NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3947

INSTRUMENT FLIGHT TRIALS WITH A HELICOPTER STABILIZED IN ATTITUDE ABOUT EACH AXIS INDIVIDUALLY

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SUMMARY

Flight investigations of single-axis attitude stabilization have been conducted during low-speed instrument approaches. A single-rotor helicopter that had been modified to include an electronic control system was used in the investigation. Pilots' opinions and a simplified statistical analysis of the pilots' control and helicopter motions were used for evaluation.

Results indicated that heading stabilization provided considerable improvements in calm air but was actually detrimental under variable-wind conditions for the task performed. This latter finding was probably the result of the characteristics of this particular control system. Roll stabilization provided only minor benefits in calm air and showed no improvements in varying winds. Conversely, stabilization in pitch provided benefits which were significant in both calm air and in varying winds.

INTRODUCTION

Helicopter instrument flights have indicated the desirability of improved stability and control characteristics. There have been a number of successful attempts at obtaining such improvements which have made use of electronic control units. These units, however, present problems in cost, weight, maintenance, and reliability.

The possibility was suggested that stabilizing attitude about a single axis would materially relieve these problems and still bring about substantial improvements in flying qualities. An investigation was therefore undertaken to evaluate the improvements in flying qualities provided by attitude stabilization about each axis individually. The helicopter configuration used for comparison in the investigation already possessed good basic flying qualities; one reason is the existence of increased damping about all three axes. In this case, the increased damping was most conveniently supplied by electronic units. This

investigation was restricted to a study of the effects of the addition of a control signal proportional to helicopter attitude. For the purposes of this investigation, stabilization is taken to mean the restoration of the helicopter to a reference attitude (angular position with respect to earth axes) after a disturbance.

DESCRIPTION OF EQUIPMENT USED IN INVESTIGATION

The helicopter used as the test vehicle is shown in figure 1. This is an extensively modified single-rotor machine of about 5,500-pound gross weight with good basic flying qualities. The helicopter has essentially two control systems: a direct mechanical linkage with hydraulic boost and a completely electronic system which operates on the mechanical one. The electronic system has been added to permit studies of the variation of stability parameters. Reference 1 presents an example of these studies and describes the control system which is illustrated in figure 2.

A signal proportional to helicopter rate was continuously operating about all three axes to provide damping in addition to that already present in the basic machine. These rate gains were the same values arrived at in reference 1. For this investigation the electronic units were further modified to include a signal proportional to helicopter attitude. The gains used for the three axes are presented as follows:

	Pitch axis	Roll axis	Yaw axis
Displacement gain	$0.16 \frac{\text{deg cyclic pitch}}{\text{deg}}$	$0.05 \frac{\text{deg cyclic pitch}}{\text{deg}}$	$0.99 \frac{\text{deg tail-rotor pitch}}{\text{deg}}$
Rate gain	$0.25 \frac{\text{deg cyclic pitch}}{\text{deg/sec}}$	$0.11 \frac{\text{deg cyclic pitch}}{\text{deg/sec}}$	$0.51 \frac{\text{deg tail-rotor pitch}}{\text{deg/sec}}$
Basic-helicopter damping	$0.13 \frac{\text{deg rotor tilt}}{\text{deg/sec}}$	$0.07 \frac{\text{deg rotor tilt}}{\text{deg/sec}}$	$0.17 \frac{\text{deg tail-rotor pitch}}{\text{deg/sec}}$
Basic-helicopter control power	$624 \frac{\text{ft-lb}}{\text{deg rotor tilt}}$	$624 \frac{\text{ft-lb}}{\text{deg rotor tilt}}$	$1{,}090 \frac{\text{ft-lb}}{\text{deg tail-rotor pitch}}$

The helicopter carried two pilots; the front pilot operated the mechanical controls and acted as the safety pilot, while the rear pilot flew the helicopter with mock cyclic stick and pedals (both with spring feel) which introduced electrical signals into the equipment. The electronic unit then responded so that the control deflection caused the helicopter to change attitude until the attitude error signal was sufficient to cancel the control signal. Thus, the helicopter stabilized about some new attitude which was proportional to control deflection.

The system was adequate in pitch and roll but had to be modified for heading. In the heading case, the pilot would frequently want to

change his reference attitude. For this reason, a switch that permitted the pilot to disconnect the heading signal was installed on the rear pilot's cyclic stick. A new heading reference was provided when the pilot reengaged the signal after a desired change in heading had been accomplished.

Initial flight trials showed that an abrupt pedal deflection resulted when the heading signal was disconnected. It was noted that the yaw signals due to heading error during flight were responsible for the abrupt pedal deflections and that pedal trim variations due to varying power were contributing to the heading error. A simple torque-compensation circuit, based entirely on throttle position, was used in an effort to reduce the undesirable pedal motion. The circuit was found to be helpful but was not completely satisfactory. Apparently the deficiency in the operation of the electronic controls did not interfere unduly with the test program. The difficulty was present only about the yaw axis and was most bothersome during severe atmospheric conditions, when the effects were readily discernible.

