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DESIGN OBJECTIVES FOR HANDLING QUALITIES OF TRANSPORT AIRCRAFT

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PREPARED BY
SAE COMMITTEE S-7,
FLIGHT DECK AND HANDLING
QUALITIES STANDARDS FOR
TRANSPORT AIRCRAFT

DEFINITIONS:

The terms and symbols used throughout this specification are defined below:

AFCS - Automatic Flight Control System

C_L - Coefficient of Lift

CAS - Calibrated air speed (air speed indicator reading corrected for position and instrument error).

min. - Minute

CG - Center of gravity.

lb. - Pound

sec. - Second

V_e - Equivalent Airspeed - True airspeed multiplied by square root of the relative density.

$V_{s_{1g}}$ - Stalling speed or minimum usable flying speed in general (see paragraph 2.6.2).

V_{s_1} - Stalling speed (see paragraph 2.6.2) obtained in a specified configuration.

V_{s_o} - Stalling speed (see paragraph 2.6.2) with wing flaps in the landing position and landing gear down.

V_2 - Takeoff safety speed or minimum speed with an engine failed. Normally 1.122 V_{s_1}.

V_{REF} - Reference speed for landing based on a specified landing configuration. Normally 1.215 V_{s_o}.

V_{RC} - Recommended climb speed with climb thrust.

V_{TRIM} - A speed chosen whereby the aircraft is trimmed to fly straight and level hands off.

V_{LOF} - Speed at which the aircraft normally lifts off the ground and first becomes airborne.

V_B - Design speed for maximum gust intensity.

V_D - Maximum design or demonstrated speed.

V_{mca} - Minimum control speed in the air with the critical engine inoperative.

DEFINITIONS (Continued):

V_{mcg}	- Minimum control speed on the ground with the critical engine inoperative.
Handling Qualities	- Those qualities of an aircraft and its flight control system that effect the ease and precision with which the pilot is able to control the aircraft's speed and flight path.
V_{FC}/M_{FC}	- Maximum speed for stability characteristics (normally speed midway between V_{mo} and V_D, M_{FC} is M_{mo} + 0.01M).
V_{mo}	- Maximum operating speed.
M_D	- Maximum design or demonstrated Mach number, associated with V_D.
M_{mo}	- Maximum operating Mach No.
K	- Constant depending upon the period of the lateral-directional oscillation - See Figure 1.
$K/T_{1/2}$	- Equals $1/C_{1/2}$ for periods less than 2.4 seconds.
$C_{1/2}$	- Number of cycles for the lateral oscillations to damp to half amplitude.
$T_{1/2}$	- Time to damp to 1/2 amplitude.
ϕ	- Bank angle, degrees.
α	- angle-of-attack.
β	- Sideslip angle, degrees.
$\left\lvert \frac{\phi}{\beta} \right\rvert$ dutchroll	- Ratio of amplitudes of bank and sideslip angles in oscillatory mode.
$\left\lvert \frac{\phi}{V_e} \right\rvert$	- Rolling parameter, degrees/feet per second.

$$\frac{\phi}{V_e} = \frac{57.3}{V_e} \left\lvert \frac{\phi}{\beta} \right\rvert \text{dutchroll}$$

Where V_e is equivalent airspeed in feet per second.

g	- Acceleration due to gravity.

DEFINITIONS (Continued):

P - Period in seconds.

Deadbeat - To come to rest without perceptible oscillation or overshoot.

Interpretation of Qualitative Objectives: In several instances through the document, qualitative terms, such as "objectionable flight characteristics", "unacceptable flight conditions", "unusual pilot technique", etc., have been employed as a means of permitting latitude where absolute quantitative criteria might be unduly restrictive. As an overall objective the aircraft's handling qualities should rate 3 or better on the Cooper-Harper rating scale.* For single system failures not improbable, flight in the operating envelope should be controllable to a degree corresponding to a Cooper-Harper rating of 4 or better, while multiple failures may degrade to 6 or better. The detailed objectives are intended to cover all engines operating conditions unless stated otherwise; where engine inoperative conditions are not specifically mentioned, some degradation from all the engines operating standards will be accepted.

Rates of Operation of Auxiliary Aerodynamic Devices: Although it has not been considered feasible to include in this document quantitative criteria for rates of operation of trim tabs, trimmable stabilizers, artificial feel trimmers, etc., or for rates of extension and retraction of flaps, speed brakes, etc., the influence of such rates on the handling qualities may be appreciable and is treated in paragraphs 2.2.3, 2.2.5 and 2.2.7. In general, trim devices should operate rapidly enough to enable the pilot to maintain trim under changing conditions as normally encountered in operation of the aircraft, and yet must not be so rapid in operation as to induce oversensitivity under any flight condition. Automatic trim rates and authorities should be airspeed scheduled and g limited to the point that pilot control applied in opposition will arrest aircraft motion sufficiently long to disengage an errant system. Flaps and other highlift devices should operate at a rate sufficient to permit transition into the high lift configuration without undue delay, and yet must not operate so rapidly as to cause sudden or erratic trim or excessive loss of lift during retraction. This limitation on rate of operation applies also to speed brakes which, nevertheless, must function at a rate sufficient to meet the operational needs.

