Federal Aviation Administration

Memorandum

Date:	November 16, 2007
To:	See Distribution
From:	Manager, Transport Airplane Directorate, Aircraft Certification Service, ANM-100
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Subject:	Policy for Certification and Continued Airworthiness of Unbalanced and Mass-Balanced Control Surfaces
Memo No.:	ANM-05-115-019
Regulatory Reference:	*§ 25.629 and related sections, § 25.1529, Appendix H,* AC 25.629-1A

Summary

This policy memorandum clarifies Federal Aviation Administration (FAA) policy for the design, certification, and continued airworthiness of control surfaces that rely on retention of restraint stiffness for flutter prevention (i.e., unbalanced or partially balanced control surfaces). These control surfaces typically do not have added mass balance; however, this policy would apply to some control surfaces that are partially mass balanced. This policy also addresses the maintenance actions necessary to ensure that mass-balanced control surfaces remain within their balance limits while in service. The guidance in this memorandum does not apply to devices used strictly for high-lift, for example, leading and trailing edge flaps. However, if a high-lift device is also used for flight control, for example, a "flaperon," this guidance would apply. Specifically, this memorandum provides acceptable means of establishing and certifying freeplay limits and inspection procedures, guidance for managing freeplay and mass balance limits over the airplane service life, and a means of finding compliance for control system designs whose failure can result in a nonlinear aeroelastic configuration and limit cycle oscillation (LCO).

The FAA found Advisory Circular (AC) 25.629-1A guidance inadequate when applying the aeroelastic stability requirements of *§ 25.629* to certain unbalanced control surfaces. This memorandum provides guidance and standardized methods of compliance to support the design and certification of unbalanced control surfaces, and the continued airworthiness of unbalanced and mass-balanced control surfaces. If the FAA revises AC 25.629-1A, this policy may be revised. The freeplay discussed in this memorandum is the overall rotational freeplay of the control surface and includes contributions to freeplay of the control surface actuating system, hinges and supporting structure.

Definition of Key Terms

In the policy statement below, the formatting (*italics*, plain text, or [square brackets]) and terms used ("must," "should," or "recommend") have a specific meaning that is explained in Attachment 1.

Current Regulatory and Advisory Material

The applicable regulations relative to the certification and continued airworthiness of unbalanced control surfaces with freeplay and other nonlinear features are *Title 14, Code of Federal Regulations (14 CFR) 25.629* (shown below), *25.1529*, and *Appendix H to part 25*. For guidance about preventing flutter and excessive vibration of control surfaces, see AC 25.629-1A, "Aeroelastic Stability Substantiation of Transport Airplanes," dated 7/23/98, or the latest revision, and Transport Airplane Directorate Memorandum No. 00-115-17, "Free-play limits and inspection procedures for flutter prevention," dated 9/27/00.

Although freeplay-induced vibration of control surfaces mimics forced structural vibration, it has no external exciting force (other than the airstream) and can be described as a self-excited LCO that is subject to the aeroelastic stability requirements of *§ 25.629.*

Section 25.629 requires that the airplane be "designed to be free from aeroelastic instability for all configurations and design conditions within the aeroelastic stability envelopes … ." While an LCO condition can lead to aeroelastic instability, it is not itself aeroelastically unstable, and so may be acceptable in some cases, as outlined in this memorandum. This memorandum also describes the testing, analysis, and maintenance actions necessary to ensure that an LCO condition does not become unstable, and to ensure that compliance to *§ 25.629* is maintained for the operational life of the airplane. The safety concern is that excessive amplitudes of aeroelastic response could lead to airframe structural fatigue, structural damage due to overloads, or divergent flutter. In addition, it could compromise the ability of pilots to perform critical mission-related tasks or reduce the controllability of the airplane.

<u>Section 25.629 at Amendment 25-77</u>

Aeroelastic stability requirements.
(a) General. The aeroelastic stability evaluations required under this section include flutter, divergence, control reversal and any undue loss of stability and control as a result of structural deformation. The aeroelastic evaluation must include whirl

modes associated with any propeller or rotating device that contributes significant dynamic forces. Compliance with this section must be shown by analyses, wind tunnel tests, ground vibration tests, flight tests, or other means found necessary by the Administrator.