The helicopter was instrumented with standard NACA recording instruments with a coordinated time scale. Altitude, airspeed, heading, and roll, pitch, and yaw velocities were recorded. In addition, records were taken of the pilot's controls: namely, the positions of lateral-cyclic, longitudinal-cyclic, and collective levers and tail-rotor pedals.

FLIGHT PROCEDURE

The evaluation of single-axis stabilization was primarily conducted during low-speed instrument approaches by use of the instrument landing system (ILS). For this investigation the rear seat was hooded, and the rear pilot flew the helicopter. The low-speed approaches were selected so that the pilot would have a repeatable task that was sufficiently difficult to enable him to readily detect any important changes in performance.

The procedure followed required the pilot to make the first approach, after practice, without any attitude stabilization. Succeeding approaches were made while a single axis was attitude stabilized. The order of stabilization was varied, and a final approach with no attitude stabilization was flown in order to evaluate, as far as possible, any effects of additional practice or fatigue. The glide slope was entered at about the same altitude (700 to 800 ft) each time, and the approach was made at the same airspeed (25 knots) in order to have each run occupy about the same period of time. All approaches during a flight were made within a short interval in order to eliminate any effects of gross wind variation. Thus, the approaches for each flight were conducted under essentially the same conditions.

Flights were conducted in smooth and gusty air and with head, tail, and cross winds. When the wind was particularly light or when steady wind conditions existed, the wind was designated as "calm." A "variable" wind was one in which there was a severe variation in wind direction or velocity, or both, with altitude or very gusty air.

METHOD OF EVALUATION OF RESULTS

Pilots' Opinions

The pilots' opinions of the various configurations of the test helicopter are the combined opinions of two NACA research pilots experienced in handling-qualities investigations, John P. Reeder and James B. Whitten. A third research pilot less experienced in helicopter flying also flew a few approaches during this investigation. All of the pilots agreed substantially on the points presented herein.

Quantitative Analysis

A simplified statistical analysis was used to provide some quantitative basis for evaluation of the variation in flight configuration. The method makes use of the fractional defective discussed in reference 2. For this investigation, it appeared to be more appropriate to substitute the expression fractional deviation for fractional defective. The fractional deviation is defined as the fraction of the total number of observations lying outside specified limits.

Initially, the data were divided into two categories: pilot's control motion and helicopter motion. The control-motion fractional deviations were determined by reading the film records at 1-second intervals and comparing adjacent readings. If a reading differed from the one preceding it by more than 0.5-percent control, a "deviation" was noted. The fractional deviation was then the total number of these deviations divided by the length of the record.

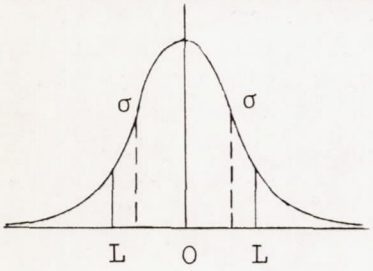
The motions considered in the analysis of the helicopter motions were heading, airspeed, altitude, and pitch, roll, and yaw velocities. Unfortunately, altitude had to be discarded because of the difficulty in correlating the recorded altitude with the desired altitude along the flight path. Heading and airspeed were considered the more important of the remaining parameters but no satisfactory weighting method was readily available; thus, all parameters had to be considered equally.

The helicopter-motion fractional deviations were determined by choosing suitable limits for each of the motions measured. The limits

were selected by the pilots' comments on the limits they set on the various parameters in flight. These limits were drawn on the film record as shown in figure 3. It was only necessary to note the position of the records with respect to the limit lines at each reading interval. If the trace fell outside of the limit lines, a deviation was noted and the fractional deviation was then determined as described for the pilot's control motions.

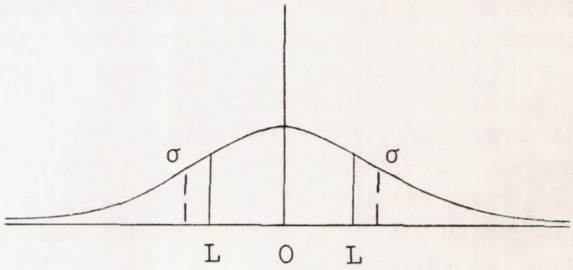
One-second intervals were used since they were conveniently marked on the film and provided a reasonable number (on the order of 200 to 300) of samples. They were considered to represent a large number of random samples of the quantity considered, and the order of reading makes no difference in the fractional deviation.

The fractional deviations obtained are essentially measures of the probability with which the variable under consideration will exceed the prescribed limits. The parameters were found to follow approximately a normal distribution which permits analysis under normal distribution laws. With this assumption, it is possible to enter table I (page 75) of reference 3 with the fractional deviation p and to determine a value of σ/L which is the ratio of the standard deviation σ of the variable to the prescribed limit L. (The value obtained in table I of reference 3 is actually a value of L/σ.) This ratio may be considered to represent a desirable performance level when equal to or less than unity. If $\sigma \leqq L$, most of the values of the parameters under consideration were at a desirable level as indicated in sketch A. Conversely, $\sigma > L$ indicates excessive variation of the parameter as illustrated in sketch B. In these sketches the areas under both curves are identical.



