NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4004

SOME EFFECTS OF VALVE FRICTION AND STICK FRICTION ON CONTROL QUALITY IN A HELICOPTER WITH HYDRUALIC-POWER CONTROL SYSTEMS

By B. Porter Brown and John P. Reeder

Langley Aeronautical Laboratory
Langley Field, Va.

Washington
May 1957

V

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4004

SOME EFFECTS OF VALVE FRICTION AND STICK FRICTION ON CONTROL QUALITY IN A HELICOPTER WITH HYDRAULIC-POWER CONTROL SYSTEMS

By B. Porter Brown and John P. Reeder

SUMMARY

Tests have been made of a hydraulic-power-controlled helicopter to determine the effect of friction in the servovalves and the effect of stick friction when the valve friction is present.

The tests showed that, when the valve friction is equivalent to about $1\frac{3}{4}$ pounds of force at the stick, precision flying is difficult and more work is required of the pilot. Control quality is improved by adding an amount of stick friction that is equal to the valve friction. The total of the two frictions, however, should not exceed 3 pounds. The lowest valve-friction value tested was $\frac{1}{4}$ pound, and the pilots considered the effect to be negligible and therefore considered any stick friction to be unnecessary. The pilots believed that the system was markedly improved when the valve friction was reduced from $1\frac{3}{4}$ pounds to $\frac{1}{4}$ pound. The addition of feel devices resulted in an overall improvement in the control systems and was, therefore, considered to be very desirable.

INTRODUCTION

Previous flight tests (ref. 1) made by the National Advisory Committee for Aeronautics on power-controlled airplanes have shown that relatively small amounts of friction in the servovalve can reduce the overall control quality to such an extent that precision flying is extremely difficult or impossible. The tests also showed that as the valve friction was increased the control quality deteriorated to the point at which pilot-induced oscillations resulted. A similar study (ref. 2) of these effects has been carried out by using a dynamic ground simulator, and the results agreed with the flight tests.

It was believed that valve friction would produce similar undesirable effects in power-controlled helicopters and for this reason some very limited tests were made. Also, previous ground simulator tests (ref. 2) have shown that stick friction can be beneficial when valve friction is present. The adjustable stick-friction device in the test helicopter presented an opportunity to check in flight the results obtained from the simulator tests. The purpose of this paper is to present the results of these tests.

EXPLANATION OF VALVE-FRICTION EFFECT

The effect of friction in the servovalve of a hydraulic-power control unit is vastly different from the effect of friction that exists in a conventional cable or push-rod control system. Static friction in a mechanical system requires a force sufficiently large to break through the friction before motion occurs (breakout) and tends to prevent motion of the control surface at all times. Valve friction also provides a breakout force and tends to prevent motion initially, but once the valve friction is overcome the breakout disappears and the friction tends to hold the servovalve open and keep the surface moving. Consider, for example, the control system shown in figure 1. When a pull force, sufficiently large to overcome the friction, is applied to the control stick, the valve stem moves up with respect to the piston rod. This valve motion allows fluid to flow into the cylinder at a rate proportional to the valve opening and thereby moves the piston rod up with respect to the valve stem. Thus, the piston-rod motion closes the valve by reestablishing the original relative position of the valve stem and piston rod. If, however, friction exists between the valve stem and piston rod, the piston-rod motion tends to drag the valve stem and control stick in the corresponding directions. This friction prevents the valve from closing and causes an overshoot in the position of the element being controlled. In order to stop the surface, when valve friction is present, the pilot, therefore, has to apply an opposite force on the stick that is sufficiently large to resist the dragging force, and then the piston-rod motion will close the valve. If the pilot attempts to control the motion, his force will be out of phase with the surface motion. If he does not attempt to stop the motion by applying the reverse force, the surface will overshoot the desired position. The severity of these effects is, of course, proportional to the amount of friction existing in the valve.

It is important to recognize that these effects are not restricted to airplanes but apply to any power-controlled machine. Unquestionably, the relatively high response and low damping exhibited by present-day helicopters magnify the end results of these effects; however, the valve friction alone can result in poor control and increased work required of the pilot.

