NOTICE OF PROPOSED AMENDMENT (NPA) No 2007-15

DRAFT DECISION OF THE EXECUTIVE DIRECTOR OF THE AGENCY

AMENDING
DECISION NO. 2006/05/R OF THE EXECUTIVE DIRECTOR OF THE AGENCY
of 25 September 2006
on Certification Specifications, including airworthiness code and acceptable means of compliance, for large aeroplanes (« CS-25 »)

and

DRAFT DECISION OF THE EXECUTIVE DIRECTOR OF THE AGENCY

AMENDING
DECISION NO. 2003/09/RM OF THE EXECUTIVE DIRECTOR OF THE AGENCY
of 24 October 2003
on Certification Specifications, including airworthiness code and acceptable means of compliance, for engines (« CS-E »)

ENGINE & AUXILIARY POWER UNIT (APU) FAILURE LOADS AND SUSTAINED ENGINE WINDMILLING

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Acronyms used in this NPA

AC	Advisory Circular
AMC	Acceptable Means of Compliance
APU	Auxiliary Power Unit
ARAC	Aviation Rulemaking Advisory Committee
CAA	Civil Aviation Authority
CAR	Civil Air Regulation
CRD	Comment Response Document
CS	Certification Specification
DGAC	Direction Générale de l'Aviation Civile
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements
LDHWG	Loads & Dynamics Harmonisation Working Group
NPA	Notice of Proposed Amendment
NPRM	Notice of Proposed Rulemaking
RIA	Regulatory Impact Assessment
ToR	Terms of Reference

Explanatory Note

I. General

1. The purpose of this Notice of Proposed Amendment (NPA) is to envisage amending Decision 2006/05/R of the Executive Director of 25 September 2006[1] and Decision 2003/09/RM of the Executive Director of 24 October 2003[2]. The scope of this rulemaking activity is outlined in ToR 25.015/016 and is described in more detail below.

2. The Agency is directly involved in the rule-shaping process. It assists the Commission in its executive tasks by preparing draft regulations, and amendments thereof, for the implementation of the Basic Regulation[3] which are adopted as "Opinions" (Article 14(1)). It also adopts Certification Specifications, including Airworthiness Codes and Acceptable Means of Compliance and Guidance Material to be used in the certification process (Article 14(2)).

3. When developing rules, the Agency is bound to follow a structured process as required by Article 43(1) of the Basic Regulation. Such process has been adopted by the Agency's Management Board and is referred to as "The Rulemaking Procedure"[4].

4. This rulemaking activity is included in the Agency's 2007 advanced rulemaking programme. It implements the rulemaking task 25.015/016: Engine & Auxiliary Power Unit (APU) Failure Loads and Sustained Engine Windmilling

5. The text of this NPA was originally developed by the JAA Structures Study Group and later developed by a dedicated EASA rulemaking group comprising of European Agency/Authority and Industry members. It is submitted for consultation of all interested parties in accordance with Article 43 of the Basic Regulation and Articles 5(3) and 6 of the EASA rulemaking procedure.

II. Consultation

6. To achieve optimal consultation, the Agency is publishing the draft decision of the Executive Director on its internet site. Comments should be provided within 3 months in accordance with Article 6(4) of the Agency rulemaking procedure.

CRT:	Send your comments using the Comment-Response Tool (CRT) available at http://hub.easa.europa.eu/crt/

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[1] Decision No 2006/05/R of the Executive Director of the Agency of 25.09.2006 on certification specifications, including airworthiness code and acceptable means of compliance, for large aeroplanes (« CS-25 »).

[2] Decision No 2003/09/RM of the Executive Director of the Agency of 24.10.2003 on certification specifications, including airworthiness code and acceptable means of compliance, for engines (« CS-E »).

[3] Regulation (EC) No 1592/2002 of the European Parliament and of the Council of 15 July 2002 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency. *OJ L 240, 7.9.2002, p. 1*. Regulation as last amended by Regulation (EC) No 334/2007 *(OJ L 88, 29.3.2007, p. 39*).

[4] Management Board decision concerning the procedure to be applied by the Agency for the issuing of opinions, certification specifications and guidance material ("Rulemaking Procedure"), EASA MB/08/2007, 13.6.2007

E-mail: In case the use of CRT is prevented by technical problems these should be reported to the CRT webmaster and comments sent by email to NPA@easa.europa.eu.