$\sigma < L$

Sketch A



$\sigma > L$

Sketch B

In sketch A, it will be noted that a large proportion of the area is contained within the limits L. In sketch B, a much smaller proportion of the area under the curve is contained within the limits L. Since the standard deviation is a measure of the distribution of the parameters being measured, it may be conveniently used in this analysis. The quantity $E = \frac{\sigma}{L} - 1$, therefore, was termed the "excess." The cumulative excess for the pilot's motions and the cumulative excess for the helicopter's motions were summed and this value of the excess E was used

for the analysis. In order to arrive at a determination of the confidence level reached in the analysis, the cumulative excess for both the first and last approaches of all the flights was determined. These approaches were flown without attitude stabilization and the difference between them would be due to extraneous causes and would be a measure of the reproducibility of a value of cumulative excess. The root-mean-square value of these differences was then taken as the standard error of any cumulative excess of an approach. A difference in the cumulative excess between approaches greater than twice the standard error was taken to be significant since on the average in only 5 cases in 100 would this difference be expected on the basis of chance alone.

The method provides a considerable saving in computing time compared with the time required for complete statistical analysis. For the purpose of comparison, the method appears to produce adequate results, although some information is lost.

RESULTS AND DISCUSSION

Figure 4 illustrates the comparative effort exerted by the pilot, as reflected in his control motions, and a comparison of helicopter-motion deviations from a standard. The values of the cumulative excess derived from the modified statistical analysis are compared for the stabilized and unstabilized configurations for two extreme cases of calm-air and variable wind flights. It should be noted that the collective-pitch value is negative whereas the other control-motion values are positive. The cumulative excess for the pilot's motion is the algebraic sum (total) of the values given and is immediately below the plot of the individual motions. The results to be discussed are based on a total of 9 flights which included 17 approaches without stabilization, 10 approaches with heading stabilized, 9 approaches with pitch stabilized, and 9 approaches with roll stabilized. A standard error equal to 1.9 was found from these approaches and twice this value was used as the test of significance.

Heading Stabilization

In general, the heading-stabilized flight in calm air (illustrated in fig. 4(a)) showed large reductions in both pilot's control motions and helicopter deviations in comparison with those values obtained for the unstabilized case. The pilots' opinions verified these results. They felt that heading stabilization was highly desirable in that it provided considerable help during the instrument landing approaches and did permit better results on approaches.

The main problem of the approach appears to be the pilot's ability to maintain the proper heading. With the machine stabilized in heading, therefore, it would be expected that considerable improvement would result. Improvement was primarily brought about in the frequency of the pilot's pedal and lateral-cyclic-stick motions. The longitudinal and collective motions were only slightly improved. The improvement in pedal and lateral motions was emphasized in the much smaller heading deviations and in the reduced roll- and yaw-velocity deviations, even with the comparatively small pilot's effort.

The heading problem is brought into sharper relief, however, under variable-wind conditions. Figure 4(a) shows that heading stabilization is not a significant aid for this condition, because a variable wind will require frequent heading corrections in order to maintain the desired ground path. With the particular electronic installation used, it was necessary for the pilot to disconnect the heading signal when a heading change was desired. As previously described, the result was a large pedal displacement. The pilot therefore had to correct for this undesirable signal as well as reach his desired heading before reengaging the heading signal. Note in figure 4(a) that this problem is reflected in the pilot's pedal and lateral cyclic motions, which reach the same order of magnitude for the stabilized as for the unstabilized case. The heading, roll-velocity, and yaw-velocity errors are all increased over the normal configuration.

In view of the added difficulty imposed on the pilot by the operation of the electronic control unit during variable-wind conditions, it was not surprising that the normal configuration was better than the heading stabilized machine. An automatic control device which was not subject to large pedal deflections when the heading signal was disconnected would probably provide significant advantages even under variable-wind conditions.

A control system specifically designed to overcome these shortcomings might be one where the pedals moved with the tail rotor in response to the automatic control signals. Disconnecting the heading signal in this case would leave the pedals in the trim position. There would then be no large unwanted displacements when the pilot wanted to change heading. The incorporation of this feature in the present installation would have been desirable but would have required a very extensive modification of this machine. For this reason no modification effort was made for the present investigation.

Pitch Stabilization

Figure 4(b) indicates the results derived from the use of automatic stabilization in pitch. Pilot's control motions and helicopter deviations have been materially decreased although not to the level attained

with heading stabilization in calm air. The statistics were again verified by the pilots' opinions. The pilots felt that the aid received in pitch was significant and did contribute to the ease and quality of the approaches.

In calm air the most important improvements were in the pilot's longitudinal cyclic and collective pitch motions. This improvement was reflected in the smaller airspeed and pitch-velocity variations of the helicopter. The pilots reported a similar reduction in the altitude variations. The improvement in airspeed control was most noticeable to the pilots and was statistically the most significant improvement. The realization of the expected advantages in pitch permitted the pilots somewhat more opportunity to monitor the other motions of the helicopter. The result was better heading control even though pedal motions remained about the same.

Under variable-wind conditions, pitch stabilization resulted in about the same overall improvement as was obtained in calm air. For this configuration, then, the pitch system operated continuously to good advantage.

