AN ABSTRACT OF THE THESIS OF

David Arthur Bassett for the Master of Science
(Name) (Degree)

in Mechanical Engineering presented on Oct. 23, 1970
(Major) (Date)

Title: FEASIBILITY STUDY OF A SURFACE VEHICLE UTILIZING A UNITARY CONTROL SYSTEM

Abstract approved: Redacted for Privacy
Linwood E. Johnson

A feasibility and practicality study was made of an automotive-type surface vehicle that employed a centralized or unitized means of control. The control functions consisted of: steering, acceleration, deceleration, clutch actuation, gear changes, turn signal operation and horn actuation. These controls were arranged in such a manner that the driver used only his right hand and arm to effect total vehicle operation and control.

The study was accomplished by three avenues of approach. They are: (1) "historical", (2) analytical, (3) experimental. For the historical analysis, a survey of similar existing systems with their particular advantages and disadvantages was completed. The analytical portion took the form of an analog simulation of the steering response to a given input.

The experimental aspects of the study dealt with both quantitative and qualitative information in that a test vehicle was constructed, instrumented and tested for steering response, sensitivity, stability, response time, and control transfer functions. The qualitative portion was achieved by utilizing different operators, (some of whom were physically handicapped) to evaluate the vehicle's handling characteristics and overall system acceptability.

The control system concept demonstrated its feasibility, practicality and desirability by successful operation, quantitative testing and driver evaluation.

Major advantages of this system concern improvements in the following areas: (1) Safety; more maneuverability, shorter response time, no distraction of remote switches, unimpaired view of instrument panel, crash protection, and reliable mechanical system. (2) Convenience; more "natural" control action, reduced physical motions and forces for operator, handicapped person's aid, driver fatigue reduced, no seat adjustment needed. (3) Historical; novel system to change the monotony of years of wheel controlled vehicles.

Feasibility Study of a Surface Vehicle Utilizing a Unitary Control System

by

David Arthur Bassett

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1971

APPROVED:

Redacted for Privacy

Professor of Mechanical Engineering

in charge of major

Redacted for Privacy

Head of Department of Mechanical Engineering

Redacted for Privacy

Dean of Graduate School

Date thesis is presented Oct. 23, 1970

Typed by Barbara Eby for David Arthur Bassett

ACKNOWLEDGEMENTS

Major Professor, Linwood E. Johnson, is greatly thanked for the many hours devoted to this thesis. Professor J. G. Mingle and mechanician J. R. Kellogg contributed much advice and patience with the construction and testing phases as did Professors W. W. Smith and C. E. Smith with the analytical and computer aspects.

Appreciation is also expressed to Dr. H. J. Dalhke for his advice that led to instrumentation of the vehicle.

The encouragement extended by my wife and the cheerful sacrifice of many many hours of togetherness leads me to lovingly dedicate this thesis to her.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF QUESTIONAIRES

FEASIBILITY STUDY OF A SURFACE VEHICLE UTILIZING A UNITARY CONTROL SYSTEM

I. INTRODUCTION

Project Definition

The project was originally conceived some years ago due to a deep rooted belief that the "stick" type of control system in certain aircraft is far superior to the later "improved" version of a wheel for roll and pitch control. It is this author's conviction that the natural adaption of man to machine was sacrificed when the wheel-type control system was introduced. The loss of control "feel" was thought to be of a magnitude such that emergency situations would be markedly more difficult to handle than they would be if the pilot were provided with a unitary type of control system or "stick".

These beliefs were strengthened both by years of personal piloting experience and by becoming familiar with Air Force jet fighter aircraft and their handling qualities specification (MIL-F8785)(19) while employed as a stability and control engineer at the Air Force Flight Test Center, Edwards AFB, California.

This project was designed to apply these beliefs to a ground or surface type of vehicle and to approach the problem from an encompassing view point. That is, the means of evaluating the feasibility, practicality and desirability of the vehicle would include analytical, experimental and qualitative information and would be supplemented by "historical" comparisons with similar existing control systems.

This method of approach is in line with the desired graduate training for being a designer or project engineer and employs not only the technical skills of the engineering profession but management and human relations skills as well.

The project simply stated, then, was to design, analytically model, historically compare, construct, empirically test, and evaluate a surface vehicle employing a unitized or centralized control system such that complete control of all necessary functions could be maintained at all times by a driver using only his right arm and hand.

Purpose and Justification of the Study

The proposed purposes of the study could be enumerated as demonstrating improvements in the following areas:

1. Safety: More maneuverability, shorter response time, no distraction of operating remote switches, unimpaired view of instrumental panel, no wheel to strike in an accident and redundent mechanical system.
2. Convenience: More natural control response, reduced physical motions and required forces for the operator, handicapped person's aide, driver fatigue reduced, no seat adjustment needed.

3. Historical: Lunar rover control system needs, many years of cumbersome wheel and pedal arrangements, automotive research vehicles using similar systems.

Each of these will be discussed in greater detail in later sections, but an example of the safety increases due to better driver visability is expressed in the following quotation (7): "Eyes-on-the road behavior is directly related to safe performance and the likelihood of crash occurrence decreases, in some as yet unspecified functional relationship, with a decrease in the time required for the driver to visually monitor panel instruments, or for his hand-arm motions to gain access to a control."

II. UNITARY CONTROL SYSTEMS

System Description

A general discussion as to the development, advantages and disadvantages of power assisted steering is well illustrated by the following passage (17): "The adverse effect on steering of further increases in vehicle weight, particularly in trucks and buses, was partly offset by increased steering ratios with the result that some are close to 40 to 1. While such a high ratio may sufficiently multiply the driver's pull at the rim of his steering wheel to permit steering of sorts, the sensitivity or "feel" of the road is greatly reduced; furthermore, in an emergency too much precious time is lost in "winding up" a high ratio gear. Flying elbows during such an emergency are in themselves hazardous! Even engineers frequently do not realize that the universal use of inclined king pins to obtain automatic straightening of front wheels has had a detrimental byproduct: during any movement of a front wheel, the driver through his steering gear must actually lift all of the weight on both front wheels! "

The particular steering gear box, hydraulic assist, and pump for this study were taken from a 1952 Chrysler. The gearbox is an integral unit with the assist cylinder built-in and was a high quality design in the year when 200,000 (8) of the units were built. The original system had an overall gear reduction ratio of 16.2 to 1 and had a total travel of the wheel of 3 1/2 turns from lock to lock. Detailed pictures of the overall vehicle, hydraulic system, and clutch actuation system are available in Appendix II. It should be noted that the vehicle was constructed in its entirity for use in this project.

The modification to the input of the steering gearbox consisted of using two gears, one with 11 teeth and the other with 132 teeth, to change the 3 1/2 turns into approximately a 100 deg. sector through which the stick now travels (Figure 1). The overall transfer function for the side to side or steering motion is 1.56 deg. input to 1 deg. of output at the front wheels. The lever arm of the stick is 22 inches in length and is topped by a regulation USAF fighter aircraft stick grip.

The forward direction of the stick provides more power from the engine by opening the throttle with a ratio of 4.9 in. input to 1 in. of output. Such a transfer function provides approximately 60 mph. in 4th gear with a forward stick motion of 3 1/2 inches (Figure 2).

Rearward motion of the control lever provides braking of the vehicle with a transfer function of 4.9 in. input to 1 in. output at the brake master cylinder (Figure 2). This arrangement provides the ability to apply maximum braking effort with a stick motion of 1 1/2 - 2 inches.

The control handle or stick grip houses a variety of finger controlled switches which provide various functions in the vehicle (Figure 3). The trigger is actuated by the right hand index finger and serves

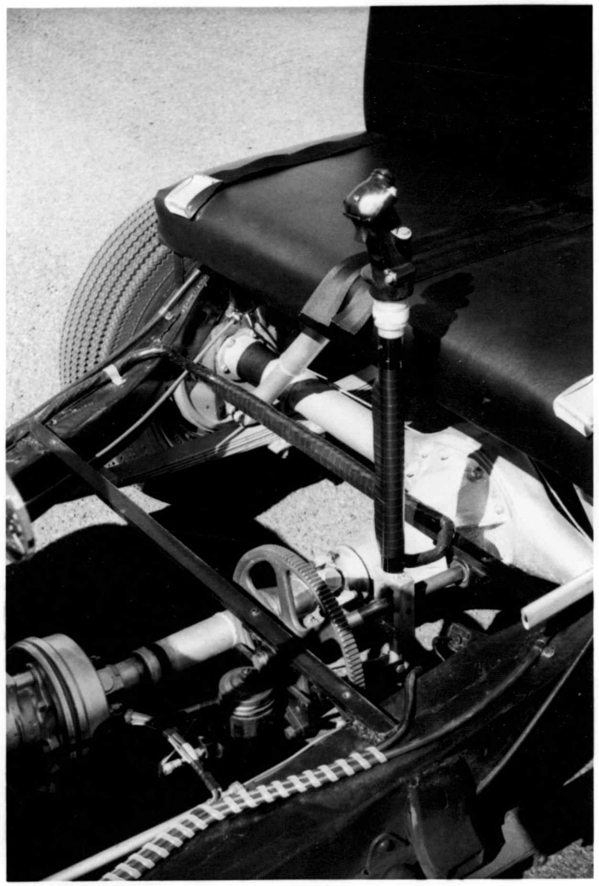


Figure 1. Stick configuration.

