HARMONIZATION OF U.S. AND EUROPEAN GUST CRITERIA FOR TRANSPORT AIRPLANES

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Abstract

This paper presents the status of the work being undertaken by an international team of specialists to re-evaluate the gust criteria for the next generation of commercial transports. The first step in the process is to harmonize the existing criteria, and minimize the analyses required for certification.

The process of harmonizing the FAR-25 and JAR-25 gust criteria began in 1983. Prior to the formation of an international ad hoc committee of gust specialists in 1986, the task became more complex by the requirement to certify airplanes with fly-by-wire and active controls. The committee established the following goals:

- Criteria and means of compliance same for FAR -25 and JAR-25
- Reduce total number of criteria to be met
- Level of strength similar to current successful transports
- Ability to handle advanced technologies such as active controls and load alleviation

A draft technical proposal for joint FAA/JAA gust criteria for transport airplanes has been prepared, and is constantly being refined. At the time of preparation of this paper, the proposal contains 4 elements compared with the 7 previously required.

Background

Having summarized the current situation and the goals, it is appropriate to review some of the history of gust criteria, and how the current situation arose

- Regardless of where a transport airplane is designed and certified, it likely will be in airline service essentially worldwide
- Even with good communication, researchers and engineers in various parts of the world could arrive with different solutions to the same problem
- As airplanes have evolved in terms of speed, altitude and flexibility, the criteria have also evolved
- As more realistic descriptions of turbulence have been introduced, these have not been allowed to supercede the earlier models. In part, this probably reflects concerns over the wisdom of relying totally on the PSD method for the prediction of design loads. In support of this view it is frequently noted from flight recorder data that the larger gusts often stand out as discrete events above a background of more moderate continuous turbulence.

It is therefore not surprising that the definition of design turbulence has evolved into several separate assumptions of discrete and continuous turbulence.

The underlying philosophy behind all structural loads criteria is that there should be sufficient structural margin around normal operating loads to ensure that, in combination with the factor of safety, the probability of catastrophic failure is acceptably low. Design load conditions are intended to produce load levels consistent with the load level which might be experienced once in the lifetime of an aircraft. In the early days of aircraft development, gust loads were assumed to be covered by conservative maneuver loads. As aircraft designs developed, however, the maneuver load criteria were reduced. It became apparent that parameters such as airspeed and wing loading were important in defining gust loads, and it was recognized that maneuver and gust loads should be treated separately.

A regulation must account for basic aircraft parameters, and operation. As aircraft structures were designed to be more flexible, it became necessary to account for dynamic response. While early criteria recognized only discrete gusts, more recent (current) criteria account for the continuous nature of atmospheric turbulence. Philosophically, however, as more detail and realism are added to the criteria it becomes increasingly difficult to define both realistic and design level criteria simultaneously. To ease the analysis burden, criteria are presented in the simplest form consistent with obtaining acceptable safety levels.

To minimize analysis complication, some simplifying assumptions are made. For example, discrete gusts are assumed to always have a one-minus-cosine shape, the atmosphere is assumed to be isotropic, continuous turbulence and discrete gusts are separated, and each presumed to result in design level loads.

Gusts and turbulence are considered stationary.

Spanwise variation in gust velocity is ignored, and combinations of maneuvers, continuous turbulence and discrete gusts are not considered.

Since the recognition that turbulence produced significant structural loads (around 1915), there have been several significant steps in the development of gust criteria. The first gust criterion was the SHARP EDGED GUST formula. This was later modified to a formula specifying RAMP-PLATFORM GUSTS and later to ONE-MINUS-COSINE gusts. Finally, the criteria for CONTINUOUS TURBULENCE were developed.

