

(14)

187

## HIGHLIGHTS OF HANDLING QUALITIES CRITERIA FOR V/STOL AIRCRAFT

By Seth B. Anderson

Ames Research Center

## INTRODUCTION

A major obstacle delaying the appearance of the operational V/STOL vehicle has been the lack of the formulation of handling qualities requirements. Past experience with airplanes and helicopters has brought out the need for handling qualities requirements to insure that these vehicles could carry out a mission in a safe and efficient manner. A similar but tentative set of handling qualities criteria have been proposed for V/STOL aircraft. These V/STOL criteria were arrived at from a broad background of flight results and pilots' comments from VTOL and STOL type aircraft, aircraft equipped with boundary-layer control, variable-stability aircraft, landing-approach studies, and flight simulators. The purpose of this paper is to point out the reasoning behind the handling qualities criteria for V/STOL vehicles.

## DISCUSSION

In this paper only a few of the V/STOL criteria are discussed briefly. A more detailed description and a more complete discussion of the reasoning behind and the sources of information leading to all the V/STOL criteria are available in NASA Technical Note D-331.

## Mechanical Characteristics of Control Systems

In regard to mechanical characteristics of control systems, flight experience has revealed the fact that in landing approach, V/STOL aircraft must be completely controllable by one man. In low-speed precision-type approaches, it was desirable for the pilot to use one hand to adjust the flight controls and the other hand to adjust the engine power to control the flight-path angle or rate of sink. In this regard, force values must be kept small for V/STOL aircraft and made equal for stick or wheel controls. This philosophy has been applied to such items as trim changes, stick-force gradients, and control for longitudinal and lateral performance. This suggests that a stick-type control could be used in a four-engine transport instead of a wheel.

**Preceding page blank**

## Longitudinal Stability and Control Characteristics

Stick-fixed static stability.- Recent tests with variable-stability aircraft have indicated for some flight conditions that stick-fixed static stability is not required as long as stick force and dynamic requirements are met. For V/STOL airplanes, however, which are to operate extensively at low speeds, flight tests have indicated the desirability of stick-fixed stability in the transition and landing regions. In particular, a pitch-up is considered unacceptable if the instability occurs in the speed range below the speed for minimum drag. Flight experience in flying on the back side of the drag curve has indicated a particular need for stable, linear stick-fixed gradients in order to make satisfactory height adjustments along a desired flight path. It is to be noted that smooth steady flight is required throughout the speed range including maximum usable speed in rearward flight.

Control effectiveness in unaccelerated flight.- The desirability of having a margin in control effectiveness at each end of the speed range to cope with effects of longitudinal disturbances is well founded. The data in figure 1 illustrate this requirement. The question of how much margin is needed for V/STOL aircraft over the speed range has yet to be determined with the desired accuracy. As a start, a margin of at least 10 percent of the maximum attainable pitching acceleration in hovering has been suggested for VTOL operation.

Dynamic longitudinal stability (short period).- For airplanes, the short period and the phugoid modes have widely different periods and have not been coupled. At the low speeds of STOL operation, however, similar periods may exist for the two modes and the combined effect on the overall behavior of the aircraft must be considered. Considerable flight and simulator experience has made possible the establishment of more specific requirements for the dynamic behavior of aircraft. In figure 2 is shown a boundary of the short-period characteristics in terms of natural frequency and damping ratio. These data, which were obtained in the cruise flight configuration, can be used to define the limits in frequency and damping applicable to V/STOL aircraft maneuvering at the higher end of the speed range. Sufficient data are not available to define a boundary for landing approach. There are indications, however, from data obtained in landing approaches for a number of aircraft and from helicopter experience, that lower frequencies and less damping may be acceptable for the landing-approach configuration.

Control effectiveness in hovering.- The ability to position VTOL aircraft accurately and rapidly over a given spot is a primary consideration used to define control power. To insure that adequate longitudinal control power is available for VTOL aircraft for maneuvering during hovering, values for control power derived from Langley

tests of a variable-response helicopter have been used. The reasoning behind these requirements with particular reference to the effect of aircraft size is discussed in a subsequent paper by Robert J. Tapscott.

#### Acceleration-Deceleration Characteristics in Transition

L  
1  
4  
2  
3

The ability to accelerate and decelerate quickly in a safe and efficient manner at constant altitude or along a constant flight path is one of the important items affecting the utility of the VTOL vehicle. Although the vehicle must be able to accelerate rapidly, a limit on thrust rotation may be necessary to prevent wing stall on some configurations. On the other hand, deceleration should not be limited because of the necessity of maintaining high percent engine power to supply power for trim and maneuvering. In addition, it should be possible to decelerate rapidly without stalling or objectionable buffeting and it should be possible to prevent settling when slowing down to hover.

