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RESEARCH MEMORANDUM

A FLIGHT INVESTIGATION OF THE HANDLING CHARACTERISTICS OF A FIGHTER AIRPLANE CONTROLLED THROUGH AUTOMATIC-PILOT CONTROL SYSTEMS

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A FLIGHT INVESTIGATION OF THE HANDLING CHARACTERISTICS OF A FIGHTER AIRPLANE CONTROLLED THROUGH AUTOMATIC-PILOT CONTROL SYSTEMS

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SUMMARY

A flight investigation has been made to obtain experimental information on the handling qualities of a fighter airplane controlled through automatic-pilot control systems. Two types of automatic pilots were used; one of these was of the attitude type and the other was of the rate type. With the attitude automatic-pilot control system, two types of stick force feel were used, spring feel and damper feel. This paper describes some results obtained in this flight program.

INTRODUCTION

The automatic pilots with which many present-day military airplanes are equipped are used for a variety of purposes. For example, they are used to provide airplane heading and attitude stabilization, and thereby relieve the pilot of these tasks, and to improve undesirable airplane stability characteristics by providing stability augmentation. Also, in some cases they are used as a part of completely automatic flight control systems such as in fire control and landing-approach systems. Recently, there has been considerable interest in making the automatic pilot an integral part of the maneuvering control system of the airplane and having the human pilot control and maneuver the airplane by supplying signals to the automatic pilot. In view of this interest, a flight investigation is being made to obtain experimental information as to what effects these automatic-pilot control systems have on airplane handling qualities and also to try to determine what constitutes desirable handling qualities with these systems. This paper describes some results obtained in this flight program.

Two types of automatic-pilot control systems have been used. One of the automatic-pilot control systems was of the attitude type and the other was of the so-called rate type.

SYMBOLS

a_n	normal acceleration, g units
g	acceleration due to gravity, 32.2 ft/sec^2
Y	side force
δ_a	total aileron deflection, deg
δ_e	elevator deflection, deg
δ_r	rudder deflection, deg
θ	angle of pitch
$\dot{\theta}$	pitching velocity
ϕ	angle of bank
$\dot{\phi}$	rolling velocity
ψ	angle of yaw
$\dot{\psi}$	yawing velocity

DESCRIPTION OF ATTITUDE AUTOMATIC-PILOT SYSTEM

The airplane used in the flight program was a Grumman F9F-2. This airplane has an unswept wing and is of conventional configuration. In general, it has good flying qualities.

The attitude automatic-pilot control system is discussed first. Figure 1 shows a block diagram of the pitch channel of the attitude automatic pilot used.

If the pilot desires to maneuver the airplane in pitch, he generates a signal by moving the automatic-pilot control stick. For steady-state conditions the airplane pitch angle as measured by the attitude gyro is proportional to the pilot's stick position. The rate gyro and servo feedback provide stability and damping to the system. The servo-feedback canceler reduces the servo-feedback signal at a slow rate and has little influence for rapid airplane motions.

Figure 2 shows block diagrams of the roll and yaw channels of the automatic pilot. The roll channel is in the lower part of the figure and the yaw channel is in the upper part. The operation of the roll channel is substantially the same as that of the pitch channel. The only differences are that no servo-feedback canceling is used in the roll channel and an additional signal source is present. The additional signal comes from a directional gyro and provides heading stabilization. The directional-gyro signal is cut out when the airplane is maneuvered in azimuth.

The yaw channel of the automatic pilot receives its operating signals from a rate gyro which increases the damping in yaw and a pendulum, the purpose of which is to provide the proper rudder motion for coordinated turns. The human pilot does not introduce signals into the yaw channel of the automatic pilot. The attitude control system used did not allow universal maneuvering. The maneuvering limits were $\pm 60^{\circ}$ in both pitch and roll.

The automatic-pilot controller consisted of a stick which quite closely simulated the control stick used in manual flying. Motion of this stick generated an electrical signal proportional to its deflection. There was no mechanical connection between the control stick and the airplane control system; therefore, motions of the airplane control surfaces were not transmitted to the stick.

