CS 25.303 Factor of safety

ED Decision 2003/2/RM

Unless otherwise specified, a factor of safety of 1·5 must be applied to the prescribed limit load which are considered external loads on the structure. When loading condition is prescribed in terms of ultimate loads, a factor of safety need not be applied unless otherwise specified.

CS 25.305 Strength and deformation

ED Decision 2005/006/R

(a) The structure must be able to support limit loads without detrimental permanent deformation. At any load up to limit loads, the deformation may not interfere with safe operation.

(b) The structure must be able to support ultimate loads without failure for at least 3 seconds. However, when proof of strength is shown by dynamic tests simulating actual load conditions, the 3-second limit does not apply. Static tests conducted to ultimate load must include the ultimate deflections and ultimate deformation induced by the loading. When analytical methods are used to show compliance with the ultimate load strength requirements, it must be shown that –

(1) The effects of deformation are not significant;

(2) The deformations involved are fully accounted for in the analysis; or

(3) The methods and assumptions used are sufficient to cover the effects of these deformations.

(c) Where structural flexibility is such that any rate of load application likely to occur in the operating conditions might produce transient stresses appreciably higher than those corresponding to static loads, the effects of this rate of application must be considered.

(d) *Reserved*

(e) The aeroplane must be designed to withstand any vibration and buffeting that might occur in any likely operating condition up to V_D/M_D, including stall and probable inadvertent excursions beyond the boundaries of the buffet onset envelope. This must be shown by analysis, flight tests, or other tests found necessary by the Agency.

(f) Unless shown to be extremely improbable, the aeroplane must be designed to withstand any forced structural vibration resulting from any failure, malfunction or adverse condition in the flight control system. These loads must be treated in accordance with the requirements of CS 25.302.

[Amdt 25/1]

CS 25.307 Proof of structure

ED Decision 2005/006/R

(See AMC 25.307)

(a) Compliance with the strength and deformation requirements of this Subpart must be shown for each critical loading condition. Structural analysis may be used only if the structure conforms to that for which experience has shown this method to be reliable. In other cases, substantiating tests must be made to load levels that are sufficient to verify structural behaviour up to loads specified in CS 25.305.

(b) Reserved

(c) Reserved

(d) When static or dynamic tests are used to show compliance with the requirements of CS 25.305(b) for flight structures, appropriate material correction factors must be applied to the test results, unless the structure, or part thereof, being tested has features such that a number of elements contribute to the total strength of the structure and the failure of one element results in the redistribution of the load through alternate load paths.

[Amdt 25/1]

AMC 25.307 Proof of structure

ED Decision 2005/006/R

1. *Purpose*

   This AMC establishes methods of compliance with CS 25.307, which specifies the requirements for Proof of Structure.

2. *Related Certification Specifications*

   CS 25.303 "Factor of safety"

   CS 25.305 "Strength and deformation"

   CS 25.651 "Proof of strength"

3. *Definitions*

   3.1. Detail. A structural element of a more complex structural member (e.g. joints, splices, stringers, stringer run-outs, or access holes).

   3.2. Sub Component. A major three-dimensional structure which can provide complete structural representation of a section of the full structure (e.g., stub-box, section of a spar, wing panel, wing rib, body panel, or frames).

   3.3. Component. A major section of the airframe structure (e.g., wing, body, fin, horizontal stabiliser) which can be tested as a complete unit to qualify the structure.

   3.4. Full Scale. Dimensions of test article are the same as design; fully representative test specimen (not necessarily complete airframe).

   3.5. New Structure. Structure for which behaviour is not adequately predicted by analysis supported by previous test evidence. Structure that utilises significantly different structural design concepts such as details, geometry, structural arrangements, and load paths or materials from previously tested designs.

   3.6. Similar New Structure. Structure that utilises similar or comparable structural design concepts such as details, geometry, structural arrangements, and load paths concepts and materials to an existing tested design.