#### Control Effectiveness in Take-Off

For control effectiveness in take-off, experience in VTOL operation has shown that it is necessary for the longitudinal control, which may depend on the main engine, to be powerful enough to adjust the attitude of the airplane so that the thrust vector is directed as necessary to prevent fore or aft translation during run-up to maximum power.

#### Control Effectiveness in Landing

For control effectiveness in landing, the longitudinal control should be powerful enough to land the airplane under a variety of approach conditions. For example, in steep descents for which it may be necessary to reduce engine power significantly, the type of longitudinal control that derives its power, in part, from the main engine must be powerful enough at reduced engine thrust to obtain maximum lift or guaranteed landing speed in ground proximity.

#### Lateral-Directional Stability and Control Characteristics

Directional control power.- Directional control power in hovering should, from the flight safety standpoint, be less critical than roll control since directional rotation at touchdown is not as serious as side velocity. In spite of this, the directional control power desired from both moving-base simulator tests and variable-response helicopter tests was large in comparison with that required for either

pitch or roll. In this case the large amount of directional control power desired was felt to be due in part to the large magnitude of the heading changes desired by the pilot. In contrast to the small attitude changes of approximately  $10^\circ$  used in pitch or roll, heading changes of the order of  $180^\circ$  are frequently made in hovering maneuvers.

Lateral control power.- It is recognized that both control power and damping are important for satisfactory lateral characteristics. It is to be noted that, because of unsatisfactory lateral control, a number of VTOL test-bed aircraft have been damaged. The significance of the relationship of lateral control power to damping was shown initially for aircraft in NASA research in 1959. A summary of these results is plotted in figure 3 in terms of the initial rolling acceleration for full lateral control input and the damping expressed in seconds. A lower boundary for V/STOL aircraft in low-speed flight and hovering is included, also. These results, which include both flight and simulator tests, showed that pilot opinion deteriorated at low values of roll control power and at low values of damping. At high values of roll power there was a loss of control precision due to sensitivity.

As would be expected, the data showed that greater control power was demanded for maneuvers in cruising flight compared with that required for hovering or low-speed flight. In addition, the results indicated that, to avoid the feeling of stiff or sluggish aircraft, more control power was required as damping was increased. With regard to damping, simulator results indicated that values of the order of 4 seconds were considered satisfactory for hovering. Although a number of V/STOL aircraft are being flown with essentially zero damping, most of the flights have been conducted under still-air conditions by skilled test pilots. It is felt that for practical VTOL operation, a value not greater than 0.7 second for roll rate damping is necessary.

#### Stalling Characteristics

The stall requirements for airplanes which allow bank angles of  $20^\circ$  at the stall have been revised to be more stringent in the landing approach and landing. In this region, it is felt necessary to limit the maximum allowable uncontrolled rolling at the stall to the roll angle at which a wing tip, pod, or propeller may strike the ground when the aircraft is resting on the landing gear. Figure 4 illustrates these criteria. This philosophy, which extends from a variety of flight experience in landing approach, is intended to place a more practical limit on the allowable roll-off at the stall.

## CONCLUDING REMARKS

A brief look at the reasoning behind a few of the V/STOL handling qualities criteria contained in NASA Technical Note D-331 has been presented. The need for meeting these requirements should be emphasized. It is noteworthy that the VTOL test-bed aircraft have been able to meet only a few of the criteria and, as a result, have been restricted to still-air flying. Many of the criteria require refinements which can be obtained only from operational experience with V/STOL aircraft. It is recognized that the criteria presented herein will be modified and added to as more information becomes available; however, it is felt that at the present time they can serve a useful function as a guide in writing specifications for an operational VTOL assault transport.

