N 62 10276

NASA TN D-1233

NASA TN D-1233

TECHNICAL NOTE

D-1233

EFFECTS OF COUPLING BETWEEN PITCH AND ROLL CONTROL INPUTS ON THE HANDLING QUALITIES OF VTOL AIRCRAFT

By John F. Garren, Jr.

Langley Research Center
Langley Air Force Base, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON March 1962

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-1233

EFFECTS OF COUPLING BETWEEN PITCH AND ROLL CONTROL INPUTS ON THE HANDLING QUALITIES OF VTOL AIRCRAFT

By John F. Garren, Jr.

SUMMARY

Various VTOL aircraft configurations which have exhibited coupling between pitch and roll inputs, requiring a combination of longitudinal and lateral motions of the stick to obtain a pure pitch or a pure roll response, have often given rise to adverse pilot comment. In order to provide a basis for establishing handling qualities criteria with respect to cross controlling, both instrument and visual flight tests were conducted in which the pilot was required to cross control (use a combination of longitudinal and lateral stick motion) to achieve a pure response.

The results of these tests indicate that for control phase angles (the angle through which the pilot must cross control to obtain a pure response) of up to 20°, the pilot is aware of coupling only when making large corrections or inputs. However, it was found that control phase angles greater than 35° resulted in unsatisfactory handling qualities for an aircraft with otherwise satisfactory to optimum characteristics.

INTRODUCTION

Various VTOL aircraft configurations which have exhibited coupling between pitch and roll inputs, requiring a combination of longitudinal and lateral motions of the stick to obtain a pure pitch or a pure roll response, have often given rise to adverse pilot comment (ref. 1). There are a number of possible sources of cross coupling which give rise to the need for cross controlling. For example, two sources in helicopters are partial restraint of rotor flapping and variation of blade lag angle with power. The existence of such conditions results in an undesirable component of moment at right angles to the direction of the control input. Also, the overall effect of some types of mechanical augmentation equipment, being dependent on rotor speed, can produce coupling for certain flight conditions.

In theory, it is possible in some cases to remove the need for cross controlling by simply skewing the pitch-roll control system. In practice, however, such considerations as the change in lateral stick trim position with forward speed limit the degree of built-in skewness which can be tolerated. In fact, the shift in the lateral trim position with speed can be so large (up to 45°) as to invite deliberate skewing of the control in order to minimize the apparent change in trim position. Therefore, the amount of cross coupling in the control system normally represents the results of a design compromise.

The problem of gyroscopic cross coupling between pitch and roll has been treated, in its own right, in reference 2. However, the response produced by gyroscopic coupling (and also the technique of cross controlling to compensate for gyroscopic coupling) is sufficiently unique for the results of that investigation not to be generally applicable to other types of coupling.

In order to provide a basis for establishing handling qualities criteria with respect to cross controlling, flight tests were conducted in which it was necessary for the pilot to cross control to achieve a pure response. The investigation included both instrument and visual flight conditions with the controls skewed by various amounts so that cross-control angles ranging from 0° to 55° were required to obtain a pure response.

TEST EQUIPMENT AND PROCEDURES

Test Helicopter

The variable-stability helicopter shown in figure 1 was used in the research flights of this investigation. Reference 3 describes the variable control system of the test helicopter which makes it possible to vary both the ratio of control moment to stick deflection (i.e., control power) and the apparent angular-velocity damping about each of the three principal inertial axes. The test vehicle is equipped to record angular velocities about all three axes as well as to record all control motions of the pilot. The general physical characteristics of the helicopter are given in table I.

The in-flight simulation of cross coupling was achieved by skewing the electronic pick-offs on the cyclic control stick (pitch and roll control) with respect to the longitudinal axis. A sketch of the modification to the cyclic control stick used to simulate coupling between control inputs is shown in figure 2.

Flight Conditions

The effects of coupling between pitch and roll control inputs were evaluated during the following flight conditions:

(1) Low-speed instrument-landing-system (ILS) approaches

(2) Circling patterns which involved a series of maneuvers including a take-off, hovering in ground effect, transitions to and from forward flight, and a vertical landing

(3) Square patterns (approximately 150 feet square) while maintaining constant heading into the wind

(4) Roll reversals at 45 knots starting from an established bank angle of 30° and terminating in a bank angle of 30° in the opposite direction. Roll rates of up to 45 deg/sec were used.

These maneuvers were performed at cross-control angles of up to 55° except for the landing phases of the circling pattern which could not be performed safely with extreme coupling. Tests were made with the controls skewed both clockwise and counterclockwise.