Roll Stabilization

Stabilization in roll resulted in some improvements in calm air, but no overall changes large enough to provide a basis for statistical comparison. With this particular installation, the pilot's lateral control motions were less effective since the attitude stabilization system made a smaller rate of turn available for a given stick displacement than was normally the case. The pilot used lateral control as well as pedals to make corrections in the flight-path direction. With the reduced control effectiveness available laterally, the required corrections were more difficult to make because of the resulting slow response.

The advantage provided by roll stabilization was the ability to establish and maintain a given attitude when desired. Under variable-wind conditions, when the pilot uses roll-attitude changes to make corrections in flight-path direction, the effect of roll stabilization is not as important as might be expected for the tasks imposed. The pilots indicated that this configuration did help by reducing the concentration required. The analysis, as shown in figure 4(c), tended to confirm this conclusion but also indicates the increased helicopter motions in a varying wind. The total result, then, for a varying wind is somewhat poorer for the stabilized than for the unstabilized helicopter. It is possible that the expected advantages of roll stabilization may be realized in normal cruising flight where the heading control problem is not as predominant.

SUMMARY OF RESULTS

A single-rotor helicopter with an electronic control system was flown at low airspeed on instrument landing approaches with each axis individually stabilized in attitude. The helicopter configuration used for comparison in this investigation already possessed good basic flying qualities which may be partly attributed to the existence of increased damping. The results of the investigation, which are based on a combination of pilots' opinions and statistical analysis, may be summarized as follows:

1. Under conditions of calm or steady air, the handling qualities of the helicopter stabilized in heading were considerably improved. Variable-wind conditions, however, largely eliminated these benefits. This deficiency was ascribed to the peculiarities of the circuit used to disconnect heading stabilization, when a heading change was desired. It is believed that the elimination of these peculiarities would yield a yaw-stabilization system that would provide significant advantages even under variable-wind conditions.

2. There was only a small general improvement while the roll axis was attitude stabilized, although the pilots reported a significant decrease in concentration required. With varying winds the roll-attitude stabilized helicopter actually produced poorer results than the helicopter without such stabilization. It is possible that these results would vary under other operational conditions such as normal cruising flight.

3. Definite improvements were brought about by attitude stabilization in pitch, both under calm-air and variable-wind conditions. The gains were important and consistent, although not as large as those obtained in calm air with heading stabilized.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 19, 1956.

REFERENCES

1. Whitten, James B., Reeder, John P., and Crim, Almer D.: Helicopter Instrument Flight and Precision Maneuvers as Affected by Changes in Damping in Roll, Pitch, and Yaw. NACA TN 3537, 1955.

2. Anon.: A.S.T.M. Manual on Presentation of Data. A.S.T.M. (Philadelphia), 1950.

3. Fisher, R. A.: Statistical Methods for Research Workers. G. E. Stechart & Co., 8th ed., 1941.

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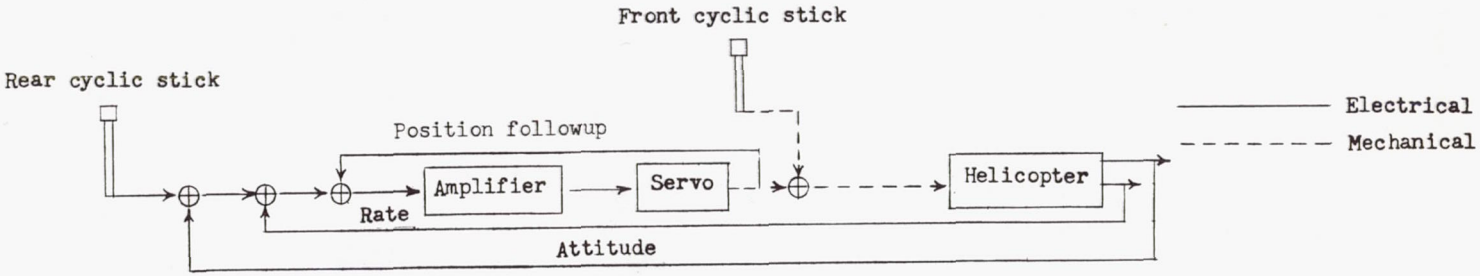
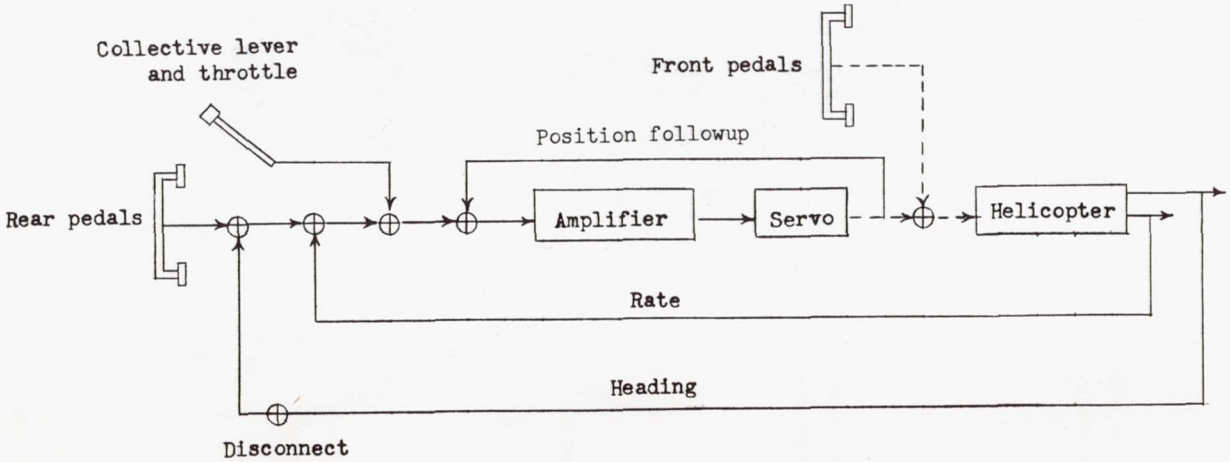
Figure 1.- Helicopter used in investigation.