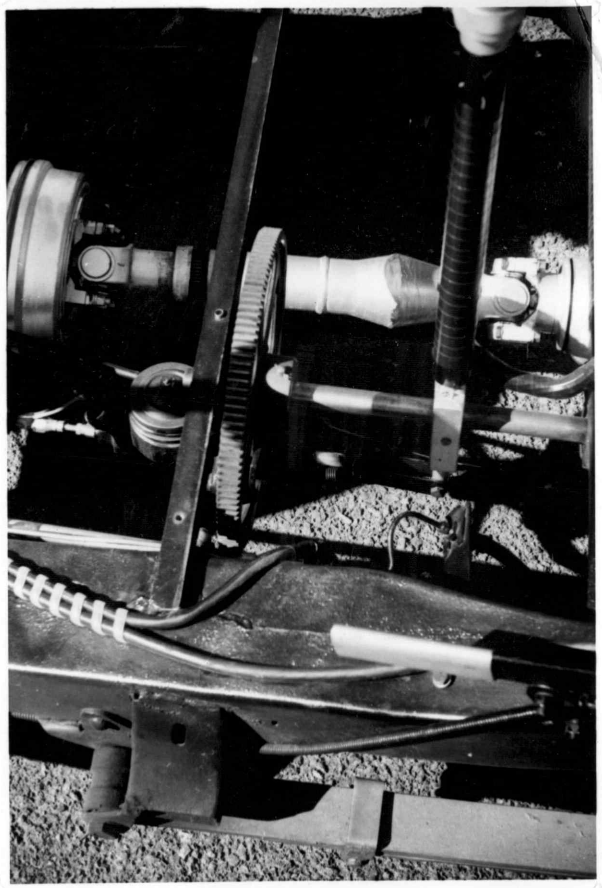
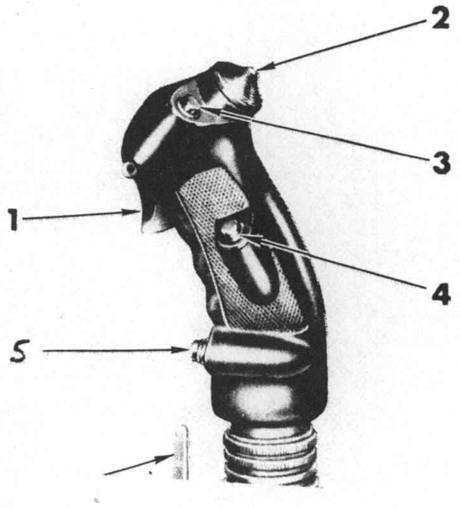


Figure 2. Throttle and brake attachment.

to disengage the hydraulically powered clutch. Clutch engagement is achieved by releasing the trigger, which in turn closes a valve and allows the clutch cylinder to gradually return to an engaged position. The "coolee-hat" button at the upper part of the grip actuates a servo motor for gear changes when pushed up, turn signals when pushed from side to side, and seeks neutral when pulled down. A red button adjacent to the "coolee-hat" achieves down shifts from 4th to 3rd and from 2nd to 1st. The next button lies about half way down the left side, is actuated by the thumb, and honks the horn. A solenoid that moves the reverse gear lever is actuated by the lowest button on the grip and must be used in conjunction with the upper position of the "Coolee-hat" switch.



Code:

1. Clutch control
2. A. Fore & aft = gear changes
   B. Side to side = turn signals
3. Downshift button
4. Horn
5. Reverse gear control

Figure 3. Stick grip switches and functions.

The only other controls that are not directly a part of the main control lever are the head light dimmer switch and the emergency brake lever, both of which are operated by the left hand. Other remotely located controls are the ignition, starter, and headlight switches.

Similar Systems

The project began by making a rather thorough literature search and by writing to General Motors, Ford, Chrysler and American Motors to inquire about any unique control systems that might have similarities to the proposed one.

General Motors has developed a similar system (15) with respect to control motions and directions but the actual control sensors are electronic. Such a system is high in cost and has no direct mechanical redundancy so that failure of a major component leaves the operator helpless to alter the vehicle's mode of operation.

The G. M. report concerning their "Unicontrol" system states that:

> The principal task of a driver operating a car is the regulation of its speed and direction. In conventional cars this is accomplished by the use of three control elements -- steering wheel, throttle and brake pedal. These elements have evolved with vehicle design along lines generally dictated by mechanical expediency, simplicity, and limitations imposed by the muscular ability of the driver. For example, we push on a brake pedal with our foot because we can exert large forces in this manner. Steering ratios and the use of a wheel have similarly been established primarily on the basis of their suitability for manual steering systems.

The G. M. report continues to discuss their control system which is fully electro-hydraulic in nature and present block diagrams to illustrate component interaction (Figures 4 and 5).

These diagrams show the method of automobile response feedback via the acceleration effects on the control system bob mass affixed to the top of the stick rather than through the system components as occurs in a more normal mechanical system.

G. M. cites the following operational advantages of a unicontrol system: "Positive front wheel positioning is provided which makes the car path less sensitive to external wind and road disturbances. Also, brake actuation time is reduced since the driver already has his hand on the proper control element as soon as he perceives the need to stop" (15).

In comparison, the system used here at O. S. U. has the same basic control motions as the G. M. system but is mechanical, reversible, and economically much more attractive. The previously cited advantages for this system would also include the more positive front wheel positioning discussed above but is accomplished without the use of elaborate electronic and sensory controls.

The Ford and Chrysler control systems are basically yoke arrangements with two small wheels (wrist twist) in the Ford system and with two pistol grip levers in the Chrysler vehicle. American

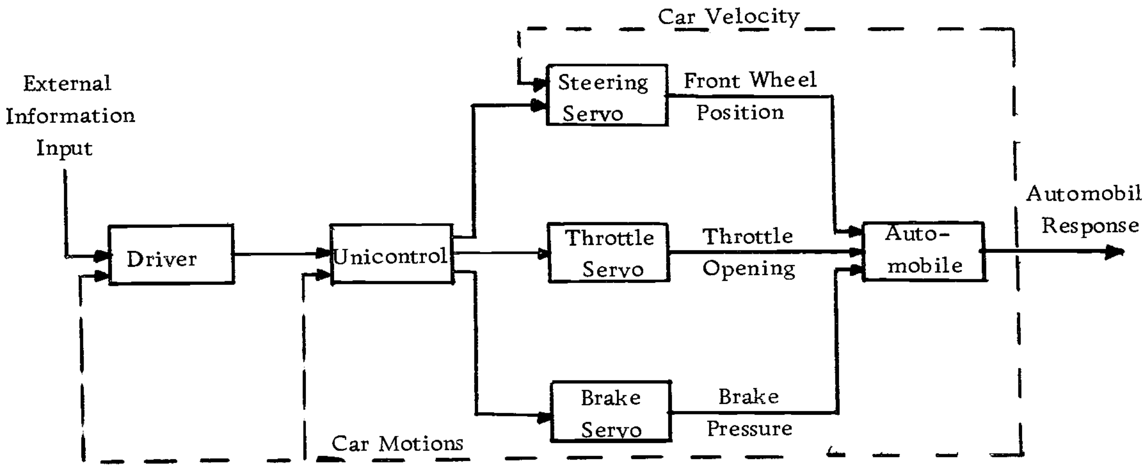


Figure 4. G. M. driver unicontrol block diagram.

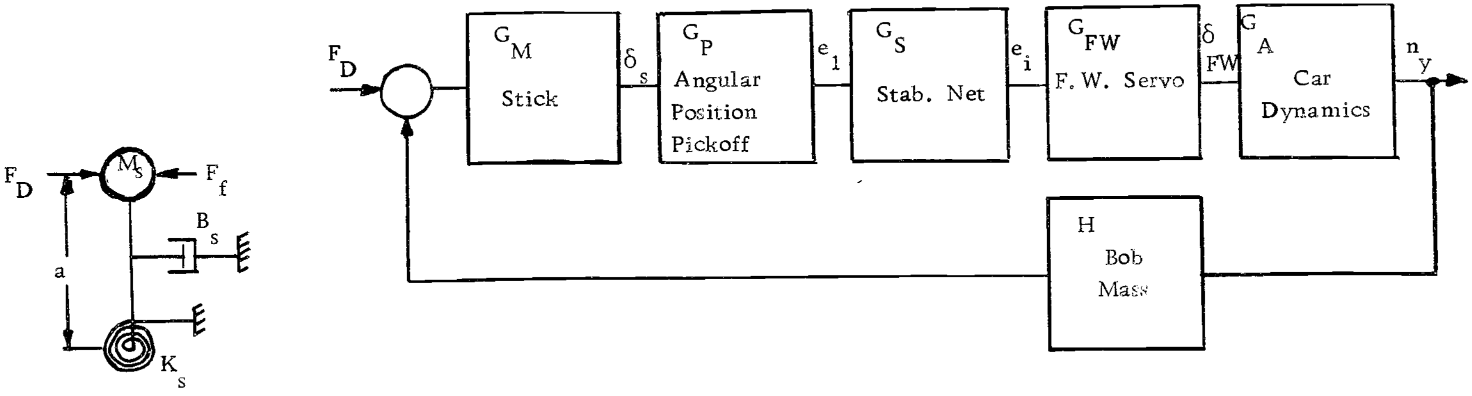


Figure 5. G. M. unicontrol steering system block diagram.

