**Flight Loads**

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**§25.321   General.**

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

(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 Airplane 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 airplane structure is obtained.

(d) The significant forces acting on the airplane 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.

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-23, 35 FR 5672, Apr. 8, 1970; Amdt. 25-86, 61 FR 5220, Feb. 9, 1996]

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**Flight Maneuver and Gust Conditions**

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**§25.331   Symmetric maneuvering conditions.**

(a) *Procedure.* For the analysis of the maneuvering flight conditions specified in paragraphs (b) and (c) of this section, 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 maneuvering conditions of paragraphs (b) and (c) of this section, the effect of corresponding pitching velocities must be taken into account. The in-trim and out-of-trim flight conditions specified in §25.255 must be considered.

(b) *Maneuvering balanced conditions.* Assuming the airplane to be in equilibrium with zero pitching acceleration, the maneuvering conditions A through I on the maneuvering envelope in §25.333(b) must be investigated.

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

(1) *Maximum pitch control displacement at V*A. The airplane is assumed to be flying in steady level flight (point A1, §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 airplane must be taken into account. Airplane loads that occur subsequent to the time when normal acceleration at the c.g. exceeds the positive limit maneuvering load factor (at point A2 in §25.333(b)), or the resulting tailplane normal load reaches its maximum, whichever occurs first, need not be considered.

(2) *Checked maneuver between VA* and *VD*. Nose-up checked pitching maneuvers must be analyzed in which the positive limit load factor prescribed in §25.337 is achieved. As a separate condition, nose-down checked pitching maneuvers must be analyzed in which a limit load factor of 0g is achieved. In defining the airplane loads, the flight deck pitch control motions described in paragraphs (c)(2)(i) through (iv) of this section must be used:

(i) The airplane is assumed to be flying in steady level flight at any speed between VA and VD and the flight deck pitch control is moved in accordance with the following formula:

δ(t) = δ1 sin(ωt) for 0 ≤ t ≤ tmax

Where—

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

δ(t) = the displacement of the flight deck pitch control as a function of time. In the initial direction, δ(t) is limited to δ1. In the reverse direction, δ(t) may be truncated at the maximum available displacement of the flight deck pitch control as limited by the control system stops, control surface stops, or by pilot effort in accordance with 25.397(b);

tmax = 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 airplane, with active control system effects included where appropriate; but not less than:



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Where

V = the speed of the airplane at entry to the maneuver.

VA = the design maneuvering speed prescribed in §25.335(c).

(ii) For nose-up pitching maneuvers, the complete flight deck pitch control displacement history may be scaled down in amplitude to the extent necessary to ensure that the positive limit load factor prescribed in §25.337 is not exceeded. For nose-down pitching maneuvers, the complete flight deck control displacement history may be scaled down in amplitude to the extent necessary to ensure that the normal acceleration at the center of gravity does not go below 0g.

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

δ(t) = δ1 sin(ωt) for 0 ≤ t ≤ t1

δ(t) = δ1 for t1 ≤ t ≤ t2

δ(t) = δ1 sin(ω[t + t1 − t2]) for t2 ≤ t ≤ tmax

Where—

t1 = π/2ω

t2 = t1 + Δt

tmax = t2 + 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).



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(iv) In cases where the flight deck 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 shall be taken into account.

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

(A) For the nose-up pitching maneuver, the time at which the normal acceleration at the center of gravity goes below 0g;

(B) For the nose-down pitching maneuver, the time at which the normal acceleration at the center of gravity goes above the positive limit load factor prescribed in §25.337;

(C) tmax..

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**§25.333   Flight maneuvering envelope.**

(a) *General.* The strength requirements must be met at each combination of airspeed and load factor on and within the boundaries of the representative maneuvering envelope (*V-n* diagram) of paragraph (b) of this section. This envelope must also be used in determining the airplane structural operating limitations as specified in §25.1501.

(b) *Maneuvering envelope.*



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**§25.335   Design airspeeds.**

The selected design airspeeds are equivalent airspeeds (EAS). Estimated values of *VS*0 and *VS*1 must be conservative.

(a) *Design cruising speed, VC*. For *VC,* the following apply:

(1) The minimum value of *VC* must be sufficiently greater than *VB* to provide for inadvertent speed increases likely to occur as a result of severe atmospheric turbulence.

(2) Except as provided in §25.335(d)(2), VC may not be less than VB + 1.32 UREF (with UREF as specified in §25.341(a)(5)(i)). However VC need not exceed the maximum speed in level flight at maximum continuous power for the corresponding altitude.

(3) At altitudes where *VD* is limited by Mach number, *VC* may be limited to a selected Mach number.