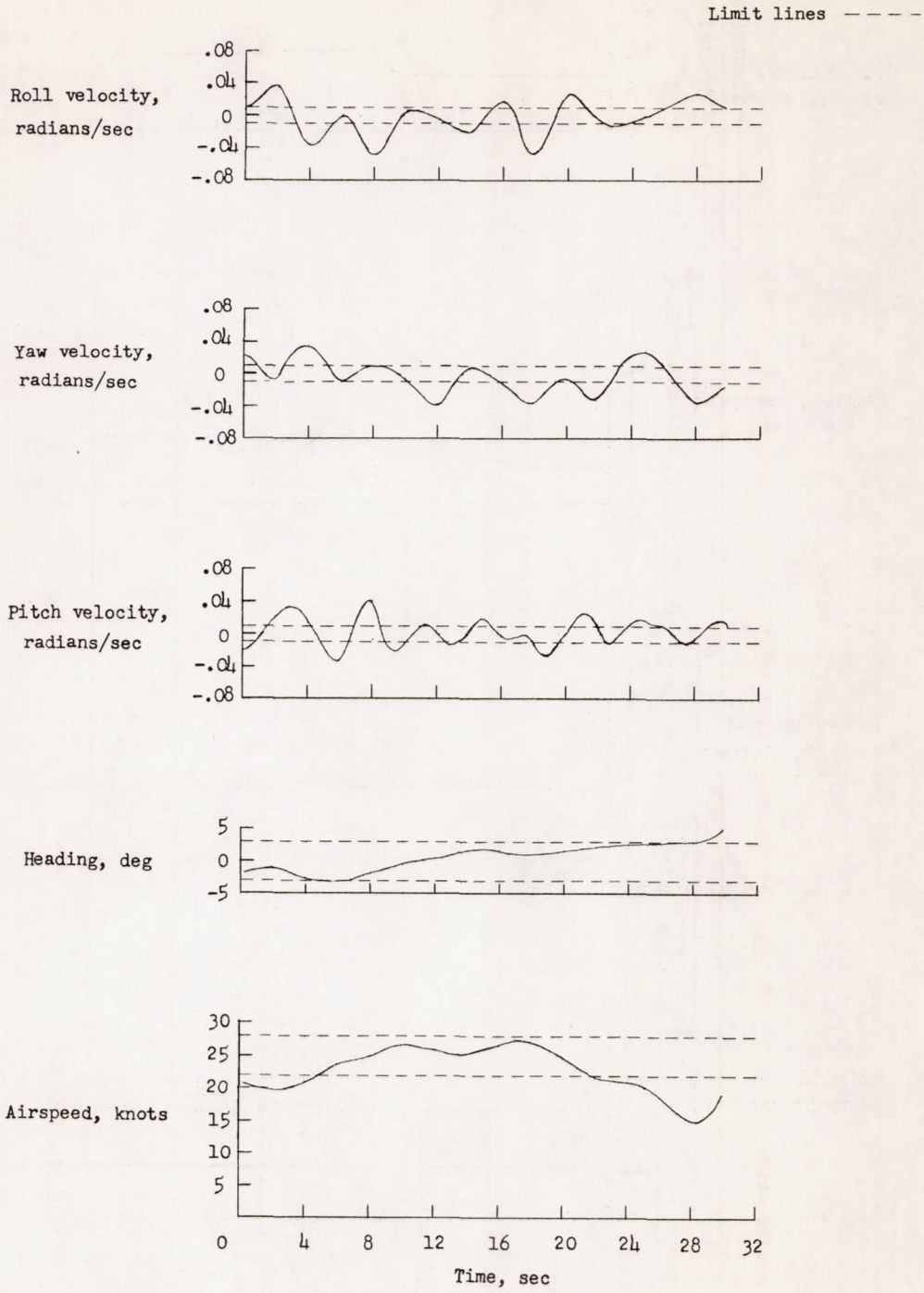


(a) Pitch and roll channels.