*See N69-22539 (NTIS) (NASA) THE USE OF PILOT RATING IN THE EVALUATION OF AIRCRAFT HANDLING QUALITIES, GEORGE E. COOPER, ROBERT P. HARPER 1969. (NASA TND-5153)

1. PURPOSE AND SCOPE: This recommended practice sets forth the design objectives for handling qualities applicable to transport aircraft operating in the subsonic, transonic and supersonic speed range. These objectives are not necessarily applicable to rotor or VTOL aircraft.

BACKGROUND: The ARP 842B Committee originally reviewed several documents and used MIL-F-8785 as a model for the material and format for ARP 842B. This revision (ARP 842C) reflects another review of MIL-F-8785-C, as well as the latest FAR's and BCAR's. In addition, the collective experience of many of the air transport industries' technical and operational specialists has also provided valuable and objective suggestions as to what are desirable modern air transport handling qualities.

2. OBJECTIVES:

2.1 General:

2.1.1 Aircraft Loading: Unless otherwise stated, the DESIGN OBJECTIVES shall apply to all aircraft weights and CG locations within the approved limits.

2.1.2 Altitudes: Unless otherwise stated, the requirements for the following regimes of flight shall apply at the altitudes listed.

a. Takeoff ---
b. Approach ---
c. Landing ---

} All certificated airport altitudes, including ground effects for takeoff and landing.

d. Climb ---
e. Descent ---
f. Cruise ---

} Within certified envelope.

2.1.3 Temperature: Unless otherwise stated, these objectives should apply to all temperatures within the approved operational envelope for the appropriate flight regime.

2.1.4 Configuration: The basic aircraft configurations should be as described below. Items not specified such as cooling provisions, wing sweep, and deceleration devices should be considered in their normal setting for the specified configuration. Additional configurations may be defined by the manufacturer.

a. Takeoff - Gear down, high lift devices at takeoff position, takeoff thrust and/or augmentation, if provided.

b. Takeoff, second segment - Gear up, high lift devices at takeoff position, takeoff thrust and/or augmentation, if provided.

2.1.4 (Continued):

c. Climb - Clean, thrust and speeds for normal operation, as specified for each climb condition.

d. Cruise - Clean and thrust for level flight at all specified operating speeds.

e. Descent - Clean, speed brakes, reverse thrust, and gear down, if appropriate, and speed, as specified, for each descent configuration.

f. Maneuvering Approach - Thrust for level flight at the recommended initial approach speed, gear up, flaps and high lift devices at specified setting.

g. Landing Approach - Thrust for approach descent at recommended landing approach speed, gear down, flaps, and high lift devices at landing setting.

h. Go-Around - Flaps and high lift devices in specified Go-Around position, gear up, thrust and speed as specified.

2.1.5 Operational Flight Envelopes: Operational flight envelopes in terms of airspeed, altitude and normal acceleration should be specified for each of the flight conditions listed in Paragraphs 2.1.1, 2.1.2, 2.1.3.

2.2 Manual or Mechanically Powered/Boosted Flight Control Systems - Characteristics:

2.2.1 Control Friction and Breakout Force: Longitudinal, lateral and directional controls should exhibit positive centering in flight at any normal trim setting. The degree of centering should be such that the combined effects of centering, breakout force, stability and force gradient do not produce objectionable flight characteristics or permit large departures from trim conditions with controls free. Control system friction in all aircraft should be as low as possible, and breakout forces, including friction feel preload, etc., should not exceed the values given in Table I. These values refer to the pilot control force required to start movement of the control surface, and apply in flight at all attainable conditions of trimmed airspeed, altitude, temperature and control deflection.

Table I

Allowable Breakout Forces - Wheel or Stick
(Including Friction)

Control	Minimum (lbs)	Maximum (lbs)
Aileron	1/2	5
Elevator	1/2	6
Rudder	1	20

2.2.2 For Abnormal Operation: Upon dual failure of a power-operated or power-boosted control system, the allowable maximum breakout forces specified in Table I may be doubled. The allowable forces should remain the same for a single failure.

2.2.3 Rate of Control Displacement: The ability of the aircraft to perform the maneuvers expected of it should not be limited by the rates of control surface deflection or auxiliary control operation, nor should the rates of operation of either primary controls or auxiliary devices result in objectionable flight characteristics. See 2.7.1.

2.2.4 Flight Deck Control Free Play: The free play in each flight deck control, i.e., the motion of the flight deck control, from the trim position, which does not move the control surface in flight, should be insignificant in normal, and not objectionable in alternate configurations.

2.2.5 Artificial Stability Systems: Normal operation of artificial stability systems for improvement of any characteristic should not introduce any objectionable flight or ground handling characteristics. Failure of any single system shall not result in a hazardous flight condition. Given a speed excursion from trim speed and return to the trim speed, the aircraft should be in trim and at the same trim device setting as before the speed change. The artificial stability trim, if used, should be smooth in operation vs. airspeed changes.

