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RESEARCH MEMORANDUM

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LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF
A B-29 AIRPLANE WITH A BOOSTER INCORPORATED IN THE
ELEVATOR CONTROL SYSTEM TO PROVIDE VARIOUS STICK-
FORCE AND CONTROL-RATE CHARACTERISTICS

By Charles W. Mathews, Donald B. Talmage,
and James B. Whitten

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LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF
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SUMMARY

The longitudinal stability and control characteristics of a B-29 airplane have been measured with a booster incorporated in the elevator control system. Tests were made to determine the effects on the handling qualities of the test airplane of variations in pilots' control-force gradients as well as the effects of variations in the maximum rate of control motion supplied by the booster system.

The variations of the elevator control force with normal acceleration for the test airplane without boost were appreciably higher than the upper limit of 60 pounds per g specified as satisfactory by present handling-qualities specifications. These control forces with boost off were considered by the test pilots to be tolerable but heavy. Use of the booster to adjust the control force gradients to fall within the limits of 22.5 to 60 pounds per g specified as satisfactory by present handling-qualities requirements appreciably improved the control characteristics of the test airplane. Further reduction of these force gradients through use of the booster to a point where the gradients were below the lower specified limit at low speeds but were above this limit at high speeds still resulted in satisfactory control characteristics though not as desirable as for the preceding condition. These results indicate that the present specification as to the upper limit of elevator-control force gradients for large airplanes adequately approximates a boundary between satisfactory and tolerable gradients; whereas the lower specified limit appears somewhat high, particularly with reference to flight conditions at low speeds.

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During landings of the test airplane high rates of control motion were used by the pilots both without the booster and with the booster operating under conditions where high control rates were available from the system. The abrupt control deflections associated with these high rates of control motion were held for such short time intervals that no significant alterations to the flight path of the airplane were apparent from the test data. Other landings which were made with the rate of elevator motion restricted to values as low as 7° per second were satisfactory from the standpoint of the pilot's opinion of the handling qualities of the airplane. This result was also obtained for other flight conditions such as take-off and normal maneuvers. A point worth noting which may have a bearing on these results is that this booster was rigged so that the pilot was afforded freedom of stick movement within certain limits even when the rate of elevator motion was restricted to low values.

From the results of this control-rate investigation it appears that large airplanes may have satisfactory handling qualities with booster adjusted to give much lower rates of control motion than those normally used by pilots.

INTRODUCTION

There is a current trend to the use of booster systems for operating the control surfaces of airplanes. The use of boosters results primarily from a need for alleviating the large control forces associated with large airplanes, for improving the maneuvering capabilities of high-speed fighter airplanes where control deflections are limited by the pilot's physical capabilities, or for improving the control force characteristics where the aerodynamic hinge moments of the control surfaces have unsatisfactory variations.

Because the requirements for boosters involve consideration of the airplane and pilot, the National Advisory Committee for Aeronautics has undertaken a flight investigation of a booster system. An analysis and bench test of this booster is presented in reference 1, and for this investigation the booster was installed in the elevator control system of a B-29 airplane.

When boosters are used, two alternatives exist with regard to the provision of pilot's control forces. For many systems a given percentage of the aerodynamic hinge moment on the control surface is fed back to the pilot's stick while for other systems, where the aerodynamic hinge moments have unsatisfactory variations, there is no feedback of the aerodynamic forces and the stick forces are created mechanically. The present investigation was concerned with the type of system which provides for a

feedback of the aerodynamic forces. The test booster system had provision for varying the magnitude of this force feedback over a wide range, and the effect of magnitude of the pilot's stick forces on the handling qualities of the test airplane were investigated.

Another important booster parameter affecting airplane handling qualities is the maximum rate of control motion supplied by the system. The test booster had provisions for varying the maximum available control rate, and the effects of such variations were investigated.

Measurements of the longitudinal stability and control characteristics were obtained for the test airplane both without the booster and with the booster operating to provide various stick-force and control-rate characteristics. Results obtained from these measurements are presented herein.

BOOSTER INSTALLATION

A description of the booster and a discussion of its operation is given in reference 1. The schematic arrangement of the system is shown in figure 1, and a photograph of the test unit is shown in figure 2. The booster was installed on the pilot's side (left side) of the elevator control system of the B-29 airplane. The orientation of the booster in the airplane is shown in figure 3. This booster system had been tested previously as a bench setup. Results of these bench tests, reported in reference 1, show that this system is satisfactorily free from chatter, deadspots, excessive lag, friction, and other undesirable characteristics which might adversely affect the pilot's opinion as to the handling qualities of the test airplane.

Several important features of the flight-test version of the booster system are not described in reference 1. With regard to variations in the magnitudes of the control forces, the part of the total elevator hinge moment fed back to the pilot was made adjustable through use of a manual control. The ratio of total control force to pilot-held force (boost ratio) is equal to the ratio of the length l to the length d shown in figure 1, and the manual control changed the boost ratio by varying the position of the point A shown in figure 1. With regard to variations in maximum available control rate, this booster is built around a variable displacement hydraulic pump and operates so that the velocity of the control surface is proportional to the error in position between the control surface and the stick. The flight-test version of the booster was rigged so that a $\frac{1}{2}^\circ$ error in position (referred to the stick) would produce the maximum available flow of

fluid from the pump. This condition corresponds to the maximum rate of control motion when the control rate is not restricted by other means that are discussed subsequently. Mechanical stops (see fig. 1) were placed in the system so that on attaining this $1\frac{1}{2}^{\circ}$ error in position, the stick could be moved no faster than at a rate corresponding to the maximum of the system (an elevator rate of 100° per second with no restriction). In addition to these fixed stops a set of adjustable stops were placed on the pump control arm as a means for further restricting the maximum control rate. The push-pull rod to the pump control arm was not rigidly attached but was attached with a preloaded spring arrangement. This device was used so that, in spite of a rate restriction, the pilot could still move his stick (against the spring force) at any rate desired until the fixed stops were contacted ($1\frac{1}{2}^{\circ}$ error in stick position). These springs were preloaded to $8\frac{1}{2}$ pounds as measured at the stick. The ratio between motions of the control arm and the stick was 15 radians per radian.

A set of centering springs was installed on the pump control arm to prevent a small residual oscillation from occurring in the boost system. This oscillation has been encountered during bench tests (see reference 1) and was eliminated through use of centering springs. These springs, which supply a damping force at the stick proportional to the rate of control motion, had a constant of 0.06-pound stick force per degree per second rate-of-control motion. A small dashpot type of viscous damper was connected to the control arm in order to smooth further the action of the servovalve which operated the pump. The damper applied 0.065 inch-pound torque to the control arm per degree per second rate of motion of the control arm. The torque on the control arm required to overcome the static friction in the servovalve was 0.047 inch-pound. The force required at the stick to overcome the friction in the linkages to the control arm was approximately $1/4$ pound. Installation of a control-position pickup on the pump control arm, however, increased the friction present at the stick to about $1\frac{1}{2}$ pounds. This control-position pickup also increased the constant of the centering springs by a small amount. The electric motor used to drive the variable displacement pump of the booster unit is rated at 2 horsepower and 4000 rpm. The pump delivers about 3.3 gallons per minute at maximum displacement and the maximum operating pressure is 1250 pounds per square inch. The estimated increase in the gross weight of the test airplane resulting from installation of the booster unit is 80 pounds. No particular effort was made to minimize the weight of the installation.

The booster output was applied to a quadrant beneath the pilot's stick and operated the elevator through the cable system in the airplane.

(See fig. 3.) Since the cable system to the elevator from the pilot's and copilot's stick are independent in the B-29 airplane, a cam-operated cable clamp was used as a safety device so that the pilot's cable system could be disconnected from the quadrant in event of boost failure. In addition, a manually operated hydraulic bypass was provided.

The longitudinal control system of the test airplane was selected for the booster investigation because elevator force variations were felt to be the most critical from handling-qualities considerations and because rate-of-elevator movement is important at least during landings and take-offs. The B-29 airplane was chosen for these tests because it represents a large airplane having inherent elevator force variations that are satisfactory, but having elevator forces that are somewhat high in relation to the present handling-qualities requirements. The test airplane was flown at a gross weight of about 108,000 pounds and with the center of gravity at about 25 percent of the mean aerodynamic chord. A three-view drawing of the B-29 airplane is presented in figure 4, and some general specifications of the airplane are listed in table I.

INSTRUMENTATION AND MEASUREMENTS

Standard NACA instruments were used. The following table presents a list of these instruments and the quantities that were measured:

Measured quantity	NACA instrument
Stick position	Mechanical-control-position recorder
Elevator position	Electrical-control-position recorder
Booster control-arm position	Mechanical-control-position recorder
Stick quadrant position	Mechanical-control-position recorder
Elevator control force	Strain-gage wheel force recorder
Booster hydraulic pressure	Hydraulic pressure recorder
Airspeed	Airspeed recorder and indicator
Normal acceleration	Recording and indicating normal accelerometers
Pitching velocity	Pitch turnmeter
Time	Timer synchronizing all records

The airspeed system utilized in these tests was the airplane's service system. The flush static orifices of this system are located

on the side of the fuselage just rearward of the pilot's cockpit. These orifices were calibrated for position error through use of a trailing airspeed bomb. The airspeed used herein is that corresponding to the reading of a standard Air Force-Navy indicator connected to a pitot-static head which is free from position error. This airspeed is equal to true airspeed under standard sea-level conditions.

RESULTS AND DISCUSSION

General.- An initial phase of the investigation was concerned with tests to determine whether the incorporation of the booster system in the B-29 airplane altered the control characteristics in any way other than to change the magnitude of the control forces.