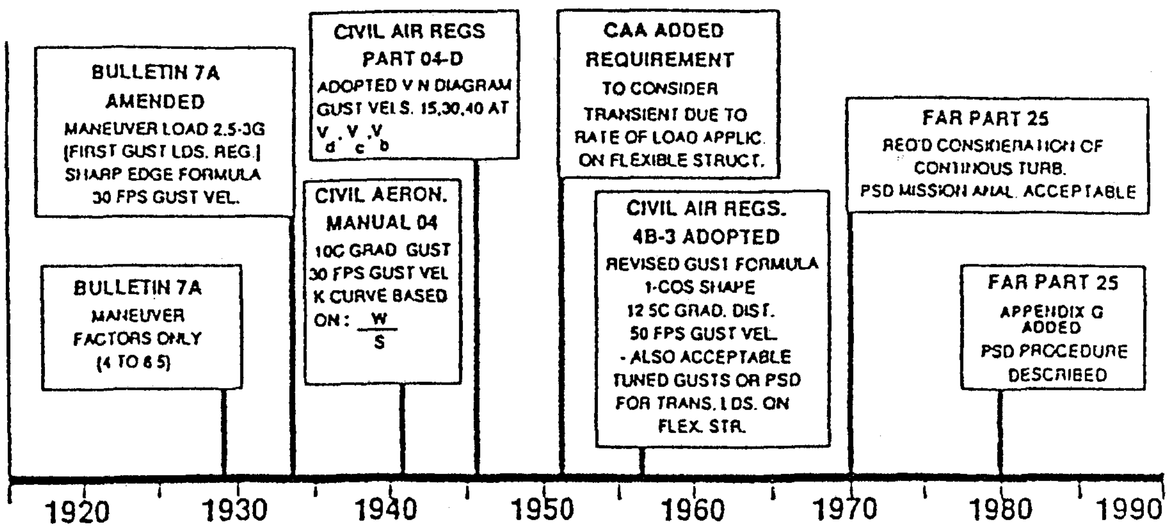
Figure 1 shows the chronology of Federal Regulatory gust loads criteria for transport aircraft design. The figure is taken from Reference 1, which traces the evolution of gust design criteria in the U.S. particularly from the standpoint of research that was used in the substantiation for the various versions in the evolution.

Some additional background and history on the development of the current FAA criteria is given in Reference 5.

In parallel with the development of criteria in the USA, various European Airworthiness Authorities were developing their own criteria. A further complication was the need to develop criteria for the certification of transports employing active load alleviation concepts. The Lockheed L-1011 (Reference 2) and Airbus A-320 (Reference 3) used interim design criteria and analysis procedures.

In Europe, up to 1979, separate airworthiness criteria were used by the major certifying authorities. At this time, after 10 years of negotiations, a Joint Airworthiness Requirement (JAR-25) has been adopted by the authorities of Belgium, Denmark, Finland, France, Fed. Rep. of Germany, Netherlands, Norway, Sweden, Switzerland and the United Kingdom. JAR-25 generally followed the layout and criteria of the U.S. Federal Aviation Regulations FAR-25, however, there are differences. In addition, each of the member countries was allowed to add "National Variants" to the basic code. The net result was that in order to certify a transport airplane in accordance with both FAR-25 and JAR-25, a manufacturer was required to perform seven separate gust analyses, and design to the most critical loads.

An FAA/JAA team is attempting to modify or eliminate some of the seven current criteria. In addition, the activity being conducted by JAA to remove National Variants from their code has already resulted in deletion of the RLD negative gust requirement.



Chronology of federal regulatory gust loads transport design criteria.

Figure 1

Even though it quickly became obvious to the gust specialists committee that no major changes in design criteria on methods of analysis could be introduced into the A-320 certification program, nevertheless the need for improved methods of analysis which could handle advanced technologies such as active controls and load alleviation was recognized. One very promising method - Statistical Discrete Gust Analysis, reference 4 - was extensively evaluated. At the request of FAA, a NASA Langley study was conducted to support the claim that the SDG and PSD methods produce essentially the same numerical results under certain circumstances. This was followed by an industry evaluation that included the development of component limit loads.

