IN-08
321715

TECHNICAL NOTE

D-331

AN EXAMINATION OF HANDLING QUALITIES CRITERIA FOR V/STOL AIRCRAFT

By Seth B. Anderson

Ames Research Center
Moffett Field, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON
July 1960

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-331

AN EXAMINATION OF HANDLING QUALITIES CRITERIA FOR V/STOL AIRCRAFT

By Seth B. Anderson

SUMMARY

A study has been undertaken to define handling qualities criteria for V/STOL aircraft. With the current military requirements for helicopters and airplanes as a framework, modifications and additions were made for conversion to a preliminary set of V/STOL requirements using a broad background of flight experience and pilots' comments from VTOL and STOL aircraft, BLC (boundary-layer-control) equipped aircraft, variable stability aircraft, flight simulators and landing approach studies. The report contains a discussion of the reasoning behind and the sources of information leading to suggested requirements.

The results of the study indicate that the majority of V/STOL requirements can be defined by modifications to the helicopter and/or airplane requirements by appropriate definition of reference speeds. Areas where a requirement is included but where the information is felt to be inadequate to establish a firm quantitative requirement include the following: Control power and damping relationships about all axes for various sizes and types of aircraft; control power, sensitivity, damping and response for height control; dynamic longitudinal and dynamic lateral-directional stability in the transition region, including emergency operation; hovering steadiness; acceleration and deceleration in transition; descent rates and flight-path angles in steep approaches, and thrust margin for approach.

INTRODUCTION

For several years the NASA has been involved in the definition of handling qualities criteria for airplanes and helicopters. It was recognized that handling qualities requirements are needed also for V/STOL aircraft to insure their safe and efficient operation. The purpose of this report is to suggest flying qualities requirements for V/STOL vehicles which could be used: (1) to guide prospective users in setting up specifications for any proposed operational V/STOL vehicle; (2) to judge the ability of various types of V/STOL vehicles to meet reasonable requirements; and (3) to guide the flight test programs of various available V/STOL testbeds. Since the data which are available for the flight conditions peculiar to V/STOL vehicles are incomplete, the requirements presented herein are tentative, and it is anticipated that requirements will be changed and added as more information becomes available.

To arrive at requirements for V/STOL vehicles, it was considered expedient to use as a background the wealth of flying qualities information contained in reference 1 for airplanes and reference 2 for helicopters. The information was examined in the light of possible V/STOL specifications to determine which areas were adequately covered and could be used directly and which areas needed further research. Modifications and additions to the airplane and helicopter requirements for conversion to V/STOL requirements were based on a broad background of flight results and pilots' comments (see pilot rating system, table I) from VTOL and STOL type aircraft, BLC (boundary-layer-control) equipped aircraft, variable stability aircraft, landing approach studies, and flight simulators. The VTOL aircraft consisted of the following: The Bell X-14 deflected turbojet (fig. 1), the Bell XV-3 convertible helicopter (fig. 2), the Ryan VZ-3RY deflected slipstream (fig. 3), and the Vertol VZ-2 tiltwing (described in ref. 3). STOL experience was obtained from a number of aircraft (refs. 4 through 9) and included recent flight studies of the C-134A twin-engine cargo airplane equipped with a full-span BLC system (fig. 4).

In addition to the V/STOL specifications, the reasoning behind and the sources of information leading to the requirements are discussed. Those areas where the existing information is felt to be inadequate and where additional flight or simulator research is required have been pointed out in order to formulate flying qualities requirements with greater confidence.

In this study an effort has been made to consider three classes of aircraft; namely, light observation, heavy surveillance or fighter, and tactical transport. The general form of reference 1 has been followed as closely as possible for organizational purposes.

STOL operation as used in this report refers to flight at speeds below the power-off stall speed or below the minimum speed with all engines inoperative for aircraft not possessing an aerodynamic stall (limited by control power, visibility, etc.) or below the speed at which it is possible to arrest sink rate to zero by aerodynamic means alone (power off). In general, therefore, STOL operation is dependent on engine power to augment aerodynamic lift and change effective lift-drag ratio. VTOL operation implies the ability to hover out of ground effect over a given ground position in no wind.

DISCUSSION

The preliminary V/STOL requirements are organized and presented in a form similar to that used in reference 1. Table II is a tabulation of the various handling qualities items along with the appropriate airplane and helicopter requirements placed side by side for reference purposes. These requirements have been paraphrased for brevity and can be reviewed in detail by referring to the appropriate numbered paragraphs in references 1 and 2. In the right-hand column are the V/STOL requirements. Definitions of airplane classes and symbols can be found in the appendix. In the following discussions the V/STOL requirements will be reviewed to point out the reasoning behind each and the areas requiring further research. In reviewing the V/STOL requirements, it should be kept in mind that they are not intended to be rigid military-type specifications, but rather those handling qualities which are felt desirable from what is known at the present state of the art.

Mechanical Characteristics of Control System

Control friction and breakout force.- The relatively low values of friction presented in the table are based on the desirability of obtaining proper centering characteristics in a flight regime where the aerodynamic restoring forces are absent. In addition, it should be noted that during operation when the pilot can have only one hand on the control, the values for wheel control should be essentially the same as for a stick type of control. For power control systems in which there is both linkage friction and valve friction, an additional requirement is that the magnitude of the linkage friction be at least twice the valve friction, the sum of the two not to exceed the values quoted for V/STOL aircraft. This relationship of linkage friction was chosen to avoid pilot-airplane instability as noted in reference 10.

The centering characteristics required are the same as those contained in the helicopter specification, chosen again on the basis of one-hand operation for either wheel or stick controls. For this type of system sufficient damping is needed to prevent undesirable cockpit control oscillations.

Cockpit control free play.- The amount of free play in the cockpit control has been specified in terms of percentage of full travel so as to include both stick and throttle type controls; ±1 percent has been specified for all types of control systems. Further work in this area will be required to define allowable values for specific types of control systems (i.e., acceleration or rate command) particularly in hovering flight where unpublished simulator results have shown this factor to be significant in the over-all suitability of the control system.

Artificial stability devices.- The general remarks for airplanes are qualitative and it is felt that a more quantitative approach is needed to define the allowable divergence rates for stability augmentation failure. Accordingly, the values for helicopters (3.4.9a) are suggested as a start in this direction; however, it is felt that more research is needed in this area to define limits for V/STOL operation.

Longitudinal Stability and Control

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 (see, e.g., refs. 11 and 12) have indicated the desirability of adequate stick-fixed stability in the transition and landing regions. In addition, the pitch-up defined in the helicopter specification (3.2.10) is considered undesirable if the instability occurs in the speed range below that for minimum drag. Here again, flight experience (see ref. 11) in flying on the back side of the drag curve has indicated a particular need for stable stick-fixed and stick-free gradients in order to make satisfactory height adjustments along a desired flight path in landing approach. It is to be noted that smooth, steady flight is required throughout the speed range including maximum designated speed in rearward flight. Since rearward flight may prove difficult for some VTOL vehicles, further research is needed to establish limits compatible with various mission requirements.

In regard to BLC failure it is specified that failure of the BLC system shall not change the longitudinal stability characteristics sufficiently that a dangerous flight condition results. Although no quantitative values can be specified at this time, flight experience with a number of BLC systems has indicated the desirability of minimizing stability changes due to BLC, particularly in landing approach where BLC effectiveness is derived from the main engine.

Elevator stick-force variation with speed in unaccelerated flight.- Stick-free stability characteristics similar to those previously discussed for the stick fixed are desired. A stable stick-force variation with speed is desirable over the complete speed range. The mild pitch-up previously mentioned for the stick-fixed case would not be tolerated if it occurs on the back side of the drag curve. In addition, the force reversal in airplane requirement 3.3.2.1 is considered too large. In order to aid in obtaining adequate precision control below the trim speed, the requirement has been revised to state that the reduction in force shall not decrease by an amount greater that the friction force for the comparable airplane class.

Exception in transonic flight.- V/STOL aircraft which operate in or through the transonic speed range should meet the characteristics specified for airplanes (3.3.3).

Stability in accelerated flight.- For reasons similar to those stated in the discussion of stick-fixed static stability, a stable gradient of elevator position variation with normal acceleration is specified for all forward flight conditions. No requirement is felt necessary for rearward flight where acceleration values would be small.

Control effectiveness in unaccelerated flight.- The desirability of a margin in control effectiveness at each end of the speed range (noted in helicopter requirement 3.2.1) to cope with effects of longitudinal disturbances is well founded. The question of how much margin in needed for V/STOL aircraft throughout the speed range has yet to be determined with the desired accuracy. As a start, however, a helicopter requirement which states a margin of at least 10 percent of the maximum attainable pitching acceleration in hovering*[1] has been suggested for VTOL operation. For STOL operation it is felt that a quantitative requirement is necessary also to insure adequate control effectiveness throughout the speed range. Further research is needed in this area, however, for a firm requirement to relate control effectiveness requirements to disturbing moments.

Control effectiveness in accelerated flight.- Because of the large effects that engine power may have on the ability to develop maximum lift, requirement 3.3.8 for airplanes has been increased in scope to include the effects of engine power.

Longitudinal response.- While no requirements have been specified for airplanes for the initial response of the longitudinal mode, operation of V/STOL aircraft at low values of dynamic pressure will require a closer examination of the desirable values for the initial response characteristics. Accordingly, the value from helicopter requirement 3.2.9 has been added as a first step in defining satisfactory response characteristics. Further research is needed to authenticate this value for V/STOL operation.

Control forces in steady accelerated flight.- The stick-force gradients for V/STOL aircraft have been chosen to remain essentially the same as for airplanes (table in 3.3.9) except that the maximum force gradients for wheel controls should be low enough that during V/STOL operation one-hand operation is feasible. In general, a major portion of V/STOL operation will be conducted at low values of acceleration and, therefore, the stick force gradients do not require as close scrutiny as for a high-speed fighter. It is felt, however, to ease the task of precision flying with V/STOL vehicles, requirements dealing with control force magnitude, linearity, and sense are highly desirable.

Control forces in sudden pull-ups.- Airplane requirement 3.3.10 was originally intended to guard against overshooting a given acceleration in a sudden pull-up where relatively little control force is generated by control deflection. A requirement of this type is felt to be even more significant for V/STOL aircraft, particularly for control systems without power boost for which large inertia of the control system combined with small restoring forces at low dynamic pressure can result in poor precision in controlling the aircraft. Requirement 3.2.8 for helicopters, which states that during and following a rapid displacement of the control, the force acting to resist the displacement shall not fall to zero, is felt to be unconservative. Therefore, in addition to airplane requirement

---

[1] Hereinafter an asterisk denotes an extension of reference 2 based on unpublished helicopter handling qualities studies and results of reference 13.

3.3.10 the stipulation is included that the stick force shall always lead the acceleration by an adequate margin to provide satisfactory anticipation of the resultant acceleration.

Control cross-coupling.- Control cross-coupling, peculiar to some helicopters without power boosted control systems, destroys control harmony. In an attempt to provide the pilot with the best possible control system, the requirement is written to discourage any control force cross-coupling.

Longitudinal short-period oscillations.- For most airplanes, the short period and the phugoid modes have widely different periods and are not coupled. At the low speeds of V/STOL operation, however, the two modes may have similar periods; the combined effect of the short period and phugoid on the over-all aircraft behavior must be such that the ensuing motion is satisfactory. Considerable flight and simulator experience has made it possible to establish more specific requirements for the short-period dynamic behavior of aircraft (see, e.g., ref. 14). The results for airplanes as obtained from reference 14 and unpublished results from tests of a YF-86D variable-stability airplane are presented in figure 5 in terms of frequency and damping ratio. These data have been used to select a boundary for V/STOL aircraft in configuration P. Data are not available to define a boundary for configuration PA. As indicated in figure 5, however, data obtained in landing approach for a number of fighter aircraft and helicopter requirement 3.5.1.1 point out that lower frequencies and less damping may be acceptable for configuration PA. As a start, therefore, a helicopter requirement is suggested in which the damping ratio must be at least 0.055 for periods less than 5 seconds.* Further research is necessary to define boundaries in configuration PA for V/STOL aircraft. In an attempt to define desirable maneuvering stability characteristics, helicopter requirements 3.2.11.1 and 3.2.11.2 are suggested.

Long-period (phugoid) oscillations.- The phugoid oscillation, which is of relatively long period for airplanes in the cruise configuration, has not had a specific damping requirement. At low speeds typical of STOL operation, however, the phugoid may become a problem as the period is reduced. The damping specifications for satisfactory dynamic stability for helicopters require damping ratios ranging from 0.055 to -0.22 in the period range from 5 to 20 sec.* For the most part these data, which are based on a background of helicopter experience in the lateral-directional oscillatory mode and in the longitudinal mode, are qualitative in nature and it is felt that additional research is required in transition and landing approach to define with greater confidence satisfactory phugoid characteristics for V/STOL aircraft. Results of simulated instrument flying with a variable-stability B-26 airplane (ref. 15) have indicated the desirability of the phugoid damping ratio being 0.15 or greater. For extremely long periods, 50 seconds or longer, a damping ratio of -0.10 was acceptable. For the period range in which the phugoid is approximately 15 seconds, experience has shown that a neutrally damped phugoid is acceptable only if the short period is satisfactorily damped also. In order to minimize the effects of longitudinal disturbances in V/STOL operation, the requirements specify a minimum damping ratio of -0.10 for periods longer than 10 seconds.

Conventional longitudinal short and long period dynamics are confined to the vertical plane of motion. A longitudinal disturbance along the thrust axis has been encountered on one V/STOL aircraft. This longitudinal acceleration-deceleration characteristic which has a period of the order of 10 seconds is felt to be associated with the large diameter rotor system employed on the aircraft. Needless to say, this characteristic was considered unsatisfactory.

Longitudinal control effectiveness in hovering.- The ability to position VTOL aircraft accurately and rapidly over a given spot is a primary consideration in defining control power and control sensitivity.[2] The effects of gust disturbances and aerodynamic and engine gyroscopic cross-coupling effects may further complicate the problem. In order to insure that adequate longitudinal control power is available for VTOL aircraft for maneuvering and gust disturbances during hovering, values for control power are suggested which were derived from the results in references 16 and 13 of tests of a variable-stability helicopter and include take-off, landing, hovering, quick stops, and forward flight at various speeds. These results, which show the relationship of control power to aerodynamic damping, represent a significant improvement in analysis of hovering control for design purposes. Unpublished results obtained on a flight simulator with pitch freedom indicate that for the longitudinal case the minimum acceptable control power values were relatively insensitive to the amount of aerodynamic damping present. This was not true in the roll mode as will be discussed later. The control power specified for VTOL aircraft may not apply accurately to all sizes of VTOL aircraft since different sizes would be disturbed different amounts by gusts; however, until further research is conducted the values specified in the helicopter requirement which take aircraft weight into account are useful. No maximum limit on control power is felt necessary.

Longitudinal steadiness in hovering.- Helicopter requirement 3.2.2 was established in an attempt to set tolerable limits on the motion induced in the vehicle by downwash-ground interference effects. The motions, characterized by erratic darting and random unsteady behavior, are considered satisfactory in helicopter requirement 3.2.2 if only a small amount of control motion (±1 inch) is required to hover over a given spot. Although this may give a rough measure of hovering steadiness, it is felt that control motion in itself is not representative of hovering steadiness since other factors, such as control sensitivity and frequency of control motion, and amplitudes of excursions are also important in assessing hovering behavior. Further research is needed in this area to define acceptable hovering steadiness more quantitatively.

---

[2] Control sensitivity may be defined as the slope of the control-power-deflection curve. For linear control characteristics the two terms may be used interchangeably.

One of the factors which has a direct effect on hovering behavior, particularly in rough air, is the amount of angular damping. In order to insure satisfactory initial response characteristics following a longitudinal control input and to minimize the effects of external disturbances, a requirement for damping has been included. No maximum damping value is considered necessary. The damping values were obtained from the results of a variable stability helicopter (refs. 16 and 13) and, as mentioned previously, may require modification for larger aircraft or for aircraft which would tend to be less disturbed by gusts. Lower acceptable limits for damping in pitch have been demonstrated in recent unpublished simulator studies. Further research on gust disturbing effects is considered necessary, however, to determine a requirement which more directly takes airplane size and type in consideration.

Height control in hovering.- The present helicopter requirement 3.2.3 for height control which specifies altitude control within ±1 foot with not more than ±1/2-inch movement of the collective control has been retained but is not considered completely definitive of height control for the same reasons as previously mentioned for control in longitudinal steadiness. In addition, in order to develop satisfactory criteria for height control, research is needed to establish limits of control power, sensitivity, and damping similar to those developed for the aerodynamic controls. Other factors, such as ground suction effects, visibility, thrust response (engine or stored rotor), and thrust margin should be considered in the over-all picture of factors influencing height control. Additional research is required to provide sufficient information relative to height control for a more quantitative requirement.

