U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: Control Systems—General

Date: D R A F T

Initiated By: AIR-600

AC No: 25.671-X

This advisory circular (AC) describes acceptable means for showing compliance with the requirements of title 14, Code of Federal Regulations (14 CFR) 25.671, *Control Systems—General*. These means are intended to provide guidance to supplement the engineering and operational judgment that forms the basis of any demonstration of compliance. Section 25.671 applies to all flight control system installations (including primary, secondary, trim, lift, drag, feel, and load alleviation and stability augmentation systems, and other systems or functions implemented through or supporting the flight control components) regardless of implementation technique (manual, powered, fly-by-wire, or other means). This AC provides guidance on means of compliance with regulatory provisions that address operation of the control systems (§ 25.671(a)), design of the control system assembly (§ 25.671(b)), failures of the control system (§ 25.671(c)), control system design in the event all engines fail (§ 25.671(d)), control authority awareness (§ 25.671(e)), and flight control system modes of operation (§ 25.671(f)).

This AC would provide guidance for changes to § 25.671 proposed in the *System Safety Assessments* Notice of Proposed Rulemaking (NPRM), Notice No. **. That NPRM was published in the *Federal Register* on ** (** FR **) and is available at http://www.regulations.gov/ under Docket No. FAA-2022-1544.

If you have suggestions for improving this AC, you may use the Advisory Circular Feedback form at the end of this AC.

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1 PURPOSE.

This advisory circular (AC) provides an acceptable means, but not the only means, of showing compliance with the control system requirements of 14 CFR 25.671, *Control Systems—General*. These means are intended to provide guidance to supplement the engineering and operational judgment that forms the basis of any demonstration of compliance. The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. This document is intended only to provide clarity to the public regarding existing requirements under the law or agency policies.

2 APPLICABILITY.

2.1 Applicability of this AC.

2.1.1 The guidance in this AC is for airplane manufacturers, modifiers, foreign regulatory authorities, and Federal Aviation Administration (FAA) transport airplane type certification engineers and their designees.

2.1.2 Conformity with the guidance is voluntary only and nonconformity will not affect rights and obligations under existing statutes and regulations. The FAA will consider other methods of demonstrating compliance that an applicant may elect to present. Terms such as “should,” “may,” and “must” are used only in the sense of ensuring applicability of this particular method of compliance when the acceptable method of compliance in this document is used. If the FAA becomes aware of circumstances in which following this AC would not result in compliance with the applicable regulations, the agency may require additional substantiation as the basis for finding compliance.

2.2 Applicability of § 25.671.

Section 25.671 applies to all flight control system installations (including primary, secondary, trim, lift, drag, feel, and stability augmentation systems) regardless of actuation type (manual, powered, fly-by-wire, or other means).

3 RELATED DOCUMENTS.

The following regulatory and advisory materials are related to this AC:

3.1 Related Regulations.

The following 14 CFR part 25 regulations are related to this AC. You can download the full text of these regulations from the Federal Register website at www.eCFR.gov, jointly administered by the Office of the Federal Register (OFR) of the National Archives and Records Administration (NARA) and the U.S. Government Publishing Office (GPO). You can order a paper copy from the U.S. Superintendent of Documents, U.S. Government Publishing Office, Washington, D.C. 20401; at www.gpo.gov, by calling telephone number (202) 512-1800; or by sending a fax to (202) 512-2250.

- Section 25.302, *Interaction of systems and structures.*
- Section 25.671, *Control Systems—General.*

- Section 25.1309, *Equipment, systems, and installations.*
- Section 25.1322, *Flightcrew alerting*.
- Section 25.1329, *Flight guidance system*.

3.2 **Advisory Circulars.**

Copies of the ACs referenced in this document are available at the FAA websites at https://drs.faa.gov.

- AC 25-7D, *Flight Test Guide for Certification of Transport Category Airplanes*, dated May 4, 2018.
- AC 25.1309-1B, *System Design and Analysis*, to be released for public comment concurrently with this proposed AC.
- AC 25.1322-1, *Flightcrew Alerting*, dated December 13, 2010.
- AC 25.1329-1C, Change 1, *Approval of Flight Guidance Systems*, dated May 24, 2016.

4 BACKGROUND.

4.1 The FAA is issuing this AC concurrently with a number of rule changes that address system safety, such as §§ 25.302, 25.671, 25.1309, and others. The FAA developed these rule changes, and corresponding advisory material, based on service experience and recommendations from several Aviation Rulemaking Advisory Committee (ARAC) working groups.

4.2 In 2001, the ARAC Flight Controls Harmonization Working Group (FCHWG) provided recommendations for changes to § 25.671 and the corresponding advisory material. The FAA used these recommendations to develop this AC. These recommendations included a requirement to minimize the risk that could be caused by latent failures in flight control systems.

4.3 In addition to the FCHWG, several other working groups separately developed different criteria for latent failures in system designs. In 2010, the ARAC Airplane-Level Safety Analysis Working Group reviewed all of the previous recommendations and developed a common approach for addressing latent failures. As a result, the FAA revised § 25.671 to remove the failure conditions previously specified in § 25.671(c)(1) and (c)(2). Flight control system failure analyses will instead be covered by § 25.1309. The FAA retained risk criteria specific to jam conditions in § 25.671(c), as described below.

5 DEFINITIONS.

The following definitions apply to the requirements of § 25.671 and the guidance in this AC.

5.1 **Closed-Loop Flight Control System.**

A control system in which the airplane or surface response is used by the pilot or other system to maintain continuous airplane control.

5.2 **Continued Safe Flight and Landing.**

The capability for continued controlled flight and landing at an airport without requiring exceptional pilot skill or strength.

5.3 **Exceptional Pilot Skill or Strength.**

Skill or strength capabilities that exceed that of the anticipated pilot population.

5.4 **Exposure Time.**

The period of time between when an item was last known to be operating properly and when it will be known to be operating properly again.

5.5 **Failure.**

An occurrence that affects the operation of a component, part, or element such that it no longer functions as intended. This includes both loss of function and malfunction.