2.2.6 Control Sensitivity: Careful attention must be given to the design of control forces and displacements on all axes, versus the aircraft response rates and accelerations throughout the operational flight envelopes and in all aircraft configurations listed in paragraph 2.1.4. This is mandatory so that the longitudinal, directional and lateral control characteristics are compatible with the requirement for precision flight path control. See 2.7.1.

2.2.7 Control Force Harmony: The peak maximum dynamic control forces required to perform maneuvers which are normal for the aircraft should have magnitudes which are related to the pilot's capability to produce such forces. As a tentative guide on this subject, it is desired that the relative magnitudes of dynamic control forces in coordinated maneuvers should be approximately in the ratio of 1:2:3 for roll, pitch, and yaw force, respectively for conventional controls.

2.3 Longitudinal Stability and Control:

2.3.1 Static Longitudinal Stability - Variation of pitch control force with airspeed at the forward and aft critical loadings should be a smooth continuous, essentially linearly varying force with a minimum average gradient that may not be less than zero up to heavy buffet in 1g flight (constant thrust lever setting). It should be stable in response to external disturbances. Under conditions of maximum takeoff or go-around thrust, a limited degree of instability is acceptable, provided that the rate of divergence is not so fast as to be objectionable. Table II lists the desirable conditions of static stability in the rest of the flight regimes.

Table II

Longitudinal Static Stability Conditions

Configuration	Speed Range - CAS	Trim Speed - CAS*
Climb	.85 V_{RC} to 1.15 V_{RC}	V_{RC}
Cruise	.85 V_{TRIM} to V_{FC}	VMax. range + V_{mo} and one other*
Descent	1.03 V_{s_1} to V_{FC}	1.31 V_{s_1}, + 15000 ft PA holding pattern speed and normal descent speed.
Maneuvering Approach	1.03 V_{s_1} to approach flap structural limit speed***	1.31 V_{s_1} **
Landing Approach	1.03 V_{s_o} to landing flap structural limit speed**	1.22 V_{s_o} **

* Trim speeds shall be so selected as to examine the most critical areas of the operating envelope.
** Substitute manufacturer's recommended speeds if different.
*** or load relief system operating speed if appropriate: in this case, the effect of system operation on stability characteristics shall not be marked and/or abrupt unless the pilot is alerted to system operation.

2.3.1.1 Static and Maneuvering Longitudinal Stability for Augmentation (CWS or Fly-by-Wire) Equipped Aircraft Following Augmentation Failure(s): The most aft flight CG locations shall not result in hazardous instability or result in a Cooper-Harper rating of greater than 6. Means should be available to make the static stability zero or greater within 15 min of the failure by configuration control or flight restriction, unless Cooper-Harper rating of 4 or better.

2.3.2 Short Period Characteristics: The dynamic response of aircraft pitch attitude and normal acceleration to the pilot's use of elevator control in performing the mission of the aircraft that is appropriate to the flight condition and aircraft configuration should be such as to produce precise flight path control. The aircraft response should be neither too sluggish nor too abrupt, nor should there be any tendency for an objectionable oscillation resulting from efforts of the pilot to control the flight path or during controls-free operation in the presence of external disturbances, such as turbulence.

2.3.3 Long Period Oscillations: There should be no objectionable flight characteristics attributable to poor phugoid damping. If the period of a longitudinal oscillation is less than 5 times the short period oscillation, the oscillation should be at least neutrally damped. The time to double-amplitude after augmentation failure should be greater than 6 seconds.

2.3.4 Control Effectiveness in Accelerated Flight: In the forward critical loading, when trimmed at any permissible speed and altitude in the configurations listed in Table II, it should be possible to develop at the trim speed, by use of the primary longitudinal control alone, the limit load factor, the lift coefficient corresponding to V_{s_1} or a load factor consistent with the operational flight envelope.

2.3.5 Control Forces in Steady Accelerated Flight: Increases in pull forces should produce an increase in normal acceleration throughout the range of likely accelerations, in steady turning flight and pull-outs. A positive slope of stick force versus g curve is not necessarily required at speeds and g combinations beyond V_{FC}/M_{FC} and/or buffet onset. Probable inadvertent excursions beyond the boundaries of buffet shall not result in unsafe conditions. The variation of force with normal acceleration at all points beyond the breakout force shall be approximately linear, except that an increase in slope is permissible above .85 limit load factor (might be introduced by an acceleration restrictor).

2.3.5.1 The average force gradient should be within the limits shown in Table III for all configurations throughout the operational flight envelope up to .85 limit load factor.

Table III

Elevator Control Force Gradient Limits for
Aircraft with Wheel/Stick Configuration
lb/g

Minimum	Maximum
20	50

2.3.5.2 The requirements of paragraph 2.3.5 apply to negative as well as positive acceleration.

2.3.6 Elevator Effectiveness in Takeoff: It should be possible on a hard surface runway with longitudinal trim set for no less than V_2 + 20 knots to takeoff at .95 V_{LOF}. This objective should be met on nosewheel aircraft at the most forward CG loading. The loadings considered for this purpose should include all full and partial loads which might normally be employed during training as well as operational takeoffs.

