NOTICE OF PROPOSED AMENDMENT (NPA) No 11/2004

DRAFT DECISION OF THE EXECUTIVE DIRECTOR OF THE AGENCY,

on certification specifications for large aeroplanes (CS-25)

Miscellaneous Structure

Contents

This Notice of Proposed Amendment is bundling the following original JAA NPAs which have followed and completed the JAA consultation process:

I) NPA 25C-199 “Interaction of Systems and Structures”

II) NPA 25BCD-236 “Vibration, Buffet and Aeroelastic Stability”

III) NPA 25D-286 “Material Strength Properties and Material Design Values”

IV) NPA 25C-290 “Proof of Structure”

V) NPA 25C-309 “Gust and Continuous Turbulence Design Loads”.

This Notice of Proposed Amendment is made up of following parts :

III-B. PROPOSALS TRANSPOSED JAA 25D-286
The actual proposed amendments.

III-C. ORIGINAL JAA NPA 25D-286 proposals justification
The proposals were already circulated for comments as a JAA NPA. This part contains the justification for the JAA NPA

III-D. JAA NPA 25D-286 COMMENT-RESPONSE DOCUMENT
This part summarizes the comments made on the JAA NPA and the responses to those comments.

IV-A. EXPLANATORY NOTE JAA NPA 25C-290
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V-A. EXPLANATORY NOTE JAA NPA 25C-309
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The proposals were already circulated for comments as a JAA NPA. This part contains the justification for the JAA NPA

V-D. JAA NPA 25C-309 COMMENT-RESPONSE DOCUMENT
This part summarizes the comments made on the JAA NPA and the responses to those comments.

0. GENERAL EXPLANATORY NOTE

General

1. The purpose of this Notice of Proposed Amendment (NPA) is to propose changes to the certifications specifications for large aeroplanes (CS-25). The reason for this proposal is outlined further below. This measure is included in the Agency's 2004 Rulemaking programme.

2. The text of this NPA was developed by the JAA Structures Steering Group. It was adapted to the EASA regulatory context by the Agency. It is now submitted for consultation of all interested parties in accordance with Article 5(3) of the EASA rulemaking procedure[1].
The review of comments will be made by the Agency unless the comments are of such nature that they necessitate the establishment of a group.

Consultation

3. Because the content of this NPA was already agreed for adoption in the Joint Aviation Authorities (JAA) system and was the subject of a full worldwide consultation, the transitional arrangements of article 15 of the EASA rulemaking procedure apply. They allow for a shorter consultation period of six weeks instead of the standard three months and also exempt from the requirement to produce a full Regulatory Impact Assessment.

4. To achieve optimal consultation, the Agency is publishing the draft decision on its internet site in order to reach its widest audience and collect the related comments.

Comments on this proposal may be forwarded *(preferably by e-mail)*, using the attached comment form, to:

By e-mail: NPA@easa.eu.int

By correspondence: **Ms.** Inge van Opzeeland
Postfach 10 12 53
D-50452 Köln, Germany
Tel: +49 221 89990 5008

Comments should be received by the Agency **before 22/12/2004** and if received after this deadline they might not be treated. Comments may not be considered if the form provided for this purpose is not used.

Comment response document

5. All comments received will be responded to and incorporated in a Comment Response Document (CRD). This will contain a list of all persons and/or organisations that have provided comments. The CRD will be widely available ultimately before the Agency adopts its final decision.

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[1] Decision of the Management Board concerning the procedure to be applied by the Agency for the issuing of opinions, certification specifications and guidance material ("rulemaking procedure"), EASA MB/7/03, 27.6.2003.

I-A. EXPLANATORY NOTE JAA NPA 25C-199

Originally JAA NPA 25C-199, Interaction of Systems and Structures (Revision 1, Final Version 9 January 2003)

1. The initial issue of CS-25 was based upon JAR-25 at amendment 16. During the transposition of airworthiness JARs into certification specifications the rulemaking activities under the JAA system where not stopped. In order to assure a smooth transition from JAA to EASA the Agency has committed itself to continue as much as possible of the JAA rulemaking activities. Therefore it has included most of it in its own rulemaking programme for 2004 and planning for 2005-2007. This part of present EASA NPA is a result of this commitment and a transposed version of the JAA NPA 25C-199 revision 1 which was circulated for comments from 2 April 2002 till 2 July 2002 and was agreed for adoption by the Regulation Sectorial Team in March 2003.

2. In 1988, the JAA, the FAA and organisations representing the European and United States aerospace industries, began a process to harmonise the airworthiness requirements of the European authorities and the airworthiness requirements of the United States. The objective was to achieve common requirements for the certification of large/transport aeroplanes without a substantive change in the level of safety. Other airworthiness authorities such as Transport Canada also participated in this process.

In 1991, the harmonisation effort was undertaken by the Aviation Regulatory Advisory Committee (ARAC). By notice in the Federal Register (1993), a working group (Loads and Dynamics Harmonisation Working Group, LDHWG) of industry and government structural specialists of Europe, the U.S., and Canada was chartered to address the issue of interaction of systems and structures.
In December 1996 the JAA published NPA 25C-199 for comment. The comments received were discussed by the JAR-25 Structures Study Group and were addressed in a comment/response document (ref. SSG/98/3).

Since then, the harmonisation effort has continued and has now progressed to the point that final proposals have been developed by the working group for the interaction of systems and structures requirements (ref. Technical Agreement, September 1999). This part of present EASA NPA contains the proposals necessary to achieve harmonisation of the interaction of systems and structures requirements. The comments received on the December 1996 issue of the JAA NPA (as far as they were accepted and are still applicable) have been incorporated into this issue of the EASA NPA.

I-B. PROPOSALS TRANSPOSED JAA NPA 25C-199

The following amendments should be included in Decision No. 2003/2/RM of the Executive Director of the Agency of 17 October 2003:

1. To add a new paragraph CS 25.302 to read as follows:

CS 25.302 Interaction of systems and structures

For aeroplanes equipped with systems that affect structural performance, either directly or as a result of a failure or malfunction, the influence of these systems and their failure conditions must be taken into account when showing compliance with the requirements of Subparts C and D. Appendix K of CS-25 must be used to evaluate the structural performance of aeroplanes equipped with these systems.

2. To renumber the existing Appendix K as Appendix L

3. To add a new Appendix K to read as follows:

APPENDIX K TO CS-25 - INTERACTION OF SYSTEMS AND STRUCTURES

K25.1 *General*.

The following criteria must be used for showing compliance with CS 25.302 for aeroplanes equipped with flight control systems, autopilots, stability augmentation systems, load alleviation systems, flutter control systems, and fuel management systems. If this appendix is used for other systems, it may be necessary to adapt the criteria to the specific system.

(a) The criteria defined herein only address the direct structural consequences of the system responses and performances and cannot be considered in isolation but should be included in the overall safety evaluation of the aeroplane. These criteria may in some instances duplicate standards already established for this evaluation. These criteria are only applicable to structure whose failure could prevent continued safe flight and landing. Specific criteria that define acceptable limits on handling characteristics or stability requirements when operating in the system degraded or inoperative mode are not provided in this appendix.

(b) Depending upon the specific characteristics of the aeroplane, additional studies may be required that go beyond the criteria provided in this appendix in order to demonstrate the capability of the aeroplane to meet other realistic conditions such as alternative gust or manoeuvre descriptions for an aeroplane equipped with a load alleviation system.

(c) The following definitions are applicable to this appendix.

Structural performance: Capability of the aeroplane to meet the structural requirements of CS-25.

Flight limitations: Limitations that can be applied to the aeroplane flight conditions following an in-flight occurrence and that are included in the flight manual (e.g., speed limitations, avoidance of severe weather conditions, etc.).

Operational limitations: Limitations, including flight limitations, that can be applied to the aeroplane operating conditions before dispatch (e.g., fuel, payload and Master Minimum Equipment List limitations).

Probabilistic terms: The probabilistic terms (probable, improbable, extremely improbable) used in this appendix are the same as those used in CS 25.1309.

Failure condition: The term failure condition is the same as that used in CS 25.1309, however this appendix applies only to system failure conditions that affect the structural performance of the aeroplane (e.g., system failure conditions that induce loads, change the response of the aeroplane to inputs such as gusts or pilot actions, or lower flutter margins).

K25.2 *Effects of Systems on Structures.*

(a) General. The following criteria will be used in determining the influence of a system and its failure conditions on the aeroplane structure.

(b) System fully operative. With the system fully operative, the following apply:

(1) Limit loads must be derived in all normal operating configurations of the system from all the limit conditions specified in Subpart C, taking into account any special behaviour of such a system or associated functions or any effect on the structural performance of the aeroplane that may occur up to the limit loads. In particular, any significant nonlinearity (rate of displacement of control surface, thresholds or any other system nonlinearities) must be accounted for in a realistic or conservative way when deriving limit loads from limit conditions.

(2) The aeroplane must meet the strength requirements of CS-25 (Static strength, residual strength), using the specified factors to derive ultimate loads from the limit loads defined above. The effect of nonlinearities must be investigated beyond limit conditions to ensure the behaviour of the system presents no anomaly compared to the behaviour below limit conditions. However, conditions beyond limit conditions need not be considered when it can be shown that the aeroplane has design features that will not allow it to exceed those limit conditions.

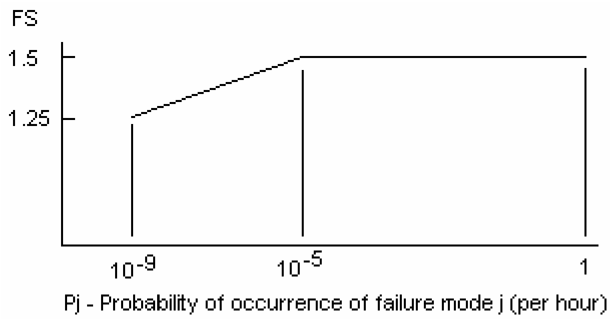
(3) The aeroplane must meet the aeroelastic stability requirements of CS 25.629.

(c) System in the failure condition. For any system failure condition not shown to be extremely improbable, the following apply:

(1) At the time of occurrence. Starting from 1-g level flight conditions, a realistic scenario, including pilot corrective actions, must be established to determine the loads occurring at the time of failure and immediately after failure.

(i) For static strength substantiation, these loads multiplied by an appropriate factor of safety that is related to the probability of occurrence of the failure are ultimate loads to be considered for design. The factor of safety (F.S.) is defined in Figure 1.

Figure 1
factor of safety at the time of occurrence



(ii) For residual strength substantiation, the aeroplane must be able to withstand two thirds of the ultimate loads defined in subparagraph (c)(1)(i). For pressurised cabins, these loads must be combined with the normal operating differential pressure.

(iii) Freedom from aeroelastic instability must be shown up to the speeds defined in CS 25.629(b)(2). For failure conditions that result in speed increases beyond V_C/M_C, freedom from aeroelastic instability must be shown to increased speeds, so that the margins intended by CS 25.629(b)(2) are maintained.

(iv) Failures of the system that result in forced structural vibrations (oscillatory failures) must not produce loads that could result in detrimental deformation of primary structure.

(2) For the continuation of the flight. For the aeroplane, in the system failed state and considering any appropriate reconfiguration and flight limitations, the following apply:

(i) The loads derived from the following conditions at speeds up to V_C / M_c, or the speed limitation prescribed for the remainder of the flight must be determined:

(A) the limit symmetrical manoeuvring conditions specified in CS 25.331 and in CS 25.345.

(B) the limit gust and turbulence conditions specified in CS 25.341 and in CS 25.345.

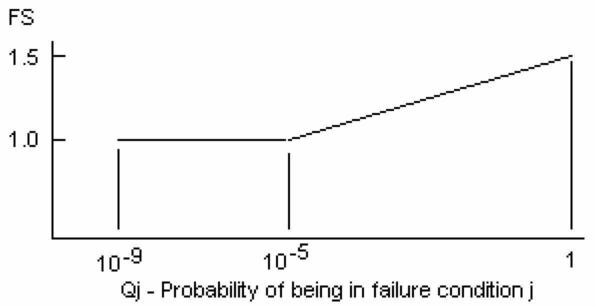
(C) the limit rolling conditions specified in CS 25.349 and the limit unsymmetrical conditions specified in CS 25.367 and CS 25.427(b) and (c).

(D) the limit yaw manoeuvring conditions specified in CS 25.351.

(E) the limit ground loading conditions specified in CS 25.473 and CS 25.491.

(ii) For static strength substantiation, each part of the structure must be able to withstand the loads in subparagraph (2)(i) of this paragraph multiplied by a factor of safety depending on the probability of being in this failure state. The factor of safety is defined in Figure 2.

Figure 2
Factor of safety for continuation of flight



$Q_j = (T_j)(P_j)$ where:

T_j = Average time spent in failure condition j (in hours)

P_j = Probability of occurrence of failure mode j (per hour)

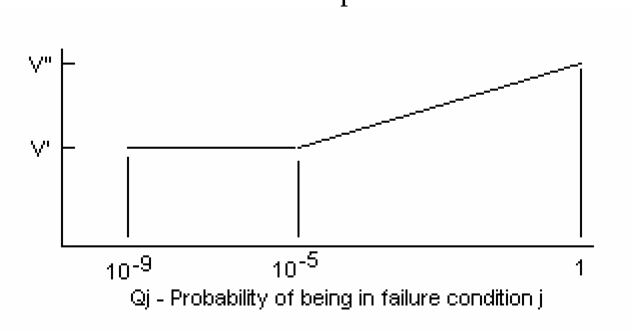
> <u>Note</u>: If P_j is greater than 10^{-3}, per flight hour then a 1.5 factor of safety must be applied to all limit load conditions specified in Subpart C.

(iii) For residual strength substantiation, the aeroplane must be able to withstand two thirds of the ultimate loads defined in subparagraph (c) (2) (ii). For pressurised cabins, these loads must be combined with the normal operating differential pressure.

(iv) If the loads induced by the failure condition have a significant effect on fatigue or damage tolerance then their effects must be taken into account.

(v) Freedom from aeroelastic instability must be shown up to a speed determined from Figure 3. Flutter clearance speeds V' and V" may be based on the speed limitation specified for the remainder of the flight using the margins defined by CS 25.629(b).

Figure 3
Clearance speed



V' = Clearance speed as defined by CS 25.629(b)(2).
V" = Clearance speed as defined by CS 25.629(b)(1).
$Q_j = (T_j)(P_j)$ where:
T_j = Average time spent in failure condition j (in hours)
P_j = Probability of occurrence of failure mode j (per hour)

Note: If P_j is greater than 10^{-3} per flight hour, then the flutter clearance speed must not be less than V".

(vi) Freedom from aeroelastic instability must also be shown up to V' in Figure 3 above, for any probable system failure condition combined with any damage required or selected for investigation by CS 25.571(b).

(3) Consideration of certain failure conditions may be required by other Subparts of CS-25 regardless of calculated system reliability. Where analysis shows the probability of these failure conditions to be less than 10^{-9}, criteria other than those specified in this paragraph may be used for structural substantiation to show continued safe flight and landing.

(d) Failure indications. For system failure detection and indication, the following apply:

(1) The system must be checked for failure conditions, not extremely improbable, that degrade the structural capability below the level required by CS-25 or significantly reduce the reliability of the remaining system. As far as reasonably practicable, the flight crew must be made aware of these failures before flight. Certain elements of the control system, such as mechanical and hydraulic components, may use special periodic inspections, and electronic components may use daily checks, in lieu of detection and indication systems to achieve the objective of this requirement. These certification maintenance requirements must be limited to components that are not readily detectable by normal detection and indication systems and where service history shows that inspections will provide an adequate level of safety.

(2) The existence of any failure condition, not extremely improbable, during flight that could significantly affect the structural capability of the aeroplane and for which the associated reduction in airworthiness can be minimised by suitable flight limitations, must be signalled to the flight crew. For example, failure conditions that result in a factor of safety between the aeroplane strength and the loads of Subpart C below 1.25, or flutter margins below V", must be signalled to the crew during flight.

(e) Dispatch with known failure conditions. If the aeroplane is to be dispatched in a known system failure condition that affects structural performance, or affects the reliability of the remaining system to maintain structural performance, then the provisions of CS 25.302 must be met for the dispatched condition and for subsequent failures. Flight limitations and expected operational limitations may be taken into account in establishing Q_j as the combined probability of being in the dispatched failure condition and the subsequent failure condition for the safety margins in Figures 2 and 3. These limitations must be such that the probability of being in this combined failure state and then subsequently encountering limit load conditions is extremely improbable. No reduction in these safety margins is allowed if the subsequent system failure rate is greater than 10^{-3} per hour.

4. To amend CS 25.629 by revising paragraph 25.629(d)(2) and by adding a new paragraph (b)(3) to read as follows:

CS 25.629 Aeroelastic stability requirements

(b) * * *

(3) For failure conditions in those systems covered by CS 25.302, the margins defined in Appendix K of CS-25 apply.

(d) * * *

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

(Note: The corresponding FAA NPRM on Interaction of Systems and Structures also contains proposals on 25.305(f), 25.629(a) and (c). These proposals however are already contained in JAA NPA 25BCD-236 (see part II of this EASA NPA) and are not repeated here.)

5. To amend the reference to Appendix K in CS 25.1435(a)(10) to refer to Appendix L

6. To amend the reference to Appendix K in CS 25.1436(b)(7) to refer to Appendix L

I-C. ORIGINAL JAA NPA 25C-199 proposals justification

1. <u>SAFETY JUSTIFICATION / EXPLANATION</u>

Active flight control systems are capable of providing automatic responses to external inputs from sources other than the pilots. Active flight control systems have been expanded in function, effectiveness, and reliability to the point that fly-by-wire flight controls, without a manual backup system in the event of system failures, are becoming standard equipment on larger transport aeroplanes. As a result of these advancements in flight controls technology, the current safety standards contained in JAR-25 do not provide an adequate basis to address an acceptable level of safety for aeroplanes equipped with these advanced systems. Instead, certification of these systems has been achieved by issuance of special conditions under the provisions of JAR 21.16.
For example, stability augmentation systems (SAS), and to a lesser extent load alleviation systems (LAS), have been used on large transport aeroplanes for many years. Past approvals of these systems were based on individual findings of equivalent level of safety with existing rules and on special conditions.

Although autopilots are also considered active control systems, typically their control authority has been limited such that the consequences of system failures could be readily counteracted by the pilot. Now, autopilot functions are integrated into the primary flight controls and are given sufficient control authority to manoeuvre the aeroplane to its structural design limits. This advanced technology with its expanded authority requires a new approach to account for the interaction of control systems and structures.

The usual deterministic approach to defining the loads envelope contained in JAR-25 does not fully account for system effectiveness and system reliability. These automatic systems may be inoperative or may operate in a degraded mode with less than full system authority. Therefore, it is necessary to determine the structural factors of safety and operating margins such that the joint probability of structural failures due to application of loads during system malfunctions is not greater than that found in aeroplanes equipped with earlier technology control systems. To achieve this objective it is necessary to define the failure conditions with their associated frequency of occurrence in order to determine the structural factors of safety and operating margins that will ensure an acceptable level of safety.

Earlier automatic control systems usually provided two states, either fully functioning or a total loss of function. These conditions were readily detected by the flight crew. The new active flight control systems have failure modes that allow the system to function in the degraded mode without full authority. This degraded mode is not readily detectable by the flight crew. Therefore, monitoring systems are required on these new systems to provide an annunciation of a condition of degraded system capability.

This NPA proposes to incorporate the safety requirements found necessary for aeroplanes equipped with active flight controls and fly-by-wire flight control systems except that the general philosophy of accounting for the impact of system failures on structural performance would be extended to include any system whose partial or complete failure, alone or in combination with other system partial or complete failures, would affect structural performance. The required structural factors of safety would be defined as a function of system reliability. This is an extension of the current philosophy that the aeroplane should be capable of continued safe flight and landing after specific failure events not shown to be extremely improbable.