Motors did not have a research vehicle with other than conventional controls.

Ford Engineers stated (21): " While a unitary control device is desirable for some applications, it was not found desirable for steering of automobiles, because of the re-education program of 100 million drivers with their ingrained reflex steering habits. " It is one of the purposes of this thesis to establish the fallacy of the preceeding statement by demonstrating the ease with which various drivers adapt to the unitized control system.

The Ford report on their "wrist twist" vehicle cites the particular advantages of good instrument panel visability, lateral body support (holding steady yoke and armrests), and slow speed precise maneuverability. They also noted in their public evaluation tests that good drivers adapted rather easily while those "people who are not particularly interested in driving a car, and who are not considered to be good drivers, tend to shy away" (24).

The Chrysler report concerned a vehicle that used a yoke with two hand-held grips for the steering function. The yoke also held various switches for controlling the windshield wiper, lights, turn signals, horn and door locks. These "finger tip" controls are analogous to the multiple buttons on the unitary control test bed that control the gear changer, clutch, horn, turn signals, and reverse. A similar idea has been developed in England and a wheel with switches for lights, heater, wiper, washer, horn, turn signals and radio is being marketed (23).

Another unitized control system (14) was developed by Ohio State University Communications and Control Systems laboratory for the purpose of studying driver response time and for maintaining a closely controlled distance behind another vehicle while traveling at freeway speeds. This system, like the G. M. and Chrysler units, is electro-hydraulic servo actuated and provides feed back artificially to the driver by means of a projecting "finger" that presses into the drivers' hand. The report gives no qualitative results for the vehicle.

The control system of this thesis is designed to provide it's own feed back, without the aid of artificial devices, to inform the driver of his vehicles' action. The means of accomplishing this are via the self aligning torque of the wheels for the steering control and spring pressure for the throttle and brakes.

III. ANALYSIS, TESTS, AND EVALUATION

Analytical Analysis

The analytical approach to the problem of describing the vehicle's response in terms of steering angles and rates began with the two degree of freedom (lateral translation and rotation about a vertical axis) equations of motion from Halfman's Dynamics Vol II (12). This approximation to the full 6 degrees of motion was deemed adequate since the pitch and roll rotations are minimal on the stiffly suspended test bed and the translatory motion is greater than either the longitudinal or vertical changes if a constant velocity is assumed.

Halfman's equation of motion for the following parameters and axis system are:

$$\dot{\beta} + \frac{4K}{mV}\beta + \left[1-(1-2a)\frac{2K\ell}{mV^2}\right]\dot{\psi} = \frac{2K}{mV}\delta$$

and

$$\ddot{\psi} - (1-2a)\frac{2K\ell}{I_z}\beta + (1-2a+2a^2)\frac{2K\ell^2}{I_z V}\dot{\psi} = \frac{2Ka\ell}{I_z}\delta$$

where δ = Steering input forcing function, --- radians.

β = Slip angle or angle between centerline of car and resultant velocity, --- radians.

K = Cornering force generated by tires, --- lbs. /radian.

m = Mass of vehicle, --- slugs.

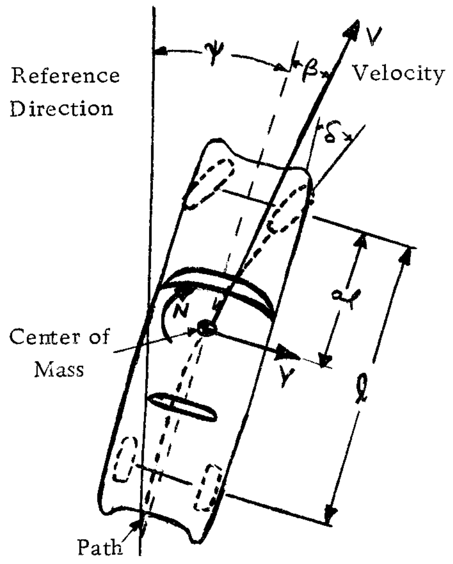


Figure 6. Illustration of vehicle parameters.

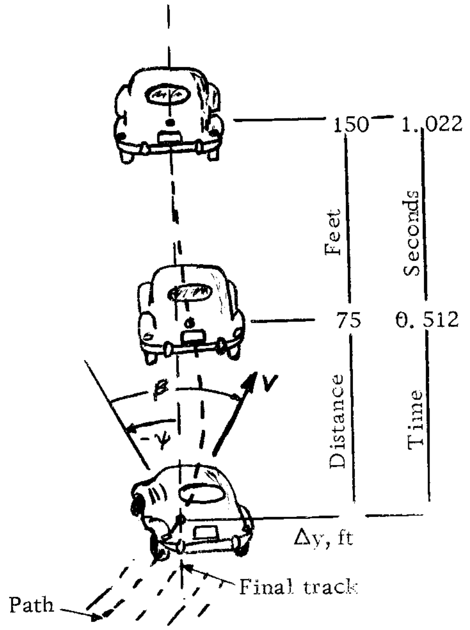


Figure 7. Test axis system.

V = Velocity of vehicle, --- ft/sec.

ℓ = Wheelbase, --- ft.

a = (distance to center of gravity (cg) from front wheels)/ℓ , --- dimensionless.

I_z = Moment of inertia of vehicle about vertical axis, --- lb. ft.^{2}.

ψ = Angle between vehicle, centerline and ground axis, --- radians.

Once these equations of motion were obtained, and their derivations reviewed, they were non-dimensionalized by the following procedure:

Let

$$\tau = \frac{2K}{mV} t \quad \text{and} \quad \frac{d\psi}{d\tau} = \gamma$$

So we have:

$$\beta' = -\left[\, 2\beta + \left[1-(1-2a)\frac{2K\ell}{mV^2}\right]\gamma - \delta \,\right]$$

and

$$\gamma' = \left[\left(\frac{(1-2a)\frac{m\ell^2}{I_z}}{\frac{2K\ell}{mV^2}} \right) \beta - \left[1-2a(1-a)\frac{m\ell^2}{I_z}\right]\gamma + \frac{a\left(\frac{m\ell^2}{I_z}\right)}{\left(\frac{2K\ell}{mV^2}\right)}\delta \right]$$

The equations are now conveniently of a non-dimensional nature and we choose four constants as the following:

$$K_1 = \left[1-(1-2a)\frac{2K\ell}{mV^2}\right] \qquad K_3 = \left[1-2a(1-a)\frac{m\ell^2}{I_z}\right]$$

$$K_2 = \left(\frac{(1-2a)\frac{m\ell^2}{I_z}}{\frac{2K\ell}{mV^2}} \right) \qquad K_4 = \left[\frac{a\left(\frac{m\ell^2}{I_z}\right)}{\frac{2K\ell}{mV^2}} \right]$$

These constants were evaluated for the particular test bed configuration over a velocity range from 0 to 100 mph.

The constants corresponding to a step input of δ are then fed into a computer program that uses an executive or master program called "Mimic" (26). This program functions to make a large digital computer (CDC 3300) simulate an analog computer's logical units, but still extends the digital capability to vary constants and recall exact number values. The computer program is available for review at the beginning of Appendix I. After writing, checkout and thorough testing of the program, it was used to generate an analytical prediction of the angles β and ψ and their rates of change with respect to the parameter τ, which is time modified by a factor.

A sample of the computer plotter results are available in Appendix I (Figures 10-12). These plots were used to search for conditions of instability of the test bed over its feasible velocity range and as analytical predictions that could be correlated with empirical data.

In addition to the computer program and the simulation it performs, there were a number of calculations performed to evaluate such items as the cornering force and turning moment developed by the tires. These calculations and the measured parameters used in them are presented in summary form as follows: The cg position relative to overall length is $a = .575$. The cornering force of the front tires is $K = 125$ lbs/deg. = 7150 lbs/radian. The vehicle mass is 2770 lbs or 86 slugs. The static turning moment is $M = 126$ ft lbs. per wheel. The wheelbase $\ell = 110$ inches and the moment of inertia, $I_z = 3.01 \times 10^4$ lb. ft^2. The more "normal" vehicle used for comparative purposes had values of: $a = .45$, $K = 200$ lb/deg., $m = 3500$ lbs., $\ell = 108$ inches and $I_z = 7.07 \times 10^4$ lb ft^2.

The calculated values are largely based on Taborek's "Mechanics of Vehicles" (29) and upon a summing procedure for generating the overall moment of inertia from the component parts. In addition, nomographs for steering system design, equations for braking distance, and stability calculations were of particular benefit during the design and construction phases of the project.

Empirical Steering Response

The experimental tests to obtain data to compare with the analytically predicted parameters discussed above, generally took the form of a "step" input steering command over a range of velocities. The method of data acquisition was a super 8 movie camera with a zoom lens and "slow motion" speed sufficiently fast to record the steering motions so that they could be analyzed from a projected image.