(b) Aeroelastic stability envelopes. The airplane must be designed to be free from aeroelastic instability for all configurations and design conditions within the aeroelastic stability envelopes as follows:

(1) For normal conditions without failures, malfunctions, or adverse conditions, all combinations of altitudes and speeds encompassed by the V_D/M_D versus altitude envelope enlarged at all points by an increase of 15 percent in equivalent airspeed at both constant Mach number and constant altitude. In addition, a proper margin of stability must exist at all speeds up to V_D/M_D and, there must be no large and rapid reduction in stability as V_D/M_D is approached. The enlarged envelope may be limited to Mach 1.0 when M_D is less than 1.0 at all design altitudes, and

(2) For the conditions described in § 25.629(d) below, for all approved altitudes, any airspeed up to the greater airspeed defined by:

(i) The V_D/M_D envelope determined by § 25.335(b); or

(ii) An altitude-airspeed envelope defined by a 15 percent increase in equivalent airspeed above V_C at constant altitude, from sea level to the altitude of the intersection of 1.15 V_C with the extension of the constant cruise Mach number line, M_C, then a linear variation in equivalent airspeed to M_C + .05 at the altitude of the lowest V_C/M_C intersection; then, at higher altitudes, up to the maximum flight altitude, the boundary defined by a .05 Mach increase in M_C at constant altitude.

(c) Balance weights. If concentrated balance weights are used, their effectiveness and strength, including supporting structure, must be substantiated.

(d) Failures, malfunctions, and adverse conditions. The failures, malfunctions, and adverse conditions which must be considered in showing compliance with this section are:

(1) Any critical fuel loading conditions, not shown to be extremely improbable, which may result from mismanagement of fuel.

(2) Any single failure in any flutter damper system.

(3) For airplanes not approved for operation in icing conditions, the maximum likely ice accumulation expected as a result of an inadvertent encounter.

(4) Failure of any single element of the structure supporting any engine, independently mounted propeller shaft, large auxiliary power unit, or large externally mounted aerodynamic body (such as an external fuel tank).

(5) For airplanes with engines that have propellers or large rotating devices capable of significant dynamic forces, any single failure of the engine structure that would reduce the rigidity of the rotational axis.

(6) The absence of aerodynamic or gyroscopic forces resulting from the most adverse combination of feathered propellers or other rotating devices capable of significant dynamic forces. In addition, the effect of a single feathered propeller or rotating device must be coupled with the failures of paragraphs (d)(4) and (d)(5) of this section.

(7) Any single propeller or rotating device capable of significant dynamic forces

rotating at the highest likely overspeed.
(8) Any damage or failure condition, required or selected for investigation by § 25.571. The single structural failures described in paragraphs (d)(4) and (d)(5) of this section need not be considered in showing compliance with this section if:
(i) The structural element could not fail due to discrete source damage resulting from the conditions described in § 25.571(e), and:
(ii) A damage tolerance investigation in accordance with § 25.571(b) shows that the maximum extent of damage assumed for the purpose of residual strength evaluation does not involve complete failure of the structural element.
(9) Any damage, failure, or malfunction considered under §§ 25.631, 25.671, 25.672, and 25.1309.
(10) Any other combination of failures, malfunctions, or adverse conditions not shown to be extremely improbable.
(e) Flight flutter testing. Full scale flight flutter tests at speeds up to V_{DF}/M_{DF} must be conducted for new type designs and for modifications to a type design unless the modifications have been shown to have an insignificant effect on the aeroelastic stability. These tests must demonstrate that the airplane has a proper margin of damping at all speeds up to V_{DF}/M_{DF}, and that there is no large and rapid reduction in damping as $V_{DF}/M_{DF,}$ is approached. If a failure, malfunction, or adverse condition is simulated during flight test in showing compliance with paragraph (d) of this section, the maximum speed investigated need not exceed V_{FC}/M_{FC} if it is shown, by correlation of the flight test data with other test data or analyses, that the airplane is free from any aeroelastic instability at all speeds within the altitude-airspeed envelope described in paragraph (b)(2) of this section.