Acceleration-deceleration characteristics.- The ability to accelerate and decelerate quickly in a safe and efficient manner at constant altitude or along a constant flight path angle is one of the important items affecting the utility of the VTOL vehicle. For a tactical transport capable of operating at high subsonic Mach numbers, the constant altitude requirement may be relaxed to fit the mission characteristics for this type vehicle. From the flight tests conducted so far a number of points have been noted. Although the vehicle must be able to accelerate rapidly, a limit on thrust rotation may be necessary to avoid wing stall on some configurations. On the other hand, deceleration should not be limited because of the necessity of maintaining high percent engine power level to supply bleed air for reaction controls, nor should deceleration be limited by ability to maintain trim with the longitudinal control. In addition, it should be possible to decelerate rapidly without stalling or objectionable buffeting, and thrust response must be rapid enough to prevent the aircraft from settling when slowing down to hover. This was particularly true on one aircraft (ref. 17) which required a large, sudden increase in power for level flight. In this case the problem was made more difficult because available power was marginal. In addition to the aforementioned items, some reasonable value of distance or time for deceleration is needed to define deceleration characteristics adequately. In the interim, until further research is completed, the requirement states that the deceleration should be compatible with the mission requirement.

Conversion[3] and transition characteristics.- Transferring smoothly from thrust lift to aerodynamic lift is important to the success of the VTOL vehicle. Although only a limited amount of information is available from flight tests at this time, the following points have been noted. Flexible operation depends on the ability to safely and readily stop conversion or transition in either direction. Both flight (ref. 3) and simulator results (ref. 18) have disclosed the desirability of minimizing pitch changes during conversion and transition. Large pitching moments may occur unless conversion controls are programed correctly with airspeed. Another factor in transition is concerned with establishing an adequate speed margin between the speed at which the weight of the aircraft can be supported completely by the wing and the maximum forward speed obtainable with the thrust directed for hovering flight. This may be a problem for some configurations for which acceleration is obtained by tilting the thrust vector forward. The large ram drag inherent in some types of propulsion systems may limit the maximum forward speed to undesirably low values. For safe operation it is highly desirable for wave-offs or landings to be possible with the critical engine inoperative at any time during transition. The aforementioned items have been placed in requirement form. Further research is required to arrive at more quantitative requirements for conversion and transition.

Steep descent characteristics.- The ability to make steep descents is important to the utility of the V/STOL vehicle. However, flight tests have indicated that a number of fundamental problems must be solved if steep descents are to be feasible. These include aircraft disturbances due to wing stalling or rotor flow instability which occur in steep descents because of the high induced angles of attack. Another problem concerns the effects of the reduction in engine power required to obtain low effective L/D values for steep descents. This was disclosed by recent flight tests of an STOL aircraft which derives large lift gains from engine power. Unpublished results show that as engine power is reduced, the minimum approach speed must be increased because the stall speed increases and the control power decreases (as a result of reduced slipstream velocity). In addition it should be possible to control attitude and rate of descent accurately for landing. In this regard sufficient visibility must be available to give the pilot the necessary cues for landing at a given spot. The requirement for angle of descent has been written in general terms since specific mission requirements will dictate approach angles and descent rates. More research and operational experience is necessary to establish more firmly values for rate of descent compatible with mission requirements. In this regard studies in reference 19 indicate that at least for helicopters it is not feasible to descent at rates greater than approximately 10 feet per second in steep approaches under instrument conditions.

Longitudinal trim changes.- The airplane requirement for trim change 3.3.19 has been followed in general but in addition wing sweep position and thrust direction are specified. Additional items may be required as

---

[3] Conversion refers to a configuration change such as wing and/or rotor tilting, flap deflection, thrust deflection, wing translation, etc.

more experience is gained in this area. Maximum allowable force changes have been reduced to ±10 pounds for stick or wheel in an attempt to minimize trim changes, thereby avoiding the necessity of operating trim devices in addition to conversion devices. Although no direction of the force changes has been specified, it may be desirable in certain cases to specify a direction. For example, in studies of landing approach techniques (refs. 11 and 20) it was found that flight path control was improved if increases in engine power produced slight nose-up trim changes and vice versa with negligible effect on airspeed. A desirable magnitude of this trim change was not determined, however, and information about a preferable direction for the other items is not available at this time.

Longitudinal, lateral, and directional trim effectiveness.- The ability to trim the control forces to zero over the speed range including zero airspeed is important for V/STOL aircraft because of the extended periods of operation in the low-speed area.

Irreversibility of trim controls.- Airplane requirement 3.5.5 is satisfactory in this regard.

Trim system failure.- Airplane requirement 3.5.6 is considered adequate for V/STOL aircraft.

Height control characteristics.- The use of collective pitch or throttle controls for height adjustment requires essentially the same mechanical characteristics as conventional stick controls since they are used in a similar manner for VTOL operation. The forces on the throttle type height control have, therefore, been proportioned according to an average representative throttle length.

Longitudinal trim change due to sideslip.- The maximum allowable longitudinal control forces for the various airplane classes have been specified sufficiently low to be held with one hand. It is felt that the longitudinal trim change due to the sideslip for the conditions specified in helicopter requirement 3.3.9 should not be so great that no margin in longitudinal control is available to cope with gust disturbances. Accordingly, a margin equal to 10 percent of the maximum hovering angular acceleration is specified for VTOL operation. No requirement is specified for STOL operation; however, a sufficient margin should exist for the same reasons. Further research is needed to define a margin for STOL operation and to determine the applicability of the 10-percent margin to all VTOL configurations.

Control effectiveness in take-off.- To insure that take-off performance is not unduly compromised, airplane requirement 3.3.11 to adjust take-off attitude has been modified to include all classes of STOL aircraft and to apply on sod and hard surfaces. For VTOL operation the helicopter requirement 3.4.4.1 has been used except that the wind velocity has been deleted since this will vary with the mission requirements of the vehicle. Experience in VTOL operation has shown that it is desirable for the longitudinal control, which may depend on the main engine for power, 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. In addition, in order to check for proper functioning (direction) of the controls it should be possible to observe control motion or the effect of control movement on the aircraft motion during run-up at reduced power.

Longitudinal control forces in take-off.- The control force limits have been reduced in magnitude to permit one-hand operation during take-off and climb for either stick or wheel type control.

Control effectiveness in landing.- The longitudinal control shall be powerful enough to land the airplane at designated wind conditions under a variety of approach conditions. For example, in steep descents when it may be necessary to reduce engine power significantly, the type of longitudinal control that derives it power, in part, from the main engine (such as reaction type using bleed air) must be able at reduced engine power to meet requirement 3.3.14 for airplanes. In addition, adequate control should be available to land the airplane safely at the minimum operating speed. The minimum operating speed for V/STOL aircraft is defined as the speed from which a safe landing can be made with the critical engine inoperative. The minimum operating speed is construed to apply to single-engine or multiengine vehicles. On multiengine VTOL aircraft, the minimum operating speed would be zero if it were possible to hover with the critical engine inoperative. The term minimum operating speed as used throughout this report is felt to be a logical approach to safe operation of V/STOL vehicles. It is recognized that except in emergencies neither commercial helicopters nor military aircraft operate in such a manner that would prevent a safe landing if the critical engine failed.

Control forces in landing.- As mentioned previously, the maximum allowable longitudinal control forces have been kept low to permit one-hand operation for stick or wheel.

Control forces in dives.- In dive maneuvers where it is felt that V/STOL aircraft will not operate over prolonged periods, the force values for airplanes have been retained.

Auxiliary dive recovery devices.- No changes have been felt necessary from the airplane requirements for V/STOL aircraft.

Effects of drag devices.- Recent studies in landing approach (ref. 20) of a continuously adjustable thrust reverser on a single-engine jet fighter and unpublished data of thrust attenuators on a twin-jet trainer have shown the feasibility of this type of device for use as a flight path control during landing approach. When used as a flight path control it was found desirable that increases in reverser deflection (reducing forward thrust) should produce mild increases in nose-down trim with negligible change in airspeed.

Lateral-Directional Stability and Control Characteristics

Damping of the lateral-directional oscillations.- The airplane requirement 3.4.1 is based on research reported in reference 21. More recent work reported in reference 22 was primarily directed toward investigating whether the requirement was too stringent for emergency operation. These latter results are presented in figure 6 along with airplane requirement 3.4.1. In the tests of reference 22, a variable-stability F-86E was used to make simulated landing approaches for various lateral-directional characteristics. Included in these studies was a rough air simulation obtained by sending random inputs to all controls. These tests disclosed that for the emergency condition (stabilization devices inoperative), the values in requirement 3.4.1 could be drastically reduced. In the landing approach configuration even slightly divergent oscillations were acceptable at the lower roll-to-yaw ratios. In addition, there were indications that the parameter $1/T_{1/2}$ would be more descriptive than $1/C_{1/2}$ to the pilot for rating damping. Other factors, such as adverse yaw, are know to influence the damping requirements. In view of the many variables which influence the lateral-directional damping and because these variables must be considered in operation of the V/STOL aircraft, further research is needed to extend airplane requirements to the low-speed region of the V/STOL vehicle. In the interim, the boundaries noted on figure 6 are suggested. It can be noted that in line with the results of reference 22 for landing approaches the boundaries for V/STOL aircraft have been shifted to reflect lower damping requirements.

Spiral stability.- From considerations such as those discussed on spiral damping in reference 23 it is felt that greater restrictions than those for airplanes may be placed on spiral divergence for STOL operation because heading changes associated with the spiral mode will become more significant at lower speeds. Until further research is conducted to set limits for V/STOL operation, however, airplane requirement 3.4.2 is useful.

Steady sideslip conditions.- In order to adequately specify the conditions under which directional characteristics are to be checked, considerably more operational experience with various types of V/STOL vehicles must be acquired. For example, the maximum sideslip condition specified for helicopters is 45°, yet flight at 90° sideslip is not uncommon. Until operational limits compatible with mission requirements can be established more accurately, the combined conditions outlined in airplane requirement 3.4.3 and helicopter requirement 3.3.9 are suggested for V/STOL aircraft.

Static directional stability (rudder position).- In general, it is desired that static directional stability be such that increases in rudder deflection accompany increases in sideslip over the full sideslip range up to 90°. However, until further research is conducted to ascertain the feasibility of this criterion for VTOL operation, airplane requirement 3.4.4 $(\partial\delta_r/\partial\beta > 0)$ shall apply over the sideslip ranges specified.

Static directional stability (rudder force).- Characteristics similar to those discussed in the foregoing section on rudder position are desirable for rudder force. As noted before, however, until further experience has been obtained in this area, a reduction is permitted in rudder force with increase in sideslip for sideslip angles greater than 15° from that for wings level. Because recent experience in STOL operation has indicated the desirability of keeping the reduction in rudder force to a minimum, the airplane requirement which allowed the force to decrease but not to zero has been changed to allow reduction of rudder force to only one half the maximum value, but not less than the friction value.

Dihedral effect (aileron force).- A similar reasoning to that used for rudder characteristics should be applied to aileron (force and position) when operating V/STOL aircraft. In addition, the aileron force should not exceed 10 pounds in keeping with one-hand operation. For transient type maneuvers, such as wave off, negative dihedral effect (not to exceed 10 pounds) is permissible.

Dihedral effect (aileron position).- As previously discussed, linear position characteristics are desired over the sideslip angle range extending to 90° sideslip. Further research is necessary for dihedral effect also to define requirements from a practical and operational standpoint. In order to have available some margin of control for gust disturbances, it is recommended that positive dihedral effect never be so great that at maximum sideslip, less than 10 percent of maximum rolling acceleration is available for all classes of V/STOL aircraft at the minimum operating speed.

Side force in sideslips.- Airplane requirement 3.4.8 specifies that increases in bank angle accompany increases in sideslip. In addition to this it would be desirable to be able to define the minimum slope of bank angle versus sideslip which at a given airspeed would give the pilot an appreciation of the magnitude of sideslip angle. Sufficient information is not on hand, however, to establish a revised requirement.

Adverse yaw.- The amount of adverse yaw tolerable for airplanes has been established at 15° as a representative value to restrict heading changes to a controllable value. Recent studies in landing approach (ref. 24) have shown, however, that sideslip itself may not be indicative of a heading change in that appreciable values of sideslip can be obtained by merely rolling around a highly inclined longitudinal axis with little or no heading change. Since it may be necessary for STOL vehicles to use relatively large angles of attack to make steep approaches, it is felt that a closer examination of allowable sideslip angles will be required to set limits for STOL operation.

Although in general, favorable yaw has not been a major handling qualities problem of conventional airplanes, recent experience with a VTOL aircraft, in which favorable yaw due to lateral control deflection was incorporated, has indicated the desirability of keeping this item to negligible values. There is not sufficient information at the present time to specify a maximum allowable value; however, the V/STOL requirement has been written to the effect that favorable yaw shall not be of sufficient magnitude to be objectionable.

Asymmetric power (rudder free).- Airplane requirement 3.4.10 has been retained in essence except that the reference speed has been changed to include all speeds above that for minimum drag.

Directional control (symmetric power).- The requirement for airplanes has been modified to extend the speed range for V/STOL aircraft down to the minimum operating speed and to reduce the maximum rudder force to 100 pounds. This value is felt to be more compatible with precision of control and safety. For VTOL operation the initial trim condition is set at hover and no maximum force values are felt to be required. Additional research is needed to extend the 10° sideslip value given in airplane requirement 3.4.11.1 for landing to cover values more representative of V/STOL operation in cross winds.

Directional control (asymmetric power).- As before, the condition for minimum speed has been referenced to the minimum operating speed rather than a stalling speed. In addition, it is felt necessary to include the wave-off condition and a margin of rudder control to maneuver. The allowable forces have been lowered to a maximum value of 100 pounds for reasons previously discussed.

Directional control during take-off, landing, and taxi.- The directional control requirements for airplanes and helicopters have been combined in an attempt to provide satisfactory directional control for the maximum designated wind velocity in any direction for all classes of V/STOL aircraft. Additional testing undoubtedly will point out the relative merits of each V/STOL concept for operating under various wind conditions.

Directional control to counteract adverse yaw.- The airplane requirement has been changed to reference trim sideslip angle and to lower the maximum allowable rudder force to 100 pounds.

Directional control in dives.- Airplane requirement 3.4.15 has been changed slightly in regard to rudder force since it is felt that no distinction should be made for maximum allowable rudder force for various classes of V/STOL airplanes. A maximum value of 100 pounds has been selected for reasons previously discussed.

Directional steadiness in hovering.- As noted in the previous discussion on longitudinal steadiness in hovering, control motion in itself as used in helicopter requirement 3.3.3 is not felt to be adequate to define directional steadiness in hovering over a given spot. Although this part of the requirement has been retained, further research is needed in this area also for more suitable parameters for measurement of directional steadiness.

It is recognized that directional damping will improve the hovering steadiness and, as discussed before, the values derived from the helicopter tests of references 16 and 13 are used as a first choice. Additional research is needed to provide values representative of the requirements for various sizes and types of VTOL vehicles.

Directional control power in hovering.- Directional control power should from the flight safety standpoint be the least demanding compared to roll since directional rotation at touchdown is not as serious as side velocity. Yet in view of this, the amount of directional control power desired from tests of the variable stability helicopter (ref. 16) was large in comparison with that required for either pitch or roll. In this case the large amount of directional control power specified was felt to be due in part to the high directional stability of the test vehicle and the particular precision task used in the flight tests. As a result of additional studies, the values recommended in reference 16 have been reduced as noted in reference 13. Until additional research is completed, however, to establish the maximum amount of control power needed for other sizes and types of VTOL aircraft, the values noted in the helicopter requirement are suggested. An additional requirement is felt necessary to set a minimum directional control power value in hover since even for large aircraft a lower limit is needed for maneuvering. For this condition it is recommended that sufficient directional control power be available to establish a yaw displacement not less than 15° after one second for full control deflection.

Hovering turns in winds.- The requirement for helicopters 3.3.6 which specifies 360° turns over a given spot in a 30 knot wind has been relaxed for VTOL aircraft to match the mission requirements for a given vehicle, since it is felt that rearward and sidewise flight at 30 knots may not be required for some VTOL concepts. To assure an adequate margin of control under these wind conditions the margin in yaw displacement in one second specified for helicopters is used. These values were derived from the results of references 16 and 13 and included an attempt to take into account the weight of the aircraft. There are indications, however, from tests of different sized helicopters that equal margins of control may be required regardless of the weight of the aircraft. This philosophy, pointed out in reference 25, suggests that, in general, all VTOL vehicles regardless of size must maneuver into similar areas with equal ability and, therefore, control power and control margins must be suitable for this kind of VTOL operation. Additional testing is felt required to check more fully the effect of aircraft size or weight. In the interim, the requirement has been modified to set as a minimum a yaw displacement value of 5° after one second, regardless of the aircraft size.

Directional control sensitivity.- As noted in previous discussions, it is felt that the directional control characteristics including sensitivity require further study to define requirements for aircraft of various sizes and weights. In the interim the sensitivity value of helicopter requirement 3.3.7 has been recommended.

Directional control in power-off flight (autorotation).- This requirement has been revised to include all types of aircraft by referencing to the minimum speed as defined in the stall section. In addition, it was felt necessary to specify a minimum acceptable value for rate of turn.

Lateral steadiness in hovering.- For reasons discussed previously, further studies are felt needed to define requirements in addition to that specified for the amount of lateral control motion required to hover over a given spot on the ground.

