NASA MEMO 2-15-59L

NASA MEMO 2-15-59L

NASA

MEMORANDUM

GROUND SIMULATOR STUDIES OF A NONLINEAR LINKAGE

IN A POWER CONTROL SYSTEM

By Arthur Assadourian

Langley Research Center
Langley Field, Va.

NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
WASHINGTON
April 1959

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MEMORANDUM 2-15-59L

GROUND SIMULATOR STUDIES OF A NONLINEAR LINKAGE IN A POWER CONTROL SYSTEM

By Arthur Assadourian

SUMMARY

An investigation was made to determine the characteristics of a nonlinear linkage installed in a power control system incorporated in a ground simulator. The nonlinear linkage provided for increased control-stick motion for relatively small simulator response at control motions near neutral. The quality of the control system was rated on the ease and precision with which various tracking tasks were performed by the pilots who operated the simulator. The results obtained with the nonlinear linkage installed in the control system were compared with those obtained by using the normal linear control system. Several combinations of nonlinearity of the linkage were tested for various dynamic characteristics of the simulator. It was found that the pilots were able to track almost as well with the nonlinear linkage installed as with the normal system. All of the pilots were of the opinion, however, that the nonlinearity was an undesirable feature in the control system because of the apparent lack of simulator response through the neutral range of the linkage where relatively large stick deflections could be made with very little simulator motion. The results showed that increased lag between the target and chair position, higher stick-force levels, and uneven stick forces due to the dynamics of the linkage were general characteristics of all the nonlinear linkage conditions tested. It was also found that for cases of low simulator damping, rapid control motions caused considerably higher overshoots when the nonlinear linkage was installed than were obtained for the normal linear control system. These characteristics were considered to be sufficiently undesirable to outweigh the advantages to be gained from the use of a nonlinear linkage in the control system of an airplane.

INTRODUCTION

Because of the large speed and altitude ranges of current high-speed airplanes, large variations in stability and control-surface effectiveness can be expected. The large variations in airplane parameters often cause the response of the airplane to control motions to be too sensitive at high airspeeds and too insensitive at the lower and landing speeds. These control characteristics make it difficult for a pilot to control an airplane precisely at all times. One of the systems offered as a solution to this problem has been the use of a linkage which provides for a nonlinear gearing between the stick and the control surface. These linkages provide for large stick motions to obtain relatively small surface deflections near neutral stick position but require smaller stick motions to obtain large control deflections for stick positions at some distance from neutral. Consequently, the greatly increased effectiveness of the control surfaces at the higher speeds results in very small deflections being required to obtain limit loads, and the airplane can be better controlled by the relatively insensitive control stick near neutral. At the lower speeds, where larger control deflections are necessary to obtain maneuverability, the more sensitive portion of the nonlinear linkage is used to provide the necessary control.

In order to determine the characteristics of such a linkage in a power control system, the ground simulator described in reference 1 was modified by the installation of a nonlinear linkage obtained from a current production fighter airplane. The quality of the control system, with and without the nonlinear linkage installed, was determined in terms of the ease and precision with which various tracking tasks were accomplished by the pilot who operated the simulator, and the tracking characteristics of a normal linear control system were then compared with a control system having various amounts of nonlinear gearing.

APPARATUS

This investigation was conducted on a ground simulator incorporating a power control system in which a nonlinear linkage was installed between the control stick and the power control unit. The design and method of operation of the simulator are fully described in reference 1. The only major modification made to the simulator for the present tests was the installation of the nonlinear linkage. Figure 1 shows photographs of the simulator, or pitch chair as it was called, and figure 2 shows a schematic drawing of the component parts of the chair in relation to the location of the nonlinear linkage. In order to illustrate the characteristics of the isolated nonlinear linkage, a calibration of the actual linkage used and several schematic drawings are presented in figure 3. The point of interest shown in figure 3(b) is the relatively small output deflection of the linkage when the stick has been moved to one-half its forward or rearward deflection.

The method of attachment of the control stick to the nonlinear linkage made it possible to vary the gearing between them. It was also possible to double the gearing between the hydraulic power actuator and the stabilizer. (See fig. 2.) By using various combinations of the possible gearing changes, which in effect caused the nonlinear portion of the calibration curve near the origin to cover different amounts of the range of stick travel, several cases of control-system nonlinearity were investigated.

The chair angle or the position that the pitch chair assumes during normal tracking operations and that is known as pitch angle is a function of angle of attack and rate of change of the flight-path angle. (See ref. 1.) The chair angle can be made to simulate a function of angle of attack alone by disconnecting the integrator which provides the rate of change of the flight-path angle. Curves showing the stick deflection for the various linkage conditions tested against angle of attack of the chair are presented in figure 4. The normal linear control-stick gearing was such that the ratio of angle of attack to stick deflection was approximately 1.10, and a curve of this variation is shown in figure 4 for comparative purposes.

A simple cantilever spring was attached to the stick in order to supply the pilot with feel forces. A spring with a linear-force gradient of about 1.5 pounds per degree of stick deflection measured at the grip was used for most of these tests. A spring with a linear-force gradient of about 4 pounds per degree of stick deflection was used for those tests made with the integrator inoperative. Airplanes equipped with the type of nonlinear linkage evaluated in these tests make use of an extensible link with which to trim out the control forces. In this way the control stick always has the same position for trim, which means that it also has the same position relative to the nonlinear linkage at trim. When trimming an airplane with such a system, the pilot is required to move the stick toward neutral as he trims.

Because of construction details of the nonlinear linkage, bobweight effects which caused undesirable stick-force characteristics were introduced into the control system. In order to reduce these effects, especially as the linkage was moved through its neutral position, the linkage was partially mass balanced with lead weights. Some inertia effects were also observed in the control system; however, these effects occurred at stick deflections beyond the range of interest of these tests. A time history is presented later to illustrate this characteristic which results, for relatively small stick deflections, from the large motions of the "clapper" (fig. 3(b)) which consists of a pair of links in the nonlinear linkage system. In designing the control system of an airplane, these effects have to be considered.

The pitch attitude of the chair was indicated visually to the pilot by means of an arc light which was mounted on the chair and which projected a spot of light onto a screen about 30 feet in front of the pilot. An additional cam-controlled spot of light was projected so as to move vertically alongside the chair light. The cam was designed so that the light spot would represent various pull-up and push-down maneuvers covering the range of operation of the chair. The task of the pilots involved maintaining alinement of the two light spots.