In an effort to determine the effect of the uncoupled aircraft control-response characteristics on the rate at which the controllability deteriorates as the coupling is increased, the tests were performed both with the basic aircraft characteristics and with three times the control power and damping of the basic aircraft. The original values of control power and damping generally represent handling qualities which are marginally satisfactory to unsatisfactory for most maneuvers. On the other hand, the increased control power and damping result in relatively good handling qualities.

The pilots were instructed to rate the overall controllability of the aircraft for each test condition. The Cooper pilot-opinion rating system, described in reference 4 and used in the evaluation, is presented in table II. Using this rating system, the pilot assigned to each test condition a numerical rating of 1 to 10 with the smallest number signifying optimum conditions and the largest number signifying catastrophic conditions.

RESULTS AND DISCUSSION

The test results are presented in figure 3 as a plot of cross-control angle against pilot rating of overall controllability. The solid-line curve represents results obtained with the control power and damping increased about all axes; the dashed-line curve represents results obtained with the basic control power and damping of the aircraft. No difference in pilot opinion was noted for coupling in one direction as opposed to the other.

For a given amount of coupling, the poorest rating of overall controllability was consistently obtained during the landing maneuver. In fact, this was the only maneuver which could not be executed at 55° coupling. At this extreme value of coupling it was not possible to steady the aircraft for a sufficient period of time to permit touchdown. One other maneuver in which coupling appeared particularly objectionable was the rapid turn reversal. In this case, the degree of objection was attributed to the fact that the large control inputs caused the pilot to be more aware of the coupling. For the remainder of the tests (ILS approaches, square patterns, and the circular patterns excluding the landing phases), the pilot rating appeared to be reasonably independent of the maneuver.

L
1
9
6
4

Figure 3 indicates that the overall controllability was considered unsatisfactory at a cross-control angle of approximately 35° for the aircraft configuration with increased control power and damping; whereas a control phase angle of 25° was considered unsatisfactory with the basic control characteristics. It should be noted, however, that even with zero coupling, the basic aircraft is considered only marginally satisfactory.

Pilot commentary indicated that a control phase angle as large as 20° was only slightly noticeable except for maneuvers in which large corrections or inputs are required - for example, the rapid roll reversals. This conclusion may also be inferred from figure 3 which indicates an insignificant change in pilot rating as the control phase angle is increased from 0° to 20°.

CONCLUSIONS

Based on a flight investigation in which coupling between pitch and roll control inputs was simulated and in which the pilot was required to use a combination of longitudinal and lateral stick motion to achieve a pure pitch or a pure roll response, the following conclusions are drawn:

1. For control phase angles up to 20°, the coupling problem is generally insignificant and the pilot is aware of an undesirable control response only when making large corrections.

2. Control phase angles greater than 35° result in unsatisfactory handling qualities for an aircraft with otherwise satisfactory to optimum characteristics.

3. Landing is the most critical maneuver from the standpoint of tolerating coupling.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., January 23, 1962.

L
1
9
6
4

REFERENCES

1. Connor, Andrew B., and Tapscott, Robert J.: A Flying-Qualities Study of a Small Ram-Jet Helicopter. NASA TN D-186, 1960.

2. Garren, John F., Jr.: Effects of Gyroscopic Cross Coupling Between Pitch and Roll on the Handling Qualities of VTOL Aircraft. NASA TN D-812, 1961.

3. Salmirs, Seymour, and Tapscott, Robert J.: Instrument Flight Trials With a Helicopter Stabilized in Attitude About Each Axis Individually. NACA TN 3947, 1957.

4. Cooper, George E.: Understanding and Interpreting Pilot Opinion. Aero. Eng. Rev., vol. 16, no. 3, Mar. 1957, pp. 47-51, 56.

TABLE I.- PHYSICAL CHARACTERISTICS OF THE TEST HELICOPTER

Gross weight, lb	5,500
Moments of inertia:	
Pitch, I_Y, slug-ft^2	7,000
Roll, I_X, slug-ft^2	2,000
Yaw, I_Z, slug-ft^2	5,000
Number of blades in main rotor	3
Rotor rotational speed, radians/sec	19.4
Rotor diameter, ft	48
Height of rotor hub with respect to center of gravity, ft	6.5
Blade mass factor	9
Control travel:	
Longitudinal cyclic, in.	13.6
Lateral cyclic, in.	13.6
Pedal, in.	4.75
Basic control power:	
Pitch, ft-lb/in. of control travel	508
Roll, ft-lb/in. of control travel	474
Yaw, ft-lb/in. of control travel	4,140
Basic damping:	
Pitch, ft-lb/radians/sec	2,495
Roll, ft-lb/radians/sec	2,495
Yaw, ft-lb/radians/sec	10,600