The "steering" input was repeatedly performed over a speed range of 0 to 70 mph by the same driver in order to obtain the most valid repetition possible and to achieve the same speed conditions on repeat trials. The data taken from the photographic record generally is in good agreement with the trends predicted by the analytical "mimic" simulation program. That is, the shape of the curves for β, ψ, $\mathring{\beta}$, and $\mathring{\psi}$ are quite acceptably correlated and the magnitude deviations may be reconciled by making adjustments so that each test has the same resultant steering angle input δ. A representative sample of empirical data appears in Appendix I (Figures 13-15) and can be compared to the "mimic" generated plots (Figures 10-12).

The interconnection between analytical aspects and empirical tests is basically that the mimic simulation is the best prediction of how the system should behave. The empirical data is collected to compare with and contrast the analytical to either reinforce or deteriorate the particular mathematical model chosen. The experimental data will, of course, have to be weighted with more significance than the analytical, yet it is of interest to note the high degree of correlation attained.

The following sections will deal with experimental tests performed both by the system designer and by a variety of drivers who evaluated the vehicle on a qualitative basis. The tests will be discussed relative to procedure, results, and significance.

Pylon Maneuverability

Pylon maneuverability tests to determine emergency lane change capability, are elaborated in an SAE paper (13) and are designed to find "the maximum speed at which a severe lane change maneuver can be performed". The study from which the paper was written found that handling characteristic changes (such as tire pressure changes) are rather easily detectable at low speeds (30-35 mph) as well as the more commonly accepted speeds of 60-80 mph. Their results also verify that some drivers perform better when turning in one direction than in the other.

With these results in mind, the test was performed as follows: The test track was laid out by placing rubber cone pylons to form three lanes (Figure 8). The driver enters the course through either the right or left leg and must perform the lane change without hitting a pylon at a set speed. For each gap distance, G , the speed is increased by 5 mph increments until failure occurs. "The most usual failure is collision with the recovery lane pylon. A collision with pylon 1, in the entrance lane, is attributed to driver error instead of to vehicular dynamics". (13)

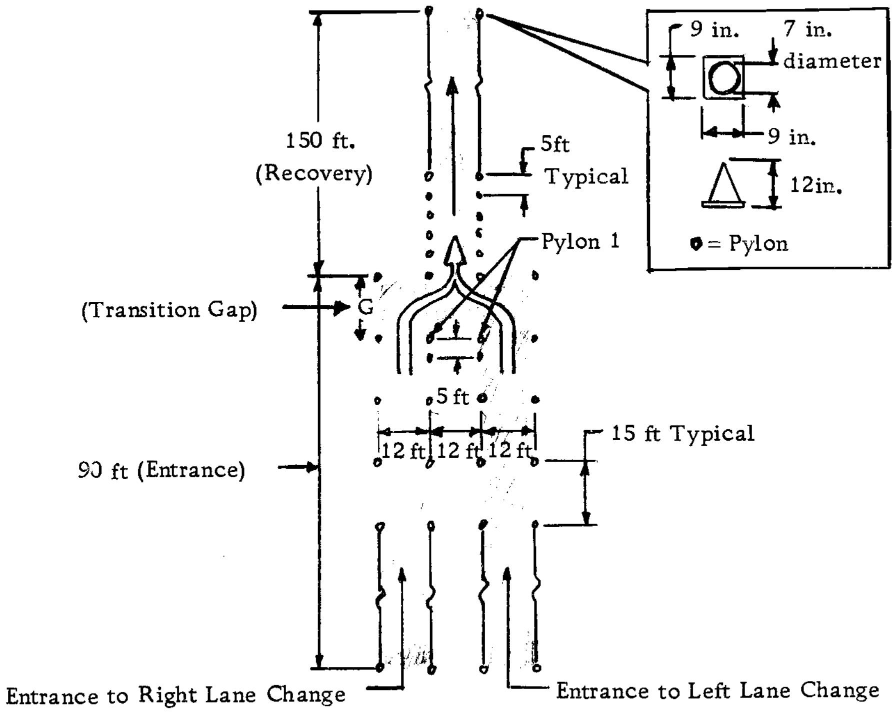


Figure 8. Pylon maneuverability test track.

The results of this test are available in Figure 9 along with the results for a more "normal" vehicle. This test is of a somewhat subjective nature but since the same driver performed all trials, a reasonable amount of repeatability and consistency of decision was achieved.

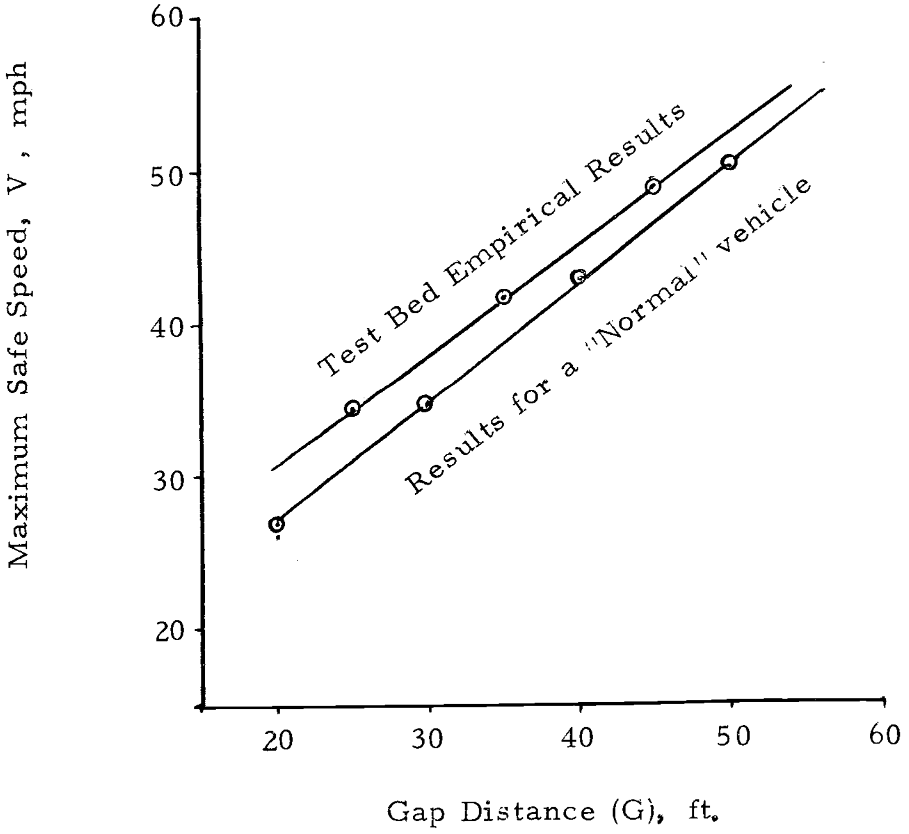


Figure 9. Pylon maneuverability test results.

Sensitivity

The sensitivity evaluation on a quantitative basis is largely dependent upon the transfer function between the steering control and the front wheel response. In this case, the function is 1.56 deg. input to 1 deg. output. This condition is believed to be satisfactory even though it is much "faster" than a normal vehicle because no feeling of oversensitivity was found at any speed. A condition of undersensitivity was noted because the stick has approximately a 15 in. throw to either side and was found to be somewhat objectionable for low speed tight turns. This condition was one of the design compromises made so that steering could still be maintained in the event of failure of the hydraulic assist.

With regard to the sensitivity of the acceleration and braking actions, the rearward stick motion of 1 1/2 in. to apply full braking effort was found to be quite acceptable and even desirable as it provided an extremely rapid response time for excellent braking performance (Tables 1 and 2). On the other hand, the 8 in. of forward throttle movement was deemed to be slightly excessive; however, it should be noted that full throttle is rarely applied. Both throttle and braking sensitivity were evaluated as acceptable with their transfer functions of 4.9 in. input to 1 in. output.

Stopping distances were empirically determined and compared to tabulated values in the Dept. of Motor Vehicles Manual, (Table 1 and Table 2). It was possible to stop the vehicle easily within the distance requirements set by the Oregon State laws.

Table 1. Oregon State required stopping distances.

Speed mph	Driver Reaction Distance Ft.	Braking Distance 15-85 Percentile Range Ft.	Total Stopping Distance 15-85 Percentile Range Ft.
20	22	18- 22	40- 44
30	33	36- 45	69- 78
40	44	64- 80	108-124
50	55	105-131	160-186
60	66	162-202	228-268
70	77	237-295	314-372
80	88	334-418	422-506

Table 2. Test bed empirical stopping distances.

Speed mph	Driver Reaction Distance Ft.	Braking Distance Ft.	Total Stopping Distance Ft.
20	12	13	25
30	18	25	43
40	24	45	69
50	30	73	103
60	36	130	166

Stability

The overall stability of the vehicle with regard to steering was tested by generating a variety of steering commands to see if a condition of deviation or self-excited oscillation could be produced. No such conditions were noted over the velocity range tested or with any manner of input attempted. In addition, the self-aligning torque of the front wheels was tested by introducing a step steering change at a particular velocity and then releasing the stick to see if the wheels would return to a straight ahead or neutral position.

This test of "stick centering" characteristics proved that the greater than normal caster angle of the front wheels was beneficial in that the system always returned to a very nearly neutral condition. This positive stability was achieved only through the front end geometry and not by any centering springs or other artificial devices. The gearing of the system gave an effective mechanical disadvantage to the stick centering capability, but the sizeable caster angle was sufficient to overcome this obstacle.