Correspondence: If you do not have access to internet or e-mail you can send your comment by mail to:
Process Support
Rulemaking Directorate
EASA
Postfach 10 12 53
D-50452 Cologne
Germany

7. Comments should be received by the Agency by 24 January 2008. If received after this deadline they might not be taken into account.

III. Comment response document

8. All comments received in time will be responded to and incorporated in a comment response document (CRD). This may contain a list of all persons and/or organisations that have provided comments. The CRD will be widely available on the Agency's website.

IV. Content of the draft decision

9. This NPA is based on the following JAA NPAs, which underwent consultation under the JAA rulemaking procedures:

   i) JAA NPA 25C-305: Engine & APU Load Conditions – published for consultation from 2 April – 2 July 2002.
   ii) JAA NPA 25E-306: Sustained Engine Imbalance - published for consultation from 1 February – 1 May 2002.

   As a result of these publications, the JAA received a considerable number of comments, many of which were critical of the proposals. In particular, the impact on engine manufacturers was highlighted and the need for engine/airframe interface issues to be well defined and responsibilities clearly prescribed. These comments were not resolved prior to the creation of the Agency.

10. In developing this EASA NPA greater consideration has therefore been given to engine/airframe interface issues. Previously, the Agency had intended to address the engine related issues in a separate rulemaking task (E.002). Following initial discussions within the rulemaking group, however, it was evident that interface issues needed a joint approach and that sufficient engine and airframe expertise was available within the group to address these issues. The Agency therefore decided to combine the two tasks under this single rulemaking task. This also had the benefit of enhancing the efficiency of the rulemaking process. The outcome, is a new proposal to change CS-E 520(c)(2) plus new AMC, to ensure that validated data is provided by the engine manufacturer to enable the airframe manufacture to ascertain the forces on the airframe as a result of engine imbalance loads.

See for a more elaborated and detailed explanation of the content of the draft decisions the explanatory notes to the original JAA NPAs and the justification of changes introduced by the Agency.

11. For each of the above JAA NPAs four different sections have been constructed in this EASA NPA as follows:

I. **Explanatory Note** - Describing the development process and explaining the contents of the proposal.
II. **Proposals -** The actual proposed amendments relative to existing published rules.
III. **Justification –** This includes further justification to support the original JAA NPA together with justification for changes introduced by EASA and the EASA rulemaking group since the JAA NPA was published.
IV. **Comment Response Document -** This section summarises the comments made on the JAA NPA and EASA responses to those comments.

V. Regulatory Impact Assessment

1. Purpose and intended effect:

a. <u>Issue which the NPA is intended to address:</u>

(i) **Engine and APU failure Loads.**
Airworthiness requirements have long been established to ensure engine mounts and supporting structure are designed to withstand engine seizure torque loads imposed by a sudden engine stoppage. However, with the development of larger high-bypass ratio turbofan engines, it has become apparent that engine seizure torque loads alone do not adequately define the full loading imposed and that in order to maintain the level of safety intended, more comprehensive rules are necessary.

(ii) **Sustained Engine Imbalance.**
There are two sustained imbalance conditions that may affect safe flight: the windmilling condition and a separate high power condition.

- The windmilling condition results after the engine is shut down or spools down but continues to rotate under aerodynamic forces. Current rules require provisions to stop the windmilling rotor where continued rotation could jeopardise the safety of the aeroplane. However, it may be impractical or undesirable to stop the windmilling rotation of large high bypass ratio engines in flight and with the progression towards larger fan diameters and fewer blades with larger chords, stopping the engine can be difficult to achieve. In order to show compliance with the rule, it is therefore necessary to ensure that a windmilling engine does not jeopardise the safety of the aeroplane.

