Driving Simulator Research

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● INCREASING AND SPREADING interest in simulators and simulation in general as well as in the specific topic of automobile driving simulation has fostered the writing of this paper about the Institute's research and development program for a driving simulation facility. Two separate devices will be described along with results of testing a number of driver subjects.

As stated in an internal report (1) several members of the Institute staff have become,

> convinced that driving simulation holds tremendous potential
> for really getting at the highway safety problem. We are al-
> so convinced that investment in driving simulation research
> will pay off hundreds of thousands of times over, merely
> through its one aspect of permitting effective pretesting of
> highway designs — such pretesting being normal in most engi-
> neering work but not now possible with highway design inso-
> far as how the driver will react to it is concerned. And fin-
> ally, we are convinced that by promising to really tell us
> something about how drivers behave on the road,. research
> with a driving simulator will provide key information, the
> lack of which is now stimying other lines of investigation.
>   We feel that the need for very extensive and expedited
> development in this simulation field is extremely urgent.
> The tremendous loss of life on our highways should have
> told us in any recent year that the time had arrived for get-
> ting at the basic causes of accidents. Now the urgency is
> multiplied, because we are embarking on a vast highway
> construction program, building-in danger features that can
> lay on us an appalling, accumulating toll of deaths and suf-
> fering and wasted dollars for years and years to come.

An ultimate facility as currently envisioned by the Institute has been described in an earlier publication (2). Certain logical and necessary steps leading to the design of this ultimate facility are being followed and have resulted at this time in two devices wherein drivers can be measured and observed as they "drive" in the research laboratory. In one device the subject drives in a mock-up of a vehicle and in the other device an actual automobile is used.

DYNAMOMETER FACILITY

In a 30- x 20- x 10-ft room, an automobile with its rear wheels on the steel rollers of a chassis dynamometer can be operated in response to two motion pictures. One picture presents the forward view and the other the rearward scene which is seen in the rear-view mirror. On a curved screen 8 ft from the driver the forward picture is shown by a projector located 1 ft above the car in line with the driver's position. The rear picture is projected from inside the car onto a screen which just covers the rear window. Stray light from the projectors is supplemented by two goose-neck lamps containing 5-watt bulbs thus providing fairly uniform illumination inside and outside the vehicle at between 5 and 10 foot-candles. The adjustable dash light is set to balance the illumination and make the speedometer clearly visible. Steering wheel movements displace the forward picture from side to side which gives the driver a strong impression

of controlability of his lateral position on the highway. A "highway feel" of steering is accomplished by having the front wheels rest on turntables to increase ease of movement. The steering system is spring loaded to simulate the self-aligning tendency of a rolling vehicle so that the steering wheel tends to return to center. Engine noise is real, but indicated speed has been made twice that of the actual speed of the wheels on the rollers. This doubling of the indicated speed has the effect of equating it with vehicle noise (engine noise and tire-on-roller noise). A flywheel attached to the rollers simulates vehicle momentum and contributes to realism of engine performance and speed changes.

Engine temperature is controlled directly by an auxilliary radiator and indirectly by a refrigeration air-conditioning unit which controls room air temperature. Tire overheating is prevented by a cooled-air system blowing on the tires. Exhaust fumes are ducted outside the building and there is a constant change of room air.

The vehicle undergoes some low-amplitude vibration at approximately 50 cps produced by the action of the tires on rollers. This action is similar to that experienced and recorded while driving on newly surfaced road.

Driver responses are recorded on four channels of a Brush six-channel, ink-writing recorder. Vehicle speed, steering movements, brake and accelerator pedal action, and the driver's galvanic skin response are recorded along with written notations about the motion picture events being shown to him.

TILTING CHAIR FACILITY

To provide simulation of the physical forces experienced while driving, a driver's compartment is mounted so that it can be tilted fore and aft (pitch) and from side to side (roll) as well as rotated (yaw). The driver's outside view is restricted to a motion picture projected on a cylindrical screen 6 ft from him. This picture, from an extremely wide-angle 160-deg lens, completely fills the driver's field of vision through the windshield aperture. Because this picture is of low brightness the entire room is made dark during projection with all stray light being trapped by a ventilated box that houses the projector.

The essence of this device lies in the fact that both the projection screen and projector are attached to the driver's compartment and, therefore, move with that cockpit when it is tilted. Thus, even when he is tilted the driver's visual world including his horizon reference does not move and the changing physical forces exerted on his body by gravity are then perceived as acceleration forces or centrifugal forces depending on the direction of tilt (pitch or roll, respectively).

At the present time this device is tilted manually in response to the driver's actions and the motion picture scene. When, for example, the driver removes his foot from the accelerator pedal or applies the brake, a signal light informs the operator and he tilts (pitch) the device an appropriate amount and rate depending on the traffic situation.