The roll and pitch angle stabilities appeared to be excellent as the three point suspension with a transverse spring in front and two longitudinal springs in the rear gave superior chassis dynamics that were damped by Houdille adjustable shock absorbers on the front and tube-type dampers on the rear.

Mil. Spec. Evaluation of Forces and Motions

A comparison of the stick forces and motions to those specified in the USAF Military specification (MIL F-8785) for "Flying Qualities of Piloted Aircraft" is of interest in that years of research have gone into the preparation of the document. It is intended to specify conditions so that minimal problems are experienced by USAF pilots while performing their flying duties. Portions of MIL F-8785 that apply were consulted during the design phases in order that an acceptable system be produced.

The tests performed involved the attachment of a spring scale to the stick to obtain forces for the braking, steering, and acceleration motions under various conditions.

A specific comparison of the test data with the specification follows: Maximum braking force of 40 lbs. is analogous to the 50 lbs.

max. acceptable for elevator control to recover from a dive. Likewise, the 3 lbs. minimum to initiate braking corresponds to 3 lbs. max. for elevator breakout forces.

With regard to the steering or side to side force of 9 to 23 lbs., the MIL. spec. states that 10 lbs. aileron control is acceptable for steady turns at small bank angles as long as no pilot induced oscillation (PIO) is noted. For other than small bank angles, aileron forces of 30 lbs. max. are acceptable. The forward or throttle force of 5 - 8 lbs. is within the MIL. spec. for 10 lbs. of push on the elevator during takeoff or dive initiation.

Stick motion specifications are not fully elaborated, but the reference states that 60° maximum both sides of center is acceptable for a wheel control so the 45-50 deg. of stick throw should not be objectionable.

Response Time

The response time evaluation was of necessity a rather subjective test since it is quite difficult to use a stop watch for such a short duration. A few tests, however, showed the time from a spoken command to "stop" to the initiation of braking to be about .4 sec. which is considerably faster than the .75 sec. stated by Oregon State Dept. of Motor Vehicles when using foot operated brakes. The response time for a throttle or steering change appeared to be very similar to those associated with a more normal vehicle, but an advantage with the test machine was that a smaller motion was necessary in order to effect the desired steering angle change.

Interaction of Controls

The interaction of controls evaluation generally was favorable in that little difficulty in unintentionally coupling one control with another was noted. The few instances that occurred were nearly always during sharp slow speed turns when the stick was well to one side or the other. In that position, interference with the driver's legs made it easy to initiate too much throttle and difficult to apply the brakes.

The finger switches proved to be of little problem except that rarely a qualitative driver would accidentally disengage the clutch by bumping the stick-grip trigger. Little difficulty was experienced in activating the turn signals and holding the switch in that position while the turn was accomplished.

Operator Adaptability

Operator adaptability will be elaborated further in the driver qualitative comments section, but it is of interest to note that every driver rated the system as easy to learn in that the primary motions are of a very natural or instinctive nature. The most notable instance of this phenomenon occurred when the qualitative driver without the use of his legs drove the vehicle. That driver had been using hand controls since 1948 which were opposite in braking and acceleration functions to those on the test machine. Even with these years of ingrained conditioning to push forward for brakes and pull back for throttle, the individual did not make one single error in all the time he drove the machine, even when somewhat stressful conditions beset him. This occurance made it quite clear that the system was of a very natural and acceptable configuration as well as being analogous with stick controlled aircraft.

Reverse Handling Characteristics

The reverse motion handling characteristics were evaluated in terms of maneuvering through the pylon course and simulating a parallel parking exercise. No difficulty with either crossing or coupling any controls was noted by the vehicle's designer but, instances of control reversal both in steering and throttle actuation were noted when the qualitative drivers evaluated the vehicle. The most frequent error seemed to be in applying more throttle when braking action was desired. Those drivers that used the same hand while in reverse gear as in forward gears appeared to experience less difficulty than those who changed hands for the reverse handling tests.

Driver Fatigue

No real driver fatigue evaluation could be performed due to the test vehicle's temporary restriction to off-highway use, but it was speculated by most drivers that long distance driving fatigue would be decreased relative to a "normal" automobile. This opinion was because of the single device necessary for complete control and the ability to shift hands, move the feet freely, and support the arm controlling the stick by resting it on the driver's leg.

IV. SUMMARY OF DRIVER QUALITATIVE COMMENTS

The justification for performing driver qualitative tests is very appropriately presented in the following passage (2):

"Numerous papers dealing with various aspects of vehicle handling have been published. Mathematical models, sophisticated computer programs, objective test methods and instrumentation relevant to vehicle handling have been described. However, despite all these advances, subjective evaluation is still the major, and best tool for appraisal of vehicle handling qualities in current automotive development practice and _for approval of prototype vehicles_."

Table 4 presents in summary form each of the qualitative driver's reactions to a standard questionaire (Questionaire 1) completed after the test drive. Table 3 presents a short description of each driver and any distinguishing characteristics peculiar to the individual.

It is especially interesting to note that not one qualitative driver complained or commented about the non-adjustable seat position. This remained true even when the physical size of drivers varied considerably.

QUESTIONAIRE ONE

DRIVER QUALITATIVE COMMENTS

I. Rate ease of learning control functions, ie, easy, difficult, fair, etc.

II. Rate configuration of control motions relative to human anatomy, ie, natural, unnatural, difficult, etc.

III. Do you feel the vehicle is adequately stable?

IV. Rate the control components as to sensitivity:

Steering ____________________

Throttle ____________________

Brakes ____________________

V. Rate YOUR response time in this vehicle relative to a normal car as: faster, slower or the same (also estimate difference in seconds)

Steering ____________________

Throttle ____________________

Brakes ____________________

VI. How do you feel about the vehicle's ability to rapidly change lanes in an emergency? ie, capable, dangerous, etc.

VII. Rate your ability to keep the various control components separated in function, ie, do you find unintentional coupling of one control function with others?

VIII. What is your evaluation of the vehicle's controllability at higher speeds?

IX. Rate the parking capability and reverse handling characteristics of the vehicle.

X. What would be your estimate as to long distance driving fatigue relative to more normal vehicles?

XI. Other comments.

Table 3. Distinguishing characteristics of qualitative drivers.

Driver No.	Overall Performance Rating (10 = excellent, 1 = loss of control)	Description
1	7	Tall, atheletic
2	7	Analytical interests, atheletic
3	7	Small, petite, woman
4	8	Muscular, runner
5	5	Fairly thin
6	7	Muscular and large
7	8	Pilot, somewhat small
8	9	Horsewoman
9	9	Ex-Air Force Pilot
10	6	Paralyzed from waist down, muscular torso
11	7	Small and light
12	9	Tall and well co-ordinated
13	8	Young man; no driver's license
14	7	Somewhat thin and small
15	7	Muscular
16	9	Pilot
17	8	Pilot, young and strong
18	8	Pilot
19	7	Teenager
20	7	Split hooks in place of hands and forearms, young
21	9	Pilot, young
22	8	Pilot
23	7	Small woman
24	8	Young and strong
25	8	Strong but fairly small
26	7	Muscular

Table 4. Summary of qualitative driver comments.

	Question No.										
Driver No.	I	II	III	IV	V	VI	VII	VIII	IX	X	Other
1	easy	natural	yes	good good low	same same same	capable	some coupling	easy	fair	less fatigue	always need seat belts sharp turns awkward
2	easy	natural	yes	good good fair	same same same	satisfactory	satisfactory	---	---	less	need lateral seat support
3	easy	natural	yes	fair fine	same same	capable	good	easy	easy & natural	same	"T" grip stick would be better
4	moderately easy	satisfactory	yes	fair good fair	--- --- ---	satisfactory	some coupling	excellent	difficult	same	---
5	fair	natural	yes	very fair fair	faster slower same	capable	some coupling	fair	somewhat difficult	slightly more tiring	---
6	easy	natural	yes	faster same same	faster	great	no problems	exceptional	slightly unnatural	minimal	tended to change hands sometimes
7	relatively easy	natural & capable	yes	good good	with practice much faster	excellent	good	excellent	satisfactory except sharp turns	less	fun to drive

Table 4 continued.

	Question No.										
Driver No.	I	II	III	IV	V	VI	VII	VIII	IX	X	Other
8	easy	natural	yes	good good fair	same slightly slower	capable	no problem	good	good	slightly more fatigue	move stick slightly more forward
9	easy	natural	yes	fair good fair	same same faster	capable	no problem	better than low speed	somewhat unnatural	same	unique and many possible advantages
10	easy	natural except brake should push forward	yes	excellent excellent fair	faster same slower	very good	easy to keep separate despite previous opposite training	good	satisfactory	less	---
11	easy	need some lateral support	satis. if supported	fair adequate adequate	same same same	good	some initial coupling	---	somewhat awkward	same	need more time to learn
12	easy	natural if supported	yes	adequate satisfactory	faster same same	capable	no problem	no problem	some cross controlling	throttle spring too stiff	fun to drive need faster steering response
13	very easy	natural	yes	good good good	faster slower slightly faster	quite capable	no problem	good	somewhat unnatural but practice would improve this	favorable	much easier to learn to drive than a normal car

Table 4 continued.