- The high power imbalance condition occurs immediately after blade failure but before the engine is shut down or otherwise spools down, and may last from several seconds to a few minutes. This condition addresses losing less than a full fan blade, which may be insufficient to cause the engine to spool down on its own. The need for higher efficiency and greater robustness has resulted in fan designs consisting of fewer blades of larger mass than have previously been used and, in some cases, this has led to excessive vibration that hampered the crew's ability to read instruments and diagnose which engine was damaged.

b. Scale of the issue:

Service experience of existing high bypass ratio engines (see Appendix Section 3) has shown instances, although very rare, of blade loss and even more rare, fan bearing/bearing support failure. Up to May 1996, 152 notable events (where significant vibration has resulted), are identified in 426 million engine flight hours. In most cases the fan continued to rotate producing an imbalanced load even after the engine had been shut down. In all cases the aeroplane landed safely, with no other significant damage or injury to persons on-board. It could therefore be concluded that current aeroplane designs have demonstrated adequate capability to withstand loss of fan blade and loss of centreline support. However, with the trend towards larger and fewer fan blades, past design practice and the criteria used in current airworthiness codes, may be insufficient to ensure the safety of future designs. The Agency has applied special conditions on recent certification and validation programmes to cover issues related to engine & APU failure loads and windmilling.

c. Brief statement of the objectives of the NPA:

This NPA proposes the following:

(i) Engine and APU failure loads – To develop enhanced CS-25 certification specifications and AMC to cater for the latest advances in engine technology and to avoid the need for special conditions to be established for individual projects. It is also intended to provide greater harmonisation between CS-25 and FAR Part 25.

(ii) Sustained Engine Imbalance - The FAA published AC 25-24 “Sustained Engine Imbalance” on August 2, 2000, based on recommendations jointly developed within the ARAC LDHWG. The proposals contained in this NPA are intended to adopt similar material in AMC to CS-25.

(iii) Engine Imbalance Loads – To introduce a change to CS-E 520 plus new AMC, to ensure that data provided by the engine manufacture is aligned with changes introduced in CS-25 and that responsibilities and interface issues are better defined.

2. Options:

a. All options identified

Option 1. Do nothing:
CS and AMC would not be upgraded to address current technologies.
Doing nothing would not take into account the consequences of engine technological and configuration changes, and may result in special conditions being imposed by the agency to ensure that an unsafe condition does not arise. This would have a detrimental

economic impact on the applicant, as will non-harmonised standards, which can result in some additional compliance demonstration being necessary.

Option 2: Amend CS and AMC

(i) Engine and APU failure Loads. Provide updated rules to adequately address modern engine technology. Changes would be based on work previously undertaken by the LDHWG. This will include a revised 25.361 together with a new CS 25.362 and associated AMC, based on the earlier JAA NPA 25C-305, which has already been published for comment. In addition, amend CS-E 520(c)(2) concerning Engine Imbalance Loads to ensure the correct airframe/engine interface.

(ii) Sustained Engine Imbalance - Add a new AMC 25-24, based on the earlier JAA NPA 25E-306, which was already published for comments.

b. The preferred option selected:
Please see paragraph V-5 below.

3. Sectors concerned:

Manufacturers of new large aeroplanes/engines/APUs and designers of significant changes to large aeroplanes/engines/APUs.

4. Impacts:

a. All identified impacts

i. Safety
Engine imbalance following a failure can create high levels of vibratory loads on the entire aeroplane. With the current trend in the design of engines, these vibratory loads could have the potential for preventing continued safe flight and landing.
The proposals contained in this NPA are intended to achieve common rules and advisory material on the engine and auxiliary power unit load conditions of CS-25 and FAR 25. Designs based on the new conditions stipulated in this NPA would achieve an improved level of safety over that provided by the existing static engine torque criterion.

ii. Economic
The changes proposed in this NPA represent current practice by engine and airframe manufacturers and would have no or little economic impact.

Harmonisation of advisory material of CS-25 and FAR 25 on this subject would yield additional cost savings by eliminating duplicate certification activities

iii. Environmental
No impact expected

iv. Social
No impact expected

v. Other aviation requirements outside EASA scope
No impact expected

vi. Foreign comparable regulatory requirements
Coordination necessary with FAA for harmonisation between CS-25 and FAR Part 25.

b. Equity and Fairness issues

No significant impact on small companies is anticipated.
Greater harmonisation will improve the equity and fairness.

5. Summary and Final Assessment:

a. Comparison of the positive and negative impacts for each option evaluated:

Option 1: Doing nothing would not take into account the consequences of engine configuration and technological changes, and dependent on the specific engine configuration and its installation may result in unsafe conditions.

