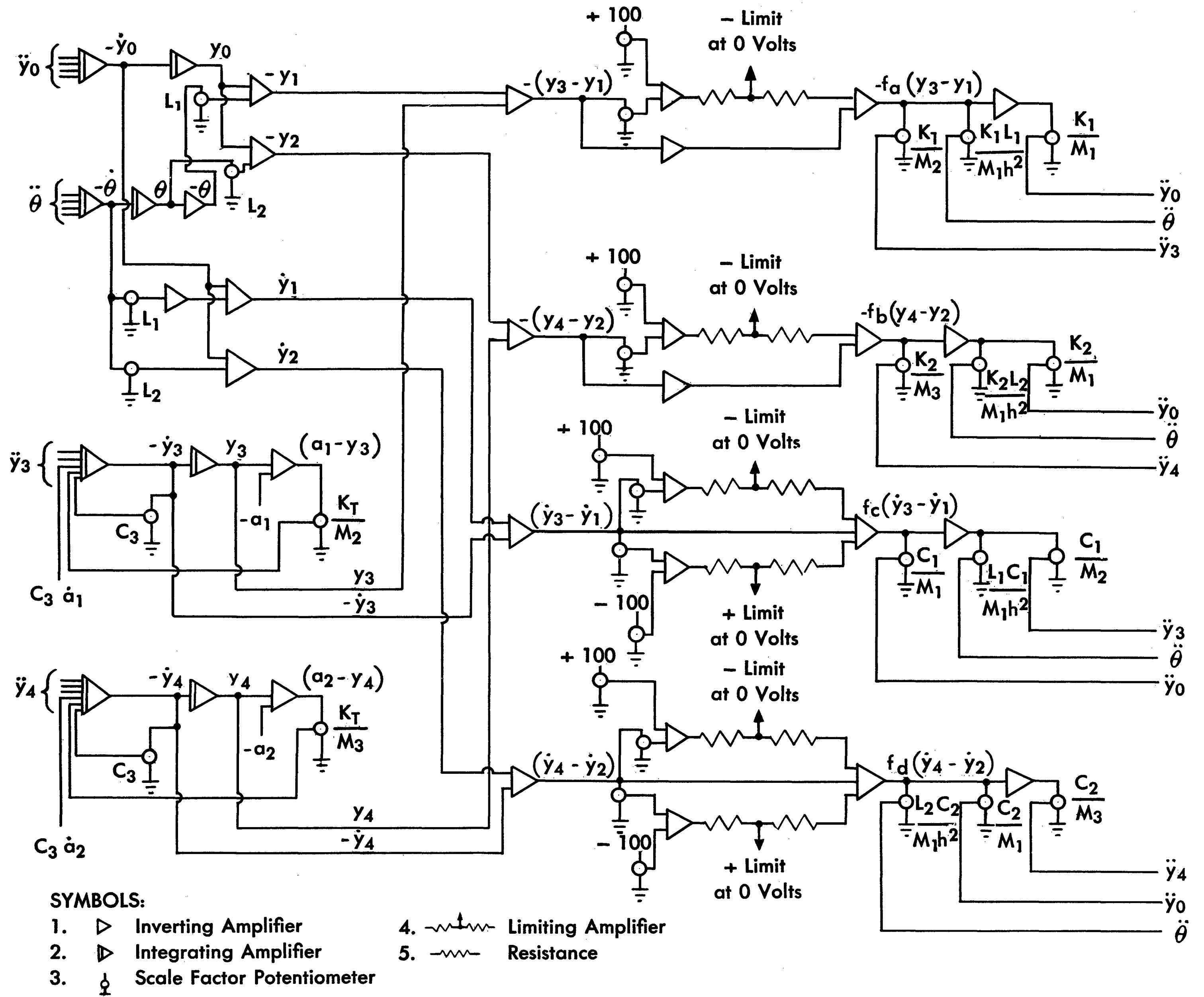