RESULTS OBTAINED WITH ATTITUDE AUTOMATIC-PILOT SYSTEM

Figure 3 shows some flight records of the response and damping characteristics of the airplane—automatic-pilot combination for abrupt stick motions. The time history on the left shows a pitching maneuver, and that on the right shows a rolling maneuver. In both pitch and roll the response and damping are good.

The solid stick-position curves show the automatic-pilot control-stick position and the dashed curves represent the stick motion for the conventional control system. Comparison of the stick-position curves shows that the stick motions required to produce a change in airplane attitude are simpler with the attitude control than with the conventional control. On the other hand, to make a pull-up with the attitude control the pilot must continuously move the stick back to maintain the acceleration, whereas with the conventional control the pilot holds the stick fixed once the acceleration is established. The pilots adapted themselves to the attitude control system quite easily and, although the stick motions required with the attitude control are generally simpler than those required with the conventional control, pilots experienced in flying with conventional control systems did not consider this of particular importance.

Probably of greater importance to the pilot than the stick motions required in maneuvering are the stick-force characteristics. In reference 1 the importance of providing the proper stick forces in relation to the airplane response is discussed. Two types of stick force feel were used with the attitude control system for both fore-and-aft and lateral stick motions. One of the feel systems provided a force to the pilot proportional to stick deflection (spring feel) and the other provided a force proportional to the rate of stick deflection (damper feel). Figure 4 shows time histories of the stick force and position and some airplane response quantities during pitching maneuvers made with the attitude control system.

The maneuver on the left was made when using the spring force feel system and that on the right was made with the damper force feel system. The pilots had several objections to the characteristics provided by the spring force feel system. One objection was that it was easy to inadvertently induce accelerations on the airplane. If the pilot makes a pull-up as shown in the first part of the figure and then reduces his pull force, the airplane may very likely develop a negative acceleration, as occurred in the maneuver shown. The pilot is not required to apply any push force to produce the negative acceleration and therefore it is very easy for him to inadvertently induce it. For the particular maneuver shown, only a small value of negative acceleration was reached, but had the pilot reduced the pull force more rapidly, an appreciable negative acceleration would have occurred. With the damper force feel system, when the pilot reduced his pull force after making the pull-up, the airplane simply returned to 1 g flight. Furthermore, the pilot must apply a push force to produce an acceleration less than 1 g and therefore he is not as likely to inadvertently induce the acceleration.

Another objection to the spring force feel system is that, whenever the pilot changes the airplane pitch or bank angle, he is required to hold a force to maintain the new attitude angle. Since the pilot might be required to hold the force for long periods of time, the forces should be light, and when the forces are light, the control tends to be too sensitive. This objection is also overcome with the damper force feel system since the pilot is required to apply a force only when he is moving the stick.

Another advantage of the damper force feel system is that the force per g in rapid pull-ups is greater than in steady or constant g pull-ups. With the spring force feel system, the force per g in rapid pull-ups is less than the force per g in steady pull-ups.

In constant g turns the damper force feel system provided no force per g as is required by the present flying-qualities specifications. However, the pilots had no objection to the lack of a force per g for the relatively low levels of acceleration at which turns were made.

The pilots liked the characteristics provided by the damper force feel system much better than those provided by the spring feel system. Considerable general flying was done with this system. The airplane was flown to near its maximum allowable Mach number of about 0.80 at an altitude of 30,000 feet and to a Mach number of about 0.75 at 5,000 feet. Stall approaches and landings were made and some flying was done in rough air. For this general flying, which involved mild maneuvering, the attitude control system had some distinct advantages over a conventional type of control system. As might be expected, the main advantage was that the automatic pilot stabilized the airplane with respect to its heading and attitude angles and thus greatly improved the control-free flying characteristics.

One characteristic of the attitude control system which was objectionable to the pilots and which may be inherent in attitude control systems which have relatively fast response was that the airplane response, particularly in roll, seemed jerky for small rapid or irregular lateral stick motions. The feeling of jerkiness or oversensitivity probably results because small rapid lateral stick motions produce larger rolling accelerations with the attitude control system than with the conventional control. Also, larger rolling accelerations than ordinarily used are present in stopping the rolling motion at the steady-state bank angle. Increasing the damping forces on the stick alleviated the feeling of jerkiness somewhat since the pilot then tended to move the stick more smoothly.