MOTION PICTURE TECHNIQUES

Electrically driven cameras are mounted fore and aft on a 1957 Chevrolet station wagon. Positioning the cameras so that they are at driver's eye level is crucial if perspective distortion is to be avoided. When highway curves (vertical or horizontal) are to be photographed, it becomes necessary to construct a view finder on the vehicle in order to plan the content of the movie. Each section of highway must be selected carefully for certain characteristics that will appear in the completed movie. The view finder is absolutely necessary for selection of a road with acceptable alignment and sight distances. Road smoothness is desirable but a ride that is too level results in a motion picture that gives the driver a floating or detached experience that is unrealistic and, therefore, undesireable for simulation use.

RESULTS TO DATE

Results can be described in two categories: first, what has been learned about driving simulation techniques, possibilities and feasibilities; and second, what has been learned about driver reactions, responses and opinions.

When presented in these devices, color motion pictures even with a narrow field (approximately 50 deg actual and 38 deg apparent) were far more realistic than was expected. Provided that care is taken in selecting the highway and traffic situations, films such as these can be extremely useful in research. This conclusion is based on the recorded driving behavior of subjects and the personal observations of the Institute staff, other research persons and the naive drivers who volunteered to be subjects. Nearly all these persons have reported without being solicited, that they felt as though they were "on the road" and "in the picture." They also "drove" as though they were truly involved; for example, slowing when sight distance was restricted, increasing speed on straight sections and steering constantly and alertly. To reach this stage of simulation fidelity, it was necessary to:

1. Make the projected front image fill at least 50 deg of the driver's view.
2. Adjust the speed of film projection to suit individual perferences.
3. Double the indicated speed to offset noise generated by the engine and dynamo-meter.
4. Mechanically link the steering mechanism to the transverse rotation movement of the front projector.
5. Simultaneously project a rearward scene to be viewed in the rear mirror.
6. Spring load the steering mechanism to return the steering wheel to center.
7. Provide approximate highway conditions of resistance to steering movements.
8. Select highway sections and traffic events so that critical information was not expected by the driver to occur outside of his field of view.
9. Instruct the driver that only normally encountered situations would occur on this trip and that he was to assume himself to be on a cross-country trip where he would continue on this road at least the next one-half hour and not have to look for turn-offs or directions.

Approximately 50 deg of visual field was judged to be the "balance point" in terms of realism of effect, in the compromise between clarity of picture and size of picture. This balance point would vary with the characteristics of the camera lens and projection lens that would be used. Apparently size distortion of objects in the picture is of minor importance providing the movie does not contain scenes showing an approach too close (approximately 20 ft) to vehicles or other objects that are directly in the path. Objects to the side (passed or passing) can undergo size distortion within wide limits and still be acceptable. Motion pictures such as these can be used successfully to simulate driving providing a two-lane highway with no stops for crossroads is used and no slower moving vehicles are encountered. Faster moving vehicles which pass are accepted but may be responded to. Horizontal curves are accepted when sight distance is not restricted by the edge of the picture. Vertical curves are accepted up to a difference in grade of approx. 10 percent. At this amount of curvature, sight distance was drastically reduced for a brief period of time (less than $\frac{1}{2}$ sec). This could conceivably be corrected by panning the camera down then up at just the correct time. Dips in the road are accepted and in fact seem to enhance the realism at least up to $\frac{1}{2}$ ft in 10 ft when driven over at 50 mph. There is an interaction between the length of the dips and the speed of the camera car (or apparent speed, when projector speed differs from camera speed) such that the longer the dips the faster the car must go in order for the duration of picture disorientation to remain within acceptable limits.

To date, in addition to trial work, 47 subjects have been tested at least once on the dynamometer driving simulator device; 12 of these subjects have been tested more than once. Seventeen of these drivers were recruited from the UCLA Medical Center outpatient population. Twenty-one of the subjects are volunteers from the student body population. Nine staff member volunteers have been tested twice and two of them three times.

Each driver on each test session experienced two simulated trips, each of approximately 15-min duration. One drive is over a straight road and the other is over a winding road. Traffic is light on both trips and no stops are required. Records of their speed, steering, brake and accelerator pedal movements and their GSR, have been analyzed for a series of traffic events during each trip and for the trip as a whole.

TABLE 1

	Students		Staff		Outpatients	
	Range	Median	Range	Median	Range	Median
(a) Speed (mph)						
Winding Road:						
Max.	33-66	55	35-57	44	29-66	46
Avg.	0-51	35	18-42	33	0-62	31
Min.	0-40	13	0-33	13	0-53	11
Straight Road:						
Max.	37-73	57.2	40-70	53	37-84	59
Avg.	31-66	48	35-62	42	29-64	44
Min.	0-59	31	0-51	35	0-57	24
(b) Steering Wheel Movement (deg)						
Winding Road:						
Max. left turn	36-360	132	72-168	120	24-288	132
Max. right turn	60-384	144	60-288	120	24-300	156
Straight Road:						
Max. left turn	0-120	72	12-84	24	24-240	60
Max. right turn	12-300	84	12-120	36	24-180	84
(c) Speed Reduction Behavior						
Winding Road:						
Times brakes used	0-21	10	0-24	1	0-30	8
Times car slowed	4-32	20	3-33	13	0-29	20
Straight Road:						
Times brakes used	0-3	0	0-3	0	0-9	0
Times car slowed	1-18	7	0-12	2	0-17	6

Table 1 (a) shows that speeds were slower on the curved road for all three groups. There is considerable overlap among the speeds and among the groups. Because there was no direct speed feedback the ranges are no doubt much larger than would be found on the actual road.