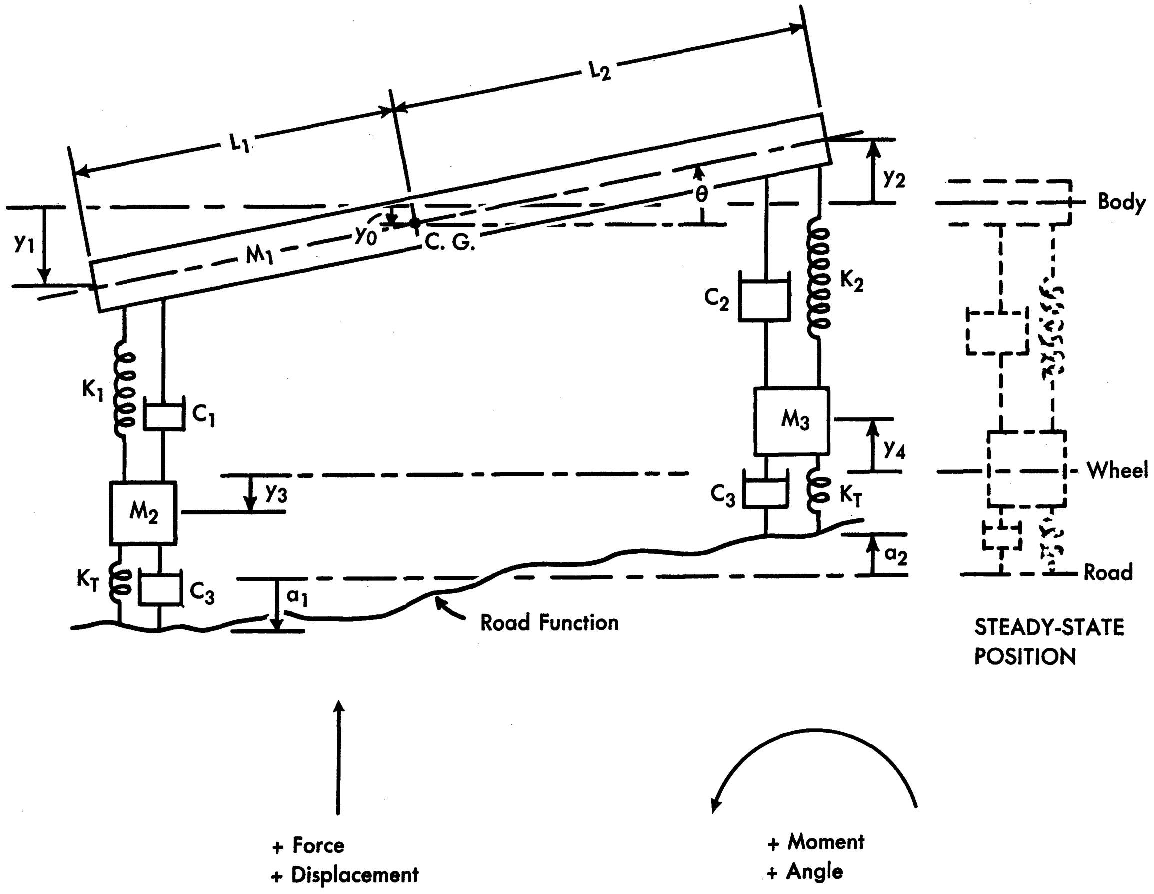