The next part of the flight program was concerned with determining the ability of the pilot to perform precision tasks when controlling the airplane through the attitude control system. The precision flight characteristics were evaluated by making tracking runs on a target airplane and also by making strafing runs in rough air on a ground target. In order to have a basis for comparison, similar runs were also made when the pilot was controlling the airplane through the conventional control system. During the tracking runs a fixed optical gunsight was used and moving pictures were taken of the gunsight presentation. The tracking data obtained were evaluated in terms of the standard deviations of the tracking errors. Table I shows a comparison of the tracking errors when using the attitude control system having the damper force feel system and the conventional control system.

In the table the tracking errors are presented with regard to the type of maneuver being performed during the tracking run and the tracking errors in pitch and yaw are presented separately. The target maneuvers were relatively mild and probably are similar to the maneuvering of a bomber-type airplane. The air-to-air tracking runs were made at a Mach number of about 0.6 at an altitude of 30,000 feet and the strafing runs were also made at a Mach number of about 0.6. In general, there are no significant differences in the tracking errors present with the two systems in either pitch or yaw. As previously mentioned, the airplane used had good flying qualities and the pilot was able to do a good tracking job when using the conventional control system. The significant fact is that the pilot was able to do about equally well when using the attitude control system. Also, it should be pointed out that in no case would the tracking errors be expected to be less than about 1 to $1\frac{1}{2}$ mils since the pilot has no incentive to do better than this. For example, the tailpipe diameter of the target airplane appeared to be of about this size on the gunsight at the tracking range used.

DESCRIPTION OF RATE AUTOMATIC-PILOT SYSTEM

Figure 5 shows a block diagram of the pitch or roll channel of the rate automatic-pilot control system. The operation of the pitch and roll channels of this automatic pilot are the same. With this system a pilot's stick deflection produces a proportional change in the airplane pitching or rolling velocity (as measured by the rate gyro). The servo-feedback signal again provides stability to the system. The servo-feedback canceler is a positional servomechanism having a relatively large time constant. For steady-state conditions, the output of the servo-feedback canceler is equal in magnitude and opposite in sign to the servo-feedback signal. Since steady-state servo-feedback signals are thus effectively canceled, the only signal which opposes a pilot's input signal comes from the rate gyro. Therefore, a given pilot's stick deflection will produce (within the capabilities of the airplane) the same pitching or rolling velocity at any airspeed. Since the servo-feedback canceler has a relatively large time constant, the stabilizing effect of the servo-feedback signal for rapid airplane motions is retained.

The yaw channel of the rate automatic-pilot control system was the same as that used with the attitude control system (see fig. 2). Also, the same automatic-pilot control stick was used with both the rate and attitude systems. Only the spring force feel system was used with the rate automatic pilot. This system was selected because the stick motions required in maneuvering with the rate automatic-pilot control are very similar to those required with a conventional control and it was known that a spring feel system could be made to provide good feel characteristics with a conventional control system.

RESULTS OBTAINED WITH RATE AUTOMATIC-PILOT SYSTEM

Figure 6 shows some flight records of the response in pitch and roll for the rate automatic-pilot system. The pitch response is on the left and the roll response is on the right. Again, the response and damping are good in both pitch and roll. As was mentioned previously and as can be seen from the figure by comparing the stick-position and elevator- and aileron-position curves, the stick motions required in maneuvering with the rate automatic-pilot system are about the same as those required with a conventional control.

The flying qualities of the airplane with the rate automatic-pilot control system were very good. Most of the flying was done with longitudinal control forces of about 2 to 4 pounds per g. For lateral stick motions, about 10 pounds of stick force was required for full lateral stick deflection and this stick deflection produced a rolling velocity of about 150° per second.

Some flying was done in moderately rough air with the rate automatic-pilot system. This limited amount of flying indicated that the airplane was appreciably steadier in roll and yaw than was the airplane alone.