During the development of power control systems, several devices and schemes have been employed in aircraft to counteract or obscure these friction effects. Among these are valve centering springs, static friction between the control stick and servovalve, and high-frequency vibration on the valve. All of these have been ground tested in regard to airplane controls and are reported in references 1, 2, and 3, respectively. The tests showed that all of these schemes are beneficial to control quality when valve friction is present. It should be noted that valve centering springs and stick friction eliminate the "motoring" but increase the initial breakout force. The vibrator is the only device tested that successfully eliminates all objections to valve friction.

APPARATUS AND TESTS

The test helicopter was a dual-place single-rotor machine that was designed originally to be manually controlled. The helicopter manufacturer issued modification kits to convert the longitudinal and lateral controls to fully powered systems. The power control systems consisted of hydraulic slide valves located inside the piston rods of the hydraulic actuators. (See fig. 1.) The power units were installed in such a way that the valve body (piston rod) served as the followup system; thereby, the need of a separate followup rod was eliminated. The systems were powered by an engine-driven pump which delivered 250 pounds per square inch of pressure to the units. Manual reversion could be selected at any time by the pilot through a cockpit control.

The power control systems were installed and it was noticed during the normal preflight checks that the systems exhibited characteristics that are peculiar to friction in the servovalve. The breakout force was noticeable, but once the breakout was exceeded the force disappeared and the stick motion continued to full travel. In order to stop the motion, a force equal but opposite to the initial breakout was required. The breakout force was measured in each direction for both the longitudinal and the lateral controls and was found to be about $2\frac{1}{2}$ pounds in terms of stick force in each system. (All following friction and breakout forces are quoted in terms of stick force.) In view of the low system pressures involved, this value seemed abnormally high to be caused by the internal seals in the valve. The mechanics therefore inspected the installation and found that extremely small misalinements in the linkages were tending to bind the valve stem. This binding resulted in increased valve friction. The installations were reworked and better alinement was achieved. This realinement reduced the valve friction to about $1\frac{3}{4}$ pounds of stick force, which was still large in terms of present-day power-control design. It should be noticed that no feel springs were provided in the change kits for these systems; therefore, the only forces required of the pilot to move the controls were those necessary to operate the servovalves.

One flight was made with $1\frac{3}{4}$ pounds of valve friction and no feel springs. During the flight, $1\frac{3}{4}$ pounds of stick friction were added at various times. The helicopter was flown both by an experienced pilot and by a "nonpilot" as a crude means of determining the importance of pilot skill when valve friction is present. The nonpilot was an engineer with no flight experience but with considerable experience in controlling simulators.

The original power actuators were then replaced with new ones since the friction was considered to be abnormally high. After the new actuators were installed, ground measurements showed that the valve friction was about $\frac{1}{4}$ pound in terms of stick force. No effort was made to determine if the friction reduction was a result of better valves in the replacement actuators or better alinement of the linkages when the new actuators were installed. When the new actuators were installed, feel springs, obtained for this particular test installation from the manufacturer, were also installed which provided force with deflection. The zero-force position of the stick could be controlled by the pilot so that the system could be trimmed for any flight condition. Also, the pilot could, in effect, disconnect the feel springs by a cockpit control. Another flight was made with the same pilot and nonpilot, and the results were compared with those of the previous systems. The helicopter was flown with $\frac{1}{4}$ pound of valve friction with and without the feel springs and with various amounts of stick friction.

During the flight, the breakout forces were measured both with and without the feel springs. Without the feel springs, the breakout was $\frac{1}{4}$ pound in each direction of both controls, or the same as was measured on the ground. Measurements with the feel springs showed $\frac{3}{4}$ pound of breakout, which indicates that the feel springs were preloaded $\frac{1}{2}$ pound.

No instrumentation was installed for these flights since the tests were of a qualitative nature, and it was believed that the pilot's opinion would provide adequate information with which to judge the systems.

DISCUSSION OF RESULTS

In the first flight, in which the valve friction was $1\frac{3}{4}$ pounds and no feel springs were used, the experienced pilot could control the movements of the machine very well in all types of flight. In fact, judging by the overall performance and deviations from the intentional flight path, no difficulties were perceptible; however, in order to accomplish this, continuous stick motion was necessary and the pilot commented that the force reversal due to the valve friction was objectionable. It should be pointed out here that the pilot has had experience in handling control systems involving valve friction and had become skilled in controlling for the friction effects.