FIG. 6 ARRANGEMENT OF THE SIMULATOR CIRCUITRY



$$M_1\ddot{y}_o = K_1 f_a (y_3 - y_1) + K_2 f_b (y_4 - y_2) + C_1 f_c (\dot{y}_3 - \dot{y}_1) + C_2 f_d (\dot{y}_4 - \dot{y}_2)$$

$$M_2\ddot{y}_3 = K_T (a_1 - y_3) + C_3 (\dot{a}_1 - \dot{y}_3) - K_1 f_a (y_3 - y_1) - C_1 f_c (\dot{y}_3 - \dot{y}_1)$$

$$M_3\ddot{y}_4 = K_T (a_2 - y_4) + C_3 (\dot{a}_2 - \dot{y}_4) - K_2 f_b (y_4 - y_2) - C_2 f_d (\dot{y}_4 - \dot{y}_2)$$

$$M_1 h^2 \ddot{\theta} = -L_1 K_1 f_a (y_3 - y_1) - L_1 C_1 f_c (\dot{y}_3 - \dot{y}_1) + L_2 K_2 f_b (y_4 - y_2) + L_2 C_2 f_d (\dot{y}_4 - \dot{y}_2)$$

$y_1 = y_o - \theta L_1$; $y_2 = y_o + \theta L_2$; $\dot{y}_1 = \dot{y}_o - \dot{\theta} L_1$; $\dot{y}_2 = \dot{y}_o + \dot{\theta} L_1$

Notes:

1. Weight of parts and opposing steady state forces not shown.
2. Term of the form $f(y_a - y_b)$ indicates non-linear function of $y_a - y_b$. Simulation is in form of straight line segments.

FIG. 7 SCHEMATIC REPRESENTATION OF THE AUTOMOBILE SUSPENSION SYSTEM AND EQUATIONS GOVERNING THIS SYSTEM

TABLE I

TYPICAL CONSTANTS USED IN AUTOMOBILE SIMULATION

Sprung mass (M_1) = 130 slugs (3 passenger load)

Front wheel masses (M_2) = 6 slugs

Rear wheel masses (M_3) = 10 slugs

Front spring constant = 100 #/in. increasing to 200 #/in.
Rear spring constant = 150 #/in. increasing to 350 #/in.
Tire spring constant (K_t) = 1000 #/in.

Front shock coefficient (C_1) = 150 #/ft/sec to 0.4 ft/sec, then 500 #/ft/sec

Rear shock coefficient (C_2) = 100 #/ft/sec to 0.9 ft/sec, then 400 #/ft/sec

C. G. to front wheel ℄ · (L_1) = 50 in.

C. G. to rear wheel ℄ (L_2) = 70 in.

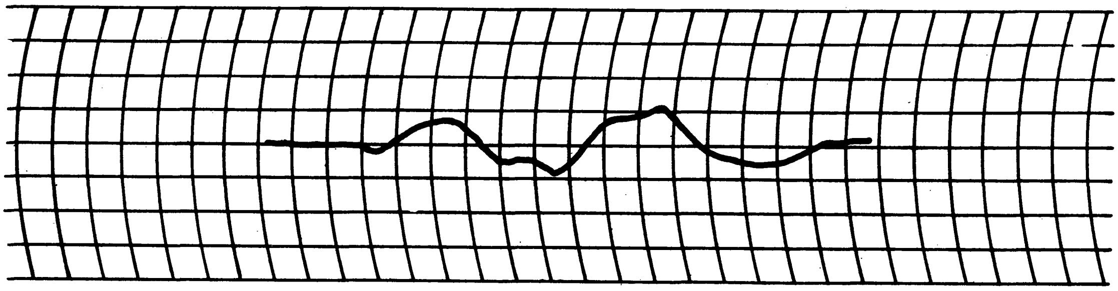
(Radius of Gyration)^2 (h^2) = 3000 in.^{2}