Sub-paragraph JAR K25.2(e) of this proposal provides for the consideration of expected operational limits in the establishment of the appropriate safety factors. These limits are the expected maximum limits for dispatch in the failure condition and would be established consistent with experience on similar equipment in service.

In addition to providing requirements for static strength in terms of ultimate load levels this NPA proposes requirements that account for the effects of system failures on fatigue, damage tolerance, residual strength, deformation and aeroelastic stability. (Note: It is not intended to define new limit load conditions.) The impact of all combinations of system failures not shown to be extremely improbable need to be investigated.

This proposal would add a new JAR 25.302 and a new Appendix K to JAR-25 to incorporate these latest safety standards. It would also amend 25.629 to make this rule compatible with the new JAR 25.302 rule. Compatibility with NPA 25BCD-236 “Vibration, Buffet and Aeroelastic Stability Requirements” also has been ensured. It is intended to introduce this NPA and NPA 25BCD-236 concurrently into JAR-25.

2. <u>COST / SAFETY BENEFIT ASSESSMENT</u>

This NPA should not have a significant economic impact on the of new aeroplanes since it incorporates the criteria already applied by special conditions to new technology aeroplanes. Nor would it place a significant design burden on the applicant because there are many design options available including conventional control systems.
In addition, harmonisation of JAR-25 and FAR 25 would yield cost savings by eliminating duplicate certification activities.

I-D. JAA NPA 25C-199 COMMENT-RESPONSE DOCUMENT

(Hoofddorp, 9 January 2003)

Note : the comments are not included in the text of below responses. Should you wish to get the content of a specific comment, please contact

Ms. Inge van Opzeeland, EASA rulemaking directorate
Postfach 10 12 53
D-50452 Köln, Germany
Tel: +49 221 89990 5008

Introduction

NPA 25C-199, Revision 1 was published for comment on April 1, 2002. This NPA is a result of a harmonisation activity between JAA and FAA.
For more details on the background of this NPA is referred to the NPA itself.

Comments & Responses

The following (eight) organisations have commented on this NPA:

- SAS, Sweden
- DGAC, France
- CAA, NL
- AECMA
- ACG, Austria
- CAA, UK
- Embraer, Brasil
- Boeing

All, except CAA/UK and Boeing, have stated to have no (adverse) comments on this NPA. The CAA/UK and Boeing comments are addressed as follows:

Comment 006

Comment (partially) accepted.
It is acknowledged that a residual strength case that includes a cabin pressure below the normal operating pressure would not be acceptable. The normal operating pressure needs to be considered in addition to 2/3 of the ultimate loads as defined in the NPA for the residual strength conditions, both at the time of occurrence and for continuation of the flight. Therefore the following sentence is added to Appendix K25.2(c)(1)(ii) and K25.2(c)(2)(iii): "For pressurised cabins, these loads must be combined with the normal operating differential pressure."

Comment 007

Comment noted.
The commenter does not suggest any revision to the proposed rule text, but to the introductory material only. Since flight crew action is already addressed in the proposed NPA (Appendix K25.2(d)) no changes are made to the NPA.

Comment 008

See discussion on Comment 013.

Comment 009

See discussion on Comment 013.

Comment 010
See discussion on Comment 013.

Comment 012
Comment (partially) accepted.
As a result of the comment, the words “Warning considerations” in Appendix K25.2(d) are replaced by “Failure indications” and the word “warning” is replaced by “detection and indication”.

Comment 013
Comment not accepted.
The text proposed by the commenter could lead to much longer inspection intervals than envisaged with the current wording of the NPA, and is therefore not acceptable. It is recognized however that not every system can be tested pre-flight. Therefore, the words “as far as reasonably practicable” are added in Appendix K25.2(d)(1) to further emphasise this point.

Comment 014
Comment not accepted.
The additional definition proposed by the commenter is not deemed necessary for a clear understanding of the text.

Comment 015
See discussion on Comments 013 and 014.

Comment 016
Comment agreed.
“V_C” in Appendix K25.2(c)(2)(i) is changed to “V_C/M_C”.

Comment 017
Comment not accepted.
When operating under MMEL conditions with system(s) inoperative, Figure 1 of Appendix K is related to the probability of failure of the remaining system(s). This probability is not related to the MMEL time of exposure, in contrast to Figure 2 and Figure 3 where the assumption can be made that the MMEL time reduces the risk (exposure time). Hence consideration of flight limitations and/or operational limitations can only apply to Figures 2 and 3.

II-A. EXPLANATORY NOTE JAA NPA 25BCD-236

Originally JAA NPA 25BCD-236 Vibration, Buffet and Aeroelastic Stability

1. The initial issue of CS-25 was based upon JAR-25 at amendment 16. During the transposition of airworthiness JARs into certification specifications the rulemaking activities under the JAA system where not stopped. In order to assure a smooth transition from JAA to EASA the Agency has committed itself to continue as much as possible of the JAA rulemaking activities. Therefore it has included most of it in its own rulemaking programme for 2004 and planning for 2005-2007. This part of present EASA NPA is a result of this commitment and a transposed version of the JAA NPA 25BCD-236 which was circulated for comments from 9 December 1996 till 10 March 1997 and was agreed for adoption by the Regulation Sectorial Team. However, this JAA NPA was linked to JAA NPA 25C-199 and its publication was put on hold, waiting for the final version of JAA NPA 25C-199 (see *supra* **I)**

2. This part of present EASA NPA proposes to revise the design standards for large aeroplanes concerning flutter, divergence, vibrations and buffet. These proposals are based upon certain changes to the FAR part 25 that were included in the Amendment 25-77.

Although the Joint Aviation Authorities Structures Steering Group (JAA SSG) agreed with the basic idea behind these changes to the FAR, it did identify some areas of disagreement which prevented JAA acceptance of all the changes. Due to the importance of the requirements covered by this part of the NPA the SSG felt it should not progress the issues independently but should seek harmonisation with the FAA and U.S. industry. That harmonisation activity became one task of the Loads and Dynamics Harmonisation Working Group of the U.S. Aviation Rulemaking Advisory Committee (ARAC). This revised original JAA NPA 25BCD-236 represents the output of that Group and presents the basis for fully harmonised requirements concerning flutter, divergence, vibrations and buffet for FAR part 25 and CS-25 without reducing the level of safety provided by the regulations. Since most manufacturers will already design to both CS-25 and FAR 25 it is not expected that these changes will result in a significant change, either positive or negative, to large aeroplane design practice. Neither is it expected that there will be a significant increase in work required to show compliance with these requirements. One benefit of these rule changes is that they will update, reorganise and clarify the intent of various paragraphs within CS-25 concerning vibration, flutter and divergence. These changes will help ensure a uniform interpretation between CS and FAR and help reduce certification costs by eliminating the need for additional compliance investigations.

Since there are no cost increases associated with these changes and since there are positive benefits associated with cost reduction to transport aeroplane manufacturers and improved organisation, consistency and clarity within CS-25, this change is cost effective.

II-B. PROPOSALS TRANSPOSED JAA NPA 25BCD-236

The following amendments should be included in Decision No. 2003/2/RM of the Executive Director of the Agency of 17 October 2003:

Final Proposal taking into accounts comments made during JAA consultation process:

1. By revising CS 25.251 (a) and (b) to read as follows:

CS 25.251 Vibrating and buffeting.

(a) The aeroplane must be demonstrated in flight to be free from any vibration and buffeting that would prevent continued safe flight in any likely operating condition.

(b) Each part of the aeroplane must be demonstrated in flight to be free from excessive vibration under any appropriate speed and power conditions up to V_{DF}/M_{DF}. The maximum speeds shown must be used in establishing the operating limitations of the aeroplane in accordance with CS 25.1505.

* * * * *

2. By revising CS 25.305 by adding sub-paragraphs (e) and (f) as follows:

(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.

3. By revising CS 25.427 by adding a new sub-paragraph (d) as follows:

(d) Unsymmetrical loading on the empennage arising from buffet conditions of CS 25.305(e) must be taken into account.

4. By revising CS 25.629 to read as follows:

CS 25.629 Aeroelastic stability requirements.

(a) *General.* The aeroelastic stability evaluations required under this paragraph 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 paragraph must be shown by analyses, tests, or some combination thereof as found necessary by the Agency (see AMC 25.629).

(b) *Aeroelastic stability envelopes.* The aeroplane 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 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 CS 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 CS 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; and

(iii) Failure conditions of certain systems must be treated in accordance with CS 25.302.

(c) *Balance weights.* If 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 paragraph are:

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

(2) Any failure in any flutter control system not shown to be extremely improbable.

(3) For aeroplanes 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 aeroplanes 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 sub-paragraphs (d)(4) and (d)(5) of this paragraph.

(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 CS 25.571. The single structural failures described in sub-paragraphs (d)(4) and(d)(5) of this paragraph need not be considered in showing compliance with this paragraph if;

(i) The structural element could not fail due to discrete source damage resulting from the conditions described in CS 25.571(e) and 25.903(d); and

(ii) A damage tolerance investigation in accordance with CS 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 CS 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 aeroplane 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 sub-paragraph (d) of' this paragraph, 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 aeroplane is free from any aeroelastic instability at all speeds within the altitude-airspeed envelope described in sub-paragraph (b)(2) of this paragraph.

5. By inserting the following AMC.

AMC 25.629
Aeroelastic stability requirements - Acceptable means of compliance

1. *General.* The general requirement for demonstrating freedom from aeroelastic instability is contained in CS 25.629, which also sets forth specific requirements for the investigation of these aeroelastic phenomena for various aeroplane configurations and flight conditions. Additionally, there are other conditions defined by the CS paragraphs listed below to be investigated for aeroelastic stability to assure safe flight. Many of the conditions contained in this AMC pertain only to the current version of CS 25. Type design changes to aeroplanes certified to an earlier CS 25 change must meet the certification basis established for the modified aeroplane.

CS 25.251 - Vibration and buffeting
CS 25.305 - Strength and deformation
CS 25.335 - Design airspeeds
CS 25.343 - Design fuel and oil loads
CS 25.571 - Damage-tolerance and fatigue evaluation of structure
CS 25.629 - Aeroelastic stability requirements
CS 25.631 - Bird strike damage
CS 25.671 - General (Control systems)
CS 25.672 - Stability augmentation and automatic and power operated systems
CS 25.1309 - Equipment, systems and installations
CS 25.1329 - Automatic pilot system
CS 25.1419 - Ice protection

2. *Aeroelastic Stability Envelope*

2.1. For nominal conditions without failures, malfunctions, or adverse conditions, freedom from aeroelastic instability is required to be shown for all combinations of airspeed and altitude encompassed by the design dive speed (V_D) and design dive Mach number (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. Figure 1A represents a typical design envelope expanded to the required aeroelastic stability envelope. Note that some required Mach number and airspeed combinations correspond to altitudes below standard sea level.

2.2. The aeroelastic stability envelope may be limited to a maximum Mach number of 1.0 when M_D is less than 1.0 and there is no large and rapid reduction in damping as M_D is approached.

2.3. Some configurations and conditions that are required to be investigated by CS 25.629 and other CS 25 regulations consist of failures, malfunctions or adverse conditions Aeroelastic stability investigations of these conditions need to be carried out only within the design airspeed versus altitude envelope defined by:

(i) the V_D/M_D envelope determined by CS 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 up 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.

Figure 1B shows the minimum aeroelastic stability envelope for fail-safe conditions, which is a composite of the highest speed at each altitude from either the V_D envelope or the constructed altitude-airspeed envelope based on the defined V_C and M_C.

Fail-safe design speeds, other than the ones defined above, may be used for certain system failure conditions when specifically authorised by other rules or special conditions prescribed in the certification basis of the aeroplane.

FIGURE 1A. MINIMUM REQUIRED AEROELASTIC STABILITY MARGIN

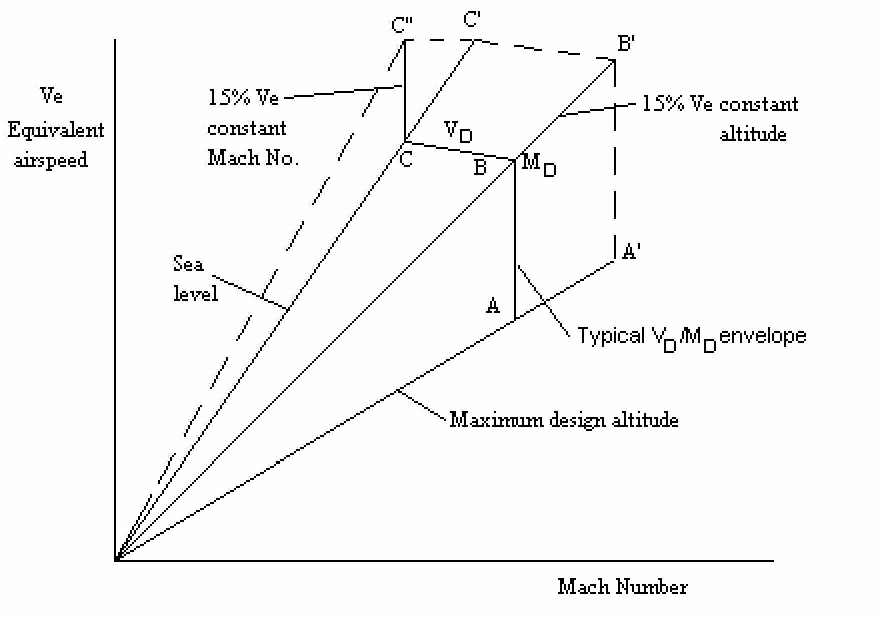
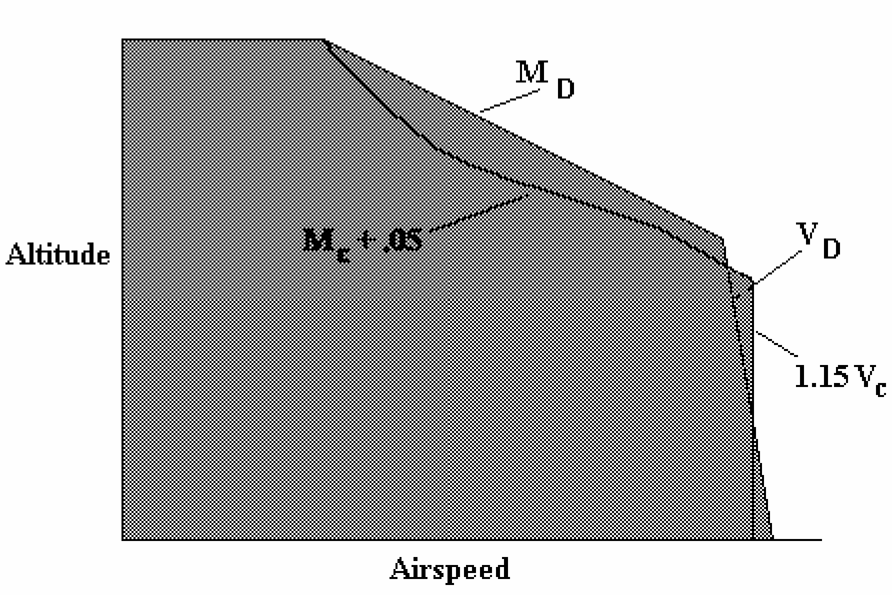


FIGURE 1B MINIMUM FAIL-SAFE CLEARANCE ENVELOPE



3. *Configurations and Conditions.* The following paragraphs provide a summary of the configurations and conditions to be investigated in demonstrating compliance with CS 25. Specific design configurations may warrant additional considerations not discussed in this AMC.

3.1. *Nominal Configurations and Conditions.* Nominal configurations and conditions of the aeroplane are those that are likely to exist in normal operation. Freedom from aeroelastic instability should be shown throughout the expanded clearance envelope described in paragraph 2.1 above for:

3.1.1. The range of fuel and payload combinations, including zero fuel in the wing, for which certification is requested.

3.1.2. Configurations with any likely ice mass accumulations on unprotected surfaces for aeroplanes approved for operation in icing conditions.

3.1.3. All normal combinations of autopilot, yaw damper, or other automatic flight control systems.

3.1.4. All possible engine settings and combinations of settings from idle power to maximum available thrust including the conditions of one engine stopped and windmilling, in order to address the influence of gyroscopic loads and thrust on aeroelastic stability.

3.2. *Failures, Malfunctions. and Adverse Conditions.* The following conditions should be investigated for aeroelastic instability within the fail-safe envelope defined in paragraph 2.3 above.

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

3.2.2. Any single failure in any flutter control system.

3.2.3. For aeroplanes not approved for operation in icing conditions, any likely ice accumulation expected as a result of an inadvertent encounter. For aeroplanes approved for operation in icing conditions, any likely ice accumulation expected as the result of any single failure in the de-icing system, or any combination of failures not shown to be extremely improbable.

3.2.4. 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).

3.2.5. For aeroplanes 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.

3.2.6. 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 3.2.4 and 3.2.5 above.

3.2.7. Any single propeller or rotating device capable of significant dynamic forces rotating at the highest likely overspeed.

3.2.8. Any damage or failure condition, required or selected for investigation by CS 25.571. The single structural failures described in paragraphs 3.2.4 and 3.2.5 above need not be considered in showing compliance with this paragraph if;

(A) The structural element could not fail due to discrete source damage resulting from the conditions described in CS 25.571(e) and CS 25.903(d); and

(B) A damage tolerance investigation in accordance with CS 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.

3.2.9. Any damage, failure or malfunction, considered under CS 25.631, 25.671, 25.672, and 25.1309. This includes the condition of two or more engines stopped or wind milling for the design range of fuel and payload combinations, including zero fuel.

3.2.10 Any other combination of failures, malfunctions, or adverse conditions not shown to be extremely improbable.

4. *Detail Design Requirements.*

4.1.Main surfaces, such as wings and stabilisers, should be designed to meet the aeroelastic stability criteria for nominal conditions and should be investigated for meeting fail-safe criteria by considering stiffness changes due to discrete damage or by reasonable parametric variations of design values.

4.2. Control surfaces, including tabs, should be investigated for nominal conditions and for failure modes that include single structural failures (such as actuator disconnects, hinge failures, or, in the case of aerodynamic balance panels, failed seals), single and dual hydraulic system failures and any other combination of failures not shown to be extremely improbable. Where other structural components contribute to the aeroelastic stability of the system, failures of those components should be considered for possible adverse effects.

4.3. Where aeroelastic stability relies on control system stiffness and/or damping, additional conditions should be considered. The actuation system should continuously provide, at least, the minimum stiffness or damping required for showing aeroelastic stability without regard to probability of occurrence for:
(i) more than one engine stopped or wind milling,
(ii) any discrete single failure resulting in a change of the structural modes of vibration (for example; a disconnect or failure of a mechanical element, or a structural failure of a hydraulic element, such as a hydraulic line, an actuator, a spool housing or a valve);

(iii) any damage or failure conditions considered under CS 25.571, 25.631 and 25.671.
The actuation system minimum requirements should also be continuously met after any combination of failures not shown to be extremely improbable (occurrence less than 10^{-9} per flight hour). However, certain combinations of failures, such as dual electric or dual hydraulic system failures, or any single failure in combination with any probable electric or hydraulic system failure (CS 25.671), are not normally considered extremely improbable regardless of probability calculations. The reliability assessment should be part of the substantiation documentation. In practice, meeting the above conditions may involve design concepts such as the use of check valves and accumulators, computerised pre-flight system checks and shortened inspection intervals to protect against undetected failures.

4.4 Consideration of free play may be incorporated as a variation in stiffness to assure adequate limits are established for wear of components such as control surface actuators, hinge bearings, and engine mounts in order to maintain aeroelastic stability margins.

