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RESEARCH MEMORANDUM

THE EFFECTS OF FRICTION IN THE CONTROL SYSTEM ON THE HANDLING QUALITIES OF A C-54D AIRPLANE

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THE EFFECTS OF FRICTION IN THE CONTROL SYSTEM ON THE HANDLING QUALITIES OF A C-54D AIRPLANE

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SUMMARY

During the handling-qualities tests of a C-54D airplane, it was found that the friction in the control system was about double the limits of the Army and Navy requirements for stability and control. The friction was reduced to about one-half of the Army-Navy limits by removing the automatic-pilot servo-units, and this investigation was conducted to determine the effects of reducing the friction. Time histories of normal landings and of attempts to bracket the edges of a radio beam are presented both with the servo-units in and out. Examination and comparison of the time histories with high and low friction reveals that friction was particularly troublesome in precision flying involving small control displacements because with high friction control movement did not necessarily follow all force applications. The comparison also shows that the friction requires excessive physical exertion on the part of the pilot. The control system with approximately double the friction allowed by the Army-Navy requirements was unsatisfactory for precision flying, whereas the control system with approximately one-half the specified friction was satisfactory.

INTRODUCTION

An investigation was conducted on a C-54D airplane to determine whether new or revised handling-qualities requirements were needed to cover the problem of precision flying of large aircraft. During this investigation, as reported in reference 1, it was found that the friction in the control system was quite high. The pilots objected to this high friction because considerable physical effort was required to fly the airplane and small control corrections were difficult to apply accurately. At the suggestion of the Air Transport Association subcommittee on handling qualities, the hydraulic servo-units of the automatic pilot were removed in an attempt to reduce the friction in the control system. Results of a test program are presented to show the effects of excessive friction.

TESTS AND RESULTS

The control friction was measured, both in flight and on the ground, by slowly moving the controls back and forth and recording the control forces and control-surface angles. The friction force was equal to one-half of the algebraic difference in the forces measured while moving the control through neutral in opposite directions where pull and right forces were considered plus, and push and left forces, minus. The control-cable tension with the servo-units removed was made the same as with the servo-units installed.

The friction in the control system, as measured on the ground, is shown in the following table:

TABLE I

Control	Friction measured on ground	
	Servo-units installed (lbs)	Servo-units removed (lbs)
Elevator	14 ± 1.5	4 ± 1.5
Aileron	13 ± 1	3 ± 1
Rudder	22 ± 3	9 ± 3

The friction as measured in flight is presented in the following table:

TABLE II

Control	Friction measured in flight	
	Servo-units installed (lbs)	Servo-units removed (lbs)
Elevator	15 ± 4	6 ± 4
Aileron	12 ± 2	2 ± 2
Rudder	30 ± 4	7 ± 4

With the servo-units installed, the control friction was roughly double that allowed in the requirements of references 2 and 3. Those requirements are as follows:

TABLE III

Control	Maximum friction allowable specified in references 3 and 4 (lbs)
Elevator	8
Aileron	6
Rudder	15

With the servo-units removed, the control friction was well within the limits.

Several flight conditions were investigated both with the servo-units in and with the servo-units out. Figure 1 presents time histories of the control forces and control movements during typical beam-bracketing operations, with the two different magnitudes of friction. Figure 2 presents time histories of typical normal power-off landings with the two different magnitudes of friction.

DISCUSSION

In the opinion of the pilots, precision flying in the test airplane was difficult with the automatic-pilot servo-units installed. For flight-path corrections involving large control displacements, the high friction was undesirable in that it added to the aerodynamic control forces and thereby increased the physical effort involved. For the small control displacements necessary in precision flying, where the aerodynamic forces were in the range of friction, pilots found it impossible to apply accurate small control corrections because, when sufficient force was applied to break the static friction, the control jumped to a new position. The amount that the control jumped was a function of the flexibility of the control system, the difference between the static friction and kinetic friction, and the inertia of the system. The pilots attempted to minimize the jumping tendency by applying forces of short duration, judging the amount of control by the response of the airplane. Pilots do not like to fly this way but prefer to anticipate the airplane's response by the amount of control force applied.

The high friction in the control system also prevented the control from returning completely to its trim position following any displacement. The angular motion of the airplane continued when the control was released and consequently the control had to be returned to its trim position by the pilot.

The small aerodynamic forces near trim were masked by the high friction, and therefore it was difficult to trim the aerodynamic forces accurately to zero. Without the aerodynamic forces trimmed to zero, the controls crept from their desired position and repeated control application was necessary to reestablish the desired attitude.