To date, most of the development problems have been resolved. The exception is the definition of a direct procedure to handle the critical condition search with non-linear systems. Suggestions have been made, and it is possible that this problem can be resolved. In this case, work will proceed on the development of acceptable design criteria.

Since the SDG method has the potential to replace both the discrete and PSD analysis methods, its continued development is considered to be prudent.

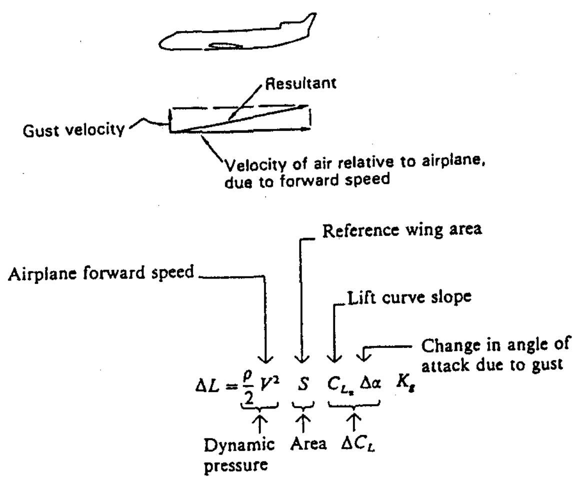
Discussion

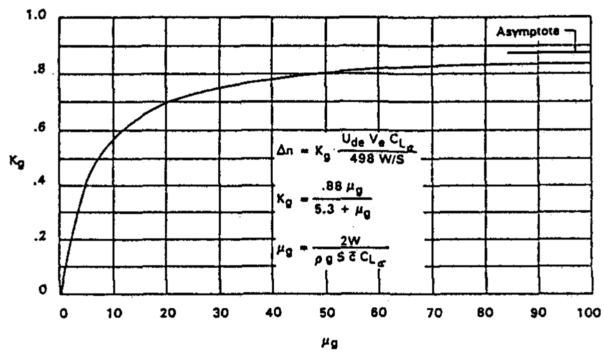
A brief description of each of the seven gust criteria in current use, the advantages and disadvantages of each, and recommendations regarding future use follow.

GUST ANALYSES FOR U.S./EUROPEAN CERTIFICATION

1. Gust Load Formula

The current regulations are based on a one-minus-cosine gust shape. In lieu of a rational analysis, the gust alleviation factor Kg may be applied to the basic gust lift equation as follows:





Gust factor K_g, current FAR gust loads formula.

Figure 2

Advantages

- Simple to apply and check
- Because it has been part of the regulations for many years, it is useful for comparison
- By using a flexible lift curve slope, it gives a good feel for airplane gust sensitivity.

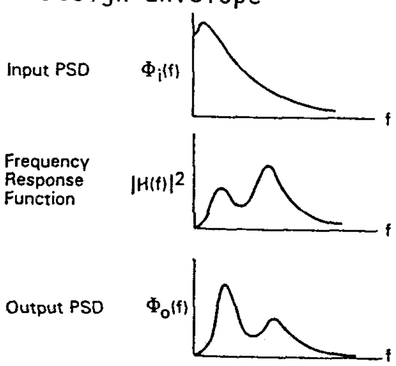
Disadvantages

- Does not consider gust response
- Cannot account for non-linear systems or active controls

RECOMMENDATION - Retain in draft FAA/JAA gust criteria proposal.

The current regulations require that dynamic response of the airplane to vertical and lateral continuous turbulence be taken into account. The regulations further define the Power Spectral Density Method as the means of compliance unless a more rational method is used.

