

Design Objectives for Handling Qualities of Transport Aircraft

RATIONALE

This document has been reaffirmed to comply with the SAE 5-Year Review policy.

1. SCOPE:

This document specifies the requirements for 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.

2. REFERENCES:

2.1 Applicable Documents:

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

2.2 Definitions:

|       |                                                                                                |
|-------|------------------------------------------------------------------------------------------------|
| 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                                                                                         |

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### 2.2 (Continued):

|                    |                                                                                                                                                                              |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $V_e$              | 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 3.1.28.2)                                                                                                      |
| $V_{s_1}$          | Stalling speed (see 3.1.28.2) obtained in a specified configuration                                                                                                          |
| $V_{s_o}$          | Stalling speed (see 3.1.28.2) with wing flaps in the landing position and landing gear down                                                                                  |
| $V_2$              | Takeoff safety speed or minimum speed with an engine failed.<br>Normally $1.122 V_{s_1}$                                                                                     |
| $V_{REF}$          | Reference speed for landing based on a specified landing configuration.<br>Normally $1.215 V_{s_o}$                                                                          |
| $V_{RC}$           | Recommended climb speed with climb thrust                                                                                                                                    |
| $V_{TRIM}$         | A speed chosen whereby the airplane is trimmed to fly straight and level hands off                                                                                           |
| $V_{LOF}$          | Speed at which the airplane 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                                                                                                        |
| $V_{mcg}$          | Minimum control speed on the ground with the critical engine inoperative                                                                                                     |
| Handling Qualities | Those qualities of an airplane and its flight control system that effect the ease and precision with which the pilot is able to control the airplane'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.                                                                                                                                                   |

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### 2.2 (Continued):

|                                |                                                                                                                                         |
|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| 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 sec                                                                                        |
| $C_{1/2}$                      | Number of cycles for the lateral oscillations to damp to half amplitude                                                                 |
| $T_{1/2}$                      | Time to damp to 1/2 amplitude                                                                                                           |
| $\phi$                         | Bank angle, degrees                                                                                                                     |
| $\alpha$                       | Angle-of-attack                                                                                                                         |
| $\beta$                        | Sideslip angle, degrees                                                                                                                 |
| $\frac{\phi}{\beta}$ dutchroll | Ratio of amplitudes of bank and sideslip angles in oscillatory mode                                                                     |
| $\frac{\phi}{V_e}$             | Rolling parameter, degrees/ft/s                                                                                                         |
|                                | $\frac{\phi}{V_e} = \frac{57.3}{V_e} \frac{\phi}{\beta} \text{ dutchroll}$ <p>Where <math>V_e</math> is equivalent airspeed in ft/s</p> |
| g                              | Acceleration due to gravity                                                                                                             |
| P                              | Period in seconds                                                                                                                       |
| Deadbeat                       | To come to rest without perceptible oscillation or overshoot                                                                            |

### 3. OPERATIONAL REQUIREMENTS:

#### 3.1 General Requirements:

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 the all-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 3.1.6.3, 3.1.6.5, and 3.1.6.7. 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 airplane, 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 high-lift 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.

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

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

- |             |   |                                                                                            |
|-------------|---|--------------------------------------------------------------------------------------------|
| a. Takeoff  | } | All certificated airport altitudes,<br>including ground effects for takeoff<br>and landing |
| b. Approach |   |                                                                                            |
| c. Landing  |   |                                                                                            |
| d. Climb    | } | Within certified envelope                                                                  |
| e. Descent  |   |                                                                                            |
| f. Cruise   |   |                                                                                            |

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

3.1.4 Configuration: The basic airplane 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.
- 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.

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3.1.5 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 3.1.1, 3.1.2, 3.1.3.

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

3.1.6.1 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 airplanes 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<br>(Including Friction) |              |              |
|--------------------------------------------------------------------|--------------|--------------|
| Control                                                            | Minimum (lb) | Maximum (lb) |
| Aileron                                                            | 1/2          | 5            |
| Elevator                                                           | 1/2          | 6            |
| Rudder                                                             | 1            | 20           |

3.1.6.2 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.

3.1.6.3 Rate of Control Displacement: The ability of the airplane 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 3.1.29.1.

3.1.6.4 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. See 3.1.29.2.

- 3.1.6.5 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 airplane 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.
- 3.1.6.6 Control Sensitivity: Careful attention must be given to the design of control forces and displacements on all axes, versus the airplane response rates and accelerations throughout the operational flight envelopes and in all airplane configurations listed in 3.1.4. This is mandatory so that the longitudinal, directional and lateral control characteristics are compatible with the requirement for precision flight path control. See 3.1.29.2.
- 3.1.6.7 Control Force Harmony: The peak maximum dynamic control forces required to perform maneuvers which are normal for the airplane 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.
- 3.1.7 Longitudinal Stability and Control:
- 3.1.7.1 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 other desirable flight conditions for static stability tests.