Note: Errors and events may cause failures or influence their effects, but are not considered to be failures.

Note: Some of the types of failures to consider in showing compliance with § 25.671(c) and § 25.1309 are listed in paragraphs 5.5.1 through 5.5.6. Since the type of failure and the failure's effect will depend on system architecture, this list is not all-inclusive, but serves as a general guideline.

5.5.1 Jam.

A failure or event that results in a control surface, pilot control, or component becoming fixed in one position.

5.5.1.1 If the control surface or pilot control is fixed in position due to a physical interference, it is regulated by § 25.671(c). Causes may include corroded bearings, interference with a foreign or loose object, control system icing, seizure of an actuator, or a disconnect that results in a jam by creating an interference. Jams of this type must be assumed to occur and should be evaluated at positions up to and including the normally encountered positions defined in paragraph 8.3 of this AC.

5.5.1.2 All other failures that result in a fixed control surface, pilot control, or component are addressed under § 25.1309. Depending on system architecture and the location of the failure, some jam failures may not always result in a fixed surface or pilot control; for example, a jammed valve could result in a surface runaway.

5.5.2 Loss of Control of Surface.

A failure that results in a control surface not properly responding to commands. Failure sources include control cable disconnection, actuator disconnection, or loss of hydraulic power. In these conditions, the position of the surface(s) or controls can be determined by analyzing the system architecture and airplane aerodynamic characteristics; common positions include surface centered (0°) or zero hinge-moment position (surface float).

5.5.3 Oscillatory Failure.

A failure that results in surface oscillation. Failure sources include control loop destabilization, oscillatory sensor failure, and oscillatory computer or actuator electronics failure. The duration of the oscillation, its frequency, and amplitude depend on the control loop, monitors, limiters, and other system features.

5.5.4 Restricted Control.

A failure that results in limitation of the achievable surface deflection. Failure sources include foreign object interference or travel limiter malfunctioning. This failure must be evaluated under § 25.1309, as the system or surface can still be operated.

5.5.5 Runaway or Hardover.

A failure that results in uncommanded control surface movement to its fully extended position. Failure sources include servo valve jamming and computer or actuator electronics malfunctioning. The speed of the runaway, the duration of the runaway (permanent or transient) and the resulting surface position (full or partial deflection) depend on the available monitoring, limiters, and other system features. This type of failure must be evaluated under § 25.1309.

5.5.6 Stiff or Binding Controls.

A failure that results in a significant increase in control forces. Failure sources include failures of artificial feel systems, corroded bearings, jammed pulleys, and failures causing high friction. This failure must be evaluated under § 25.1309, as the system or surface can still be operated. In some architectures, the higher friction may result in reduced centering of the controls.

5.6 **Flight Control System.**

This term refers to the following: primary flight controls from the pilots' controls to the primary control surfaces; trim systems from the pilots' trim input devices to the trim surfaces (including stabilizer trim); speedbrake/spoiler (drag devices) systems from the pilots' control lever to the spoiler panels or other drag/lift-dumping devices; high lift systems from the pilots' controls to the high lift surfaces; feel systems; automatic or power-operated systems; load alleviation systems; stability augmentation systems; and other systems implemented through the flight control components. Other systems or devices that alter the flow around the airplane, for example suction or blowing systems, should also be considered part of the flight control system. Supporting systems (for example, hydraulic systems, electrical power systems, and avionics) should also be included if failures in these systems have an impact on the function of the flight control system.

6 EVALUATION OF FLIGHT CONTROL OPERATION—§ 25.671(a).

6.1 The first sentence of § 25.671(a) states: "Each flight control and flight control system must operate with the ease, smoothness, and positiveness appropriate to its function." Flight control systems should be designed so that, when a movement to one position has been selected, a different position can be selected without waiting for the completion of the initially selected movement, and the system should arrive at the final selected position without further attention. The movements that follow and the time taken by the system to allow the required sequence of selection should not adversely affect the airworthiness of the airplane. Additionally, pilot tasks associated with closed-loop flight control systems should be shown to be free from discontinuities in forces or gains that result in excessive forces, lack of control harmony, over-control, or pilot-induced oscillation. Such conditions are typically evaluated for compliance during flight testing. AC 25-7D provides additional guidance.

6.2 The second sentence of § 25.671(a) states: "The flight control system must continue to operate and respond appropriately to commands, and must not hinder airplane recovery, when the airplane is experiencing any pitch, roll, or yaw rate, or vertical load factor that could occur due to operating or environmental conditions, or when the airplane is in any attitude." This requirement is intended to ensure there are no features or unique characteristics (including, for example, computer errors that might occur at certain airplane bank angles) that could restrict the pilot's ability to recover from any attitude, rate of rotation, or vertical load factor. The extent of "operating or environmental conditions" is the same as used in § 25.1309(a)(1). This phrase is intended to include the full normal operating envelope of the airplane, as defined by the airplane flight manual (AFM), together with any modification to that envelope associated with abnormal or emergency procedures, and any anticipated flightcrew action. Other external environmental conditions that the airplane is reasonably expected to encounter should also be considered, such as atmospheric turbulence.

7 EVALUATION OF FLIGHT CONTROL ASSEMBLY—§ 25.671(b).

7.1 Section 25.671(b) requires that each element of each flight control system be designed, or distinctively and permanently marked, to minimize the probability of incorrect assembly that could result in failure of the system to perform its intended function. Distinctive and permanent marking may be used only where design means are impractical. Examples of the consequences of incorrect assembly include the following:

- An out-of-phase action.
- Reversal in the sense of the control.

- Interconnection of the controls between two systems where this is not intended.
- Loss of function.

7.2 Applicants should take adequate precaution in the design process to prevent the incorrect installation, connection, or adjustment of parts in the flight control system. The design should be such that no flight control system element can be installed in the incorrect location, or in the wrong direction or alignment, or otherwise assembled incorrectly. The maintenance manual should specify adequate procedures, but the applicant should not rely on those procedures to ensure correct assembly. The applicant should account for any possible manner in which system elements could be misassembled, and if incorrect assembly is possible, the design should be modified accordingly. Also, the design should be such that only appropriate software can be loaded into the flight control system.