4.5. If balance weights are used on control surfaces, their effectiveness and strength, including that of their support structure, should be substantiated.

4.6 The automatic flight control system should not interact with the airframe to produce an aeroelastic instability. When analyses indicate possible adverse coupling, tests should be performed to determine the dynamic characteristics of actuation systems such as servo-boost, fully powered servo-control systems, closed-loop aeroplane flight control systems, stability augmentation systems, and other related powered-control systems.

5. *Compliance.* Demonstration of compliance with aeroelastic stability requirements for an aircraft configuration may be shown by analyses, tests, or some combination thereof. In most instances, analyses are required to determine aeroelastic stability margins for normal operations, as well as for possible failure conditions. Wind tunnel flutter model tests, where applicable, may be used to supplement flutter analyses. Ground testing may be used to collect stiffness or modal data for the aircraft or components. Flight testing may be used to demonstrate compliance of the aircraft design throughout the design speed envelope.

5.1. *Analytical Investigations.* Analyses should normally be used to investigate the aeroelastic stability of the aircraft throughout its design flight envelope and as expanded by the required speed margins. Analyses are used to evaluate aeroelastic stability sensitive parameters such as aerodynamic coefficients, stiffness and mass distributions, control surface balance requirements, fuel management schedules, engine/store locations, and control system characteristics. The sensitivity of most critical parameters may be determined analytically by varying the parameters from nominal. These investigations are an effective way to account for the operating conditions and possible failure modes which may have an effect on aeroelastic stability margins, and to account for uncertainties in the values of parameters and expected variations due to in-service wear or failure conditions.

5.1.1. *Analytical Modelling.* The following paragraphs discuss acceptable, but not the only, methods and forms of modelling aircraft configurations and/or components for purposes of aeroelastic stability analysis. The types of investigations generally encountered in the course of aircraft aeroelastic stability substantiation are also discussed. The basic elements to be modelled in aeroelastic stability analyses are the elastic, inertial, and aerodynamic characteristics of the system. The degree of complexity required in the modelling, and the degree to which other characteristics need to be included in the modelling, depend upon the system complexity.

5.1.1.1. *Structural Modelling.* Most forms of structural modelling can be classified into two main categories: (1) modelling using a lumped mass beam, and (2) finite element modelling. Regardless of the approach taken for structural modelling, a minimum acceptable level of sophistication, consistent with configuration complexity, is necessary to satisfactorily represent the critical modes of deformation of the primary structure and control surfaces. The model should reflect the support structure for the attachment of control surface actuators, flutter dampers, and any other elements for which stiffness is important in prevention of aeroelastic instability. Wing-pylon mounted engines are often significant to aeroelastic stability and warrant particular attention in the modelling of the pylon, and pylon-engine and pylon-wing interfaces. The model should include the effects of cut-outs, doors, and other structural features which may tend to affect the resulting structural effectiveness. Reduced stiffness should be considered in the modelling of aircraft structural components which may exhibit some change in stiffness under limit design flight conditions. Structural models include mass distributions as well as representations of stiffness and possibly damping characteristics. Results from the models should be compared to test data, such as that obtained from ground vibration tests, in order to determine the accuracy of the model and its applicability to the aeroelastic stability investigation.

5.1.1.2. *Aerodynamic Modelling.*

(a) Aerodynamic modelling for aeroelastic stability requires the use of unsteady, two-dimensional strip or three-dimensional panel theory methods for incompressible or compressible flow. The choice of the appropriate technique depends on the complexity of the dynamic structural motion of the surfaces under investigation and the flight speed envelope of the aircraft. Aerodynamic modelling should be supported by tests or previous experience with applications to similar configurations.

(b) Main and control surface aerodynamic data are commonly adjusted by weighting factors in the aeroelastic stability solutions. The weighting factors for steady flow (k=0) are usually obtained by comparing wind tunnel test results with theoretical data. Special attention should be given to control surface aerodynamics because viscous and other effects may require more extensive adjustments to theoretical coefficients. Main surface aerodynamic loading due to control surface deflection should be considered.

5.1.2. *Types of Analyses.*

5.1.2.1. Oscillatory (flutter) and non-oscillatory (divergence and control reversal) aeroelastic instabilities should be analysed to show compliance with CS 25.629

5.1.2.2. The flutter analysis methods most extensively used involve modal analysis with unsteady aerodynamic forces derived from various two- and three-dimensional theories. These methods are generally for linear systems. Analyses involving control system characteristics should include equations describing system control laws in addition to the equations describing the structural modes.

5.1.2.3. Aeroplane lifting surface divergence analyses should include all appropriate rigid body mode degrees-of-freedom since divergence may occur for a structural mode or the short period mode.

5.1.2.4. Loss of control effectiveness (control reversal) due to the effects of elastic deformations should be investigated. Analyses should include the inertial, elastic, and aerodynamic forces resulting from a control surface deflection.

5.1.3 *Damping Requirements.*

5.1.3.1. There is no intent in this AMC to define a flight test level of acceptable minimum damping.

5.1.3.2. Flutter analyses results are usually presented graphically in the form of frequency versus velocity (V-f, Figure 2) and damping versus velocity (V-g, Figures 3 and 4) curves for each root of the flutter solution.

5.1.3.3. Figure 3 details one common method for showing compliance with the requirement for a proper margin of damping. It is based on the assumption that the structural damping available is 0.03 (1.5% critical viscous damping) and is the same for all modes as depicted by the V-g curves shown in Figure 3. No significant mode, such as curves (2) or (4), should cross the g=0 line below V_D or the g=0.03 line below 1.15 V_D. An exception may be a mode exhibiting damping characteristics similar to curve (1) in Figure 3, which is not critical for flutter. A divergence mode, as illustrated by curve (3) where the frequency approaches zero, should have a divergence velocity not less than 1.15 V_D.

5.1.3.4. Figure 4 shows another common method of presenting the flutter analysis results and defining the structural damping requirements. An appropriate amount of structural damping for each mode is entered into the analysis prior to the flutter solution. The amount of structural damping used should be supported by measurements taken during full scale tests. This results in modes offset from the g=0 line at zero airspeed and, in some cases, flutter solutions different from those obtained with no structural damping. The similarity in the curves of Figures 3 and 4 are only for simplifying this example. The minimum acceptable damping line applied to the analytical results as shown in Figure 4 corresponds to 0.03 or the modal damping available at zero airspeed for the particular mode of interest, whichever is less, but in no case less than 0.02. No significant mode should cross this line below V_D or the g=0 line below 1.15 V_D.

5.1.3.5. For analysis of failures, malfunctions or adverse conditions being investigated, the minimum acceptable damping level obtained analytically would be determined by use of either method above, but with a substitution of V_C for V_D and the fail-safe envelope speed at the analysis altitude as determined by paragraph 2.3 above.

FIGURE 2. FREQUENCY VERSUS VELOCITY

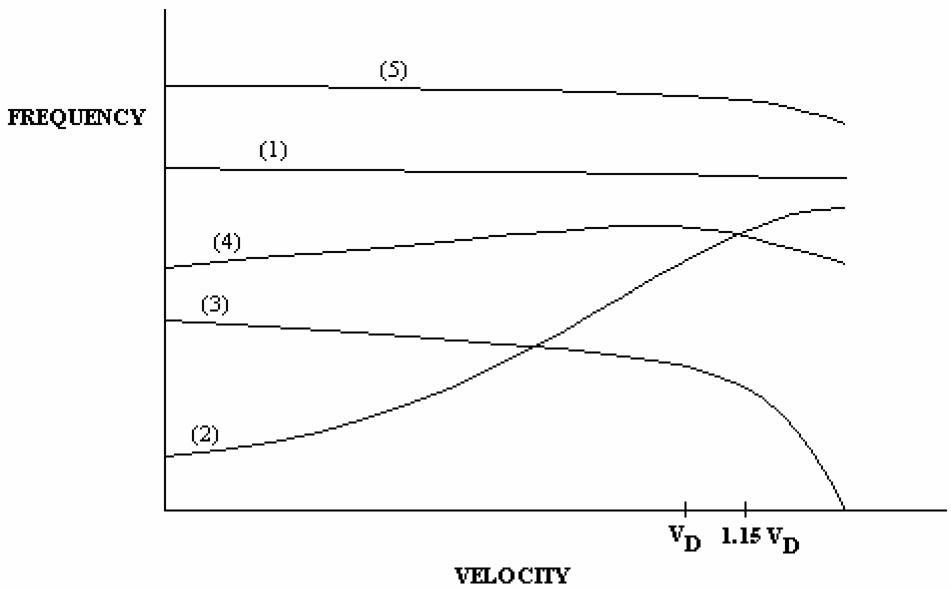


FIGURE 3. DAMPING VERSUS VELOCITY - Method 1

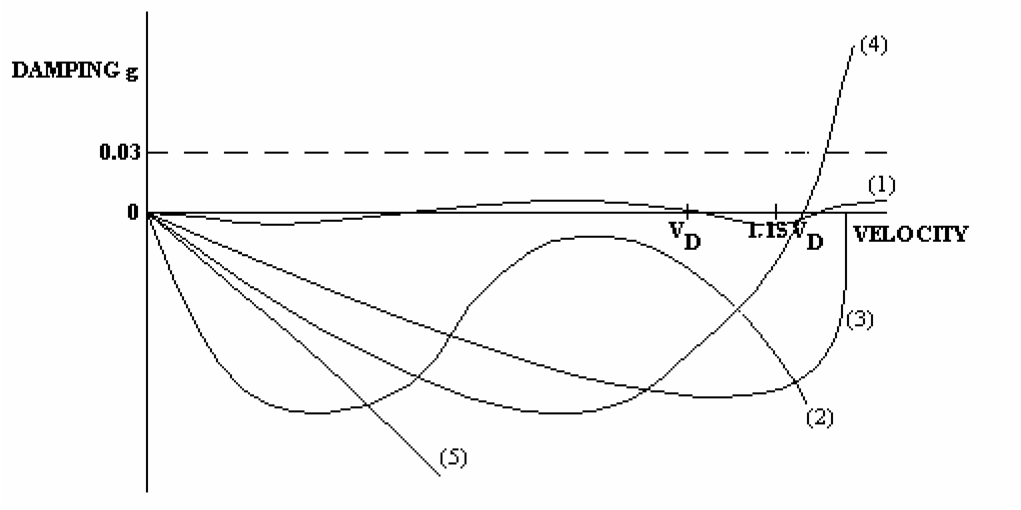
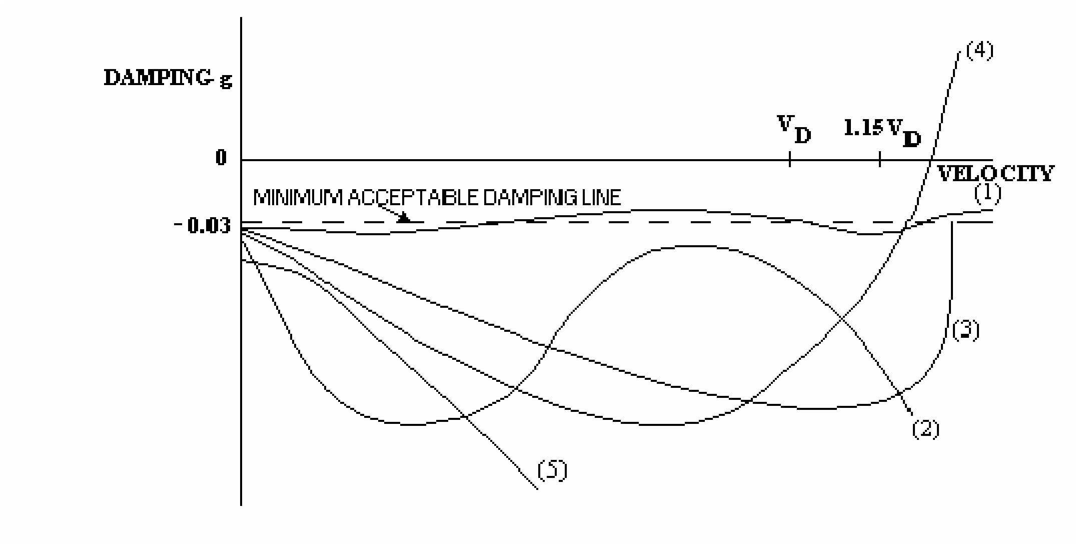


FIGURE 4. DAMPING VERSUS VELOCITY - Method 2



5.1.4. *Analysis Considerations* Airframe aeroelastic stability analyses may be used to verify the design with respect to the structural stiffness, mass, fuel (including in-flight fuel management), automatic flight control system characteristics, and altitude and Mach number variations within the design flight envelope. The complete aeroplane should be considered as composed of lifting surfaces and bodies, including all primary control surfaces which can interact with the lifting surfaces to affect flutter stability. Control surface flutter can occur in any speed regime and has historically been the most common form of flutter. Lifting surface flutter is more likely to occur at high dynamic pressure and at high subsonic and transonic Mach numbers. Analyses are necessary to establish the mass balance and/or stiffness and redundancy requirements for the control surfaces and supporting structure and to determine the basic surface flutter trends. The analyses may be used to determine the sensitivity of the nominal aircraft design to aerodynamic, mass, and stiffness variations. Sources of stiffness variation may include the effects of skin buckling at limit load factor, air entrapment in hydraulic actuators, expected levels of in-service free play, and control system components which may include elements with non-linear stiffness. Mass variations include the effects of fuel density and distribution, control surface repairs and painting, and water and ice accumulation.

5.1.4.1. *Control Surfaces* Control surface aeroelastic stability analyses should include control surface rotation, tab rotation (if applicable), significant modes of the aeroplane, control surface torsional degrees-of-freedom, and control surface bending (if applicable). Analyses of aeroplanes with tabs should include tab rotation that is both independent and related to the parent control surface. Control surface rotation frequencies should be varied about nominal values as appropriate for the condition. The control surfaces should be analysed as completely free in rotation unless it can be shown that this condition is extremely improbable. All conditions between stick-free and stick-fixed should be investigated. Free play effects should be incorporated to account for any influence of in-service wear on flutter margins. The aerodynamic coefficients of the control surface and tab used in the aeroelastic stability analysis should be adjusted to match experimental values at zero frequency. Once the analysis has been conducted with the nominal, experimentally adjusted values of hinge moment coefficients, the analysis should be conducted with parametric variations of these coefficients and other parameters subject to variability. If 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.

5.1.4.2. *Mass Balance*

(a) The magnitude and spanwise location of control surface balance weights may be evaluated by analysis and/or wind tunnel flutter model tests. If the control surface torsional degrees of freedom are not included in the analysis, then adequate separation must be maintained between the frequency of the control surface first torsion mode and the flutter mode.

(b) Control surface unbalance tolerances should be specified to provide for repair and painting. The accumulation of water, ice, and/or dirt in or near the trailing edge of a control surface should be avoided. Free play between the balance weight, the support arm, and the control surface must not be allowed. Control surface mass properties (weight and static unbalance) should be confirmed by measurement before ground vibration testing.

(c) The balance weights and their supporting structure should be substantiated for the extreme load factors expected throughout the design flight envelope. If the absence of a rational investigation, the following limit accelerations, applied through the balance weight centre of gravity should be used.

100g normal to the plane of the surface
30g parallel to the hinge line
30g in the plane of the surface and perpendicular to the hinge line

5.1.4.3. *Passive Flutter Dampers* Control surface passive flutter dampers may be used to prevent flutter in the event of failure of some element of the control surface actuation system or to prevent control surface buzz. Flutter analyses and/or flutter model wind tunnel tests may be used to verify adequate damping. Damper support structure flexibility should be included in the determination of adequacy of damping at the flutter frequencies. Any single damper failure should be considered. Combinations of multiple damper failures should be examined when not shown to be extremely improbable. The combined free play of the damper and supporting elements between the control surface and fixed surfaces should be considered. Provisions for in-service checks of damper integrity should be considered. Refer to paragraph 4.3 above for conditions to consider where a control surface actuator is switched to the role of an active or passive damping element of the flight control system.

5.1.4.4. *Intersecting Lifting Surfaces* Intersecting lifting surface aeroelastic stability characteristics are more difficult to predict accurately than the characteristics of planar surfaces such as wings. This is due to difficulties both in correctly predicting vibration modal characteristics and in assessing those aerodynamic effects which may be of second order importance on planar surfaces, but are significant for intersecting surfaces. Proper representation of modal deflections and unsteady aerodynamic coupling terms between surfaces is essential in assessing the aeroelastic stability characteristics. The in-plane forces and motions of one or the other of the intersecting surfaces may have a strong effect on aeroelastic stability; therefore, the analysis should include the effects of steady flight forces and elastic deformations on the in-plane effects.

5.1.4.5. *Ice Accumulation* Aeroelastic stability analysis should use the mass distributions derived from any likely ice accumulations. The ice accumulation determination can take account of the ability to detect the ice and the time required to leave the icing condition. The analyses need not consider the aerodynamic effects of ice shapes.

5.1.4.6. *Whirl Flutter*

(a) The evaluation of the aeroelastic stability should include investigations of any significant elastic, inertial, and aerodynamic forces, including those associated with rotations and displacements in the plane of any turbofan or propeller, including propeller or fan blade aerodynamics, powerplant flexibilities, powerplant mounting characteristics, and gyroscopic coupling.

(b) Failure conditions are usually significant for whirl instabilities. Engine mount, engine gear box support, or shaft failures which result in a node line shift for propeller hub pitching or yawing motion are especially significant.

(c) A wind tunnel test with a component flutter model, representing the engine/propeller system and its support system along with correlative vibration and flutter analyses of the flutter model, may be used to demonstrate adequate stability of the nominal design and failed conditions.

5.1.4.7. *Automatic Control Systems* Aeroelastic stability analyses of the basic configuration should include simulation of any control system for which interaction may exist between the sensing elements and the structural modes. Where structural/control system feedback is a potential problem the effects of servo-actuator characteristics and the effects of local deformation of the servo mount on the feedback sensor output should be included in the analysis. The effect of control system failures on the aeroplane aeroelastic stability characteristics should be investigated. Failures which significantly affect the system gain and/or phase and are not shown to be extremely improbable should be analysed.

5.2. *Testing* The aeroelastic stability certification test programme may consist of ground tests, flutter model tests, and flight flutter tests. Ground tests may be used for assessment of component stiffness and for determining the vibration modal characteristics of aircraft components and the complete airframe. Flutter model testing may be used to establish flutter trends and validate aeroelastic stability boundaries in areas where unsteady aerodynamic calculations require confirmation. Full scale flight flutter testing provides final verification of aeroelastic stability. The results of any of these tests may be used to provide substantiation data, to verify and improve analytical modelling procedures and data, and to identify potential or previously undefined problem areas.

5.2.1. *Structural Component Tests.* Stiffness tests or ground vibration tests of structural components are desirable to confirm analytically predicted characteristics and are necessary where stiffness calculations cannot accurately predict these characteristics. Components should be mounted so that the mounting characteristics are well defined or readily measurable.

5.2.2. *Control System Component Tests* When reliance is placed on stiffness or damping to prevent aeroelastic instability, the following control system tests should be conducted. If the tests are performed off the aeroplane the test fixtures should reflect local attachment flexibility.

(i) Actuators for primary flight control surfaces and flutter dampers should be tested with their supporting structure. These tests are to determine the actuator/support structure stiffness for nominal design and failure conditions considered in the fail-safe analysis.

(ii) Flutter damper tests should be conducted to verify the impedance of damper and support structure. Satisfactory installed damper effectiveness at the potential flutter frequencies should, however, be assured. The results of these tests can be used to determine a suitable, in-service maintenance schedule and replacement life of the damper. The effects of allowable in-service free play should be measured.