Table 1 (b) reveals greater amounts of maximum steering wheel movement on the winding road for all three groups. Some tests were conducted without steering feedback (linkage between wheel and projector). Under these conditions, steering wheel movements were grossly oversize. Differences between the winding road and straight road are clearly evident in Table 1 (c) which shows consistently smaller numbers of speed reduction actions on the straight road.

All of the previously mentioned conclusions are in accordance with what one would expect drivers to do on these two roads. The extent of the ranges for the recorded values is perhaps surprising when one considers that all drivers were exposed to identical driving environments.

In order to assess the extent of practice effects, 12 drivers (7 students and 5 staff) were tested more than once. At least three weeks elapsed between first and second drivers. Subjects were instructed to look on these trips as repeat journeys over the same routes they had driven during the initial test session.

TABLE 2

GROUP COMPARISONS OF FIRST WITH SECOND DRIVE

	First Drive		Second Drive	
	Range	Median	Range	Median
(a) Speeds (mph)				
Winding Road:				
Max.	37-61	46	37-59	35
Min.	0-17	7	0-31	17
Straight Road:				
Max.	42-73	59	37-59	48
Min.	0-22	33	15-44	35
(b) Steering Wheel Movement (deg)				
Winding Road:				
Max. left turn	36-240	120	36-252	120
Max. right turn	72-384	96	60-288	120
Straight Road:				
Max. left turn	12-240	60	0-204	24
Max. right turn	12-300	60	0-216	24
(c) Speed Reduction Behavior				
Winding Road:				
Times brakes used	0-22	11	0-10	4
Times car slowed	5-33	21	4-32	17
Straight Road:				
Times brakes used	0-3	0	0-3	0
Times car slowed	0-18	9	0-13	4

Group comparisons are given in Table 2 (a), 2 (b), and 2 (c). There is no clear evidence of differences between the group of first drives and the group of second drives.

Collections of individual comparisons between first and second drives are given in Table 3 (a), 3 (b), and 3 (c). No consistent, statistically significant differences appear. The greater number of braking actions during the first drives over the winding road is statistically significant but there is no evidence of a similar difference for the straight road drives. Conversely the difference in number of times car slowed that occurred during the straight road trip did not occur during the winding road trip. Thus, there is little or no evidence in these data for any practice effect. Verbal reports from the subjects suggest that they found the second drive to be more "natural" in that they "felt more confident" and "had time to look around a little at the scenery."

The behavior of these 47 drivers as they negotiated the winding road made quite clear the fact that many of these drivers had difficulty steering around curves. A recent study by Stewart (3) provides field data that also show drivers have trouble with curves. A possible rating system for sections of highway is suggested by Chandler, Herman and Montroll, et al. (4) in their concept "acceleration-noise" which resembles the "number of times braked" and "number of times slowed" scores reported in this paper. These scores are apparently more sensitive than some of the others that were used and are not difficult to record.

With the tilting chair device it has been possible to produce accelerometer records quite similar to those taken in a vehicle making normal and panic stops.

Ten naive experimental subjects and 12 research persons report experiencing a greater degree of realism when the cab was tilted than when it remained stationary.

TABLE 3

	Number of Drives		
	1st > 2nd	2nd > 1st	1st = 2nd
(a) Speed Comparisons Between 1st Drive and 2nd Drives			
Winding Road:			
Max.	5	5	1
Min.	2	8	1
Straight Road:			
Max.	9	3	0
Min.	4	6	2
(b) Steering Wheel Movement Comparisons Between 1st and 2nd Drives			
Winding Road:			
Max. left turn	4	6	3
Max. right turn	7	5	1
Straight Road:			
Max. left turn	8	4	0
Max. right turn	7	3	1
(c) Speed Reduction Comparisons Between 1st and 2nd Drives			
Winding Road:			
Times brakes used	11	0	1
Times car slowed	6	5	0
Straight Road:			
Times brakes used	4	3	6
Times car slowed	10	1	1

Realistic simulation of centrifugal forces and positive acceleration has been easier to accomplish than simulation of negative accelerations. This is due to the fact that negative accelerations are usually of greater amplitude with shorter onset times and, therefore, require more skill and strenuous action on the part of the human operator and often result in a less appropriate motion of the device. This empirical evidence has been supplemented by conclusions reached by analytical methods, as follows:

During an automobile ride, the human body is subjected to a number of forces which can be classified into three groups: disturbance forces due to car action or road deficiencies, gravity, and inertia forces. In the first group are included such forces as those caused by vibration of the car, rough surface of the road, etc. Gravitational force remains constant but the reactions (that is, the reaction of the car seat on the human body) change with different orientations of the car with respect to the earth; thus any road incline changes these reactions. Inertia forces are due to changes in velocity and direction. Simulation of the first two types of forces does not represent a serious problem. However, simulation of inertia forces is a more complicated matter. Before discussing the methods of simulating inertia forces it is appropriate to analyze these forces as they appear during a ride.