L
1
9
6
4

TABLE II.- COOPER PILOT-OPINION RATING SYSTEM

Operating conditions	Adjective rating	Numerical rating	Description	Primary mission accomplished	Can be landed
Normal operation	Satisfactory	1	Excellent, includes optimum	Yes	Yes
		2	Good, pleasant to fly	Yes	Yes
		3	Satisfactory, but with some mildly unpleasant characteristics	Yes	Yes
Emergency operation	Unsatisfactory	4	Acceptable, but with unpleasant characteristics	Yes	Yes
		5	Unacceptable for normal operation	Doubtful	Yes
		6	Acceptable for emergency condition only[1]	Doubtful	Yes
No operation	Unacceptable	7	Unacceptable even for emergency condition[1]	No	Doubtful
		8	Unacceptable - dangerous	No	No
		9	Unacceptable - uncontrollable	No	No
	Catastrophic	10	Motions possibly violent enough to prevent pilot escape	No	No

[1]Failure of a stability augmenter.

Figure 1.- Helicopter used in investigation. L-88302.1

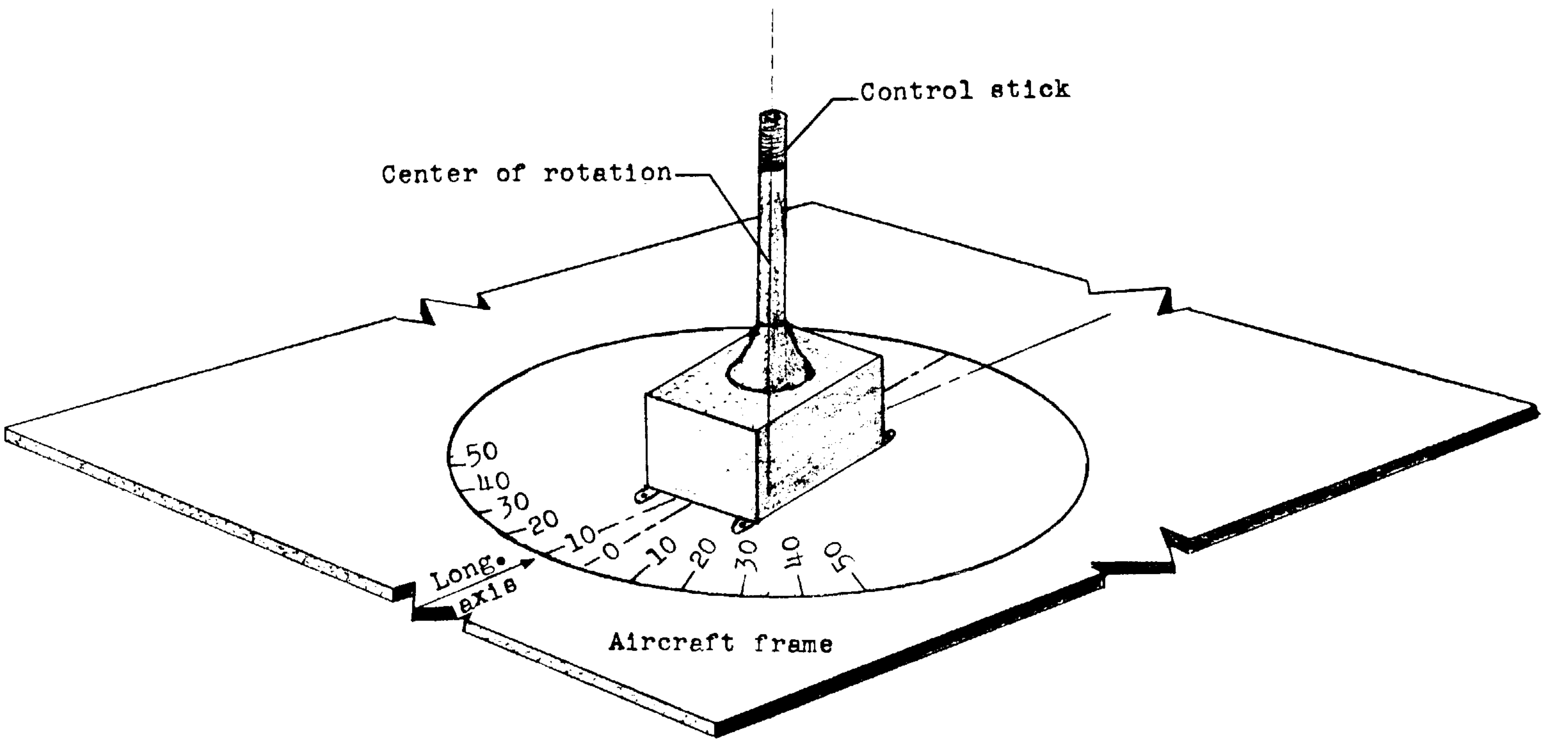

Figure 2.- Modification to pitch and roll control stick to simulate coupling between control inputs.