Driver No.	Question No. I	II	III	IV	V	VI	VII	VIII	IX	X	Other
14	easy	natural except too much stick movement	yes	fair good	slower same	capable if driver experienced	not difficult	satisfactory	somewhat difficult	same	amazing machine "Super Stick"
15	easy	natural	yes	fair good	slower same	capable	no problems	good	good (used left hand)	same	too much lateral stick at slow speeds
16	easy	natural except sharp turns	very stable	fair good	faster same	better than wheel since stick is more rapid on return	no problems	excellent!	somewhat awkward	less fatigue	variable steering ratio with speed would be better
17	easy	natural except sharp turns	yes	very very large forces	faster same faster	capable	same coupling	very	somewhat difficult	better	move stick a little forward "I like it."
18	exceptionaly easy	natural & convienent	yes	excellent excellent excellent	faster	capable	some coupling but very desirable to use for maneuvering	excellent	some	better	reduce motion laterally. very easy to learn to drive

Table 4 continued.

	Question No.										
Driver No.	I	II	III	IV	V	VI	VII	VIII	IX	X	Other
19	very easy, all one handed	natural	yes	very good very good	faster faster	very capable	very easy due to good visability	steady	---	faster	centralized switches are great!
20	easy	natural even with artificial arms	yes	good good good	faster same same	capable	no problems	very good	somewhat difficult	better	enjoy driving any car, but especially this one
21	very easy	natural	yes	fair fine fine	faster slower faster	very capable	no coupling	very good	very easy	very relaxed	too much side motion
22	easy	natural		good fair good	same same same	good potential	some coupling	very good	very good	same	need more rapid recovery from turn
23	easy	natural except sharp turns		good good fair	--- --- ---	capable	some coupling	good	very natural	somewhat tiring	more time for practice would solve problems
24	easy	fairly natural	yes	good good good	same same same	capable	no trouble	comparable to normal car	some confusion	uncertain	may have advantages not readily apparent
25	easy	natural	yes	fair good	same same	capable	no problems	good	minor problems	better	too much lateral movement

Table 4 continued.

	Question No.										
Driver No.	I	II	III	IV	V	VI	VII	VIII	IX	X	Other
26	easy	natural	yes	fair good good	slower (1 sec) slower (.2sec) same	questionable	some trouble	good	somewhat difficult	use left hand also	too much stick throw. good idea

V. SUMMARY OF RESULTS, WITH CONCLUSIONS AND RECOMMENDATIONS

In summary, the feasibility, practicality, and desirability of the proposed vehicular control system appears to be quite good in all aspects evaluated.

The system is technologically feasibile to mass produce since it is basically composed of existing automotive components and is simple, mechanical, and reliable in nature. The various components of the overall control system are generally existing parts and are fairly easy to employ.

The practicality of the proposed control system is increased when one considers that some twenty-six qualitative drivers drove the vehicle without experiencing any significant difficulties and all exemplified a rapid adaptation to the primary control functions. Most driver problems experienced were a result of the particular vehicle, not from the conceptual control motions (Table 4). The concept seems to be practical for open road, freeway useage or city traffic.

The desirability of the control system is enhanced by the successful evaluation of increases in safety, convenience and novelty. That is, the vehicle is more rapidly maneuverable, encourages shorter driver response time, has little distraction of remotely mounted switches, affords an unimpaired view of the instrument panel, gives better crash protection than a wheel and is still a redundant mechanical control system. The system has proven to be more "natural" for human adaptation, to give reduced motions and forces for the operator, to be driveable by handicapped persons, to reduce driver fatigue and need no seat adjustment. It is also a unique and novel system that brought comments, stares and a barrage of questions during construction and testing.

In times of such crowded traffic conditions, one realizes that any system which enhances the ability of a driver to react to an emergency or demanding situation is highly desirable and should be available to the public.

It is therefore concluded, that a unitized control system can be employed to advantage on a surface or automotive-type vehicle and is feasible, practical, and in many respects, highly desirable.

On the basis of this thesis research, it is recommended that the automotive industry develop a similar system. In addition, it is recommended that after a trial period to allow for public evaluation, this system be made available as an optional item to provide the driver with a maximum degree of controllability.

BIBLIOGRAPHY

1. Bassett, David A. Evaluation of modifications to balance and overbalance the longitudinal control system of F-4 aircraft. Air Force Flight Test Center. Edwards A. F. B., Calif. July 1969. Technical Report #69-25.

2. Bergman, Walter. Consideration in determining vehicle handling requirements. Ford Motor Company. S. A. E. Detroit, Michigan. January 1969. Paper 690234.

3. Bundorf, Thomas J. and Leonard Segel. The variable stability automobile. S. A. E. Detroit, Michigan February 1965. Paper SP-275.

4. Cherne, Jack M. Educating the complete designer. TRW. American Institute of Astronautics and Aeronautics. March 1970.

5. Chrysler Corporation. Handgrips in Chrylser 300X car used for steering research. News Bureau. Detroit, Michigan. pp. 1-3.

6. Conde, John A. American Motors. Detroit, Michigan. May 1970. Letter.

7. Conover, D. W., W. E. Woodson, P. H. Selby and G. E. Miller. Location, accessibility and identification of controls and displays in 1969 passenger automobiles. S. A. E. Detroit, Michigan May 1969. pp. 1-10. Paper 69048.

8. Creson, W. K. Power steering in 1952. S. A. E. Detroit, Michigan. March 1952. Paper 699.

9. Dunne, J. Ford's new steering system. Automobile Industries. May 1965. pp. 62-62. Vol. 132 No. 9.

10. Filburn, Lt. Ralph B. A review and comparison of MIL F-008785 (USAF) and MIL F-8785 (ASG). USAF Flight Research Branch. Edwards AFB, Calif.

11. Gresham, Lee M. Driving aids-you too can drive. Wixom, Michigan. Spring 1970. Brocure.

12. Halfman, Dynamics. pp. 398-402. Vol. II.

13. Hildebrandt, Thomas J. and Authur B. Objective testing in handling research, Ford Motor Company and University of Michigan. S. A. E. Detroit, Michigan. January 1969. Paper 680015.

14. Joy Stick Helps Driver to Keep Safe Distance. Product Engineering. Nov. 7, 1966. pp. 33-34. Vol. 37, No. 23.

15. Karshner, Joseph H. General Motors Report on Firebird III. (1959) February 1970. pp. 20-26. Letter.

16. Kohno, T., S. Tsuchiya and N. Komoda. On the dynamic response to the steering control - experimental evaluation of the response and analytical approach to the design of the performance with seven degrees model. S. A. E. Chicago, Illinois. May 1969. Paper 690488.

17. Lubrication, Hydraulic Power Steering for Passenger Cars. The Texas Company, New York, February 1953. pp. 17-25. Vol. 39, No. 2.

18. MacDuff, S. E., J. G. Rivard, and E. J. McGlenn. Technological development directing the path to fully automatic vehicle control system. S. A. E. Detroit, Michigan. January 1969. Paper 690260.

19. Military Specification "Flying qualitites of piloted airplanes" MIL F-8785 (USAF). Wright Patterson AFB, 31 Oct. 1968.

20. Motor Vehicles Division, Oregon Drivers Manual 1969-1970. Salem, Oregon p. 22.

21. Muller, George H. Concepts and features planning manager, Ford Motor Company, Product Development Group, Detroit, Michigan. March 1970. Letter.

22. Okada, Tadashi and Takeo Sigishima. Effect of tractive force on directional stability and controllability of vehicles, S. A. E. Chicago, Illinois, May 1969. Paper 690527.

23. Popular Science Magazine. July 1970. p. 62. Vol. 197, No. 1.

24. Ranney, Lt. R. J. Washington state patrol evaluation of wrist twist in 1967. Furnished by Ford Motor Company. March 1970.

25. Sharp, Earl D. Human factor consideration to the design, placement and function of vehicle controls. Aerospace Medical Research

Laboratory. Wright Patterson AFB. S. A. E. Chicago, Illinois. May 1969. Paper 690459.

26. Skinner, David. Mimic-a digital-analog simulator. Oregon State University Computer Center. Corvallis, Oregon April 1969. cc. 69-5.

27. Smith, Dr. C. E. Dynamics of physical systems. Mechanical Engineering 474G lectures. O. S. U. Corvallis, Oregon. May 1970.

28. Stewart, Edwin E. and Lauren L. Bowler. Road testing of wheel slip control systems in the laboratory. Detroit, Michigan. S. A. E. January 1969. Paper 690215.

29. Taborek, Jaroslav J. Mechanics of vehicles. Machine Design Reprint. Cleveland, Ohio. Chapters 1-4. May-July 1957. pp. 4-29.

30. Winans, J. G. Natural flying in unnatural airplanes. AIAA. State University of New York at Buffallo. June 1970. pp. 23 & 26.

APPENDICES

APPENDIX I.