5.2.3. *Ground vibration Tests*

5.2.3.1. Ground vibration tests (GVT) or modal response tests are normally conducted on the complete conforming aeroplane. A GVT may be used to check the mathematical structural model. Alternatively, the use of measured modal data alone in aeroelastic stability analyses, instead of analytical modal data modified to match test data, may be acceptable provided the accuracy and completeness of the measured modal data is established. Whenever structural modifications or inertia changes are made to a previously certified design or a GVT validated model of the basic aeroplane, a GVT may not be necessary if these changes are shown not to affect the aeroelastic stability characteristics.

5.2.3.2. The aeroplane is best supported such that the suspended aeroplane rigid body modes are effectively uncoupled from the elastic modes of the aeroplane. Alternatively, a suspension method may be used that couples with the elastic aeroplane provided that the suspension can be analytically de-coupled from the aeroplane structure in the vibration analysis. The former suspension criterion is preferred for all ground vibration tests and is necessary in the absence of vibration analysis.

5.2.3.3. The excitation method needs to have sufficient force output and frequency range to adequately excite all significant resonant modes. The effective mass and stiffness of the exciter and attachment hardware should not distort modal response. More than one exciter or exciter location may be necessary to insure that all significant modes are identified. Multiple exciter input may be necessary on structures with significant internal damping to avoid low response levels and phase shifts at points on the structure distant from the point of excitation. Excitation may be sinusoidal, random, pseudo-random, transient, or other short duration, non stationary means. For small surfaces the effect of test sensor mass on response frequency should be taken into consideration when analysing the test results.

5.2.3.4. The minimum modal response measurement should consist of acceleration (or velocity) measurements and relative phasing at a sufficient number of points on the aeroplane structure to accurately describe the response or mode shapes of all significant structural modes. In addition, the structural damping of each mode should be determined.

5.2.4. *Flutter Model Tests.*

5.2.4.1. Dynamically similar flutter models may be tested in the wind tunnel to augment the flutter analysis. Flutter model testing can substantiate the flutter margins directly or indirectly by validating analysis data or methods. Some aspects of flutter analysis may require more extensive validation than others, for example control surface aerodynamics, T-tails and other configurations with aerodynamic interaction and compressibility effects. Flutter testing may additionally be useful to test configurations that are impractical to verify in flight test., such as fail-safe conditions or extensive store configurations. In any such testing, the mounting of the model and the associated analysis should be appropriate and consistent with the study being performed.

5.2.4.2. Direct substantiation of the flutter margin (clearance testing) implies a high degree of dynamic similitude. Such a test may be used to augment an analysis and show a configuration flutter free throughout the expanded design envelope. All the physical parameters which have been determined to be significant for flutter response should be appropriately scaled. These will include elastic and inertia properties, geometric properties and dynamic pressure. If transonic effects are important, the Mach number should be maintained.

5.2.4.3. Validation of analysis methods is another appropriate use of wind tunnel flutter testing. When the validity of a method is uncertain, correlation of wind tunnel flutter testing results with a corresponding analysis may increase confidence in the use of the analytical tool for certification analysis. A methods validation test should simulate conditions, scaling and geometry appropriate for the intended use of the analytical method.

5.2.4.4. Trend studies are an important use of wind tunnel flutter testing. Parametric studies can be used to establish trends for control system balance and stiffness, fuel and payload variations, structural compliances and configuration variations. The set of physical parameters requiring similitude may not be as extensive to study parametric trends as is required for clearance testing. For example, an exact match of the Mach number may not be required to track the effects of payload variations on a transonic aeroplane.

5.2.5. *Flight Flutter Tests*

5.2.5.1 Full scale flight flutter testing of an aeroplane configuration to V_{DF}/M_{DF} is a necessary part of the flutter substantiation. An exception may be made when aerodynamic, mass, or stiffness changes to a certified aeroplane are minor, and analysis or ground tests show a negligible effect on flutter or vibration characteristics. If a failure, malfunction, or adverse condition is simulated during a flight test, 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 requirements of CS 25.629(b)(2) are met.

5.2.5.2. Aeroplane configurations and control system configurations should be selected for flight test based on analyses and, when available, model test results. Sufficient test conditions should be performed to demonstrate aeroelastic stability throughout the entire flight envelope for the selected configurations.

5.2.5.3. Flight flutter testing requires excitation sufficient to excite the modes shown by analysis to be the most likely to couple for flutter. Excitation methods may include control surface motions or internal moving mass or external aerodynamic exciters or flight turbulence. The method of excitation must be appropriate for the modal response frequency being investigated. The effect of the excitation system itself on the aeroplane flutter characteristics should be determined prior to flight testing.

5.2.5.4. Measurement of the response at selected locations on the structure should be made in order to determine the response amplitude, damping and frequency in the critical modes at each test airspeed. It is desirable to monitor the response amplitude, frequency and damping change as V_{DF}/M_{DF} is approached. In demonstrating that there is no large and rapid damping reduction as V_{DF}/M_{DF} is approached, an endeavour should be made to identify a clear trend of damping versus speed. If this is not possible, then sufficient test points should be undertaken to achieve a satisfactory level of confidence that there is no evidence of an adverse trend.

5.2.5.5. An evaluation of phenomena not presently amenable to analyses, such as shock effects, buffet response levels, vibration levels, and control surface buzz, should also be made during flight testing.

II-C. ORIGINAL JAA NPA 25BCD-236 proposals justification

1. BACKGROUND TO THE PROPOSALS

The term "aeroelastic" is applied to an important class of phenomena which involves the mutual interaction between the inertial, aerodynamic, and elastic forces in a structure. These forces can interact to give rise to a variety of aeroelastic conditions ranging from transient or dynamic responses as a result of external forces (vibration or buffeting) to aeroelastic instabilities (flutter or divergence). The important distinction between response and instability phenomena is that instabilities are self-excited, that is, they can exist even in smooth air in the absence of any external forces. A slight perturbation of the structure at or above the critical airspeed is all that is needed to initiate the unstable condition which then may be maintained or grow to destructive proportions in the absence of any external forces.

Few aeroelastic phenomena fit neatly into classification where exact definitions can be considered to apply without qualification. As an aid to better understanding of the proposals in this NPA the following definitions are provided. They should be considered to apply to classical aeroelastic phenomena and used with a certain amount of judgement since not even the experts in the field would agree completely on any set of definitions.

1. **Vibration:** An oscillation of the structure or of a control surface resulting from an independent external excitation.

2. **Buffeting:** A random oscillation of the structure resulting from unsteady aerodynamic forces, usually associated with separated flow.

3. **Flutter:** An unstable self-excited structural oscillation at a definite frequency where energy is extracted from the airstream by the motion of the structure. The deformation and motion of the structure result in forces on the structure that tend to maintain or augment the motion. The displacement modes associated with potential flutter instabilities are often called "flutter modes" even though they may be well damped or do not become unstable within the flight envelope.

4. **Whirl Flutter:** Flutter in which the aerodynamic and gyroscopic forces associated with rotations and displacements in the plane of a propeller or large turbofan play an important role. The displacement modes associated with whirl flutter are frequently called "whirl modes".

5. **Divergence:** A static instability at a speed where the aerodynamic forces resulting from the deformation of the structure exceed the elastic restoring forces resulting from the same deformation.

6. **Control Reversal:** A condition in which the intended effects of displacing a given component of the control system are completely overcome by the aeroelastic effects of structural deformation, resulting in reversed command at higher speeds.

7. **Deformation Instability:** The loss of aeroplane stability and control as a result of the aeroelastic effects of structural deformation.

Many of the above terms have been used in the airworthiness regulations and associated advisory material for many years and there is no intent to redefine these phenomena or require consideration of new phenomena by this proposal.

Regulations dealing with flutter and divergence for transport category aeroplanes were first introduced in part 04 of the U.S. Civil Air Regulations (CAR) in the 1940's. A safety margin was established by requiring that the aeroplane was designed to be free from flutter and divergence at an airspeed 20 percent greater than the maximum design dive speed. Flutter analyses, using the available theoretical methods of that time, were used to show compliance. The 20 percent margin was intended to account for the inaccuracy in the analytical prediction of the flutter speed, as established by those early methods, and to provide for production and service variations. A 20 percent margin was chosen as the safety margin for civil aeroplanes after comparing analytical studies with the results of model testing conducted by the U.S. Army Air Corps. Based on the same studies and tests, a 15 percent margin was chosen by the U.S. Army Air Corps as the safety margin for the related U.S. military specification.

The flutter requirement of part 04 evolved into section 4b.308 of the CAR, where developing fail-safe philosophy continued to change the scope of the flutter and divergence substantiation requirements. Among the early fail-safe provisions were the requirements that control surface tabs and flutter damper systems be fail-safe. A more comprehensive fail-safe requirement was adopted into the U.S. Federal Aviation Regulations (FAR) part 25 in 1964 and required compliance with the single failure criteria for the entire aeroplane, as well as compliance with special provisions for turbopropeller aeroplanes. The most recent substantive change in the fail-safe provisions was the addition of a requirement in § 25.629(d) of the FAR for freedom from flutter with any combination of failures not shown to be extremely improbable (Amendment 25-46, 43 FR 50578; October 30, 1978). This same standard has formed the basis for JAR-25 flutter requirements up to the present time.

The design margin for the fail-safe design conditions has been the margin between design cruise speed, V_C/M_C and design dive speed, V_D/M_D. This margin originally was 25 percent, but has since been reduced by the incorporation of an upset criterion to establish V_D/M_D (§ 25.335(b)). This criterion generally results in a margin of between 15 and 20 percent on modern conventional transport aeroplanes at altitudes where V_C is not limited by Mach number.

While the scope of the flutter requirements was being widened by additional fail-safe criteria, the ability of the industry to substantiate freedom from flutter and other aeroelastic instability phenomena was continually improving. At the time the 20 percent margin was established, the analytical capability was minimal and unreliable without a large speed margin. Current analytical methods employ finite element solutions with advanced unsteady aerodynamic theories and can accommodate aeroplanes of complex configurations. In addition, model testing, ground vibration testing and flight flutter testing techniques have all undergone significant improvements. Complete aeroplane experimental modal analyses are now commonplace. Furthermore the cost of these analytical methods and testing techniques has been kept reasonable by the advances in computer technology.

At present the requirement to withstand vibration and buffet, is contained in JAR 25.251. As this is a Subpart B requirement, there is a tendency to interpret the vibration and buffet requirements as applicable to flight requirements only. Also, because of the reference to the fail-safe requirements of JAR 25.629(d), JAR 25.251 literally requires that freedom from excessive vibration be demonstrated with failure conditions. The rule also continues to reference the structural design dive speed V_D rather than a flight speed such as V_{DF}.

2. DISCUSSION AND JUSTIFICATION

The scope of this proposal is to revise JAR 25.629 "Flutter, deformation and fail-safe criteria" which includes several substantive changes, and to reorganise some requirements of JAR 25.251 "Vibration and buffeting", without substantive changes.

The proposed changes to JAR 25.251 involve the creation of a new JAR 25.305(e) to incorporate the design requirements for buffet and vibration of JAR 25.251(a) into JAR 25.305, creating a new JAR 25.305(e). This requirement is a structural design requirement and should be set forth in subpart C. JAR 25.251(a) would be revised to require only a flight demonstration for freedom from vibration and buffet in any likely operating condition, including probable inadvertent excursions beyond the buffet boundaries. Furthermore, the third sentence of JAR 25.251(b) would be deleted. This would provide relief from the requirement that freedom from excessive vibration be demonstrated in flight for the failure and damage conditions of JAR 25.629(d). The speed referenced in JAR 25.251 would be changed to the flight speed V_{DF} while the corresponding structural requirements that are moved to JAR 25.305(e) would continue to reference the structural design dive speed V_D.

It is also proposed to relocate the requirement for the evaluation of loads resulting from forced structural vibration after failures in the automatic flight control system. This requirement is currently located in JAR 25.629(d)(4)(vi), although it is a structural loading condition for oscillatory failures rather than for aeroelastic instability. It is proposed that it be set forth in subpart C, specifically in JAR 25.305, creating a new paragraph JAR 25.305(f). Furthermore, it is proposed to clarify that the loads resulting from these forced structural vibrations are limit loading conditions.

JAR 25.629 would be retitled "Aeroelastic stability requirements" to more accurately describe the objective. Originally the Federal Aviation Regulation on which JAR 25.629 is based contained vibration, buffet requirements and oscillatory failure load requirements, as well as flutter, divergence, control reversal and deformation instability requirements. However, as a result of this proposal, the rule would only contain flutter (including whirl flutter), divergence, control reversal, and deformation instability requirements, all of which can be considered aeroelastic instabilities.

The references to propellers and turbopropellers in JAR 25.629 would be replaced by "propeller or rotating device that contributes significant dynamic forces" to encompass all types of rotating machinery which could influence the basic aeroelastic modes or create new "whirl modes." The general growth of compressors to large bypass fans and now to unducted fans has obscured the differences between propellers and other rotating machinery. The proposed rule would impose the requirements for the consideration of gyroscopic inertial forces and whirl flutter analysis on a more objective basis.

It is proposed to reduce the design envelope in which freedom from aeroelastic instability is to be shown for the normal (undamaged) aeroplane. The requirement for a 20 percent increase in equivalent airspeed at both constant altitude and constant Mach number would be reduced to a 15 percent increase. Historically, the principal purpose of the 20 percent margin has been for substantiation reliability. When the 20 percent margin was first established, flutter and divergence substantiation was in its infancy, and a large margin was needed because of the unreliability of the techniques. In addition, there were no failure or damage conditions at that time and the 20 percent margin by virtue of the added stiffness, provided some degree of protection against damage and failure conditions as well as production and service variations. The transport aeroplane aeroelastic stability requirements, as provided in this proposal, and advances in aeroelastic substantiation techniques are now sufficient to justify a reduction in the substantiation margin. These provisions now require a complete programme of analyses validated with test data and full-scale flight flutter testing. Furthermore, previous amendments, as well as the provisions of this proposal, have significantly amplified the specific fail-safe and damage conditions which must be considered with a separate fail-safe aeroelastic stability envelope.

A further proposal affecting the normal envelope would be the inclusion of a general statement concerning aeroelastic stability criteria within the design envelope. The statement would require that, for the normal aeroplane without failures, malfunctions, or adverse conditions, there must be a proper margin of damping up to V_D/M_D and no large and rapid reduction in stability as V_D/M_D is approached. These words are currently in the rule but are stated as a condition required in order to allow the limiting of the aeroelastic stability substantiation envelope to Mach 1.0 when M_D is less than 1.0. This Mach 1.0 limitation would still be allowed, but the damping criteria would be a requirement in any case. The proposed ACJ 25.629 contains acceptable criteria for establishing a proper margin of damping.

It is also proposed that the fail-safe stability envelope be modified to provide a minimum speed margin. The margins between V_C/M_C and V_D/M_D have provided a sufficient margin in the past. However, with the advent of new types of propulsion systems, speed protection systems and unusual configurations, there is concern that this margin may be reduced to the point that it might not always serve as a sufficient margin for aeroelastic stability substantiation in the failed or damaged condition. Failures and damage conditions are typically substantiated by analyses or wind tunnel tests with very little flight test verification. The proposal would still require fail-safe aeroelastic stability substantiation within the structural design envelope, V_D/M_D; however, a minimum margin would be provided to ensure protection against substantiation unreliability if the V_D/M_D envelope did not provide sufficient margin over V_C. The minimum margin would be a 15 percent increase in equivalent airspeed over design cruise speed, V_C at all altitudes from sea level up to the altitude of the intersection of the extension of the constant cruise Mach number line, M_C with 1.15 V_C. Then the minimum margin would be a linear variation in equivalent airspeed from that intersection to the point of intersection of the constant M_C + .05 line with the altitude of the lowest V_C/M_C intersection and a Mach increment of .05 over M_C at higher altitudes. Figure 1 shows the minimum flutter substantiation envelope for fail-safe conditions.

Also proposed are additions to the specified failure, malfunction, damage and adverse conditions specified in JAR 25.629(d). The list of conditions would be revised to add mismanagement of fuel not shown to be extremely improbable, the bird strike requirements of JAR 25.631, and the discrete source damage conditions of JAR 25.571(e) and JAR 25.903(d). Also included is a provision to consider inadvertent encounter with icing conditions, even though the aeroplane may not be approved for operation in icing conditions. Many of these are conditions that have generally required aeroelastic stability substantiation in order to show "safe flight and landing." This placement of the requirements in JAR 25.629(d) would make the margins and substantiation criteria of JAR 25.629 directly applicable to these aeroelastic stability substantiations.

The mismanagement of fuel condition is not specifically mentioned in JAR-25, although its consideration has been a practice for many years and has been required under general rules such as JAR 25.629(d)(1)(ii). There is an increasing complexity in fuel loading configurations including empennage fuel and automatic fuel distribution systems and these can have a significant effect on aeroelastic stability. Therefore, it is proposed to specifically require consideration of fuel mismanagement conditions, not shown to be extremely improbable, in order to provide a probability basis consistent with other fail-safe flutter conditions and to assure that this condition is not overlooked.

The combinations of feathered propellers in JAR 25.629(d) would also be revised to include any combination of feathered propellers (or rotating devices capable of significant dynamic forces) including all propellers feathered. The requirement in JAR 25.671 for the aeroplane to be controllable with all engines inoperative has made the current requirement inconsistent since the power failure requirement necessitates the feathering of all propellers.

The current JAR 25.629(d) requires single failures to be considered in engine mounts, other attachments of external bodies and engine structure supporting propeller shafts. Relief from this requirement for structural elements of these attachments is provided if "conservative static strength margins" or "sufficient fatigue strength" are shown. This provision was intended to require design integrity of mounts and engine structures sufficiently above the normal design load and fatigue requirements so that the probability of their failure could be considered "negligible." This has resulted in confusion and inconsistencies in the application of the regulation. It is proposed that the damage-tolerance requirements of JAR 25.571(b) be used as a basis of evaluating these structures to determine if they should be treated under the single failure criteria of JAR 25.629(d). However, in order to assure conservative margins above the normal requirements of JAR 25.571, the damage-tolerance requirements would be applied with the specific loading conditions of JAR 25.571(b) replaced by "all ground and flight load conditions specified in this part." The quoted phrase is taken from the current rule (JAR 25.629(d)(3)(i)), and when combined with the damage-tolerance requirements of JAR 25.571(b), should provide the conservatism necessary to warrant relief from the single failure requirement for the structural elements of these attachments. The proposal also provides a further alternative damage-tolerant method in case the inspection provisions of JAR 25.571 are impracticable.

It is also proposed to revise the full-scale flight flutter test requirement to the extent that full-scale flight flutter tests would always be required for new designs. Currently, flight flutter tests are specifically required if M_D is greater than .8. Indirectly, flight tests have always been necessary and required on large aeroplanes, either as proof of freedom from flutter or as a means of validating the flutter analysis. The specific requirement for flight flutter testing on all new designs is considered necessary and consistent with the reduction of the normal flutter margins from 1.2 V_D to 1.15 V_D. It is also proposed to add a requirement that the flight test show a proper damping margin and that there be no large and rapid reduction in damping as V_{DF}/M_{DF} is approached.

<u>3. RELATIONSHIP TO FAR 25</u>

The proposals of this NPA have been fully harmonised with the requirements of FAR 25 under the auspices of the Loads and Dynamics Harmonisation Working Group of the Aviation Rulemaking Advisory Committee (ARAC). A Notice of Proposed Rulemaking (NPRM) is being produced by the FAA that will match the requirement changes described herein. An Advisory Circular (AC 25.629-1A) is also being produced that will align with the proposed ACJ 25.629.