Lateral control power in hovering and in forward flight.- It is recognized that both control power and damping are important for satisfactory lateral control characteristics. The significance of the relationship of lateral control power to damping was shown initially for fighter aircraft in the results of reference 26. These results, from 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 precision of control due to sensitivity. At low damping the control behaved as an acceleration command control with unsatisfactory characteristics. A summary of the results of reference 26, which represent both flight and simulator tests, is plotted in figure 7 in terms of $L_{\delta_a}\delta_{a_{max}}$ and τ. Included in figure 7 are data points from a number of V/STOL aircraft. In addition, the lateral control criteria of reference 15 are presented (assuming 5 inches of stick travel) and also unpublished results of moving base simulator tests. The latter sets of data represent both hovering and low-speed forward flight. It can be noted that the lines of constant pilot opinion (see table II for number definitions) forming the boundaries are approximated by lines of constant bank angle in one second. It can be shown that the parameter $pb/2V$ is not suitable for design purposes since it does not take into account roll damping and indicates that increased roll rates are required as speed is increased. These considerations are not borne out by the pilot opinion data in figure 7 obtained from reference 26.

The data in figure 7 show as would be expected that greater control power was demanded at low values of τ for airplane flight where evasive type maneuvers are made compared to that required for hovering or transition flight (typified by the larger τ values). In addition, the results indicate that greater control power is required as damping is increased in order to avoid the feeling of a stiff or sluggish aircraft. With regard to damping, the simulator results indicate that τ values of the order of 4 seconds were considered satisfactory for hover. These simulator results were obtained with no disturbing effects, however, and, in addition, the pilot had to cope with only one degree of freedom. Although a number of V/STOL aircraft are being flown with essentially zero damping, these flights are conducted under still-air conditions and it is felt that for practical VTOL operation damping is necessary.

On the basis of the foregoing, the requirements for lateral control for configuration P have been rewritten to delete the parameter pb/2V used in airplane requirement 3.4.16 and include the roll time constant τ and the use of a given bank angle obtained in one second chosen according to the lines of constant pilot opinion. A helicopter requirement which takes airplane weight into account is used for lateral control for hover and transition (ref. 13). As discussed previously for directional control, a lower limit is felt necessary to prevent undesirably low roll performance for heavy aircraft. The roll damping specified for low speeds is that from the helicopter requirement since this is the best information available.

The foregoing applies to rolling performance for full lateral control. Recent flight experience with the XV-3 has shown that particularly in hovering where roll damping is generally small, the variation of rolling acceleration with lateral control displacement should be essentially linear over the control deflection range. In addition, a sensitivity requirement which is essentially that specified for helicopters (3.3.14) is used to avoid overcontrolling tendencies in hover and low-speed flight.

It is recognized that additional research is needed to more clearly define lateral control requirements for all V/STOL concepts and sizes. For example, lateral velocity can be obtained either by tilting the thrust vector, by banking the aircraft, or by remaining vertical and supplying a side thrust. For aircraft with large inertia about the roll axis the latter method may be more practical when possible performance losses are considered. It is felt, however, that roll displacement may provide the pilot with an important cue in a quickening sense and may, therefore, be desirable for satisfactory lateral positioning. To clarify the necessity for physical roll displacement in hovering, further research is required.

Roll response.- The requirement for time delay in obtaining roll response is necessary to cover aerodynamic lags inherent in some spoiler systems. It is felt, however, that for the classes of V/STOL aircraft considered herein, the requirement for time delay in attaining the maximum roll acceleration should be independent of the class of aircraft and should preclude the possibility of incorrect initial rolling direction.

Peak lateral control forces for rolling performance.- The peak lateral control forces for rolling performance have been written to conform with one-hand operation in approach and landing where frequent use of the control is required.

Lateral wheel throw limits.- The use of ±90° for wheel throw with one hand operation may prove undesirable; however, until sufficient information is obtained to justify a change to a smaller value, the aircraft requirement has been used with the added stipulation that full throw shall be readily obtainable with one hand.

Peak lateral forces for various maneuvers.- The requirements for helicopters and airplanes have been combined to express a maximum lateral force not to exceed 20 pounds for stick or wheel for V/STOL operation.

Lateral trim changes and effectiveness.- The use of a fixed value of lateral stick movement to define a trim change is not considered adequate for V/STOL aircraft since lateral force or margin available is not taken into account. It is felt preferable, therefore, to specify the ability to balance the airplane laterally for the various conditions with an allowable maximum force change and to include a margin of control of 10 percent of the maximum attainable value to cope with disturbances.

Lateral control effectiveness in dives.- The airplane requirement has been used unaltered.

Control cross-coupling and transient effects.- The airplane requirement 3.5.7 is intended to provide protection from excessive loads at high speeds generated by inertia cross-coupling effects. The maneuver for airplanes specifies rolls through 360° which is considered too large to be applicable to all V/STOL aircraft. Accordingly, the roll displacement has been stated to conform with the mission designation for each aircraft.

In addition, as discussed previously for longitudinal control, lateral control forces acting to resist displacement shall not decrease appreciably with control displacement.

Lateral and directional control force cross-coupling effects, which are peculiar to some helicopters, are considered undesirable as noted in a previous discussion of longitudinal control. The helicopter requirement has been reworded to eliminate any control force cross-coupling characteristics.

Control for spin recovery.- The requirement for airplanes has been made more general to include all aircraft capable of being spun and to cover possible effects of engine power on control power. The relatively high control forces allowed for recovery are considered satisfactory in view of the emergency nature of the maneuver.

Stalling Characteristics

Required flight conditions.- Because the stalling characteristics are of particular interest in the transition region, it is felt necessary to include, in addition to the standard airplane configurations, a check of the stall behavior in wave-off. In addition, the large effects which engine power and BLC may possibly have on the stalling behavior require flight tests with engine power for shallow and steep descent approaches and BLC on and off.

Definitions of stalling speed.- The stalling speed for conventional airplanes is defined in reference 1 as the minimum speed attainable in flight, and is normally associated with breakdown of air flow over the wing immediately after the maximum over-all trim lift coefficient is attained. The complete stall is characterized by large magnitude pitching or rolling or by a decrease in normal acceleration in turning flight. Stalling speed for STOL airplanes which fall into the conventional stall category will be strongly dependent on engine power, thrust angle, or slipstream magnitude and, therefore, stalling speed in configuration PA will vary appreciably depending on whether a shallow or steep descent is being made.

For V/STOL aircraft which do not possess a conventional stall, the stalling speed may be defined as in airplane requirement 3.6.2.1 or 3.6.2.2 with an addition for V/STOL operation. Accordingly, the minimum operating speed has been added which was previously defined.

Stall warning requirements.- Although the stall warning characteristics defined in airplane requirement 3.6.3 shall be generally applicable for V/STOL aircraft with conventional stalling behavior, it is felt that the expression of airspeed at which the warning is felt as a percentage of stall speed is inadequate at low airspeeds. Flight experience under STOL conditions has pointed out that for low stall speeds the pilots desired a minimum fixed margin in speed above the stall to have sufficient margin for safety from stalling due to finite gust disturbances. For this purpose a 5-knot minimum value for stall warning margin is specified. A similar relationship applies to the minimum landing approach speed; however, in this case a 10-knot minimum speed margin from the stall is desired.

For aircraft which are limited in longitudinal control (defined in airplane requirement 3.6.2.1) and others where a conventional stall cannot be obtained, no stall warning has been specified provided no dangerous flight behavior occurs.

Requirements for acceptable stalling characteristics.- The stalling characteristics in airplane requirement 3.6.4 have been revised to be more stringent in the landing approach and landing configurations. In this area it is felt necessary to limit the maximum allowable initial roll-off at the stall to the roll angle at which a wing tip or pod may strike the ground when the aircraft is resting on the landing gear. 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.

For the case of failure of the BLC system, the allowable magnitude of angular displacement has been relaxed to permit excursions to 30° pitchdown, roll, or yaw, provided, however, no dangerous flight characteristics arise.

Prevention of the complete stall and definition of recovery characteristics are felt to be covered adequately by airplane requirement 3.6.4.1 with the addition of the effects of engine power on control effectiveness.

Performance (engine) considerations.- Because of the closer tie-in of engine operation to flight characteristics for V/STOL aircraft, it is considered desirable to include the effect of engine operation in certain areas of flying qualities requirements. Some of the items to be considered include the following: Engine power changes over the range used operationally should not appreciably affect control power of reaction controls or other controls (including BLC) which derive their effectiveness in part from the main engine. Engine thrust response shall not compromise the ability to hold altitude in hover or in going from transition to hover. Power controls shall not require complicated procedures for power changes. Thrust control shall be fine enough to permit control of flight path by the use of engine controls.

Although the effect of thrust to weight ratio is normally considered a performance characteristic, the effect on the over-all flying qualities should not be overlooked. In particular, the results of flight tests of a number of jet aircraft in landing approach (ref. 11) have indicated the necessity that the thrust weight margin $\Delta T/W$ be at least equal to or greater than 0.12 at the minimum approach speed. Further tests are needed to redefine this item for V/STOL operation.

Gyroscopic effects.- Because of the greater ratio of engine gyroscopic inertial moments to airplane inertial moments characteristic of VTOL aircraft and because of the low aerodynamic damping available, engine gyroscopic coupling effects can have an appreciable effect on airplane dynamic motions. From the flight experience gained on V/STOL aircraft thus far (see, e.g., ref. 27) it would appear that gyroscopic coupling effects cannot be tolerated to any appreciable degree. Accordingly, a requirement to minimize the effects of gyroscopic coupling has been included for V/STOL aircraft.

CONCLUDING REMARKS

The results of a study of handling qualities of V/STOL aircraft have indicated that the majority of V/STOL requirements can be defined by modifications to the current military helicopter and airplane requirements in part by appropriate use of reference speeds. Since the available data for the flight conditions peculiar to V/STOL vehicles are incomplete, a number of the requirements can only be presented in qualitative form. Areas where a more firm quantitative requirement is felt necessary include control power and damping relationships about all axes for various sizes and types of aircraft; control power, sensitivity, damping, and response for height control; dynamic longitudinal and dynamic lateral-directional stability in transition including emergency operation; hovering steadiness; acceleration and deceleration in transition; characteristics in steep approaches; and thrust margin in approach.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., May 23, 1960

APPENDIX

NOTATION

For purposes of this report, V/STOL airplanes are divided into the following classes:

Class I - Light observation
Class II - Heavy surveillance and fighter
Class III - Tactical transport

Configurations used for V/STOL airplanes are similar to those for airplanes (ref. 1).

Symbols used in this report are defined as follows:

b	wing span, ft
C_l	rolling moment coefficient, $\frac{\text{rolling moment}}{qSb}$
C_{l_p}	$\frac{\partial C_l}{\partial(pb/2V)}$, per radian
$C_{1/2}$	number of cycles to damp to half amplitude
C_2	cycles required to double amplitude
F	cockpit control force, lb
I	inertia, slug-ft^2
L_p	$\frac{qSb^2}{2VI_X} C_{l_p}$, per sec
$L_{\delta_a}\delta_{a_{max}}$	initial rolling acceleration for full lateral control input, radians/sec^2
n,A_2	normal load factor, in g units
n_L	limit load factor
p	rolling velocity, radians/sec
$\frac{pb}{2V}$	helix angle, radians

q	dynamic pressure, lb/ft^2
S	wing area, sq ft
$T_{1/2}$	time to damp to half amplitude, sec
V	true airspeed, ft/sec
V_i	indicated airspeed
V_S	stalling speed
v_e	$V\sqrt{\sigma}\sin\beta$
W	airplane gross weight, lb
β	sideslip angle, deg
$\frac{\Delta T}{W}$	thrust margin
δ_e	elevator angle, deg
$\frac{\partial\delta_r}{\partial\beta}$	slope of rudder deflection - sideslip curve
ζ	damping ratio (fraction of critical)
$\dot{\theta}$	pitching velocity, radians/sec
$\ddot{\theta}$	pitching acceleration, radians/sec^2
σ	density ratio
τ	roll time constant, $-\frac{1}{L_p}$, sec
ϕ	bank angle, deg
$\ddot{\phi}$	rolling acceleration, radians/sec^2
$\frac{\lvert\phi\rvert}{\lvert v_e\rvert}$	rolling parameter, deg/ft/sec
ψ	angle of yaw, deg

Subscripts

a	aileron
e	elevator
L, TO, WO, etc.	airplane configurations
r	rudder
x,y,z	roll, yaw, and pitch axes, respectively

REFERENCES

1. Anon.: Military Specification - Flying Qualities of Piloted Airplanes. MIL-F-8785 (ASG), Nov. 12, 1957.

2. Anon.: Military Specification - Helicopter Flying Qualities, Requirements for Military Specification. MIL-H-8501, Nov. 5, 1952.

3. Thomas, Lovic P., III: A Flight Study of the Conversion Maneuver of a Tilt-Wing VTOL Aircraft. NASA TN D-153, 1959.

4. Cooper, George E., and Innis, Robert C.: Effect of Area-Suction-Type Boundary-Layer Control on the Landing-Approach Characteristics of a 35° Swept-Wing Fighter. NACA RM A55K14, 1956.

5. Anderson, Seth B., Faye, Alan E., Jr., and Innis, Robert C.: Flight Investigation of the Low-Speed Characteristics of a 35° Swept-Wing Airplane Equipped With an Area-Suction Ejector Flap and Various Wing Leading-Edge Devices. NACA RM A57G10, 1957.

6. Bray, Richard S., and Innis, Robert C.: Flight Tests of Leading-Edge Area Suction on a Fighter-Type Airplane With a 35° Sweptback Wing. NACA RM A55C07, 1955.

7. Anderson, Seth B., Quigley, Hervey C., and Innis, Robert C.: Flight Measurements of the Low-Speed Characteristics of a 35° Swept-Wing Airplane With Blowing-Type Boundary-Layer Control on the Trailing-Edge Flaps. NACA RM A56G30, 1956.

8. Quigley, Hervey C., Anderson, Seth B., and Innis, Robert C.: Flight Investigation of the Low-Speed Characteristics of a 45° Swept-Wing Fighter-Type Airplane With Blowing Boundary-Layer Control Applied to the Trailing-edge Flaps. NACA RM A58E05, 1958.

9. Quigley, Hervey C., Anderson, Seth B., and Innis, Robert C.: Flight Investigation of the Low-Speed Characteristics of a 45° Swept-Wing Fighter-Type Airplane With Blowing Boundary-Layer Control Applied to the Leading- and Trailing-Edge Flaps. NASA TN D-321, 1960.

10. Brown, B. P.: Ground Simulator Studies of the Effects of Valve Friction, Stick Friction, Flexibility and Backlash on Power Control System Quality. NACA Rep. 1348, 1958.

11. Drinkwater, Fred J., III, and Cooper, George E.: A Flight Evaluation of the Factors Which Influence the Selection of Landing Approach Speeds. NASA MEMO 10-6-58A, 1958.

12. Rhoads, Donald W.: A Qualitative Flight Test Investigation of Some Handling Qualities of Liaison Type Airplanes. Cornell Aeronautical Lab., Inc., Rep. TC-1214-F-1, Sept. 1959.

13. Tapscott, Robert J.: Criteria for Control and Response Characteristics of Helicopters and VTOL Aircraft in Hovering and Low Speed Flight. IAS Paper No. 60-51, Jan. 1960.

14. Chalk, Charles R.: Additional Flight Evaluations of Various Longitudinal Handling Qualities in a Variable-Stability Jet Fighter. WADC TR 57-719, Jan. 1958.

15. Newell, Fred, and Rhoads, Donald W.: Flight Evaluations of the Effect of Variable Phugoid Damping in a JTB-26B Airplane. WADC TR 56-223, Dec. 1956.

16. Salmirs, Seymour, and Tapscott, Robert J.: The Effects of Various Combinations of Damping and Control Power on Helicopter Handling Qualities During Both Instrument and Visual Flight. NASA TN D-58, 1959.

17. Deckert, W. H., and Ferry, R. G.: AFFTC Flight Evaluation of the XV-3. Preliminary Report. Air Force Flight Test Center. July 22, 1959.

18. James, Harry A., Wingrove, Rodney C., Holzhauser, Curt A., and Drinkwater, Fred J., III: Wind Tunnel and Piloted Flight Simulator Investigation of a Deflected-Slipstream VTOL Airplane, the Ryan VZ-3RY. NASA TN D-89, 1959.

19. Reeder, John P., and Whitten, James B.: Notes on Steep Instrument Approaches in a Helicopter. (NACA paper presented at the 12th Annual Helicopter Society Forum, May 1956).

20. Anderson, Seth B., Cooper George E., and Faye, Alan E., Jr.: Flight Measurements of the Effect of a Controllable Thrust Reverser on the Flight Characteristics of a Single-Engine Jet Airplane. NASA MEMO 4-26-59A, 1959.

21. Liddell, Charles J., Jr., Creer, Brent Y., and Van Dyke, Rudolph D., Jr.: A Flight Study of Requirements for Satisfactory Lateral Oscillatory Characteristics of Fighter Aircraft. NACA RM A51E16, 1951.