   3.7. Derivative/Similar Structure. Structure that uses structural design concepts such as details, geometry, structural arrangements, and load paths, stress levels and materials that are nearly identical to those on which the analytical methods have been validated.

   3.8. Previous Test Evidence. Testing of the original structure that is sufficient to verify structural behaviour in accordance with CS 25.305.

4. *Introduction*

As required by subparagraph (a) of CS 25.307, the structure must be shown to comply with the strength and deformation requirements of Subpart C of CS-25. This means that the structure must:

(a) be able to support limit loads without detrimental permanent deformation, and:

(b) be able to support ultimate loads without failure.

This implies the need of a comprehensive assessment of the external loads (addressed by CS 25.301), the resulting internal strains and stresses, and the structural allowables.

CS 25.307 requires compliance for each critical loading condition. Compliance can be shown by analysis supported by previous test evidence, analysis supported by new test evidence or by test only. As compliance by test only is impractical in most cases, a large portion of the substantiating data will be based on analysis.

There are a number of standard engineering methods and formulas which are known to produce acceptable, often conservative results especially for structures where load paths are well defined. Those standard methods and formulas, applied with a good understanding of their limitations, are considered reliable analyses when showing compliance with CS 25.307. Conservative assumptions may be considered in assessing whether or not an analysis may be accepted without test substantiation.

The application of methods such as Finite Element Method or engineering formulas to complex structures in modern aircraft is considered reliable only when validated by full scale tests (ground and/or flight tests). Experience relevant to the product in the utilisation of such methods should be considered.

5. *Classification of structure*

(a) The structure of the product should be classified into one of the following three categories:

— New Structure

— Similar New Structure

— Derivative/Similar Structure

(b) Justifications should be provided for classifications other than New Structure. Elements that should be considered are:

(i) The accuracy/conservatism of the analytical methods, and

(ii) Comparison of the structure under investigation with previously tested structure.

Considerations should include, but are not limited to the following:

— external loads (bending moment, shear, torque , etc.);

— internal loads (strains, stresses, etc.);

— structural design concepts such as details, geometry, structural arrangements, load paths;

— materials;

— test experience (load levels achieved, lessons learned);

— deflections;

— deformations;

— extent of extrapolation from test stress levels.

6. *Need and Extent of Testing*

The following factors should be considered in deciding the need for and the extent of testing including the load levels to be achieved:

(a) The classification of the structure (as above);

(b) The consequence of failure of the structure in terms of the overall integrity of the aeroplane;

(c) The consequence of the failure of interior items of mass and the supporting structure to the safety of the occupants.

Relevant service experience may be included in this evaluation.

7. *Certification Approaches*

The following certification approaches may be selected:

(a) Analysis, supported by new strength testing of the structure to limit and ultimate load. This is typically the case for New Structure.

Substantiation of the strength and deformation requirements up to limit and ultimate loads normally requires testing of sub-components, full scale components or full scale tests of assembled components (such as a nearly complete airframe). The entire test program should be considered in detail to assure the requirements for strength and deformation can be met up to limit load levels as well as ultimate load levels.

Sufficient limit load test conditions should be performed to verify that the structure meets the deformation requirements of CS 25.305(a) and to provide validation of internal load distribution and analysis predictions for all critical loading conditions.

Because ultimate load tests often result in significant permanent deformation, choices will have to be made with respect to the load conditions applied. This is usually based on the number of test specimens available, the analytical static strength margins of safety of the structure and the range of supporting detail or sub-component tests. An envelope approach may be taken, where a combination of different load cases is applied, each one critical for a different section of the structure.

These limit and ultimate load tests may be supported by detail and sub-component tests that verify the design allowables (tension, shear, compression) of the structure and often provide some degree of validation for ultimate strength.

(b) Analysis validated by previous test evidence and supported with additional limited testing. This is typically the case for Similar New Structure.

The extent of additional limited testing (number of specimens, load levels, etc.) will depend upon the degree of change, relative to the elements of paragraphs 5(b)(i) and (ii).