III

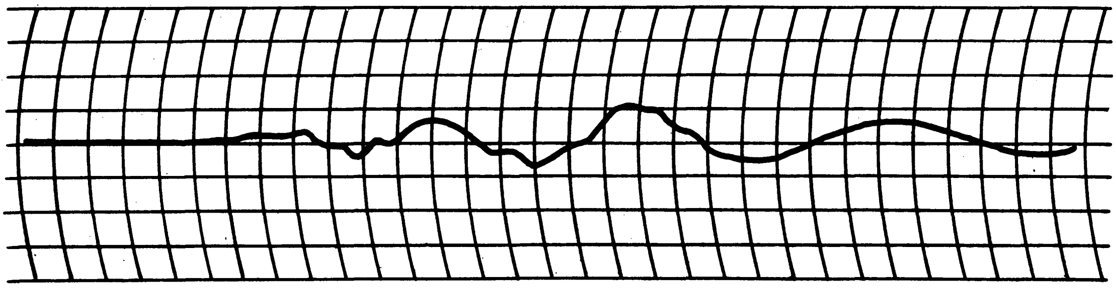
RESULTS

Agreement was obtained between the Chrysler accelerometer data and the simulator data. Figures 8 and 9 show the vertical and rotational accelerations as obtained by the two methods plotted separately and on the same graphs. The simulated results are well within the limits of errors in the experimental data. The small discrepancies were probably caused by such factors as the following:

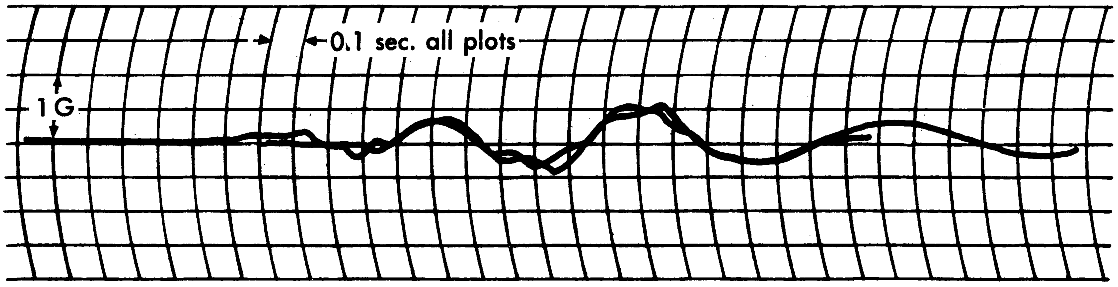
1. The experimental accelerometer data may not have been recorded at constant vehicle speed.
2. The non-linear characteristics of the springs and shock absorbers were approximated by straight line segments and by neglecting coulomb friction, because of the limitations of the simulation equipment.
3. Accurate data on tire characteristics are not available. An elasticity coefficient of 1000 pounds per inch and slightly less than critical damping were assumed in this simulation.
4. The three passengers in the car were considered as part of the main body mass rather than as sprung masses which would affect the main mass motion.
5. Because of photographic limitations, the street had to be considered as perfectly horizontal and smooth for 10 feet on either side of the disturbance. Examination of Figure 3 shows that the approach is neither perfectly horizontal nor smooth.
6. The experimental acceleration data had been recorded with a filter which had a sharp cut-off to eliminate all frequencies above 1.5 cps. Because the computer was operated in 1/10 real time, a comparable filter would require a cut-off at 0.15 cps. Such a filter was used in the simulation, but it did not have as sharp a cut-off as the actual filter. The filter is used to