2.3.7 Takeoff Control Forces: The mean elevator control forces required throughout the take off described in 2.3.6 and during the ensuing acceleration to a speed of V_2 + 20 knots, in the takeoff configuration should be within the following limits: 25 lbs pull, 25 knots below trim speed to 15 lbs push, 15 knots above trim speed.

2.3.8 Elevator Effectiveness in Landing Configuration: The elevator effectiveness, with the aircraft loaded at the most forward CG and trimmed for the landing configuration and speed, should be such that C_{Lmax} can be obtained in and out of ground effect.

2.3.9 Normal Landing Control Force: The longitudinal control force should not require an average control pull force greater than 30 lbs for wheel/stick controls.

2.3.10 Control Forces in Descents:

2.3.10.1 With the aircraft trimmed and thrust set for level flight at maximum cruising speed, a dive to any higher speed within V_{mo}/M_{mo} should not require a pull force at the higher speed. The push force, if any, shall not be such that instantaneous release of the control column would induce more than limit load factor on the aircraft.

2.3.10.2 With the aircraft trimmed for V_{mo}/M_{mo}, it should be possible at any attainable higher speed within V_D/M_D, and using elevator control alone, to pull 2.0 g load factor without exceeding 75 lbs pull force for wheel/stick controls.

2.3.10.3 The longitudinal trim system should be capable of being operated at the normal rate while holding the pull force required to perform the maneuver described in 2.3.10.2.

2.3.11 Longitudinal Trim Changes: The wheel/stick control forces due to the longitudinal trim changes caused by changes in thrust, flap setting, gear operation, deceleration devices, wing sweep, variable geometry, etc. should not exceed 25 lbs when such configuration changes are made in flight under conditions representative of operational procedure and including automatic flap structural protection retraction. Generally, the conditions listed in Table IV will suffice for determination of compliance with this objective. With the aircraft trimmed for each specified initial condition, the force required to maintain the specified constant parameter following the specified configuration change should not exceed 25 lbs push or pull. This objective should apply to a time interval of at least 15 sec following the completion of the pilot action initiating the configuration change, or the time for configuration change, whichever is longer. The magnitude and rate of trim change subsequent to this time period should be such that the forces are easily trimmable by use of the normal trimming devices.

2.3.12 Longitudinal Trim Change Caused by Sideslip: With the aircraft trimmed for straight flight in each of the configurations and at the trim speeds specified in Table II, the longitudinal control force required to maintain constant speed in sideslips (full rudder control), should not exceed numerically the lowest force which in the same configuration would produce a normal acceleration change of 0.2 g in the accelerated maneuvers of paragraph 2.3.5. In no event, however, should the force exceed a 20-lbs pull or push for wheel/stick control.

2.4 Lateral-Directional Stability and Control:

2.4.1 Damping of the Lateral-Directional Oscillations: In the configurations and over the corresponding speed ranges specified in Table II, the damping of the lateral-directional oscillations, with pilot's controls fixed and with pilot's controls free, when excited by rudder pulses, should be such that the damping parameter $K/T_{1/2}$ has a value not less than that required by line A of Figure 1. Residual undamped oscillations are unacceptable. This criterion should apply throughout the entire operational envelope.

2.4.1.1 If artificial stabilization is employed, the damping parameter $K/T_{1/2}$ with any failure in the artificial stabilization system should be at least 0.24 in all configurations. In the approach configurations, the parameter should, moreover, have a value at least as high as that required by line B of Figure 1.