The measured static-longitudinal-stability characteristics of the test airplane are presented in figure 5 for conditions of boost ratio 1 (no boost), boost ratio 2.8, and boost ratio 4.6 where boost ratio is defined as the ratio of the total control force to the control force held by the pilot. In the figure, pilot's elevator force divided by impact pressure F_e/q_c and elevator deflection from neutral δ_e are plotted against airplane normal-force coefficient C_N . Results measured in steady flight for the clean condition are shown in figure 5(a), and corresponding results are presented in figure 5(b) for the landing condition.

As would be expected, no alterations in stick-fixed characteristics (δ_e against C_N) resulted from use of the booster. Although the elevator force variations with normal-force coefficient were reduced approximately in inverse proportion to the boost ratio, the general behavior of these variations were not significantly altered by the booster. Note, for example, that the results for the clean condition (fig. 5(a)), both with and without boost, show that the control forces tended to lighten as the stalling speed was approached. The flight data obtained from these static-stability tests showed appreciably more scatter with boost off than with boost on particularly at high normal-force coefficients (low speeds). The difference in the scatter obtained between boost-on and boost-off tests is a reflection of the fact that the pilots could attain and hold a given trim speed more easily with the booster operating. This result probably derives from the large magnitude of the friction present in the elevator control system of the test airplane (about 25 lb as measured on the ground). This friction was reduced along with the aerodynamic forces through use of the booster.

In order to determine whether the booster altered the control characteristics of the test airplane under conditions of rapid control movements or with the controls free, a series of abrupt pull-ups were made, each followed by release of the control stick. These maneuvers were made both with boost ratio 2.8 and without boost. The available

rate of control motion for the tests with boost on was 100° per second. Time histories of the airplane motions, control motions, and control forces obtained during these tests at an indicated airspeed of 160 miles per hour are presented in figure 6(a), and time histories obtained at 250 miles per hour are presented in figure 6(b). The curves showing the rate of control motion presented in the time histories with boost on were determined from measurements of the position of the pump control arm which is proportional to control rate. Similar variations were not obtained for the boost-off tests because the method of measurement was not applicable to the direct control system.

Comparison of the boost-off and boost-on time histories at both airspeeds shows that the pilot applied a much more abrupt control deflection when working against the smaller forces encountered with the booster in operation. In both cases the pilot intended to apply control as abruptly as possible. Even for the rapid control motions used in the boost-on tests, no appreciable lag existed between motion of the stick and the control surface. (See fig. 6.) For the abrupt pull-up at 160 miles per hour with boost ratio 2.8 the stick-force variation shown in figure 6(a) exhibits a peak which is not present for the pull-up without boost. This force peak, which is in phase with the rate of control motion, results at least in part from the use of centering springs on the pump control arm. This component of the control force opposes the control velocity. The force is of significant magnitude only when this rate of control motion is very high as may be seen by the lack of this force peak for the abrupt pull-up, boost on, at 250 miles per hour where the stick was moved at a slower rate. This characteristic was not objectionable to the pilots. Results of other handling-qualities investigations have indicated that such forces may be advantageous since a more adequate warning of possible large normal accelerations is presented to the pilot whenever control is applied rapidly. Another point worth noting from these time histories is that the largest control rate used by the pilot, when he purposely attempted to apply abrupt control, was about 70° per second.

The stick-free dynamic characteristics of the test airplane are also indicated by the time histories presented in figure 6. For both airspeeds and for both boost conditions the motions of the controls and airplane following release of the stick were deadbeat. At an indicated airspeed of 160 miles per hour, both with and without boost, the elevator did not return to its trim position following release of the stick. This condition results from the aforementioned control friction, and since the friction exists between the booster and the elevator, the use of boost does not affect the centering tendency. At higher speeds the centering tendency of the elevator was much improved due to the larger magnitude of the aerodynamic hinge moments in relation to the control friction. (See fig. 6(b).)

Control-force investigation.- The variations of elevator force with normal acceleration (in g units) as measured in turns are presented in figure 7 for various values of boost ratio. Variations are shown for indicated airspeeds of 160, 200, and 250 miles per hour in figures 7(a), 7(b), and 7(c), respectively.

The use of the booster in the B-29 airplane decreased the elevator force gradients in approximately inverse proportion to the boost ratio but otherwise did not significantly affect the control characteristics of the test airplane in steady turning flight. As indicated in figure 7, the control force gradients of the test airplane increased with increasing airspeed. Without boost and at an indicated airspeed of 250 miles per hour the force gradient is about twice the maximum value of 60 pounds per g normal acceleration specified by the present requirements for satisfactory handling qualities (reference 2); whereas at 160 miles per hour the force gradient approaches this maximum specified value. The pilots conducting these tests felt that the control forces encountered without boost were tolerable but heavy. The decrease in force gradient with decreasing airspeed, however, had the advantage of improving the handling qualities of the test airplane during landings over those existing for several other large airplanes. Because of this decrease with speed, the test airplane could be landed, boost off, with one hand on the control wheel and without the necessity for retrimming when the power is cut prior to ground contact although the forces were high under this condition. The large force gradients at high speed limited the maneuvering capabilities of the airplane.

With the booster operating at boost ratio 2.8 the control force gradients in turns were reduced to about 20 pounds per g at 160 miles per hour and to about 50 pounds per g at 250 miles per hour. This range of force gradients falls roughly within the range of $22\frac{1}{2}$ to 60 pounds per g specified as satisfactory by handling-qualities requirements. In the opinion of the test pilots, force gradients of these magnitudes were much superior to those encountered without boost. The maximum permissible normal acceleration could be obtained at high speed, and the gradients at moderate and low speeds were still large enough to provide the pilot with adequate feel. The longitudinal control characteristics of the airplane during landings were considered excellent. With the lower force gradients the pilots found that it was easier to correct for errors in the approach just prior to ground contact enabling good touchdowns to be made even with relatively poor approaches.

As shown in figure 7, use of boost ratio 4.6 resulted in force gradients of the test airplane of about 35 pounds per g at 250 miles per hour (above the lower specified limit) and about 9 pounds per g at 160 miles per hour (appreciably below the lower specified limit). The pilots, however, still considered force gradients of these magnitudes

satisfactory, and although these gradients were not as desirable as those obtained with boost ratio 2.8, they were superior to the gradients obtained without boost. Possibly this opinion might have been altered if the force gradients of the test airplane had not increased with speed. This contention is borne out to some extent by the test results for boost ratio 8.2. Under this condition the force gradients were near the lower specified limit at 250 miles per hour, but were extremely low at lower speeds and were considered undesirably light by the pilots throughout the speed range of the tests.

The effect of the magnitude of the elevator force gradients on the handling qualities of the test airplane during landings is indicated in figure 8. Time histories of three landings are presented. A landing without boost is shown in figure 8(a), a landing with boost ratio 2.8 is shown in figure 8(b), and a landing with boost ratio 4.6 is shown in figure 8(c).

The time histories indicate that pilot technique in performing landings is similar regardless of the magnitude of the control forces. In general, control was applied during the test landings by a series of abrupt applications of pull force followed almost immediately by a partial release of the force without actually pushing on the stick. The peak pull forces which were applied during the landings without boost were about 80 pounds. This peak value is high in terms of the physical capabilities of a normal pilot when using one hand for control application. Because control was applied in an almost continuous series of abrupt force applications, the magnitude of these peak forces is also indicative of appreciable work required on the part of the pilot.

During the landing with the booster operating at boost ratio 2.8 (fig. 8(b)) the peak pull forces used were about 40 pounds. Although the peak force reduction over the zero boost condition is appreciable, the force reduction is not as great as would be expected from the difference in boost ratio. These results indicate that the pilot used larger elevator deflections to control the airplane when the forces were reduced. For the landing with boost ratio 4.6 the peak pull forces were about 20 pounds (fig. 8(c)) except immediately before ground contact where the pilot applied rapid corrective control. This characteristic of applying rapid corrections just before touchdown was noted for several other landings where the booster was used while without boost such action was rarely taken, apparently because the forces involved were large.

Control-rate investigation. - There are several additional results concerned with pilot technique during landings that are worth noting. As shown in figure 8, the largest rate of elevator motion used during the abrupt control applications was about 40° per second. In spite of these rapid control movements, however, the time histories show that the normal accelerations and pitching velocities were small and that abrupt

control deflections were applied over such short time intervals that the flight path of the airplane was not significantly altered. These observations indicate that the rapid control application is merely a feature of pilot technique.

The preceding statements concerning the usual pilot control technique used in landings may have an important bearing on the maximum control rates that are required in a booster system. Since the airplane does not significantly respond to control applications applied over a short time interval, possibly satisfactory landings could be made with smoother control movements involving much lower rates of control motion. In order to investigate this possibility, a series of boost-on landings were made with the maximum control rate of the system restricted to low values. Time histories of three landings using restricted control rates in the booster system are presented in figure 9. Landings with rate restrictions of approximately 20° , 10° , and 7° per second are shown in figures 9(a), 9(b), and 9(c), respectively.

During landings with restricted control rates, just before ground contact the pilot invariably called for higher rates than were available. This condition is indicated in figure 9 by the dashed lines representing the maximum available control rate. For these conditions, the pilot moved the control stick faster than the rate at which the elevator was moved by the booster, but these differences in stick and elevator rate did not exist over a sufficiently long time interval to cause the pilot's stick to contact the fixed stops in the system ($1\frac{1}{2}^\circ$ error in position). The lag in the elevator motion even for the largest rate restriction was never large enough to be detected by the pilot in terms of the airplane response.