The preceding considerations indicate that the act of piloting with high friction in the control system becomes a continual process of quick force applications while moving the control very little. An example is presented in figure 1 which shows comparable time histories of beam-bracketing operations with high and low friction. The continual process of quick force applications with high friction is immediately apparent in figure 1(a).

The elevator force varies continually with little motion of the elevator; the aileron force, especially around 28 seconds and 46 seconds, varies without motion of the ailerons, and the rudder force, especially around 16 and 46 seconds, varies with little movement of the rudder. In figure 1(b) the continual quick force applications are nearly absent. The physical effort put forth by the pilot is therefore considerably increased when friction is present.

Aside from the standpoint of less physical work for the pilot, there is the more important consideration of making the control deflection follow closely the control force. Figure 2, which presents time histories of power-off landings with high and low control friction, shows how excessive friction can destroy the response of the control surface to applications of force at the control column. An equal amount of physical effort was involved in both landings, but the increased friction in figure 2(a) over that in figure 2(b) was sufficient to eliminate any correlation between the respective control forces and deflections.

For precision flying, the airplane with high friction in the control system was unsatisfactory from the controllability standpoint while the airplane with low friction was completely satisfactory. The pilot's opinions substantiated this conclusion.

Tests were not made of the servo-units themselves to determine whether high friction was inherent in the design or whether it was due to improper installation of the units. It is felt, however, that more attention should be given to the reduction of friction in the design and installation of automatic-pilot servo-units.

CONCLUSIONS

From the results of this investigation, it may be concluded that:

1. High friction in the control system impairs the response of the control surface to an application of force at the control column to such an extent as to make precision flying extremely difficult.

2. High control friction requires excessive physical exertion on the part of the pilot.

3. A control system with double the friction limit specified by the Army and Navy was unsatisfactory for precision flying, whereas a control system with one-half the friction limit was satisfactory.