Kinematics of a Human Body Considered as a Point in Motion on a Plane Curve

The path of a point P along the plane curve is shown in Figure 1. V_1 and V_2 are the velocity vectors, they are tangent to the path. The values of the tangential and normal accelerations are:

$$a^T = \frac{V_1 - V_2}{dt} = \frac{dV}{dt} = s\,\overset{o}{w} = s\,\frac{d^2\theta}{dt^2} \qquad (1)$$

$$a^N = \frac{Vd\theta}{dt} = \frac{d\theta}{ds}\,V^2 = \frac{V^2}{s} = w^2 s = \left(\frac{d\theta}{dt}\right)^2 s \qquad (2)$$

It is clear that in order to evaluate a^T and a^N the values of s and θ have to be known.

Consider a point P representing a human body in a car proceeding a long flat curve (Fig. 2). It is known that for any flat curve the curvature can be expressed as follows:

$$\frac{1}{s} = \frac{d\phi}{ds} \qquad (3)$$

Inasmuch as the dimensions "a" and "b" are much smaller than s,

$$ds \approx b \qquad\qquad d\phi \approx \phi$$

thus

$$\frac{1}{s} = \frac{\phi}{b}$$

Further, from the geometrical relationship in Figure 2

$$\frac{b}{\phi} = \frac{a}{a - \phi} \qquad\qquad \phi = \frac{b}{a}\left(a - \phi\right)$$

$$\phi + \frac{b}{a}\phi = \frac{b}{a}\,a \qquad\qquad \phi = \frac{b/a\;a}{1 + b/a} = \frac{a\,b}{a + b}$$

$$s = \frac{a + b}{a} = \frac{L}{a} \qquad (4)$$

in which L = a + b = wheel base in feet
      a = average turn angle, in radians.
For Figure 1 Eq. 3 can be written

$$d\theta = \frac{ds}{s} \qquad (5)$$

$$\underline{v} = v\,\hat{v}$$

$$\underline{a} = \frac{dV}{dt} = \frac{dV}{dt}\,\hat{v} + v\,\frac{d\hat{v}}{dt}$$
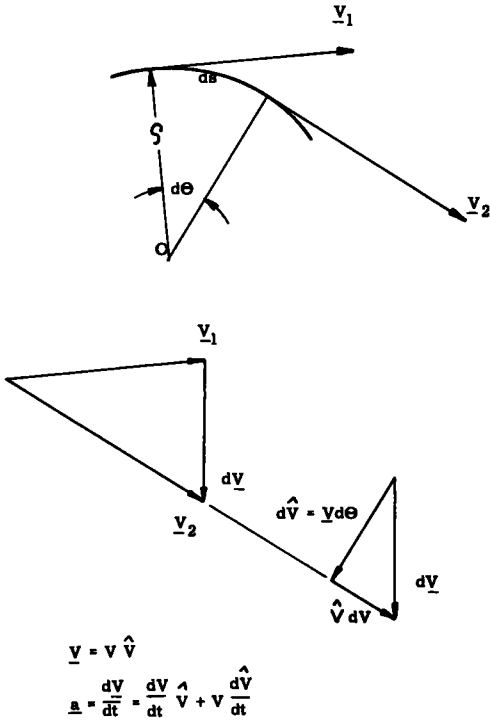
Figure 1.

but

$$ds = R\,d\psi \qquad (6)$$

in which R = radius of the wheel in feet
      ψ = angle of rotation of the wheel in radians.
Substituting the values for s and ds in Eq. 5

$$d\theta = \frac{R\,a\,d\psi}{L} \qquad (7)$$

thus

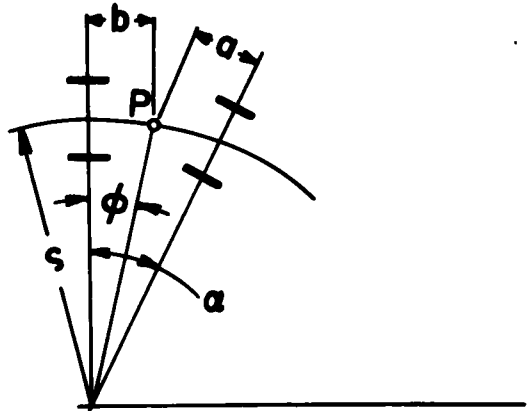$$w = \frac{d\theta}{dt} = \frac{Ra}{L}\,\frac{d\psi}{dt} \qquad (8)$$

Figure 2.

and

$$\overset{\circ}{w} = \frac{d^2\theta}{dt^2} = \frac{R}{L}\left[\alpha\frac{d^2\psi}{dt^2} + \frac{d\alpha}{dt}\frac{d\psi}{dt}\right] \tag{9}$$

Now the tangential and normal accelerations can be written

$$a^T = s\,\overset{\circ}{w} = \frac{R}{\alpha}\left[\alpha\frac{d^2\psi}{dt^2} + \frac{d\psi}{dt}\frac{d\alpha}{dt}\right] \tag{10}$$

$$a^N = w^2 s = \frac{R^2\alpha}{L}\left(\frac{d\psi}{dt}\right)^2 \tag{11}$$

These are the general equations for a^T and a^N.