Also indicated by the time histories in figure 9 is a progressive reduction in the rate which the pilot moved the stick as the available elevator rate was reduced even though the stick could be moved at any desired rate within the fixed stop limits. This result apparently derives from the force feedback of the preloaded springs which connected the push-pull rod to the pump control arm. These springs deflected whenever higher rates than maximum were called for by the pilot. Although this force feedback was not objectionable to the pilots, there is a possibility of making this force feedback small (weak springs) and eliminating the fixed stops in the system. With such modifications the pilot could move the stick without limit at any rate even though the system rate was restricted. The pilot would then have no indication of a restricted rate of control motion unless the restriction could be detected in the response of the airplane.

With the system as used for the present tests the pilots felt that the handling qualities of the airplane were satisfactory even with the

control rate restricted to the lowest value of 7° per second. As mentioned previously, some detection of the rate restriction was possible because of the forces applied by the preloaded springs. Apparently no real sense of lack of control was encountered, however, possibly because the pilot could continue to move the stick against the spring force.

During several landings with restricted control rates the pilot intentionally started the landing flare well off the ground and had to correct for this error. Other landings were made in which the flare was delayed beyond the point where it would normally have been initiated. Even with the lowest available control rates used in these tests no complications were involved in correcting for these conditions.

Although results are presented herein only for landings, which were felt to be the most important maneuver from the standpoint of rate of elevator motion, the handling characteristics of the test airplane with restricted control rates were qualitatively investigated for other flight conditions. No unsatisfactory characteristics were evident during normal take-offs where the control stick is held forward until take-off speed is approached, and then gradually pulled back to lift the nose wheel. Another take-off technique was also investigated as being more critical than the normal procedure. For this test, the stick was held full back from the beginning of the take-off run. Under these conditions, the airplane has an unstable pitching tendency when the nose wheel rises off the ground, but even with the lowest available rate of elevator motion, the pilot experienced no difficulty in controlling this pitching tendency. During the tests, the pilots could easily contact the fixed stops ($1\frac{1}{2}^{\circ}$ error in stick position) during taxiing and also in flight by purposely moving the stick in an abrupt manner. In normal maneuvers, other than landings, however, the elevator rates used did not exceed a value corresponding to the greatest rate restriction of 7° per second.

The results of this investigation indicate that airplanes may have satisfactory handling qualities with booster having much lower control rates available than those normally used by pilots. These results, however, are not intended to provide a quantitative indication of minimum satisfactory control rates since they apply strictly to the test airplane in the configurations used in the tests. The static stability characteristics of the test airplane shown in figure 5 indicate that at the test center-of-gravity position only moderate variations of elevator deflection with normal-force coefficient were required. Possibly with a more forward center-of-gravity position somewhat larger control rates would be necessary in order to provide satisfactory control characteristics. In addition, past handling-qualities experience on other airplane types indicates a possibility that higher rates of control motion would be required on smaller airplanes.

CONCLUSIONS

Measurements of the longitudinal stability and control characteristics of a B-29 airplane have been made with a control-surface booster incorporated in the elevator control system. Effects of variations in the magnitude of the pilot's control force were determined as well as effects of variations in the maximum rate of control motion supplied by the booster system. The following conclusions were obtained:

(1) The longitudinal stability and control characteristics of the B-29 airplane were not significantly altered through use of the booster other than to reduce the magnitude of the control force variations.

(2) The elevator force variations with normal acceleration for the B-29 airplane without boost were about 140 pounds per g at an indicated airspeed of 250 miles per hour and 80 pounds per g at 160 miles per hour. These values are appreciably higher than the upper limit of 60 pounds per g specified as satisfactory by the present handling-qualities requirements. The pilots conducting these tests felt that the control forces without boost were tolerable but heavy.

(3) Use of the booster to adjust the control force gradients to about 50 pounds per g at 250 miles per hour and about 20 pounds per g at 160 miles per hour appreciably improved the handling qualities of the test airplane. These values of control force gradients fall roughly within the present specified limits of $22\frac{1}{2}$ to 60 pounds per g.

(4) Further reduction in control force gradients through use of the booster to about 35 pounds per g at 250 miles per hour and about 9 pounds per g at 160 miles per hour still provided satisfactory control forces in the opinion of the pilots. These force gradients were considered superior to those encountered without boost but were not as desirable as the range indicated in conclusion (2).

(5) The highest rate of elevator control motion used by the pilots during landings of the test airplane was about 40° per second. The highest rate of control motion obtained when the pilot purposely moved the control rapidly in an abrupt pull-up was about 70° per second.

(6) During the part of the landings where high control rates were used, large control deflections were held for such short time intervals that the flight path of the airplane was not significantly altered.

(7) During boost-on landings with the available rate of control motion restricted to values as low as 7° per second, no unsatisfactory

control characteristics were encountered. The pilots did not note any undesirable restrictions on their ability to move the control stick rapidly regardless of the rate of control motion available possibly because the stick could be moved at any rate desired (against light preloaded springs) until a stick-control-surface error of $1\frac{1}{2}^{\circ}$ was attained. This large a value of error was not encountered during these landings.

(8) Qualitative investigation of other flight conditions such as take-offs and normal flying indicated that no unsatisfactory control characteristics resulted from restricting the rate of control motion to 7° per second.

(9) Incorporation of the booster in the longitudinal control system of the B-29 airplane resulted in no undesirable effects on handling qualities.

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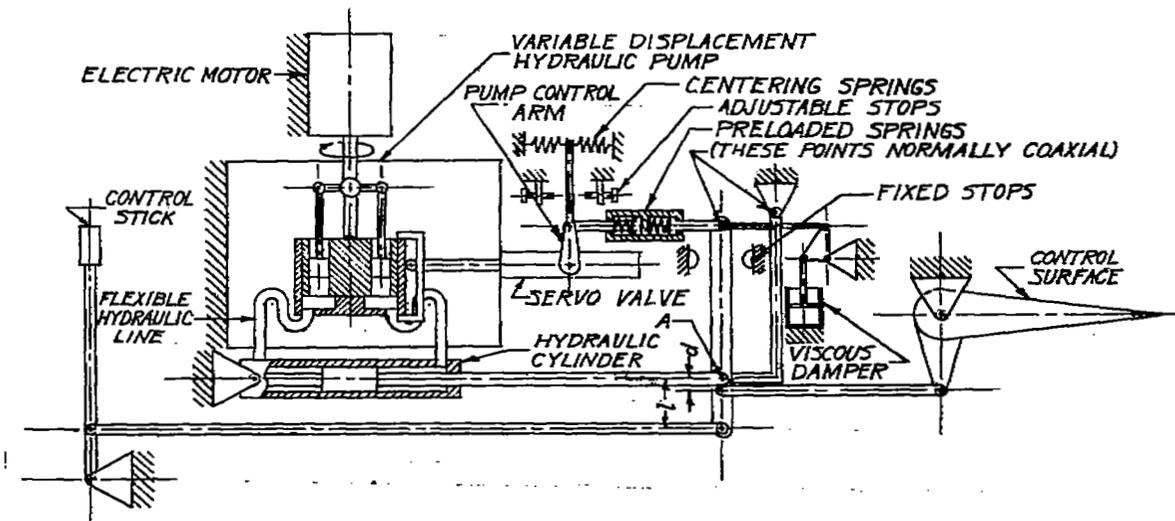
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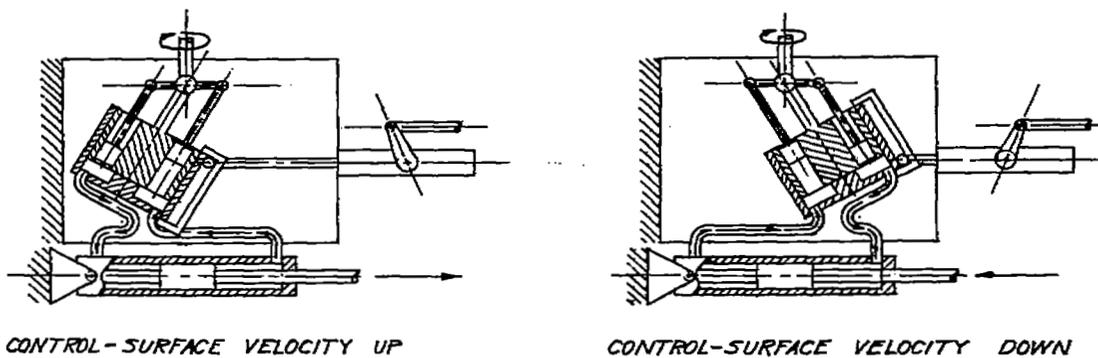
TABLE I
GENERAL SPECIFICATIONS OF B-29 AIRPLANE

General:	
Manufacturer	Boeing Aircraft Corp.
Type	TB-29-56-BW
Air Force number	469700
Engines:	
Manufacturer	Pratt & Whitney Aircraft
Type	R3350-23A
Normal rating	2000 hp at 2400 rpm
Propellers:	
Manufacturer	Hamilton Standard
Hub No.	24-F60-25
Blade No.	6521A-6
Wing:	
Area (including ailerons), sq ft	1739
Area (flaps extended), sq ft	2071
Aspect ratio	11.5
Taper ratio	0.43
Aileron area (total), sq ft	129
Flap area, sq ft	332
Horizontal tail:	
Area, sq ft	333
Aspect ratio	5.15
Taper ratio	0.42
Elevator area, sq ft	115
Vertical tail:	
Fin area (including dorsal), sq ft	115
Rudder area, sq ft	65.5





BOOSTER ARRANGEMENT



CONTROL-SURFACE VELOCITY UP

CONTROL-SURFACE VELOCITY DOWN

HYDRAULIC - PUMP OPERATION



Figure 1.- Schematic arrangement of the booster unit used in the elevator control system of the B-29 airplane.