Tracking runs were also made with the rate automatic-pilot control system and table II shows a comparison of the standard deviations of the tracking errors which occurred with the rate autopilot and conventional control systems. The tracking runs were again made at a Mach number of about 0.6 and an altitude of 30,000 feet. A stick force of about 4 pounds per g was used for the tracking runs together with a stick motion of about 3/4 inch per g. The tracking errors present with the rate automatic-pilot control system are again of about the same magnitude as those which occurred with the conventional control.

CONCLUDING REMARKS

A flight investigation has been made to obtain experimental information on the handling qualities of a fighter airplane controlled through automatic-pilot control systems. Two types of automatic pilots were used; one of these was of the attitude type and the other was of the rate type. With the attitude automatic-pilot control system, two types of stick force feel were used, spring feel and damper feel. The pilots liked the characteristics provided by the damper force feel system much better than those provided by the spring feel system. The flying qualities of the airplane with the rate automatic-pilot control system were very good. For precision flying such as tracking, the pilot was able to do about equally well with either of the automatic-pilot systems or with the airplane conventional control.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 18, 1955.

REFERENCE

1. Mathews, Charles W.: Analog Study of the Effects of Various Types of Control Feel on the Dynamic Characteristics of a Pilot-Airplane Combination. NACA RM L55F01a, 1955.

TABLE I

STANDARD DEVIATIONS OF TRACKING ERRORS WITH ATTITUDE AND CONVENTIONAL CONTROL

	PITCH ERROR, MILS		YAW ERROR, MILS	
	ATTITUDE CONTROL	CONVENTIONAL CONTROL	ATTITUDE CONTROL	CONVENTIONAL CONTROL
NO MANEUVERING	2.6	2.2	1.7	1.7
TURNS (ϕ = 30° TO 60°)	4.6	3.6	3.1	3.8
PULL-UP AND PUSH-DOWN (a_n = 2.5 TO .25 g UNITS)	5.4	4.4	2.7	3.1
GROUND STRAFING IN ROUGH AIR	5.1	4.0	7.3	6.9

TABLE II

STANDARD DEVIATIONS OF TRACKING ERRORS WITH RATE AUTOPILOT AND CONVENTIONAL CONTROL

MANEUVER	PITCH ERROR, MILS		YAW ERROR, MILS	
	RATE AUTOPILOT	CONVENTIONAL CONTROL	RATE AUTOPILOT	CONVENTIONAL CONTROL
NO MANEUVERING	1.9	2.2	2.2	1.7
2 "g" TURNS	3.7	3.6	3.7	3.8
PULL-UP AND PUSH-DOWN 2.5 "g" TO .25 "g"	5.1	4.4	3.8	3.1