TESTS AND PROCEDURE

Because previous simulator studies have shown that control-valve friction and stick friction have detrimental effects on control-system quality, the present tests were made with negligible amounts of both in order to eliminate their effects from the study of the nonlinear linkage. The pitch chair was adjusted to have a period of about 1.2 seconds for all of the tests. At the beginning of each test the linkage was adjusted so that it was at the neutral point of its nonlinearity with the chair level and the control stick trimmed. The tracking cam which programmed the light spot through its range of simulated maneuvers remained unchanged for all of the tests. In order to evaluate the characteristics of the nonlinear linkage in the control system for various degrees of difficulty of tracking, the dynamic characteristics of the chair were changed. This change was accomplished by varying the damping ratio and the steady-state ratio of pitching velocity to angle of attack (pitch-rate gain) of the pitch chair. Generally, it was found that low damping and high values of pitch-rate gain made tracking more difficult. Increasing the pitch-rate gain corresponds to maintaining the same dynamic pressures but operating at lower and, therefore, more dense altitudes. The following table gives, in order of increasing difficulty, the various conditions tested and the figures in which typical results appear.

Figure number	Gearing between input to linkage and stick deflection, deg/deg (See fig. 4)	Damping ratio	Pitch-rate gain, deg/sec/deg
5(a)	Normal stick	0.4	0.96
(b)	2:1	.4	.96
(c)	5.5:1	.4	.96
(d)	3.3:1	.4	.96
6(a)	Normal stick	0.4	2.22
(b)	2:1	.4	2.22
(c)	5.5:1	.4	2.22
(d)	3.3:1	.4	2.22
7(a)	Normal stick	0.2	2.22
(b)	2:1	.2	2.22
(c)	5.5:1	.2	2.22
(d)	3.3:1	.2	2.22

It should be noted that the case of the 3.3:1 gearing was used only in conjunction with doubled stabilizer gearing. The intention was to obtain a variation of stick deflection against chair angle of attack which would be similar to that when using the 2:1 gearing but with the travel of the nonlinear linkage approximately doubled. It was intended, in this manner, to concentrate the nonlinearity of the variation of the stick angle with the chair angle of attack nearer the neutral stick position. The curves of figure 4 show that the slope produced through zero was somewhat steeper.

The pilots operating the simulator were asked to track the cam-driven light with the chair light. The ease and precision with which the operators could follow the cam-driven light spot provided the basis for judging the quality of the control system. When the various configurations were evaluated, the opinions of the pilots were carefully weighed along with the examination of the recorded data. At least one NASA test pilot and the author obtained data for each of the cases tested.

RESULTS AND DISCUSSION

The results are presented as typical time histories of chair position, target position, stick position, and stick force in figures 5 to 8 for the various conditions tested. General notes were also taken of the opinions of the operators of the simulator in regard to the control-system characteristics for all conditions tested. From a consideration of all of the records taken, not just those presented herein, and from the opinions of the pilots operating the pitch chair it may be said that the pilots could track almost as well with the nonlinear linkage in the control system as with the normal stick. This was generally the case whether the tracking was made relatively easy (see fig. 5) or more difficult (see figs. 6 and 7) by varying the chair dynamics. However, some differences are apparent during the transient portion of the maneuvers. Generally, there were larger amounts of lag present between the target and the chair position for all cases with the nonlinear linkage than with the normal stick. This fact can be attributed to the very low sensitivity of the stick near neutral which results in little or no chair motion for the initial stick displacements made by the pilot. (See figs. 5(b), 6(c), 6(d), and 7(d).) For those cases with the nonlinear linkage where the lag between chair position and target position is small, the chair angle is seen to overshoot somewhat. (See fig. 5(c).)

It may be noted in some of the time histories concerning the nonlinear linkage that the stick-position trace did not linearly follow the stick-force trace. (For examples, see figs. 6(d), 7(c), and 7(d).) This fact is believed to be due to the intermittent introduction of a form of stick friction into the control system by the pivots of the many links required to install the nonlinear linkage. However, these forces are seen to be small (on the order of 1 or 2 pounds) and, from studies reported in reference 1, were found to be unobjectionable in tracking performance if the forces were less than about 3 pounds.

In order to examine the problem of overshoot a little further, additional simulator tests were made with the integrator inoperative. With this arrangement the simulator motion did not include the effects of flight-path angle and, therefore, represented angle-of-attack or normal-acceleration changes. Several pull-ups and push-downs, as well as pull-ups from a nose-down attitude, were made at different rates of control input for several values of damping ratio. The tests were made with the normal linear control stick and with the 5.5:1 nonlinear linkage installed. It was found that for the tests made at damping ratios of 0.3 and 0.2, the various pull-up transients were about the same for both control systems. However, the pull-up and push-down transients for a damping ratio of 0.1 showed that considerably more overshoot was obtained with the nonlinear linkage installed than with the normal linear stick. Typical data showing these effects are presented in figure 8. It is believed that the overshoots obtained with the nonlinear linkage are a result of the large changes in gearing as the stick is moved through neutral. (See fig. 4.) It should be noted that the higher overshoots were obtained with the nonlinear linkage installed for only the higher rates of control input. Nevertheless, situations requiring rapid control motions in low-damped airplanes equipped with nonlinear linkages could easily result in overshoots exceeding the design limits of the airplane.

Another characteristic of the control system was the dynamic inertia effects. These effects were attributable to the "clapper" of the nonlinear linkage which moves rather rapidly near neutral stick position but slows down as it moves away from neutral. In order to illustrate these effects, a test was made with the output link of the nonlinear linkage disconnected from the power control unit. The control stick was then moved rapidly back and forth through its full range of deflection, and a typical time history of the results obtained is presented in figure 9. As can be seen, there is a decided inertia effect at the higher values of stick deflection which caused undesirable irregularities in the stick-force trace. These inertia effects were felt by the pilots to be much larger than was indicated by the results. Even though the rates of stick motion and the large deflections were beyond the scope of the present tests and did not affect the tracking results, this characteristic of the nonlinear linkage is included so that it can be given consideration in control-system design.