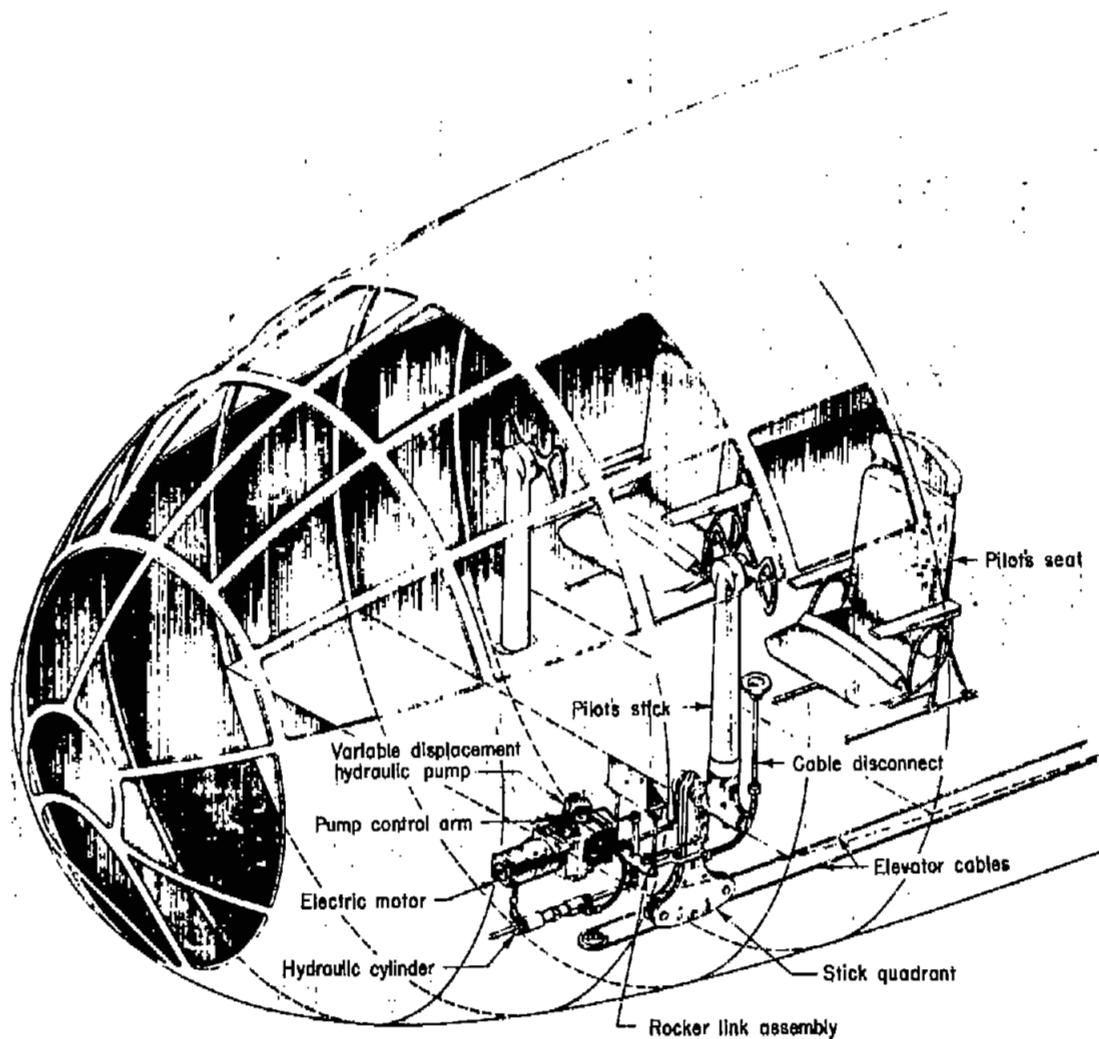
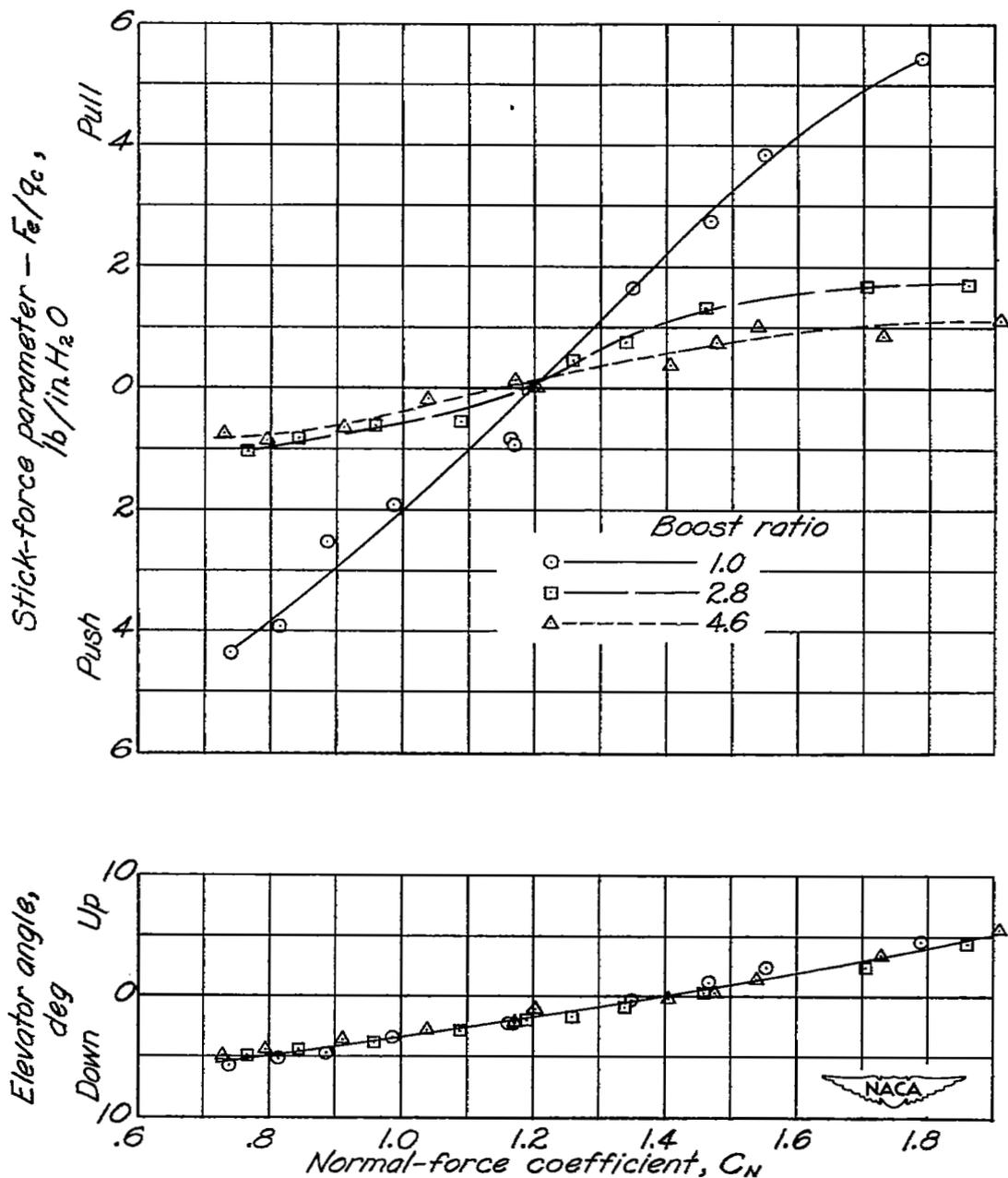
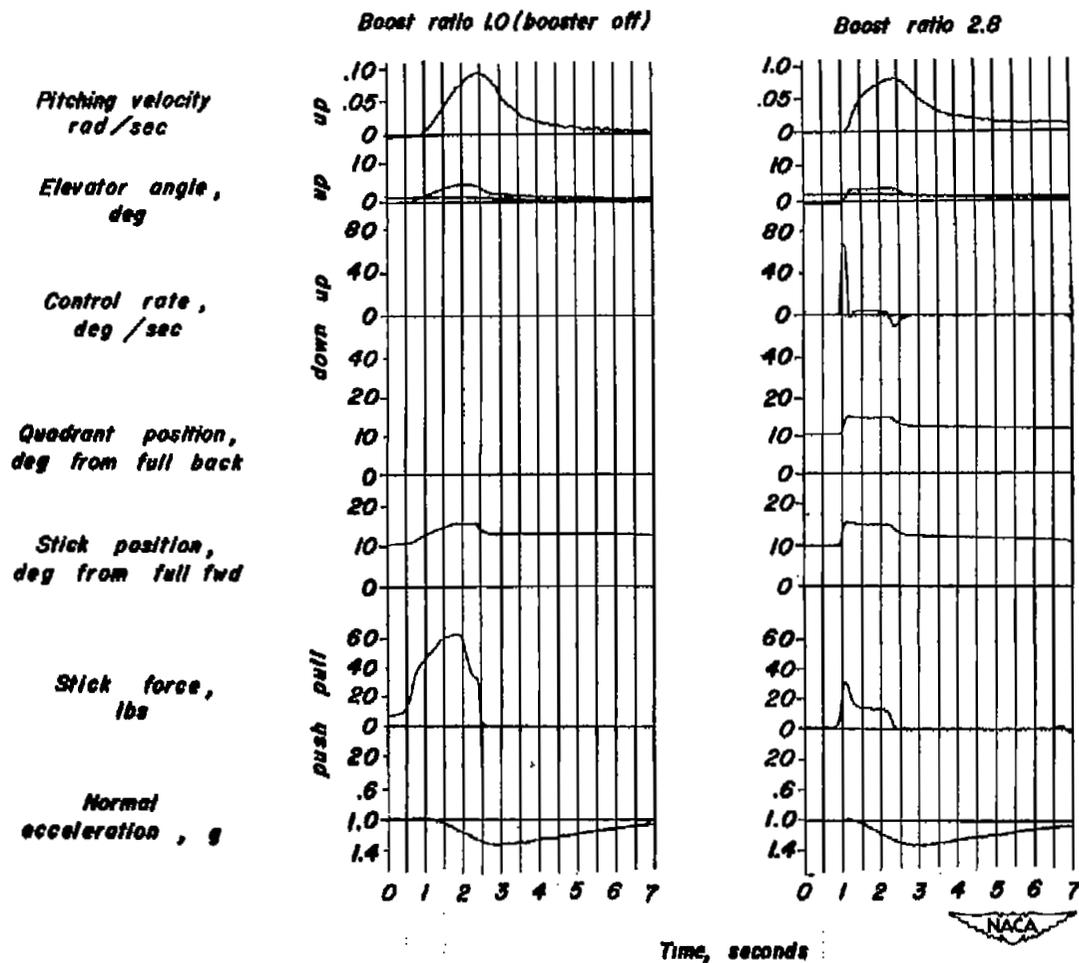