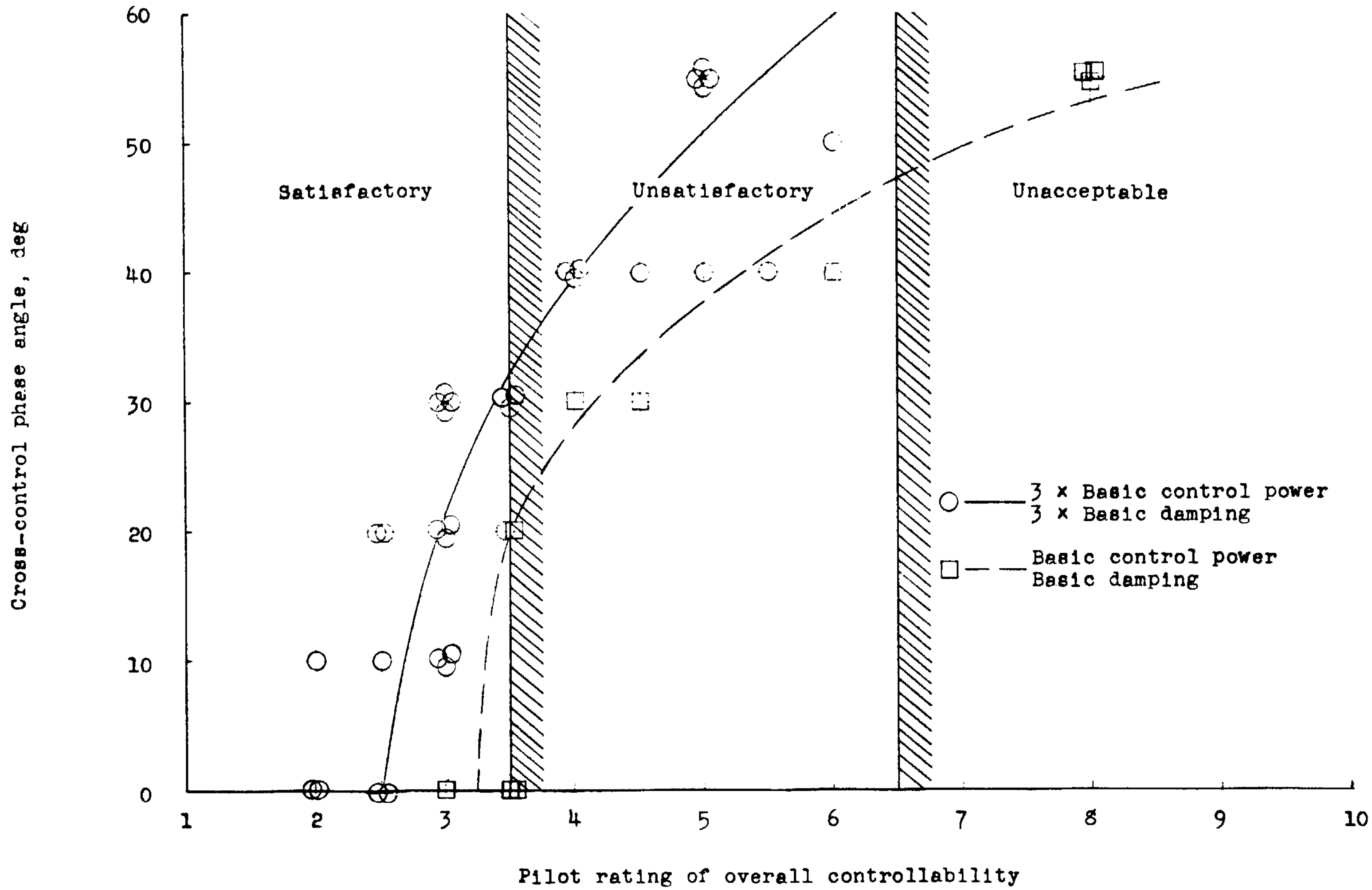

Figure 3.- Effect of coupling between pitch and roll control inputs on pilot rating.