II-D. JAA NPA 25BCD-236 COMMENT-RESPONSE DOCUMENT

DISPOSITION OF COMMENTS

A number of supportive comments were received indicating acceptance of the proposed amendments without change to the text. Other comments were considered in detail by the Structures Study Group (SSG) at its Meeting No. 97 held in Stockholm on 24-25 June 1997 and were resolved as follows:-

COMMENT: It is noted that whilst this NPA includes a proposal to amend JAR 25.251, which is a flight requirement located in sub-part B, there has been no inter-discipline consultation with the Flight Study Group prior to issue.
SSG RESPONSE: Comment noted.

COMMENT: Proposal 1 is headed "By revising JAR 25.251 to read as follows:". As the subsequent text only includes sub-paragraphs (a) and (b) taken literally, this implies that sub-paragraphs (c), (d) and (e) are to be deleted. It is suggested that the introduction should read "By revising JAR 25.251 (a) and (b) to read as follows:".
SSG RESPONSE: Comment accepted. The heading will be changed as suggested.

COMMENT: The proposed amendment to JAR 25.251(b) would remove the stipulation that the aircraft must be demonstrated in flight up to at least the minimum value of V_D that satisfies the structural requirements. However, it is believed that this is the accepted practice and is covered by the recent amendments proposed for the FAA AC 25-7. It is noted that there is no specific statement that V_{DF}/M_{DF} may not exceed V_D/M_D. This again is commonly accepted, but would benefit from being stated in either 25.253 or 25.1505.
SSG RESPONSE: Comment noted. This matter will be referred to the JAA Flight Study Group for action.

COMMENT: The last sentence of the proposed JAR 25.305(f) does not meet the declared objective of clarifying that the relevant loads are limit loading conditions. It is suggested the text should be amended to make reference to the 25.302 and its associated Appendix, now being introduced by NPA 25C-199, and should read: "These loads must be treated in accordance with the requirements of JAR 25.302."
SSG RESPONSE: Comment accepted. The wording will be changed as suggested. This assumes that JAA will progress NPA 25C-199 and 25BCD-236 simultaneously.

COMMENT: It is noted that the proposed revised JAR 25.629(d)(8)(i) refers to JAR 25.571(e) and 25.903(d) whereas the FAR 25.629(d)(8)(i) refers only to FAR 25.571(e). The justification for a reference to JAR 25.903(d) might also justify the need for a reference to JAR 25.905(d), i.e. discrete source damage resulting from propeller failure debris.
SSG RESPONSE: Comment rejected. Unlike JAR 25.903(d), JAR 25.905 does not allow the concept of a residual risk assessment. This would give manufacturers difficulty in complying with any reference to JAR 25.905 (i.e. no flutter under any circumstances of propeller failure). This problem will be considered again during harmonisation of JAR/FAR 25.905.

COMMENT: The proposal to include consideration of icing conditions in the revised JAR 25.629 and an associated new ACJ raises various points:

1. the proposed requirement only refers to inadvertent icing encounters by aeroplanes not approved for flight in icing, whereas the ACJ also talks about ice on unprotected surfaces for aeroplanes approved for icing conditions and to single failures, or combinations of failures not shown to be extremely improbable, of de-icing systems.

2. The proposals talk of "likely icing accumulation", without any further guidance. We presume that this would be harmonised with the ice accumulations for handling and performance, but this should be clearly stated.
3. The ACJ sates that consideration of ice accumulations need only address the mass distribution of ice shapes and not the aerodynamic effects. Given our knowledge that ice shapes can have significant effects on aerodynamic forces and moments, it is surprising that these are dismissed as not relevant to structural aspects, including buffeting and aeroelasticity.

SSG RESPONSE:
1. Comment noted. The SSG agrees that the ACJ goes further in specifying icing conditions than the rule, but holds the view that it is appropriate to do so.
2. Comment rejected. The term "likely ice accumulation" is well understood in the context of flutter analyses and is always approached in a conservative manner.
3. Comment rejected. The effects of ice shapes are important in calculation of static aerodynamic coefficients. The effects of ice shapes on oscillatory, unsteady aerodynamics is less certain. The SSG believes that it is entirely adequate to take account the influence of ice on unsteady aerodynamics through parametric sensitivity studies. On the other hand the effect of ice mass has a primary effect on flutter stability and must be taken into account directly.

COMMENT: General comment. It is suggested that it would be helpful to the reader if all NPAs could, where possible, highlight differences from existing JARs.
SSG RESPONSE: Comment noted. This will be pointed out to JAA Headquarters when the NPA is returned.

COMMENT: In ACJ 25.629, paragraph 2.3 the subscripts on design speeds (Vd, Md etc.) in Figures 1A and 1B are presented in lower case, whereas throughout the text they are presented as upper case (VD, MD etc.). For consistency the subscripts should be in upper case throughout.
SSG RESPONSE:. Comment accepted. The subscripts will be presented as suggested.

COMMENT: ACJ 25.629, paragraph 3.2.8 uses the phrase "sub-paragraphs 3.2.4 and 3.2.5" while paragraph 3.2.6 refers to the "paragraphs 3.2.4 and 3.2.5" without the "sub". For consistency 3.2.8 should use the phrase "paragraphs 3.2.4 and 3.2.5".
SSG RESPONSE:. Comment accepted. The wording will be changed as suggested.

COMMENT: In ACJ 25.629, paragraph 5.1.3, "The ice accumulation determination can take account the ability ..." should read "The ice accumulation determination can take into account the ability ..."
SSG RESPONSE: Comment accepted. The wording will be changed as suggested.

COMMENT: In ACJ 25.629, paragraph 5.2.4, "When methods validity is uncertain ..." would be better understood if written in plain English as "When the validity of a method is uncertain ..."
SSG RESPONSE: Comment accepted. The wording will be changed as suggested.

COMMENT: In JAR 25.629(e) the text of the third sentence should be amended to remove a redundant "to" to read "... investigated need not exceed V_{FC}/M_{FC} ..."
SSG RESPONSE: Comment accepted. The wording will be changed as suggested.

COMMENT: In ACJ 25.629, paragraph 5.1.3 the text of the second sentence should be amended to read "... can take account of the ability ..."
SSG RESPONSE: Comment accepted. The wording will be changed as suggested.

COMMENT: ACJ 25.629, paragraph 5.1.3 "Analysis Considerations" should be renumbered 5.1.4.
SSG RESPONSE: Comment accepted. The numbering will be changed as suggested.

COMMENT: The FAR Amendment 25-86 has introduced a new sub-paragraph 25.427(d) with a cross reference to 25.305(e). This change was not adopted in JAR-25 since, prior to this NPA 25BCD-236, the paragraph 25.305(e) did not exist in JAR. Now the change to JAR 25.427(d) can be

added.
<u>SSG RESPONSE</u>: Comment accepted. A new sub-paragraph 25.427(d) will be added to JAR as a conforming and harmonising change.

<u>COMMENT:</u> Regarding the term DAMPING used in the diagrams on pages 12 and 13: In those diagrams a negative value of what is labelled damping means that the vibrations are damped. The reason for this sign convention is probably due to the complex representation p= s + I * om for solutions to the stability problem. The imaginary term expresses the frequency and the real part, s here, controls the time evolution of a perturbation, and we believe it is s (properly scaled) that is given in the diagrams.
It would be preferred to use a word like INCREMENT for the quantity that is plotted in the present diagrams on pages 12 and 13. However, a better presentation of damping characteristics would be to have "Damping" or "Decrement" on the vertical axis, but then to present the curves such that a positive value means a damped behaviour.
<u>SSG RESPONSE</u>: Comment agreed in principle. However, for the purposes of harmonisation the Working Group agreed to use the American sign convention. Since the proposal is consistent with the current FAA Advisory Circular and this has not led to any compliance problems the SSG reluctantly propose to stay with the current diagrams.

<u>COMMENT:</u> On page 19, in the middle of the second part: "... increase in equivalent airspeed over design cruise speed, V_D at all altitudes ..." should probably read "... increase in equivalent airspeed over the design cruise speed V_C at all altitudes ..."
<u>SSG RESPONSE</u>: Comment accepted. This was an error in the discussion and justification section.

III-A. EXPLANATORY NOTE JAA NPA 25D-286

Originally NPA 25D-286 Material Strength Properties and Material Design Values
<u>Final Version 9 January 2003</u>

1. The initial issue of CS-25 was based upon JAR-25 at amendment 16. During the transposition of airworthiness JARs into certification specifications the rulemaking activities under the JAA system where not stopped. In order to assure a smooth transition from JAA to EASA the Agency has committed itself to continue as much as possible of the JAA rulemaking activities. Therefore it has included most of it in its own rulemaking programme for 2004 and planning for 2005-2007. This part of present EASA NPA is a result of this commitment and a transposed version of the JAA NPA 25D-286 which was circulated for comments from 2 April 2002 till 2 July 2002 and agreed for adoption by the Regulation Sectorial Team in March 2003.

2. The Aviation Rulemaking Advisory Committee (ARAC) was established in 1991, with the purpose of providing information, advice, and recommendations to be considered in rulemaking activities. The FAA and JAA have worked toward the harmonisation of JAR-25 and FAR 25 by assigning ARAC specific tasks. One of the tasks assigned to the ARAC General Structures Harmonisation Working Group (GSHWG) concerned the requirements and interpretative material for material strength properties and material design values.

The GSHWG has completed this task (ref. Technical Agreement, October 10, 1996). This part of present NPA contains the proposals necessary to achieve harmonisation of the requirements and interpretative material for material strength properties and design values, taking also into account the proposed rule (25.613) and notice (AC 25.613-1X) as published for comment by the FAA in January 2002.
Note: In the mean time the FAA has adopted (in amendment 25-112) the revised rule 25.613 and has published AC 25.613-1

III-B. PROPOSALS TRANSPOSED JAA NPA 25D-286

The following amendments should be included in Decision No. 2003/2/RM of the Executive Director of the Agency of 17 October 2003:

1. To amend CS 25.613 by adding a reference to AMC 25.613, and by revising sub-paragraphs (b) to (e) and by adding a new sub-paragraph (f) to read as follows:

CS 25.613 Material Strength Properties and Material Design Values (<u>See AMC 25.613</u>)

(a) * * *

(b) Material design values must be chosen to minimise the probability of structural failures due to material variability. Except as provided in sub-paragraphs (e) and (f) of this paragraph, compliance must be shown by selecting material design values which assure material strength with the following probability:

(1) * * *
(2) * * *

(c) The effects of environmental conditions, such as temperature and moisture, on material design values used in an essential component or structure must be considered where these effects are significant within the aeroplane operating envelope.

(d) [Revoked]

(e) Greater material design values may be used if a “premium selection” of the material is made in which a specimen of each individual item is tested before use to determine that the actual strength properties of that particular item will equal or exceed those used in design.

(f) Other material design values may be used if approved by the Agency.

2. To add a new AMC 25.613 to read as follows:

AMC 25.613
Material Strength Properties and Material Design Values (Interpretative Material)

1. *Purpose*. This AMC sets forth an acceptable means, but not the only means, of demonstrating compliance with the provisions of CS-25 related to material strength properties and material design values.

2. *Related CS Paragraphs*.

CS 25.571 “Damage-tolerance and fatigue evaluation of structure”
CS 25.603 “Materials”
CS 25.613 "Material strength properties and material design values”

3. *General*. CS 25.613 contains the requirements for material strength properties and material design values. Material properties used for fatigue and damage tolerance analysis are addressed by CS 25.571 and AMC 25.571(a).

4. *Material Strength Properties and Material Design Values.*

4.1. *Definitions.*

Material strength properties. Material properties that define the strength related characteristics of any given material. Typical examples of material strength properties are: ultimate and yield values for compression, tension, bearing, shear, etc.

Material design values. Material strength properties that have been established based on the requirements of CS 25.613(b) or other means as defined in this AMC. These values are generally statistically determined based on enough data that when used for design, the probability of structural failure due to material variability will be minimised. Typical values for moduli can be used.

Aeroplane operating envelope. The operating limitations defined for the product under Subpart G of CS-25.

4.2. *Statistically Based Design Values.* Design values required by CS 25.613(b) must be based on sufficient testing to assure a high degree of confidence in the values. In all cases, a statistical analysis of the test data must be performed.

The "A" and "B" properties published in MIL-HDBK-5 or ESDU 00932 are acceptable, as are the statistical methods specified in the applicable chapters/sections of these handbooks. Other methods of developing material design values may be acceptable to the Agency.

The test specimens used for material property certification testing should be made from material produced using production processes. Test specimen design, test methods and testing should:

(i) conform to universally accepted standards such as those of the American Society for Testing Materials (ASTM), European Aerospace Series Standards (EN), International Standard Organisation (ISO), or other national standards acceptable to the Agency, or:

(ii) conform to those detailed in the applicable chapters/sections of MIL-HDBK-5, MIL-HDBK-17, ESDU 00932 or other accepted equivalent material data handbooks, or:

(iii) be accomplished in accordance with an approved test plan which includes definition of test specimens and test methods. This provision would be used, for example, when the material design values are to be based on tests that include effects of specific geometry and design features as well as material.

The Agency may approve the use of other material test data after review of test specimen design, test methods, and test procedures that were used to generate the data.

4.3. *Consideration of Environmental Conditions.* The material strength properties of a number of materials, such as non-metallic composites and adhesives, can be significantly affected by temperature as well as moisture absorption. For these materials, the effects of temperature and moisture should be accounted for in the determination and use of material design values. This determination should include the extremes of conditions encountered within the aeroplane operating envelope. For example, the maximum temperature of a control surface may include effects of direct and reflected solar radiation, convection and radiation from a black runway surface and the maximum ambient temperature. Environmental conditions other than those mentioned may also have significant effects on material design values for some materials and should be considered.

4.4. *Use of Higher Design Values Based on Premium Selection.* Design values greater than those determined under CS 25.613(b) may be used if a premium selection process is employed in accordance with CS 25.613(e). In that process, individual specimens are tested to determine the actual strength properties of each part to be installed on the aircraft to assure that the strength will not be less than that used for design.

If the material is known to be anisotropic then testing should account for this condition.

If premium selection is to be used, the test procedures and acceptance criteria must be specified on the design drawing.

4.5. *Other Material Design Values*. Previously used material design values, with consideration of the source, service experience and application, may be approved by the Agency on a case by case basis (e.g. "S" values of MIL-HDBK-5 or ESDU 00932).

4.6. *Material Specifications and Processes*. Materials should be produced using production specifications and processes accepted by the Agency.

III-C. ORIGINAL JAA NPA 25D-286 proposals justification

1. SAFETY JUSTIFICATION / EXPLANATION

JAR 25.613 prescribes requirements for material static strength properties and design values. Metallic material strength properties for aircraft manufactured in Europe have been based on those contained in MIL-HDBK-5, MIL-HDBK-17, ESDU 00932 or other equivalent material data handbooks. For metallic materials not listed in MIL-HDBK-5 or ESDU 00932, the statistical procedures in these handbooks were normally used to determine design values. Until Change 14 of JAR-25, the "A" or "B" material design values were required to be used unless a "premium selection" of the material was made. JAR 25.613 and JAR 25.615 were amended in 1993, combining them into one requirement, JAR 25.613. As part of the revision, the requirement to use "A" and "B" material design values was replaced by a more general requirement specifying probabilities and confidence levels for strength, with the test procedures and statistical methods unspecified. Those probability and confidence levels apply to metallic as well as non-metallic materials.

The title to JAR 25.613 has been revised to clarify that the design values are material design values. There are no proposed revisions to JAR 25.613(a).

JAR 25.613(b) has been revised to clarify that the design values are material design values. The A and B allowables published in MIL-HDBK-5 and MIL-HDBK-17, ESDU 00932, or in equivalent handbooks are acceptable without further statistical analysis. The statistical methods specified in MIL-HDBK-5, MIL-HDBK-17, or ESDU 00932 are acceptable for use in establishing material design values. Other statistical methods, amounts of data and material property data may also be accepted by JAA.

JAR 25.613(c) now requires consideration of the effects of environment on allowable stresses used for design. This proposal would require consideration of conditions such as temperature and moisture on material design values used in an essential component or structure, where those effects are significant in the aeroplane operating envelope.

JAR 25.613(d) would be revoked by this proposal. Fatigue is now adequately addressed by JAR 25.571.

The premium selection process of JAR 25.613(e) remains unchanged; however, the paragraph has been revised to clarify that design values are material design values.

A new JAR 25.613(f) is proposed which would permit other design values if they are approved by the JAA on a case-by-case basis.

A new ACJ 25.613, which describes acceptable methods of compliance with JAR 25.613, is included with this proposal.

2. COST / SAFETY BENEFIT ASSESSMENT

The proposals contained in this NPA are intended to achieve common requirements and interpretation related to material strength properties and design values, without reducing the safety provided by the regulations below the level that is acceptable to Authorities and Industry.

Harmonisation of JAR-25 and FAR 25 on this subject would yield cost savings by eliminating duplicate certification activities.

III-D. JAA NPA 25D-286 comment response document

(Hoofddorp, 9 January 2003)

Note : the comments are not included in the text of below responses. Should you wish to get the content of a specific comment, please contact

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Introduction

NPA 25D-286 was published for comment on April 1, 2002. This NPA is a result of a harmonisation activity between JAA and FAA.
For more details on the background of this NPA is referred to the NPA itself.

Comments & Responses

The following (seven) organisations have commented on this NPA:

- Police Aviation, UK
- DGAC, France
- CAA, NL
- ACG, Austria
- AECMA
- CAA, UK
- Embraer, Brasil

All, except CAA/UK, have stated to have no (adverse) comments on this NPA.
The CAA/UK comments are addressed as follows:

Comment 006

Comment not accepted.
The text proposed by the commenter is mainly seen as an attempt to improve the text from an editorial point of view. Sine this may create more confusion than clarification, and will cause disharmony with the FAA as well, these proposals are not adopted.
The proposal by the commenter to clarify the 99/95 and 90/95 probability/confidence levels is also considered not to be necessary, as the existing text has not caused any misinterpretation in the past.

Comment 007

Comment not accepted.
Paragraph 4.1. of the proposed ACJ 25.613 states that typical values for moduli can be used. This is considered to be sufficient guidance.

Comment 008

Comment not accepted.
The term “proof” proposed by the commenter is subject to interpretation (e.g. “proof strength” is often associated with limit load conditions). The term “yield” is sufficiently common in the aviation industry and is considered to be appropriate in the context of this ACJ.

Comment 009

Comments not accepted.

The addition of the word “material” proposed by the commenter is not deemed necessary, as this is already sufficiently clear from the title of the proposed JAR 25.613.
The use of the word “must” in an ACJ is acceptable when used to explain an acceptable means of compliance and/or to repeat rule text.

Conclusion
This final version of NPA 25D-286 is proposed for adoption in JAR-25. This final version is identical to the one published for public comments.
(*Note*: The FAA has informed the JAA that no (adverse) comments have been received on the corresponding NPRM and AC published in the Federal Register. Hence adoption of this NPA in JAR-25 would achieve full harmonisation on this subject.)

IV-A. EXPLANATORY NOTE JAA NPA 25C-290

Originally NPA 25C-290 Proof of Structure
Final Version 9 January 2003

1. The initial issue of CS-25 was based upon JAR-25 at amendment 16. During the transposition of airworthiness JARs into certification specifications the rulemaking activities under the JAA system where not stopped. In order to assure a smooth transition from JAA to EASA the Agency has committed itself to continue as much as possible of the JAA rulemaking activities. Therefore it has included most of it in its own rulemaking programme for 2004 and planning for 2005-2007. This part of present EASA NPA is a result of this commitment and a transposed version of the JAA NPA 25C-290 which was circulated for comments from 2 April 2002 till 2 July 2002 and was agreed for adoption by the Regulation Sectorial Team in March 2003.