Figure 3.- Orientation of booster unit in B-29 airplane.



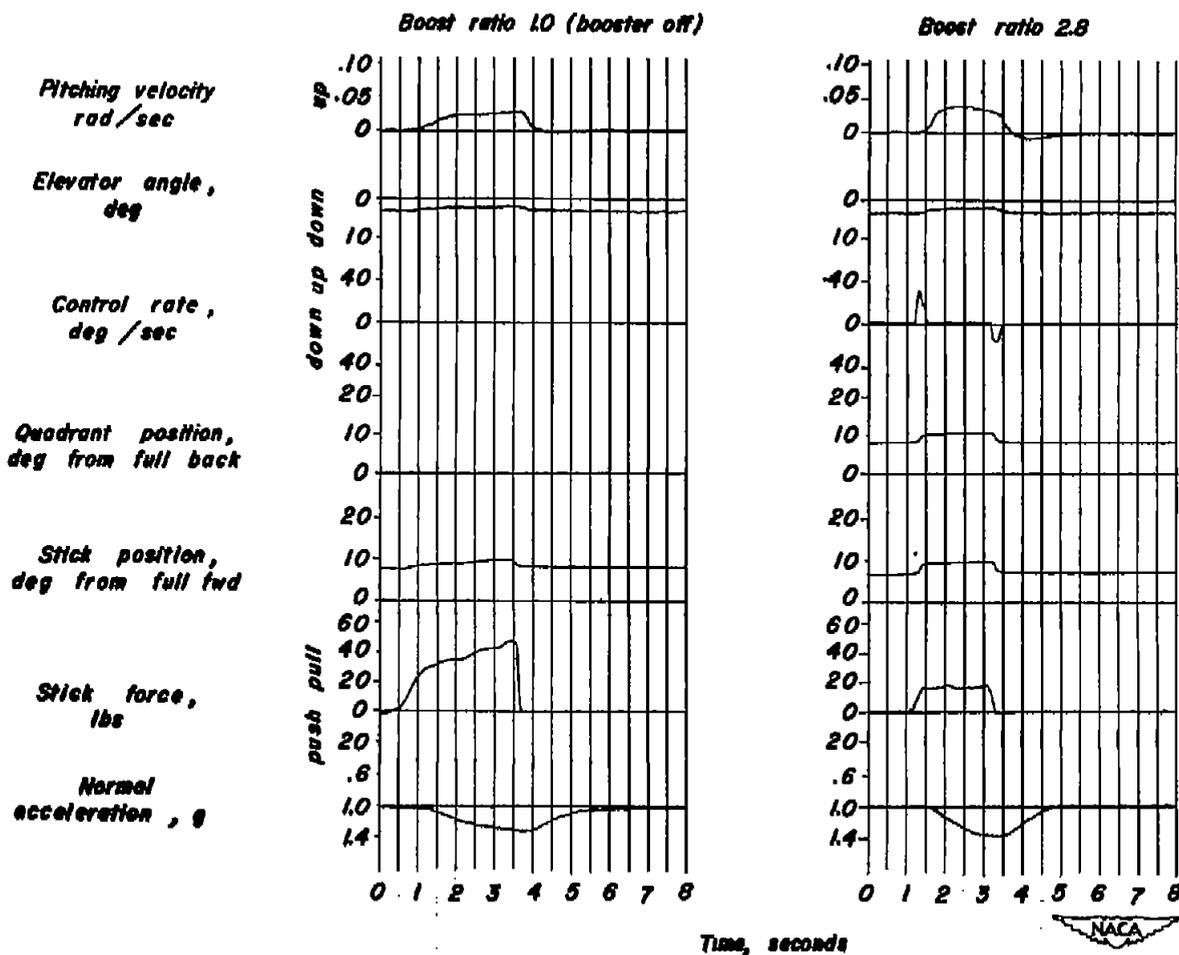
(b) Landing condition - flaps and gear down, power off.

Figure 5.- Concluded.



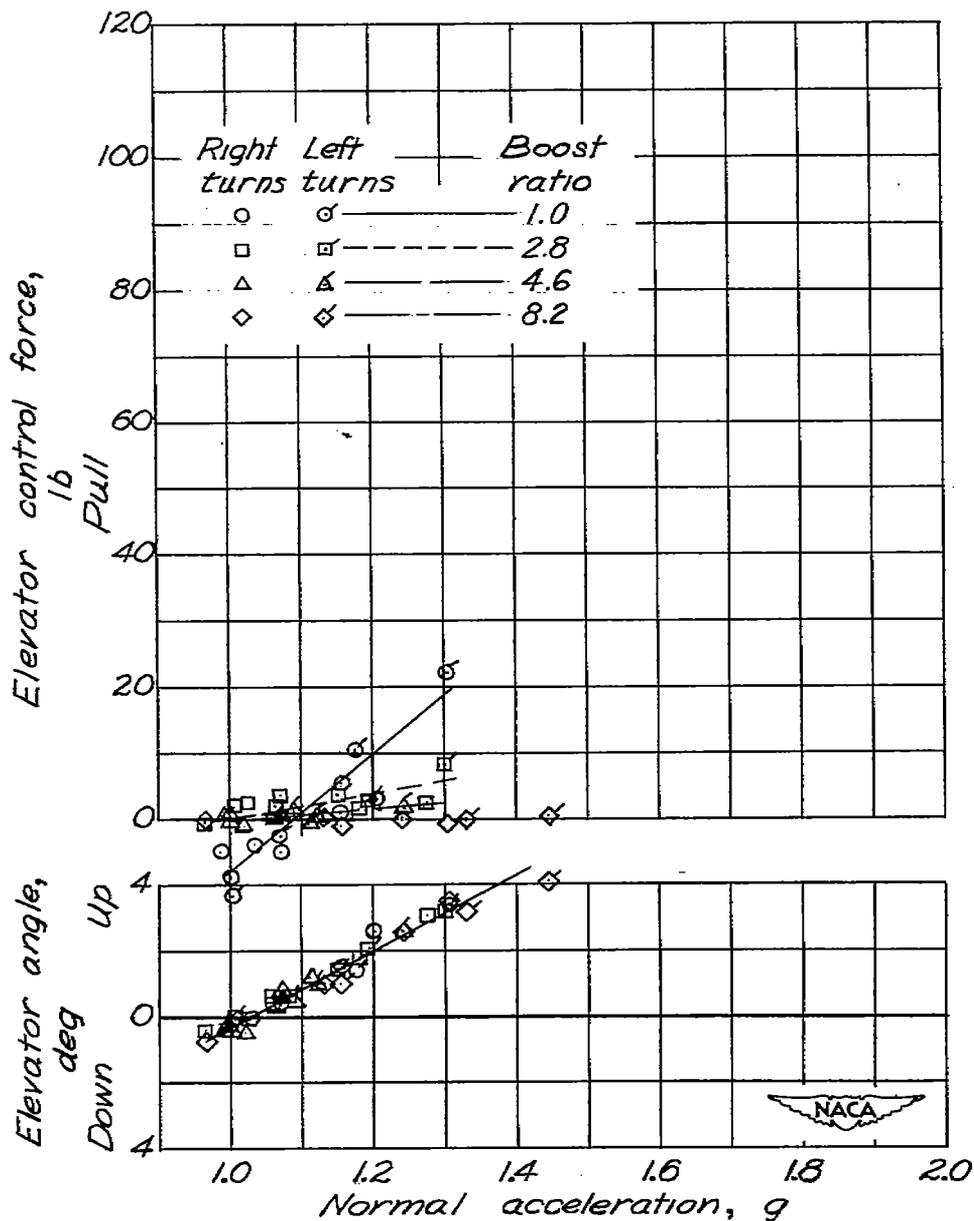
(a) Indicated airspeed - 160 miles per hour.

Figure 6.- Time histories of abrupt pullups of the B-29 airplane each followed by release of the control stick showing the effects of the booster.