Relevant Past Practice

In-flight vibration incidents occurring during the past ten years indicate that some transport category airplanes with unbalanced control surfaces have been prone to recurring vibration in service. In several of the in-flight vibration incidents, troubleshooting or inspections found the cause, and corrections were made before the vibration became excessive. However, in some cases the presence of freeplay in control surfaces was not addressed until excessive vibration occurred. Subsequent evaluation of these vibration incidents revealed that this type of vibration was caused by freeplay in the control system and/or supporting structure. Following a review of existing guidance material, the FAA concluded that supplementing AC 25.629-1A would clarify and standardize guidance on the certification of control surface configurations with freeplay and other nonlinear features. The current AC is inadequate for validating maintenance requirements during certification, as well as for preparing instructions for continued airworthiness to manage wear and freeplay during the airplane service life.

Accounting for the effect of control surface freeplay on airplane flutter margins has been a long-standing certification practice for compliance with *§ 25.629,* as discussed in AC 25.629-1A. In addition, it is general industry practice to manage freeplay of irreversible control surfaces in service by making periodic checks and adjustments. Troubleshooting procedures used by operators to detect and correct wear-induced

freeplay have generally resolved vibration problems. When control systems and supporting structures on certain airplane models were found to be subject to persistent wear, design changes were made to improve wear qualities and reduce maintenance action. However, the procedure did not usually distinguish nuisance vibration from freeplay-induced LCO of control surfaces that could have more serious safety implications. Due to the progressive nature of wear or fatigue in a continually oscillating system, LCO events in transport category airplanes during normal operation are unacceptable.

To ensure compliance with *§ 25.629* throughout an airplane's service life, it has been FAA policy to certify and maintain in-service freeplay limits for control surfaces that depend on retention of stiffness for flutter prevention. However, this policy has not been followed consistently. This memorandum discusses the need to establish freeplay limits, and provides an acceptable means of compliance for establishing these limits. In the past, the FAA considered the freeplay limits of military specification MIL-A-8870C adequate to provide assurance of freedom from control surface vibration and has accepted these limits for certification without further proof. The FAA has also accepted higher freeplay limits than the military limits when based on service experience or flight test.

Advisory Circular 25.629-1A states that freeplay should be accounted for analytically by making a change in control surface restraint stiffness and calculating the effect on flutter margins in a conventional linear flutter analysis. In the same manner, the velocity-squared damping provided by hydraulic actuators has been approximated by a linear damping element and included in the flutter analysis, again assessing the effect on flutter margins. However, accounting for freeplay by linear analysis utilizing a single stiffness or damping constant for the entire space-time domain has been inadequate to evaluate LCO. Thus, in the past, the stability and structural integrity of components affected by LCO may not have been adequately addressed in the compliance finding for *§ 25.629*. This memorandum provides guidance on the evaluation of LCO using a validated nonlinear aeroelastic analysis.

Policy

This policy addresses the design, certification testing and analysis, and continued airworthiness of control surfaces that rely on retention of restraint stiffness for flutter prevention (i.e., unbalanced or partially balanced control surfaces). Specifically, this guidance provides an acceptable means of establishing and certifying adequate freeplay limits and inspection procedures, and managing freeplay over the airplane service life. This guidance also provides a means of compliance for failure cases that result in a nonlinear aeroelastic configuration and LCO.

a. <u>Freeplay Limits For Unbalanced Control Surfaces</u>

In-service freeplay limits should be established for all control surfaces that depend on the retention of stiffness to comply with the aeroelastic stability requirements of *§ 25.629*. The freeplay limits defined in military specification MIL-A-8870C are reproduced below. Although not required, these limits are recommended because of their past successful use.

MIL-A-8870C CONTROL SURFACE AND TAB IN-SERVICE FREEPLAY LIMITS
• For a trailing edge control surface which extends outboard of the 75 percent span station of main surface, the total freeplay shall be not greater than 0.13°. • For a trailing edge control surface which extends outboard of the 50 percent but inboard of the 75 percent span station of main surface, the total freeplay shall be not greater than 0.57°. • For a trailing edge control surface which is inboard of the 50 percent span station of main surface, the total freeplay shall be not greater than 1.15°. • For an all-movable control surface, the total freeplay shall be not greater than 0.034°. • For a tab span that is less than 35 percent of the span of supporting control surface, the total freeplay shall be not greater than 1.15°. • For a tab span that is equal to or greater than 35 percent of the span of supporting control surface, the total freeplay shall be not greater than 0.57°.