Perhaps the most important considerations in evaluating the control system with and without the nonlinear linkage installed are the higher stick-force levels and the greater concentration required for tracking with the nonlinear linkage in the system. The implication is that even though the pilot can track almost as well with as without the nonlinear linkage in the control system, he must use larger stick forces and a larger degree of concentration; therefore, he tends toward earlier fatigue. These foregoing comments, of course, apply only to the small range of stick and simulator deflections of this investigation.

The differences just noted for the control systems with and without the nonlinear linkage installed should be considered in accounting for the unanimous opinion of the pilots that the nonlinear linkage was an undesirable feature. The major objection of the pilots was the lack of simulator response through the neutral range of the nonlinear linkage where relatively large stick deflections could be made with very little chair motion. This objection was especially true where the tracking task consisted of a pull-up from a nose-down attitude covering the complete range of the pitch chair. In a maneuver of this type, the pilot was faced with a continuously changing stick sensitivity as he moved in and out of the relatively insensitive neutral range of the linkage. As was just pointed out, rapid control motions in a maneuver of this type easily produced undesirable overshoots. There was little apparent difference to the pilots in tracking performance between the various types of nonlinearity tried with the linkage in the control system.

SUMMARY OF RESULTS

From an investigation to determine the characteristics of a nonlinear linkage during tracking maneuvers by means of a ground simulator incorporating a power control system, the following results were obtained:

1. Pilots operating the simulator were able to perform various tracking tasks almost as well with the nonlinear linkage in the control system as with the normal linear control system.

2. The pilots considered that the nonlinearity of the linkage was an undesirable control feature because of the apparent lack of simulator response through the neutral range of the linkage during the tracking maneuvers.

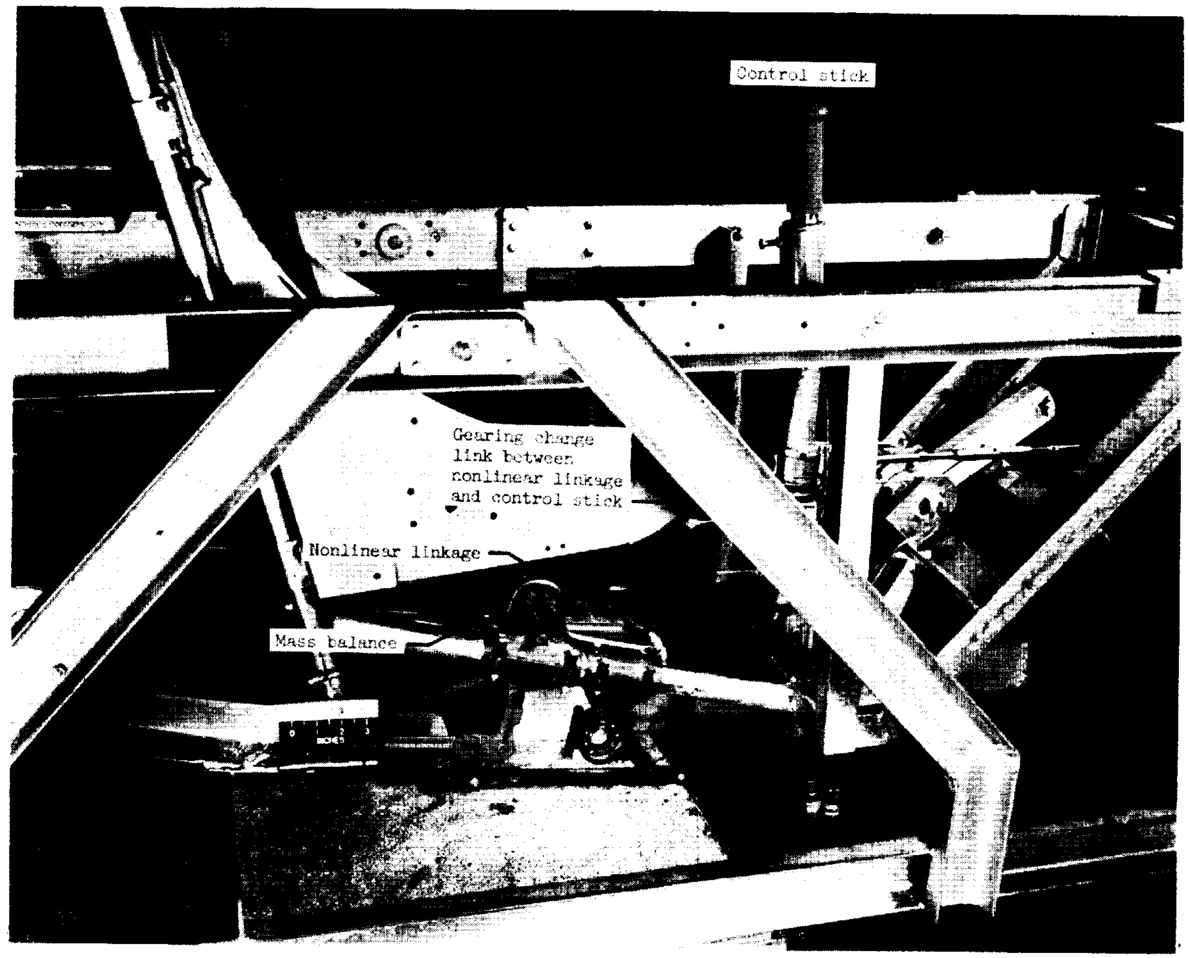
3. The tests showed that in comparison with the linear system, the nonlinear linkage system resulted in increased lag between the target and the chair positions, higher stick-force levels, and greater concentration on the part of the pilot during the tracking maneuvers.

4. For cases of low simulator damping, the tendency to overshoot during rapid pull-up maneuvers was much more prevalent for the simulator control system with the nonlinear linkage installed.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., November 25, 1958.