For example, if the changes to an existing design and analysis necessitate extensive changes to an existing test-validated finite element model (e.g. different rib spacing) additional testing may be needed. Previous test evidence can be relied upon whenever practical.

These additional limited tests may be further supported by detail and sub-component tests that verify the design allowables (tension, shear, compression) of the structure and often provide some degree of validation for ultimate strength.

(c) Analysis, supported by previous test evidence. This is typically the case for Derivative/ Similar Structure.

Justification should be provided for this approach by demonstrating how the previous static test evidence validates the analysis and supports showing compliance for the structure under investigation. Elements that need to be considered are those defined in paragraphs 5(b)(i) and (ii).

For example, if the changes to the existing design and test-validated analysis are evaluated to assure they are relatively minor and the effects of the changes are well understood, the original tests may provide sufficient validation of the analysis and further testing may not be necessary. For example, if a weight increase results in higher loads along with a corresponding increase in some of the element thickness and fastener sizes, and materials and geometry (overall configuration, spacing of structural members, etc.) remain generally the same, the revised analysis could be considered reliable based on the previous validation.

(d) Test only.

Sometimes no reliable analytical method exists, and testing must be used to show compliance with the strength and deformation requirements. In other cases it may be elected to show compliance solely by tests even if there are acceptable analytical methods. In either case, testing by itself can be used to show compliance with the strength and deformation requirements of CS-25 Subpart C. In such cases, the test load conditions should be selected to assure all critical design loads are encompassed.

If tests only are used to show compliance with the strength and deformation requirements for single load path structure which carries flight loads (including pressurisation loads), the test loads must be increased to account for variability in material properties, as required by CS 25.307(d). In lieu of a rational analysis, for metallic materials, a factor of 1.15 applied to the limit and ultimate flight loads may be used. If the structure has multiple load paths, no material correction factor is required.

8. *Interpretation of Data*

The interpretation of the substantiation analysis and test data requires an extensive review of:

— the representativeness of the loading ;

— the instrumentation data ;

— comparisons with analytical methods ;

— representativeness of the test article(s) ;

— test set-up (fixture, load introductions) ;

— load levels and conditions tested ;

— test results.

Testing is used to validate analytical methods except when showing compliance by test only. If the test results do not correlate with the analysis, the reasons should be identified and appropriate action taken. This should be accomplished whether or not a test article fails below ultimate load.

Should a failure occur below ultimate load, an investigation should be conducted for the product to reveal the cause of this failure. This investigation should include a review of the test specimen and loads, analytical loads, and the structural analysis. This may lead to adjustment in analysis/modelling techniques and/or part redesign and may result in the need for additional testing. The need for additional testing to ensure ultimate load capability, depends on the degree to which the failure is understood and the analysis can be validated by the test.

[Amdt 25/1]

FLIGHT LOADS

CS 25.321 General

ED Decision 2003/2/RM

(a) Flight load factors represent the ratio of the aerodynamic force component (acting normal to the assumed longitudinal axis of the aeroplane) to the weight of the aeroplane. A positive load factor is one in which the aerodynamic force acts upward with respect to the aeroplane.

(b) Considering compressibility effects at each speed, compliance with the flight load requirements of this Subpart must be shown –

(1) At each critical altitude within the range of altitudes selected by the applicant;

(2) At each weight from the design minimum weight to the design maximum weight appropriate to each particular flight load condition; and

(3) For each required altitude and weight, for any practicable distribution of disposable load within the operating limitations recorded in the Aeroplane Flight Manual.

(c) Enough points on and within the boundaries of the design envelope must be investigated to ensure that the maximum load for each part of the aeroplane structure is obtained.

(d) The significant forces acting on the aeroplane must be placed in equilibrium in a rational or conservative manner. The linear inertia forces must be considered in equilibrium with the thrust and all aerodynamic loads, while the angular (pitching) inertia forces must be considered in equilibrium with thrust and all aerodynamic moments, including moments due to loads on components such as tail surfaces and nacelles. Critical thrust values in the range from zero to maximum continuous thrust must be considered.