When $1\frac{3}{4}$ pounds of stick friction were introduced, no appreciable improvement in controllability could be noticed; however, the pilot remarked that the undesirable force reversal was eliminated. The stick friction also reduced the amount of stick "jockeying" and restored the pilot's feeling of confidence in controlling the helicopter. The pilot, however, objected to the $3\frac{1}{2}$ pounds of breakout force on the basis of the work invloved in making small corrections.

The nonpilot flew the machine with the same control systems that were used by the pilot. As would be expected, the results were very different. The valve-friction effect was far more noticeable with the nonpilot. Not only did the helicopter tend to oscillate in all directions but the nonpilot was very conscious of not having control over the machine. Adding stick friction to the system improved the control, not necessarily from the standpoint of precise control but very definitely from a psychological standpoint, in that control confidence was restored. The nonpilot believed that the high breakout forces were the main reason for no improvement in precise control.

The replacement actuators and trimmable feel devices were then installed and another flight was made. The total breakout forces with the feel devices connected were about $\frac{3}{4}$ pound which resulted from $\frac{1}{4}$ pound of valve friction and $\frac{1}{2}$ pound of preload in the feel springs. Again, the experienced pilot detected no differences in the behavior of the machine from past flights, and the $\frac{1}{4}$ pound of valve friction was hardly noticeable. The pilot believed that the forces with stick deflection provided by the feel springs were very desirable. In the pilot's opinion this system was far superior in all respects to any of the systems previously discussed. Some stick friction was added to the system but the pilot believed that, since the valve-friction effect was not objectionable, the stick friction did not add to the quality of control and the increased breakout due to adding stick friction was undesirable.

The nonpilot's opinion paralleled the pilot's opinion of the systems. The main improvement noticed by the nonpilot was also reflected in the precision with which the machine could be controlled. The ability to control the helicopter precisely was improved since the nonpilot had confidence in hovering and was successful. With all of the other systems previously discussed, the degree of successful hovering varied from only fair to practically impossible. The improvement is attributed not only to the large reduction in valve friction but also to the fact that the low valve friction eliminated the need for stick friction and made the total breakout force only $\frac{3}{4}$ pound.

These limited tests substantiate the ground simulator tests of reference 2. The ground tests showed that $1\frac{1}{2}$ pounds of valve friction were undesirable but some improvement could be gained through the addition of $1\frac{1}{2}$ pounds of stick friction if no flexibility or backlash existed between the stick and the valve. In the test helicopter, the stick was connected to the valves by means of push rods and the flexibility was thereby eliminated. Backlash in the systems was negligible because the valves and stick were very close and required only a few connections. The ground tests also showed that the effect of about $\frac{1}{4}$ pound of valve friction was not sufficiently large to be objectionable to the pilots. Also, the comments regarding total breakout force were in agreement between the two types of tests. The breakout should not exceed 3 pounds, but the ground tests also indicated that control quality improved as the breakout was reduced to a lower limit of $\frac{1}{2}$ pound.

CONCLUDING REMARKS

Friction in the servovalve of power-controlled helicopters can affect the control quality. Friction values of about $1\frac{3}{4}$ pounds make precision flying difficult and require more work of the pilot. Even though higher friction values were not studied in the present tests, it is strongly suspected that higher values can lead to pilot-induced oscillations.

When the valve friction is sufficiently large to be objectionable to the pilot $\left(\text{above } \frac{1}{4} \text{ pound}\right)$, some improvement can be gained by the use of an equal amount of stick friction. The total breakout force, however, should not exceed 3 pounds. It should be remembered that the control quality improves as the breakout is decreased; therefore, every effort should be made to reduce the valve friction as much as possible and, thereby, to allow an equal reduction in the necessary stick friction or the elimination of stick friction entirely when the valve friction is about $\frac{1}{4}$ pound or less.

The pilots considered the trimmable feel springs to be very desirable to the control characteristics and to contribute greatly to the overall quality and confidence of control.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 7, 1957.

REFERENCES

1. Phillips, William H., Brown, B. Porter, and Matthews, James T., Jr.: Review and Investigation of Unsatisfactory Control Characteristics Involving Instability of Pilot-Airplane Combination and Methods for Predicting These Difficulties From Ground Tests. NACA RM L53F17a, 1953.

2. Brown, B. Porter: Ground Simulator Studies of the Effects of Valve Friction, Stick Friction, Flexibility, and Backlash on Power Control System Quality. NACA TN 3998, 1957.