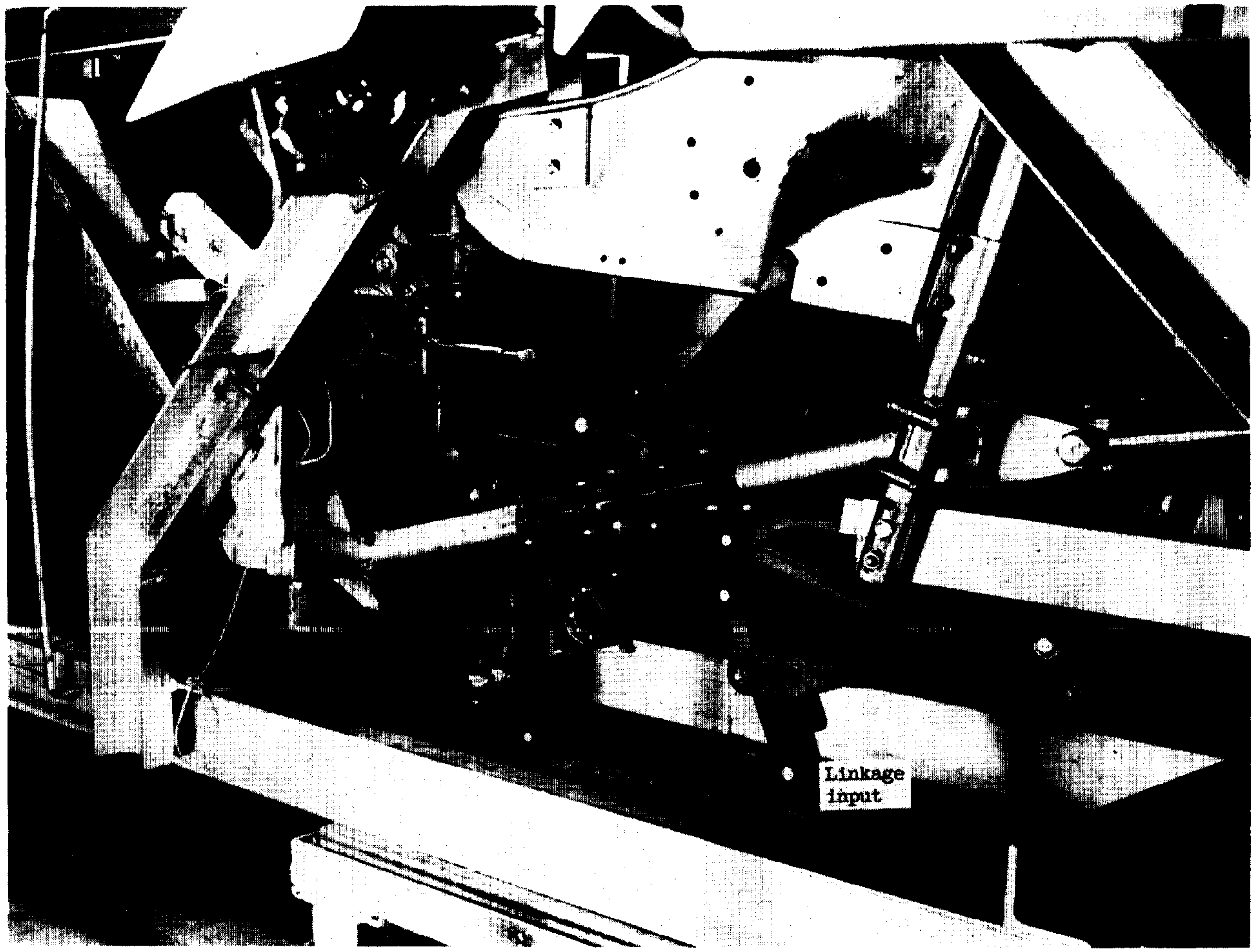
REFERENCE

1. Brown, B. Porter: Ground Simulator Studies of the Effects of Valve Friction, Stick Friction, Flexibility, and Backlash on Power Control System Quality. NACA Rep. 1348, 1958. (Supersedes NACA TN 3998.)



(a) View from right side of simulator. L-57-3636.1

Figure 1.- Photographs of longitudinal power control simulator (pitch chair) equipped with a nonlinear linkage in the control system.



(b) Three-quarter left rear view. L-57-3635.1

Figure 1.- Concluded.