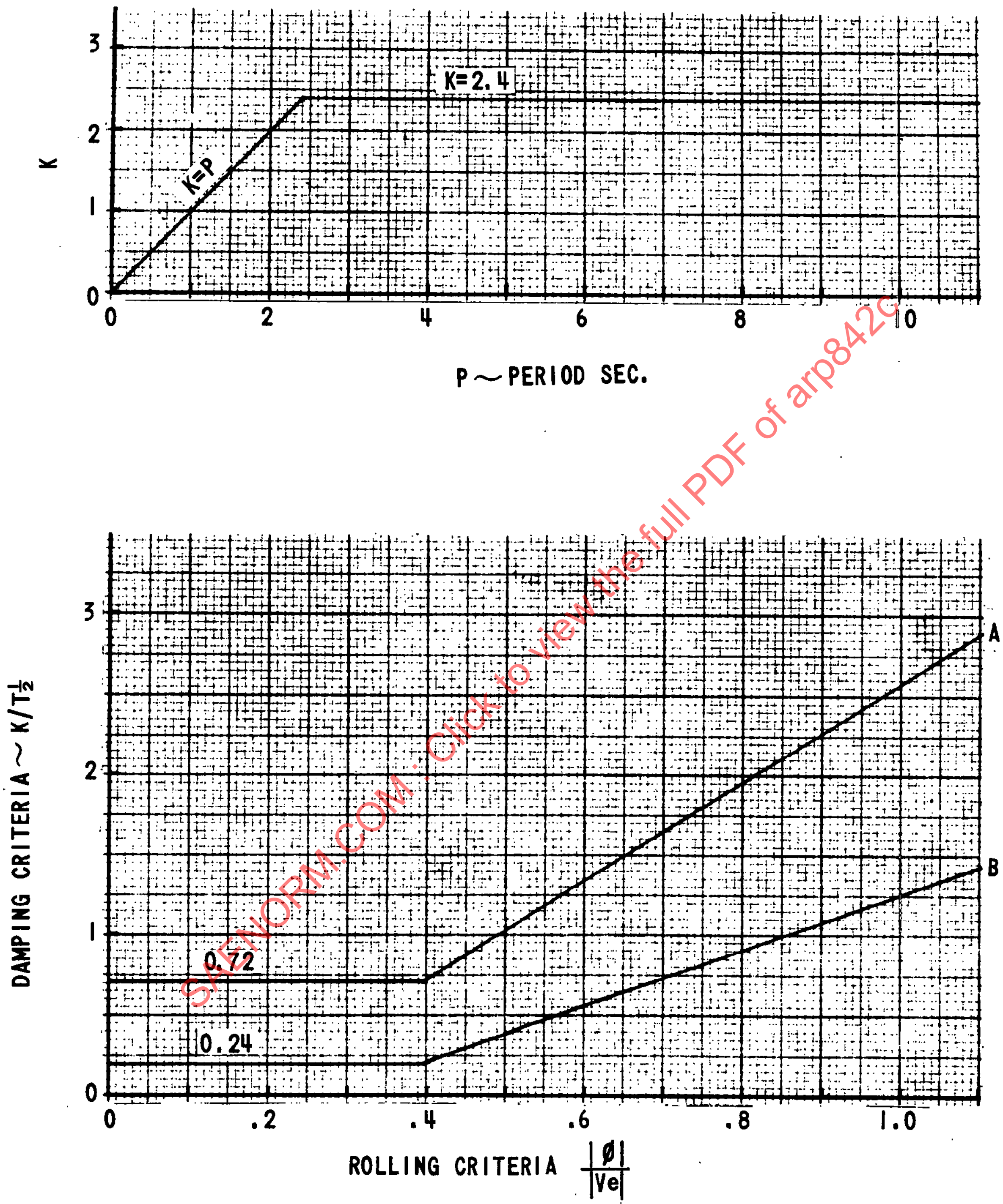
K
3
2
1
0
K=2.4
K=P
0
2
4
6
8
10
P ~ PERIOD SEC.
DAMPING CRITERIA ~ K/T½
3
2
1
0
A
B
0.72
0.24
0
.2
.4
.6
.8
1.0
ROLLING CRITERIA |Ø|/|Ve|

FIGURE 1

Table IV

Longitudinal Trim Change Conditions

Condition No.	INITIAL TRIM CONDITION Altitude	Speed	Gear	Flaps	Thrust	Configuration Change	Parameter To Be Held Constant
1	1500 ft PA	1.31 V_{s_1}	Up	Up	For Level flight	Gear Down	Speed
2	1500 ft PA	1.31 V_{s_1}	Down	Up	For Level flight	Flaps Down	Opnl Speed (Follow speed schedule)
3	1500 ft PA	1.31 V_{s_o}	Down	Down	For level flight	Idle Thrust	Speed
4	1500 ft PA	V_{ref}	Down	Down	Idle	Takeoff Thrust	Speed
5	1500 ft PA	V_2	Down	Takeoff	For level flight	Gear Up	Speed
6	1500 ft PA	V_2	Up	Takeoff	Takeoff	Flaps Up, follow speed schedule	Altitude
7	.1 Max Approved	Climb	Up	Up	Maximum Continuous	Idle Thrust	Speed
8	Most Critical	Max Cruise not to Exceed M_{mo}	Up	Up	Maximum Continuous	Idle Thrust	Speed
9	Most Critical Altitudes	Most Critical Speeds	Up	Up	For level flight	Deceleration Device	Speed

Table IV (Continued)

Longitudinal Trim Change Conditions

Condition No.	INITIAL TRIM CONDITION: Altitude	Speed	Gear	Flaps	Thrust	Configuration Change	Parameter To Be Held Constant
10	1500 ft PA	1.4 V_{s_o}	Down	Down	Approach	Deceleration Device	Speed
11	.5 Max Approved	1.5 V_{s_1}	Up	Up	For level flight	Go-Around Thrust	Speed
12	1500 ft PA	V_{ref}	Down	Down	Thrust for 3° Glide Slope	Go-Around Thrust, Incr Spd & Retract Flaps Including Automatic Flap Retraction and Gear	Level Flight Follow Flap/Speed Schedule
13	As Scheduled	As Scheduled	Up	Up	As Scheduled	Variable Geometry	Flight Profile

2.4.2 Spiral Stability: Neutral or convergent spiral stability is desired; however, if the spiral motion is divergent, the rate of divergence should not be so great that, following a small disturbance in bank with controls fixed, the bank angle is doubled in less than 30 sec in the approach and cruise configurations, or 20 sec in any of the other flight conditions.