The applicant must provide analyses and/or flight tests to confirm the adequacy of freeplay limits. The applicant should verify the absence of freeplay-induced vibration by flight test to V_{DF}/M_{DF}, or to V_D/M_D by aeroelastic analysis validated by flight test at the proposed in-service freeplay limits. The applicant should use a validated method of analysis, as described in section c, "Aeroelastic Stability Analyses." Alternatively, if LCO exists, it should be evaluated as described in section b, "Acceptability of Freeplay-Induced LCO within the Design Envelope."

If control surfaces are used on a new derivative model with similar aeroelastic characteristics, the same freeplay limits may be applied without additional substantiation.

b. <u>Acceptability of Freeplay-Induced LCO within the Design Envelope</u>

Section 25.629(b) states, "The airplane must be designed to be free from aeroelastic instability for all configurations and design conditions within the aeroelastic stability envelopes …."

Freeplay-induced limit cycle oscillation can lead to accelerated component wear, structural fatigue or other failures, and ultimately aeroelastic instability. To avoid this

progressive deterioration, recurring LCO must not be allowed within the airplane normal operating envelope (at speeds less than or equal to V_C/M_C). However, LCO is not itself aeroelastically unstable, and accelerated wear may not be an issue for short exposure periods. Therefore, LCO may be acceptable, as described below, at speeds above V_C/M_C when exposure time to an LCO condition would be limited. Similarly, LCO may be acceptable when resulting from a failure condition.

If LCO exists, in any case, it must be carefully evaluated. The following guidance should be used:

Within the defined freeplay limits:

(1) At speeds less than or equal to V_C/M_C, no LCO is allowed.

(2) At speeds above V_C/M_C, LCO may be accepted, provided the criteria shown in paragraph (4) are met.

(3) For the failure conditions defined in *§ 25.629(d)*, at any speed, LCO may be accepted, provided the criteria shown in paragraph (4) are met.

(4) Criteria for acceptable LCO. The LCO:

(a) is stable and decays to an acceptable limited amplitude once an external perturbing force is removed;

(b) does not result in loads that would cause static or fatigue failure of structure during the expected exposure period;

(c) does not result in repeated loads that would cause an additional failure during the expected exposure period that precludes safe flight and landing; and

(d) does not result in a vibration condition on the flight deck that is severe enough to interfere with control of the airplane or to cause excessive fatigue to the crew.

If LCO occurs when operating below V_D/M_D within the defined freeplay limits and without a failure condition, then compliance with the criteria shown in paragraph (4) should be demonstrated at the maximum freeplay limits by flight test out to V_{DF}/M_{DF}, or by analysis to V_D/M_D validated by flight test with freeplay. For LCO predicted above V_D/M_D, compliance may be shown by analysis, or, alternatively, the use of freeplay limits defined in military specification MIL-A-8870C may be used without additional substantiation.

If LCO will occur within the defined freeplay limits as a result of a failure condition, then compliance with the criteria shown in paragraph (4) may be shown by analysis or flight test.

If the manufacturer determines that the freeplay limits established using the criteria in section a, "Freeplay Limits For Unbalanced Control Surfaces," would not prevent freeplay-induced LCO in normal operation, then an additional design or compensating feature should be provided. Two possible features are:

(1) The design feature may be a structural element added in parallel with the control system to provide adequate restraint stiffness to preclude freeplay-induced vibration. It should be established that the design feature is effective over the permitted range of freeplay expected to occur in service.