22. McNeill, Walter E., and Vomaske, Richard F.: A Flight Investigation to Determine the Lateral Oscillatory Damping Acceptable for an Airplane in the Landing Approach. NASA MEMO 12-10-58A, 1959.

23. Rhoads, D. W.: Flight Evaluations of the Effect of Variable Spiral Damping in a JTB-26B Airplane. Cornell Aeronautical Laboratory Rep. TB-1094-F-1, Oct. 19, 1957.

24. White, Maurice D., and Innis, Robert C.: A Flight Investigation of the Low-Speed Handling Qualities of a Tailless Delta-Wing Fighter Airplane. NASA MEMO 4-15-59A, 1959.

25. Putnam, K. V.: Some Human Engineering Aspects of Several Unconventional Aircraft. Paper presented to the joint meeting of the AGARD Aeromedical and Flight Test Panels. Athens, Greece, May 11-15, 1959.

26. Creer, Brent Y., Stewart, John D., Merrick, Robert B., and Drinkwater, Fred J., III: A Pilot Opinion Study of Lateral Control Requirements for Fighter-Type Aircraft. NASA MEMO 1-29-59A, 1959.

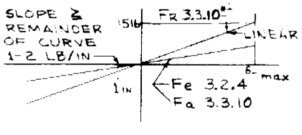
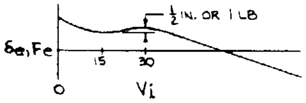
27. Davis, W. B.: General Flying Qualities in the Transition Flight Regime Based on Flight Test Results, USAF Model X-13 Airplane. Ryan Aeronautics Rep. 6954-10, April 1, 1958.

TABLE I.- PILOT OPINION RATING SYSTEM

	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

TABLE II.- FLYING QUALITIES REQUIREMENTS

<table>
<tr><th>ITEM</th><th>HELICOPTER SPECS. MIL-H-8501</th><th>AIRPLANE SPECS. MIL-F-8785 (ASG)</th><th>V/STOL REQUIREMENTS</th></tr>
<tr>
<td><u>Mechanical characteristics of control system</u>
Control friction and breakout force and centering characteristics</td>
<td>Centering Characteristics

Friction values, lb.*
<table>
<tr><th>Control</th><th>Min.</th><th>Max.</th><th></th></tr>
<tr><td>Long. cyclic</td><td>0.5</td><td>1.5</td><td>3.2.7</td></tr>
<tr><td>Lateral cyclic</td><td>.5</td><td>1.5</td><td>3.3.12*</td></tr>
<tr><td>Collective</td><td>1</td><td>3</td><td>3.2.13</td></tr>
<tr><td>Rudder</td><td>3</td><td>[illegible]</td><td>3.3.12</td></tr>
</table>
Friction ref.</td>
<td>3.2.1
Longitudinal, lateral, and directional control breakout forces including friction and preload shall not exceed the following values and shall possess positive self-centering characteristics.
<table>
<tr><th>Control</th><th></th><th>Classes I, II-C, and III (min. to max.) lb.</th><th>Class II-L (min. to max.) lb.</th></tr>
<tr><td>Elevator</td><td>Stick
Wheel</td><td>0.5 - 3
.5 - 4</td><td>0.5 - 5
.5 - [illegible]</td></tr>
<tr><td>Aileron</td><td>Stick
Wheel</td><td>.5 - 2
.5 - 3</td><td>.5 - 4
.5 - [illegible]</td></tr>
<tr><td>Rudder</td><td></td><td>1 - 7</td><td>1 - 14</td></tr>
</table></td>
<td>Longitudinal, lateral, and directional controls shall exhibit positive centering in flight with force gradients equivalent to those of helicopter requirements 3.2.- and 3.3.10. The effects of centering, breakout force, feel, preload, etc., combined with the stability and force gradient shall not result in objectionable flight characteristics, or permit large departures from trim conditions with controls free. Breakout forces, including friction, feel, preload, etc., shall be within the limits given in the accompanying table. The friction within the hydraulic valves shall never be greater than 1/2 the friction in the control linkages; the sum of the two types must be within the values in the table.
<table>
<tr><th>Control</th><th></th><th>Class I & II (min. to max.), lb.</th><th>Class III (min. to max.) lb.</th></tr>
<tr><td>Elevator</td><td>Stick
Wheel</td><td>0.5 - 3
.5 - 4</td><td>0.5 - 4
.5 - [illegible]</td></tr>
<tr><td>Aileron</td><td>Stick
Wheel</td><td>.5 - 2
.5 - 3</td><td>.5 - 3
.5 - 5</td></tr>
<tr><td>Rudder</td><td></td><td>1.0 - [illegible]</td><td>1.0 - 14</td></tr>
<tr><td>Height control</td><td>Stick
Throttle(s)</td><td>1.0 - 2
.25 - 2</td><td>1.0 - 2
.25 - 2</td></tr>
</table></td>
</tr>
<tr>
<td>Cockpit control free play</td>
<td>3.4.10
No dead spots more than ±0.2 inch motion of cockpit control.</td>
<td>3.2.4
Free play of cockpit control shall not be excessive.</td>
<td>The free play in each cockpit control, i.e., the motion of the cockpit control, from the trim position, which does not move the control surface in flight shall not cause objectionable handling characteristics nor in any case exceed ±1 percent of total travel.</td>
</tr>
<tr>
<td>Artificial stability devices
Stability augmentor failure</td>
<td>3.4.9a
Complete failure of stability augmentation equipment shall not result in rates of yaw, pitch, or roll in excess of 10° per second or ΔA_Z greater than ±0.5 g for 3 seconds following failure.</td>
<td>3.2.5
Normal operation of device shall not introduce any objectionable flight or ground handling characteristics.
Failure of such device shall not result in a dangerous or objectionable flight condition.</td>
<td>Normal operation of an artificial device for improvement of any characteristic shall not introduce any objectionable flight or ground handling characteristics. Failure of such a device shall not result in a dangerous or intolerable flight condition nor exceed the values given in helicopter requirement 3.4.9a.</td>
</tr>
<tr>
<td><u>Longitudinal stability and control</u>
Elevator-fixed-static</td>
<td>3.2.10
Rearward displacement to decrease speed and forward to increase speed. Allow 1/2 inch unstable movement in speed range of 15 to 30 knots.*
 </td>
<td>3.3.1
For speed ranges and config. of table II elevator-fixed neutral points shall be aft of rear c.g. loading for all classes.
3.3.1.1
At aft c.g. $(\partial\delta_e/\partial\alpha)_{V=K}$ shall be positive over speed ranges and configs. of table II.</td>
<td>With the aft critical loading for all steady forward flight conditions for which the aircraft might be operated for more than a short time interval, the aircraft shall possess positive, static longitudinal control position, and control force stability with respect to speed, except as noted in the following. A moderate degree of instability such as noted in helicopter requirement 3.2.10 shall be permitted provided that it does not occur in the speed range below the speed for minimum drag. In configurations PA and P (climb) the force reversal below trim speed shall not decrease by an amount greater than the allowable friction force. The foregoing requirements shall apply both in and out of ground effect.</td>
</tr>
</table>

[1] Throughout, an asterisk is used to denote extension of reference 2 based on unpublished helicopter handling qualities studies and results of reference 13.

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

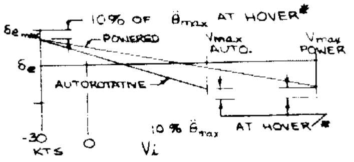
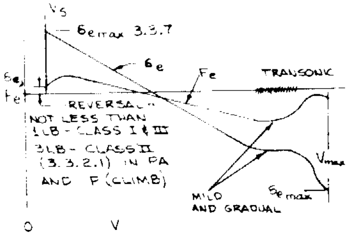
ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F-[illegible] ASG)	V/STOL REQUIREMENTS
Elevator-free-static	3.2.10 (continued) Stick-free stability characteristics same as stick-fixed with 1 lb force change allowed for instability.* 3.2.10.1 Above requirements for conditions and speed ranges shown in the table of 3.2.10.1. 3.2.1 Obtain smooth flight over speed range. 	3.3.2 Variation of force with speed shall be a smooth curve.  3.3.3 At transonic speeds a force reversal > 10 lb. (III) or 15 lb. (II) or gradient > 3 lb./0.01M (III) or 5 lb./0.01M (II) would be considered excessive. 3.3.2 shall apply for aircraft with prolonged operational requirements at transonic speeds.	The variation of elevator position and control force with speed shall be a smooth curve over the speed range from maximum designated rearward speed to maximum forward speed. Failure of BLC shall not change the longitudinal stability characteristics such that a dangerous flight condition results. The requirements for longitudinal stability may be relaxed, if necessary, in the transonic speed range, provided that any reversals in slope of elevator position and control force are mild and gradual and do not exceed values of and are in general agreement with airplane requirement 3.3.3.
Stability in accelerated flight		3.3.4 $\partial\delta_e/\partial A_Z$ shall be stable (increasing up elevator required for increasing A_Z) for all conditions of flight and in all configs.	The slope of the curve of elevator position versus normal acceleration at constant speed shall be stable (increasing up elevator required for increasing acceleration) throughout the range of attainable load factors.
Control effectiveness in unaccelerated flight	3.2.1 (continued) 10% of maximum hovering $\ddot{\theta}$ shall be available at each end of speed range to control for effects of longitudinal disturbances.*	3.3.7 Attainment of any permissible speed above V_S not be limited by effectiveness of longitudinal control for all configurations and loadings.	In erect unaccelerated flight at any altitude, the attainment of any permissible speed forward or rearward shall not be limited by the effectiveness of the longitudinal control. Throughout the specified speed range a sufficient margin of control power shall be available at each end to control the effects of longitudinal disturbances. For VTOL operation a margin of 10 percent of the maximum attainable pitching acceleration in hovering shall be available.
Control effectiveness in accelerated flight		3.3.8 It shall be possible to develop limit load factor or maximum lift coefficient by elevator alone.	In the forward critical loading, when trimmed at any permissible speed and altitude and for any condition of engine power, it shall be possible to develop at the trim speed, by use of the longitudinal control alone, the limit load factor, the lift coefficient corresponding to V_S, or a load factor consistent with the operational flight envelope.
Longitudinal response	3.2.9 No objectionable delay in $\ddot{\theta}$ following control displacement. $\ddot{\theta}$ shall be in proper direction within 0.2 sec. after control displacement over complete speed range.		There shall be no objectionable or excessive delay in the development of angular velocity in response to control displacement. The angular acceleration shall be in the proper direction within 0.2 sec. after longitudinal control displacement. This requirement shall apply over the complete speed range including rearward flight when applicable.

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

<table>
<tr><th>ITEM</th><th>HELICOPTER SPECS. MIL-H-8501</th><th>AIRPLANE SPECS. MIL-F8785 (ASG)</th><th>V/STOL REQUIREMENTS</th></tr>
<tr><td>Control forces in steady accelerated flight</td><td></td><td>3.3.9
Increases in pull force required for increases in positive acceleration (see following table for gradient values).
<table>
<tr><th>Class</th><th>Maximum</th><th>Minimum</th></tr>
<tr><td>I & III</td><td>$\frac{56}{n_L - 1}$</td><td>$\frac{21}{n_L - 1}$</td></tr>
<tr><td>II</td><td>$\frac{120}{n_L - 1}$</td><td>$\frac{45}{n_L - 1}$</td></tr>
</table></td><td>In steady turning flight and in pull-outs, increases in pull force shall be required to produce increases in positive normal acceleration throughout the range of attainable accelerations. The variation of force with normal acceleration at all points beyond the breakout force shall be approximately linear, except that an increase in slope upward (such as might be introduced by an acceleration restrictor) is permissible above 0.85 n_L. In general, a departure from linearity resulting in a local gradient which differs from the average gradient by more than 50 percent is considered excessive. The average force gradient shall be within the limits specified in the accompanying table.
<table>
<tr><th>Class</th><th>Maximum</th><th>Minimum</th></tr>
<tr><td>I & II
(config. P, CO, D, & PA)</td><td>$\frac{56}{n_L - 1}$</td><td>$\frac{21}{n_L - 1}$</td></tr>
<tr><td>III
(config. PA)</td><td>$\frac{28}{n_L - 1}$</td><td>$\frac{10}{n_L - 1}$</td></tr>
<tr><td>III
(config. P, CO, & D)</td><td>$\frac{120}{n_L - 1}$</td><td>$\frac{45}{n_L - 1}$</td></tr>
</table></td></tr>
<tr><td>Minimum force gradient</td><td></td><td>3.3.9.1
Local value of gradient shall never be less than 3 lb. per g.

3.3.9.3
When max. attainable g is less than n_L (stall or control effectiveness), max. force gradient may increase to 50 percent greater than that specified in table above.</td><td></td></tr>
<tr><td>Gradients in negative g</td><td></td><td>3.3.9.5
Max. stick force gradients in negative g not to exceed 50 percent of values in table above.</td><td>In all configurations at all permissible speeds and accelerations, the local value of the force gradient shall never be less than 3 lb per g nor exceed 50 percent of above values in negative g.</td></tr>
<tr><td>Control forces in sudden pull-ups</td><td>3.2.8
Controls shall be free from objectionable transient forces. During a pulse, force should not fall to zero.</td><td>3.3.10
In sudden pull-ups (pulses) ratio of max. elev. force to max. (peak) change in A_z shall never be less than same ratio obtained in steady accelerated flight.</td><td>In sudden pull-ups from trimmed straight flight, in which the elevator cockpit control is rapidly deflected and returned to its initial position, the stick force shall not fall to zero and shall lead the normal acceleration sufficiently to prevent overshoot.</td></tr>
<tr><td>Control cross-coupling effects</td><td>Longitudinal control displacement shall not produce lateral forces in excess of 20 percent and pedal forces in excess of 75 percent of longitudinal force. No cross-force feedback permitted for powered boosted controls.*</td><td></td><td>Longitudinal control displacement shall not produce objectionable lateral or directional control forces.</td></tr>
</table>

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

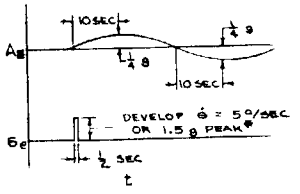
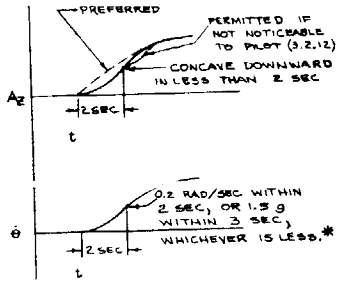
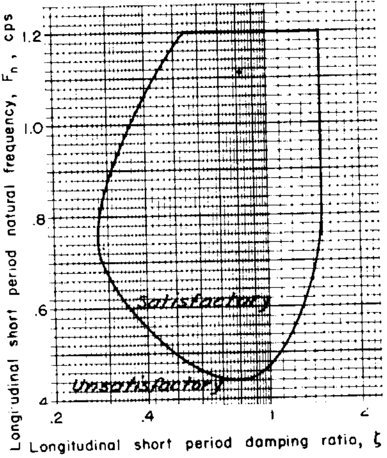
ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F8785 (ASG)	V/STOL REQUIREMENTS
Dynamic longitudinal stability and control Short-period oscillations	For satisfactory dynamic stability, for a period less than 5 seconds, damp to 1/2 amplitude in 2 cycles.* 3.2.11.2 To provide for corrective action following a gust disturbance acceleration shall not exceed 1/4 g from trim in 10 sec.  3.2.11.1 To insure good maneuvering stability characteristics  	3.3.5 Oscillation of normal acceleration (from elevator pulse) shall damp to 1/10 amplitude in 1 cycle and the residual oscillations shall not be of objectionable magnitude. (Periods < 6 sec)	The dynamic oscillations of normal acceleration which occur at approximately constant speed, and which may be produced by abruptly deflecting and returning the longitudinal control to the trimmed position, shall meet the requirements of the accompanying figure for configuration P. For configuration PA the damping ratio shall be at least 0.055 for periods less than 5 seconds. If small amplitude residual oscillations exist, they shall not affect the utility of the airplane. 
		3.3.5.1 Elevator motion following pulse shall be essentially deadbeat or shall not result in objectionable A_z oscillations.	When the longitudinal control is abruptly deflected and released, the motion of the control following release shall be essentially deadbeat, unless the oscillations are of such frequency and magnitude that they do not result in an objectionable oscillation in normal acceleration.
		3.3.5.2 There shall be no tendency for sustained or uncontrollable oscillations from pilot effort to maintain steady flight.	There shall be no tendency for a sustained or uncontrollable oscillation resulting from the efforts of the pilot to maintain a steady flight path. The foregoing short period requirements shall apply at all permissible forward airspeeds and loadings, both in straight and turning flight. As a further aid in defining desirable dynamic characteristics, helicopter requirements 3.2.11.1 and 3.2.11.2 shall apply.