2.4.3 Static Lateral-Directional Stability Conditions: In the configurations and over the corresponding speed ranges specified in Table II, static directional stability, dihedral effect and variation of side force are expressed below in terms of steady sideslip characteristics. These characteristics should be measured while flying a straight path with zero turn rate sideslips up to the maximum sideslip angles produced by maximum available rudder deflection, with the aircraft trimmed for straight and level flight, at the lightest operational aircraft weight or structural limit.

2.4.4 Static Directional Stability (Rudder Position): The aircraft should possess rudder pedal fixed directional stability such that, in the sideslip specified in paragraph 2.4.3, right rudder pedal deflection from the wings-level position is required in left sideslips, and left rudder pedal deflection is required in right sideslips. For angles of sideslip between ± 10 degrees or structural limits from the wings-level condition, the variation of sideslip angle with rudder pedal deflection should be essentially linear. Throughout the remainder of the range of required pedal deflections, an increase in pedal deflection should always be required for an increase in sideslip.

2.4.5 Static Directional Stability (Rudder Force): The aircraft should possess rudder pedal stability such that, in the sideslips specified in paragraph 2.4.3, right rudder force is required in left sideslip and left rudder force is required in right sideslip. For angles of sideslip between ± 10 degrees from the wings-level, straight-flight condition, the variation of sideslip angle with rudder force should be essentially linear. At greater angles of sideslip, a lightening of the rudder force by 10% is acceptable, however, for dynamic sideslip conditions throughout the design envelope of rudder deflection and sideslip, the rudder force should never reduce to zero or overbalance.

2.4.6 Dihedral Effect (Aileron Position): The aircraft should possess positive control-fixed dihedral effect as indicated by the smooth and proportional variation of lateral control deflection opposite to applied rudder with sideslip in the maneuvers specified in paragraph 2.4.3.

2.4.6.1 The positive dihedral effect should never be so great that more than 75% of full lateral cockpit control deflection is required in any of sideslips specified.

2.4.7 Dihedral Effect (Aileron Force): The aircraft should possess control-free dihedral effect as indicated by the smooth and proportional variation of lateral control force opposite to applied rudder force with sideslip in the maneuvers specified in paragraph 2.4.3.

2.4.8 Side Force Sideslips: The side force characteristics should be such that in the sideslips specified in paragraph 2.4.3 an increase in right bank angle accompanies an increase in right sideslip, and an increase in left bank angle accompanies an increase in left sideslip.

2.4.9 Yaw Due to Roll Control: The resulting roll rate caused by steadily applied lateral control displacement, with rudder pedal free, should not induce significant amounts of sideslip and/or associated variation in roll rate, throughout the operational flight envelope.

2.4.10 Asymmetric Power (Rudder Pedal Free): In all normal flight conditions at speeds above 1.31 V_{s_1} at 1.25 times the operating empty weight, including turns up to 30 degrees bank angle, the aircraft motions following a sudden malfunction or failure of the critical propulsion system shall be such that 45° bank angles can be avoided by immediate pilot corrective action with aileron control only (no rudder force).

Further, with the aircraft trimmed for straight, wings-level flight and symmetrical thrust, it should be possible, with rudder pedals free, to return the wings to a level attitude following the sudden critical engine malfunction at speeds greater than 1.31 V_s at aircraft weights greater than 1.25 times operating empty weight.

2.4.11 Directional Control (Symmetric Power): Directional control should be sufficiently effective to maintain wings-level straight flight in the configurations and speed ranges specified in Table II with rudder control forces not greater than 30 lbs when the aircraft is trimmed directionally at the trim speeds specified in Table II.

2.4.11.1 Directional control should be sufficient to permit development of at least 10 degrees of steady sideslip in landing configuration at V_{ref} with rudder control forces not greater than 100 lbs.

2.4.12 Static Directional Control (Asymmetric Power): Multi-engine aircraft in the takeoff configuration with the most critical engine inoperative, loaded to the lightest practicable takeoff loading, CG in most critical condition, with takeoff thrust on the remaining engine(s) should be capable of maintaining straight flight with a bank angle no greater than 5 degrees at all speeds above V_{mca}. The rudder pedal force required to maintain straight flight with the most critical engine inoperative should not exceed 100 lbs with the rudder trim set for symmetric thrust. In flight at speeds in excess of V_{mca}, the heading change resulting from a sudden critical engine failure should not be greater than 15 degrees with no pilot intervention within the first 3 sec following the failure. Directional control capability on the ground should be such that following an abrupt failure of the critical engine the lateral deviation should not exceed 25 feet with zero crosswind at speeds above V_{mcg}.

The nose wheel should be free to caster and differential braking not used for the ground segment of this requirement.

2.4.13 Directional Control During Takeoff and Landing: The rudder control, in conjunction with other normal means of control such as nose wheel steering, should be adequate to maintain a straight path on the ground during normal takeoffs and landings. Directional control should be sufficiently effective to conduct takeoff and landings in a 90-degree crosswind of a magnitude to 30% V_{SO} or 40 knots, whichever is less. If necessary, a combination of crab angle and sideslip may be used in conducting these demonstrations. This criterion shall be met with not more than a 100 lbs rudder pedal force.