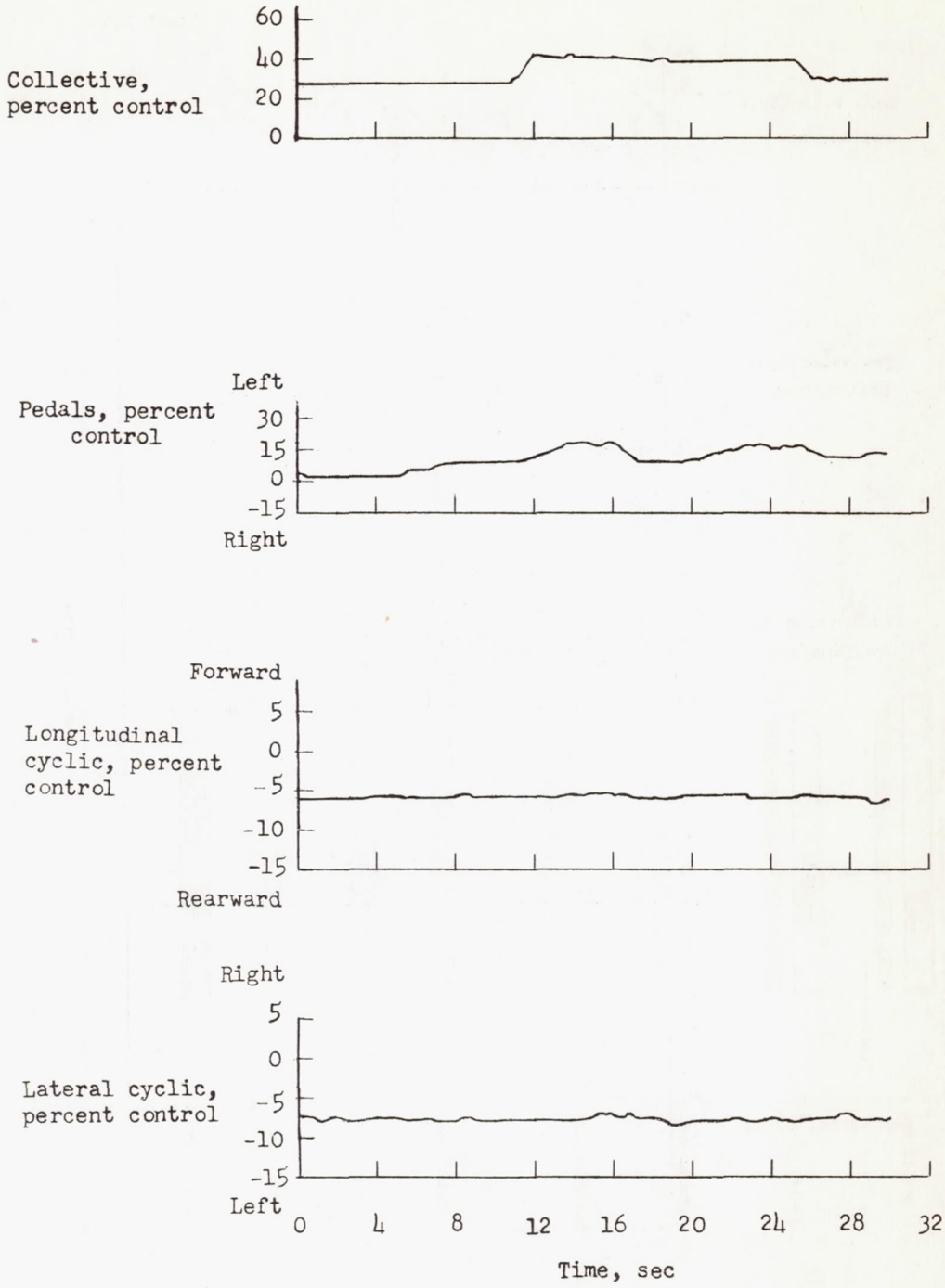
(b) Heading channel.

Figure 2.- Block diagram of electronic control system.