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F8785 (ASG)	V/STOL REQUIREMENTS
Long-period oscillations	For satisfactory dynamic stability Oscillation greater than 5 sec. but less than 10 sec at least lightly damped.* Oscillation greater than 10 sec but less than 20 sec shall not double amplitude in less than 10 sec.*	3.3.6 No objectionable flight characteristics attributable to apparent poor phugoid damping. If the period is less than 15 sec, oscillation shall be at least neutrally stable.	Although positive damping of the conventional long-period or phugoid oscillation is desired for all conditions, a negative damping ratio of -0.10 is acceptable provided the period of the oscillation is 10 seconds or longer. Any oscillation having a period greater than 5 seconds but less than 10 seconds shall have a damping ratio no less than zero. For the period range wherein essentially zero damping of the phugoid is tolerated, the longitudinal short period must be satisfactorily damped.
Longitudinal control effectiveness in hovering	Longitudinal control power shall be such that 1.0 inch motion of cyclic control shall produce an angular displacement at the end of 1 sec $\geq 45/(W+1000)^{1/3}$ deg. For full travel $\theta \geq 180/(W+1000)^{1/3}$ deg.*		To insure satisfactory longitudinal control for maneuvering, control power in hovering in still air shall be sufficient to produce an angular displacement of at least $45/(W+1000)^{1/3}$ degrees at the end of one second for one inch of control motion and $180/(W+1000)^{1/3}$ degrees at the end of one second for full control displacement.
Longitudinal steadiness in hovering	3.2.2 The helicopter shall be reasonably steady while hovering in still air (winds up to 3 knots) with less than ±1.0 inch movement of cyclic control (in and out of ground effect). To insure satisfactory initial response and minimize effects of external disturbances, pitch angular velocity damping shall be at least $8(I_y)^{0.7}$ ft-lb/radian/sec.*		The effects of downwash-ground interference shall not result in unsatisfactory hovering characteristics while hovering over a given spot in still air (winds less than 3 knots) for all terrain clearances up to the disappearance of ground effect. It shall be possible to accomplish this with less than ±1 inch movement of longitudinal control. In order to minimize the effects of external disturbances, the aircraft shall possess pitch angular velocity damping (that is, a moment tending to oppose the angular motion and proportional in magnitude to the pitch angular velocity) of at least $8(I_y)^{0.7}$ ft-lb/radian/sec.
Height control	3.2.3 It shall be possible to maintain control of altitude within ±1 ft by use of collective pitch control with less than ±1/2 inch movement of collective control in still air in and out of ground effect.		It shall be possible to maintain satisfactory control of altitude within ±1 ft by use of the height control while hovering in still air at all design altitudes both in and out of ground effect, with less than 1/2 inch movement of the height control.
Acceleration-deceleration characteristics	3.2.5 From maximum speed in steady, level, horizontal flight it shall be possible to readily and safely decelerate to stop and hover. From trimmed flight in hover it shall be possible to accelerate to V_{max} maintaining approximately constant altitude.		With the aircraft trimmed in hovering flight it shall be possible to readily and safely accelerate rapidly to maximum forward speed at constant altitude without encountering undesirable stalling characteristics. From trimmed steady, level unaccelerated flight at maximum forward speed, it shall be possible to readily and safely decelerate quickly to a stop and hover at a rate designated by the mission requirements. The ability to decelerate rapidly shall not be limited by longitudinal control power, longitudinal trim, stalling or buffeting, or engine thrust or response characteristics. The foregoing requirements apply both in and out of ground effect. For aircraft capable of operation to high subsonic speeds the constant altitude requirement may be relaxed.

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

<table>
<tr><th>ITEM</th><th>HELICOPTER SPECS. MIL-H-8501</th><th>AIRPLANE SPECS. MIL-F-8785 (ASG)</th><th>V/STOL REQUIREMENTS</th></tr>
<tr><td>Conversion and transition characteristics</td><td></td><td></td><td>In order to provide flexibility of operation it shall be possible to readily and safely stop conversion or transition in either direction. Rapidity of conversion or transition shall not be limited because of poor longitudinal stability and control characteristics or insufficient stall margin. For safe operation it shall be possible at any time during transition to make wave-offs or landings with the critical engine inoperative. These requirements are to apply both in ground effect and at the highest altitude designated for transition.</td></tr>
<tr><td>Steep descent characteristics</td><td></td><td></td><td>It shall be possible to make steep descents to landing with adequate control of airplane attitude and rate of descent without encountering unsatisfactory stall or buffet characteristics. The ability to make steep descents shall not be limited because of engine power effects. These requirements shall apply to as steep an angle as is compatible with the mission requirements of the aircraft</td></tr>
<tr><td>Longitudinal trim changes</td><td>3.2.6
The control forces required to change from any trim and power condition to any other trim and power condition shall not exceed 8 lb (cyclic longitudinal).*
Not more than 3 inches of longitudinal control displacement shall be required to maintain a constant airspeed over the available climb or descent range at V_{max}, 0, and 0.5 $V_{D_{max}}$.*</td><td>3.3.19
Longitudinal trim changes for power, flap, gear, etc., shall not exceed ±10 lb for classes I and II, and ±20 lb for class III airplanes, for conditions listed in table IV.</td><td>The longitudinal trim changes caused by changes in power, wing sweep position, flap setting, gear, thrust direction, deceleration device, etc., shall not be so large that peak longitudinal control forces in excess of 10 lb are required when such configuration changes are made in flight under conditions representative of operational procedure. Generally, the conditions listed in airplane requirement 3.3.19, table IV, will be sufficient to show compliance with this requirement. The magnitude and rate of trim change subsequent to a 5 second period after the configuration change shall be such that the forces are easily trimable by use of the normal trimming devices.</td></tr>
<tr><td>Longitudinal, lateral, and directional trim effectiveness</td><td>3.2.4
For all conditions in 3.2.1 (complete speed range) it shall be possible to trim to zero force and the controls shall exhibit positive self-centering.</td><td rowspan="2">[illegible]
Trim to zero control force over speed range with positive self-centering.
<table><tr><th>Cond.</th><th>Config.</th><th>Class</th><th>Min. V</th></tr><tr><td>1</td><td>P all c.g.</td><td>All</td><td>1.2 $V_{S_{CR}}$</td></tr><tr><td>2</td><td>L all c.g.</td><td>All</td><td>1.4 V_{S_L}</td></tr><tr><td>3</td><td>PA all c.g.</td><td>Carr.
Other</td><td>^{1}1.15 V_{S_L}
1.4 V_{S_L}</td></tr><tr><td>4</td><td>CR 2 crit. eng. out; wings level</td><td>All multi-eng.</td><td>V_{max} range</td></tr></table>^{1}Or normal approach speed, whichever is lower</td><td rowspan="2">The trimming devices shall be capable of reducing the elevator, rudder, and aileron control forces to zero, at all speeds between zero and the upper boundary of the operational flight envelope for VTOL operation and between the minimum designated approach speed and the upper boundary of the flight envelope for STOL operation. For multi-engine aircraft, trimmability is required down to the minimum operating speed for the critical engine inoperative in the approach configuration and down to the speed for maximum range with up to two most critical engines on one side inoperative for the cruise configuration.</td></tr>
<tr><td>Lateral-directional trim effectiveness</td><td>3.3.10
For all conditions of 3.2.1 and at 30 k left and right side velocities specified in 3.3.2, trim to zero laterally and directionally. At these trim conditions, controls shall exhibit positive self-centering characteristics. Stick "jump" undesirable.</td></tr>
<tr><td>Irreversibility of trim controls</td><td></td><td>3.5.5
All trim devices shall maintain a given setting indefinitely. Artificial stability or automatic interconnect devices shall have provision for return of device to its initial trim position following operation of device.</td><td>All trimming devices shall maintain a given setting indefinitely and shall meet airplane requirement 3.5.5.</td></tr>
</table>

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F8785 (ASG)	V/STOL REQUIREMENTS
Trim system failure		3.5.6 Failure of a power-actuated trim system (including sticking or runaway) shall not result in an unsafe flight condition. Following failure it shall be possible to cruise for extended periods and make a safe landing.	Failure of a power-actuated trim system (including sticking or runaway in either direction) shall not result in an unsafe flight condition. Following such a failure, it shall be possible to cruise for extended periods and make a safe landing.
Height control characteristics	3.2.13 The collective-pitch control shall not creep; limit forces of 7 lb shall not be exceeded; breakout forces not less than 1 lb or more than 3 lb permitted.* Collective pitch movement shall not produce objectionable cyclic forces; in no case greater than 1 lb. No force coupling for power boosted controls.*		The height control shall remain fixed at all times unless moved by the pilot and shall be essentially irreversible in order that it will not creep. The maximum effort for stick and throttle type controls shall not exceed 7 lb and 3 lb, respectively. There shall be no objectionable control force cross coupling.
Longitudinal trim change caused by sideslip	3.3.9 For the sideslip conditions specified in 3.3.9 (all forward speeds above approximately 50 k) a 10-percent margin of longitudinal control effectiveness (as defined in 3.2.1) shall remain.	3.3.20 For various configurations (table II) the longitudinal control force in sideslips (V = K) shall not exceed the lowest force for a ΔA_z of 1 g in turning flight; however, not to exceed 10 lb pull or 3 lb push for classes I, III, and II-C, and 25 lb + and 10 - on all others. Pull forces should accompany increasing sideslip and should be similar for ±β. Sideslip angles are those obtainable with 50 lb rudder force.	With the airplane trimmed for straight flight in each configuration and at the trim speeds specified for longitudinal stability tests, the longitudinal control force shall not exceed 10 lb pull or 3 lb push for all classes in sideslips up to that obtained with 50 lb rudder force. In addition, at the steady sideslip conditions specified for directional control effectiveness, a sufficient margin of longitudinal control shall exist to cope with gust disturbances. For VTOL operation a margin of 10 percent of the maximum hovering pitch angular acceleration shall be available.
Longitudinal control effectiveness in take-off	3.4.4.1 Make satisfactory safe vertical take-offs and landings in steady winds to 45 k and winds with gusts to 45 k. For < 1000 lb helicopters, 35 k.* 3.4.4.2 From a level paved surface, it shall be possible to make satisfactory, safe running take-offs with wheel type gear at ground speeds to 35 k.*	3.3.11 Elevator effectiveness shall not unduly restrict take-off performance. On a hard surface runway at V_{STO} it shall be possible to obtain take-off attitude for critical c.g. loadings. For class I tail wheel a/c thrust line level at 0.5 V_{STO} on sod and hard surface runway.	Longitudinal control effectiveness shall not unduly restrict the take-off performance of the airplane. As a minimum, control effectiveness shall be adequate to permit compliance with take-off performance guaranties or to obtain take-off attitude at no greater than V_{STO} on nose-wheel airplanes or attitude up to thrust line level at 0.5 V_{STO} on tail-wheel airplanes. These requirements shall be met with the airplane loading which produces the most critical moment and shall be applicable on sod as well as hard-surface runways. In addition, for VTOL operation it shall be possible to make satisfactory, safe vertical take-offs in steady winds up to the maximum designated wind velocity. The longitudinal control shall be powerful enough to prevent fore or aft translation during run-up to maximum power and it should be possible to check for proper control functioning during run-up at less than take-off power.
Longitudinal control in ground positioning	3.4.2 It shall be possible without use of wheel chocks to maintain a fixed ground position while power is increased to take-off in winds as specified in 3.4.4.1		
Longitudinal control forces in take-off		3.3.13 During take-off to 1.3 V_{STO} forces shall not exceed the following: Nose-wheel and bicycle gear a/c Classes I and III-C 20+ to 10- Classes III-L and II-C 30+ to 10- Class II-L 50+ to 20- Tail-wheel a/c Classes I, II-C, and III 20- to 10+ Class II-L 35- to 15+	With trim optional but constant, the longitudinal control forces required for take-offs and during the ensuing acceleration to the speed for minimum drag shall not exceed 20 lb pull or 10 lb push for nose wheel and bicycle gear aircraft and 20 lb push or 10 lb pull for tail-wheel aircraft.

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

ITEM	HELICOPTER SPECS. MIL-H-850.	AIRPLANE SPECS. MIL-F-8785 (ASG)	V/STOL REQUIREMENTS
Longitudinal control effectiveness in landing	3.4.1.3 For powered and autorotative conditions, make satisfactory, safe landings with wheel and skid gear up to 35 K ground speed. Construed to cover landings with 6 K side drift.*	3.3.14 At forward critical loading trimmed at 1.2 V_{S_L}, V_{S_L} or guaranteed landing speed can be reached in ground proximity.	At the forward critical loading, with the airplane trimmed at the approach speed, the longitudinal control shall be sufficiently effective to land at the guaranteed landing speed or the minimum operating speed for both shallow and steep approach angles. For VTOL operation it shall be possible to make satisfactory safe vertical landings in winds up to the maximum designated wind velocity.
Longitudinal control force in landing		3.3.15 It shall be possible to meet the requirements of 3.3.14 with F_e not exceeding 35 lb+ for classes I, II-C, and III a/c, or 50 lb for II-L.	It shall be possible to meet the landing requirements with a longitudinal pull force not to exceed 20 lb for all classes of airplanes.
Longitudinal control forces in dives		3.3.16 From level vlight trim at V_H, F_e at any attainable speed not to exceed 50 lb push or 10 lb pull in class III or 75- or 15+ in II a/c. After dive entry, ±10 lb for III or ±20 lb for class II allowable by adjusting trim. 3.3.16.1 From initial trim at V_H, but with optional trim during dive 50 lb push or 35 lb pull permitted to any permissible speed. Recovery forces not to exceed 120 lb.	With the airplane trimmed for level flight at V_H, the longitudinal control forces required in dives to any attainable speed within the operational flight envelope shall not exceed 50 lb push or pull for class II airplanes or 75 lb in class III airplanes.
Auxiliary dive recovery devices		3.3.17 Auxiliary dive recovery device shall always produce a positive Δg not to exceed a total of $0.8 n_L$, controls free, c.g. aft.	Operation of an auxiliary device for dive recovery at any speed shall always produce a positive increment of normal acceleration, but the total normal load factor shall never be greater than $0.8 n_L$, controls free, at the most aft critical loading.
Effects of drag devices		3.3.18 Operation of speed brakes or other drag devices shall not produce objectionable buffet or flight characteristics at any deflection. No objectionable nose-down trim change in landing approach.	Operation of the speed brakes or other drag devices provided for deceleration, dive-speed limitation, glide path control, etc., at any deflection shall not produce objectionable buffet or other undesirable characteristics. Drag devices used for flight path control in landing approach shall produce a mild nose down trim change with increasing drag and vice versa with negligible change in airspeed.

A406

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

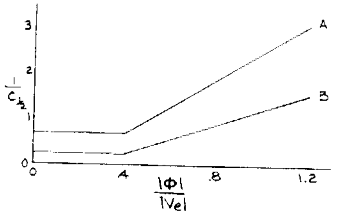
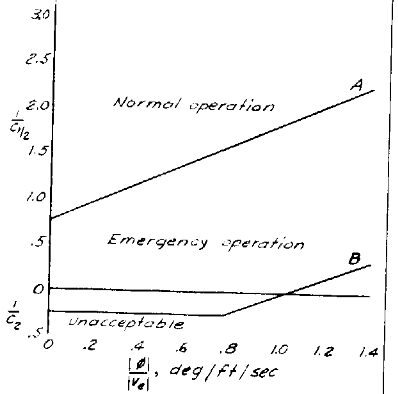
ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F8785 (ASG)	V/STOL REQUIREMENTS
Lateral-directional stability and control			
Damping of the lateral-directional oscillations		3.4.1 For various configurations and speed ranges, damping, controls fixed and free, shall not be less than curve A. Residual oscillations tolerated if small amplitude.  	In the configurations and over the speed ranges specified for longitudinal stability, the damping of the lateral-directional oscillations with the cockpit controls fixed or free, shall meet the requirements of curve A shown on the accompanying figure. Residual undamped oscillations may be tolerated only if the amplitude is sufficiently small that the motions are not objectionable. Generally, the conditions listed in table V of airplane requirement 3.4.1 will suffice for determination of compliance with these requirements. With stability augmenter inoperative, $1/C_2$ shall be no greater than 0.25 in all configurations and in configuration PA at least as high as curve B. Armed aircraft shall meet airplane requirement 3.4.1.1. 
Stability augmenter inoperative		3.4.1.2 With stability augmenter inoperative, $1/C_{1/2}$ shall be at least 0.24 in all configurations; in configuration PA values should be at least as high as curve B. 3.4.1.1 For armed airplanes under the critical flight conditions consistent with tactical mission requirements, damping parameter shall be at least that required by curve A or at least 1.03, whichever is higher.	
Spiral stability		3.4.2 Spiral stability not required, but rate of divergence shall not exceed double bank angle in less than 20 sec in PA and CR or 4 sec in any other flight condition of table II.	Spiral stability is not required, but if the spiral motion is divergent, the rate of divergence shall not be so great that, following a small disturbance in bank with controls fixed, the bank angle is doubled in less than 20 seconds in configurations PA and CR or 4 seconds for any other flight condition.