2 In 1993, the Aviation Rulemaking Advisory Committee (ARAC) chartered by notice in the Federal Register a General Structures Harmonisation Working Group (GSHWG) of industry and government structural specialists of Europe, the United States and Canada, to work on a number of issues to harmonise Part 25 of the Federal Aviation Regulations (FAR 25) and the European Joint Airworthiness Requirements for Large Aeroplanes, JAR-25. One of these issues was Proof of Structure.
This part of present NPA proposes to revise the proof of structure requirements of CS-25 by incorporating the changes developed and agreed (ref. Fast Track Report, 15 June 2000) by the GSHWG. It is proposed to improve the wording of the existing subparagraph 25.307(a), and to significantly expand the existing AMC 25.307.

IV-B. PROPOSALS TRANSPOSED JAA NPA 25C-290

The following amendments should be included in Decision No. 2003/2/RM of the Executive Director of the Agency of 17 October 2003:

1. To amend CS 25.307 as follows:

CS 25.307 Proof of structure (<u>See AMC 25.307</u>)

(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) ***

(c) ***

(d) ***

2. To replace the existing AMC 25.307 by a new AMC 25.307 as follows:

AMC 25.307
Proof of Structure (Acceptable Means of Compliance)

1. *Purpose*

This AMC establishes methods of compliance with CS 25.307, which specifies the requirements for Proof of Structure. Other compliance methods may be used if approved by the Agency.

2. *Related CS Paragraphs*

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.

IV-C. ORIGINAL JAA NPA 25C-290 proposals justification

1. SAFETY JUSTIFICATION / EXPLANATION

Both FAR and JAR 25.307(a) require compliance with the static strength and deformation requirements for each critical loading condition. Both FAR and JAR state that structural analysis may be used only if the structure conforms to that for which experience has shown the analysis to be reliable.

The difference between FAR and JAR 25.307(a) is related to the cases where additional substantiating load tests must be made. According to the FAR, the Administrator may require ultimate load tests where limit load tests are inadequate ("bottom-up approach"). The corresponding requirement in JAR-25 however states that if the manufacturer proposes to conduct any tests below ultimate load, this proposal must be approved by the Authority ("top-down approach").

Because of this difference in the rule, the FAA has traditionally placed more emphasis on (full scale) tests to limit load, and substantiation of ultimate strength and deformation by analysis supported by tests, whereas the JAA has placed more emphasis on the validation of the structural analysis by (full scale) tests to ultimate load levels.
To avoid the use of the words "limit load" or "ultimate load", the proposed text of 25.307(a) now states that substantiating load tests must be made that are sufficient to verify structural behaviour up to the load levels required by 25.305 (strength and deformation). Where it is justified, these test load levels may be reduced.

The proposed advisory material gives further guidance on how to determine the need for and the extent of testing (including the load levels), by first classifying (with a proper justification) the structure into one of three possible categories, and second, matching the outcome of this classification with a number of certification approaches.

The advisory material also contains guidance on 25.307(d), when compliance is shown by static or dynamic tests only. This only applies to flight structure, so the GSHWG concluded that landing gears are excluded from this subparagraph.

The issue of primary versus secondary structure was also discussed by the GSHWG. After some discussion it was decided that 25.307 applies to both categories of structure, although initially the U.S. Civil Aeronautics Manual 04 only referred to primary structure. The reason for the GSHWG decision not to distinguish between both categories was mainly based on the argument that anyway every reasonable effort should be made to prevent separation (failure) of elements (components) from the aeroplane. This means that all elements (components) should be subjected to at least some form of stress checking. The consequence of failure however of a particular component in terms of the overall integrity of the aeroplane could be taken into account when determining the need for and the extent of testing (including the load levels).

Subparagraph (a) of 25.651 was also discussed in the GSHWG in relation to proof of structure. This subparagraph requires limit load tests of control surfaces. It is unclear however from the rule whether this means that under all circumstances limit load tests of control surfaces are required, or that, if substantiating load tests are required, limit load tests are sufficient instead of ultimate load tests. The GSHWG concluded that 25.307 applies to control surfaces as well, and

that the proposed advisory material could be used to determine the need for and the extent of testing (including the load levels).
A proposal to modify or even delete this subparagraph was rejected by the GSHWG, because this task was beyond the original charter in the Federal Register.

2. COST / SAFETY BENEFIT ASSESSMENT

These proposals are intended to achieve common requirements and language between the structural requirements of JAR-25 and FAR 25, without reducing the safety provided by the regulations below the level that is acceptable to Authorities and Industry. Since these proposals put more emphasis than before on providing test evidence up to ultimate load to support the required structural analyses, there may be an increase in economical burden for some applicants.

IV-D. JAA NPA 25C-290 COMMENT-RESPONSE DOCUMENT

(Hoofddorp, 9 January 2003)

Note : the comments are not included in the text of below responses. Should you wish to get the content of a specific comment, please contact

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Introduction

NPA 25C-290 was published for comment on April 1, 2002. This NPA is a result of a harmonisation activity between JAA and FAA.

For more details on the background of this NPA it is referred to the NPA itself.

Comments & Responses

The following (eight) organisations have commented on this NPA:

- Police Aviation, UK
- SAS, Sweden
- DGAC, France
- AECMA
- ACG, Austria
- CAA, UK
- Embraer, Brasil
- CAA, NL

All, except Embraer and CAA/NL, have stated to have no comments on this NPA.

The Embraer and CAA/NL comments are addressed as follows:

Comment 007

Comment not accepted.

The additional text proposed by the commenter seems to be adding more confusion than clarification, and may not even be in line with JAR 25.305.

Comment 008

Comment (partially) accepted.

To address the comment, a new definition (3.8 of ACJ 25.307) is added to clarify that previous test evidence is testing of the original structure that is sufficient to verify structural behaviour in accordance with JAR 25.305.

Conclusion

The final version of NPA 25C-290 proposed for adoption in JAR-25 includes the one change resulting from the disposition of comments above.

V-A. EXPLANATORY NOTE JAA NPA 25C-309

Originally NPA 25C-309 "Gust and Continuous Turbulence Design Loads"
Final Version 9 January 2003

1. The initial issue of CS-25 was based upon JAR-25 at amendment 16. During the transposition of airworthiness JARs into certification specifications the rulemaking activities under the JAA system where not stopped. In order to assure a smooth transition from JAA to EASA the Agency has committed itself to continue as much as possible of the JAA rulemaking activities. Therefore it has included most of it in its own rulemaking programme for 2004 and planning for 2005-2007. This part of present EASA NPA is a result of this commitment and a transposed version of the JAA NPA 25C-309 which was circulated for comments from 2 April 2002 till 2 July 2002 and was agreed for adoption by the Regulation Sectorial Team in March 2003.

2. The Aviation Rulemaking Advisory Committee (ARAC) was established in 1991, with the purpose of providing information, advice, and recommendations to be considered in rulemaking activities. The FAA and JAA have worked toward the harmonisation of JAR-25 and FAR 25 by assigning ARAC specific tasks. By notice in the Federal Register (1994), several new tasks were assigned to an ARAC working group (Loads and Dynamics Harmonisation Working Group, LDHWG) of industry and government structural loads specialists from Europe, the United States, and Canada. Task 2 of this charter concerned the requirement to account for continuous turbulence loads. The assigned task was to review the current requirement for continuous turbulence in FAR 25 and JAR 25 in order to determine if the continuous turbulence requirement was still needed and if it was in need of revision to be consistent with the discrete gust requirement of JAR 25.341(a).
The ARAC LDHWG has now completed its work for this task (ref. Technical Agreement, September 1999). This part of present NPA contains the proposals necessary to achieve harmonisation of the gust and continuous turbulence design loads requirements.

V-B. PROPOSALS TRANSPOSED JAA NPA 25C-309

The following amendments should be included in Decision No. 2003/2/RM of the Executive Director of the Agency of 17 October 2003:

1. To amend CS 25.341 by adding a reference to new AMC 25.341 in the title, and by revising the subparagraphs 25.341(a)(5)(i), 25.341(b) and 25.341(c) to read as follows:

CS 25.341 Gust and turbulence loads (See AMC 25.341)

(a) * * * * *

(5) The following reference gust velocities apply:

(i) At aeroplane speeds between V_B and V_C:

Positive and negative gusts with reference gust velocities of 17.07 m/s (56.0 ft/s) EAS must be considered at sea level. The reference gust velocity may be reduced linearly from 17.07 m/s (56.0 ft/s) EAS at sea level to 13.41 m/s (44.0 ft/s) EAS at 4572 m (15 000 ft). The reference gust velocity may be further reduced linearly from 13.41 m/s (44.0 ft/s) EAS at 4572 m (15 000 ft) to 6.36 m/s (20.86 ft/sec) EAS at 18288 m (60 000 ft).

* * * * *

(b) *Continuous Turbulence Design Criteria*. The dynamic response of the aeroplane 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 CS 25.321(b), and all critical speeds within the ranges indicated in subparagraph (b)(3).

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

$$P_L = P_{L-1g} \pm U_\sigma \overline{A}$$

Where:

P_L = limit load;

P_{L-1g} = steady 1-g load for the condition;

$\overline{A}$ = ratio of root-mean-square incremental load for the condition to root-mean-square turbulence velocity; and

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

(2) Values of $\overline{A}$ must be determined according to the following formula:

$$\overline{A} = \sqrt{\int_0^\infty \left|\mathrm{H}(\Omega)\right|^2 \Phi_I(\Omega)\, d\Omega}$$

Where:

$\mathrm{H}(\Omega)$ = the frequency response function, determined by dynamic analysis, that relates the loads in the aircraft structure to the atmospheric turbulence; and

$\Phi_I(\Omega)$ = normalised power spectral density of atmospheric turbulence given by:

$$\Phi_I(\Omega) = \frac{L}{\pi} \frac{1 + \frac{8}{3}(1.339\Omega L)^2}{[1 + (1.339\Omega L)^2]^{11/6}}$$

Where:

Ω = reduced frequency, rad/ft; and

L = scale of turbulence = 2,500 ft.

(3) The limit turbulence intensities, U_σ, in m/s (ft/s) true airspeed required for compliance with this paragraph are:

(i) At aeroplane speeds between V_B and V_C:

$$U_\sigma = U_{\sigma ref} F_g$$

Where:

$U_{\sigma ref}$ is the reference turbulence intensity that varies linearly with altitude from 27.43 m/s (90 ft/s) (TAS) at sea level to 24.08 m/s (79 ft/s) (TAS) at 7315 m (24000 ft) and is then constant at 24.08 m/s (79 ft/s) (TAS) up to the altitude of 18288 m (60000 ft); and

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

(ii) At speed V_D: U_σ is equal to 1/2 the values obtained under subparagraph (3)(i) of this paragraph.

(iii) At speeds between V_C and V_D: U_σ 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 aeroplane 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 aeroplanes with significant non-linearities, it must be assumed that the turbulence field has a root-mean-square velocity equal to 40 percent of the U_σ values specified in subparagraph (3). The value of limit load is that load with the same probability of exceedance in the turbulence field as $\bar{A} U_\sigma$ of the same load quantity in a linear approximated model.

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

(1) A discrete gust determined in accordance with CS 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 CS 25.341(a). The penetration of the aeroplane 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:

$$P_L = P_{L-1g} \pm 0.85 \sqrt{(L_{Vi}^2 + L_{Li}^2)}$$

Where:

P_L = limit load;
P_{L-1g} = steady 1-g load for the condition;
L_V = peak incremental response load due to a vertical gust according to CS 25.341(a); and
L_L = peak incremental response load due to a lateral gust according to CS 25.341(a).

2. To amend CS 25.343 by revising subparagraph 25.343(b)(1)(ii) to read as follows:

(b) * * * * *
(1) * * * * *
(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).

3. To amend CS 25.345 by revising subparagraph 25.345(c)(2) to read as follows:

(c) * * * * *
(2) The vertical gust and turbulence conditions prescribed in CS 25.341. (<u>See AMC 25.345(c)</u>.)

4. To amend CS 25.371 to read as follows:

CS 25.371 Gyroscopic loads.

The structure supporting any engine or auxiliary power unit must be designed for the loads, including gyroscopic loads, arising from the conditions specified in CS 25.331, CS 25.341, CS 25.349, CS 25.351, CS 25.473, CS 25.479, and CS 25.481, with the engine or auxiliary power unit at the maximum rpm appropriate to the condition. For the purposes of compliance with this paragraph, the pitch manoeuvre in CS 25.331(c)(1) must be carried out until the positive limit manoeuvring load factor (point A_2 in CS 25.333(b)) is reached.

5. To amend CS 25.373 by revising subparagraph 25.373(a) to read as follows:

(a) The aeroplane must be designed for the symmetrical manoeuvres and gusts prescribed in CS 25.333, CS 25.337, the yawing manoeuvres in CS 25.351, and the vertical and lateral gust and turbulence conditions prescribed in CS 25.341(a) and (b) at each setting and the maximum speed associated with that setting; and;
* * * * *

6. To amend CS 25.391 to read as follows:

CS 25.391 Control surface loads: general

The control surfaces must be designed for the limit loads resulting from the flight conditions in CS 25.331, CS 25.341(a) and (b), CS 25.349 and CS 25.351 and the ground gust conditions in CS 25.415, considering the requirements for------

*   *   *   *   *

7. To amend CS 25.1517 to read as follows:

CS 25.1517 Rough air speed V_{RA}

(a) A rough air speed V_{RA} for use as the recommended turbulence penetration air speed, and a rough air Mach number M_{RA}, for use as the recommended turbulence penetration Mach number, must be established to ensure that likely speed variation during rough air encounters will not cause the overspeed warning to operate too frequently.

(b) At altitudes where V_{MO} is not limited by Mach number, in the absence of a rational investigation substantiating the use of other values, V_{RA} must be less than V_{MO} - 35 KTAS.

(c) At altitudes where V_{MO} is limited by Mach number, M_{RA} may be chosen to provide an optimum margin between low and high speed buffet boundaries.

8. To amend AMC 25.341(b) to read as follows:

AMC 25.341
Gust and Continuous Turbulence Design Criteria (Acceptable Means of Compliance)

1. PURPOSE. This AMC sets forth an acceptable means of compliance with the provisions of CS-25 dealing with discrete gust and continuous turbulence dynamic loads.

2. RELATED CS PARAGRAPHS. The contents of this AMC are considered by the Agency in determining compliance with the discrete gust and continuous turbulence criteria defined in CS 25.341. Related paragraphs are:

CS 25.343	Design fuel and oil loads
CS 25.345	High lift devices
CS 25.349	Rolling conditions
CS 25.371	Gyroscopic loads
CS 25.373	Speed control devices
CS 25.391	Control surface loads
CS 25.427	Unsymmetrical loads
CS 25 445	Auxiliary aerodynamic surfaces
CS 25.571	Damage-tolerance and fatigue evaluation of structure

Reference should also be made to the following CS paragraphs: 25.301, 25.302, 25.303, 25.305, 25.321, 25.335, 25.1517.

3. OVERVIEW. This AMC addresses both discrete gust and continuous turbulence (or continuous gust) requirements of CS-25. It provides some of the acceptable methods of modelling aeroplanes, aeroplane components, and configurations, and the validation of those modelling methods for the purpose of determining the response of the aeroplane to encounters with gusts.

How the various aeroplane modelling parameters are treated in the dynamic analysis can have a large influence on design load levels. The basic elements to be modelled in the analysis are the elastic, inertial, aerodynamic and control system characteristics of the complete, coupled aeroplane (Figure 1). The degree of sophistication and detail required in the modelling depends on the complexity of the aeroplane and its systems.

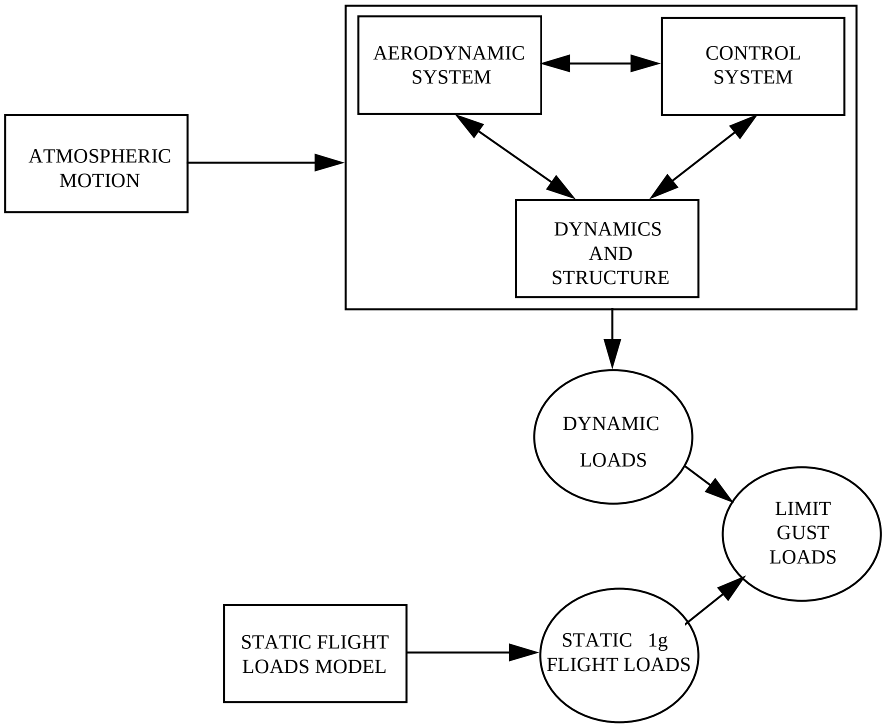

Figure 1 Basic Elements of the Gust Response Analysis

Design loads for encounters with gusts are a combination of the steady level 1-g flight loads, and the gust incremental loads including the dynamic response of the aeroplane. The steady 1-g flight loads can be realistically defined by the basic external parameters such as speed, altitude, weight and fuel load. They can be determined using static aeroelastic methods.

The gust incremental loads result from the interaction of atmospheric turbulence and aeroplane rigid body and elastic motions. They may be calculated using linear analysis methods when the aeroplane and its flight control systems are reasonably or conservatively approximated by linear analysis models.

Non-linear solution methods are necessary for aeroplane and flight control systems that are not reasonably or conservatively represented by linear analysis models. Non-linear features generally raise the level of complexity, particularly for the continuous turbulence analysis, because they often require that the solutions be carried out in the time domain.

The modelling parameters discussed in the following paragraphs include:

- Design conditions and associated steady, level 1-g flight conditions.
- The discrete and continuous gust models of atmospheric turbulence.
- Detailed representation of the aeroplane system including structural dynamics, aerodynamics, and control system modelling.

- Solution of the equations of motion and the extraction of response loads.
- Considerations for non-linear aeroplane systems.
- Analytical model validation techniques.

4. DESIGN CONDITIONS.

a. General. Analyses should be conducted to determine gust response loads for the aeroplane throughout its design envelope, where the design envelope is taken to include, for example, all appropriate combinations of aeroplane configuration, weight, centre of gravity, payload, fuel load, thrust, speed, and altitude.

b. Steady Level 1-g Flight Loads. The total design load is made up of static and dynamic load components. In calculating the static component, the aeroplane is assumed to be in trimmed steady level flight, either as the initial condition for the discrete gust evaluation or as the mean flight condition for the continuous turbulence evaluation. Static aeroelastic effects should be taken into account if significant.

To ensure that the maximum total load on each part of the aeroplane is obtained, the associated steady-state conditions should be chosen in such a way as to reasonably envelope the range of possible steady-state conditions that could be achieved in that flight condition. Typically, this would include consideration of effects such as speed brakes, power settings between zero thrust and the maximum for the flight condition, etc.

c. Dynamic Response Loads. The incremental loads from the dynamic gust solution are superimposed on the associated steady level flight 1-g loads. Load responses in both positive and negative senses should be assumed in calculating total gust response loads. Generally the effects of speed brakes, flaps, or other drag or high lift devices, while they should be included in the steady-state condition, may be neglected in the calculation of incremental loads.

d. Damage Tolerance Conditions. Limit gust loads, treated as ultimate, need to be developed for the structural failure conditions considered under CS 25.571(b). Generally, for redundant structures, significant changes in stiffness or geometry do not occur for the types of damage under consideration. As a result, the limit gust load values obtained for the undamaged aircraft may be used and applied to the failed structure. However, when structural failures of the types considered under CS 25.571(b) cause significant changes in stiffness or geometry, or both, these changes should be taken into account when calculating limit gust loads for the damaged structure.