8 EVALUATION OF FLIGHT CONTROL SYSTEM FAILURES—§ 25.671(c).

8.1 General.

While not explicitly stated in § 25.671(c), the flight control system must meet the requirements of § 25.1309. Guidance on complying with § 25.1309 is provided in AC 25.1309-1B, or later revision. Additional guidance on complying with § 25.1309, specific to flight control systems, is provided in paragraph 8.4 of this AC. Section 25.671(c) also includes specific requirements for flight control jam conditions, which are not addressed by § 25.1309. Guidance on complying with the flight control jam requirements of § 25.671(c) is provided in paragraphs 8.2, 8.3, and 8.4 of this AC.

8.2 Evaluation of Flight Control Jam Conditions.

8.2.1 Section 25.671(c) requires the applicant to evaluate any failure or event that results in a jam of a flight control surface or pilot control. Section 25.671(c) is intended to address failure modes that would result in the control surface or pilot's control being fixed, at the position commanded at the time of the failure, due to some physical interference. The position at the time of the jam should be any control position that would be normally encountered during takeoff, climb, cruise, normal maneuvering, descent, approach, and landing. In some architectures, component jams within the system may result in failure modes other than a fixed surface or pilot control. Those types of jams must be evaluated under § 25.1309.

8.2.2 In the past, determining a consistent and reasonable definition of normally encountered control positions has been difficult. A review of in-service fleet experience showed that the overall rate of control system jams is approximately 10^{-6} to 10^{-7} per flight hour. The numerical definition of "extremely improbable" is a failure rate of less than 10^{-9} per flight hour. Therefore, considering the in-service data, a reasonable definition of normally encountered positions represents the range of control surface deflections (from neutral to the largest deflection) expected to occur in 1000 random operational flights, without considering other failures, for each of the flight segments within the normal flight envelope. The applicant may determine appropriate "normally encountered positions" using this criterion, if it has adequate data that is relevant to the airplane being certified.

8.2.3 In lieu of using in-service data as described paragraph 8.2.2 of this AC, an applicant may use the performance-based criteria outlined in paragraph 8.3 of this AC to establish acceptable control surface deflections. These criteria were developed to eliminate any differences between airplane types. The performance-based criteria prescribe environmental and operational maneuver conditions. The resulting deflections may be considered normally encountered positions for compliance with § 25.671(c).

8.2.4 An applicant may use alleviation to show compliance with § 25.671(c). For this purpose, alleviation may include automatic or manual system reconfigurations, or any other features that eliminate or reduce the consequences of a jam or permit continued safe flight and landing.

8.2.5 Section 25.671(c)(3) states that in the presence of a jammed flight control surface or pilot control, additional failure conditions that could prevent continued safe flight and landing must have a combined probability of less than 1/1000. This is intended to reduce the risk of latent failures of the flight control systems that are needed to mitigate the effects of a flight control jam.

8.2.5.1 To show compliance with § 25.671(c)(3), the applicant should evaluate elements of the flight control system that are needed to help the pilot recover from the flight control jam condition. These could include elements such as a jam breakout or override, disconnect means, alternate surface control, alternate electrical or hydraulic sources, alternate cable paths, or automated systems designed to address jams, such as automatic flare systems. The failure rate of any such element should be multiplied by its maximum exposure time to determine the probability that the element will be failed when the jam occurs. The probability of all such failure conditions, when combined, must total less than 1/1000.

8.2.5.2 The probability criterion of 1/1000 is not a failure rate but a time-based probabilistic parameter intended to ensure a minimum residual airplane capability following a jam regulated by § 25.671(c)(3). This analysis should help determine intervals for scheduled maintenance activity or operational checks that ensure the availability of alleviation or compensation means.

8.2.6 Section 25.671(c) requires that the airplane be capable of landing with a flight control jam, and that the airplane be evaluated for jams anywhere in the normal flight envelope. However, the regulation allows the applicant to not account for jams that occur immediately before touchdown if shown to be extremely improbable. Also, the applicant may assume that if the jam is detected prior to V_1, the takeoff will be rejected.

8.2.7 Only the airplane rigid body modes need to be considered when evaluating the airplane response to maneuvers and continued safe flight and landing. All approved airplane gross weights and center-of-gravity locations should be considered when complying with § 25.671(c). However, only critical combinations of gross weight and center of gravity need be demonstrated.

8.3 Determination of Normally Encountered Flight Control Surface or Pilot Control Positions.

8.3.1 General.

8.3.1.1 Section 25.671(c) requires the evaluation of a jammed flight control surface or pilot control at any normally-encountered position of that flight control surface or pilot control. The control positions specified below pertain to both the pilot control and the control surface deflections that are associated with those control positions, and they may be considered normally encountered positions for compliance with § 25.671(c)(1). Lateral (roll), longitudinal (pitch), and directional (yaw) control positions are provided for the takeoff and in-flight phases. Takeoff is considered to be the time period between brake release and 35 feet above ground. The in-flight phase includes climb, cruise, normal maneuvering, descent, and approach, and it is considered to be from 35 feet following a takeoff to 50 feet above ground prior to touchdown.

8.3.1.2 Although 1 in 1000 operational takeoffs is expected to include crosswinds on the order of 25 knots, the short exposure time associated with a jam occurring between V_1 and V_{LOF} allows usage of a less conservative crosswind magnitude when determining normally encountered lateral and directional control positions. Given that lateral and directional controls are continuously used to maintain runway centerline in a crosswind takeoff, and control inputs greater than that necessary at V_1 will occur at speeds below V_1, any jam in these control axes during a crosswind takeoff will normally be detected prior to V_1. Considering the control jam failure rate of approximately 10^{-6} to 10^{-7} per flight hour combined with the short exposure time between V_1 and V_{LOF}, a reasonable crosswind level for determination of jammed lateral or directional control positions during takeoff is 15 knots.