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REFERENCES

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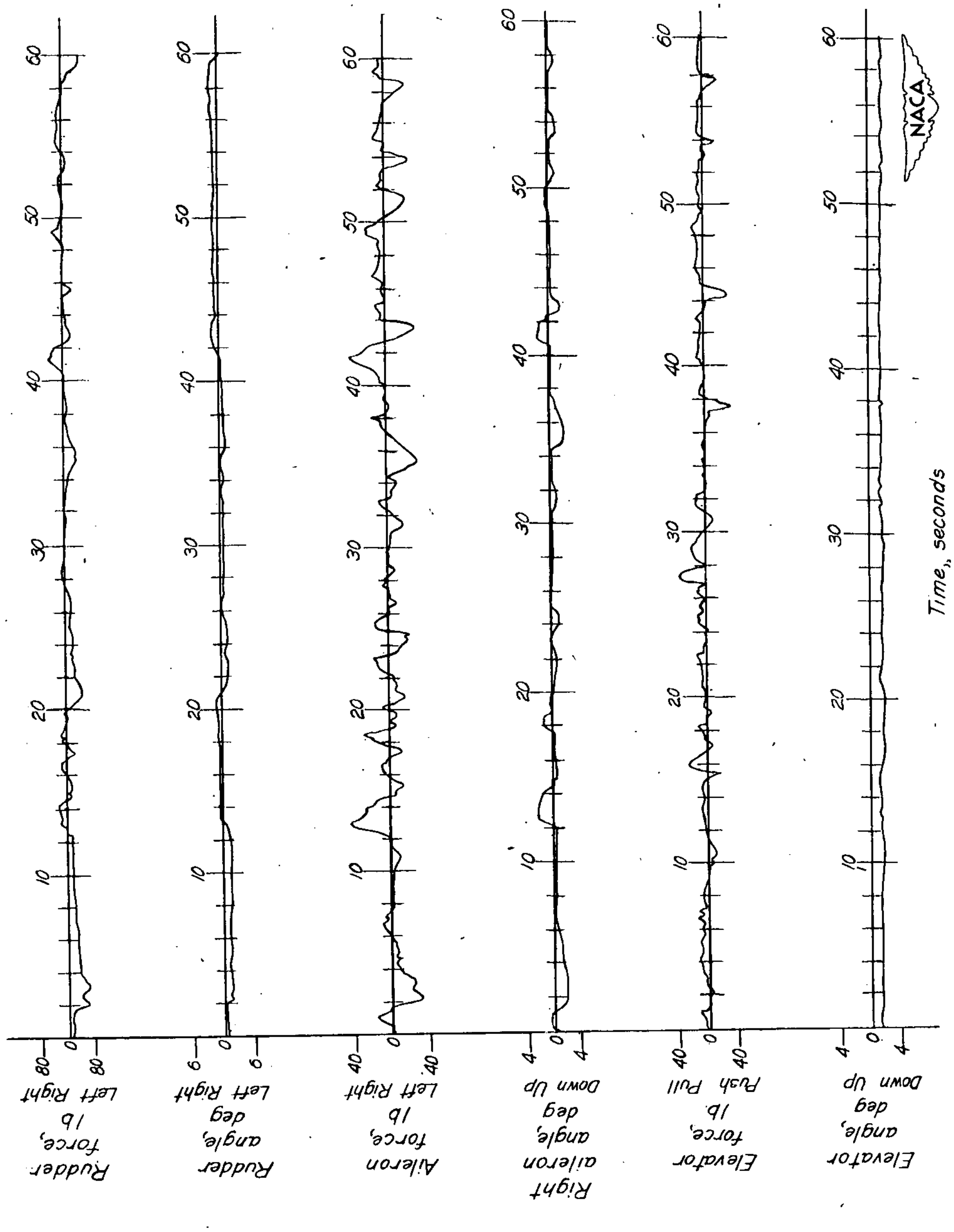
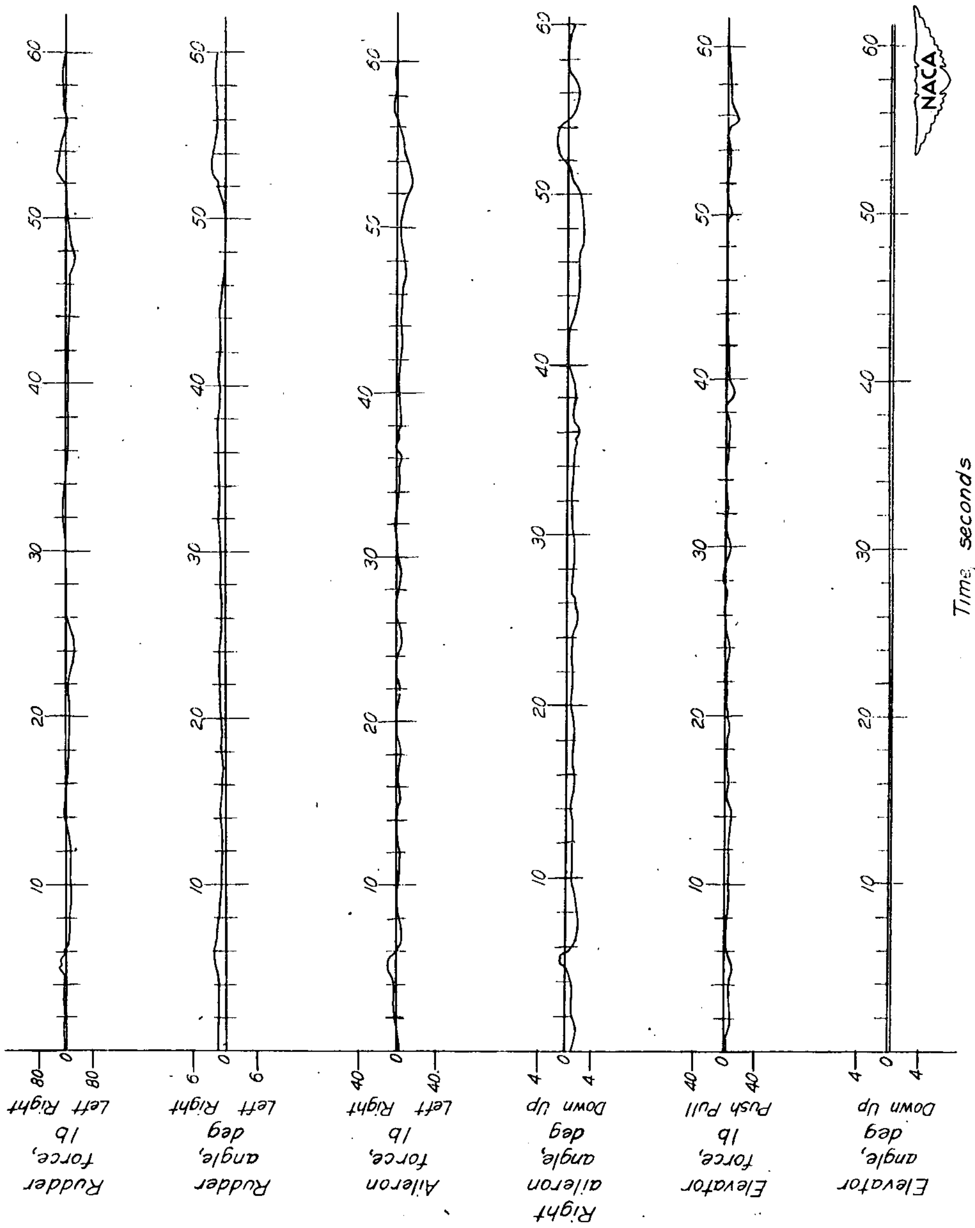
2. Anon.: Stability and Control Characteristics of Airplanes. AAF Specification No. R-1815A, April 7, 1945.

