and

$$P_{Lj} = P_{(1-g)j} -/+ \overline{A}_i U_\sigma \left[(1 - \rho_{ij})/2\right]^{1/2}$$

For tangents to lines CD and GH

$$P_{Li} = P_{(1-g)i} \pm \overline{A}_j U_\sigma \left[(1 + \rho_{ij})/2\right]^{1/2}$$

and

$$P_{Lj} = P_{(1-g)j} \pm \overline{A}_i U_\sigma \left[(1 + \rho_{ij})/2\right]^{1/2}$$

All correlated or equiprobable loads developed using correlation coefficients will provide balanced load distributions.

A more comprehensive approach for calculating critical design stresses that depend on a combination of external load quantities is to evaluate directly the transfer function for the stress quantity of interest from which can be calculated the gust response function, the value for RMS response, Ā, and the design stress values P(1-g) ± U_σ Ā.

6. AEROPLANE MODELLING CONSIDERATIONS

a. General. The procedures presented in this paragraph generally apply for aeroplanes having aerodynamic and structural properties and flight control systems that may be reasonably or conservatively approximated using linear analysis methods for calculating limit load. Additional guidance material is presented in Paragraph 8 of this AMC for aeroplanes having properties and/or systems not reasonably or conservatively approximated by linear analysis methods.

b. Structural Dynamic Model. The model should include both rigid body and flexible aeroplane degrees of freedom. If a modal approach is used, the structural dynamic model should include a sufficient number of flexible aeroplane modes to ensure both convergence of the modal superposition procedure and that responses from high frequency excitations are properly represented.

Most forms of structural modelling can be classified into two main categories: (1) the so-called “stick model” characterised by beams with lumped masses distributed along their lengths, and (2) finite element models in which all major structural components (frames, ribs, stringers, skins) are represented with mass properties defined at grid points. Regardless of the approach taken for the structural modelling, a minimum acceptable level of sophistication, consistent with configuration complexity, is necessary to represent satisfactorily the critical modes of deformation of the primary structure and control surfaces. Results from the models should be compared to test data as outlined in Paragraph 9.b. of this AMC in order to validate the accuracy of the model.

c. Structural Damping. Structural dynamic models may include damping properties in addition to representations of mass and stiffness distributions. In the absence of better information it will normally be acceptable to assume 0.03 (i.e. 1.5% equivalent critical viscous damping) for all flexible modes. Structural damping may be increased over the 0.03 value to be consistent with the high structural response levels caused by extreme gust intensity, provided justification is given.

d. Gust and Motion Response Aerodynamic Modelling. Aerodynamic forces included in the analysis are produced by both the gust velocity directly, and by the aeroplane response.

Aerodynamic modelling for dynamic gust response analyses requires the use of unsteady two-dimensional or three-dimensional panel theory methods for incompressible or compressible flow. The choice of the appropriate technique depends on the complexity of the aerodynamic configuration, the dynamic motion of the surfaces under investigation and the flight speed envelope of the aeroplane. Generally, three-dimensional panel methods achieve better modelling of the aerodynamic interference between lifting surfaces. The model should have a sufficient number of aerodynamic degrees of freedom to properly represent the steady and unsteady aerodynamic distributions under consideration.

The build-up of unsteady aerodynamic forces should be represented. In two-dimensional unsteady analysis this may be achieved in either the frequency domain or the time domain through the application of oscillatory or indicial lift functions, respectively. Where three-dimensional panel aerodynamic theories are to be applied in the time domain (e.g. for non-linear gust solutions), an approach such as the 'rational function approximation' method may be employed to transform frequency domain aerodynamics into the time domain.

Oscillatory lift functions due to gust velocity or aeroplane response depend on the reduced frequency parameter, k. The maximum reduced frequency used in the generation of the unsteady aerodynamics should include the highest frequency of gust excitation and the highest structural frequency under consideration. Time lags representing the effect of the gradual penetration of the gust field by the aeroplane should also be accounted for in the build-up of lift due to gust velocity.