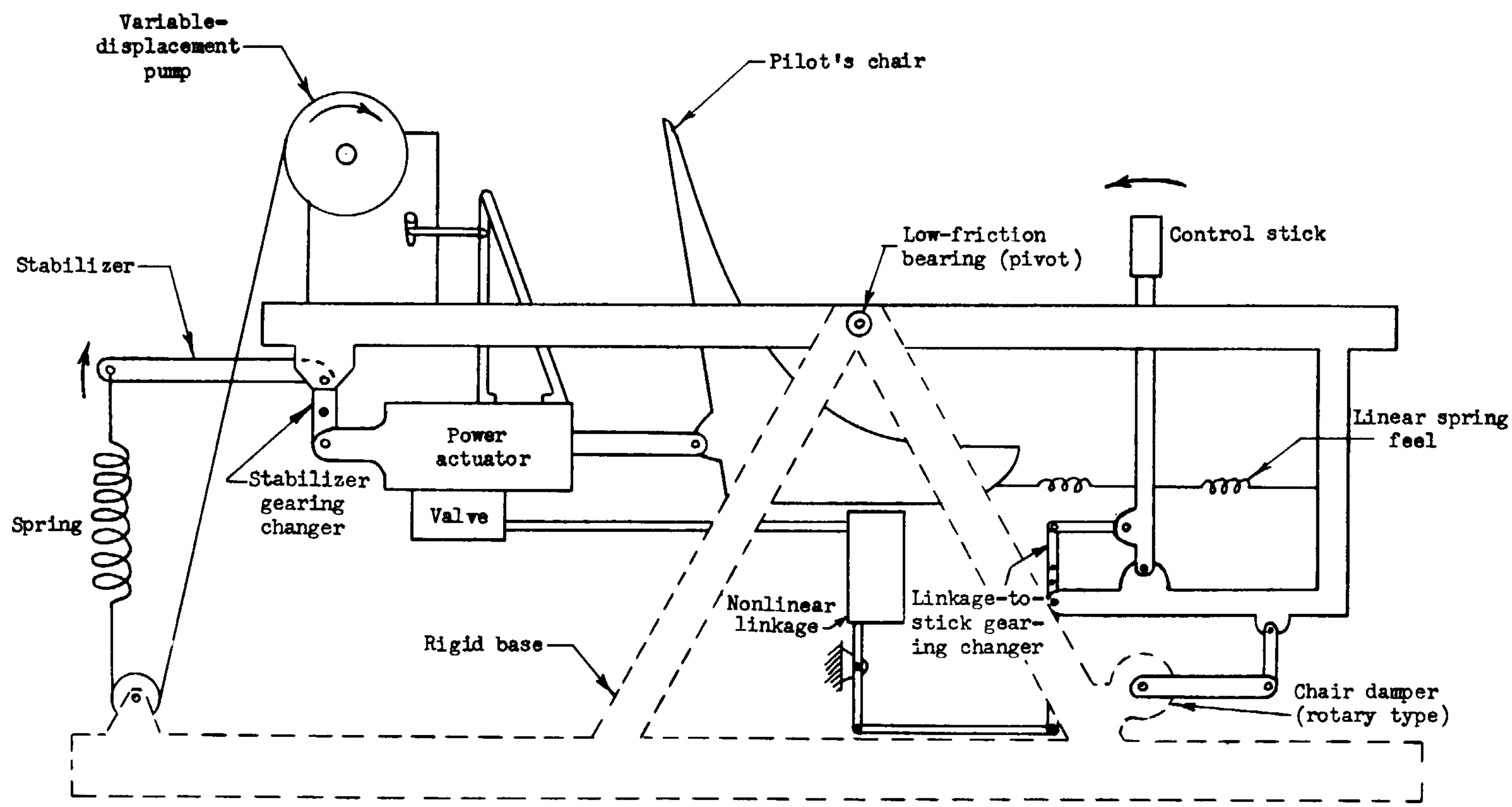
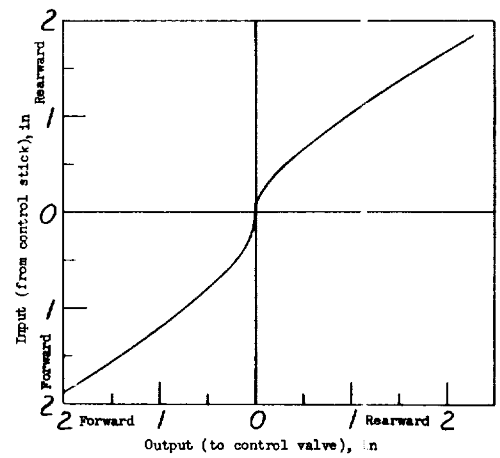
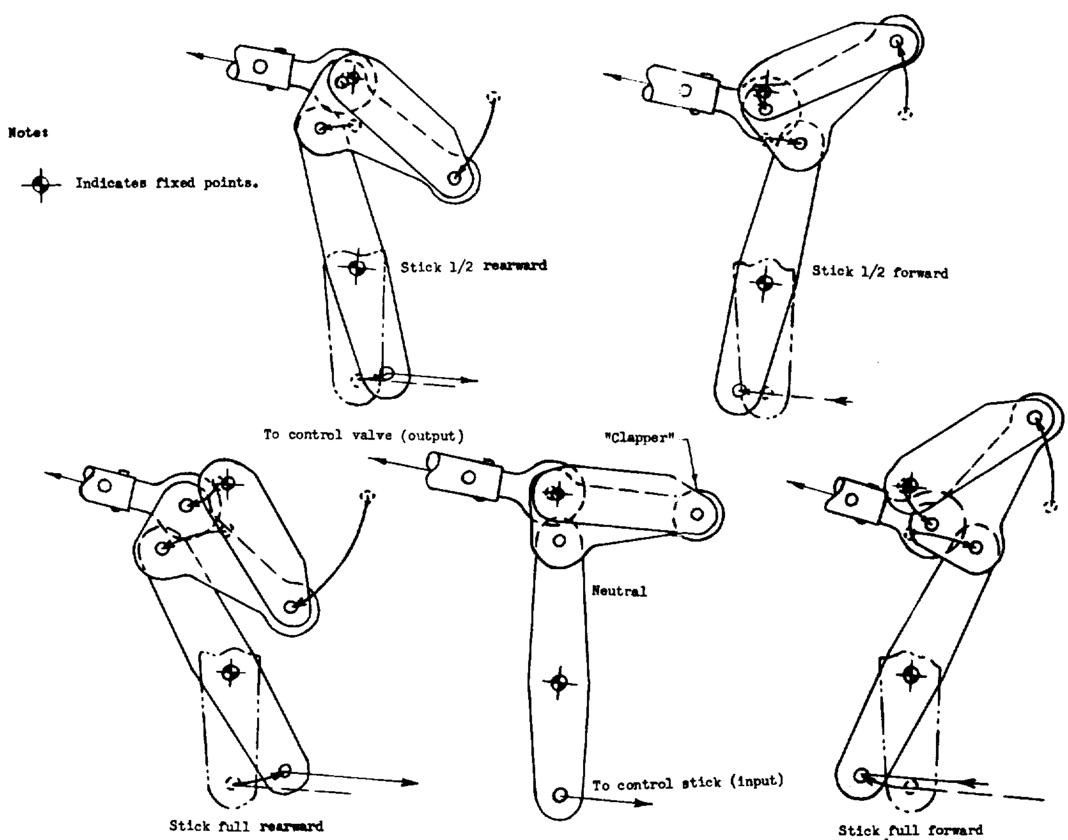


Figure 2.- Schematic drawing of simulator. Solid lines indicate moving parts. Arrows indicate direction of motion of stick, stabilizer, and pump drum associated with a pull-up.



(a) Calibration of actual nonlinear linkage used in these tests.



(b) Schematic drawings of nonlinear linkage for various stick deflections.

Figure 3.- A calibration and schematic drawings of nonlinear linkage installed in the simulator.