8.3.1.3 The jam positions to be considered in showing compliance include any position up to the maximum position determined by the following maneuvers. The maneuvers and conditions described in this section are only to provide the control surface deflection to evaluate continued safe flight and landing capability, and are not to represent flight test maneuvers for such an evaluation. For airplanes with stability augmentation or other systems that move control surfaces independent of pilot controller positions, the control surface deflections used to evaluate continued safe flight and landing capability should be established by the normal airplane control system response to the maneuvers and conditions described in this section.

8.3.2 Jammed Lateral Control Positions.

8.3.2.1 **Takeoff.**

The lateral control position for wings-level at V_1 in a steady crosswind of 15 knots at a height of 35 feet above the takeoff surface. Variations in wind speed from a height of 35 feet can be obtained using the following relationship:

8.3.2.1.1 $V_{alt} = V_{35\ feet} * (H_{desired}/35.0)^{1/7}$

8.3.2.1.2 Where $V_{35\ feet}$ = Wind speed in knots at 35 feet above ground level (AGL)

8.3.2.1.3 V_{alt} = Wind speed at desired altitude (knots)

8.3.2.1.4 $H_{desired}$ = Desired altitude in feet AGL for which wind speed is sought, but not lower than 5 feet

8.3.2.2 **In-flight.**

The lateral control position to sustain a 12 degree-per-second steady roll rate from 1.23 V_{SR1} to V_{MO}/M_{MO} or V_{FE}, as appropriate, but not greater than 50 percent of the control input.

8.3.3 Jammed Longitudinal Control Positions.

8.3.3.1 **Takeoff.**

Three longitudinal control positions should be evaluated:

8.3.3.1.1 Any control position from the position the controls naturally assume without pilot input at the start of the takeoff roll to the position that occurs at V_1 using the manufacturer's recommended procedures.

Note: It may not be necessary to consider this case if it can be demonstrated that the pilot is aware of the jam before reaching V_1 (for example, through a manufacturer's recommended AFM procedure).

8.3.3.1.2 The longitudinal control position at V_1 based on the manufacturer's recommended procedures including consideration for any runway condition for which the airplane is approved to operate.

8.3.3.1.3 Using the manufacturer's recommended procedures, the peak longitudinal control position to achieve a steady airplane pitch rate of the lesser of 5 degrees per second or the pitch rate necessary to achieve the speed used for all-engines-operating initial climb procedures (V_2+XX) at 35 feet.

8.3.3.2 **In-flight.**

The maximum longitudinal control position is the greater of the following:

8.3.3.2.1 The longitudinal control position required to achieve steady state normal accelerations from 0.8g to 1.3g at speeds from 1.23 V_{SR1} to V_{MO}/M_{MO} or $V_{FE,}$ as appropriate.

8.3.3.2.2 The peak longitudinal control position commanded by the stability augmentation or other automatic system in response to atmospheric discrete vertical gust defined by 15 feet per second (fps) from sea level to 20,000 feet.

8.3.4 Jammed Directional Control Positions.

8.3.4.1 **Takeoff.**

The directional control position for takeoff at V_1 in a steady crosswind of 15 knots (at a height of 35 feet above the takeoff surface).

8.3.4.2 **In-flight.**

The directional control position is the greater of the following:

8.3.4.2.1 The peak directional control position commanded by the stability augmentation or other automatic system in response to atmospheric discrete lateral gust defined by 15 fps from sea level to 20,000 feet.

8.3.4.2.2 Directional control position required for lateral/directional trim from 1.23 V_{SR1} to the maximum all engines operating airspeed in level flight with climb power, but not to exceed V_{MO}/M_{MO} or V_{FE} as appropriate. While more commonly a characteristic of propeller aircraft, this addresses any lateral or directional asymmetry that can occur in flight with symmetric power.

8.3.5 Control Tabs, Trim Tabs, and Trimming Stabilizers.

8.3.5.1 Any tabs installed on control surfaces are assumed jammed in the position associated with the normal deflection (as defined in this section) of the control surface on which they are installed.

8.3.5.2 Trim tabs and trimming stabilizers are assumed jammed in the positions associated with the manufacturer's recommended procedures for takeoff, and normally used throughout the flight to trim the airplane from 1.23 V_{SR1} to V_{MO}/M_{MO} or V_{FE}, as appropriate.

8.3.6 Speed Brakes.

The applicant should assume that speed brakes are jammed in any position for which the speed brakes are approved to operate during flight at any speed from 1.23 V_{SR1} to V_{MO}/M_{MO} or V_{FE}, as appropriate. Asymmetric extension and retraction of the speed brakes should be considered. Roll spoiler jamming (asymmetric spoiler panel) is addressed under paragraph 8.3.2 of this AC.

8.3.7 High Lift Devices.

Leading edge and trailing edge high lift devices should be assumed to jam in any position for takeoff, climb, cruise, approach, and landing. Applicants should analyze the potential for skew, and asymmetric extension and retraction, of high lift devices. Section 25.701 contains a requirement for flap and slat mechanical interconnection unless the airplane has safe flight characteristics with asymmetric flap and slat positions.

8.3.8 Load Alleviation Systems.

8.3.8.1 **Gust Load Alleviation Systems.**

At any airspeed between 1.23 V_{SR1} (1.3 V_S) to V_{MO}/M_{MO} or $V_{FE,}$ as appropriate, the control surfaces are assumed to jam in the maximum position commanded by the gust load alleviation system in response to a discrete atmospheric gust with the following reference velocities:

- 15 fps equivalent airspeed (EAS) from sea level to 20,000 feet (vertical gust),
- 15 fps EAS from sea level to 20,000 feet (lateral gust).

8.3.8.2 **Maneuver Load Alleviation Systems.**

At any airspeed between 1.23 V_{SR1} to V_{MO}/M_{MO} or V_{FE}, as appropriate, the control surfaces are assumed to jam in the maximum position commanded by the maneuver load alleviation system during a pull-up maneuver to 1.3g or a pushover maneuver to 0.8g.