SAMPLE EXECUTIVE "MIMIC" COMPUTER PROGRAM

```
]LIST
00001:PROGRAM AUTOMOBILE STEERING RESPONSE
00002:                      CON(DELTA, K1, K2, K3, K4)
00003:        DT            EQL(0. 1)
00004:        B             INT(DELTA-2. *B-K1*PSIDOT, 0. 0)
00005:        BDOT          DER(B, T, 0. 0)
00006:        PSIDOT        INT(K2*B-K3*PSIDOT+K4*DELTA, 0. 0)
00007:        PSI           INT(PSIDOT, 0. 0)
00008:        B1            EQL(B*1000. )
00009:        BDOT1         EQL(BDOT*1000. )
00010:        PSI1          EQL(PSI*1000. )
00011:        PSIDO1        EQL(PSIDOT*1000. )
00012:                      HDR(BETA, BETADT, PSI, PSIDOT)
00013:                      OUT(B, BDOT, PSI, PSIDOT)
00014:                      OUT(B1, BDOT1, PSI1, PSIDO1)
00015:                      PLO(2., 2., B1, BDOT1, PSI1,PSIDO1)
00016:                      FIN(T, 3. 0)
00017:                      END
00018:0. 005        1. 087         -1. 99         3. 94         7. 85
```

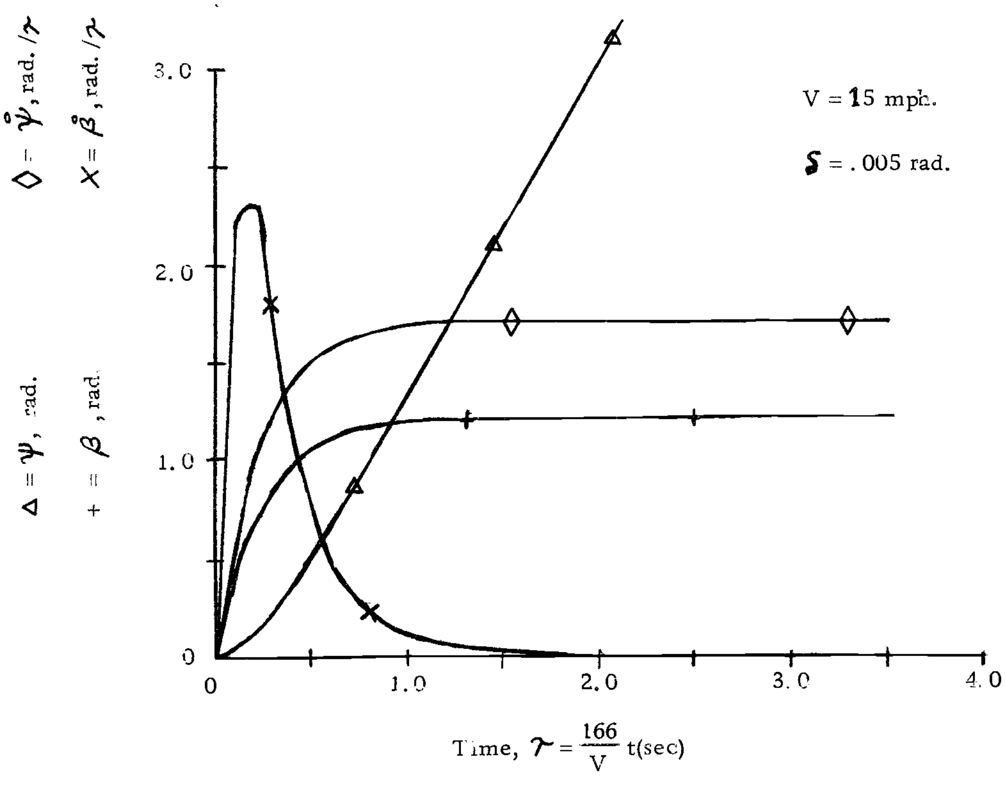


Figure 10. Analytical prediction of steering response.

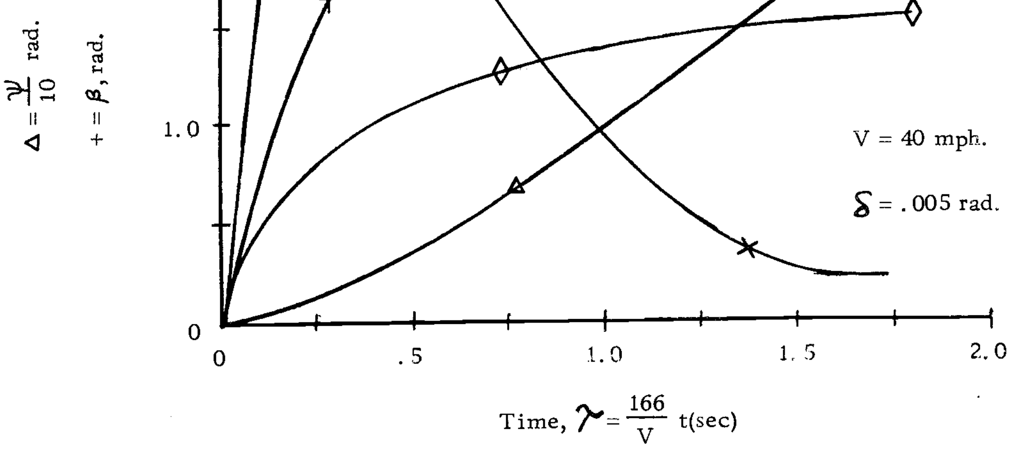


Figure 11. Analytical prediction of steering response.

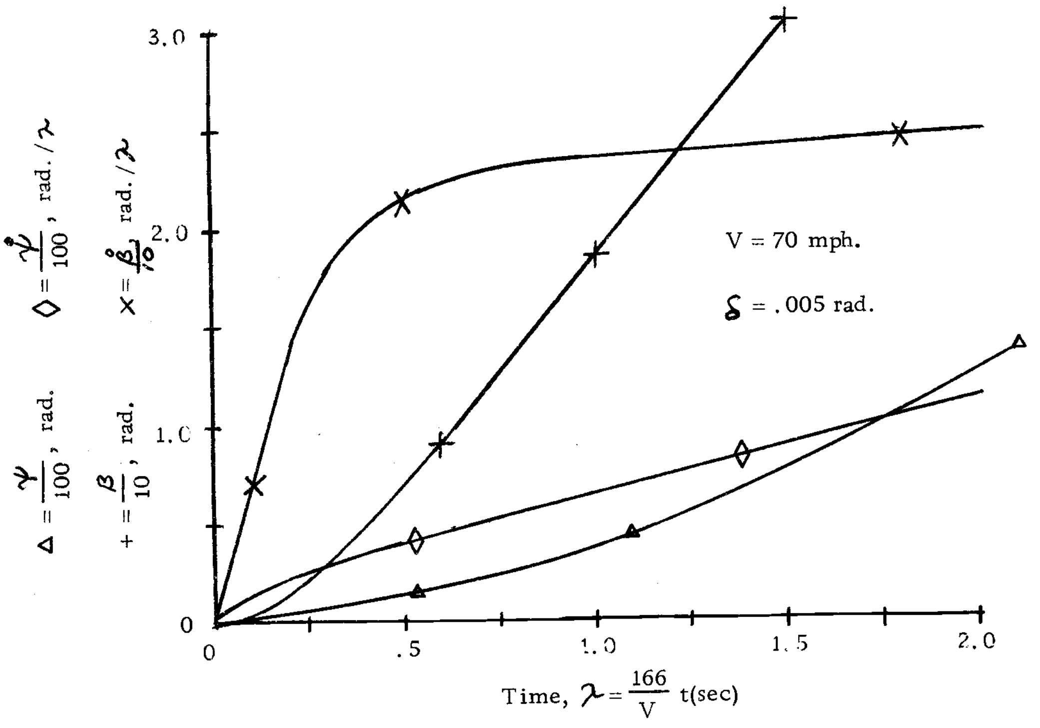


Figure 12. Analytical prediction of steering response.

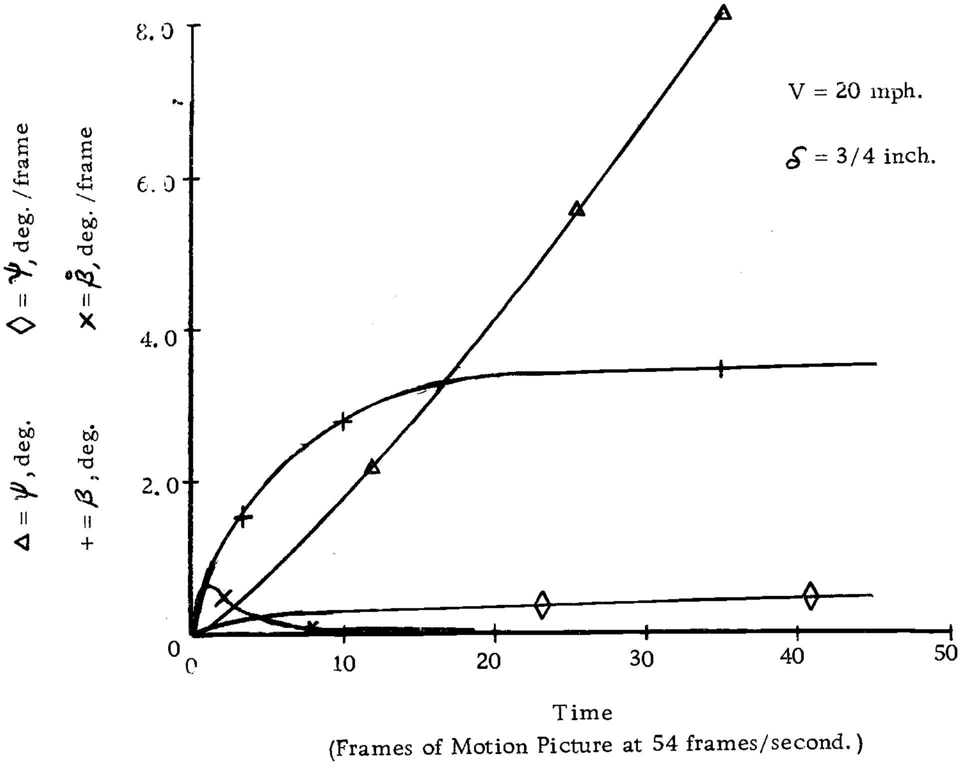


Figure 13. Experimental results for steering response.