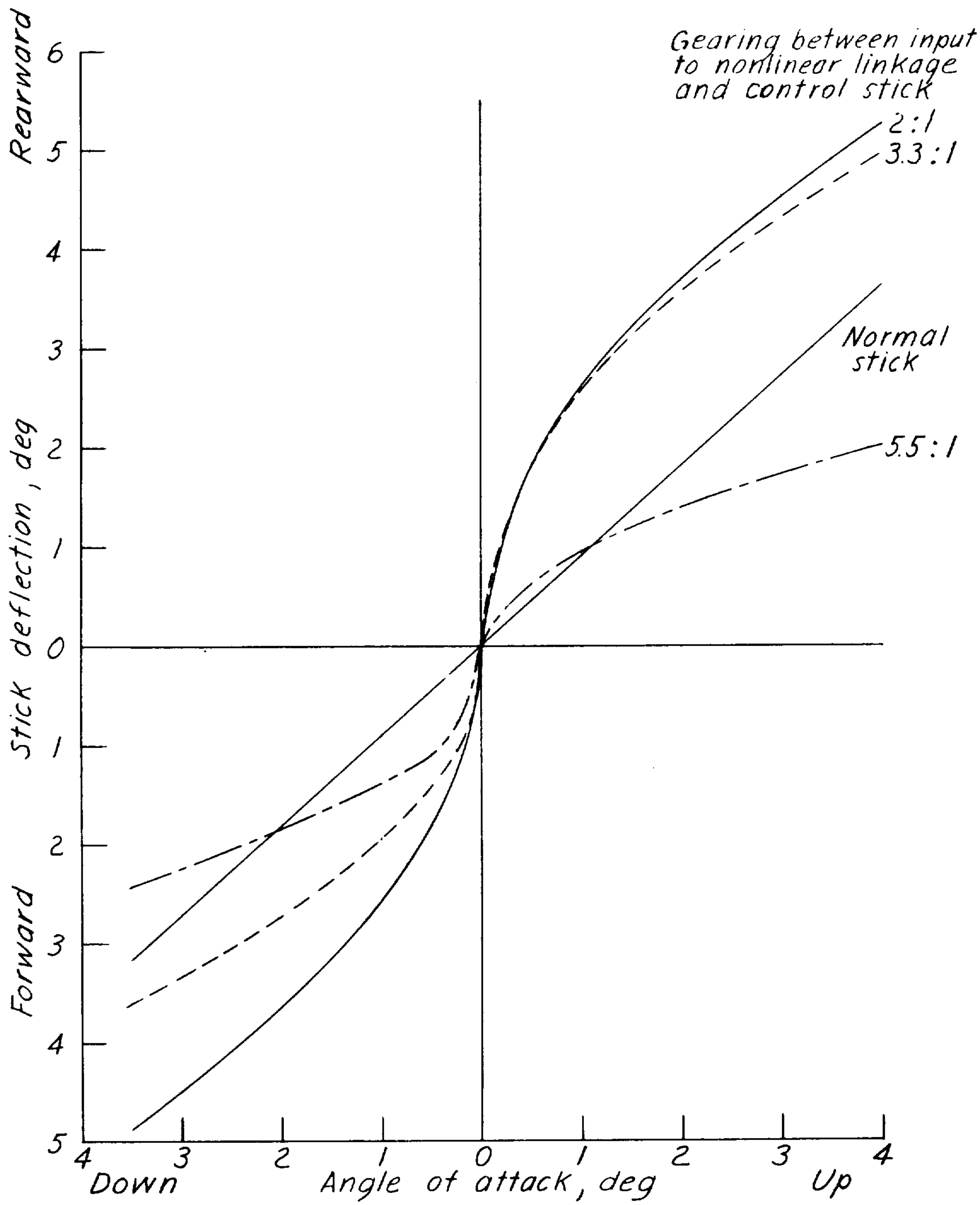
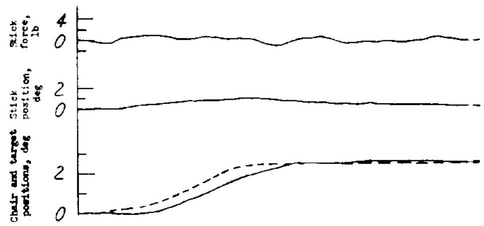
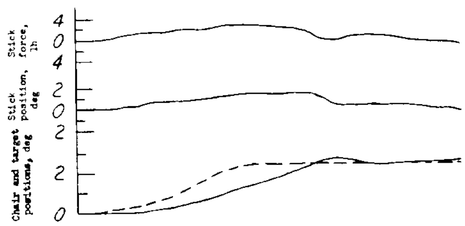


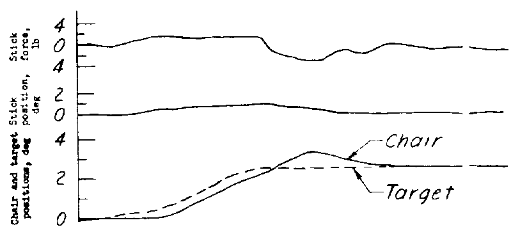
Figure 4.- Variation of control-stick deflection with angle of attack for normal linear control system and for various gearings between nonlinear linkage and control stick. Note that the 3.3:1 gearing was used with the doubled stabilizer gearing only.



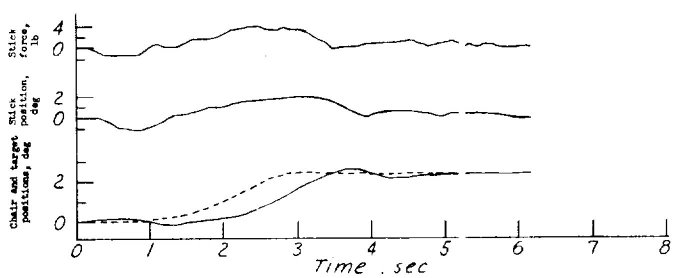
(a) Normal linear system.



(b) Ratio between input to nonlinear linkage and control stick, 2:1.

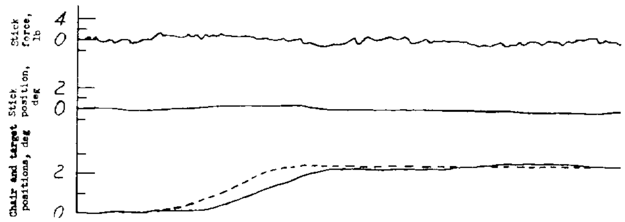


(c) Ratio between input to nonlinear linkage and control stick, 5.5:1.

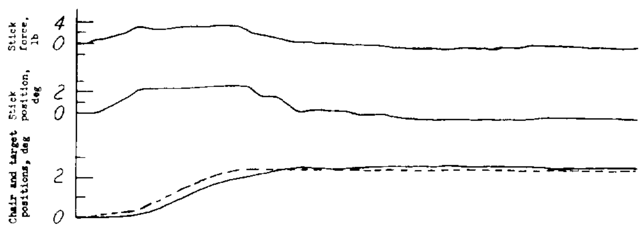


(d) Ratio between input to nonlinear linkage and control stick, 3.3:1 (stabilizer gearing doubled).