(b) *Design dive speed, VD*. *VD* must be selected so that *VC*/*MC* is not greater than 0.8 *VD*/*MD,* or so that the minimum speed margin between *VC*/*MC* and *VD*/*MD* is the greater of the following values:

(1) From an initial condition of stabilized flight at *VC*/*MC,* the airplane is upset, flown for 20 seconds along a flight path 7.5° below the initial path, and then pulled up at a load factor of 1.5*g* (0.5*g* acceleration increment). The speed increase occurring in this maneuver may be calculated if reliable or conservative aerodynamic data is used. Power as specified in §25.175(b)(1)(iv) is assumed until the pullup is initiated, at which time power reduction and the use of pilot controlled drag devices may be assumed;

(2) The minimum speed margin must be enough to provide for atmospheric variations (such as horizontal gusts, and penetration of jet streams and cold fronts) and for instrument errors and airframe production variations. These factors may be considered on a probability basis. The margin at altitude where MC is limited by compressibility effects must not less than 0.07M unless a lower margin is determined using a rational analysis that includes the effects of any automatic systems. In any case, the margin may not be reduced to less than 0.05M.

(c) *Design maneuvering speed VA*. For *VA*, the following apply:

(1) V*A* may not be less than V*S*1 √n where—

(i) *n* is the limit positive maneuvering load factor at *VC*; and

(ii) *VS*1 is the stalling speed with flaps retracted.

(2) *VA* and *VS* must be evaluated at the design weight and altitude under consideration.

(3) *VA* need not be more than *VC* or the speed at which the positive *CN max* curve intersects the positive maneuver load factor line, whichever is less.

(d) *Design speed for maximum gust intensity, V*B.

(1) VB may not be less than



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where—

VS1 = the 1-g stalling speed based on CNAmax with the flaps retracted at the particular weight under consideration;

Vc = design cruise speed (knots equivalent airspeed);

Uref = the reference gust velocity (feet per second equivalent airspeed) from §25.341(a)(5)(i);

w = average wing loading (pounds per square foot) at the particular weight under consideration.



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ρ = density of air (slugs/ft3);

c = mean geometric chord of the wing (feet);

g = acceleration due to gravity (ft/sec2);

a = slope of the airplane normal force coefficient curve, CNA per radian;

(2) At altitudes where VC is limited by Mach number—

(i) VB may be chosen to provide an optimum margin between low and high speed buffet boundaries; and,

(ii) VB need not be greater than VC.

(e) *Design flap speeds, VF*. For *VF*, the following apply:

(1) The design flap speed for each flap position (established in accordance with §25.697(a)) must be sufficiently greater than the operating speed recommended for the corresponding stage of flight (including balked landings) to allow for probable variations in control of airspeed and for transition from one flap position to another.

(2) If an automatic flap positioning or load limiting device is used, the speeds and corresponding flap positions programmed or allowed by the device may be used.

(3) *VF* may not be less than—

(i) 1.6 *VS*1 with the flaps in takeoff position at maximum takeoff weight;

(ii) 1.8 *VS*1 with the flaps in approach position at maximum landing weight, and

(iii) 1.8 *VS*0 with the flaps in landing position at maximum landing weight.

(f) *Design drag device speeds, VDD*. The selected design speed for each drag device must be sufficiently greater than the speed recommended for the operation of the device to allow for probable variations in speed control. For drag devices intended for use in high speed descents, *VDD* may not be less than *VD*. When an automatic drag device positioning or load limiting means is used, the speeds and corresponding drag device positions programmed or allowed by the automatic means must be used for design.

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**§25.337   Limit maneuvering load factors.**

(a) Except where limited by maximum (static) lift coefficients, the airplane is assumed to be subjected to symmetrical maneuvers resulting in the limit maneuvering load factors prescribed in this section. Pitching velocities appropriate to the corresponding pull-up and steady turn maneuvers must be taken into account.

(b) The positive limit maneuvering load factor *n* for any speed up to *Vn* may not be less than 2.1 + 24,000/ (*W* + 10,000) except that *n* may not be less than 2.5 and need not be greater than 3.8—where *W* is the design maximum takeoff weight.

(c) The negative limit maneuvering load factor—

(1) May not be less than −1.0 at speeds up to *VC*; and

(2) Must vary linearly with speed from the value at *VC* to zero at *VD*.

(d) Maneuvering load factors lower than those specified in this section may be used if the airplane has design features that make it impossible to exceed these values in flight.

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-23, 35 FR 5672, Apr. 8, 1970]

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**§25.341   Gust and turbulence loads.**

(a) *Discrete Gust Design Criteria.* The airplane is assumed to be subjected to symmetrical vertical and lateral gusts in level flight. Limit gust loads must be determined in accordance with the provisions:

(1) Loads on each part of the structure must be determined by dynamic analysis. The analysis must take into account unsteady aerodynamic characteristics and all significant structural degrees of freedom including rigid body motions.

(2) The shape of the gust must be:



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for 0 ≤s ≤2H

where—

s = distance penetrated into the gust (feet);

Uds = the design gust velocity in equivalent airspeed specified in paragraph (a)(4) of this section; and

H = the gust gradient which is the distance (feet) parallel to the airplane's flight path for the gust to reach its peak velocity.