In case when α = const.

$$\frac{d\alpha}{dt} = 0$$

$$a^T = R\frac{d^2\psi}{dt^2} \tag{12}$$

and

$$a^N = \frac{R^2\alpha}{L}\left(\frac{d\psi}{dt}\right)^2 \tag{13}$$

Figure 3.

in case when

$$\frac{d\psi}{dt} = \text{const.} = n$$

$$a^T = 0 \text{ and } a^N = \frac{R^2\alpha}{L}n^2 \tag{14}$$

For the motion on a straight line

$$\alpha = 0 \quad a^N = 0$$

$$a^T = R\frac{d^2\psi}{dt^2} \tag{15}$$

SIMULATION OF INERTIA FORCES

Let a be the value of simulated acceleration. The simplest way to simulate an acceleration is to rotate the subject and in this manner obtain the tangential component of g equal to the desired value a. Analyze the process of deceleration in the case of a sudden stop. The simplified deceleration graph is shown in Figure 3.

To simulate acceleration (or deceleration) by means of an orientation of vector g it will be useful to determine the value of a_1 and the angle of tilt θ_1 that is associated with it.

Consider now the forces acting on a point (body of mass m) moving along an arc of radius r in a vertical plane, when simulating the deceleration (Fig. 4).

NORMAL FORCE
$$F_N = mg\cos\theta + m(\overset{\circ}{\theta})^2 r \tag{16}$$

Tangential force
$$F_T = m\theta v + mg\sin\theta \tag{17}$$

Because
$$F_T = ma^T \text{ and } F_N = ma^N,$$

$$a^N = g\cos\theta + (\dot{\theta})^2 r \tag{18}$$

$$a^T = r\ddot{\theta} + g\sin\theta \tag{19}$$

Figure 4.
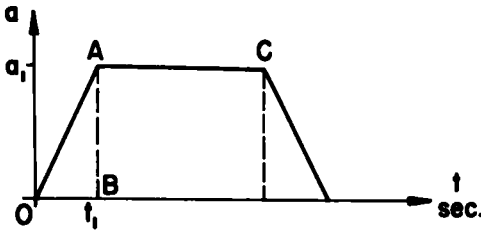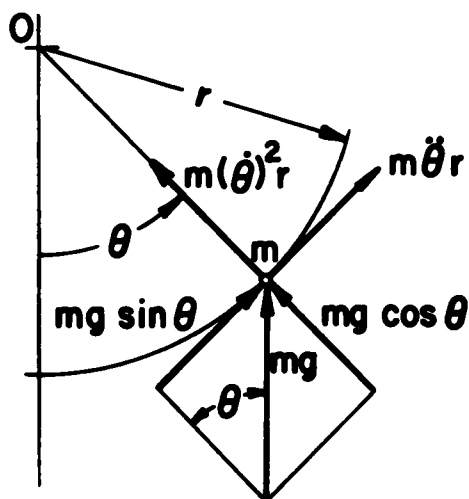
The acceleration simulating the deceleration is a^T, given by Eq. 19. It consists of two terms $\ddot{\theta} r$ and $g \sin \theta$. Component $g \sin \theta$ is a tangential component of vector g and component $\ddot{\theta} r$ which is the result of motion of point m from the state of rest to some position defined by the angle of tilt θ_1. There are two possible situations when the component $\ddot{\theta} r$ is equal to zero:

1. When the point m is at rest (ruling out motion with constant angular velocity).
2. When $r = 0$ (point m lies on the axis of rotation).

Figure 5. Angular acceleration.

Inasmuch as a human body cannot be considered as a point, it is quite clear that different parts of the body will have different values of $\ddot{\theta} r$ (due to difference in r). This component will only appear in the intervals $0 < t < t_1$ and $t_2 < t < t_3$ and because it is an undesired term it may be called a disturbance.

During the transition from 0 to θ_1, $\ddot{\theta}$ changes its value from 0 to $+\ddot{\theta}_{max}$ to 0 to $-\ddot{\theta}_{max}$ and to 0.