The aerodynamic modelling should be supported by tests or previous experience as indicated in Paragraph 9.d. of this AMC. Primary lifting and control surface distributed aerodynamic data are commonly adjusted by weighting factors in the dynamic gust response analyses. The weighting factors for steady flow ($k = 0$) may be obtained by comparing wind tunnel test results with theoretical data. The correction of the aerodynamic forces should also ensure that the rigid body motion of the aeroplane is accurately represented in order to provide satisfactory short period and Dutch roll frequencies and damping ratios. Corrections to primary surface aerodynamic loading due to control surface deflection should be considered. Special attention should also be given to control surface hinge moments and to fuselage and nacelle aerodynamics because viscous and other effects may require more extensive adjustments to the theoretical coefficients. Aerodynamic gust forces should reflect weighting factor adjustments performed on the steady or unsteady motion response aerodynamics.

e. Gyroscopic Loads. As specified in CS 25.371, the structure supporting the engines and the auxiliary power units should be designed for the gyroscopic loads induced by both discrete gusts and continuous turbulence. The gyroscopic loads for turbopropellers and turbofans may be calculated as an integral part of the solution process by including the gyroscopic terms in the equations of motion or the gyroscopic loads can be superimposed after the solution of the equations of motion. Propeller and fan gyroscopic coupling forces (due to rotational direction) between symmetric and antisymmetric modes need not be taken into account if the coupling forces are shown to be negligible.

The gyroscopic loads used in this analysis should be determined with the engine or auxiliary power units at maximum continuous rpm. The mass polar moment of inertia used in calculating gyroscopic inertia terms should include the mass polar moments of inertia of all significant rotating parts taking into account their respective rotational gearing ratios and directions of rotation.

f. Control Systems. Gust analyses of the basic configuration should include simulation of any control system for which interaction may exist with the rigid body response, structural dynamic response or external loads. If possible, these control systems should be uncoupled such that the systems which affect “symmetric flight” are included in the vertical gust analysis and those which affect “antisymmetric flight” are included in the lateral gust analysis.

The control systems considered should include all relevant modes of operation. Failure conditions should also be analysed for any control system which influences the design loads in accordance with CS 25.302 and Appendix K.

The control systems included in the gust analysis may be assumed to be linear if the impact of the non-linearity is negligible, or if it can be shown by analysis on a similar aeroplane/control system that a linear control law representation is conservative. If the control system is significantly non-linear, and a conservative linear approximation to the control system cannot be developed, then the effect of the control system on the aeroplane responses should be evaluated in accordance with Paragraph 8. of this AMC.

g. Stability. Solutions of the equations of motion for either discrete gusts or continuous turbulence require the dynamic model be stable. This applies for all modes, except possibly for very low frequency modes which do not affect load responses, such as the phugoid mode. (Note that the short period and Dutch roll modes do affect load responses). A stability check should be performed for the dynamic model using conventional stability criteria appropriate for the linear or non-linear system in question, and adjustments should be made to the dynamic model, as required, to achieve appropriate frequency and damping characteristics.

If control system models are to be included in the gust analysis it is advisable to check that the following characteristics are acceptable and are representative of the aeroplane:

— static margin of the unaugmented aeroplane

— dynamic stability of the unaugmented aeroplane

— the static aeroelastic effectiveness of all control surfaces utilised by any feed-back control system

— gain and phase margins of any feedback control system coupled with the aeroplane rigid body and flexible modes

— the aeroelastic flutter and divergence margins of the unaugmented aeroplane, and also for any feedback control system coupled with the aeroplane.

7. DYNAMIC LOADS

a. General. This paragraph describes methods for formulating and solving the aeroplane equations of motion and extracting dynamic loads from the aeroplane response. The aeroplane equations of motion are solved in either physical or modal co-ordinates and include all terms important in the loads calculation including stiffness, damping, mass, and aerodynamic forces due to both aeroplane motions and gust excitation. Generally the aircraft equations are solved in modal co-ordinates. For the purposes of describing the solution of these equations in the remainder of this AMC, modal co-ordinates will be assumed. A sufficient number of modal co-ordinates should be included to ensure that the loads extracted provide converged values.

b. Solution of the Equations of Motion. Solution of the equations of motion can be achieved through a number of techniques. For the continuous turbulence analysis, the equations of motion are generally solved in the frequency domain. Transfer functions which relate the output response quantity to an input harmonically oscillating gust field are generated and these transfer functions are used (in Paragraph 5.c. of this AMC) to generate the RMS value of the output response quantity.