L  
1  
4  
2  
3

LONGITUDINAL CONTROL EFFECTIVENESS MARGIN

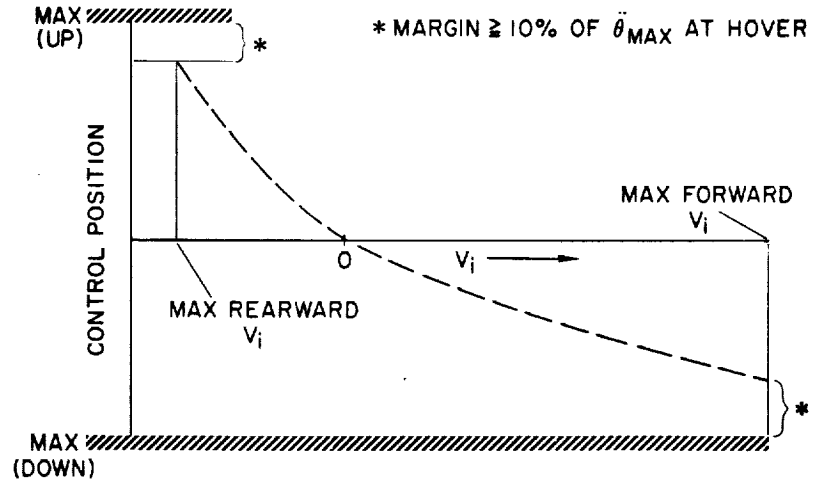


Figure 1

SHORT-PERIOD LONGITUDINAL CHARACTERISTICS

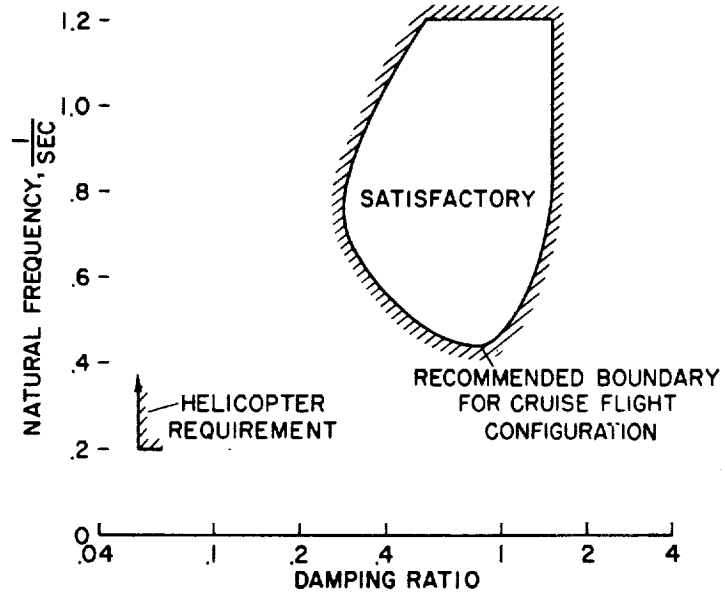


Figure 2

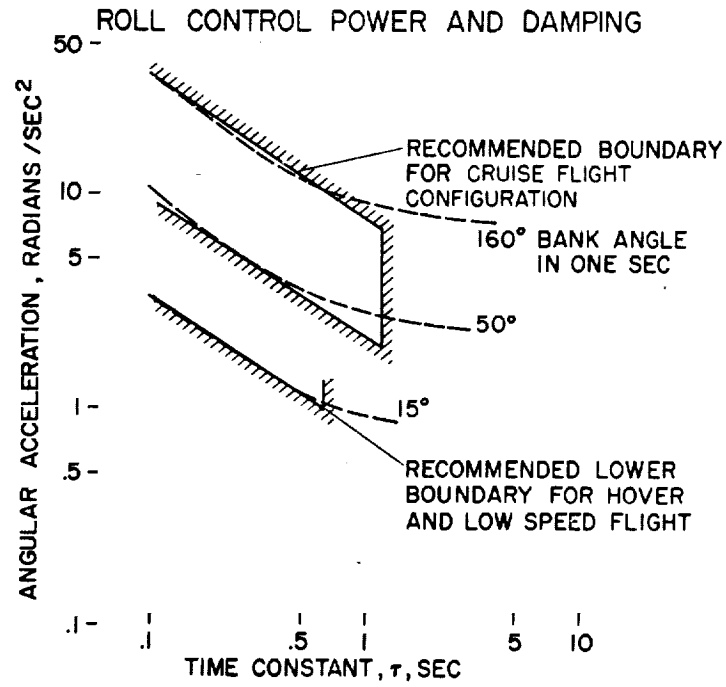


Figure 3

STALL CRITERIA

ALLOWABLE ROLL-OFF AT STALL LIMITED  
TO ROLL ANGLE AT WHICH A WING TIP,  
POD, OR PROPELLER MIGHT STRIKE THE  
GROUND

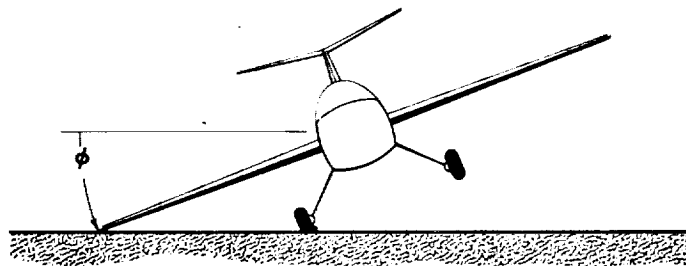


Figure 4