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

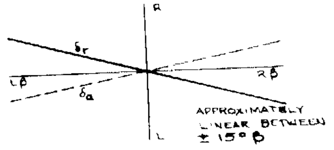
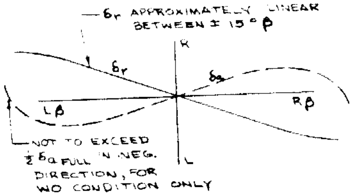
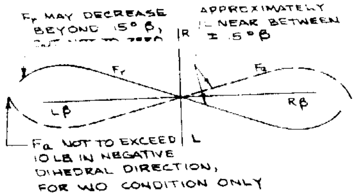
ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F-[illegible] (ASG)	V/STOL REQUIREMENTS
Steady sideslip conditions	3.3.7 Positive, control-fixed, directional stability and effective dihedral in powered and autorotative flight at all forward speeds above [illegible], 0.5 V_{max}, or $V_{climb\ max}$, whichever is lowest, up to full pedal, but not necessarily beyond β = 15° at V_{max}, [illegible] at the low speed determined above, or beyond a [illegible] determined by a linear variation with speed between these two angles. For above flight conditions, ability to apply lateral trim shall exist.	3.[illegible].3 Steady sideslips to values produced by full rudder, 250 lb F_r, or full δ_a, whichever is reached first. Obtained at lightest G.W. in configurations and speed ranges of table II. For class III and II-C in configuration WC at all permissible speeds above $V_{S_{PA}}$ trimmed at 1.15 V_{S_L} in config. PA. Limit β to -10° for single engine, single rotation prop a/c.	Requirements for static directional stability, dihedral effect, and side force variation shall apply in straight path (zero turn rate) sideslips up to the sideslip angles produced by full rudder deflection, 250 lb of rudder force, sideslip angles up to ±5° or up to sideslip angles which might be required in normal operation or tactical employment in the configurations specified for longitudinal stability. Although the requirements apply over the entire speed range, investigation at designated trim speeds will ordinarily suffice for determination of compliance.
Static directional stability (rudder position)	3.3.9 (continued) For steady sideslips  	3.[illegible] For the sideslip conditions specified in 3.[illegible].3  	The airplane shall possess rudder-fixed directional stability such that, in the sideslips specified, right rudder pedal deflection from the wings-level position is required in left sideslips and vice versa. For angles of sideslip between ±15° from the wings-level condition, the variation of sideslip angle with rudder pedal deflection shall be essentially linear. Throughout the remainder of the range of required pedal deflections, an increase in pedal deflection shall always be required for an increase in sideslip.
Static directional stability (rudder force) [illegible] effect (aileron force)		3.[illegible].5 For sideslips specified in 3.[illegible].3  	The airplane shall possess rudder-free stability such that, in the sideslips specified, right rudder force is required in left sideslip and vice versa. For angles of sideslip between ±15° from the wings-level straight flight condition, the variation of sideslip angle with rudder force shall be essentially linear. At greater angles of sideslip, a lightening of rudder force is acceptable, but the rudder force shall never reduce to less than one-half the maximum value nor less than the allowable friction value. The airplane shall exhibit positive control-free dihedral effect as indicated by the variation of aileron control force with sideslip. Left aileron control force shall be required for left sideslip and vice versa. The variation of aileron control force with sideslip angle shall be essentially linear, and the aileron force shall not exceed 10 lb for stick or wheel control airplanes. For transient type maneuvers such as wave-off negative dihedral effect not to exceed 10 lb is permissible.

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F8785 (ASG)	V/STOL REQUIREMENTS
Dihedral effect (aileron position	See 3.3.9 above. 3.3.9.2 At all speeds in 3.3.9 no reversal in roll velocity is permitted. Stick deflection chosen so that $\varphi = 30^\circ$ in 6 sec (rudder fixed).	3.4.6 Positive dihedral effect as shown in figure of 3.4.4. 3.4.6.1 Configuration WO may be excepted from requirement of 3.4.6; however, cockpit control δ_a shall never exceed 1/2 full deflection in negative dihedral direction. 3.4.6.2 Positive dihedral effect shall never be so great that more than 75 percent full δ_a is required for β of 10° in configuration L at 1.1 V_{S_L}. 3.4.6.3 Throughout rolls, similar to those of 3.4.16, but rudder free, rolling velocity shall always be in correct direction.	The airplane shall exhibit positive control-fixed dihedral effect in that left aileron deflection shall be required for left sideslip and vice versa. For transient type maneuvers, such as wave-off, negative dihedral effect not to exceed 1/2 of full deflection is permissible. The positive dihedral effect in the sideslips specified shall never be so great that less than 10 percent of maximum rolling acceleration is available at the minimum operating speed.
Side force in sideslips		3.4.8 For sideslips specified in 3.4.3 right bank for right sideslip, etc.	The side force characteristics shall be such that in the sideslips specified, an increase in right bank angle accompanies an increase in right sideslip and vice versa.
Adverse yaw	3.3.9.2 At conditions specified in 3.3.9 it shall be possible to make complete turns in each direction, rudder fixed, by use of cyclic control, alone. At all speeds in 3.3.9 no reversal in φ permitted. Stick deflection chosen so that $\varphi = 30^\circ$ in 6 sec.	3.4.9 Angle of sideslip from a 45° - 45° roll (rudder fixed) at 1.4 $V_{S_{CR}}$ and 1.4 $V_{S_{PA}}$ shall not exceed 15°. Aileron deflection used is that to meet minimum roll criteria (3.4.16). For smaller values of δ_a, $\beta \approx \delta_a$.	The angle of sideslip developed during a rudder-fixed abrupt rollout of a trimmed, level, steady banked turn in configuration PA at the speed for minimum drag shall not exceed 15°. The aileron deflection held during the roll shall be at least that required for compliance with lateral control performance tests. For smaller aileron deflections a proportional angle of sideslip is required. For aircraft which exhibit favorable yaw, the values of sideslip in the favorable direction obtained during the aforementioned rolls shall not be so large as to cause objectionable flight characteristics.
Asymmetric power (rudder free)		3.4.10 In configuration P, critical engine out, NRP on other engine(s) it shall be possible to maintain straight flight by banking and sideslipping. Lightest normal service gross weight for all speeds above 1.4 V_{S_G}.	On multiengine airplanes the motions following sudden failure of the critical engine shall be such that dangerous flight conditions can be avoided by normal pilot corrective action. In configuration P, with the most critical engine inoperative, and with other engine(s) developing normal rated power, it shall be possible at all speeds greater than the speed for minimum drag to maintain straight flight by banking and sideslipping.

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F8785 (ASG)	V/STOL REQUIREMENTS
Directional control (symmetric power)	3.3.2 From hovering, it shall be possible to obtain steady, level translational flight at left and right sidewise velocities of 35 k.* Controls and helicopter shall be free from objectionable shake, vibration, or roughness.	3.4.11 For configurations and speeds of table II, directional control shall be sufficient for straight, wings level flight with $F_R < 180$ lb. For class III a/c in WO down to $V_{S_{PA}}$ with $F_R \leq 100$ lb when trimmed at 1.15 V_{S_L}, maintain straight, wings level flight. 3.4.11.1 For all airplanes, except cross-wind gear a/c, directional control to develop 10° β in configuration L at 1.1 V_{S_L} with $F_R < 180$ lb.	For all airplanes, directional control shall be sufficiently effective to maintain wings-level straight flight in the configurations and speed ranges specified for longitudinal stability, with rudder control forces not greater than 100 lb when the airplane is trimmed directionally at the designated trim speeds. For STOL operation, directional control shall be sufficient to permit development in the critical direction of at least 10° sideslip angle or to the maximum value specified in normal operation for cross-wind landings at the minimum operating speed. For all airplanes in configuration WO at the lightest normal loading, directional control shall be sufficiently effective to maintain wings-level straight flight at all speeds down to $V_{S_{PA}}$ with rudder control force not exceeding 100 lb when trimmed at the approach speed. For VTOL operation, from a trimmed hovering condition, it shall be possible to obtain steady, level translational flight at the maximum designated sidewise velocity to both the right and left.
Directional control (asymmetric power)		3.4.12 On multiengine a/c in configuration TO critical outboard engine inoperative, it should be possible to maintain straight flight with $\beta < 5°$ at speeds above 1.2 $V_{S_{TO}}$ for lightest normal take-off loading. With trim adjusted for symmetrical take-off power, $F_R < 180$ lb.	On all multiengine airplanes in configuration TO with the critical engine inoperative, it shall be possible, at the lightest normal take-off loading and with take-off power on the remaining engine(s), to achieve and maintain straight flight with a bank angle not greater than 5 degrees at all speeds above the minimum operating speed. In addition, a sufficient margin of directional control shall be available to perform a standard rate turn (3° per sec) in the critical direction. With trim settings normally employed in a symmetric power take-off, the rudder pedal force required to perform the foregoing maneuvers shall not exceed 100 lb.
Directional control during take-off, landing, and taxi	3.3.1 Control shall be sufficiently powerful to permit easy execution of all normal taxi maneuvers on land and water, using normal rotor speeds. In particular, it shall be possible to maintain a straight path in any direction in a wind of 35 k.* It shall be possible to make a complete turn in either direction by pivoting on one wheel for the foregoing wind velocity.	3.4.13 Without exceeding 180 lb (F_R), control shall be adequate to maintain straight paths on ground during normal take-offs and landings. For class I a/c this shall apply in calm air, 90° cross winds of at least 50 percent V_{S_L} or 20 k, whichever is less. For classes II and III in calm air, 30 percent V_{S_L} or 40 k cross wind. 3.5.2 Perform all normal taxi without undue effort or inconvenience. 3.4.13.1 Without use of wheel brakes for classes II-C and III-C, straight ground paths shall be maintained on ground at 30 k and greater during take-offs and landings in a 90° cross wind of at least 10 percent V_{S_L} with $F_R < 180$ lb.	The rudder control, in conjunction with other normal means of control, shall be adequate to maintain straight paths on the ground during taxi, normal take-offs, and landing in winds in any direction up to the maximum designated wind velocity. This requirement shall be met with not more than 100 lb pedal force. In addition, it shall be possible to make a complete turn in either direction by pivoting on one wheel in winds up to the maximum designated.

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

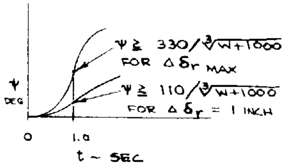
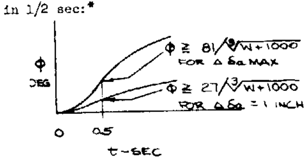
ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F8785 (ASG)	V/STOL REQUIREMENTS
Directional control to counteract adverse yaw		3.4.14 For -5° - 45° rolls specified in 3.4.9, directional control effectiveness shall be adequate to maintain zero sideslip with $F_R < 180$ lb.	In the rolling maneuvers specified for adverse yaw, the rudder control shall be adequate to maintain trim sideslip with rudder pedal forces not to exceed 100 lb.
Directional control in dives		3.4.15 When trimmed at service ceiling in configuration P, rudder control shall keep $\beta = 0$ throughout dives and pull-outs (3.3.16) with $F_R < 50$ lb for classes I and III a/c and < 180 lb for class II.	When trimmed directionally at the service ceiling in configuration P, the rudder control shall be capable of maintaining zero sideslip throughout the specified dives and pull-outs without exceeding 100 lb rudder pedal force.
Directional steadiness in hovering	3.3.3 For still air, it shall be possible to hover over a given spot in and out of ground effect with less than ±1.0 inch of lateral control and less than ±1 inch of rudder pedal control. To minimize effects of external disturbances, yaw damping shall be $\geqq 27(I_z)^{0.7}$ ft-lb per radians per sec.*		The aircraft shall be reasonably steady while hovering in still air (winds up to 3 knots) requiring less than ±1 inch rudder pedal movement for all terrain clearances up to the disappearance of ground effect. In order to minimize the effect of directional disturbances, the yaw angular velocity damping should be no less than $27(I_z)^{0.7}$ ft-lb/radians/sec.
Directional control power	3.3.5 When hovering, still air, at maximum overload gross weight or at rated take-off power (in and out of ground effect) directional control power shall fall within the following:* 		Directional-control power shall be such that when the aircraft is hovering in still air, a one-inch displacement of the directional control shall produce a yaw displacement of the end of one second which is at least $110/(W+1000)^{1/3}$ degrees and for full-directional control, $330/(W+1000)^{1/3}$ deg. These requirements shall apply both in and out of ground effect and at both maximum gross weight and the lightest normal take-off weight at take-off power. In no case shall the yaw displacement be less than 15° at the end of one second for full-directional control deflection.
Turns in winds	3.3.6 Turn 360° over a given spot at max. gross weight or at take-off power (in and out of ground effect) in a wind of at least 30 k. When starting at zero yawing velocity for adequate margin of control during 360's at most critical angle to relative wind, application of full directional control in critical direction results in a yaw displacement of at least $\psi \geq 110/(W+1000)^{1/3}$ deg in the first second.*		It shall be possible to execute a 360° turn in each direction while hovering over a given spot at the maximum designated wind velocity. This requirement shall apply in and out of ground effect at both maximum gross weight and the lightest normal take-off weight at take-off power. To insure adequate margin of control when starting at zero yaw rate at the most critical azimuth angle relative to the wind, the application of full-directional control in the critical direction should result in a yaw displacement of at least $110/(W+1000)^{1/3}$ deg in the first second. In no case shall the yaw displacement be less than 5° at the end of one second for full-directional control deflection.
Directional control sensitivity	3.3.7 Directional control sensitivity shall not be so high as to cause overcontrol and will be considered excessive if greater than 50° for the first sec for 1.0" of sudden pedal displacement when hovering at lightest normal service loading.		The response of the aircraft to directional-control displacement in hover shall not be so high as to cause a tendency for the pilot to overcontrol. In any case, the sensitivity shall be considered excessive if the yaw displacement is greater than 50° in the first second following a sudden pedal displacement of 1 inch from trim while hovering at the lightest normal service loading.

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

<table>
<tr><th>ITEM</th><th>HELICOPTER SPECS. MIL-H-8501</th><th>AIRPLANE SPECS. MIL-F8785 (ASG)</th><th>V/STOL REQUIREMENTS</th></tr>
<tr><td>Directional control in power off flight (autorotation)</td><td>3.3.8
It shall be possible to make turns in each direction at all autorotation speeds.</td><td></td><td>It shall be possible to make at least standard rate turns (3° per second) in either direction at all speeds down to the speed for minimum drag in configuration L.</td></tr>
<tr><td>Lateral steadiness in hovering</td><td>3.3.3
For still air, it shall be possible to hover over a given spot in and out of ground effect with less than ±1 inch of lateral control movement.</td><td></td><td>The aircraft shall be reasonably steady while hovering in still air requiring a minimum of pilot effort to keep the aircraft positioned laterally over a given spot on the ground with less than ±1 inch of lateral control movement, for all terrain clearances up to the disappearance of ground effect.</td></tr>
<tr><td>Lateral control power in forward flight and hovering</td><td>Lateral control power for hovering shall produce in 1/2 sec:*


To minimize effect of external disturbances roll damping ≥ $18(I_X)^{0.7}$ ft-lb/radians/sec.*</td><td>3.4.16
Minimum Roll Requirements[1]
<table>
<tr><th></th><th>Configurations P, CO (to V_H)</th><th>P, CO at 0.95 V_M (2)</th><th>L, PA 1.1 V_{S_L}</th></tr>
<tr><td>hp</td><td>Low, medium, high</td><td>Lowest for highest V_M</td><td>Low</td></tr>
<tr><td>Class I</td><td>$\frac{pb}{2V}$ = 0.09 at speeds to 0.8 V_H</td><td>$\frac{pb}{2V}$ = 0.03</td><td>0.09</td></tr>
<tr><td>Class II</td><td>$V_H < 500$ k
$\frac{pb}{2V}$ = 0.07
$V_H > 500$ k
$\frac{pb}{2V}$ = 0.07 to 0.06 V_H
$\frac{pb}{2V}$ = 0.05 at 0.8 V_H</td><td>$\frac{pb}{2V}$ = 0.015</td><td>$\frac{pb}{2} = 10^{1/5}$
II-L
$\frac{pb}{2V}$ = 0.07
II-C
Same as III</td></tr>
<tr><td>Class III</td><td>$\frac{pb}{2V}$ = 0.07 from 1.1 V_{S_G} to max V_{combat}
φ = 100° in 1 sec from min combat V up to hp, 20,000</td><td>ϕ = 50° in 1 sec</td><td>$\frac{pb}{2V}$ = 0.05 for first 30°</td></tr>
</table>
[1] Need not exceed 220°/sec.
[2] Should be in correct direction above 0.95 V_M.</td><td>Lateral control shall be adequate for compliance with the rolling performance specified below. In obtaining the required rolling performance, the rudder pedals may be held fixed or may be employed to reduce adverse yaw (not to produce favorable yaw). At the trim speeds specified for longitudinal stability and for configurations L, PA, and WO the airplane shall be capable of obtaining a bank angle ≧ $81/(W+1000)^{1/3}$ deg in 1/2 second, but not less than 15° within 1 second of initiation of abrupt, full lateral control displacement. In addition, the roll angular velocity damping shall be at least $18(I_X)^{0.7}$ ft-lb/radians/sec. If stability augmentation is used to obtain the desired roll time constant, failure of the system shall not result in a time constant greater than 4 seconds. In configuration P the airplane shall be capable of obtaining a bank angle of at least 50° but not greater than 160° in 1 second with the roll time constant not to exceed 1.5 seconds.</td></tr>
<tr><td>Roll rates and sensitivity</td><td>3.3.14
The lateral control sensitivity shall not cause pilot to overcontrol and shall be considered excessive if $\dot{\varphi} > 20$ deg/sec/inch of stick displacement.</td><td></td><td>The lateral response of the aircraft in hover shall not be so large as to cause a tendency for the pilot to overcontrol. In any case, the control effectiveness shall be considered excessive if the maximum displacement is greater than 20° at the end of 1 second for 1 inch of control displacement.</td></tr>
</table>