2. PSD Design Envelope



$\Phi_o(f) = \Phi_i(f)|H(f)|^2$

Input-output relationship

PSD DESIGN LOADS
(DESIGN ENVELOPE)

OUTPUT SPECTRUM	-	PRODUCT OF INPUT GUST SPECTRUM AND SQUARE OF FREQUENCY RESPONSE (TRANSFER) FUNCTION.
RMS LOAD PER RMS GUST VELOCITY	-	AREA UNDER OUTPUT SPECTRUM DIVIDED BY AREA UNDER INPUT SPECTRUM.
$\frac{(\sigma^2 LOAD)}{(\sigma^2 GUST)}$	-	$\bar{A}$
DESIGN LOAD	-	$\bar{A}\,\sigma_W\,\eta_D$
σ_W	-	MAXIMUM DESIGN GUST INTENSITY
η_D	-	RATIO OF PEAK LOAD TO RMS LOAD
$\sigma_W \eta_D$	-	U_σ WHICH WAS CHOSEN BASED ON AN EXTENSIVE EVALUATION OF SUCCESSFUL COMMERCIAL TRANSPORTS.

Figure 3

In the design envelope approach, unit load ratios ($\bar{A}$) are defined, and these are multiplied by a gust intensity factor (U_σ) to obtain the design loads. Specific values of U_σ are defined for V_B, V_C and V_D.

Advantages

- Relatively straight-forward to apply
- Accounts for airplane dynamic response

Disadvantages

- Difficult to check
- If loads are critical, a separate procedure must be used to develop stressing loads

RECOMMENDATION - Retain in draft FAA/JAA gust criteria proposal.

3. PSD Mission Analysis

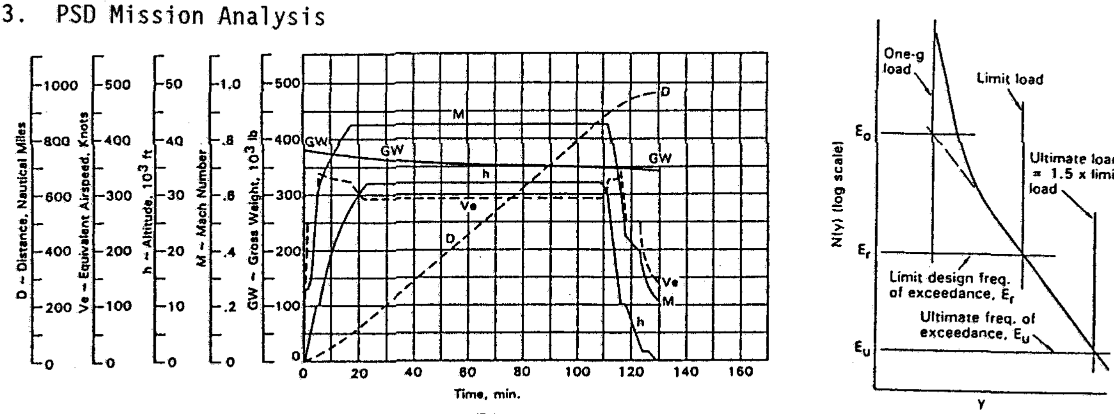


Figure 4

In the mission analysis approach, the designer selects typical anticipated mission profiles, and establishes a mix. The profiles are divided into segments for analysis, and the frequencies of load exceedance are established by adding the data from each segment. The design limit load is then established by reading off the load vs. exceedance curve at an exceedance rate of 2×10^{-5} per hour.

<u>Advantages</u>

- Accounts for airplane dynamic response
- Accounts for anticipated airplane usage

<u>Disadvantages</u>

- Difficult to check
- If loads are critical, a separate procedure must be used to develop stressing loads
- Resulting design loads are very sensitive to selection and mix of mission profiles, and to definition of flight segments within the profiles

RECOMMENDATION - Delete from draft FAA/JAA gust criteria proposal.

4. JAR 12.5 Chord Gust

Full dynamic analysis. Gust shape different for each airplane.