FLIGHT MANOEUVRE AND GUST CONDITIONS

CS 25.331 Symmetric manoeuvring conditions

ED Decision 2016/010/R

(See AMC 25.331)

(a) *Procedure*. For the analysis of the manoeuvring flight conditions specified in sub-paragraphs (b) and (c) of this paragraph, the following provisions apply:

(1) Where sudden displacement of a control is specified, the assumed rate of control surface displacement may not be less than the rate that could be applied by the pilot through the control system.

(2) In determining elevator angles and chordwise load distribution in the manoeuvring conditions of sub-paragraphs (b) and (c) of this paragraph, the effect of corresponding pitching velocities must be taken into account. The in-trim and out-of-trim flight conditions specified in CS 25.255 must be considered.

(b) *Manoeuvring balanced conditions.* Assuming the aeroplane to be in equilibrium with zero pitching acceleration, the manoeuvring conditions A through I on the manoeuvring envelope in CS 25.333(b) must be investigated.

(c) *Manoeuvring pitching conditions*. The following conditions must be investigated:

(1) *Maximum pitch control displacement at V_A*. The aeroplane is assumed to be flying in steady level flight (point A1, CS 25.333(b)) and the cockpit pitch control is suddenly moved to obtain extreme nose up pitching acceleration. In defining the tail load, the response of the aeroplane must be taken into account. Aeroplane loads which occur subsequent to the time when normal acceleration at the c.g. exceeds the positive limit manoeuvring load factor (at point A2 in CS 25.333(b)), or the resulting tailplane normal load reaches its maximum, whichever occurs first, need not be considered (See AMC 25.331(c)(1)).

(2) *Checked manoeuvre between V_A and V_D*. Nose up checked pitching manoeuvres must be analysed in which the positive limit load factor prescribed in CS 25.337 is achieved. As a separate condition, nose down checked pitching manoeuvres must be analysed in which a limit load factor of 0 is achieved. In defining the aeroplane loads the cockpit pitch control motions described in sub-paragraphs (i), (ii), (iii) and (iv) of this paragraph must be used:

(See AMC 25.331(c)(2))

(i) The aeroplane is assumed to be flying in steady level flight at any speed between V_A and V_D and the cockpit pitch control is moved in accordance with the following formula:

$$\delta(t) = \delta_1 \sin(\omega t) \; for \; 0 \le t \le t_{max}$$

where:

δ1 = the maximum available displacement of the cockpit pitch control in the initial direction, as limited by the control system stops, control surface stops, or by pilot effort in accordance with CS 25.397(b);

δ(t) = the displacement of the cockpit pitch control as a function of time. In the initial direction δ(t) is limited to δ_1. In the reverse direction, δ(t) may be truncated at the maximum available displacement of the cockpit pitch control as limited by the control system stops, control surface stops, or by pilot effort in accordance with CS 25.397(b);

t_{max} = 3π/2ω;

ω = the circular frequency (radians/second) of the control deflection taken equal to the undamped natural frequency of the short period rigid mode of the aeroplane, with active control system effects included where appropriate; but not less than:

$$\omega = \frac{\pi V}{2V_A} \ radians\ per\ second;$$

where:

V = the speed of the aeroplane at entry to the manoeuvre.

V_A = the design manoeuvring speed prescribed in CS 25.335(c)

(ii) For nose-up pitching manoeuvres the complete cockpit pitch control displacement history may be scaled down in amplitude to the extent just necessary to ensure that the positive limit load factor prescribed in CS 25.337 is not exceeded. For nose-down pitching manoeuvres the complete cockpit control displacement history may be scaled down in amplitude to the extent just necessary to ensure that the normal acceleration at the c.g. does not go below 0g.