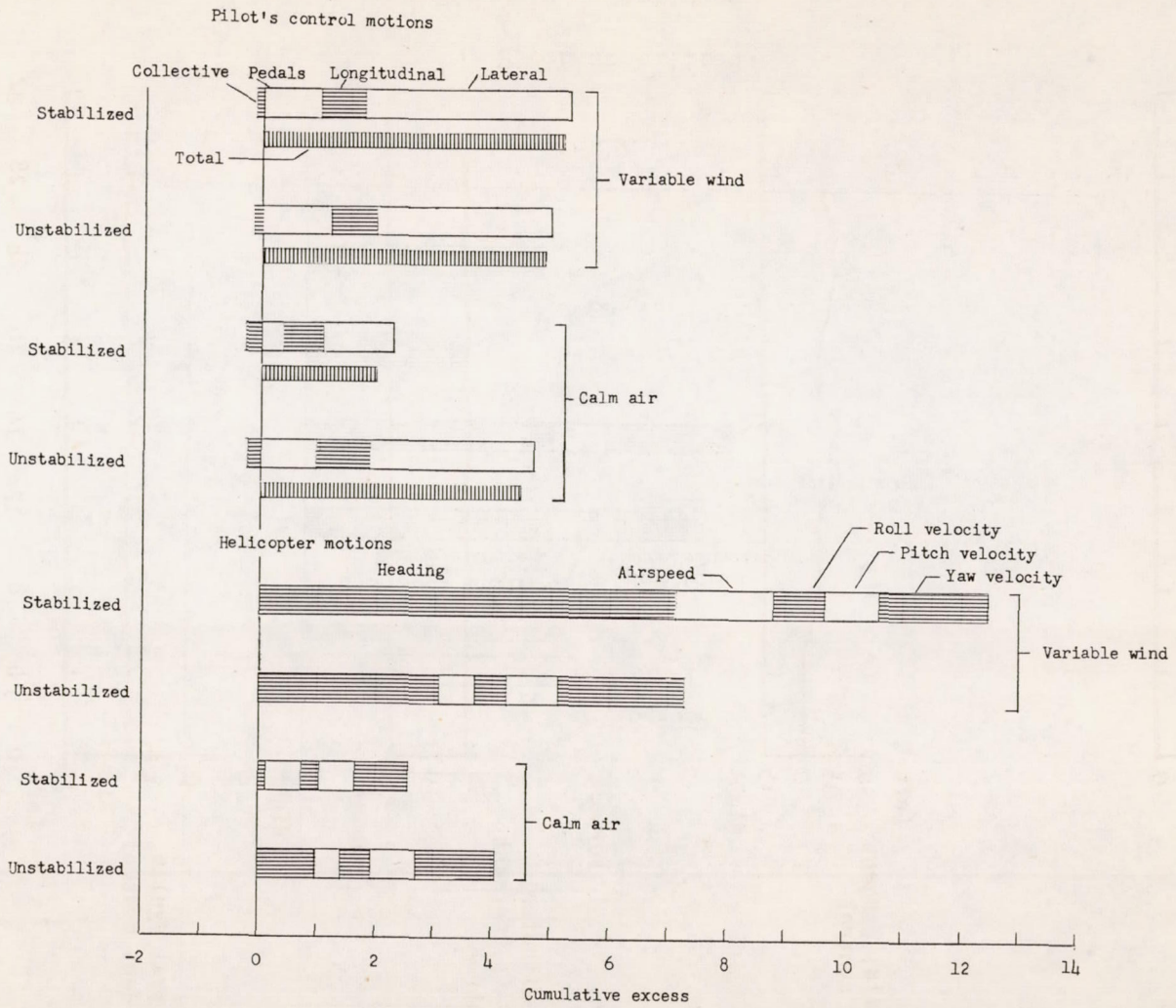
(a) Helicopter motions indicating error limits.

Figure 3.- Sample time histories.



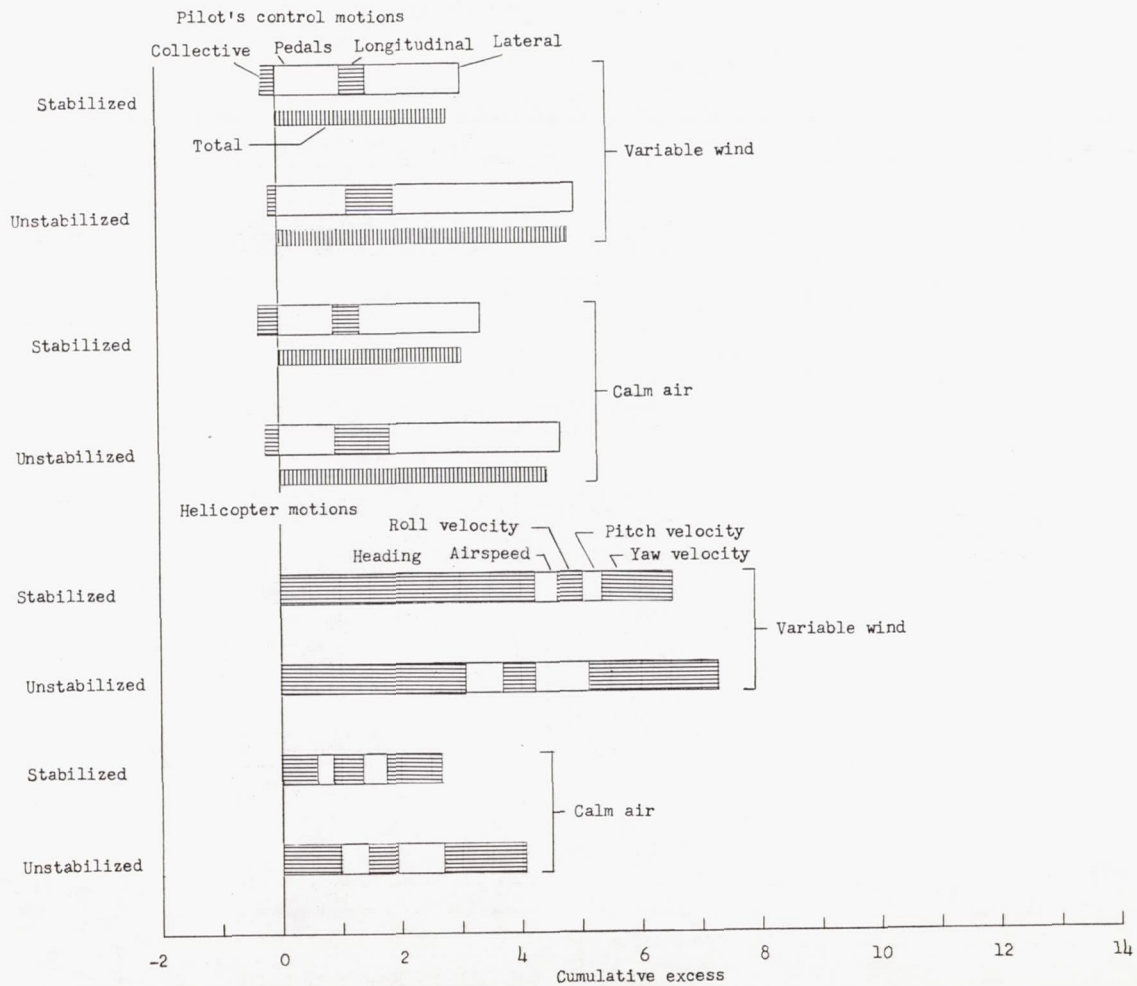
(b) Pilot's motions.