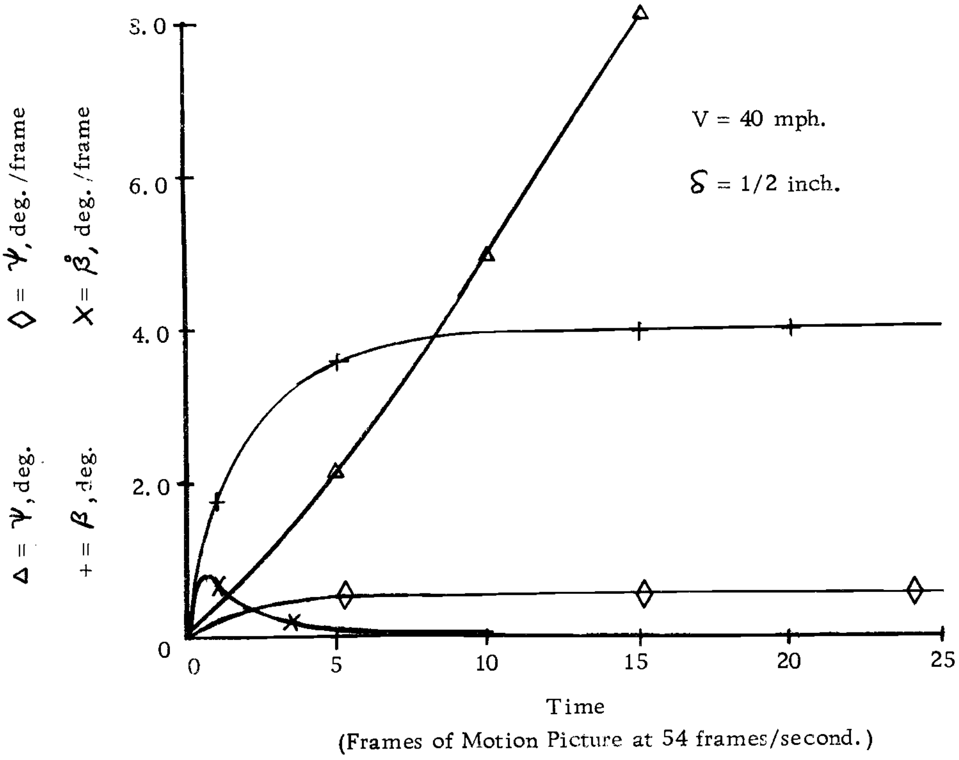


Figure 14. Experimental results for steering response.

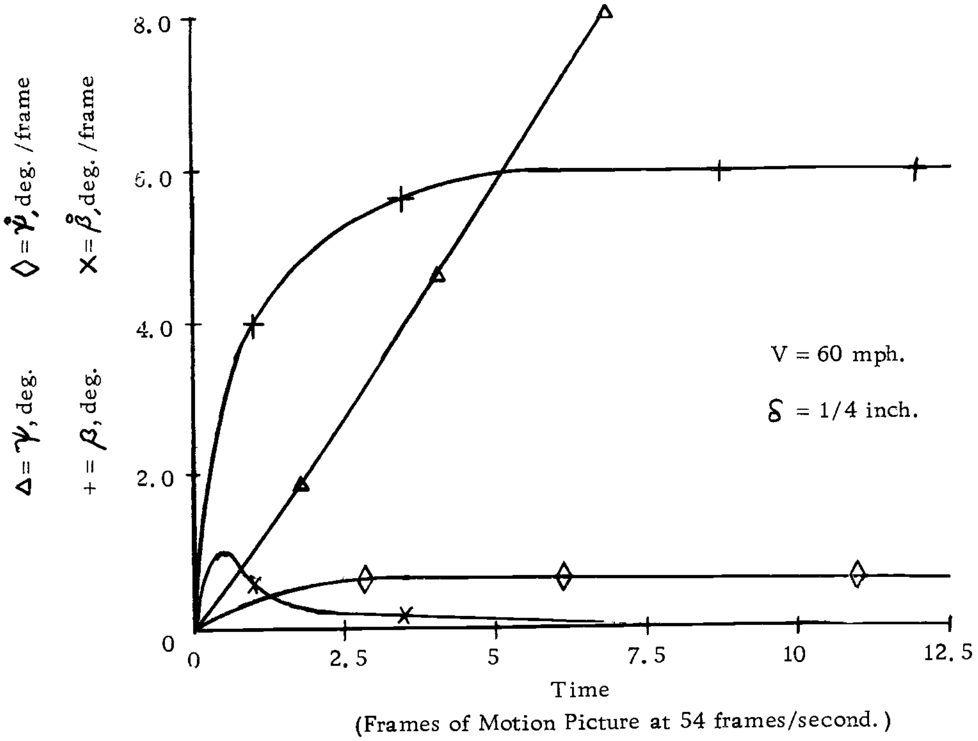


Figure 15. Experimental results for steering response.

APPENDIX II.

Figure 16. Overall vehicle.

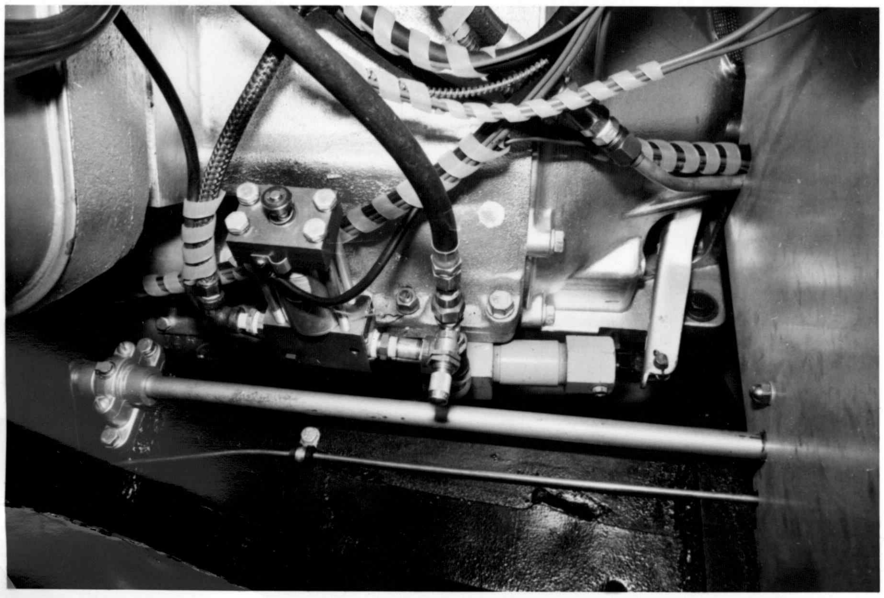


Figure 17. Clutch actuation system.

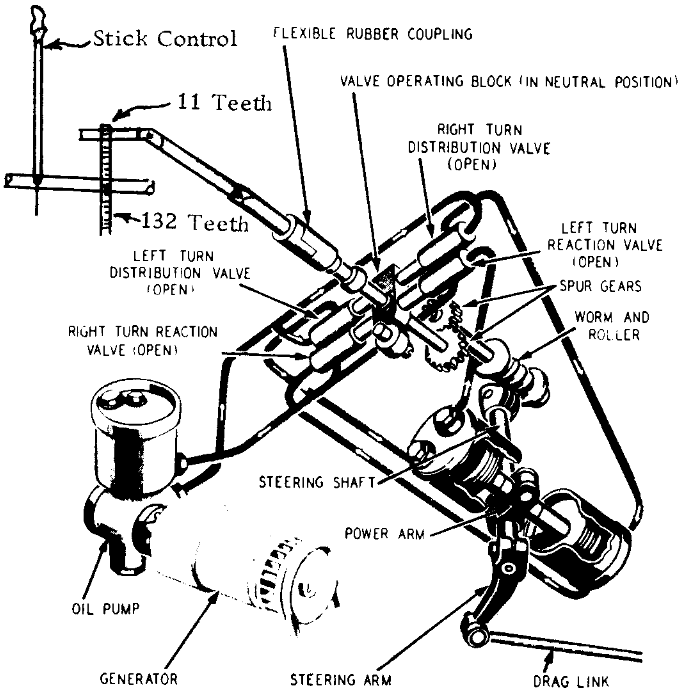


Figure 18. Steering hydraulic system.