There are two primary approaches used to generate the output time histories for the discrete gust analysis; (1) by explicit integration of the aeroplane equations of motion in the time domain, and (2) by frequency domain solutions which can utilise Fourier transform techniques.

c. Extraction of Loads and Responses. The output quantities that may be extracted from a gust response analysis include displacements, velocities and accelerations at structural locations; load quantities such as shears, bending moments and torques on structural components; and stresses and shear flows in structural components. The calculation of the physical responses is given by a modal superposition of the displacements, velocities and accelerations of the rigid and elastic modes of vibration of the aeroplane structure. The number of modes carried in the summation should be sufficient to ensure converged results.

A variety of methods may be used to obtain physical structural loads from a solution of the modal equations of motion governing gust response. These include the Mode Displacement method, the Mode Acceleration method, and the Force Summation method. All three methods are capable of providing a balanced set of aeroplane loads. If an infinite number of modes can be considered in the analysis, the three will lead to essentially identical results.

The Mode Displacement method is the simplest. In this method, total dynamic loads are calculated from the structural deformations produced by the gust using modal superposition. Specifically, the contribution of a given mode is equal to the product of the load associated with the normalised deformed shape of that mode and the value of the displacement response given by the associated modal co-ordinate. For converged results, the Mode Displacement method may need a significantly larger number of modal co-ordinates than the other two methods.

In the Mode Acceleration method, the dynamic load response is composed of a static part and a dynamic part. The static part is determined by conventional static analysis (including rigid body “inertia relief”), with the externally applied gust loads treated as static loads. The dynamic part is computed by the superposition of appropriate modal quantities, and is a function of the number of modes carried in the solution. The quantities to be superimposed involve both motion response forces and acceleration responses (thus giving this method its name). Since the static part is determined completely and independently of the number of normal modes carried, adequate accuracy may be achieved with fewer modes than would be needed in the Mode Displacement method.

The Force Summation method is the most laborious and the most intuitive. In this method, physical displacements, velocities and accelerations are first computed by superposition of the modal responses. These are then used to determine the physical inertia forces and other motion dependent forces. Finally, these forces are added to the externally applied forces to give the total dynamic loads acting on the structure.

If balanced aeroplane load distributions are needed from the discrete gust analysis, they may be determined using time correlated solution results. Similarly, as explained in Paragraph 5.c of this AMC, if balanced aeroplane load distributions are needed from the continuous turbulence analysis, they may be determined from equiprobable solution results obtained using cross-correlation coefficients.

8. NONLINEAR CONSIDERATIONS

a. General. Any structural, aerodynamic or automatic control system characteristic which may cause aeroplane response to discrete gusts or continuous turbulence to become non-linear with respect to intensity or shape should be represented realistically or conservatively in the calculation of loads. While many minor non-linearities are amenable to a conservative linear solution, the effect of major non-linearities cannot usually be quantified without explicit calculation.

The effect of non-linearities should be investigated above limit conditions to assure that the system presents no anomaly compared to behaviour below limit conditions, in accordance with Appendix K, K25.2(b)(2).

b. Structural and Aerodynamic Non-linearity. A linear elastic structural model, and a linear (unstalled) aerodynamic model are normally recommended as conservative and acceptable for the unaugmented aeroplane elements of a loads calculation. Aerodynamic models may be refined to take account of minor non-linear variation of aerodynamic distributions, due to local separation etc., through simple linear piecewise solution. Local or complete stall of a lifting surface would constitute a major non-linearity and should not be represented without account being taken of the influence of rate of change of incidence, i.e., the so-called 'dynamic stall' in which the range of linear incremental aerodynamics may extend significantly beyond the static stall incidence.

c. Automatic Control System Non-linearity. Automatic flight control systems, autopilots, stability control systems and load alleviation systems often constitute the primary source of non-linear response. For example,

— non-proportional feedback gains

— rate and amplitude limiters

— changes in the control laws, or control law switching

— hysteresis

— use of one-sided aerodynamic controls such as spoilers

— hinge moment performance and saturation of aerodynamic control actuators

The resulting influences on response will be aeroplane design dependent, and the manner in which they are to be considered will normally have to be assessed for each design.