3. Anon.: Specification for Stability and Control Characteristics of Airplanes. SR-119A, Bur. Aero., April 7, 1945.



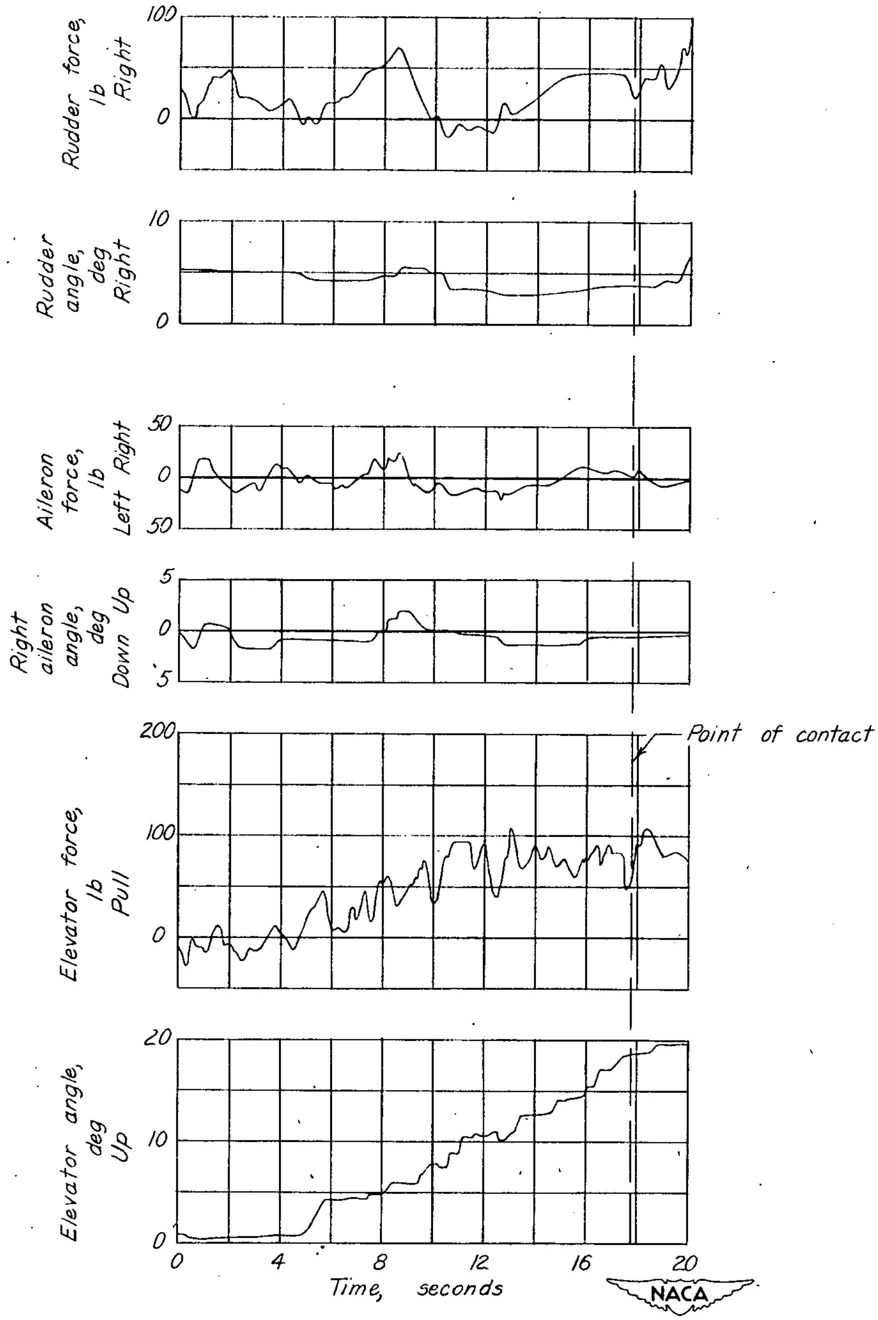
(a) Automatic-pilot servo-units installed.