Assuming a sinusoiodal character for these changes (Fig. 5), the amplitude of θ is inversely proportional to the square of time t_1 (time at which θ_1 is reached) and proportional to θ_1 itself. Thus for great t_1 (that is, for a moderate rate of deceleration) one has disturbances of low amplitude which may not be detected by human senses. On the other hand for small values of time t_1 the amplitude of the disturbance is high but of short duration. This is shown in Figure 6 where for const. θ_1 two values of t_1 are considered; a'_T, a''_T are the sums of the disturbances $\ddot{\theta} r$ (r taken as unity) and $g \sin \theta$ which for small angles (up to 30 deg) can be written with sufficiently good approximation $g \theta$ It is a goal of this research to investigate whether these disturbances are within the limits of human perception and if so to find the way to minimize them.
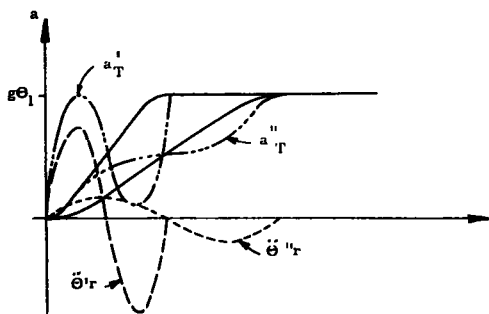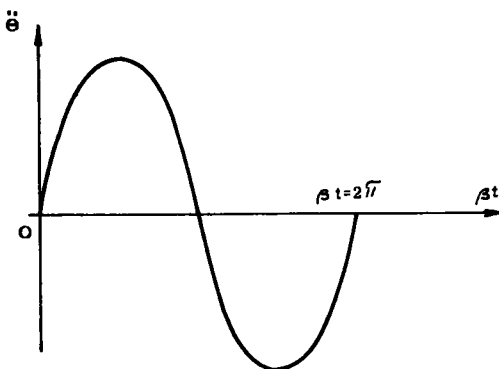
It is fair to assume that a great part of these disturbances is damped out before they reach the sensing organs. An important part of this research is to find if there is an optimum point in a human body which should be taken as a center of rotation (a point for which $r = 0$ and therefore $\ddot{\theta} r = 0$).
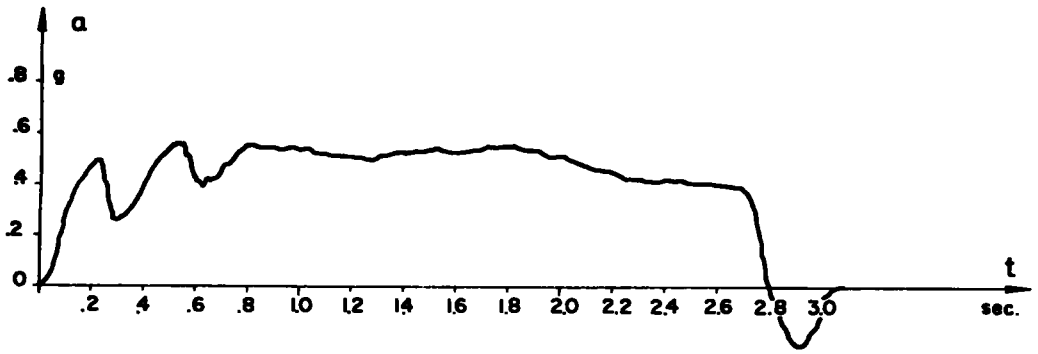

Figure 6.

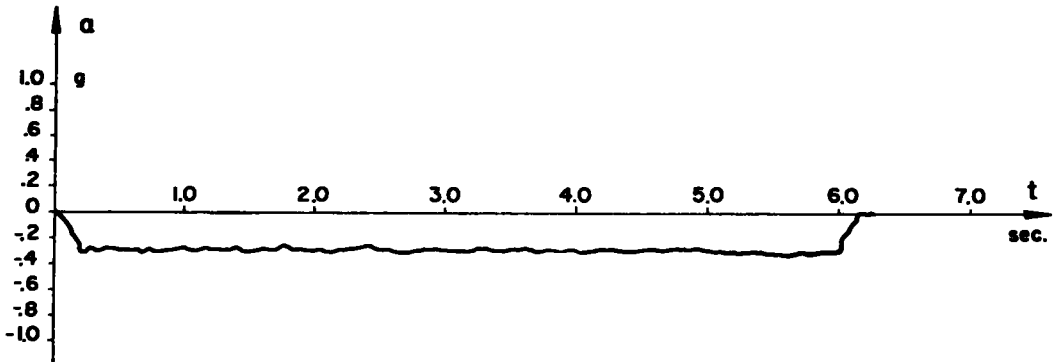Figure 7. Sudden stop from 35 mph.
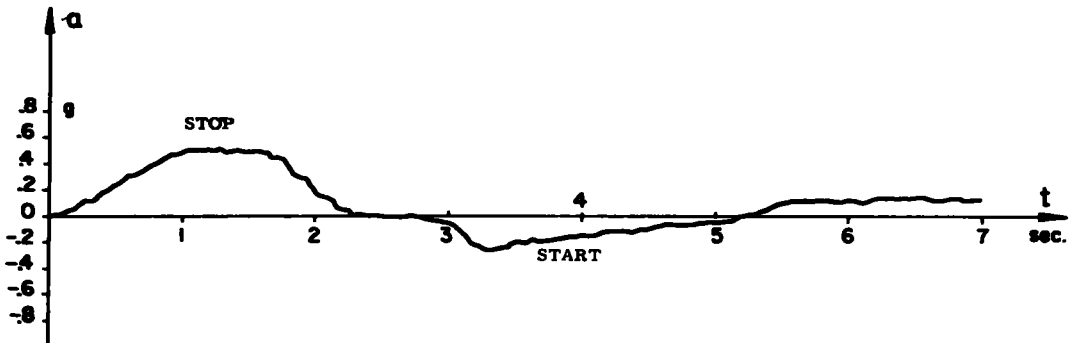