8.4 **Assessment of Continued Safe Flight and Landing.**

To show, as required by §§ 25.671 and 25.1309, that the airplane remains capable of safe flight and landing after a flight control system failure, the applicant should consider the following maneuverability and structural strength criteria:

8.4.1 Flight Characteristics.

8.4.1.1 **General.**

8.4.1.1.1 Following a control system failure, appropriate operating procedures may be used, including system reconfiguration, operating limitations, and flightcrew resource management. The procedures necessary for safe flight and landing should not require exceptional piloting skill or strength.

8.4.1.1.2 Additional means of control, such as a trim system, may be used if the applicant can show that the systems are available and effective. Credit should not be given for use of differential engine thrust to maneuver the airplane. However, differential thrust may be used following the recovery to maintain lateral or directional trim following the flight control system failure.

8.4.1.1.3 For the longitudinal control surface jam during takeoff prior to rotation, the applicant should show that the airplane can be safely rotated for liftoff without consideration of field length available.

8.4.1.2 **Transient Response.**

8.4.1.2.1 The applicant must show the airplane is capable of continued safe flight during the transient condition following a flight control system failure. The evaluation of failures, or maneuvers leading to jamming, may be assumed to begin at 1g wings-level flight. However, single failures should be assumed to occur in combination with anticipated operational or environmental conditions, which may include non-1g flight conditions. Continued safe flight and landing is generally defined as not exceeding any one of the following:

- A load on any part of the primary structure sufficient to cause a catastrophic structural failure.
- Catastrophic loss of flight path control.
- Exceedance of V_{DF}/M_{DF}.
- Catastrophic flutter or vibration.
- Bank angle in excess of 90°.

8.4.1.2.2 In connection with the transient response, applicants must show compliance with § 25.302. While V_F is normally an appropriate airspeed limit to be considered regarding continued safe flight and landing, temporary exceedance of V_F may be acceptable as long as the requirements of § 25.302 are met.

8.4.1.2.3 Section 8.3 of this AC provides a means of determining control surface deflections for the evaluation of flight control jams. In some cases, airplane roll or pitch rate, or normal acceleration are used as a basis to determine these deflections. The roll or pitch rate and/or normal acceleration used to determine the control surface deflection need not be included in the evaluation of the transient condition. For example, the in-flight lateral control position determined in paragraph 8.3.2.2 of this AC is based on a steady roll rate of 12 degrees per second. When evaluating this condition, whether by analysis, simulation, or in-flight demonstration, the resulting control surface deflection is simply input while the airplane is in wings-level flight, at the appropriate speed, altitude, and so forth. During this evaluation, the airplane’s actual roll or pitch rate may or may not be the same as the roll or pitch rate used to determine the jammed control surface position.

8.4.1.3 **Delay Times.**

8.4.1.3.1 Applicants should account for potential delays in pilot recognition, reaction, and operation of any disconnect systems, if applicable:

Delay = Recognition + Reaction + Operation of Disconnect

8.4.1.3.2 Recognition is the time from the failure condition to the point at which a typical pilot may be expected to recognize the need to take action. Recognition of the malfunction may be through the behavior of the airplane or a reliable failure warning system, and the recognition point should be identified but should not normally be less than 1 second. For flight control system failures, except the type of jams addressed in § 25.671(c), control column or wheel movements alone should not be used for recognition.

8.4.1.3.3 Applicants should use the reaction times in the following table:

Table 1. Reaction Times for Flight Conditions

Flight Condition	**Reaction Time**
On ground	Not less than 1 second*
In air (<1,000 feet AGL)	Not less than 1 second*
Manual flight (>1,000 feet AGL)	Not less than 1 second*
Automatic flight (>1,000 feet AGL)	Not less than 3 seconds

* 3 seconds if control must be transferred between pilots.

8.4.1.3.4 The time required to operate any disconnect system should be measured either through ground tests or during flight testing. This value should be used during all analysis efforts. However, flight testing or manned simulation that requires the pilot to operate the disconnect includes this extra time; therefore, no additional delay time would be needed for these demonstrations.

8.4.1.4 **Maneuver Capability for Continued Safe Flight and Landing.** The applicant should show that each of the following maneuvers can be performed, using the manufacturer's recommended procedures, following the failure:

8.4.1.4.1 A steady 30° banked turn to the left or right.

8.4.1.4.2 A roll from a steady 30° banked turn through an angle of 60° so as to reverse the direction of the turn in not more than 11 seconds. (In this maneuver, the rudder may be used to the extent necessary to minimize sideslip, and the maneuver may be unchecked.)

8.4.1.4.3 A pushover maneuver to 0.8g, and a pull-up maneuver to 1.3g.

8.4.1.4.4 A wings-level landing flare in a 90° crosswind of up to 10 knots (measured at 10 meters above the ground).

Note: For the case of a lateral or directional control system jam during takeoff that is described in paragraph 8.3.2.1 or 8.3.4.1, respectively, the applicant should show that the airplane can safely land on a suitable runway with any crosswind from 0 knots to the crosswind level and direction at which the jam was established.

8.4.1.5 **Control Forces.**

8.4.1.5.1 Any short- or long-term control forces that exceed the short- and long-term control forces permitted by § 25.143 must be evaluated for acceptability. This evaluation should consider the strength capability of the expected pilot population (including consideration of age, size, and gender), and the duration of the stick force needed to conduct anticipated maneuvers.

8.4.1.5.2 The FAA has typically considered "short-term," as used in § 25.143, to mean the time required to accomplish a configuration or trim change. However, taking into account the capability of the flightcrew to share the workload, the short-term forces of § 25.143 may be appropriate for a longer duration, such as the evaluation of a jam on takeoff and return to landing. Additionally, flightcrews may be able to control the airplane by other means, such as applying alternate control in lieu of the jammed control. In such case, procedures on load sharing or control by other means should be provided in the AFM and should be demonstrated.

8.4.1.5.3 During the recovery following the failure, transient control forces may exceed these criteria to a limited extent.