(2) The compensating feature for some designs may be a continuous aerodynamic loading of the control surface. For such a design, it should be shown by tests or analyses that the aerodynamic loading is sufficient in any phase of flight with the control surface at the in-service freeplay limits.

c. <u>Aeroelastic Stability Analyses</u>

The applicant should evaluate the effect on flutter margins of freeplay due to in-service wear in components, such as control surface actuators and hinge bearings, when showing compliance with the aeroelastic stability requirements of *§ 25.629*. Freeplay may be addressed as a variation in nominal control surface restraint stiffness in the conventional linear flutter analysis. The applicant should evaluate the effect of the variability of other nonlinear elements, such as hydraulic damping, on flutter margins in a similar manner. If, however, aeroelastic stability margins are found to be sensitive to these parameters, then additional verification in the form of model or flight tests may be required. The analysis should account for freeplay that could develop between freeplay checks.

In addition to conventional flutter analyses, nonlinear aeroelastic analyses may be necessary to establish the stability and oscillatory amplitude of configurations with LCO. This would include failure conditions for which divergent flutter is prevented by devices with nonlinear characteristics, such as a hydraulic damper. Acceptability of an LCO should be evaluated by including freeplay, velocity-squared damping, or any other nonlinear element into the equations of motion and solving for the resulting motion, forces, and stability of the aeroelastic system. The applicant should validate the analysis methodology by flight test if it can be done safely, or by wind tunnel test. They should use a combination of ground vibration test, component test, and lab tests to establish essential nonlinear characteristics for analytical model validation.

d. <u>Instructions for Continued Airworthiness</u>

The applicant should establish maintenance instructions to ensure that control surface mass balance limits or freeplay limits are not exceeded throughout the life of the airplane. This includes incorporation of necessary maintenance actions into the instructions for continued airworthiness required by *§ 25.1529 and Appendix H.*

(1) *Section 25.671* requires designing or marking each element of the flight control systems to minimize the potential for incorrect assembly or installation.

The applicant should prepare the maintenance manuals, which include any reassembly and reinstallation instructions with a similar objective.

(2) For control surfaces that depend on mass balance for flutter prevention, the applicant should establish static and/or dynamic balance limits during certification. The applicant should also establish mass balancing procedures that ensure the control surface will remain within these balance limits while in service. The applicant should give particular importance to maintaining the required mass balance following repaint, repair, or any other event that might alter the control surface mass properties. The mass balance limits and procedures for maintaining those limits should be set forth in the Instructions for Continued Airworthiness.

(3) For control surfaces that rely on the retention of stiffness for flutter prevention, freeplay should be certified and managed throughout the life of the airplane. The applicant should account for wear and growth in freeplay between inspections so the certified freeplay limits are not exceeded. The applicant should give special attention to areas of the control surfaces where the control system and supporting structure can wear, allowing freeplay and looseness to develop. The applicant should include the inspection intervals and related inspection procedures, which include freeplay limits and measurement procedures, in the Instructions for Continued Airworthiness. The freeplay inspection should be established as a “Two Star” Certification Maintenance Requirement and managed as defined in Advisory Circular 25-19, Certification Maintenance Requirements.

(4) The applicant should establish reliable inspection procedures during certification and validate them by engineering test, which would include a determination of load versus deflection characteristics to isolate freeplay from elastic deformation of the airframe. The applicant should assess the human factors of the inspection procedure to avoid the possibility of not measuring freeplay accurately.

In some cases, freeplay in individual parts may exist, but the control system rigging is purposely set to eliminate overall freeplay. Although this practice may prevent low-level vibrations that might contribute to rapid wear, it may also mask increasing wear in the individual parts. If this wear occurs and is undetected to a significant level, and a single failure in the system occurs, a large amount of freeplay could suddenly exist with severe consequences. This masked wear condition should be taken into account in developing freeplay check procedures.

Control surfaces vary in size and weight so inspection procedures are generally tailored for each surface. For small tabs, an inspector can simply move the surface with his or her hand while using a dial indicator to measure trailing edge freeplay. On the other hand, it might be impossible to check for freeplay in large unbalanced control surfaces without the assistance of ground equipment to move the surface. Some manufacturers have employed automatic powered means, including on-board systems that check or continuously monitor freeplay.