2.4.14 Directional Control Forces: The rudder pedal forces that provide maximum available rudder deflection, throughout the speed range, should not exceed 100 lbs.

2.4.14.1 Nose Steering Controller Force: Rudder pedal ground steering control forces should be less than 100 lbs. Tiller/wheel type ground steering forces should be less than 15 lbs.

2.4.14.2 Wheel Brake Pedal Force: Wheel brake pedal force for maximum brake pressure should not exceed 60 lbs per pedal. The pedal force to obtain initial braking (minimum brake pressure) should be approximately 10 lbs. and should increase linearly with increasing brake pressure.

2.4.15 Lateral Control: Lateral control should be adequate for compliance with the rolling performance specified in 2.4.15.1. In those requirements involving measurement of time, the time shall be measured from the instant of initiation of pilot control force. The rudder pedals are to be free in obtaining the required rolling performance.

2.4.15.1 Lateral Control Effectiveness: Roll performance should be such as to achieve a 30 degree bank angle change within 3 sec for nonterminal flight phase configurations and 3 sec for terminal flight phase configurations (i.e., flaps/high lift devices extended). No rudder inputs are allowed except those from an automatic system such as a turn co-ordinator.

2.4.15.2 A lateral control force of 25 lb, tangentially applied at the control wheel or to a control stick should produce a 30 degree bank angle change in the times specified in 2.4.15.1.

2.4.15.3 The wheel throw necessary to meet the lateral control requirements should not exceed 60 degrees in each direction for all aircraft with wheel-type controls.

2.4.15.4 Lateral control should be sufficiently effective to balance the aircraft laterally under the conditions specified in paragraphs 2.4.10, 2.4.11, 2.4.11.1, 2.4.12 and 2.4.13, with aileron control forces not exceeding those specified in paragraph 2.4.15.2.

2.4.15.5 When trimmed laterally at the maximum approved ceiling in climb configuration, lateral control should be adequate to maintain the wings level throughout the speed range with aileron control forces not exceeding 10 lbs for wheel or stick controls.

2.4.15.6 Lateral control motion and force in the correct direction relative to aircraft response is required at all permissible speeds.

2.5 General Control and Trimmability Objectives:

2.5.1 Deceleration Devices: The aircraft should incorporate deceleration means capable of providing:

a. Adequate deceleration from cruising speed to holding speed at all altitudes.

b. Rapid descent from cruise altitudes to sea level at V_B and Air Traffic Controlled area speeds.

c. Adequate ability to maintain approach and glide path angles for all possible landing configurations.

These deceleration devices in any selectable position should have no objectionable buffet, trim change or other significant adverse effect on the aircraft's handling qualities. It shall not be required to exceed V_{mo}/M_{mo} in order to execute a rapid descent.

2.5.2 Control for Taxiing: It should be possible to perform all normal taxiing operations without undue pilot effort or inconvenience.

2.5.2.1 Nose Wheel Centering: On nose wheel type aircraft with power steering, nose wheel should caster returning smoothly to a centered position if the steering control is released. With loss of steering power, the nose wheel should caster to center such that the aircraft will maintain direction when there is no turning moment applied. Under this condition it should be possible to turn the nose wheel by application of asymmetric turning moments.

2.5.3 Control Surface Oscillations: All control surfaces, and surfaces such as flaps, slats and speed brakes, should be free of any tendency toward significant sustained oscillations at all speeds up to V_D/M_D.

2.5.4 Pilot Induced Oscillations: There should be no tendency for a sustained or uncontrollable oscillation about or along any axis resulting from efforts of the pilot to maintain steady flight. Phase lag between the flight deck control deflection and/or force and control surface deflection should be kept to a minimum for reasonably large amplitude motions and should not increase unduly at very small control amplitudes.

2.5.5 Primary Flight Control Trimmability: The normal trimming system should be capable of rapidly reducing the elevator, rudder and aileron control forces to zero, at all speeds between the minimum trim speeds specified in Table V and the upper limits of the speed ranges specified in Table II.

Table V
Conditions For Trimming To Zero Control Forces

Conditions	Configuration	Minimum Trim Speed
1	Climb - at forward and aft CG limits	1.1 V_{s_1} or minimum flight speed
2	Landing - at forward and aft CG limits	V_{ref}
3	Approach - at forward and aft CG limits	V_{ref}
4	Climb - the most critical engine inoperative - wings level	1.31 V_{s_1}
5	Climb - most critical engine(s) on one side inoperative - wings less than 5 degrees bank	Speed for best climb gradient
6	Cruise - most critical engine(s) on one side inoperative - wings less than 5 degrees bank	Speed for maximum range

2.5.5.1 Longitudinal Trim: The pilot should not be required to give undue attention to the longitudinal trim of an aircraft.