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F8785 (ASG)	V/STOL REQUIREMENTS
Roll response	3.3.15 No objectionable or excessive delay in $\dot{\phi}$ in response to lateral or directional control displacement. $\ddot{\phi}$ shall be in proper direction within 0.2 sec for all flight conditions of 3.2.1 including vertical autorotation.	3.4.16.8 There shall be no objectionable nonlinearities in rolling response with lateral control deflection or force causing sensitivity or sluggishness in response to small cockpit control motions or force. 3.4.16.2 On class II-L, $\ddot{\phi}$ shall be obtained in $(0.5 + b/100)$ seconds with peak control forces $<$ 25 lb (stick) and 50 lb (wheel) for most critical I_{x-x} and for $pb/2V$ values specified above.	There shall be no objectionable nonlinearities in the variation of rolling response with lateral deflection or force causing sensitivity or sluggishness in response to small cockpit control deflections or forces. In addition, there shall be no objectionable or excessive delay in the development of angular velocity in response to lateral control deflection. For all airplanes the angular acceleration shall be in the proper direction within 0.2 sec after the initiation of pilot-control action. This requirement shall apply to the loading condition which produces the most critical rolling moment of inertia and for all flight conditions specified for roll performance.
Peak lateral control forces for rolling performance		3.4.16.3 Peak lateral control forces for rolling performance not to exceed: Classes I & II - 25 lb (stick) or 50 lb (wheel) Class III - 20 lb (stick) or 40 lb (wheel) Classes II-C & III-C in config. L - 20 lb stick or wheel At 0.8 V_H, F_a shall not be less than half the above values.	The peak lateral control force required to obtain the specified rolling performance shall not exceed 20 lb for stick or wheel in take-off, landing, landing approach, and wave-off configurations. In all other configurations 25 lb stick force and 50 lb wheel force is permissible.
Lateral wheel throw limits		3.4.16.4 For wheel-type controls, wheel throw to meet lateral control requirements shall not exceed 90° in each direction.	For all airplanes with wheel-type controls, the wheel throw necessary to meet the lateral-control requirements shall be readily obtainable with one hand and shall not in any case exceed 90° in each direction.
Peak lateral and directional forces for various maneuvers	3.3.11 Lateral and directional control forces due to power and speed changes, landings and take-offs, ground handling, sidewise flight, asymmetrical lateral c.g., rudder kicks, turns while hovering, turns in autorotation, and turns using cyclic alone shall not exceed:* Lateral 7 lb Rudder 15 lb 3.3.4 In all normal service loading conditions, including asymmetrical lateral c.g. locations and steady flight over the complete speed range (including autorotation) and sidewise flight at 35 k, a sufficient margin of control effectiveness, and at least enough to produce 10 percent of max. attainable hovering $\ddot{\phi}$, shall remain at each end.*	3.4.16.5 Lateral control shall be sufficiently effective to balance airplane laterally in asymmetric power, 10° β in landing, during take-off and landing in cross winds, in steady sideslips (3.4.11.1) and (3.4.7) with forces not to exceed values given in 3.4.16.3.	Lateral control shall be sufficiently effective to balance the airplane laterally under the specified conditions for asymmetric power, symmetric power, cross-wind landings, landings and take-offs, engine power changes, longitudinal stability, ground handling, sidewise flight, asymmetrical lateral c.g., hovering turns, rudder-free turns, and turns at the minimum operating speed; and a sufficient margin of control effectiveness shall remain. For VTOL operation a margin of 10 percent of the maximum attainable hovering rolling acceleration shall remain. For these conditions the peak aileron control force shall not exceed 20 lb for stick or wheel control.
Lateral trim change and effectiveness	It shall be possible to maintain lateral trim with a control displacement of no more than 1.0" from the initial trim condition (at a constant speed) as the power and/or collective pitch is varied slowly or rapidly in either direction throughout the available range.*		The airplane shall not exhibit excessive lateral trim changes with changes in power and/or height control. When starting from trim at any combination of power and airspeed within the flight envelope, it shall be possible to maintain lateral trim within the force limitations and with the control margin noted in the previous requirement as engine power and/or height control is varied either slowly or rapidly in either direction throughout the available range.

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

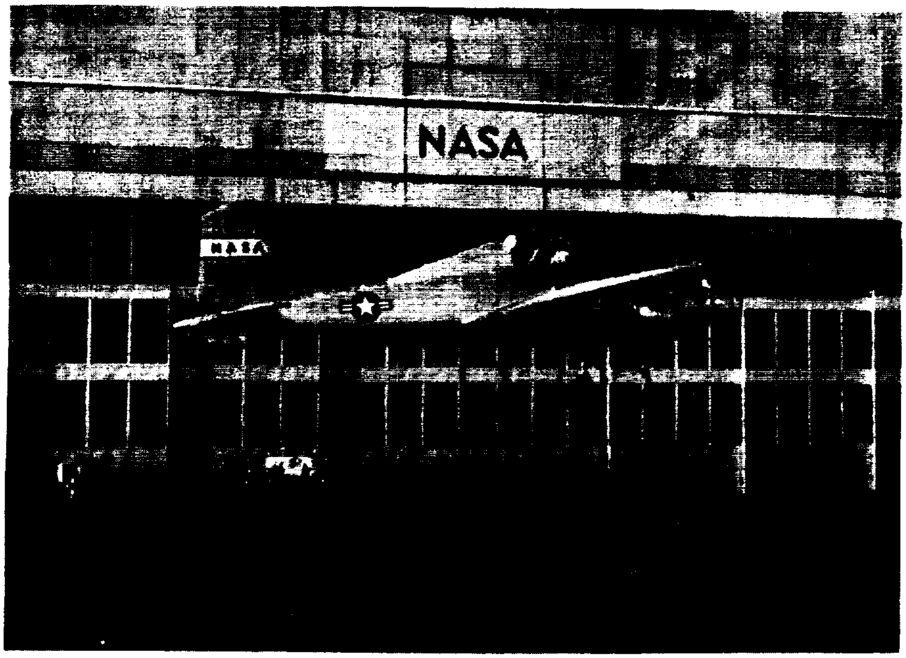
ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F8785 (ASG)	V/STOL REQUIREMENTS
Lateral control effectiveness in dives		3.4.16.6 From trim at service ceiling in configuration P, lateral control effectiveness shall be adequate to maintain wings level in dives and pull-outs with $F_a < 10$ lb stick or 20 lb wheel (dives and pull-outs specified in 3.3.16).	When trimmed laterally at the service ceiling in configuration P, lateral-control effectiveness shall be adequate to maintain the wings level throughout the specified dives and pull-outs with lateral-control forces not exceeding 10 lb for stick or 20 lb for wheel control.
Lateral and directional control cross-coupling and transient effects Roll-pitch-yaw-coupling	3.3.13 The controls shall be free from objectionable transient forces. During aileron or rudder steps, force acting to resist displacement shall not fall to zero. Lateral control shall not produce longitudinal forces in excess of 40 percent or pedal forces in excess of 100 percent of lateral force. Pedal displacement shall not produce F_e in excess of 8 percent or F_a in excess of 6 percent of the associated pedal force. No force feedback for power-boosted controls.*	3.5.7 In rudder and elevator-cockpit control-fixed 360° rolls entered from all flight conditions from 0 g to 2/3 N_L, resulting yaw motion, β, and A_z shall neither exceed structural limits nor cause dangerous flight oscillations. In combat rolls to 180°, resultant motions shall not impair seriously the tactical effectiveness of the maneuver.	In rudder- and elevator-cockpit control-fixed rolls to the maximum designated bank angle at all altitudes and permissible speeds, the resulting yaw motion, sideslip angle, and normal acceleration shall neither exceed structural limits nor cause other dangerous flight conditions such as uncontrollable oscillations. In addition, the controls shall be free from objectionable transient forces in any direction following a lateral step input and the force acting to resist displacement shall not decrease to zero.
Control for spin recovery		3.5.1 In configurations G and L, normal controls of classes I and III a/c shall provide prompt consistent recoveries from erect and inverted spins without exceeding 250 lb (F_R), 75 lb (F_e), and 35 lb (F_a).	For all aircraft capable of being spun the spin characteristics shall be such that controls shall be adequate to provide consistent prompt recoveries from fully developed erect and inverted spins power off. Recovery shall not require abnormal pilot effort, and recovery-control forces shall not exceed 250 lb (directional), 75 lb (longitudinal) or 35 lb (lateral).
Stall characteristics Required flight conditions		3.6.1 Requirements for stall shall apply at all c.g. for configurations G, CR, L, and PA in straight flight and in accelerated flight up to limits of operational envelope. Apply also to normal external [illegible]	The requirements for stall characteristics shall apply at all permissible c.g. positions for configurations G, CR, L, PA, and WO and with and without BLC operating and for various power settings in configuration PA corresponding to shallow and steep approaches. The stall characteristics shall be checked in straight unaccelerated flight and with normal acceleration up to the limits of the operational flight envelope.

TABLE II.- FLYING QUALITIES REQUIREMENTS - Continued

ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F8785 (ASG)	V/STOL REQUIREMENTS
Definition of conventional stalling speed (minimum speed)		3.6.2 Stalling speed V_s is defined as the minimum speed attainable in flight, normally associated with airflow breakdown after $C_{L_{max}}$. To minimize dynamic lift effects, approach to stall shall be no greater than 1 k per sec. Complete stall is characterized by uncontrollable pitching or rolling, or by a decrease in A_z in turning flight.	The stalling speed, V_s, is defined as the minimum speed attainable in flight at a given power or thrust angle setting, and can be associated with flow breakdown over the wing upon attaining the maximum over-all trimmed airplane lift coefficient. The complete stall can be characterized by large magnitude pitching, rolling, or yawing, or by a decrease in normal acceleration in turning flight or a large sudden increase in sink rate in straight flight. For airplanes with limited longitudinal control power, the stalling speed shall be defined as the minimum speed attainable in the applicable configuration and power setting for the aft critical c.g. loading. In the event that considerations other than wing maximum lift or available longitudinal control determine the minimum usable flying speed, the stalling speed, V_s, for that configuration shall be equal to the minimum operating speed defined as the speed at which a safe landing can be made with the critical engine inoperative or as noted in airplane requirement 3.6.2.2.
Definition when limited by longitudinal control		3.6.2.1 For some airplanes with insufficient longitudinal control, V_s is defined as the minimum speed attainable at the aft c.g. loading.	
Definition by visibility, performance, etc.		3.6.2.2 When considerations other than wing $C_{L_{max}}$ or δ_e determine minimum usable flying speed in any configuration (e.g., ability to perform altitude corrections, take a wave-off, visibility, etc.), V_s shall be speed agreed upon by contractor and procuring activity; however, such definition is consistent with V_s used for structural design considerations performance guarantees, etc.	
Stall warning requirements		3.6.3 The approach to the stall shall be accompanied by an easily perceptible warning occurring at 1.05 to 1.15 V_s in configurations G, L, and CR and between 1.05 and 1.10 V_s in PA. Acceptable stall warning shall consist of shaking of cockpit controls, buffeting or shaking of airplane, or both.	The approach to the complete stall shall be accompanied by an easily perceptible stall warning which occurs between 1.05 and 1.15 times the stalling speed in configurations G, L, and CR, and between 1.05 and 1.10 times the stalling speed in configurations PA and WO, but in no case less than 5 k. Acceptable stall warning shall consist of shaking of the cockpit controls, buffeting or shaking of the airplane, or both.
Artificial stall warning		3.6.3.1 Artificial stall warning permitted only if it can be shown that aerodynamic stall warning is not feasible and if device approved by procuring activity.	Artificial stall warning, if necessary, shall provide a warning similar to aerodynamic stall warning. As an adjunct to either type of stall warning an angle-of-attack indicator is considered highly desirable.
Warning for limited longitudinal control cases		3.6.3.2 For airplanes with limiting elevators, no stall warning is required provided a true aerodynamic stall cannot be obtained at aft c.g. and no dangerous flight motions occur at minimum speed.	For airplanes which do not have a true aerodynamic stall as previously defined, no stall warning is required provided no dangerous flight characteristics occur at the minimum speed.
Requirements for acceptable stalling characteristics		3.6.4 Although it is desired that no nose-up pitch-up occurs at the stall, a mild pitch-up may be accepted provided no dangerous or objectionable flight results. Stall is unacceptable if roll-off or pitch-down exceeds 20° for classes I and II or 30° for III. These requirements apply to all stall definitions.	Although it is desired that no nose-up pitch occur at the stall, a mild nose-up pitch may be accepted provided that no dangerous or seriously objectionable flight conditions result. The stall shall be considered unacceptable if the airplane exhibits initial rolling or downward pitching at the stall in excess of 20° from level for configurations G and CR. In configurations L, WO, and PA for all airplanes the initial roll-off at the stall shall not exceed the bank angle at which a wing tip or pod may strike the ground when the airplane is resting on the landing gear. Failure of the BLC system at the stall shall not result in initial excursions in roll, pitch-down, or yaw exceeding 30° nor shall a dangerous flight condition occur.

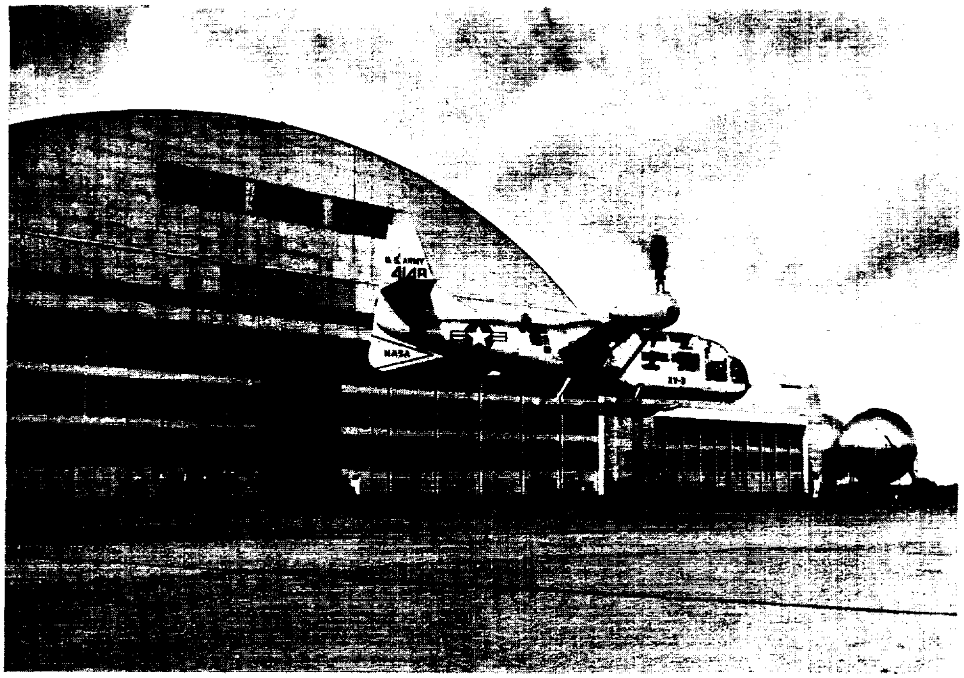
TABLE II.- FLYING QUALITIES REQUIREMENTS - Concluded

ITEM	HELICOPTER SPECS. MIL-H-8501	AIRPLANE SPECS. MIL-F8785 (ASG)	V/STOL REQUIREMENTS
Prevention of complete stall		3.6.4.1 It shall be possible to prevent complete stall by normal use of controls at the onset of stall warning.	It shall be possible to prevent the complete stall by normal use of the controls at the onset of the stall warning. In the event of a complete stall, it shall be possible to recover by normal use of the controls with reasonable control forces regardless of engine power, and without excessive loss of altitude or buildup of speed.
Recovery characteristics		Recovery from complete stall shall be possible by normal use of controls with reasonable forces and without excessive altitude loss or speed buildup.	
Performance (engine) considerations		6.10 The effects of engine operation on flying qualities design requirements are covered under "trim changes with power, etc." Other secondary effects such as engine control and response, effects of engine gyroscopic moments on airplane dynamic motions, and the effects of engine operation in spins and spin recoveries shall not be overlooked.	The engine power changes required for normal flight operations shall not result in inadequate control power of reaction-type controls or other controls which derive their effectiveness from the main engine. Engine-thrust response shall be adequate for height control in hovering and for altitude and/or flight-path control in transition and landing approach. Thrust control shall be capable of fine enough adjustment to permit control of flight path by use of engine power, and engine-power controls shall not require unnecessarily complicated procedures for power changes.
Gyroscopic coupling effects			The effects of engine, fan, or rotor gyroscopic moments on the airplane dynamic behavior shall not result in objectionable flight characteristics. Upon failure of stability augmentation equipment for gyroscopic effects, the aircraft shall possess a sufficient degree of controllability to allow continuation of normal level flight and maneuvering necessary to permit a safe landing under visual flight conditions.