Figure 8. Acceleration up to 35 mph.

Figure 9. Stop and start.

Accelerations Experienced in Driving

Because knowledge of actual accelerations is of great importance in simulation of inertia forces, the Institute conducted numerous road tests. Deceleration values were of primary interest and they were taken in several traffic situations. In addition to these road tests, the accelerations experienced in the tilting chair were measured. Positive values are shown for deceleration and negative for acceleration in Figures 7-12.
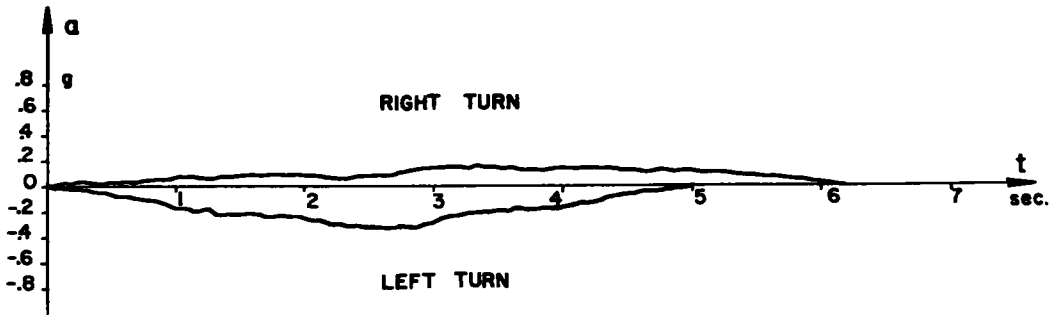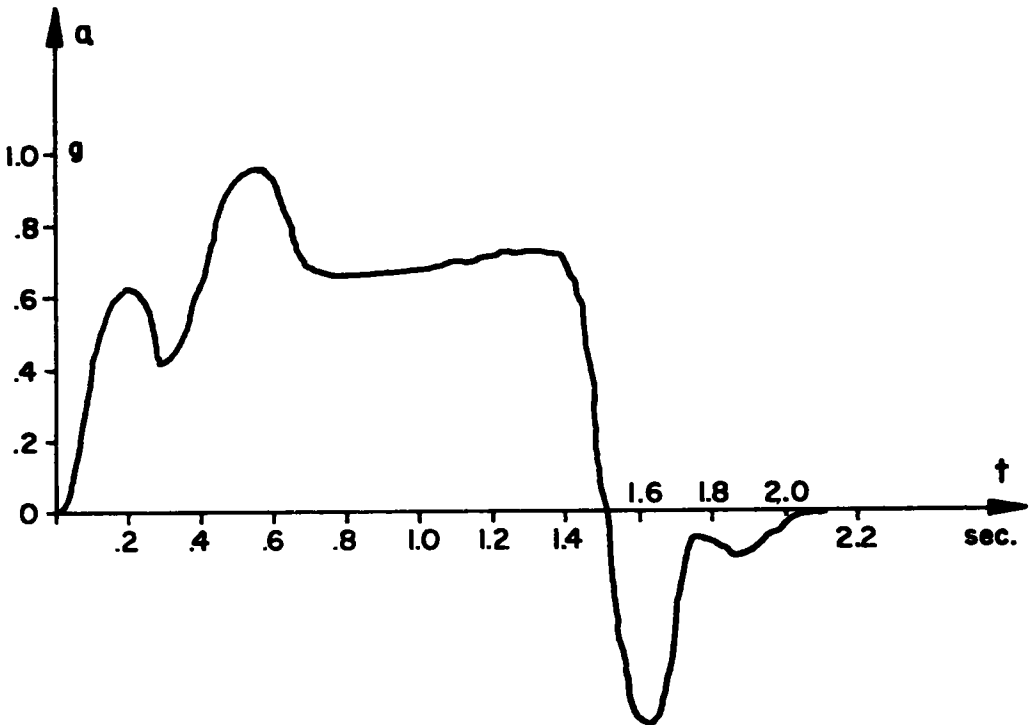
Figure 10. Left and right turn.

Figure 11. Sudden stop from 20 mph (in actual car).