8.4.2 <u>Structural Strength for Flight Control System Failures.</u>

8.4.2.1 **Failure Conditions Specified in § 25.1309.**

The applicant should show that the airplane maintains structural integrity for continued safe flight and landing. This should be accomplished by showing compliance with § 25.302. See also § 25.1329(g).

8.4.2.2 **Jam Conditions Specified in § 25.671(c).**

The applicant should show that the aircraft maintains structural integrity for continued safe flight and landing. For these conditions, the loads, considered as ultimate, should be derived from the following conditions, considered separately, at speeds up to the maximum speed allowed for the jammed position or for the failure condition:

8.4.2.2.1 Balanced maneuver of the airplane between 0.25g and 1.75g with high lift devices fully retracted and in en route configurations, and between 0.6g and 1.4g with high lift devices extended.

8.4.2.2.2 Vertical and lateral discrete gusts corresponding to 40 percent of the limit gust velocity specified at V_C in § 25.341(a) with high lift devices fully retracted, and a 17 fps vertical and 17 fps head-on gust with high lift devices extended.

9 EVALUATION OF ALL-ENGINES-FAILED CONDITION—§ 25.671(d).

9.1 Explanation.

Section 25.671(d) states: "If all engines fail at any point in the flight, the airplane must be controllable, and an approach and flare to a landing and controlled stop must be possible without requiring exceptional piloting skill or strength. The applicant may show compliance with this requirement by analysis where the applicant has shown that analysis to be reliable."

9.1.1 The intent of § 25.671(d) is to assure that in the event of failure of all engines, and given the availability of an adequate runway, the airplane will be controllable, and an approach and flare to a landing and controlled stop is possible. Although the rule assumes that a suitable runway would be available, the FAA recognizes that, with all engines inoperative, it may not be possible to reach an adequate runway or landing surface; in this case, the airplane must still be able to make a flare to landing attitude.

9.1.2 Compliance with § 25.671(d) generally necessitates airplanes with fully powered or electronic flight control systems to have a source for emergency power, such as an air-driven generator, windmilling engines, batteries, or other power source capable of providing adequate power to the flight control system through landing. The applicant should also show that, with all engines failed, adequate braking capability exists to meet the stopping distance specified in § 25.735(b)(1).

9.1.3 An applicant may use analysis, simulation, or any combination thereof to show compliance in lieu of flight test, if the applicant shows the method to be reliable.

9.2 Procedures.

9.2.1 Section 25.671(d) requires applicants to show that it is possible, without requiring exceptional piloting skill or strength, to maintain control following the failure of all engines. This showing should include the time it takes for activating any backup systems. The airplane should also remain controllable during restart of the most critical engine, while following the engine restart procedures recommended in the AFM.

9.2.2 The most critical flight phases, especially for airplanes with emergency power systems dependent on airspeed, are likely to be takeoff and landing. Credit may be taken for hydraulic pressure or electrical power produced while the engines are spinning down and any residual hydraulic pressure remaining in the system. Sufficient power must be available to complete a wings-level approach and flare to a landing and controlled stop. Analyses or tests may be used to demonstrate the capability of the control systems to maintain adequate hydraulic pressure and electrical power during the time between the failure of the engines and the activation of any backup systems. If any of the backup systems rely on aerodynamic means to generate power, then a flight test demonstration should be performed to demonstrate that the backup system could supply adequate electrical and hydraulic power to the flight control systems. The flight test should be conducted at the minimum practical airspeed required to perform an approach and flare to a safe landing attitude.

9.2.3 The maneuver capability following the failure of all engines should be sufficient to complete an approach and flare to a landing. Note that the airplane weight could be extremely low (for example, the engine failures could be due to fuel exhaustion). The maximum speeds for approach and landing may be limited by other requirements (for example, ditching, tire speeds, flap or landing gear speeds, and so forth), or by an evaluation of the average pilot's ability to conduct a safe landing. At an operational weight determined for this case and for any other critical weights and centers of gravity identified by the applicant, and at speeds down to the approach speeds appropriate to the airplane configuration, the airplane should be capable of the following:

9.2.3.1 A steady 30° banked turn to the left or right.

9.2.3.2 A roll from a steady 30° banked turn through an angle of 60° so as to reverse the direction of the turn in not more than 11 seconds. (In this maneuver, the rudder may be used to the extent necessary to minimize sideslip, and the maneuver may be unchecked.)

9.2.3.3 A pushover maneuver to 0.8g, and a pull-up maneuver to 1.3g.

9.2.3.4 A wings-level landing flare in a 90° crosswind of up to 10 knots (measured at 10 meters above the ground).

Note: If the loss of all engines has no effect on the control authority of the aircraft (for example, manual controls) then the results of the basic handling qualities flight tests with all engines operating may be used to demonstrate the satisfactory handling qualities of the airplane with all engines failed.

9.2.4 The applicant should show that it is possible to perform a flare to a safe landing attitude, in the most critical configuration, from a stabilized approach using the recommended approach speeds and the appropriate AFM procedures, without requiring exceptional piloting skill or strength. For transient maneuvers, any short or long-term control forces that exceed the short- and long-term control forces permitted by § 25.143 must be evaluated for acceptability.

10 EVALUATION OF CONTROL AUTHORITY AWARENESS—§ 25.671(e).

10.1 Section 25.671(e) requires the flight control system to indicate to the flightcrew whenever the primary control means is near the limit of control authority. This requirement can be met through natural or artificial control feel forces and/or cockpit control movement if shown to be effective, or by flightcrew alerting in accordance with §§ 25.1309 and 25.1322. Suitability of alerting should take into account that some pilot-demanded maneuvers (for example, rapid roll) are necessarily associated with intended full performance, which may saturate the surface. Therefore, simple alerting systems, which would function in both intended and unexpected control-limiting situations, should be properly balanced between needed flightcrew awareness and nuisance alerting. Nuisance alerting should be minimized.

10.2 Depending on the application, suitable annunciations may include cockpit control position, annunciator light, or surface position indicators. Furthermore, this requirement applies at the limits of control authority for a given flight condition and configuration, not necessarily at the limits of any individual surface travel.