2.5.5.1.1 The pilot should be able to easily maintain the aircraft in trim by intermittently actuating the trim system for the following flight phases, i.e., trim operation time should be less than one third the time for the maneuver, at the most forward c.g.

a. Takeoff configuration and V_2 speed to enroute climb speed, clean, thrust as specified.

b. Holding speed to V_{mo}.

c. Enroute climb Mach to M_{mo}.

d. V_{mo} to V_{ref} flaps and gear down, level flight, idle thrust.

2.5.5.1.2 The trim rate should be such as not to cause the pilot to overcontrol due to its actuation. Trim rate proportional to pressure or displacement of the trim control is desirable.

2.5.5.2 Directional Trim: There should be no significant directional trim changes in normal operation. Particular attention should be given to rudder trim requirements as the aircraft changes speed and thrust. Trim should not change as a result of ambient pressure or temperature.

2.5.6 Trim Controls: All trimming devices should maintain a given setting indefinitely unless changed by the pilot, by a special automatic interconnect, such as to the landing flaps, or by the operation of an artificial stability device. Operation of the automatic trim devices should be visually discernible to the pilots.

2.5.7 Trim System Failure: Failure of a power-actuated trim system (including runaway in either direction) should not result in an unsafe flight condition. Following such failure, it shall be possible to cruise for extended periods and to make a safe landing. Override provisions or alternate trim mechanisms should be available to the pilot. This objective should apply to both aerodynamic and artificial trim devices.

2.6 Stall:

2.6.1 Required Flight Conditions: Except where otherwise stated, the criteria for stall characteristics and for stall warning should apply for all configurations and for all CG's within the approved limits, in straight unaccelerated flight, in turning flight with bank angles up to 45 degrees and at thrust settings between idle and the maximum thrust normally required for the flight regime under consideration.

2.6.2 Definition of Stalling Speed: The stalling speed, $V_{s_{1g}}$, is the speed obtained in flight at 'g-break' (maximum lift coefficient), adjusted for acceleration perpendicular to the flight path. In establishing the stalling speed, the CG should be at the most adverse location (normally the forward limit), the wings should be level, and the engines should be at idle or zero thrust at 1.1 $V_{s_{1g}}$. A trim speed not less than 1.2 $V_{s_{1g}}$ should be used.

NOTE: In the event considerations other than maximum available lift determine the minimum usable flying speed in any configuration (e.g. ability to maintain straight flight, to perform flight path and speed control, or lateral/directional characteristics), speed increments or suitable percentages of this minimum flying speed should be used in place of the percentages of the stall speed specified in this document. Natural or artificial warning of approach to such minimum speeds must be provided.

2.6.3 Stall-Warning Objectives: The approach to the stall shall, in all cases, be accompanied by an unmistakable natural aerodynamic buffeting and/or by an unmistakable audible noise (artificial shaking of the control column optional) at 1.01 times the $V_{s_{1g}}$ stall speed or greater.

In case natural aerodynamic warning is not present or is marginal for identification under such conditions as turbulent air, it may be necessary to duplicate the artificial stick shaker system. The requirement for redundancy is dependent on the individual aircraft handling characteristics at speeds below the desired warning speed and also on the stalling and stall recovery characteristics.

Since the stall condition may be approached with no pitch control force change, as in the case of an autopilot attitude-hold mode or a neutral longitudinal force gradient the stall warning system requires special design attention or automatic stall margin control with adequate crew warning.

Strong consideration should be given to the need for anticipatory (angle of attack rate) inputs to the stick shaker warning system to prevent overshooting critical angles of attack.

2.6.4 Criteria for Acceptable Stalling Characteristics: Although it is desired that no nose-up pitch occurs at the stall, a mild nose-up of 2 degrees pitch may be accepted, provided that no dangerous or seriously objectionable flight conditions such as roll off result. It should be possible to recover from a complete stall by normal use of controls without excessive control forces, loss of altitude or buildup of speed. In a complete unaccelerated stall it should be possible to prevent the aircraft from rolling in excess of 20 degrees following the stall without resorting to extraordinary means of control such as asymmetric thrust.

In unaccelerated stalls with the aircraft trimmed for not greater than 1.01 $V_{s_{1g}}$ and an approach rate of 1 knot/sec, it shall be possible by use of primary longitudinal control alone to recover from the angle of attack at which a clear stall warning is evident, both with thrust idle and with maximum takeoff thrust at all operational flap settings and gear configurations.

2.7 Objectives for Power and Boost Flight Control Systems:

2.7.1 Normal Control System Operation: The control system should satisfy the applicable mechanical design requirements as well as the objectives of this document. The system should be capable of providing rapid repeated control movements as might be required in very rough air operation and control surface resolution adequate to precisely control the aircraft.

2.7.2 Power or Boost Failures:

2.7.2.1 Single Most Critical Failure: Aircraft employing power or boost control should have provisions so that following the most critical failure in the flight control system, the planned flight may be completed without significant degradation of flying qualities.

2.7.2.2 Second Most Critical Failure: Following a second critical failure in the flight control system, the flying qualities should satisfy the objectives listed in paragraph 2.7.2.3.

After takeoff, following the second most critical flight control system failure, it shall be possible to safely complete the flight to a suitable airport with the most critical engine inoperative at the most critical phase of flight.