Minor influences such as occasional clipping of response due to rate or amplitude limitations, where it is symmetric about the stabilised 1-g condition, can often be represented through quasi-linear modelling techniques such as describing functions or use of a linear equivalent gain.

Major, and unsymmetrical influences such as application of spoilers for load alleviation, normally require explicit simulation, and therefore adoption of an appropriate solution based in the time domain.

The influence of non-linearities on one load quantity often runs contrary to the influence on other load quantities. For example, an aileron used for load alleviation may simultaneously relieve wing bending moment whilst increasing wing torsion. Since it may not be possible to represent such features conservatively with a single aeroplane model, it may be conservatively acceptable to consider loads computed for two (possibly linear) representations which bound the realistic condition. Another example of this approach would be separate representation of continuous turbulence response for the two control law states to cover a situation where the aeroplane may occasionally switch from one state to another.

d. Non-linear Solution Methodology. Where explicit simulation of non-linearities is required, the loads response may be calculated through time domain integration of the equations of motion.

For the tuned discrete gust conditions of CS 25.341(a), limit loads should be identified by peak values in the non-linear time domain simulation response of the aeroplane model excited by the discrete gust model described in Paragraph 5.b. of this AMC.

For time domain solution of the continuous turbulence conditions of CS 25.341(b), a variety of approaches may be taken for the specification of the turbulence input time history and the mechanism for identifying limit loads from the resulting responses.

It will normally be necessary to justify that the selected approach provides an equivalent level of safety as a conventional linear analysis and is appropriate to handle the types of non-linearity on the aircraft. This should include verification that the approach provides adequate statistical significance in the loads results.

A methodology based upon stochastic simulation has been found to be acceptable for load alleviation and flight control system non-linearities. In this simulation, the input is a long, Gaussian, pseudo-random turbulence stream conforming to a Von Kármán spectrum with a root-mean-square (RMS) amplitude of 0.4 times U_σ (defined in Paragraph 5.c (1) of this AMC). The value of limit load is that load with the same probability of exceedance as $\bar{A}\, U_\sigma$ of the same load quantity in a linear model. This is illustrated graphically in Figure 5. When using an analysis of this type, exceedance curves should be constructed using incremental load values up to, or just beyond the limit load value.

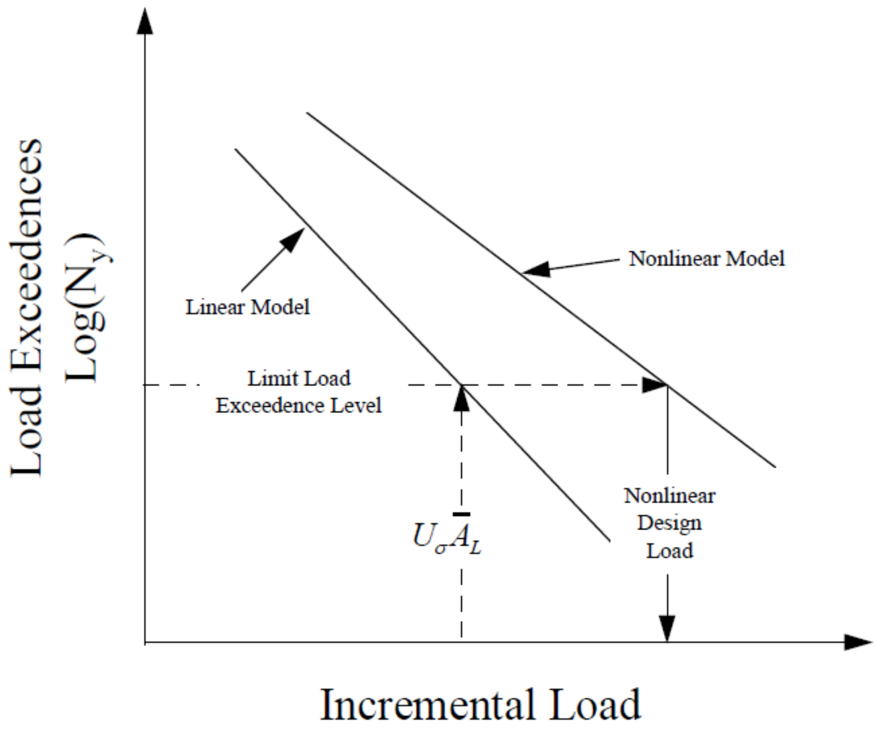

Figure-5 Establishing Limit Load for a Non-linear Aeroplane

The non-linear simulation may also be performed in the frequency domain if the frequency domain method is shown to produce conservative results. Frequency domain methods include, but are not limited to, Matched Filter Theory and Equivalent Linearisation.