5. GUST MODEL CONSIDERATIONS.

a. General. The gust criteria presented in CS 25.341 consist of two models of atmospheric turbulence, a discrete model and a continuous turbulence model. It is beyond the scope of this AMC to review the historical development of these models and their associated parameters. This AMC focuses on the application of those gust criteria to establish design limit loads. The discrete gust model is used to represent single discrete extreme turbulence events. The continuous turbulence model represents longer duration turbulence encounters which excite lightly damped modes. Dynamic loads for both atmospheric models must be considered in the structural design of the aeroplane.

b. Discrete Gust Model

(1) Atmosphere. The atmosphere is assumed to be one dimensional with the gust velocity acting normal (either vertically or laterally) to the direction of aeroplane travel. The one-dimensional assumption constrains the instantaneous vertical or lateral gust velocities to be the same at all points in planes normal to the direction of aeroplane travel. Design level discrete gusts are assumed to have 1-cosine velocity profiles. The maximum velocity for a discrete gust is calculated using a reference gust velocity, U_{ref} ,a flight profile alleviation factor, F_g, and an expression which modifies the maximum velocity as a function of the gust gradient distance, H. These parameters are discussed further below.

(A) Reference Gust Velocity, U_{ref} - Derived effective gust velocities representing gusts occurring once in 70,000 flight hours are the basis for design gust velocities. These reference velocities are specified as a function of altitude in CS 25.341(a)(5) and are given in terms of feet per second equivalent airspeed for a gust gradient distance, H, of 350 ft.

(B) Flight Profile Alleviation Factor, F_g - The reference gust velocity, U_{ref} , is a measure of turbulence intensity as a function of altitude. In defining the value of U_{ref} at each altitude, it is assumed that the aircraft is flown 100% of the time at that altitude. The factor F_g is then applied to account for the expected service experience in terms of the probability of the aeroplane flying at any given altitude within its certification altitude range. F_g is a minimum value at sea level, linearly increasing to 1.0 at the certified maximum altitude. The expression for F_g is given in CS 25.341(a)(6).

(C) Gust Gradient Distance, H - The gust gradient distance is that distance over which the gust velocity increases to a maximum value. Its value is specified as ranging from 30 to 350 ft. (It should be noted that if 12.5 times the mean geometric chord of the aeroplane’s wing exceeds 350 ft, consideration should be given to covering increased maximum gust gradient distances.)

(D) Design Gust Velocity, U_{ds} - Maximum velocities for design gusts are proportional to the sixth root of the gust gradient distance, H. The maximum gust velocity for a given gust is then defined as:

$$U_{ds} = U_{ref}\ F_g\ (H/350)^{(1/6)}$$

The maximum design gust velocity envelope, U_{ds}, and example design gust velocity profiles are illustrated in Figure 2.

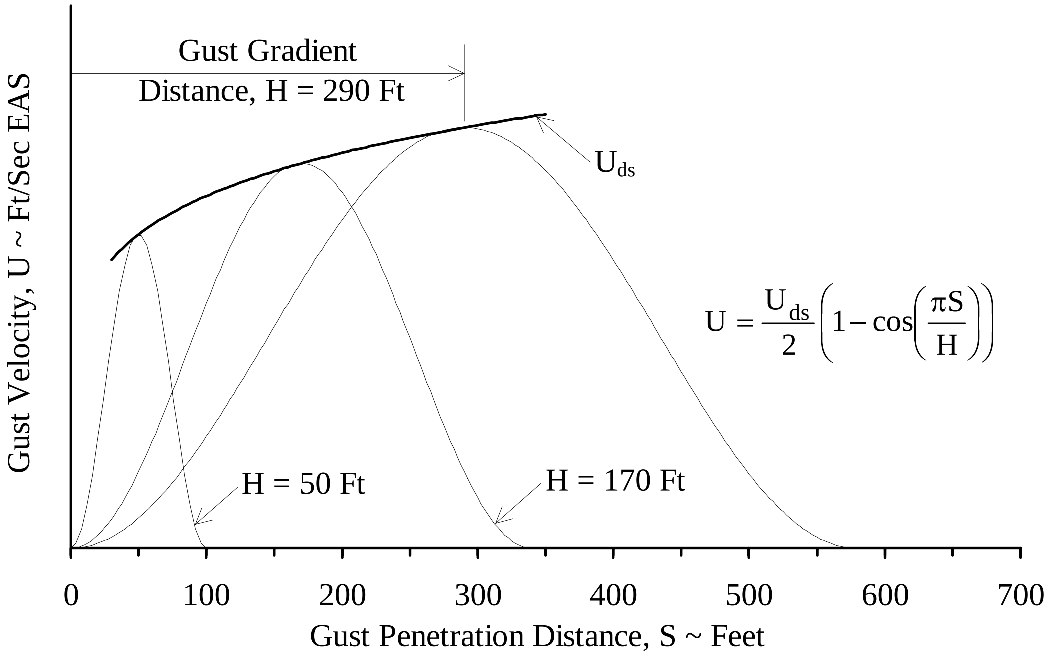

Figure-2 Typical (1-cosine) Design Gust Velocity Profiles

(2) Discrete Gust Response. The solution for discrete gust response time histories can be achieved by a number of techniques. These include the explicit integration of the aeroplane equations of motion in the time domain, and frequency domain solutions utilising Fourier transform techniques. These are discussed further in Paragraph 7.0 of this AMC.

Maximum incremental loads, P_{Ii}, are identified by the peak values selected from time histories arising from a series of separate, 1-cosine shaped gusts having gradient distances ranging from 9.1 to 107 m (30 to 350 ft). Input gust profiles should cover this gradient distance range in sufficiently small increments to determine peak loads and responses. Historically 10 to 20 gradient distances have been found to be acceptable. Both positive and negative gust velocities should be assumed in calculating total gust response loads. It should be noted that in some cases, the peak incremental loads can occur well after the prescribed gust velocity has returned to zero. In such cases, the gust response calculation should be run for sufficient additional time to ensure that the critical incremental loads are achieved.

The design limit load, P_{Li}, corresponding to the maximum incremental load, P_{Ii} for a given load quantity is then defined as:

$$P_{Li} = P_{(1\text{-}g)i} \pm P_{Ii}$$

Where $P_{(1\text{-}g)i}$ is the 1-g steady load for the load quantity under consideration. The set of time correlated design loads, P_{Lj}, corresponding to the peak value of the load quantity, P_{Li}, are calculated for the same instant in time using the expression:

$$P_{Lj} = P_{(1\text{-}g)j} \pm P_{Ij}$$

Note that in the case of a non-linear aircraft, maximum positive incremental loads may differ from maximum negative incremental loads.

When calculating stresses which depend on a combination of external loads it may be necessary to consider time correlated load sets at time instants other than those which result in peaks for individual external load quantities.

(3) Round-The-Clock Gust. When the effect of combined vertical and lateral gusts on aeroplane components is significant, then round-the-clock analysis should be conducted on these components and supporting structures. The vertical and lateral components of the gust are assumed to have the same gust gradient distance, H and to start at the same time. Components that should be considered include horizontal tail surfaces having appreciable dihedral or anhedral (i.e., greater than 10º), or components supported by other lifting surfaces, for example T-tails, outboard fins and winglets. Whilst the round-the-clock load assessment may be limited to just the components under consideration, the loads themselves should be calculated from a whole aeroplane dynamic analysis.

The round-the-clock gust model assumes that discrete gusts may act at any angle normal to the flight path of the aeroplane. Lateral and vertical gust components are correlated since the round-the-clock gust is a single discrete event. For a linear aeroplane system, the loads due to a gust applied from a direction intermediate to the vertical and lateral directions - the round-the-clock gust loads - can be obtained using a linear combination of the load time histories induced from pure vertical and pure lateral gusts. The resultant incremental design value for a particular load of interest is obtained by determining the round-the-clock gust angle and gust length giving the largest (tuned) response value for that load. The design limit load is then obtained using the expression for P_L given above in paragraph 5(b)(2).

(4) Supplementary Gust Conditions for Wing Mounted Engines.

(A) Atmosphere - For aircraft equipped with wing mounted engines, CS 25.341(c) requires that engine mounts, pylons and wing supporting structure be designed to meet a round-the-clock discrete gust requirement and a multi-axis discrete gust requirement.

The model of the atmosphere and the method for calculating response loads for the round-the-clock gust requirement is the same as that described in Paragraph 5(b)(3) of this AMC.

For the multi-axis gust requirement, the model of the atmosphere consists of two independent discrete gust components, one vertical and one lateral, having amplitudes such that the overall probability of the combined gust pair is the same as that of a single discrete gust as defined by CS 25.341(a) as described in Paragraph 5(b)(1) of this AMC. To achieve this equal-probability condition, in addition to the reductions in gust amplitudes that would be applicable if the input were a multi-axis Gaussian process, a further factor of 0.85 is incorporated into the gust amplitudes to account for non-Gaussian properties of severe discrete gusts. This factor was derived from severe gust data obtained by a research aircraft specially instrumented to measure vertical and lateral gust components. This information is contained in Stirling Dynamics Laboratories Report No SDL –571-TR-2 dated May 1999.

(B) Multi-Axis Gust Response - For a particular aircraft flight condition, the calculation of a specific response load requires that the amplitudes, and the time phasing, of the two gust components be chosen, subject to the condition on overall probability specified in (A) above, such that the resulting combined load is maximised. For loads calculated using a linear aircraft model, the response load may be based upon the separately tuned vertical and lateral discrete gust responses for that load, each calculated as described in Paragraph 5(b)(2) of this AMC. In general, the vertical and lateral tuned gust lengths and the times to maximum response (measured from the onset of each gust) will not be the same.

Denote the independently tuned vertical and lateral incremental responses for a particular aircraft flight condition and load quantity i by L_{Vi} and L_{Li}, respectively. The associated multi-axis gust input is obtained by multiplying the amplitudes of the independently-tuned vertical and lateral discrete gusts, obtained as described in the previous paragraph, by $0.85{*}L_{Vi}/\sqrt{(L_{Vi}^2+L_{Li}^2)}$ and $0.85{*}L_{Li}/\sqrt{(L_{Vi}^2+L_{Li}^2)}$ respectively. The time-phasing of the two scaled gust components is such that their associated peak loads occur at the same instant.

The combined incremental response load is given by:

$$P_{Ii} = 0.85\sqrt{(L_{Vi}^2+L_{Li}^2)}$$

and the design limit load, P_{Li}, corresponding to the maximum incremental load, P_{Ii}, for the given load quantity is then given by:

$$P_{Li} = P_{(1\text{-}g)i} \pm P_{Ii}$$

where $P_{(1\text{-}g)i}$ is the 1-g steady load for the load quantity under consideration.

The incremental, time correlated loads corresponding to the specific flight condition under consideration are obtained from the independently-tuned vertical and lateral gust inputs for load quantity i. The vertical and lateral gust amplitudes are factored by $0.85{*}L_{Vi}/\sqrt{(L_{Vi}^2+L_{Li}^2)}$ and $0.85{*}L_{Li}/\sqrt{(L_{Vi}^2+L_{Li}^2)}$ respectively. Loads L_{Vj} and L_{Lj} resulting from these reduced vertical and lateral gust inputs, at the time when the amplitude of load quantity i is at a maximum value, are added to yield the multi-axis incremental time-correlated value P_{Ij} for load quantity j.

The set of time correlated design loads, P_{Lj}, corresponding to the peak value of the load quantity, P_{Li}, are obtained using the expression:

$$P_{Lj} = P_{(1\text{-}g)j} \pm P_{Ij}$$

Note that with significant non-linearities, maximum positive incremental loads may differ from maximum negative incremental loads.

c. Continuous Turbulence Model.

(1) Atmosphere. The atmosphere for the determination of continuous gust responses is assumed to be one dimensional with the gust velocity acting normal (either vertically or laterally) to the direction of aeroplane travel. The one-dimensional assumption constrains the instantaneous vertical or lateral gust velocities to be the same at all points in planes normal to the direction of aeroplane travel.

The random atmosphere is assumed to have a Gaussian distribution of gust velocity intensities and a Von Kármán power spectral density with a scale of turbulence, L, equal to 2500 feet. The expression for the Von Kármán spectrum for unit, root-mean-square (RMS) gust intensity, $\Phi_I(\Omega)$, is given below. In this expression $\Omega = \omega/V$, where ω is the circular frequency in radians per second, and V is the aeroplane velocity in feet per second true airspeed.

$$\Phi_I(\Omega) = \frac{L}{\pi} \frac{1 + \frac{8}{3}(1.339\Omega L)^2}{[1 + (1.339\Omega L)^2]^{11/6}}$$

The Von Kármán power spectrum for unit RMS gust intensity is illustrated in Figure 3.

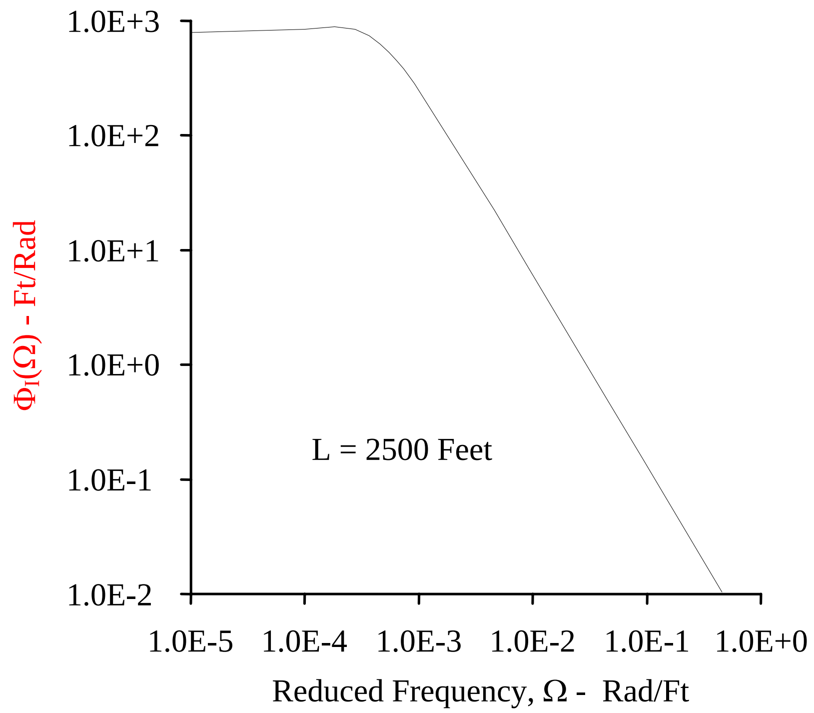

Figure-3 The Von Kármán Power Spectral Density Function, $\Phi_I(\Omega)$

The design gust velocity, U_σ, applied in the analysis is given by the product of the reference gust velocity, $U_{\sigma ref}$, and the profile alleviation factor, F_g, as follows:

$$U_\sigma = U_{\sigma ref} \; F_g$$

where values for $U_{\sigma ref}$, are specified in CS 25.341(b)(3) in feet per second true airspeed and F_g is defined in CS 25.341(a)(6). The value of F_g is based on aeroplane design parameters and is a minimum value at sea level, linearly increasing to 1.0 at the certified maximum design altitude. It is identical to that used in the discrete gust analysis.

As for the discrete gust analysis, the reference continuous turbulence gust intensity, $U_{\sigma ref}$, defines the design value of the associated gust field at each altitude. In defining the value of $U_{\sigma ref}$ at each altitude, it is assumed that the aeroplane is flown 100% of the time at that altitude. The factor F_g is then applied to account for the probability of the aeroplane flying at any given altitude during its service lifetime.

It should be noted that the reference gust velocity is comprised of two components, a root-mean-square (RMS) gust intensity and a peak to RMS ratio. The separation of these components is not defined and is not required for the linear aeroplane analysis. Guidance is provided in Paragraph 8.d. of this AMC for generating a RMS gust intensity for a non-linear simulation.

(2) <u>Continuous Turbulence Response</u>. For linear aeroplane systems, the solution for the response to continuous turbulence may be performed entirely in the frequency domain, using the RMS response. $\overline{\mathrm{A}}$ is defined in CS 25.341(b)(2) and is repeated here in modified notation for load quantity i, where:

$$\overline{\mathrm{A}}_{\mathrm{i}} = \left[\int_0^\infty \left| h_i(\Omega) \right|^2 \ \phi_I(\Omega) d\Omega \right]^{1/2}$$

or

$$\overline{\mathrm{A}}_{\mathrm{i}} = \left[\int_0^\infty \phi_I(\Omega) h_i(i\Omega) h_i^{\,*}(i\Omega) d\Omega \right]^{1/2}$$

In the above expression $\phi_I(\Omega)$ is the input Von Kármán power spectrum of the turbulence and is defined in Paragraph 5.c.(1) of this AMC, $h_i(i\Omega)$ is the transfer function relating the output load quantity, i, to a unit, harmonically oscillating, one-dimensional gust field, and the asterisk superscript denotes the complex conjugate. When evaluating $\overline{\mathrm{A}}_{\mathrm{i}}$, the integration should be continued until a converged value is achieved since, realistically, the integration to infinity may be impractical. The design limit load, $P_{Li,}$ is then defined as:

$$P_{Li} = P_{(1\text{-g})i} \pm P_{Ii}$$

$$= P_{(1\text{-g})i} \pm U_\sigma \overline{\mathrm{A}}_{\mathrm{i}}$$

where U_σ is defined in Paragraph 5.c.(1) of this AMC, and $P_{(1\text{-g})i}$ is the 1-g steady state value for the load quantity, i, under consideration. As indicated by the formula, both positive and negative load responses should be considered when calculating limit loads.

Correlated (or equiprobable) loads can be developed using cross-correlation coefficients, $\rho_{ij,}$ computed as follows:

$$\rho_{ij} = \frac{\int_0^\infty \phi_I(\Omega) real\left[h_i(i\Omega) h^*{}_j(i\Omega) \right] d\Omega}{\overline{A}_i \overline{A}_j}$$

where, 'real[...]' denotes the real part of the complex function contained within the brackets. In this equation, the lowercase subscripts, i and j, denote the responses being correlated. A set of design loads, P_{Lj}, correlated to the design limit load P_{Li}, are then calculated as follows:

$$P_{Lj} = P_{(1-g)j} \pm U_{\sigma} \rho_{ij} \overline{A}_j$$

The correlated load sets calculated in the foregoing manner provide balanced load distributions corresponding to the maximum value of the response for each external load quantity, i, calculated.

When calculating stresses, the foregoing load distributions may not yield critical design values because critical stress values may depend on a combination of external loads. In these cases, a more general application of the correlation coefficient method is required. For example, when the value of stress depends on two externally applied loads, such as torsion and shear, the equiprobable relationship between the two parameters forms an ellipse as illustrated in Figure 4.