SIMULATED

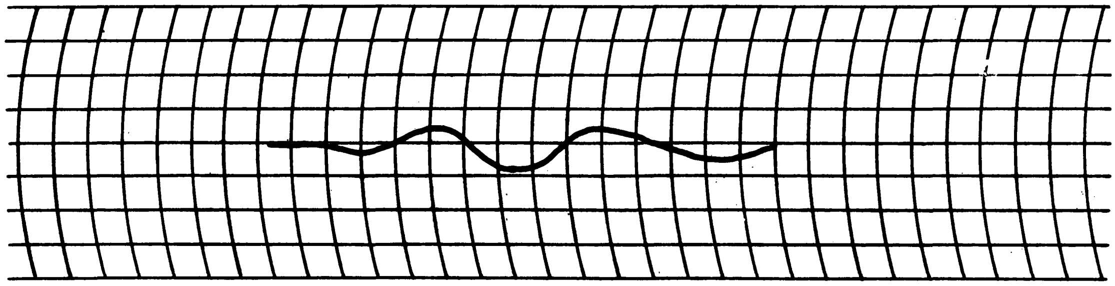


EXPERIMENTAL

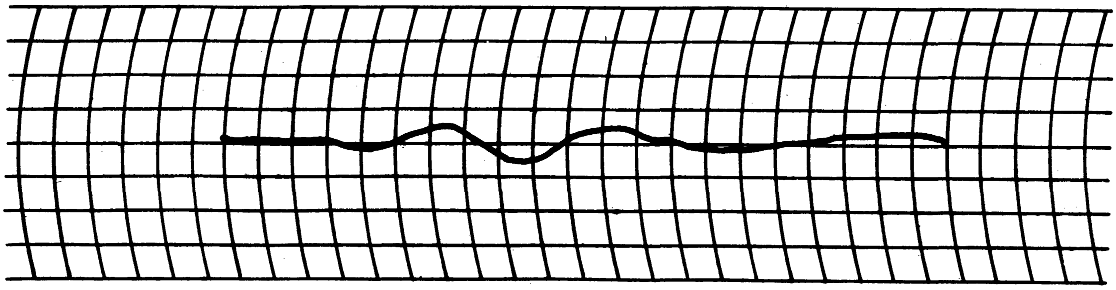


COMPARISON BETWEEN EXPERIMENTAL AND SIMULATED RUNS

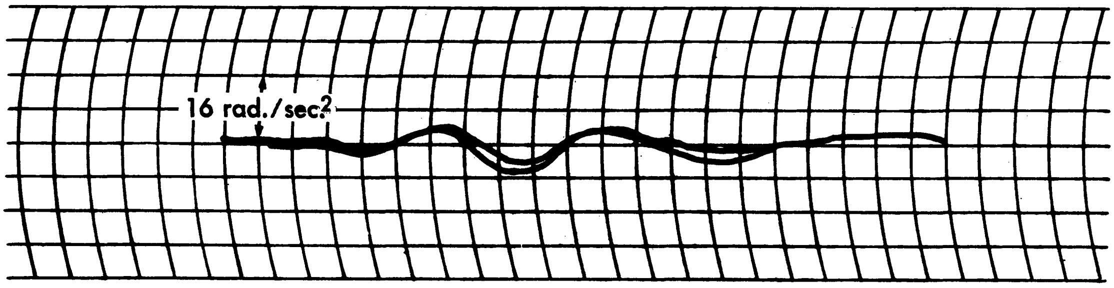
FIG. 8 VERTICAL ACCELERATION WITH FILTER



EXPERIMENTAL



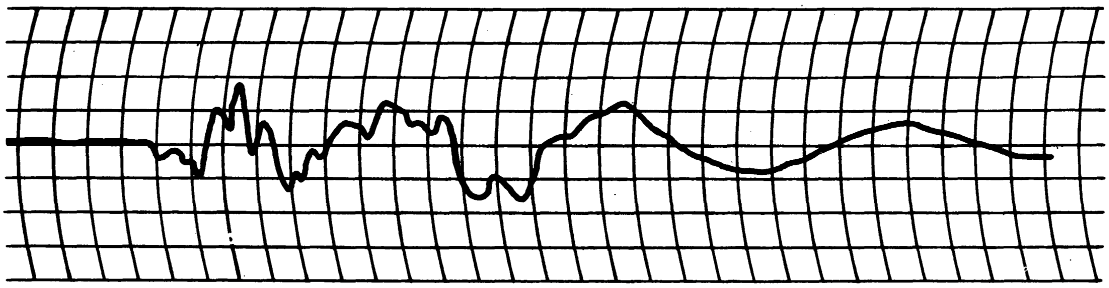
SIMULATED



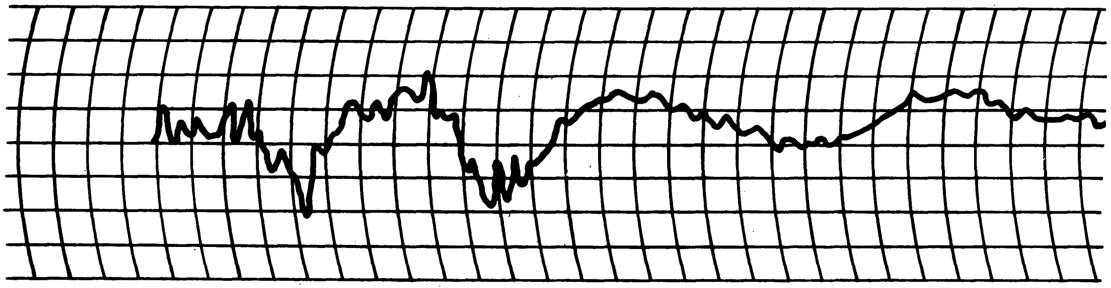
COMPARISON BETWEEN EXPERIMENTAL AND SIMULATED RUNS

FIG. 9 ROTATIONAL ACCELERATION WITH FILTER eliminate road noise, obtained through the springs and shock absorbers, and other background disturbances.

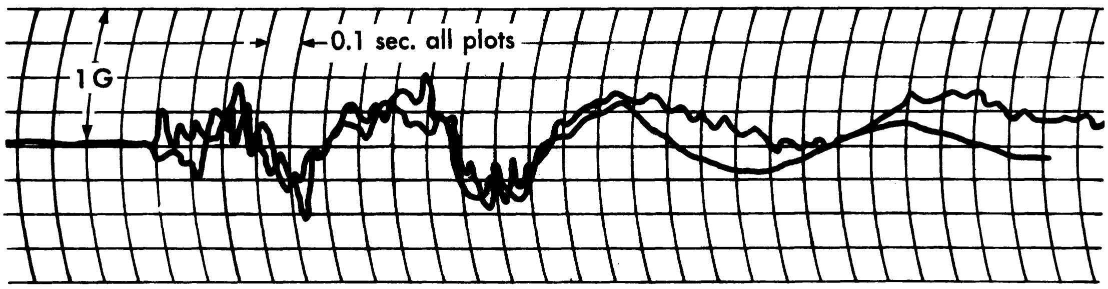
A run was also made on the simulator for vertical acceleration without use of a filter for comparison with a similar experimental run. The results of this comparison are shown in Figure 10. It can be seen from this figure that the 10-cycle wheel hop is very distinct in the simulation, while it cannot be distinguished easily from noise in the actual experimental data.



SIMULATED



EXPERIMENTAL



COMPARISON BETWEEN EXPERIMENTAL AND SIMULATED RUNS

FIG. 10 VERTICAL ACCELERATION WITHOUT FILTER

IV

CONCLUSIONS

Because the simulated results correlate very well with the experimental results, it can be concluded that the simulator is able to provide design data which are at least as good as, if not better than, that provided by the accelerometers. Furthermore, it is also possible to obtain, from the simulation, data on the instantaneous position, velocity, force, or acceleration of any component. Such records, which are very difficult to obtain and to interpret with the available field test methods, are required for the proper design of suspension systems. By use of these data it will be possible to determine easily and cheaply the effect of small changes of parameters on the suspension system being studied.

As was pointed out by the unfiltered run, the simulator can give more useful information than the actual experimental runs because the effects of noise can be separated from the effects being measured. Further refinements in the simulation described herein, such as including passengers as sprung masses, accounting for the coulomb damping in shock-absorbers and spring, and the design and use of a filter with a sharp cut-off at 0. 15 cps, could be included in simulations which are used for design purposes. Such simulations might be expected to yield an even more accurate picture of what occurs in a suspension system.

This experiment has shown that the use of analog simulation is a valid technique in the field of suspension engineering and that it can serve as an invaluable aid to the suspension engineer in the performance of his work.

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