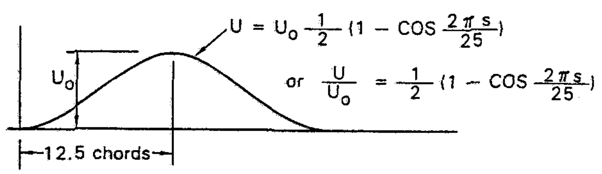


Figure 5

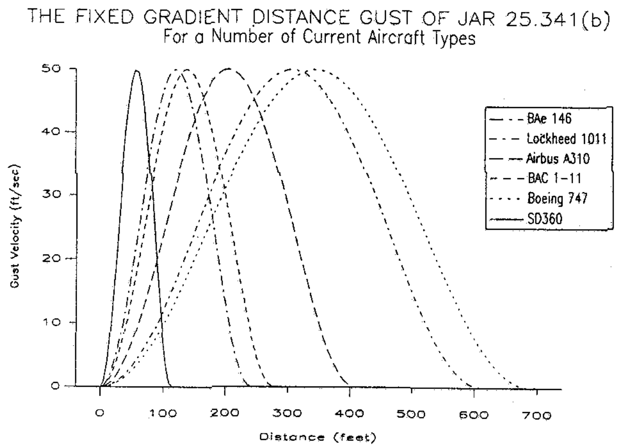


Figure 6

<u>Advantages</u>

- Provides time correlated loads which can be used directly for stressing

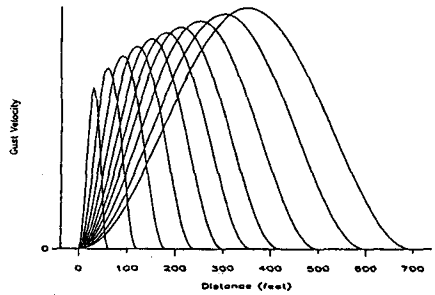
<u>Disadvantages</u>

- Unrealistic in defining a different gust shape for each airplane.
- Gust intensity does not vary with gust gradient distance

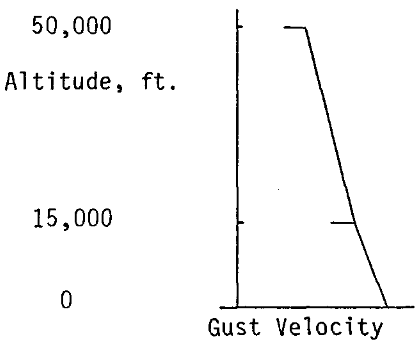
RECOMMENDATION - Combine with modified CAA-UK tuned discrete gust proposal. Delete as separate requirement in draft FAA/JAA criteria proposal.

5. JAA Discrete Dynamic Gust

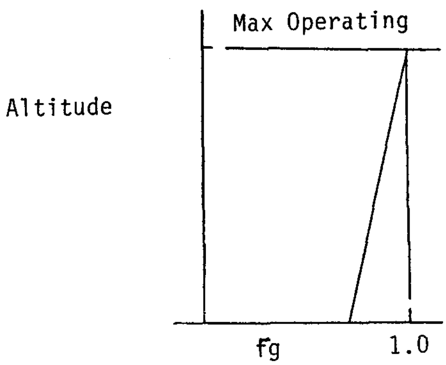
The current proposal contains three key elements:



Gust Tuning Law



Variation of Reference Gust Velocity



Flight Profile Alleviation Factor, Fg

Figure 7

<u>Advantages</u>

- Accounts for airplane dynamic response
- Provides time correlated loads which can be used directly for stressing
- Can handle non-linear systems and active controls
- Accounts for the primary effects of flight profile

<u>Disadvantages</u>

- Does not cover continuous turbulence

RECOMMENDATION - Continue development so that it will become a part of the draft FAA/JAA gust criteria proposal.