3. Phillips, William H.: Investigation of Effect of Reduction of Valve Friction in a Power Control System by Use of a Vibrator. NACA RM L55E18a, 1955.

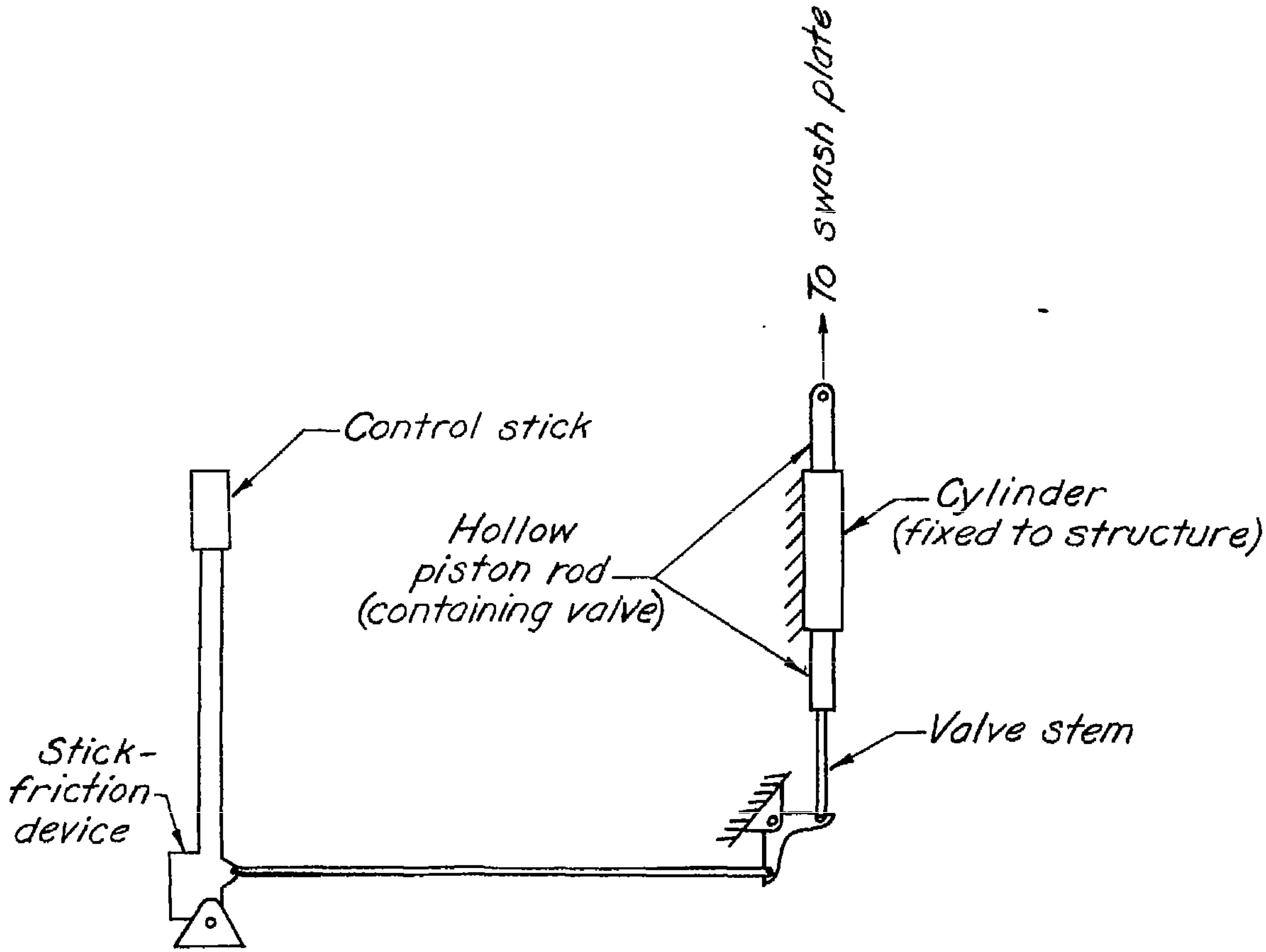

Figure 1.- Schematic drawing of longitudinal power control system.

NACA - Langley Field, Va.