11 EVALUATION OF FLIGHT CONTROL SYSTEM SUBMODES—§ 25.671(f).

Section 25.671(f) requires the flight control system to alert the flightcrew whenever the airplane enters any mode that significantly changes or degrades the normal handling or operational characteristics of the airplane. Flightcrew alerting must meet the requirements of §§ 25.1309 and 25.1322. Some systems, especially electronic flight control systems, have submodes of operation not restricted to being either on or off. The means provided to the flightcrew to indicate the current submode of operation may be different from the classic “failure warning.”

12 ACCEPTABLE MEANS OF COMPLIANCE.

The FAA recognizes that it may be neither practical nor appropriate to demonstrate compliance by flight test for all of the failure conditions noted in this AC. Except as provided elsewhere by regulation or policy, an applicant may show compliance by analysis, background simulation, a piloted simulator, flight test, or combination of these methods as agreed with the FAA. Simulation methods should include an accurate representation of the airplane characteristics and of the pilot response, including time delays as specified in paragraph 8.4.1.3 of this AC. Compliance with § 25.671 may necessitate flight manual abnormal procedures. Verification of the efficacy of these procedures may be accomplished in flight, or by using a validated piloted simulator if the agreement of the FAA is previously obtained.

12.1 Acceptable Use of Simulations.

It is difficult to define the types of simulations that might be acceptable in place of flight testing without identifying specific conditions or issues. However, the following principles can be used as guidance for making this kind of decision:

12.1.1 In general, flight test demonstrations are the preferred method to show compliance.

12.1.2 Simulation may be an acceptable alternative to flight demonstrations, especially when—

12.1.2.1 A flight demonstration would be too risky even after attempts to mitigate these risks (for example, “simulated” takeoffs or landings at high altitude);

12.1.2.2 The required environmental conditions are too difficult to attain (for example, wind shear, high crosswinds);

12.1.2.3 The simulation is used to augment a reasonably broad flight test program; or

12.1.2.4 The simulation is used to demonstrate repeatability.

12.2 **Simulation.**

If the applicant and the FAA agree that a simulation will be used to show compliance with the performance and handling qualities criteria in this AC, the simulation should meet the following conditions:

12.2.1 The simulation should be validated by flight test data and shown to be reliable for the conditions of interest.

12.2.1.1 This does not mean that there must be flight test data at the exact conditions of interest; the reason simulation is being used may be that it is too difficult or risky to obtain flight test data at the conditions of interest.

12.2.1.2 The level of substantiation of the simulator to flight correlation should be commensurate with the level of compliance. For example, unless it is determined that the simulation is conservative, the closer the case is to being non-compliant, the higher the required quality of the simulation.

12.2.2 The simulation should be conducted in a manner appropriate to the case and conditions of interest.

12.2.2.1 If closed-loop responses are important, the simulation should be piloted by a human pilot. Consideration should also be given to multiple pilot evaluations for critical closed-loop cases.

12.2.2.2 For piloted simulations, the controls, displays, cues and handling qualities should be substantially equivalent to what would be available in the real airplane, unless it is determined that not doing so would provide added conservatism.

Appendix A. Command Signal Integrity

A.1 OVERVIEW.

A.1.1 This appendix provides guidance and identifies issues related to command signal integrity that should be investigated for fly-by-wire (FBW) flight controls to comply with the provisions of §§ 25.671, 25.1301, and 25.1309.

A.1.2 An airplane that uses FBW technology as the means of sending command signals to control the airplane has different characteristics and failure modes than mechanical and hydro-mechanical systems. Accordingly, it is necessary to ensure that control signals from the flightcrew or any automated flight control system equipment will not be adversely altered from internal and external interference.

A.1.3 In the past, command signals were transmitted to primary and secondary flight control surfaces through conventional mechanical and hydro-mechanical means. It was relatively straightforward to determine the origin of perturbations (see paragraph A.2.1) because failure cases could usually be classified in a limited number of categories (e.g., maintenance error, jamming, disconnection, runaway or failure of a mechanical element, structural failure of a hydraulic component, etc.). Therefore, for conventional flight control systems, it was usually possible to identify the most severe failure cases that would encompass all other cases with the same consequence.

A.1.4 For systems using FBW technology, which incorporates digital devices and software, experience has shown that perturbation of signals on the electronic digital transmission lines from internal and external sources can occur. Further, given the complex nature of the FBW equipment and control laws, failure cases are not as easy to predict, classify, and address as those associated with conventional control systems. This appendix documents a means of compliance with §§ 25.671, 25.1301, and 25.1309 that ensures control signals are not adversely altered from internal and external interference.

A.2 CONDITIONS THAT MODIFY COMMAND SIGNAL OR SYSTEM RESPONSE.

A.2.1 Perturbations, as referred to in this appendix, are described as signals that result from any condition that is able to modify the command signal or system response from its intended characteristics. Such perturbations have either internal or external causes.

A.2.1.1 Internal causes include, but are not limited to, the following:

- Loss of data bits.
- Unwanted transients.
- Computer capacity saturation.
- Processing of signals by asynchronous microprocessors.

- Adverse effects caused by transport lag.
- Poor resolution of digital signals.
- Sensor noise.
- Corrupted sensor signals.
- Aliasing effects.
- Inappropriate sensor monitoring thresholds.
- Single event effects due to atmospheric radiation.
- Structural interactions (such as control surface compliance or coupling of rigid body modes with control modes) that may adversely affect the system operation.

A.2.1.2 External causes include, but are not limited to, the following:

- Lightning.
- Electromagnetic interference effects (e.g., motor interference, ship's electrical power and power switching transients, smaller signals if they can affect flight control, transients due to electrical failures, etc.).
- High intensity radiated fields (HIRF).

A.3 COMPLIANCE.