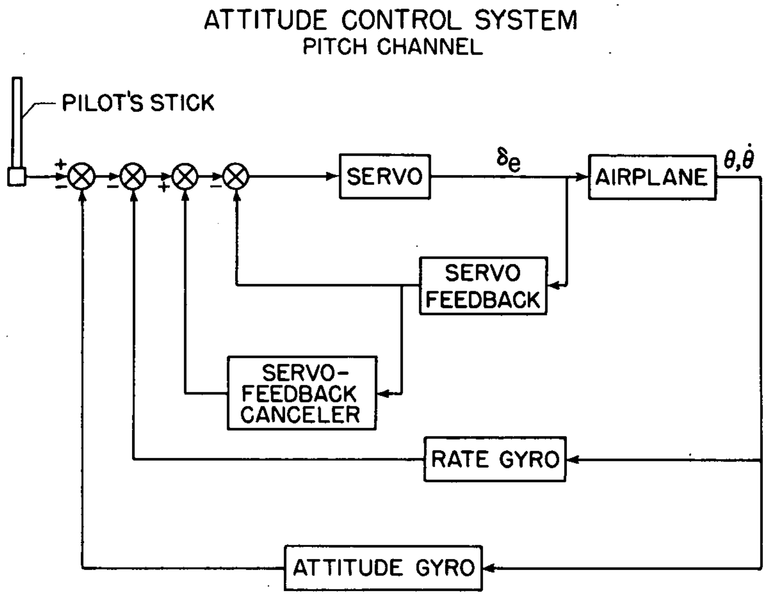


Figure 1

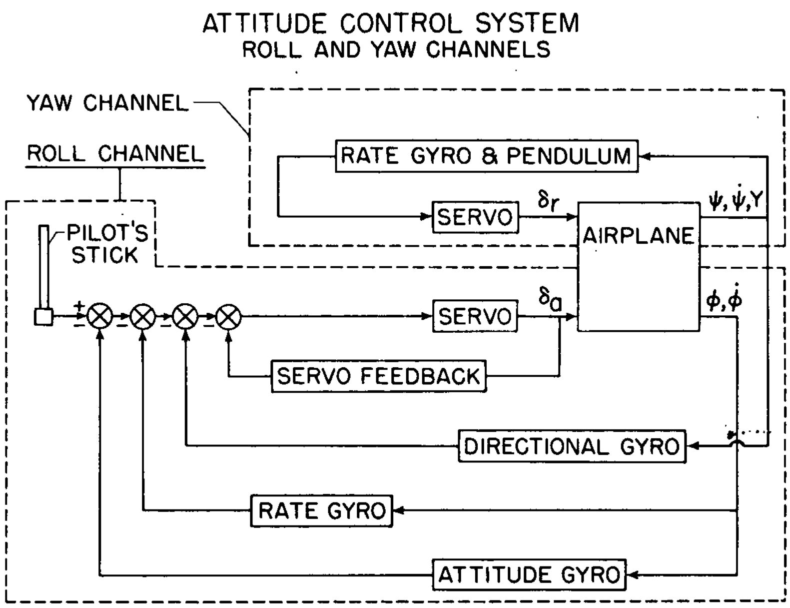


Figure 2

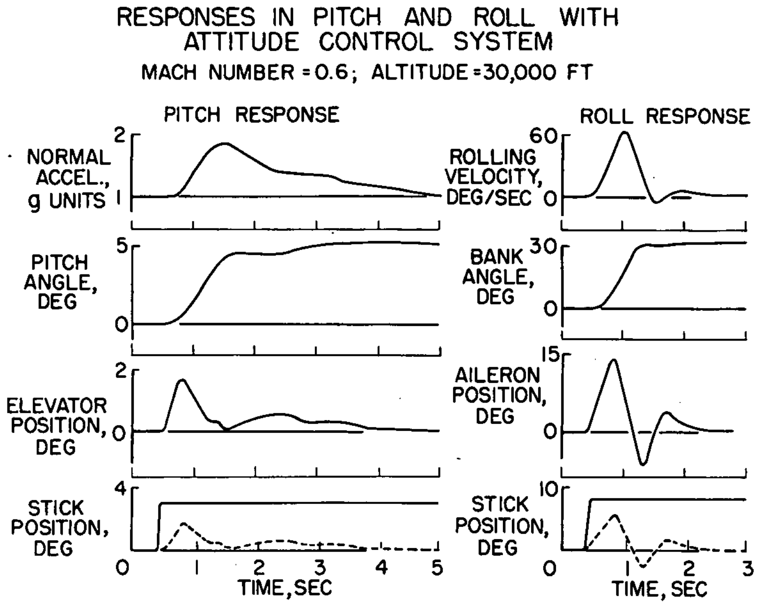
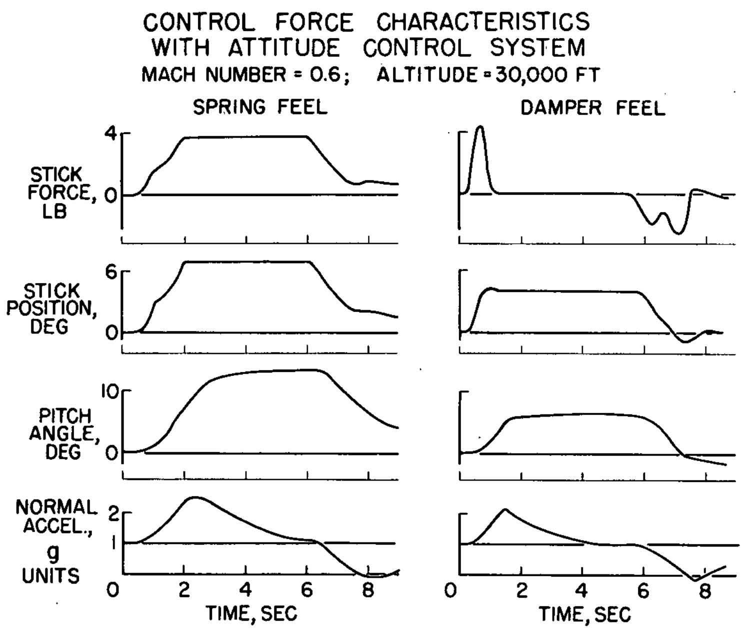