A-25897

Figure 1.- The X-14 deflected turbojet airplane.

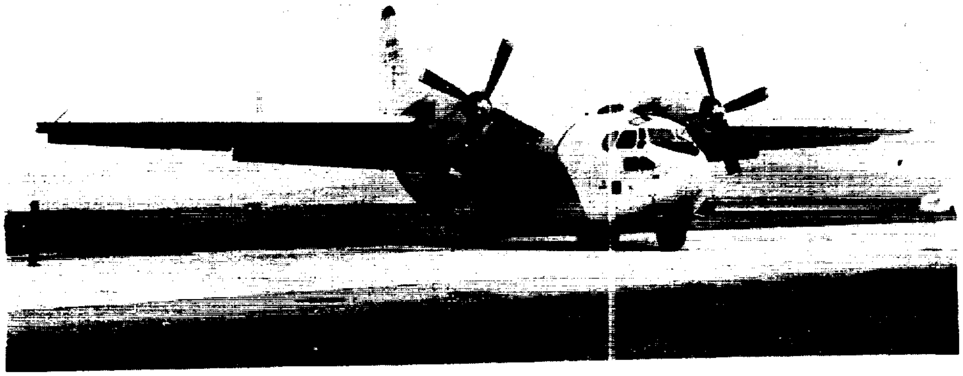


A-25685

Figure 2.- The XV-3 convertiplane.

A-26052

Figure 3.- The VZ-3RY deflected slipstream airplane.



A-26297

Figure 4.- The C-134A STOL airplane.

C

A 406

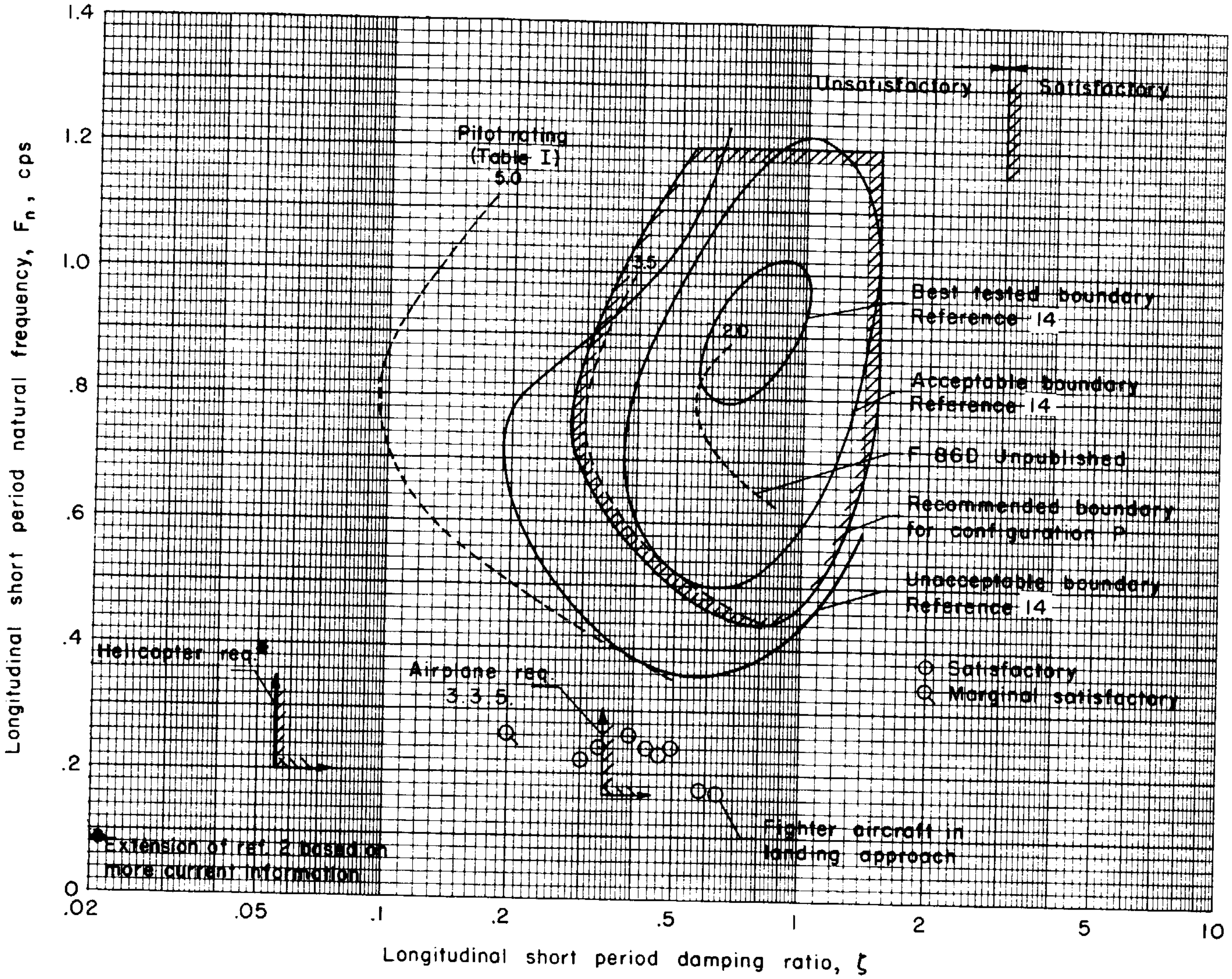


Figure 5.- Dynamic short-period longitudinal characteristics.

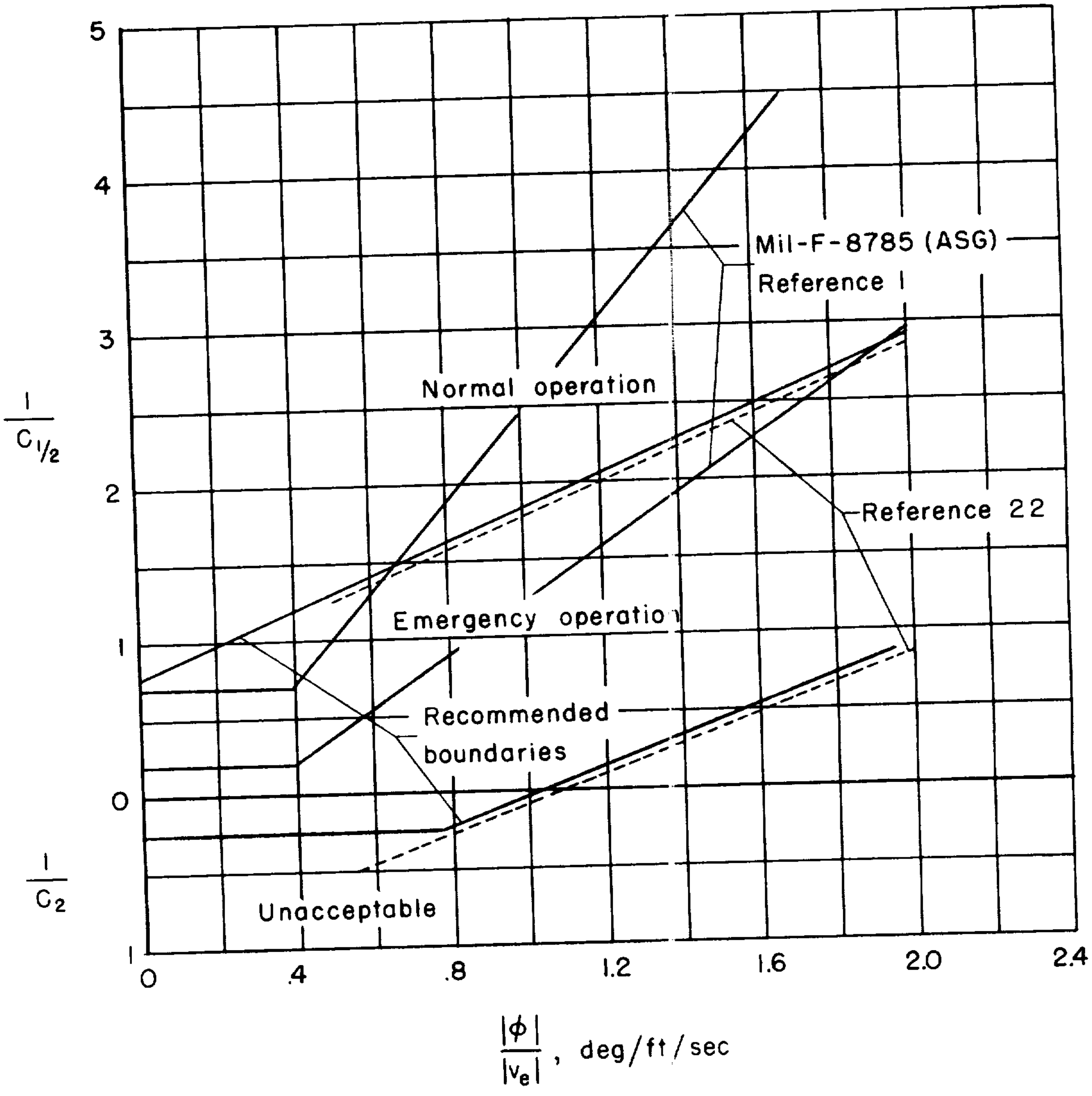


Figure 6.- Lateral directional damping characteristics.

A
4
0
6

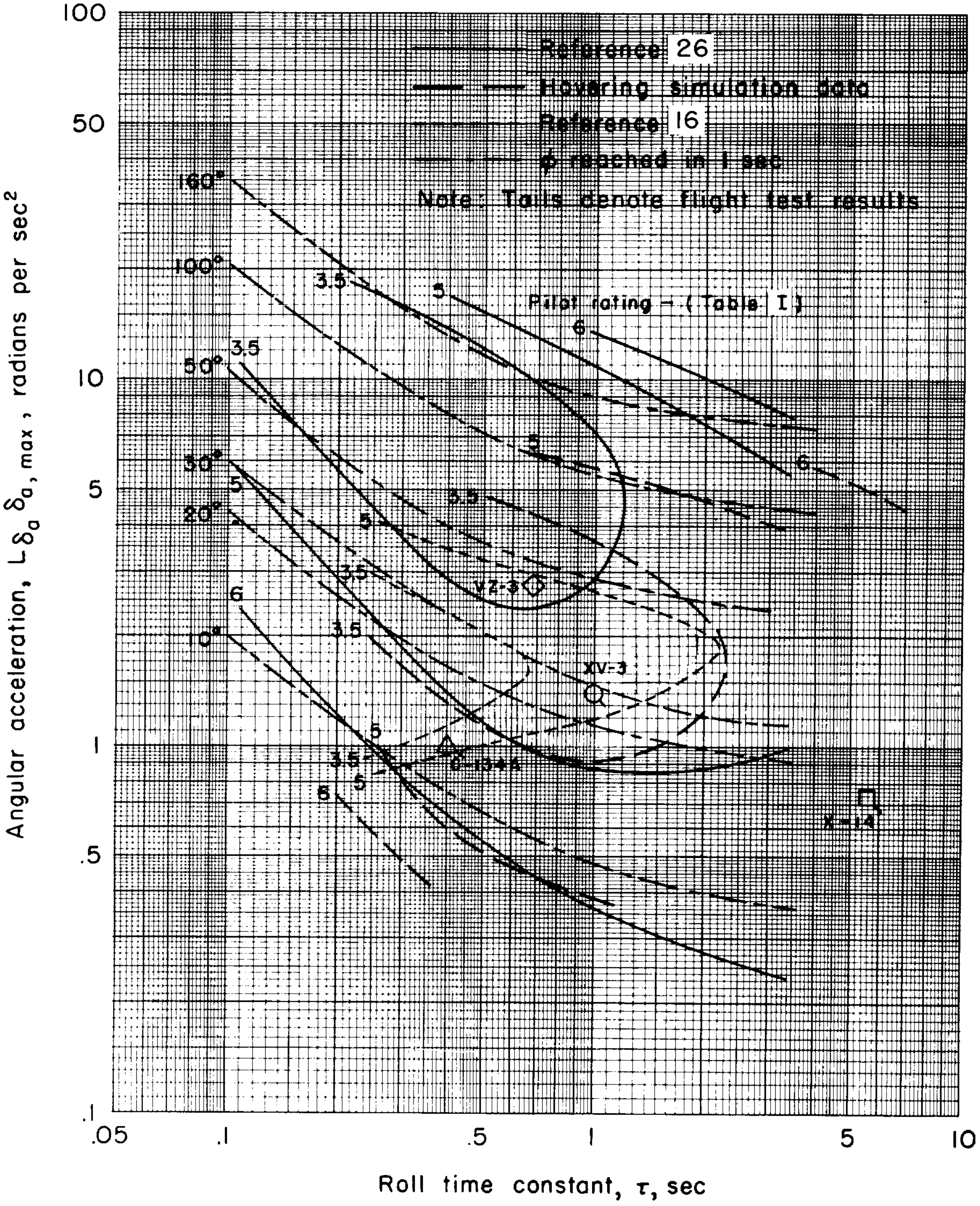


Figure 7.- Roll-control-power and damping characteristics.

NASA TN D-331
National Aeronautics and Space Administration.
AN EXAMINATION OF HANDLING QUALITIES CRITERIA FOR V/STOL AIRCRAFT. Seth B. Anderson.
July 1960. 51p. OTS price, $1.50.
(NASA TECHNICAL NOTE D-331)

A study has been made of handling qualities of V/STOL aircraft. With the current military requirements for airplanes and helicopters as a framework, modifications and additions have been made for conversion to V/STOL requirements using flight results and pilots' comments from a limited number of V/STOL aircraft, BLC equipped aircraft, and flight simulators. The report contains a discussion of the reasoning behind suggested V/STOL requirements and of the areas where existing information is inadequate and further research is required.

(Initial NASA distribution: 1, Aerodynamics, aircraft; 4, Aircraft safety and noise; 50, Stability and control; 53, Vehicle performance.)
Copies obtainable from NASA, Washington

I. Anderson, Seth B.
II. NASA TN D-331

NASA

NASA TN D-331
National Aeronautics and Space Administration.
AN EXAMINATION OF HANDLING QUALITIES CRITERIA FOR V/STOL AIRCRAFT. Seth B. Anderson.
July 1960. 51p. OTS price, $1.50.
(NASA TECHNICAL NOTE D-331)

A study has been made of handling qualities of V/STOL aircraft. With the current military requirements for airplanes and helicopters as a framework, modifications and additions have been made for conversion to V/STOL requirements using flight results and pilots' comments from a limited number of V/STOL aircraft, BLC equipped aircraft, and flight simulators. The report contains a discussion of the reasoning behind suggested V/STOL requirements and of the areas where existing information is inadequate and further research is required.

(Initial NASA distribution: 1, Aerodynamics, aircraft; 4, Aircraft safety and noise; 50, Stability and control; 53, Vehicle performance.)
Copies obtainable from NASA, Washington

I. Anderson, Seth B.
II. NASA TN D-331

NASA

NASA TN D-331
National Aeronautics and Space Administration.
AN EXAMINATION OF HANDLING QUALITIES CRITERIA FOR V/STOL AIRCRAFT. Seth B. Anderson.
July 1960. 51p. OTS price, $1.50.
(NASA TECHNICAL NOTE D-331)

A study has been made of handling qualities of V/STOL aircraft. With the current military requirements for airplanes and helicopters as a framework, modifications and additions have been made for conversion to V/STOL requirements using flight results and pilots' comments from a limited number of V/STOL aircraft, BLC equipped aircraft, and flight simulators. The report contains a discussion of the reasoning behind suggested V/STOL requirements and of the areas where existing information is inadequate and further research is required.

(Initial NASA distribution: 1, Aerodynamics, aircraft; 4, Aircraft safety and noise; 50, Stability and control; 53, Vehicle performance.)
Copies obtainable from NASA, Washington

I. Anderson, Seth B.
II. NASA TN D-331

NASA

NASA TN D-331
National Aeronautics and Space Administration.
AN EXAMINATION OF HANDLING QUALITIES CRITERIA FOR V/STOL AIRCRAFT. Seth B. Anderson.
July 1960. 51p. OTS price, $1.50.
(NASA TECHNICAL NOTE D-331)

A study has been made of handling qualities of V/STOL aircraft. With the current military requirements for airplanes and helicopters as a framework, modifications and additions have been made for conversion to V/STOL requirements using flight results and pilots' comments from a limited number of V/STOL aircraft, BLC equipped aircraft, and flight simulators. The report contains a discussion of the reasoning behind suggested V/STOL requirements and of the areas where existing information is inadequate and further research is required.

(Initial NASA distribution: 1, Aerodynamics, aircraft; 4, Aircraft safety and noise; 50, Stability and control; 53, Vehicle performance.)
Copies obtainable from NASA, Washington

I. Anderson, Seth B.
II. NASA TN D-331

NASA