Figure 3.- Concluded.



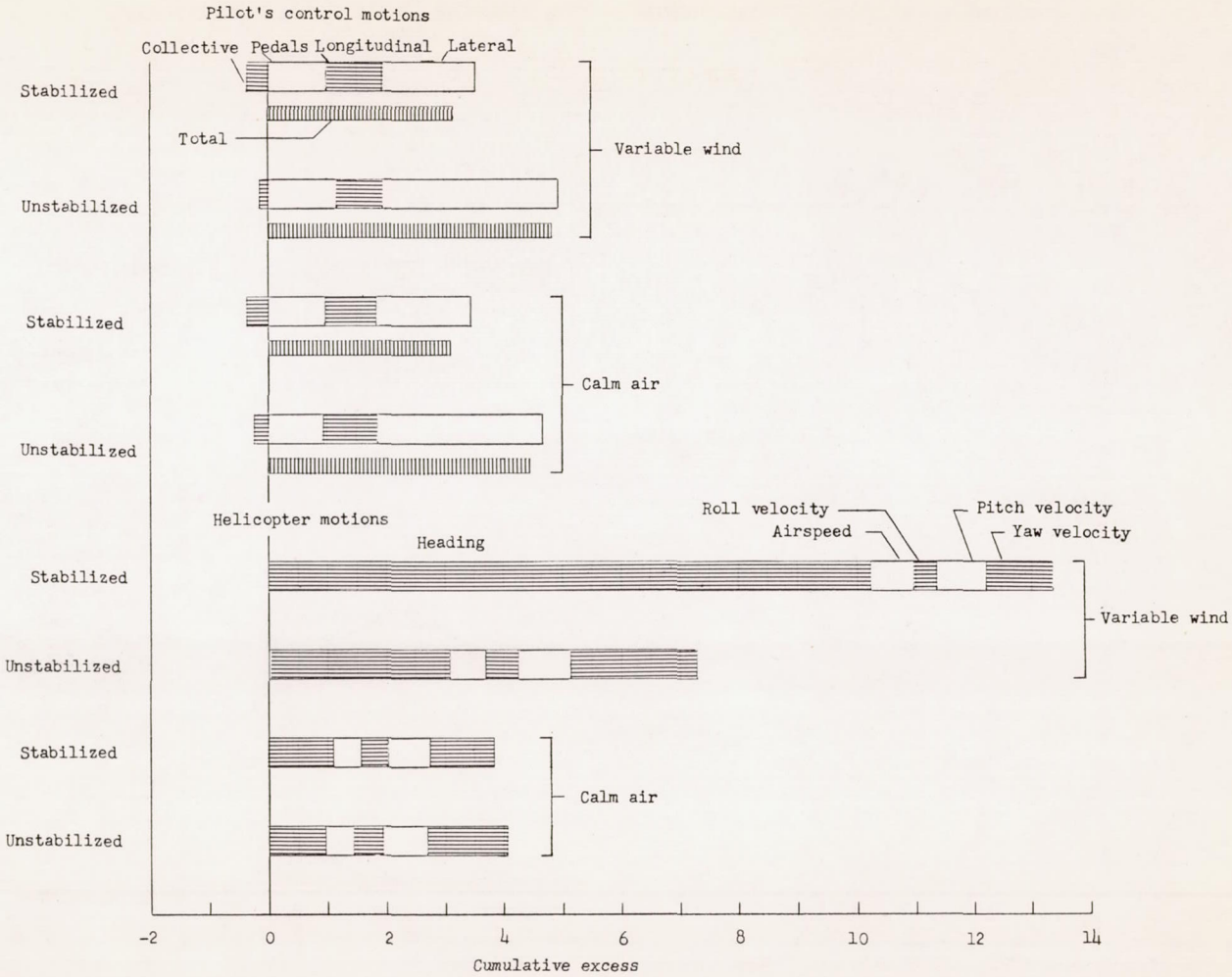
(a) Heading stabilized.

Figure 4.- Pilot's and helicopter motions.



(b) Pitch stabilized.

Figure 4.- Continued.



(c) Roll stabilized.

Figure 4.- Concluded.

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