Figure 3



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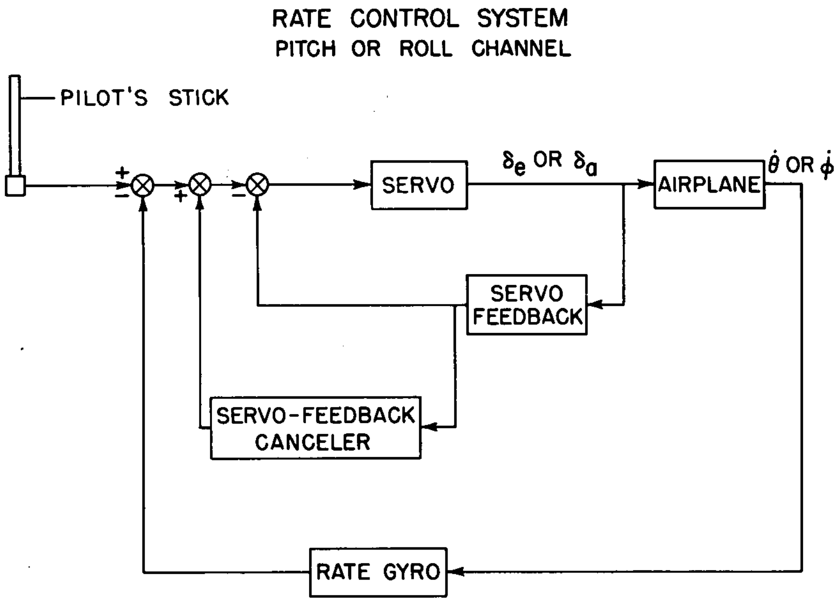

Figure 5

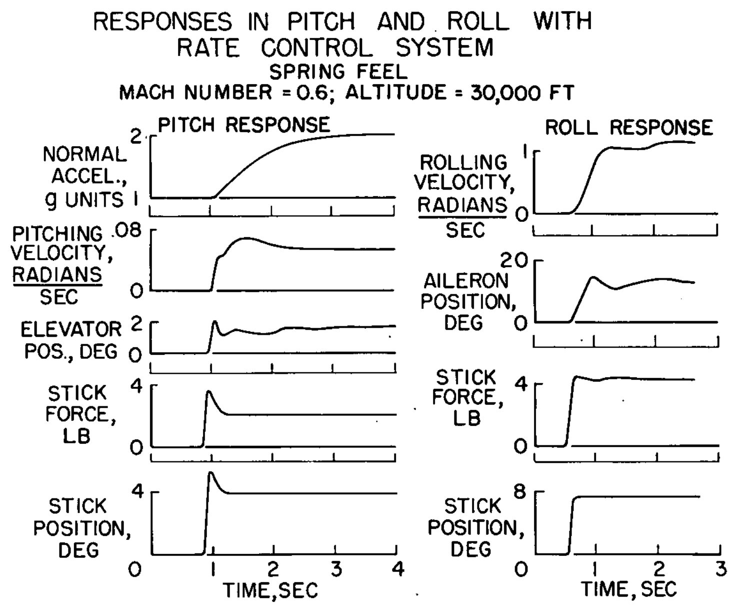

Figure 6