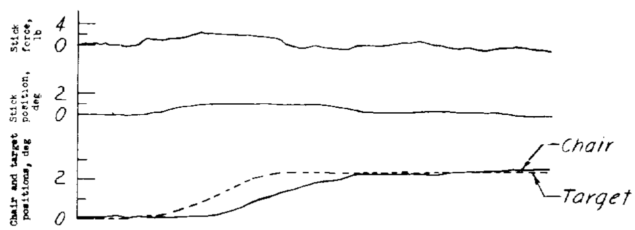
Figure 5.- Typical time histories obtained with pitch chair for normal linear system and with nonlinear linkage installed. Period = 1.2 sec; damping = 0.4; pitch rate gain = 0.96°/sec/deg.



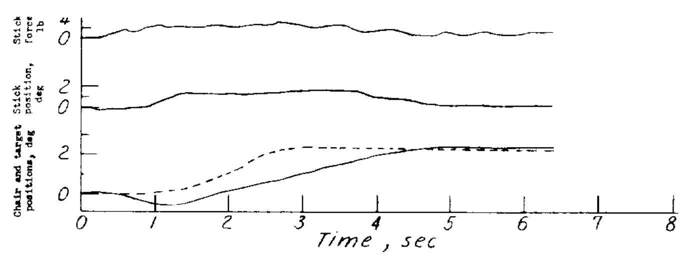
(a) Normal linear system.



(b) Ratio between input to nonlinear linkage and control stick, 2:1.

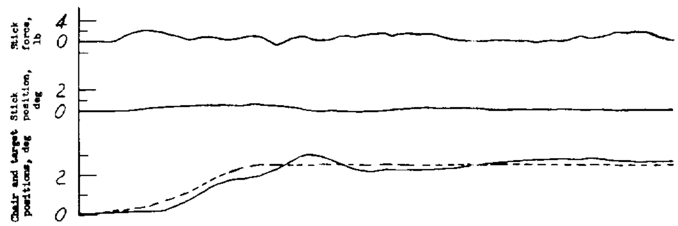


(c) Ratio between input to nonlinear linkage and control stick, 5.5:1.

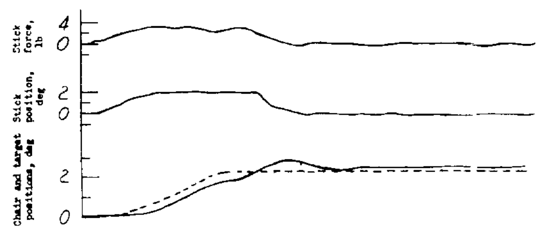


(d) Ratio between input to nonlinear linkage and control stick, 3.3:1 (stabilizer gearing doubled).

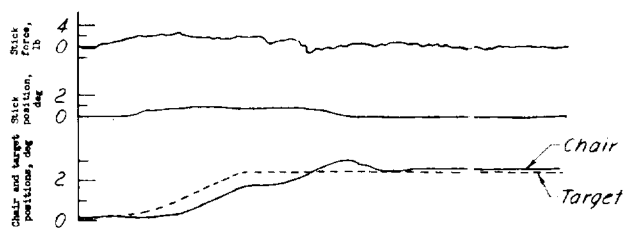
Figure 6.- Typical time histories obtained with pitch chair for normal linear system and with nonlinear linkage installed. Period = 1.2 sec; damping = 0.4; pitch rate gain = 2.22°/sec/deg.



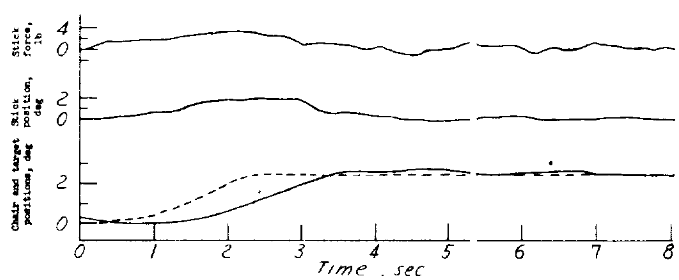
(a) Normal linear system.



(b) Ratio between input to nonlinear linkage and control stick, 2:1.



(c) Ratio between input to nonlinear linkage and control stick, 5.5:1.



(d) Ratio between input to nonlinear linkage and control stick, 3.3:1 (stabilizer gearing doubled).

Figure 7.- Typical time histories obtained with pitch chair for normal linear system and with nonlinear linkage installed. Period = 1.2 sec; damping = 0.2; pitch rate gain = 2.22°/sec/deg.