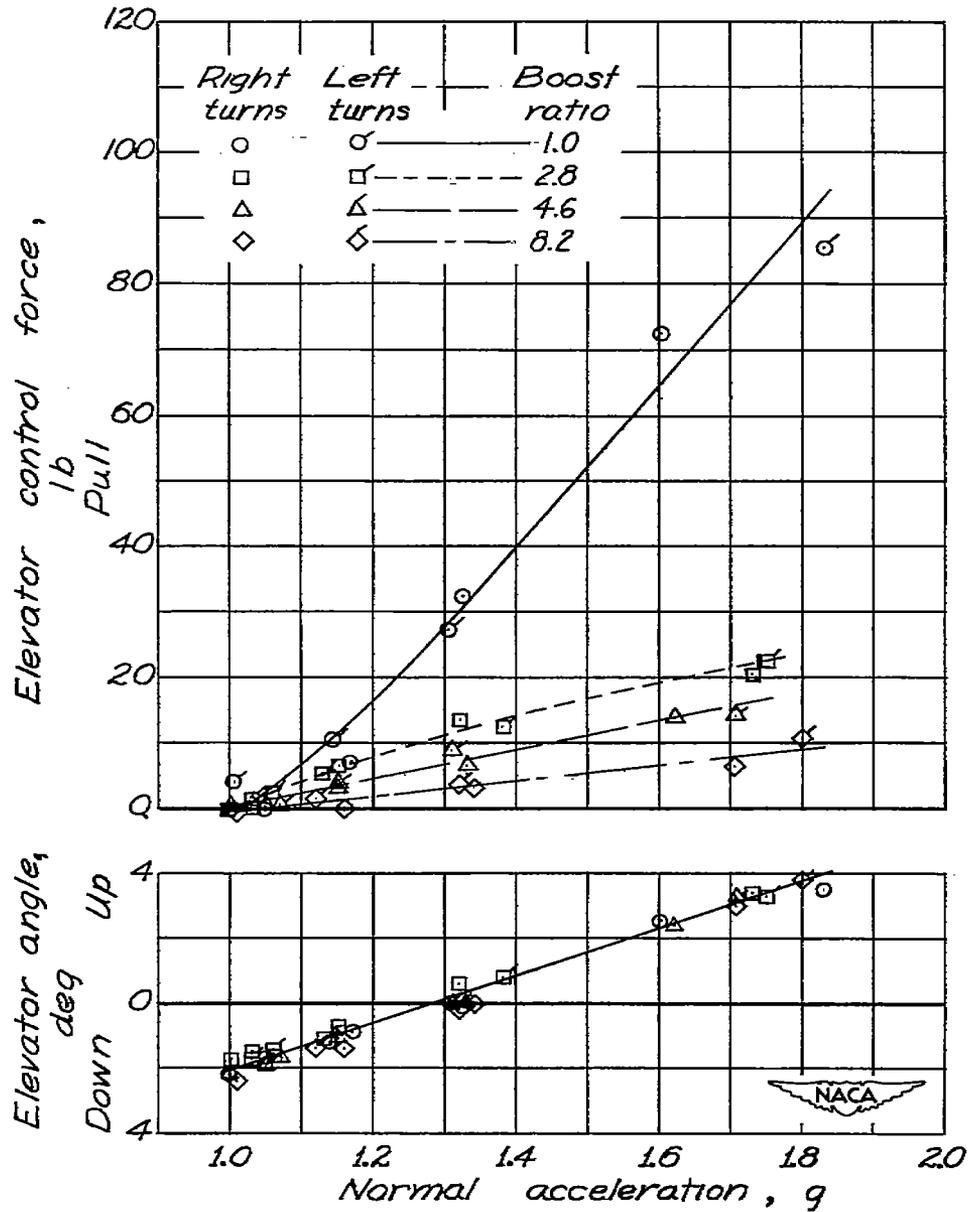
(b) Indicated airspeed - 250 miles per hour.

Figure 6.- Concluded.



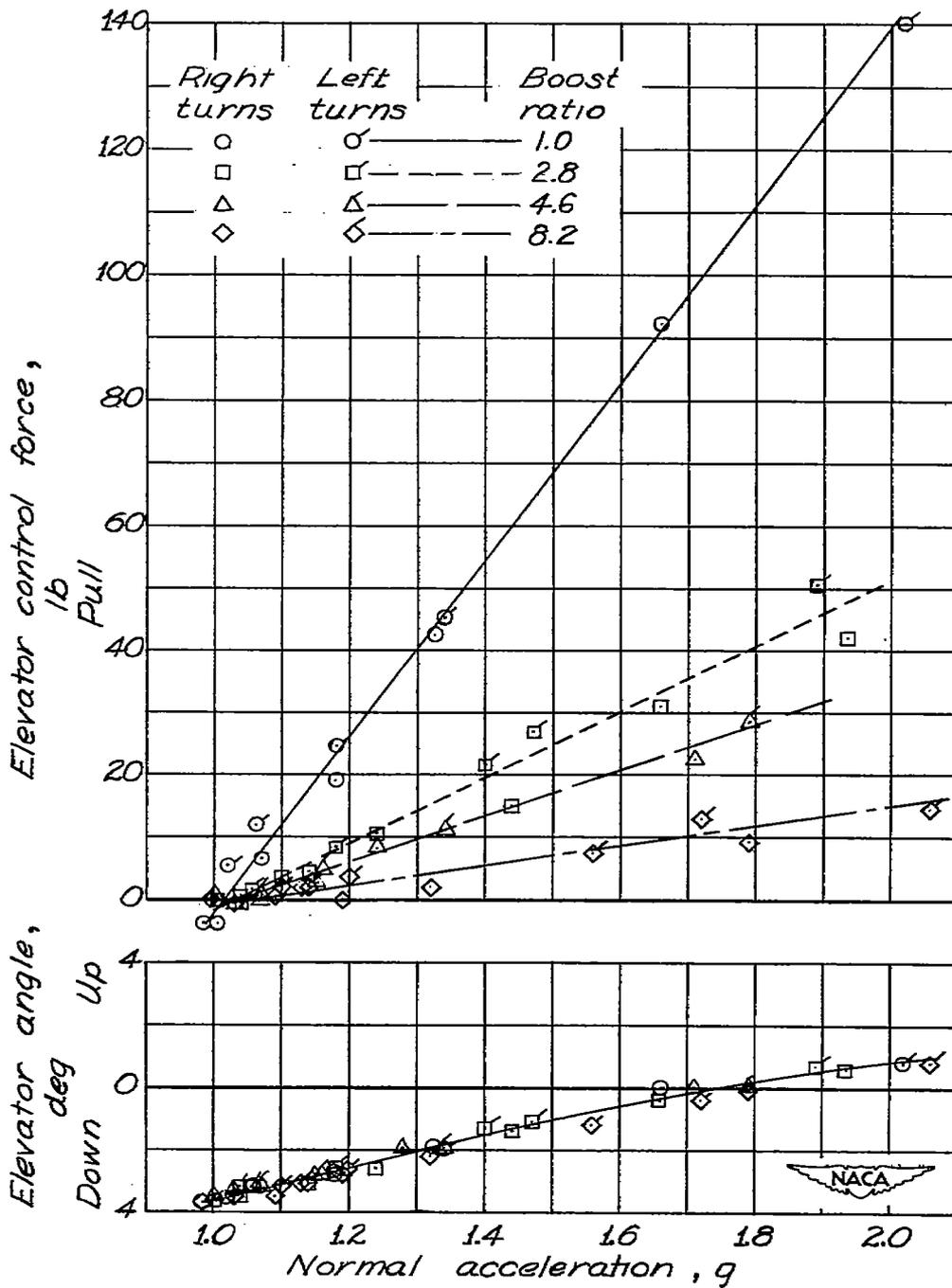
(a) Indicated airspeed - 160 miles per hour.

Figure 7.- Effect of the booster on the variation of elevator control force with normal acceleration for the B-29 airplane as measured in turns.