It is important to observe a resemblance of curves in Figures 11 and 12, where Figure 12 represents the deceleration in a simulated drive in the tilting chair. The only difference is a "wrong direction" (negative) disturbance caused by the fact that the axis of rotation was placed about $1\frac{1}{2}$ ft below the seat. Were this axis taken above the center of gravity of the body this disturbance would have a positive sign.

The fact that there is an intimate relation between types of research problem and varieties of simulation techniques has been made increasingly clear as experience has been gained with drivers on the Institute's simulation devices. There is no doubt a positive relation between fidelity of simulation and realism of the resulting driver behavior. It is helpful, however, to consider the types of simulatable traffic situations separately from the fidelity with which those situations can be simulated. The visual
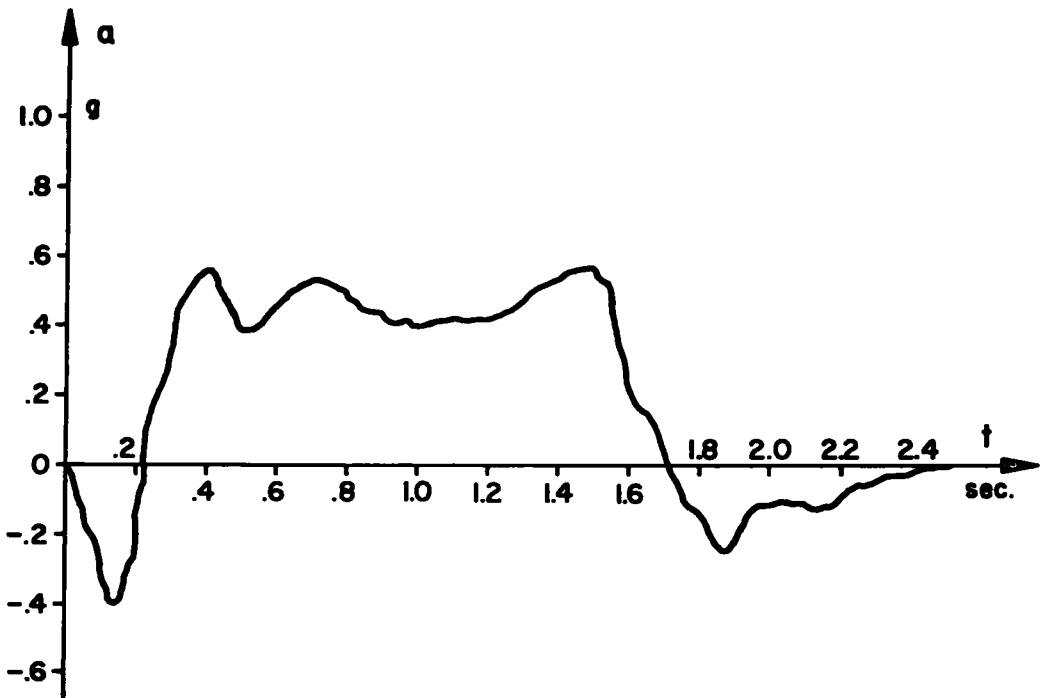
Figure 12. Simulated sudden stop from 20 mph in tilting chair.

TABLE 4

Traffic Situation	Examples of Research Problems	Type of Simulation Visual Display
Cross-country or freeway driving where no cross traffic is encountered and no vehicles overtake or are passed, and either there is only one lane or no reason for changing lanes or making unusual speed changes.	Steering systems, some highway signing and pavement markings, physical and mental conditions of drivers, temperature and noise effects on driving, highway design features not involving actions of other vehicles or drastic speed changes.	Motion picture, forward view, steering feedback (moving projector) projection speed variable but not linked, camera car attempts to follow normal patterns of speed and lateral placement, camera speed normal (24 frames/sec).
Add overtaking vehicles.	Tendencies to speed up when being overtaken, reactions to being followed at various distances.	Same, plus motion picture rearward view.
Add events that will cause large speed changes for some drivers and small or none for others (for example, object on or near road, dips). Subtract other moving objects at locations where slowdowns might occur.	Reactions to more unusual events, classification of driver's, highway signing and pavement markings where speed changes are intimately involved, highway design features involving speed changes.	Projection speed linked to vehicle speed, camera car attempts uniform speed and lateral placement, camera speed high (35 frames per sec).
Add two lanes available or freeway situation where changes between two lanes may be desirable.	Greater range of steering system use, highway signs and pavement markings involving lane changes, highway design features and conditions requiring lane change.	Two projectors forward, two projectors rearward (only one set exposed at a time). Two camera cars running alongside each other or two passes of single car over deserted road.

display system is the limiting factor in determining the types of traffic situations that can be presented. Aspects other than visual (for example, sound and physical forces) are important as they bring about the fidelity of simulation. Thus, fidelity is in this sense a different dimension which can be considered separately for each type of visual display system. In Table 4 traffic situations are given along with the corresponding type of visual display system and examples of the types of problems that may be investigated. Only those systems currently under trial at the Institute are included in this table.

REFERENCES

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