Effect of Policy

The general policy stated in this document does not constitute a new regulation. The FAA individual who implements policy should follow this policy when it is applicable to a specific project. Whenever a proposed method of compliance is outside this established policy, that individual has to coordinate it with the policy issuing office using an issue paper. Similarly, if the implementing office becomes aware of reasons that an applicant's proposal should not be approved, the office must coordinate its response with the policy issuing office.

Applicants should expect that certificating officials would consider this information when making findings of compliance relevant to new certificate actions. In addition, as with all advisory material, this statement of policy identifies one means, but not the only means, of compliance.

Implementation

This policy discusses compliance methods that should be applied to type certificate, amended type certificate, supplemental type certificate, and amended supplemental type certification programs. The compliance methods apply to those programs with an application date that is on or after the effective date of the final policy. If the date of application precedes the effective date of the final policy, and the methods of compliance have already been coordinated with and approved by the FAA or its designee, the applicant may choose to either follow the previously acceptable methods of compliance or follow the guidance contained in this policy.

Conclusion

This memorandum supplements AC 25.629-1A by including guidelines pertaining to the certification and continued airworthiness of unbalanced control surfaces with freeplay and other nonlinear features, as well as mass-balanced control surfaces. This guidance has been coordinated informally with members of the Aviation Rulemaking Advisory Committee Loads and Dynamics Harmonization Working Group, and U.S. and European aviation industry specialists. The FAA may include these guidelines in a future revision to AC 25.629-1A.

/s/
Ali Bahrami

2 Attachments

Distribution List:
Manager, Los Angeles Aircraft Certification Office, ANM-100L
Manager, Denver Aircraft Certification Office, ANM-100D
Manager, Seattle Aircraft Certification Office, ANM-100S
Manager, Anchorage Aircraft Certification Office, ACE-115N
Manager, Wichita Aircraft Certification Office, ACE-115W
Manager, Chicago Aircraft Certification Office, ACE-115C
Manager, Atlanta Aircraft Certification Office, ACE-115A
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Manager, Standardization Branch, ANM-113
Manager, Rotorcraft Directorate Standards Staff, ASW-110
Manager, Small Airplane Directorate Standards Office, ACE-110
Manager, Engine and Propeller Directorate Standards Staff, ANE-110

Definition of Key Terms

Table A-1 defines the use of key terms in this policy statement. The table describes the intended functional impact, and the formatting used to highlight these items.

- The term "must" refers to a regulatory requirement that is mandatory for design approval. Text communicating a requirement is in *italics*.
- The term "should" refers to instructions for a particular method of compliance. If an applicant wants to deviate from these instructions, he has to coordinate the alternate method of compliance with the Transport Standards Staff using an issue paper. There is no special text formatting used for methods of compliance.
- The term "recommend" refers to a recommended practice that is optional. Enclose recommendations in [ ] brackets.

Table A-1 Definition of Key Terms

	Regulatory Requirements	**Acceptable Methods of Compliance**	**Recommendations**
Language	Must	Should	Recommend
Format	*Italics*	Regular text (No special formatting)	[Square brackets]
Functional Impact	No Design Approval if not met	Alternative has to be approved by issue paper.	None, because it is optional

Definition of Speeds

Table A-2 provides definitions of the speed terms used in 14 CFR Part 25 and referenced in this policy statement.

Table A-2 Definition of Speeds

Speed	FAR Reference	Definition
V_C/M_C	§ 25.335	Design cruising speed. Used for design loads and flutter analysis. Must be equal to or greater than maximum operating limit speed (V_{MO}/M_{MO}).
V_D/M_D	§ 25.335	Design dive speed. Used for design loads and flutter analysis. Must be equal to or greater than demonstrated flight diving speed (V_{DF}/M_{DF}).
V_{FC}/M_{FC}	§§ 1.1, 25.253(b)	Maximum speed for stability characteristics. May not be less than a speed midway between maximum operating limit speed (V_{MO}/M_{MO}) and demonstrated flight diving speed (V_{DF}/M_{DF}), except that, for altitudes where the Mach number is the limiting factor, M_{FC} need not exceed the Mach number at which effective speed warning occurs.
V_{DF}/M_{DF}	§ 1.1	Demonstrated flight diving speed. The maximum airspeed and Mach number demonstrated in flight.