9. ANALYTICAL MODEL VALIDATION

a. General. The intent of analytical model validation is to establish that the analytical model is adequate for the prediction of gust response loads. The following paragraphs discuss acceptable but not the only methods of validating the analytical model. In general, it is not intended that specific testing be required to validate the dynamic gust loads model.

b. Structural Dynamic Model Validation. The methods and test data used to validate the flutter analysis models presented in AMC 25.629 should also be applied to validate the gust analysis models. These procedures are addressed in AMC 25.629.

c. Damping Model Validation. In the absence of better information it will normally be acceptable to assume 0.03 (i.e. 1.5% equivalent critical viscous damping) for all flexible modes. Structural damping may be increased over the 0.03 value to be consistent with the high structural response levels caused by extreme gust intensity, provided justification is given.

d. Aerodynamic Model Validation. Aerodynamic modelling parameters fall into two categories:

(i) steady or quasi-steady aerodynamics governing static aeroelastic and flight dynamic airload distributions

(ii) unsteady aerodynamics which interact with the flexible modes of the aeroplane.

Flight stability aerodynamic distributions and derivatives may be validated by wind tunnel tests, detailed aerodynamic modelling methods (such as CFD) or flight test data. If detailed analysis or testing reveals that flight dynamic characteristics of the aeroplane differ significantly from those to which the gust response model have been matched, then the implications on gust loads should be investigated.

The analytical and experimental methods presented in AMC 25.629 for flutter analyses provide acceptable means for establishing reliable unsteady aerodynamic characteristics both for motion response and gust excitation aerodynamic force distributions. The aeroelastic implications on aeroplane flight dynamic stability should also be assessed.

e. Control System Validation. If the aeroplane mathematical model used for gust analysis contains a representation of any feedback control system, then this segment of the model should be validated. The level of validation that should be performed depends on the complexity of the system and the particular aeroplane response parameter being controlled. Systems which control elastic modes of the aeroplane may require more validation than those which control the aeroplane rigid body response. Validation of elements of the control system (sensors, actuators, anti-aliasing filters, control laws, etc.) which have a minimal effect on the output load and response quantities under consideration can be neglected.

It will normally be more convenient to substantiate elements of the control system independently, i.e. open loop, before undertaking the validation of the closed loop system.

(1) System Rig or Aeroplane Ground Testing. Response of the system to artificial stimuli can be measured to verify the following:

— The transfer functions of the sensors and any pre-control system anti-aliasing or other filtering.

— The sampling delays of acquiring data into the control system.

— The behaviour of the control law itself.

— Any control system output delay and filter transfer function.

— The transfer functions of the actuators, and any features of actuation system performance characteristics that may influence the actuator response to the maximum demands that might arise in turbulence; e.g. maximum rate of deployment, actuator hinge moment capability, etc.

If this testing is performed, it is recommended that following any adaptation of the model to reflect this information, the complete feedback path be validated (open loop) against measurements taken from the rig or ground tests.

(2) Flight Testing. The functionality and performance of any feedback control system can also be validated by direct comparison of the analytical model and measurement for input stimuli. If this testing is performed, input stimuli should be selected such that they exercise the features of the control system and the interaction with the aeroplane that are significant in the use of the mathematical model for gust load analysis. These might include:

— Aeroplane response to pitching and yawing manoeuvre demands.

— Control system and aeroplane response to sudden artificially introduced demands such as pulses and steps.

— Gain and phase margins determined using data acquired within the flutter test program. These gain and phase margins can be generated by passing known signals through the open loop system during flight test.