A.3.1 Spurious signals or false data that are a consequence of the conditions identified in paragraphs A.2.1.1 and A.2.1.2 may result in malfunctions that produce unacceptable system responses, such as limit cycle or oscillatory failures, control surface runaway conditions, disconnection, lockups, false indication/warning, and inappropriate attitudes at landing. Since any of these responses could present a flight hazard, it is imperative that the command signal remain continuous and free from perturbations and common cause failures. Accordingly, special design measures should be employed to maintain system integrity to ensure capability for continued safe flight and landing. These special design measures can be evaluated through the systems safety analysis process provided specific care is directed to development methods and quantitative/qualitative demonstrations of compliance.

A.3.2 The FAA recognizes that § 25.671, in conjunction with §§ 25.672, 25.677, and 25.697, are the primary requirements for ensuring control signal integrity. The FAA also recognizes that §§ 25.1301, 25.1309(a) through (c), 25.1329, 25.1353(a), and 25.1431 are essential requirements for ensuring the integrity of equipment incorporating complex digital hardware and software, and of systems previously independent of the flight control system that now contribute to the integrated system. However, with particular reference to the subject of this appendix, applicants should consider the following when evaluating compliance with the requirements of §§ 25.671, 25.1301, and 25.1309:

A.3.2.1 The ability of the flight control system to perform its intended function, regardless of any malfunction in the integrated systems environment of the airplane.

A.3.2.2 Any system in the aerodynamic loop that has a malfunction should not produce an unsafe level of un-commanded motion of the flight control surface, and the flight control system must automatically recover its ability to perform critical functions after the effects of that malfunction are removed.

A.3.2.3 Systems in the aerodynamic loop should not be adversely affected during or after exposure to any sources of a malfunction.

A.3.2.4 Any disruption to an individual unit or component that occurs as a consequence of a malfunction, and that requires annunciation and flightcrew action, should be evaluated to ensure that the failure can be recognized by the flightcrew, and that the recommended flightcrew action can be expected to result in continued safe flight and landing.

A.3.2.5 An automatic change from a normal to a degraded mode that is caused by spurious signal(s) or malfunction(s) should meet the probability guidelines associated with the hazard assessment established in AC 25.1309-1B, or later revision. For example, a condition assessed as major should have a frequency of occurrence that is no more than probable (no more than 1×10^{-5} per flight hour).

A.3.2.6 Exposure to a spurious signal or malfunction should meet the probability guidelines associated with the hazard assessment established in AC 25.1309-1B, or later revision. The impact on handling qualities should be evaluated.

A.3.2.7 The flight control systems that rely on system voting should use appropriate voting processes, for example mid-value voting versus signal averaging.

A.3.2.8 The flight control system should operate appropriately considering other systems' behaviors. The applicant should assure the compatibility of automatic functions that may dynamically interact or affect flight control in both normal and anticipated abnormal operating conditions and ensure that such interactions (either by airplane response, or by data transfer or data saturation) do not result in inappropriate flight control responses. This should include any potential for adverse coupling of the dynamics of one automated flight function with another (e.g., coupling between automated thrust and flight control functions).

A.3.2.9 When the airplane is in an envelope-protected state, rigid body modes may result in oscillations. Such oscillations should be considered and addressed if they can result in an unsafe condition, such as landing at an inappropriate attitude or vertical speed.

A.4 ADDITIONAL TESTING.

A.4.1 The complexity and criticality of the FBW flight control system typically necessitates additional laboratory testing beyond that required as part of individual equipment qualification, validation, and software verification. It should be shown that the flight control laws interact with the airplane appropriately, and that either the FBW flight control system signals cannot be altered unintentionally, or that altered signal characteristics meet the following criteria:

A.4.1.1 Acceptable system and airplane stability and control: In some cases, this may be demonstrated by showing that stable gain and phase margins are maintained for all control surface closed-loop systems. Pilot control inputs (pilot in the loop) are excluded from this evaluation.

A.4.1.2 Sufficient pitch, roll, and yaw control power is available to provide control for continued safe flight and landing, i.e., the failure is not catastrophic (considering all FBW flight control system signal malfunctions that are not extremely improbable).

A.4.1.3 The effect of spurious signals on the systems that are included in the aerodynamic loop do not result in unacceptable transients or degradation of the airplane's performance. Specifically, signals that would cause a significant un-commanded motion of a control surface actuator are readily detected and deactivated, or the surface motion is arrested by other means in a satisfactory manner. Small amplitude residual system motions and oscillations may be acceptable if they are easily controllable.

A.4.2 It should be demonstrated that the output from the control surface closed-loop system does not result in un-commanded, sustained oscillations of flight control surfaces that can hinder safe flight and landing. The effects of minor instabilities may be acceptable, provided that they are thoroughly investigated, documented, and understood. An example of an acceptable condition would be one where a computer input is perturbed by spurious signals, but the output signal remains within the design tolerances, and the system is able to continue in its selected mode of operation unaffected by that perturbation.

A.4.3 In the context of showing and demonstrating these system characteristics, an acceptable means of compliance with § 25.671 should include:

A.4.3.1 Systematic airplane or laboratory validation that includes a realistic representation of all relevant interfacing systems and associated software, including the control system components that are part of pitch, roll, and yaw control. Closed-loop airplane simulation/testing, and environmental characteristics (temperature, damping, HIRF) as necessary, should be included in this laboratory validation.

A.4.3.2 Laboratory or airplane testing to demonstrate unwanted coupling of electronic command signals and their effects on the mechanical actuators and interfacing structure over the spectrum of operating frequencies.

A.4.3.3 Analysis or inspection to substantiate that physical or mechanical separation and segregation of equipment or components are used to minimize any potential hazards.

A.4.4 A successful demonstration of signal integrity should include all elements that contribute command and control signals to the "aerodynamic closed-loop," which actuates the aerodynamic control surfaces (e.g., ailerons, elevator, rudder, stabilizer, flaps, spoilers, etc.). The "aerodynamic closed-loop" should be evaluated for the normal and degraded modes. Elements of the integrated aerodynamic closed-loop may include, for example, digital or analog flight control computers, power control units, control feedback, major data busses, and sensor signals for items such as air data, acceleration, rate sensors, commands to the surface position, respective power supply sources, etc. Autopilot systems (including feedback functions) should be included in this demonstration if they are integrated with the FBW flight control system.

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