Figure 1.- Time history of a beam-bracketing operation. C-54 airplane, clean condition, 200 miles per hour.



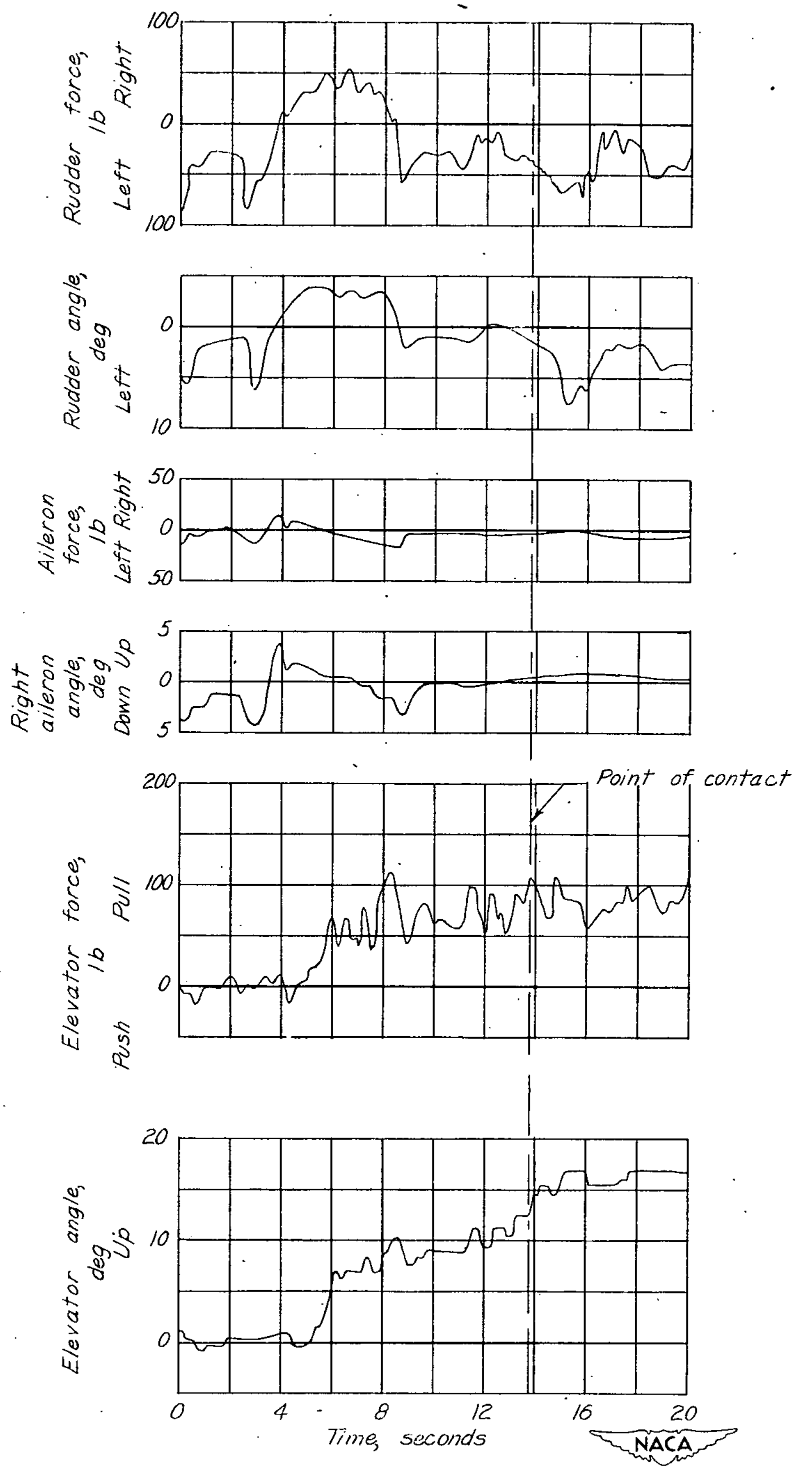
(b) Automatic-pilot servo-units removed.

Figure 1.- Concluded.



(a) Servo-units installed.

Figure 2.- Time history of a landing. C-54 airplane, flaps full down, gear down, power off.



(b) Servo-units removed.

Figure 2.- Concluded.