(iii) In addition, for cases where the aeroplane response to the specified cockpit pitch control motion does not achieve the prescribed limit load factors then the following cockpit pitch control motion must be used:

$$\delta(t) = \delta_1 \sin(\omega t) \ \ for\ \ 0 \le t \le t_1$$
$$\delta(t) = \delta_1 \ \ for\ \ t_1 \le t \le t_2$$
$$\delta(t) = \delta_1 \sin(\omega[t + t_1 - t_2]) \ \ for\ \ t_2 \le t \le t_{max}$$

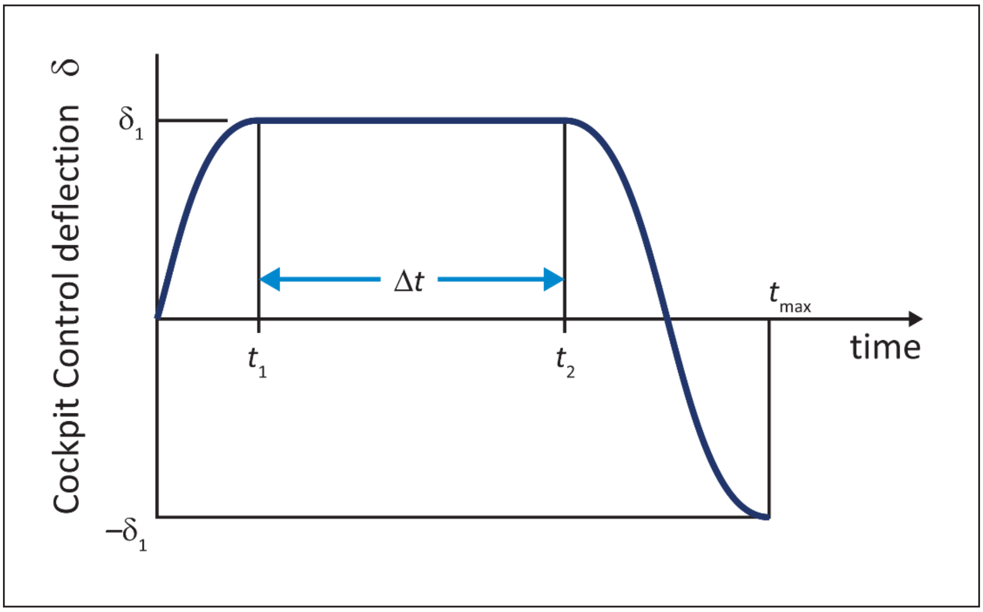
where:

t_1 = π/2ω

t_2 = t_1 + Δt

t_{max} = t_2 + π/ω;

Δt = the minimum period of time necessary to allow the prescribed limit load factor to be achieved in the initial direction, but it need not exceed five seconds (see figure below).



(iv) In cases where the cockpit pitch control motion may be affected by inputs from systems (for example, by a stick pusher that can operate at high load factor as well as at 1g) then the effects of those systems must be taken into account.

(v) Aeroplane loads that occur beyond the following times need not be considered:

(A) For the nose-up pitching manoeuvre, the time at which the normal acceleration at the c.g. goes below 0g;

(B) For the nose-down pitching manoeuvre, the time at which the normal acceleration at the c.g. goes above the positive limit load factor prescribed in CS 25.337;

(C) t_{max}.

[Amdt 25/13]
[Amdt 25/18]

AMC 25.331(c)(1) Maximum pitch control displacement at V_A

ED Decision 2013/010/R

The physical limitations of the aircraft from the cockpit pitch control device to the control surface deflection, such as control stops position, maximum power and displacement rate of the servo controls, and control law limiters, may be taken into account.

[Amdt 25/13]

AMC 25.331(c)(2) Checked manoeuvre between V_A and V_D

ED Decision 2013/010/R

The physical limitations of the aircraft from the cockpit pitch control device to the control surface deflection, such as control stops position, maximum power and displacement rate of the servo controls, and control law limiters, may be taken into account.

For aeroplanes equipped with electronic flight controls, where the motion of the control surfaces does not bear a direct relationship to the motion of the cockpit control devices, the circular frequency of the movement of the cockpit control 'ω' shall be varied by a reasonable amount to establish the effect