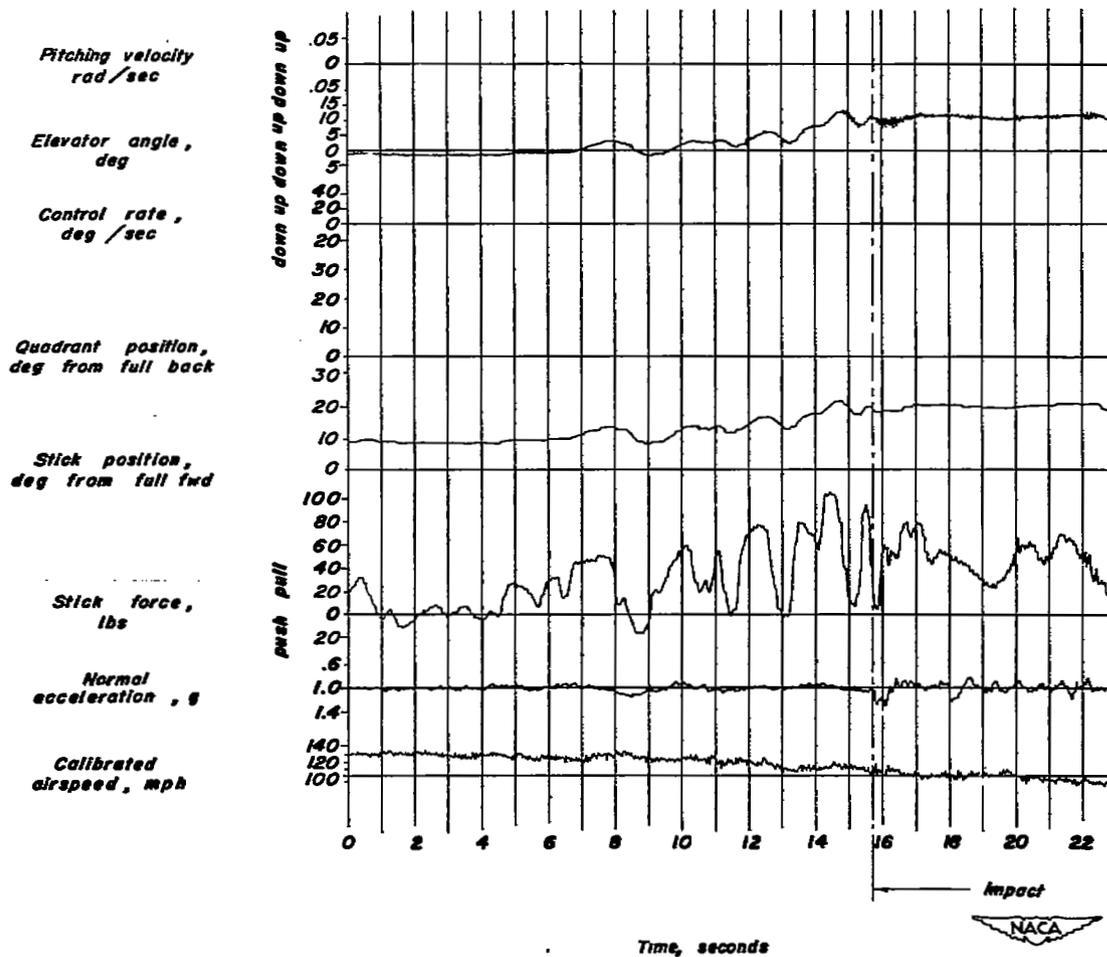
(b) Indicated airspeed - 200 miles per hour.

Figure 7.- Continued.



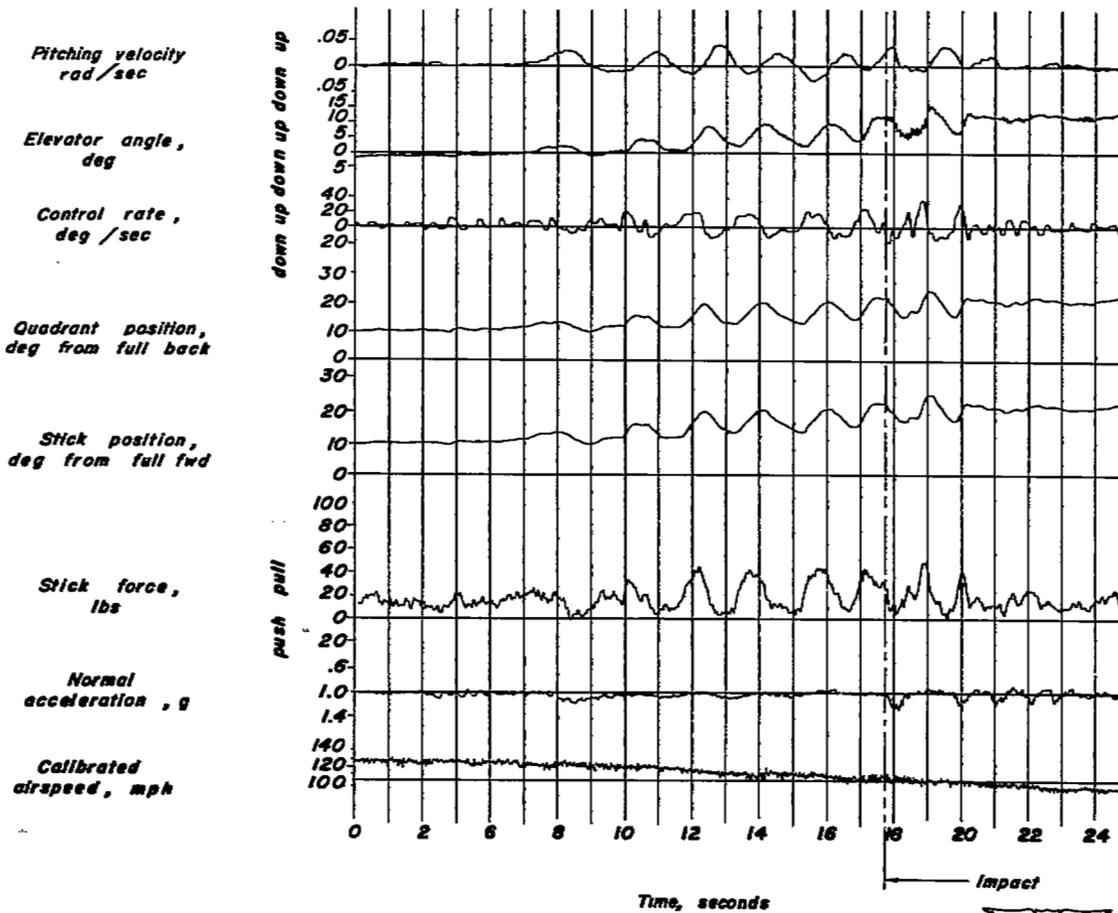
(c) Indicated airspeed - 250 miles per hour.

Figure 7.- Concluded.



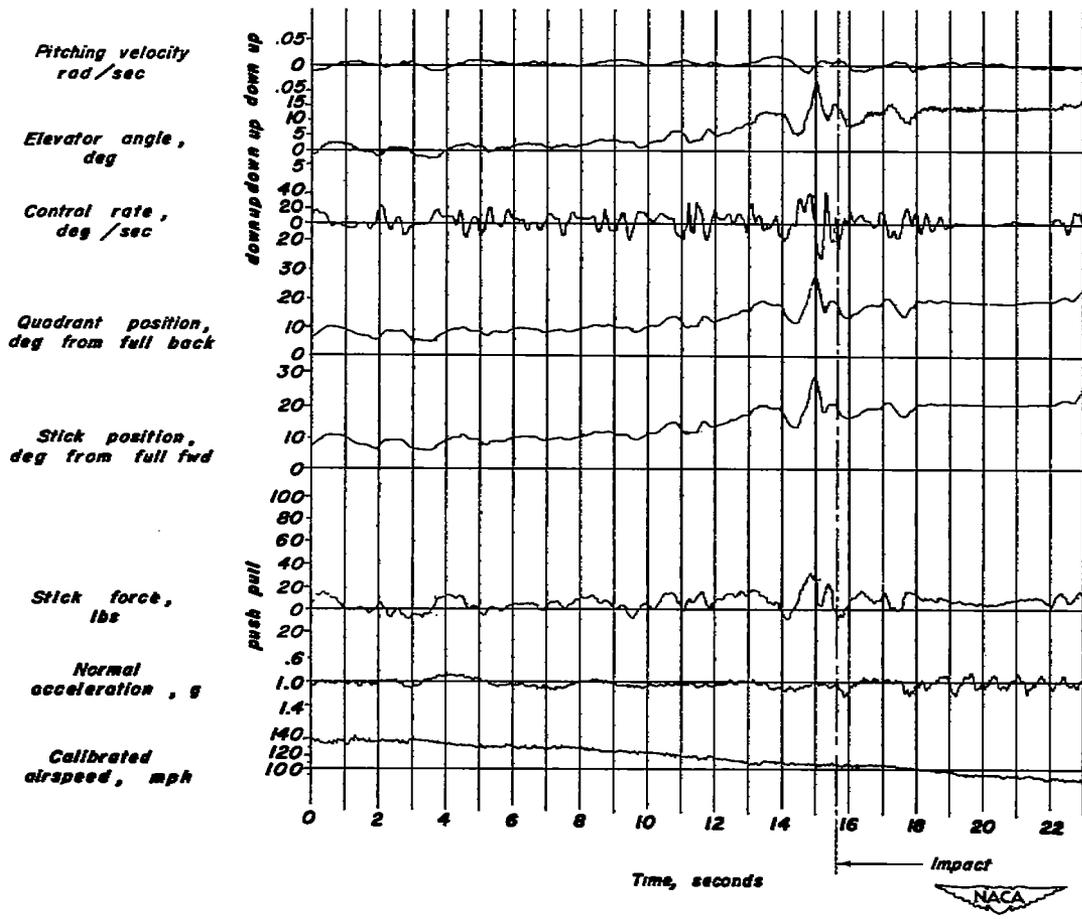
(a) Boost ratio - 1.0:1 (booster off).

Figure 8.- Time histories of landings of the B-29 airplane showing the effects of variation in control force gradient through use of the booster.