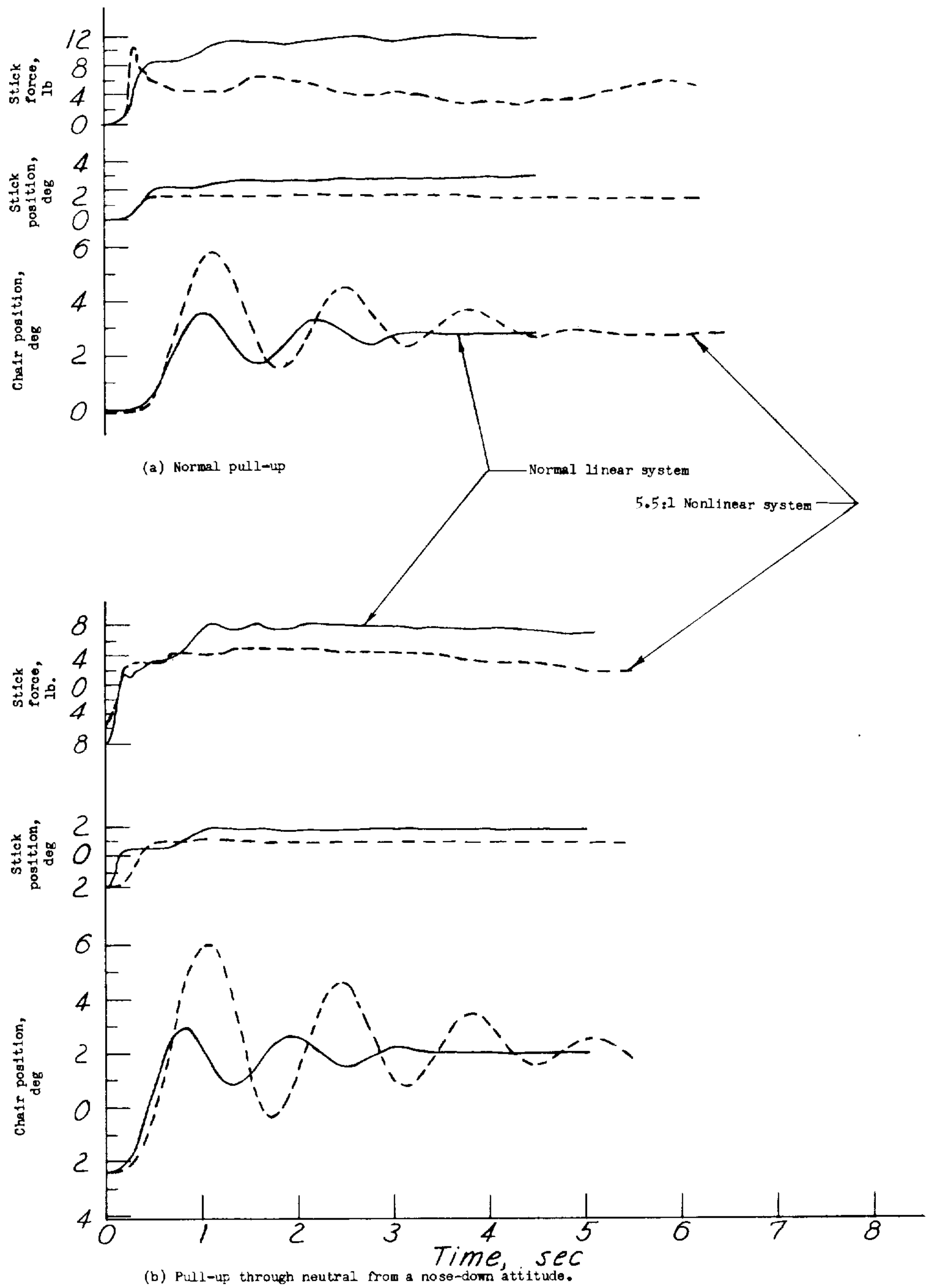


Figure 8.- Typical time histories of pull-up maneuvers made with normal linear control system and with 5.5:1 nonlinear control system with the integrator providing flight-path angle inoperative. Period = 1.2 sec; damping = 0.1; pitch rate gain = 0; spring feel, 4 pounds per degree.

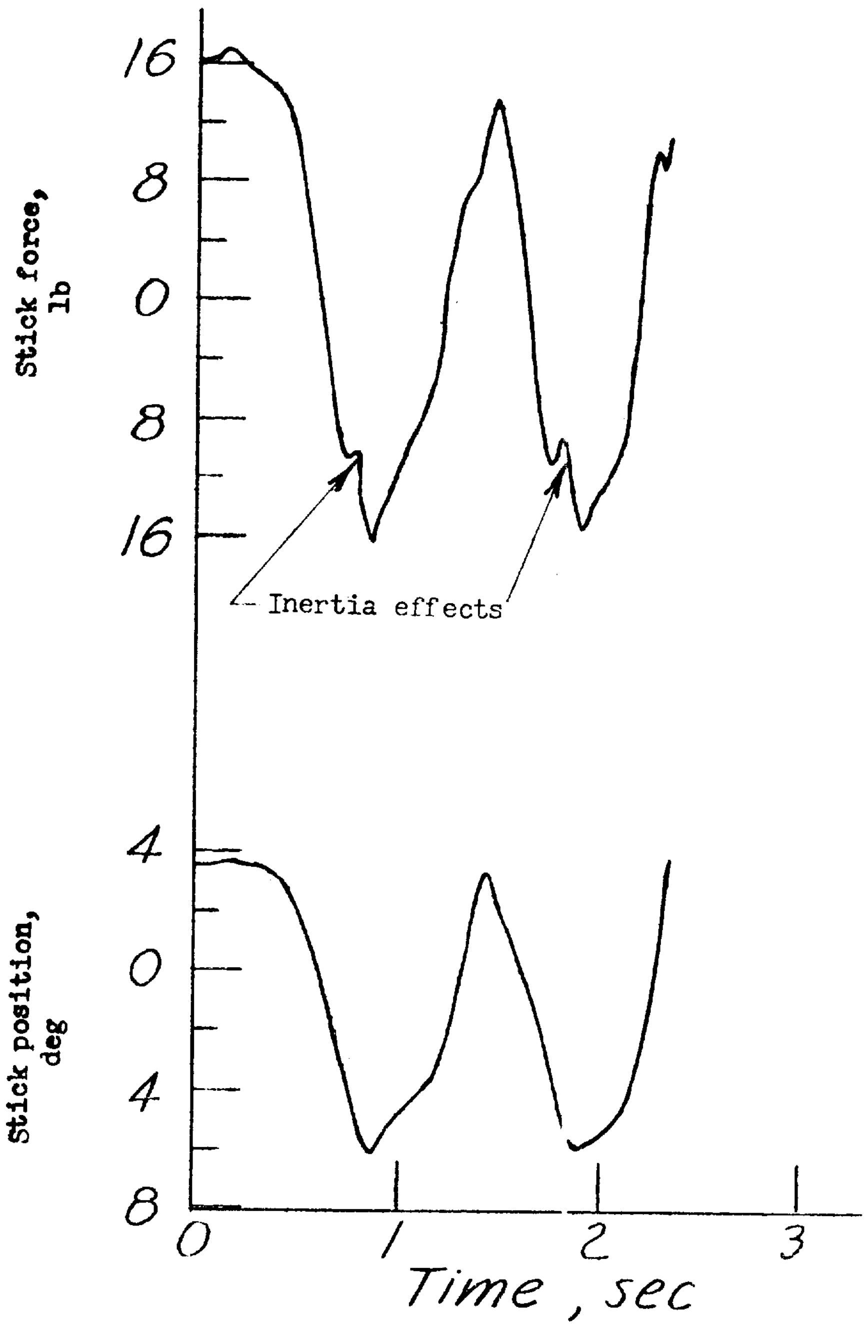


Figure 9.- Typical time history of rapid control-stick motions to illustrate inertia effects due to nonlinear linkage. Power control unit disconnected; spring feel, 4 pounds per degree.