6. RLD Negative Gust

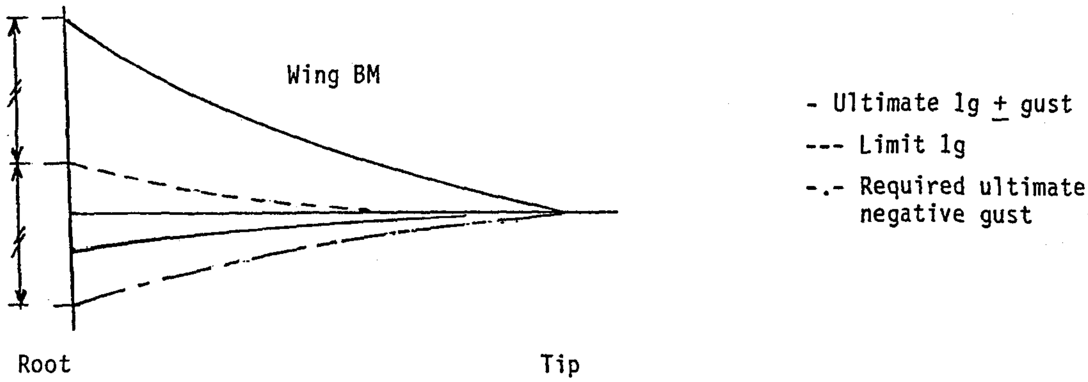


Figure 8

Limit load conditions are defined starting from the 1-g condition. After multiplying these limit loads by the 1.5 safety factor, the ultimate load conditions are defined in the positive and negative directions. Due to the unbalancing effect of the 1-g condition, the gust capability at ultimate load is larger in the positive direction than in the negative direction. The RLD special condition compensated this unbalancing effect.

As discussed above, this criterion is no longer a part of JAR-25.

7. Round-the-clock gust

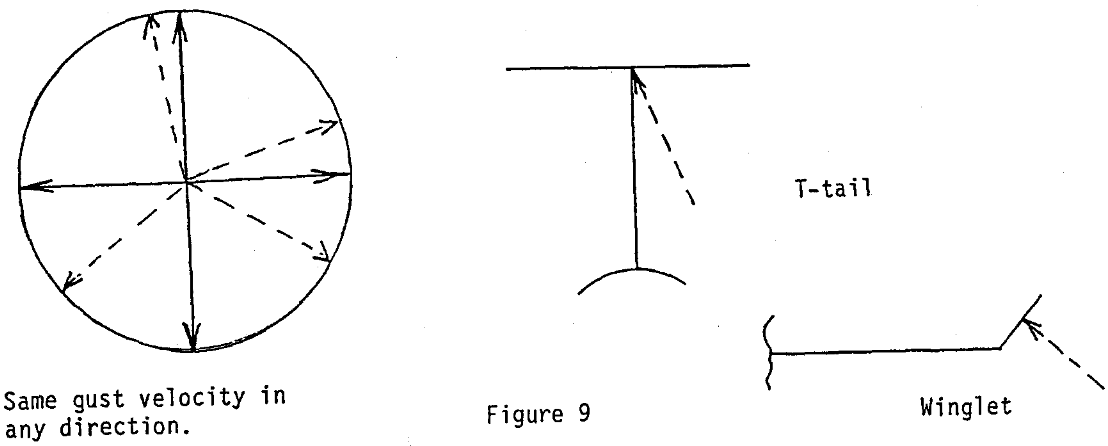


Figure 9

The round-the-clock gust is based on the assumption that a gust inclined at any angle has the same probability as a gust of the same magnitude in the vertical or lateral direction. The regulation is currently in JAR-25.

RECOMMENDATION - Retain in draft FAA/JAA gust criteria proposal.

CONCLUSIONS: The draft joint FAA/JAA gust criteria proposal for transport airplanes is constantly being refined. At the time of preparation of this paper, the proposal contains 4 elements compared with the 7 previously required, as shown in Figure 10

PROPOSAL FOR JOINT FAA/JAA
TRANSPORT AIRPLANE GUST CRITERIA

	CURRENT FAR-25	CURRENT JAR-25
- FAR GUST (PRATT FORMULA)	X	
- PSD DESIGN ENVELOPE	X	X
- REVISED JAA DISCRETE GUST		PROPOSED
- ROUND-THE-CLOCK GUST		X

Figure 10

At the time of presentation of this paper, the latest draft proposal will be addressed.

Acknowledgements

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