[Amdt No: 25/1]
[Amdt No: 25/23]

CS 25.343 Design fuel and oil loads

ED Decision 2005/006/R

(a) The disposable load combinations must include each fuel and oil load in the range from zero fuel and oil to the selected maximum fuel and oil load. A structural reserve fuel condition, not exceeding 45 minutes of fuel under operating conditions in CS 25.1001(f), may be selected.

(b) If a structural reserve fuel condition is selected, it must be used as the minimum fuel weight condition for showing compliance with the flight load requirements as prescribed in this Subpart. In addition –

(1) The structure must be designed for a condition of zero fuel and oil in the wing at limit loads corresponding to –

(i) A manoeuvring load factor of +2·25; and

(ii) The gust and turbulence conditions of CS 25.341, but assuming 85% of the gust velocities prescribed in CS 25.341(a)(4) and 85% of the turbulence intensities prescribed in CS 25.341(b)(3).

(2) Fatigue evaluation of the structure must account for any increase in operating stresses resulting from the design condition of sub-paragraph (b)(1) of this paragraph; and

(3) The flutter, deformation, and vibration requirements must also be met with zero fuel.

[Amdt 25/1]

CS 25.345 High lift devices

ED Decision 2016/010/R

(See AMC 25.345)

(a) If wing-flaps are to be used during take-off, approach, or landing, at the design flap speeds established for these stages of flight under CS 25.335(e) and with the wing-flaps in the corresponding positions, the aeroplane is assumed to be subjected to symmetrical manoeuvres and gusts. The resulting limit loads must correspond to the conditions determined as follows:

(1) Manoeuvring to a positive limit load factor of 2·0; and

(2) Positive and negative gusts of 7.62 m/sec (25 ft/sec) EAS acting normal to the flight path in level flight. Gust loads resulting on each part of the structure must be determined by rational analysis. The analysis must take into account the unsteady aerodynamic characteristics and rigid body motions of the aircraft. (See AMC 25.345(a).) The shape of the gust must be as described in CS 25.341(a)(2) except that –

U_{ds} = 7.62 m/sec (25 ft/sec) EAS;

H = 12.5 c; and

c = mean geometric chord of the wing (metres (feet)).

(b) The aeroplane must be designed for the conditions prescribed in sub-paragraph (a) of this paragraph except that the aeroplane load factor need not exceed 1·0, taking into account, as separate conditions, the effects of –

(1) Propeller slipstream corresponding to maximum continuous power at the design flap speeds V_F, and with take-off power at not less than 1·4 times the stalling speed for the particular flap position and associated maximum weight; and

(2) A head-on gust of 7.62m/sec (25 fps) velocity (EAS).

(c) If flaps or other high lift devices are to be used in en-route conditions, and with flaps in the appropriate position at speeds up to the flap design speed chosen for these conditions, the aeroplane is assumed to be subjected to symmetrical manoeuvres and gusts within the range determined by –

(1) Manoeuvring to a positive limit load factor as prescribed in CS 25.337(b) ; and

(2) The vertical gust and turbulence conditions prescribed in CS 25.341. (See AMC 25.345(c).)

(d) The aeroplane must be designed for a manoeuvring load factor of 1.5 g at the maximum take-off weight with the wing-flaps and similar high lift devices in the landing configurations.

[Amdt 25/1]
[Amdt 25/18]

AMC 25.345(a) High lift devices (Gust conditions)

ED Decision 2003/2/RM

Compliance with CS 25.345(a) may be demonstrated by an analysis in which the solution of the vertical response equations is made by assuming the aircraft to be rigid. If desired, the analysis may take account of the effects of structural flexibility on a quasi-flexible basis (i.e. using aerodynamic derivatives and load distributions corresponding to the distorted structure under maximum gust load).

AMC 25.345(c) High lift devices (Procedure flight condition)

ED Decision 2003/2/RM

1 En-route conditions are flight segments other than take-off, approach and landing. As applied to the use of high lift devices the following flight phases are to be included in en-route conditions:

— holding in designated areas outside the terminal area of the airport, and

— flight with flaps extended from top of descent.

The following flight phases are not to be included in en-route conditions:

— portion of the flight corresponding to standard arrival routes preceding the interception of the final approach path, and

— holding at relatively low altitude close to the airport.