(3) A sufficient number of gust gradient distances in the range 30 feet to 350 feet must be investigated to find the critical response for each load quantity.

(4) The design gust velocity must be:



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where—

Uref = the reference gust velocity in equivalent airspeed defined in paragraph (a)(5) of this section.

Fg = the flight profile alleviation factor defined in paragraph (a)(6) of this section.

(5) The following reference gust velocities apply:

(i) At airplane speeds between VB and VC: Positive and negative gusts with reference gust velocities of 56.0 ft/sec EAS must be considered at sea level. The reference gust velocity may be reduced linearly from 56.0 ft/sec EAS at sea level to 44.0 ft/sec EAS at 15,000 feet. The reference gust velocity may be further reduced linearly from 44.0 ft/sec EAS at 15,000 feet to 20.86 ft/sec EAS at 60,000 feet.

(ii) At the airplane design speed VD: The reference gust velocity must be 0.5 times the value obtained under §25.341(a)(5)(i).

(6) The flight profile alleviation factor, Fg, must be increased linearly from the sea level value to a value of 1.0 at the maximum operating altitude defined in §25.1527. At sea level, the flight profile alleviation factor is determined by the following equation:



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Zmo = Maximum operating altitude defined in §25.1527 (feet).

(7) When a stability augmentation system is included in the analysis, the effect of any significant system nonlinearities should be accounted for when deriving limit loads from limit gust conditions.

(b) *Continuous turbulence design criteria.* The dynamic response of the airplane to vertical and lateral continuous turbulence must be taken into account. The dynamic analysis must take into account unsteady aerodynamic characteristics and all significant structural degrees of freedom including rigid body motions. The limit loads must be determined for all critical altitudes, weights, and weight distributions as specified in §25.321(b), and all critical speeds within the ranges indicated in §25.341(b)(3).

(1) Except as provided in paragraphs (b)(4) and (5) of this section, the following equation must be used:

*P*L = PL−1*g* ± UσA̅

Where—

PL = limit load;

PL−1g = steady 1g load for the condition;

A = ratio of root-mean-square incremental load for the condition to root-mean-square turbulence velocity; and

Uσ = limit turbulence intensity in true airspeed, specified in paragraph (b)(3) of this section.

(2) Values of A must be determined according to the following formula:



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Where—

H(Ω) = the frequency response function, determined by dynamic analysis, that relates the loads in the aircraft structure to the atmospheric turbulence; and

Φ(Ω) = normalized power spectral density of atmospheric turbulence given by—



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Where—

Ω = reduced frequency, radians per foot; and

L = scale of turbulence = 2,500 ft.

(3) The limit turbulence intensities, Uσ, in feet per second true airspeed required for compliance with this paragraph are—

(i) At airplane speeds between VB and VC:

Uσ = Uσref Fg

Where—

Uσref is the reference turbulence intensity that varies linearly with altitude from 90 fps (TAS) at sea level to 79 fps (TAS) at 24,000 feet and is then constant at 79 fps (TAS) up to the altitude of 60,000 feet.

Fg is the flight profile alleviation factor defined in paragraph (a)(6) of this section;

(ii) At speed VD: Uσ is equal to 1⁄2 the values obtained under paragraph (b)(3)(i) of this section.

(iii) At speeds between VC and VD: Uσ is equal to a value obtained by linear interpolation.

(iv) At all speeds, both positive and negative incremental loads due to continuous turbulence must be considered.

(4) When an automatic system affecting the dynamic response of the airplane is included in the analysis, the effects of system non-linearities on loads at the limit load level must be taken into account in a realistic or conservative manner.

(5) If necessary for the assessment of loads on airplanes with significant non-linearities, it must be assumed that the turbulence field has a root-mean-square velocity equal to 40 percent of the Uσ values specified in paragraph (b)(3) of this section. The value of limit load is that load with the same probability of exceedance in the turbulence field as AUσ of the same load quantity in a linear approximated model.

(c) *Supplementary gust conditions for wing-mounted engines.* For airplanes equipped with wing-mounted engines, the engine mounts, pylons, and wing supporting structure must be designed for the maximum response at the nacelle center of gravity derived from the following dynamic gust conditions applied to the airplane:

(1) A discrete gust determined in accordance with §25.341(a) at each angle normal to the flight path, and separately,

(2) A pair of discrete gusts, one vertical and one lateral. The length of each of these gusts must be independently tuned to the maximum response in accordance with §25.341(a). The penetration of the airplane in the combined gust field and the phasing of the vertical and lateral component gusts must be established to develop the maximum response to the gust pair. In the absence of a more rational analysis, the following formula must be used for each of the maximum engine loads in all six degrees of freedom:



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Where—

PL = limit load;

PL-1g = steady 1g load for the condition;

LV = peak incremental response load due to a vertical gust according to §25.341(a); and

LL = peak incremental response load due to a lateral gust according to §25.341(a).

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