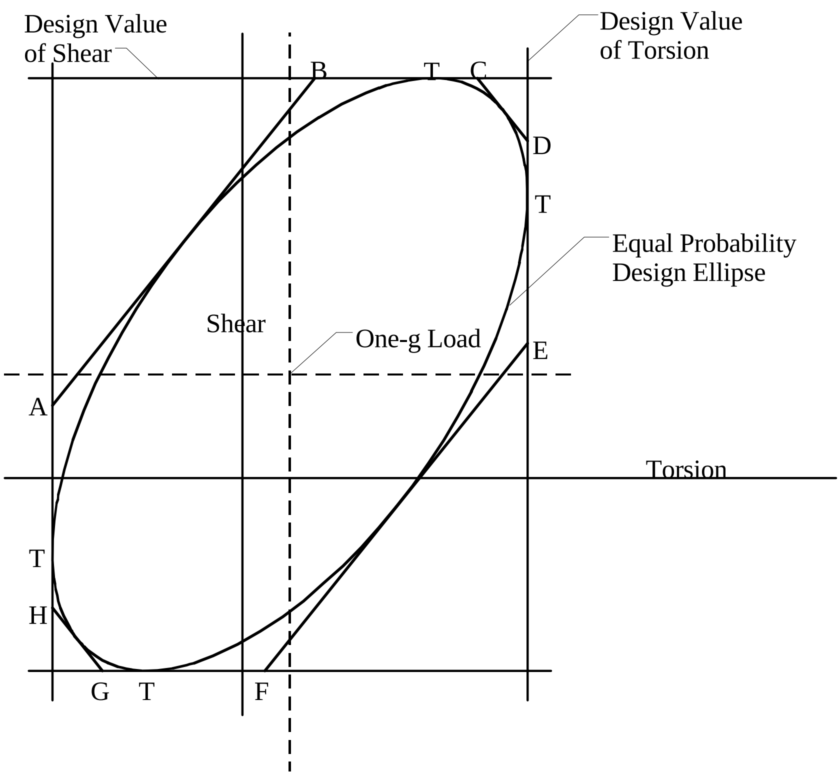

Figure-4 Equal Probability Design Ellipse

In this figure, the points of tangency, T, correspond to the expressions for correlated load pairs given by the foregoing expressions. A practical additional set of equiprobable load pairs that should be considered to establish critical design stresses are given by the points of tangency to the ellipse by lines AB, CD, EF and GH. These additional load pairs are given by the following expressions (where i = torsion and j = shear):

For tangents to lines AB and EF

$$P_{Li} = P_{(1\text{-}g)i} \; +/- \; \bar{A}_i U_\sigma [(1 - \rho_{ij})/2]^{1/2}$$

$$\text{and} \quad P_{Lj} = P_{(1\text{-}g)j} \; -/+ \; \bar{A}_j U_\sigma [(1 - \rho_{ij})/2]^{1/2}$$

For tangents to lines CD and GH

$$P_{Li} = P_{(1\text{-}g)i} \pm \bar{A}_i U_\sigma [(1 + \rho_{ij})/2]^{1/2}$$

$$\text{and} \quad P_{Lj} = P_{(1\text{-}g)j} \pm \bar{A}_j U_\sigma [(1 + \rho_{ij})/2]^{1/2}$$

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, $\bar{A}$, and the design stress values $P_{(1\text{-}g)} \pm U_\sigma \bar{A}$.

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 CS 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.

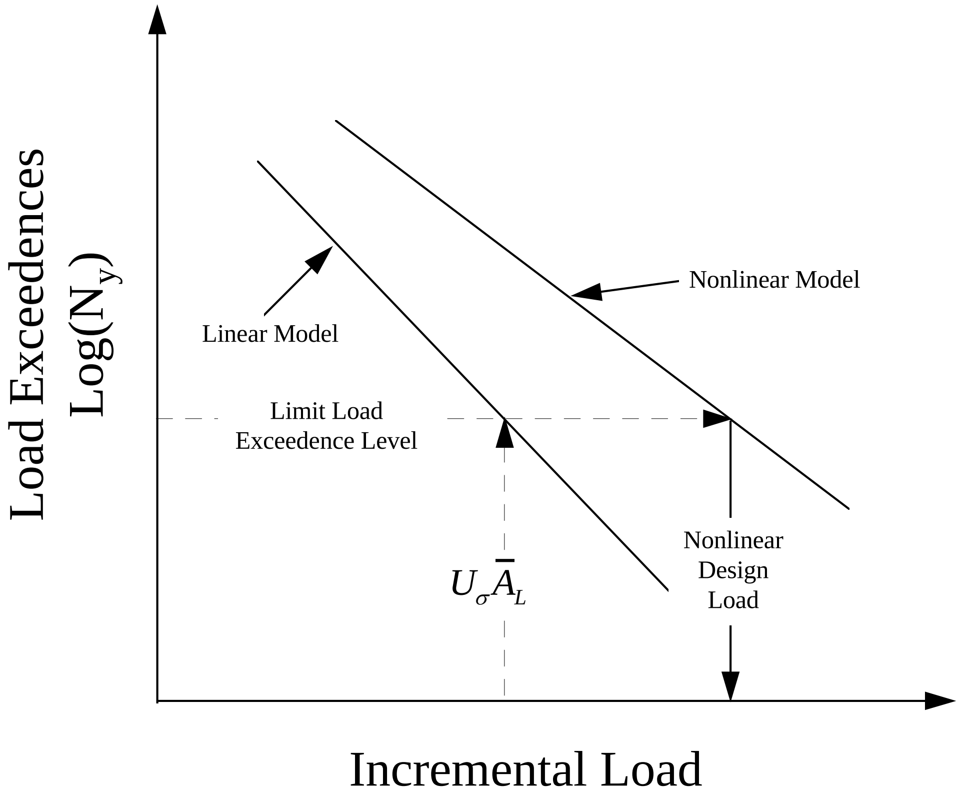

Figure-5 Establishing Limit Load for a Non-linear Aeroplane

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.

V-C. ORIGINAL JAA NPA 25C-309 proposals justification

1. SAFETY JUSTIFICATION / EXPLANATION

The current requirement to account for the loads produced by continuous turbulence (sometimes referred to as continuous gusts) is contained in JAR 25.341(b) and its associated ACJ, that describes (as interpretative material) two methodologies (design envelope and mission analysis) for showing compliance and also specifies the levels of required gust intensities for use in design.
Although the ACJ provides a sea level value for gust intensity of 25.90 m/s (85 ft/s) for the design envelope method, the JAA has allowed reduction to 22.75 m/s (75 ft/s) based on a simplified mission analysis with a restricted number of mission segments.

The mission analysis method has been the subject of considerable debate and controversy. With this method, the manufacturer must define a mission for the aeroplane which includes range, altitude, payload and other operational variables. Then, using a statistical model of the atmosphere, the manufacturer must show that the design strength will not be exceeded, within a certain probability, during the aeroplane operational life. Predicting the mission is not always reliable since missions can change after the aeroplane goes into operation. Furthermore, the mission analysis design loads are sensitive to small changes in the definition of the aircraft mission. Therefore, small variations in approach can provide inconsistent results.

Additional shortcomings in the current continuous turbulence requirement have been brought to light by experience in applying the current criteria, experience in service, and by the changing design features of large/transport aeroplanes. Many large/transport aeroplanes now incorporate automatic flight control systems and other features that can result in significant non-linearities while the methodology normally employed for continuous turbulence is inherently linear.

Efforts to better define the atmospheric model have continued since the adoption of ACJ 25.341(b). Recent flight measurement programs conducted by FAA and the National Aeronautics and Space Administration (NASA) have been aimed at utilising measurements from the digital flight data recorders (DFDR) to derive gust load design information for airline transport aeroplanes. The Civil Aviation Authority (CAA) of the United Kingdom has conducted a comprehensive DFDR gust measurement program for transport aeroplanes in airline service. The program, called CAADRP (Civil Aircraft Airworthiness Data Recording Program), has resulted in an extensive collection of reliable gust data which has provided an improved insight into the distribution of gusts in the atmosphere.

Recently, the regulatory authorities and the aviation industries of the U.S., Canada and Europe have engaged in studies with the aim of finding a single gust design methodology that would account for both discrete gust and continuous turbulence. Although several promising methods are still under study, no single method is considered to be sufficient, at this time, for treating both phenomena. Therefore, ARAC has proceeded with developing harmonised improvements to the continuous turbulence and discrete gust design load conditions as separate requirements.

ARAC believes, and the JAA agrees, that a continuous turbulence criterion is still needed in addition to the discrete gust criterion since it accounts for the response to totally different, but still realistic, atmospheric characteristics. However, it is recognised that the current turbulence intensity model is inconsistent with the CAADRP data, and with the new atmospheric model prescribed for discrete gusts, and is in need of updating to accommodate modern transport aeroplanes.

The proposed requirement includes a revision to the gust intensity model used in the design envelope method for continuous turbulence, elimination of the mission analysis method, provisions for treating non-linearities, and reorganisation and clarification of the requirement. It is proposed to retain the design envelope criterion, but with a revised gust intensity distribution with altitude. The proposed gust intensities are based on analysis of gust measurements from the CAADRP program. The CAADRP data is the most recent gust information available and it represents measurements of gusts and turbulence on transport aeroplanes in actual operation. In addition, the flight profile alleviation factor already defined for the discrete gust in JAR 25.341(a) would be used to adjust the gust intensity distribution according to certain aircraft parameters that relate to the intended use of the aeroplane. This is considered to be a reliable means of accounting for aeroplane mission and it would be capable of being applied in a uniform manner.

One member of the ARAC Working Group objected to the definition of a flight profile alleviation factor that changes the design turbulence intensity versus altitude based on selected aircraft design parameters. That member believed that the once in 70,000 hour gust represented an acceptable level of turbulence for design purposes. He accepted that the intensity of the 70,000 hour gust properly varies with altitude; but he believed the probability of encountering a gust of that intensity at any point in time should be constant, regardless of the design parameters of a particular aircraft.
The majority of the ARAC Working Group disagreed. In their view the proposal does not assume that atmospheric turbulence is dependent upon aircraft speed and altitude, or any other aircraft design parameter. The flight profile alleviation factor is simply a mathematical device that allows the expected operation of the aeroplane to be taken into account by introducing multiplying factors, based on fuel loading and maximum operating altitude, that adjust the required design turbulence intensities. The flight profile alleviation factor in this proposal is identical in magnitude and effect to that used in the discrete gust requirements of JAR 25.341(a). To support this proposal, an effort has been undertaken by the industries and airworthiness authorities of the United States, Canada and Europe to evaluate the new proposed criteria and ensure that they are adequate for current conventional transport aeroplanes as well as for new technology aeroplanes that may include systems that react in a non-linear manner. Furthermore, the proposed design turbulence intensity distributions are believed to represent the best available measurements of the turbulence environment in which the aeroplane is likely to be operated.

The mission analysis method for accounting for continuous turbulence loads would be eliminated as an option since the use of this method can provide inconsistent results depending on the assumptions made concerning the potential use of the aeroplane. The elimination of this method would not be significant since few manufacturers currently use it as the primary means of addressing continuous turbulence. In addition, the mission would be taken into account in the proposed design envelope criterion, since a flight profile alleviation factor is provided as discussed above.

The introduction of advanced flight control systems into transport aeroplanes has presented special problems in the treatment of continuous turbulence. Some of these systems can exhibit significant non-linearities, while the standard mathematical approaches to continuous turbulence (i.e. frequency domain solutions) are valid only for linear systems. The current rule requires consideration of non-linearities only in relation to stability augmentation systems, however, with modern transport aeroplanes it is possible that the primary flight control systems and the aeroplane itself could exhibit significant non-linearities. The proposed rule would require that any significant non-linearity be considered in a realistic or conservative manner, and it would provide additional criteria which can be used with other rational approaches that can account for non-linearities (e.g. time domain solutions).

Following an accident in which an aeroplane shed a large wing mounted nacelle, the National Transportation Safety Board (NTSB) recommended (Safety Recommendation A-93-137, November 15, 1993) that the design load requirements should be amended to consider multiple axis loads encountered during severe turbulence. This recommendation was specifically addressed at gust loads on wing-mounted engines. Although it is believed that the existing designs are adequate and that the existing gust criteria have already been improved to the point that they should be adequate for current and future configurations, there remains a possibility that a multi-axis gust encounter could produce higher loads under certain situations. To address the NTSB concern, an independent organisation was contracted to develop a method of performing multi-axis discrete gust analysis for wing mounted nacelles. The results of that study were reported in Stirling Dynamics Laboratories Report No SDL – 571-TR-2 dated May 1999. The recommendations of that report were accepted by ARAC and are set forth in this proposal. The proposal addresses the NTSB recommendation by prescribing two dynamic gust criteria for aeroplanes with wing mounted engines. These are a round-the-clock discrete gust criterion and a multi-axis dual discrete gust criterion. These criteria are set forth in a new paragraph 25.341(c). The current 25.445 already requires the effects of combined gust loading to be considered on auxiliary aerodynamic surfaces such as outboard fins and winglets. Furthermore, the current 25.427(c) requires the effects of combined gust loading to be considered on some empennage arrangements such as T-tails. For aeroplanes with wing mounted engines, this proposal would extend the round the clock dynamic discrete gust criterion to wing mounted nacelles and provide an additional multi-axis dynamic discrete gust criterion. These criteria, set forth in JAR 25.341(c), would be applied as aeroplane dynamic conditions although the assessment would be limited to the engine mounts, pylons and wing supporting structure.

JAR 25.571, "Damage tolerance and fatigue evaluation of structure", currently references the entire JAR 25.341 as one source of residual strength loads for the damage tolerance assessment. No changes are proposed for this reference to JAR 25.341, so the additional gust loads derived from the new JAR 25.341(c) would be included in the damage tolerance assessment required by JAR 25.571.

Some current JAR-25 aeroplanes have maximum certified operating altitudes up to 51,000 ft. To be fully applicable to these, and future JAR-25 aeroplanes, this proposal defines gust intensities for all altitudes up to 60,000 ft. This is inconsistent with the discrete gust requirements of JAR 25.341(a), that define the discrete gust velocities at altitudes up to 50,000 ft only. Therefore, as a conforming change, it is proposed to amend JAR 25.341(a)(5)(i) to define discrete gust velocities up to 60,000 ft, thereby achieving consistency between discrete gust and continuous turbulence criteria.

With the adoption of the discrete gust in JAR 25.341(a), JAR 25.343 “Design fuel and oil loads” was amended as a conforming change so that the design criterion for the structural reserve fuel condition included only the discrete gust of JAR 25.341(a) and not the continuous turbulence of JAR 25.341(b). However, it is believed that both a continuous turbulence criterion and a discrete gust criterion are needed since they account for the response to totally different, but still realistic, atmospheric characteristics. Therefore, to meet the level of safety intended by the structural reserve fuel requirements it was deemed necessary to include a continuous turbulence loads criterion in paragraph (b)(1)(ii) of 25.343.

With the adoption of the discrete gust in JAR 25.341(a), JAR 25.345 “High lift devices” was amended as a conforming change so that the design criterion for en-route conditions with flaps deployed included only the discrete gust of JAR 25.341(a) and not the continuous turbulence of JAR 25.341(b). However, it is believed that both a continuous turbulence criterion and a discrete gust criterion are needed since they account for the response to totally different, but still realistic, atmospheric characteristics. Therefore, to meet the level of safety intended by the en-route requirements it was deemed necessary to include a continuous turbulence loads criterion in paragraph (c)(2) of JAR 25.345.

With the adoption of the discrete gust in JAR 25.341(a), JAR 25.371 "Gyroscopic loads" was amended as a conforming change so that gyroscopic loads were associated only with the discrete gust of JAR 25.341(a) and not the continuous turbulence of JAR 25.341(b). However, it is believed that in order to meet the level of safety intended by the revised continuous turbulence requirements it will be necessary to include gyroscopic effects, where appropriate, in calculation of total loads due to continuous turbulence. To this end a change is proposed to JAR 25.371 so that it would reference the entire JAR 25.341 and include both continuous turbulence loads as well as discrete gust loads.

With the adoption of the discrete gust in JAR 25.341(a), JAR 25.373 “Speed Control Devices” was amended as a conforming change so that the design requirement for these devices referenced only the discrete gust of JAR 25.341(a) and not the continuous turbulence of JAR 25.341(b). It is believed that encounters with continuous turbulence can result in the activation of speed brakes to slow the aeroplane to the recommended turbulence penetration speeds, and so the loads induced by turbulence should be considered while these devices are deployed. To this end, a change is proposed to 25.373 so that it would reference the entire 25.341 and include both continuous turbulence loads as well as discrete gust loads.

With the adoption of the discrete gust in JAR 25.341(a), JAR 25.391 “Control surface loads: general” was amended as a conforming change so that the design load criterion for control surfaces included only the discrete gust of JAR 25.341(a) and not the continuous turbulence of JAR 25.341(b). However, it is believed that both a continuous turbulence criterion and a discrete gust criterion are needed since they account for the response to totally different, but still realistic, atmospheric characteristics. Therefore, to meet the level of safety intended for the aircraft as a whole it was deemed necessary to design control surfaces for limit loads resulting from the continuous turbulence conditions. To this end a change is proposed to JAR 25.391 so that it would include 25.341(a) and JAR 25.341(b) for discrete gust as well as continuous turbulence loads.

The proposal does not include a unique continuous turbulence design intensity at $V_{B.}$ The design turbulence intensities established for the gust design conditions at V_C, "structural design cruising speed," and V_D, "structural design diving speed," were developed in consideration of the full operational envelope so that a different continuous turbulence design intensity at V_B is not considered necessary, provided the current practices for operating in severe turbulence are continued. The discrete gust requirements of JAR 25.341 do not contain a specific discrete gust design condition at V_B. Without any specific discrete gust or continuous turbulence design intensity at $V_{B,}$ there is no technical reason to prescribe a rough air speed based upon V_B. Therefore, it is proposed to amend JAR 25.1517 to remove the link between V_{RA} and V_B.

2. COST / SAFETY BENEFIT ASSESSMENT

The proposals contained in this NPA are intended to achieve common gust and continuous turbulence requirements of JAR-25 and FAR 25, without reducing the safety provided by the regulations below the level that is acceptable to Authorities and Industry. Although the proposed supplementary gust condition for wing mounted engines may lead to an increase in economical burden for some airframe manufacturers, it is believed that the overall rationalisation and harmonisation of the gust and continuous turbulence requirements sufficiently outweigh this increased burden.

V-D. JAA NPA 25C-309 COMMENT-RESPONSE DOCUMENT

(Hoofddorp, 9 January 2003)

Note : the comments are not included in the text of below responses. Should you wish to get the content of a specific comment, please contact

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Introduction

NPA 25C-309 was published for comment on April 1, 2002. This NPA is a result of a harmonisation activity between JAA and FAA.

For more details on the background of this NPA is referred to the NPA itself.

Comments & Responses

The following (seven) organisations have commented on this NPA:

- SAS, Sweden
- DGAC, France
- CAA, NL
- AECMA
- ACG, Austria
- CAA, UK
- Embraer, Brasil

All, except AECMA, have stated to have no comments on this NPA.

The AECMA comments are addressed as follows:

Comment 004

Comment not accepted.

The current wording of the NPA would provide for an equal treatment of all types of wing mounted engines. Although the conditions of the proposed JAR 25.341(c) may not be an issue for e.g. current turboprop installations, it is not possible to envision all possible (future) configurations, including those that may be affected by these conditions. So it would not be sensible to exclude certain aeroplane configurations from the start by only focusing on wing pylon mounted turbojet engines.

Comment 005

Comment accepted.

The corresponding change is made to the proposed JAR 25.341(b)(3)(iv).

Comment 006

Comment accepted.

The corresponding change is made to the proposed JAR 25.1517.

Comment 007

Comment accepted.

The corresponding changes are made to the proposed ACJ 25.341 section 5.c.(1). Also the proposed 25.341(b) is amended correspondingly ($\Phi_I(\Omega)$ in lieu of $\Phi(\Omega)$).

Comment 008
Comment accepted.
The corresponding changes are made to the proposed ACJ 25.341 section 5.c.

Comment 009
Comment accepted.
The corresponding change is made to the proposed ACJ 25.341 section 5.c.(1).

Comment 010
Comment accepted.
The corresponding change is made to the proposed ACJ 25.341 section 6.