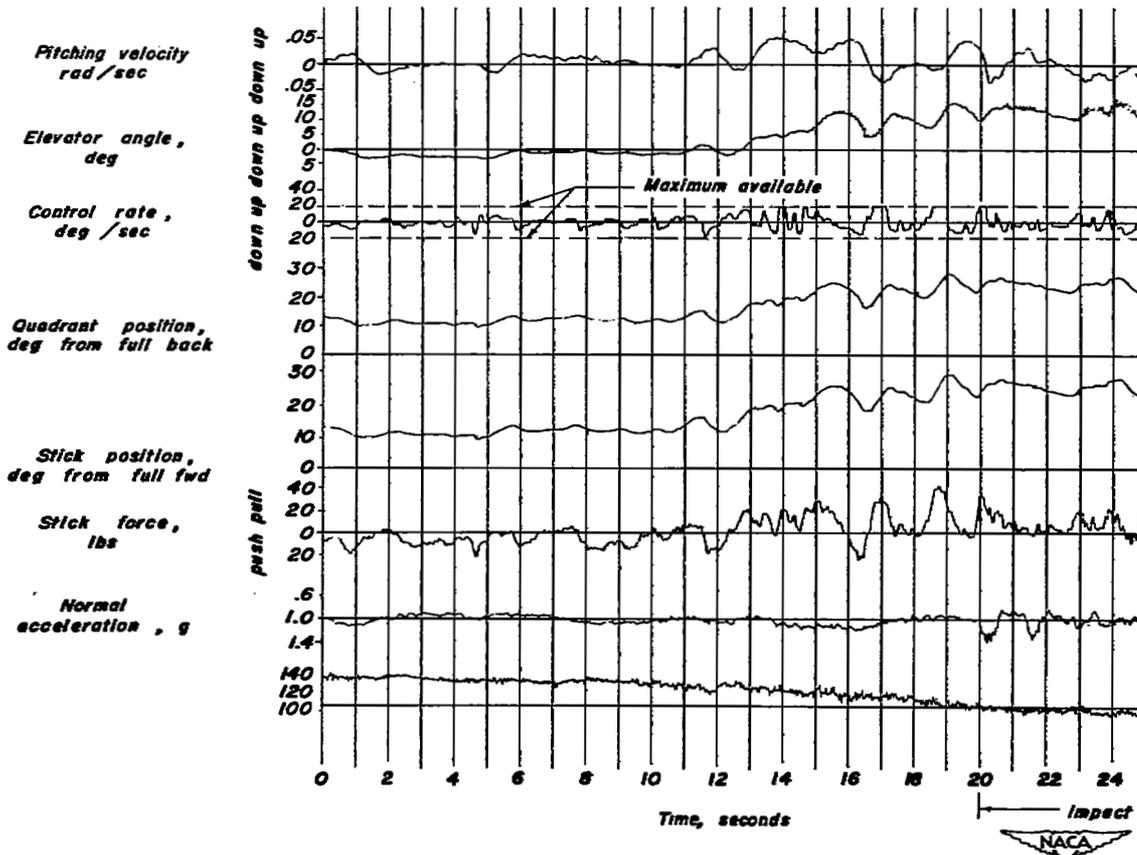
(b) Boost ratio - 2.8:1.

Figure 8.- Continued.



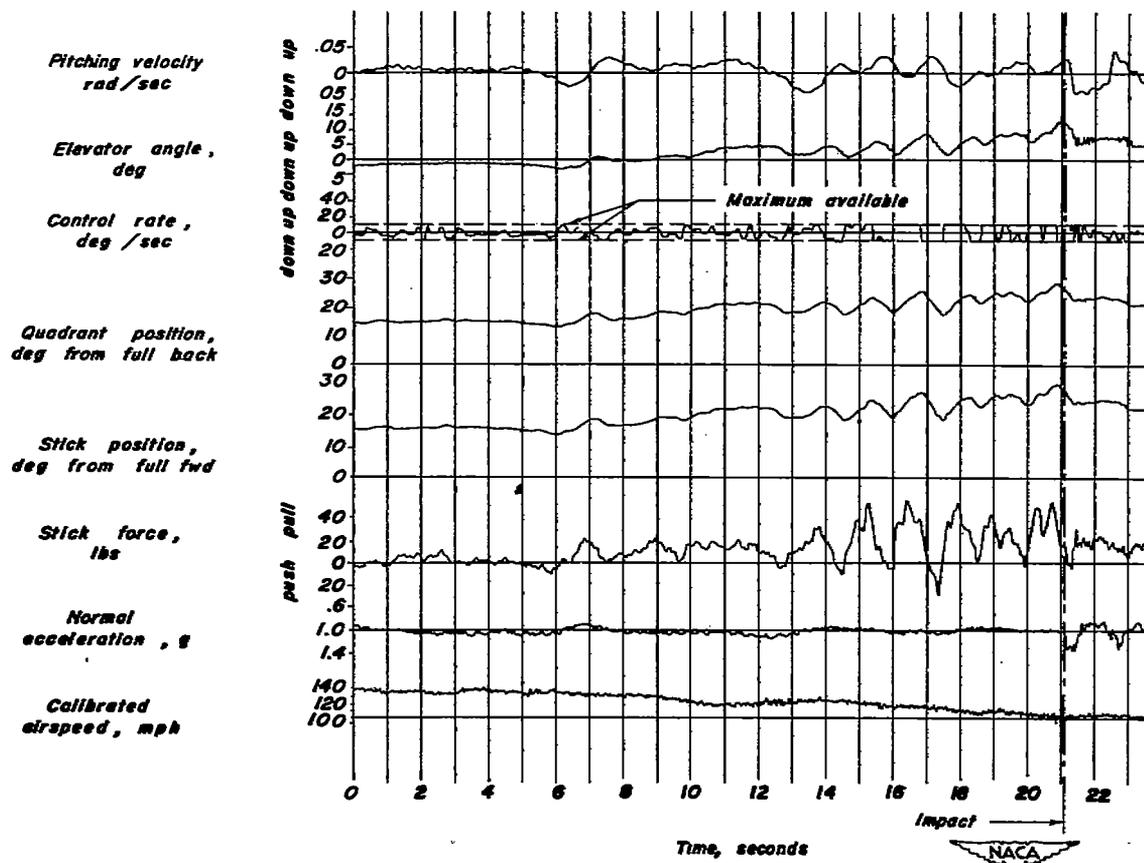
(c) Boost ratio - 4.6:1.

Figure 8.- Concluded.



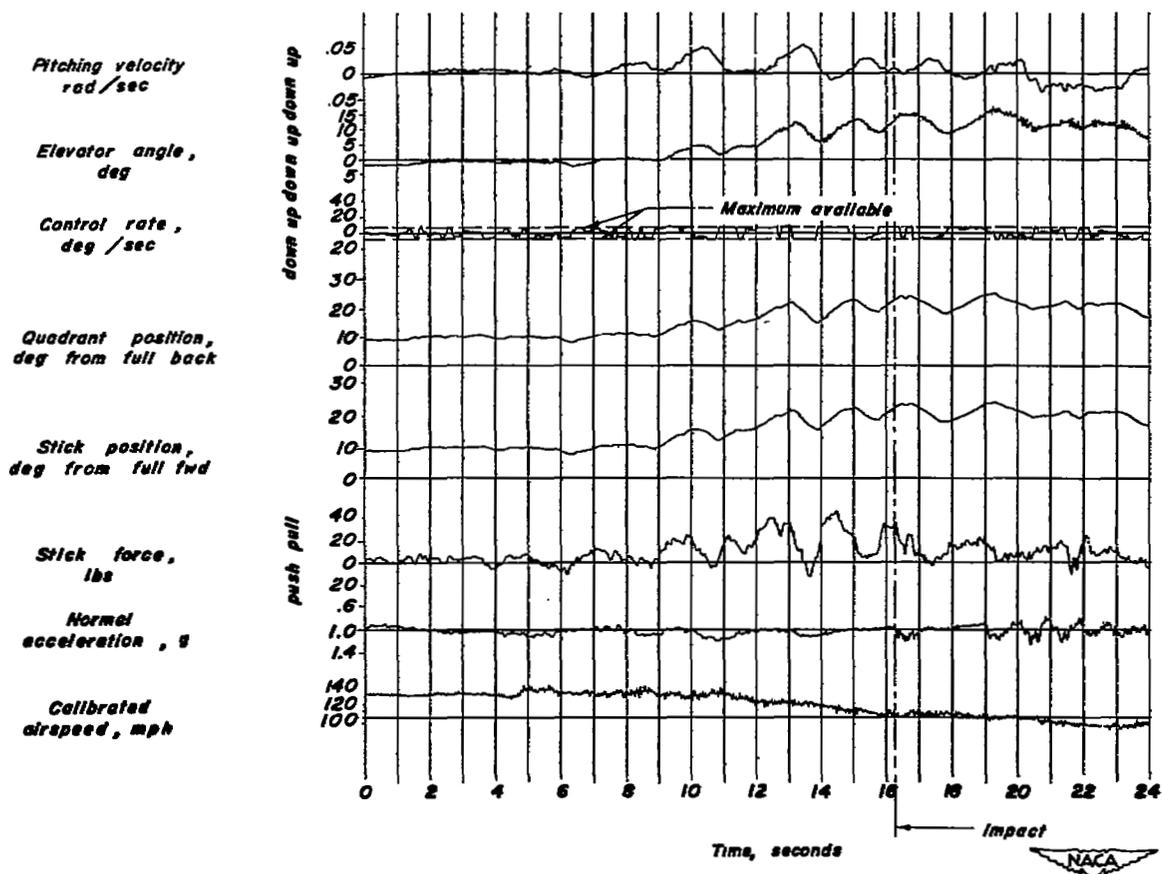
(a) Maximum available rate - 20 degrees per second.

Figure 9.- Time histories of landings of the B-29 airplane showing the effects of variation in maximum available rate of control motion supplied by the booster. Boost ratio - 2.8:1.



(b) Maximum available rate - 10 degrees per second.

Figure 9.- Continued.



(c) Maximum available rate - 7 degrees per second.

Figure 9.- Concluded.

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ABSTRACT

The longitudinal stability and control characteristics of a B-29 airplane have been measured with a control-surface booster incorporated in the elevator control system. The measurements were obtained with the booster operating to provide various control force gradients and various maximum rates of control motion. Results are presented which show the effect of these booster parameters on the handling qualities of the test airplane.

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