Option 2: The proposals contained in this NPA are intended to achieve greater commonality of rules and advisory material on the engine and auxiliary power unit load conditions of CS-25 and FAR Part 25. It has been determined that designing for the new conditions in the NPA would achieve an improved level of safety over that provided by the existing static engine torque criterion.
Greater harmonisation of advisory material of CS-25 and FAR Part 25 on this subject would yield additional cost savings by eliminating duplicate certification activities.

b. A summary of who would be affected by these impacts and issues of equity and fairness:
Manufacturers of new Large Aeroplanes, engines and APUs or significantly changed Large Aeroplanes, engines or APUs.
No significant impact on small companies is anticipated.
Greater harmonisation will improve the equity and fairness.

c. Final assessment and recommendation of a preferred option:
After due consideration the Agency believes that option 2 is to be preferred.

B. <u>JAA NPA 25C-305: Engine & APU Load Conditions</u>

I) Explanatory Note

(See also “A.I: General Explanatory Note”)

1. General

In 1988, the FAA, the JAA and other organisations representing the American and European aerospace industries, began a process to harmonise the airworthiness requirements of the United States and the airworthiness requirements of Europe, especially in the areas of Flight Test and Structures. Later, in 1992, the harmonisation effort was undertaken by the Aviation Rulemaking Advisory Committee (ARAC). The ARAC was formally established on January 22, 1991 (56 FR 2190), to provide advice and recommendations concerning the full range of safety-related rulemaking activity.

The ARAC establishes working groups to develop proposals for resolving specific issues. Tasks assigned to working groups are published in the Federal Register. The Loads and Dynamics Harmonisation Working Group (LDHWG) was chartered by notice in the Federal Register (58 FR 13819, March 15, 1993). The Working Group is made up of structural specialists from the aviation industry and government of Europe, the United States, and Canada. The task given to this Working Group was to harmonise the design loads section of Subpart C (“Structure”) of FAR 25 and JAR-25. The Working Group developed specific recommendations for harmonising the engine and auxiliary power unit load conditions. JAA NPA 25C-305 contained those proposals and was released for consultation in April 2002. As a result of this consultation, the JAA received 34 comments, many of which were critical of the proposals and were seen as impacting on traditional engine/airframe interfaces. These comments were not resolved prior to the creation of the Agency. However, the task was identified in the transition inventory and placed on the Agency’s rulemaking programme, together with the related task on Sustained Engine Imbalance, (Tasks 25.015 and 25.016, respectively).

In March 2006, an EASA rulemaking group was formed to progress tasks 25.015 and 25.016. The group was composed of representative from EASA, NAAs and the airframe and engine manufactures. This NPA is the output from this group.

2. Safety Justification / Explanation

The current airworthiness standards contained in FAR Part 25 require that turbine engine mounts and supporting structures must be designed to withstand “...a limit engine torque load imposed by sudden engine stoppage due to malfunction or structural failure (such as compressor jamming).” This was first made a specific requirement for U.S. transport category aeroplanes in 1957 by Civil Air Regulation (CAR) 4b.216(a)(4). It was later carried forward in § 25.361(b)(1) of FAR 25 when the Federal Aviation Regulations were recodified. This same requirement is contained in CS 25.361(b), except that this subparagraph also addresses auxiliary power unit (APU) installations.

Previous methods of complying with this requirement have entailed either:

- designing to a specific torque value prescribed by the engine (or APU) manufacturer, or:
- designing to a torque level established by the polar moment of inertia of the rotating sections and the time required to stop the rotation, as defined by the engine (or APU) manufacturer.

Since the circumstances and the events from which these loads are generated are dependent on the characteristics of the particular engine (or APU), the engine (or APU) manufacturers traditionally have provided the airframe manufacturers with the information necessary to install each engine (or APU).

The size, configuration, and failure modes of jet engines have changed considerably since FAR/JAR 25.361(b) was first adopted. The original requirement addressed primarily turbine engine failure conditions that resulted in sudden engine deceleration and, in some cases, seizures. Those failure conditions were usually caused by internal structural failures or ingestion of foreign objects such as birds or ice. Whatever the source, those conditions could produce significant structural loads on the engine, engine mounts, pylon, and adjacent supporting airframe structure.

With the development of larger high-bypass ratio turbofan engines, however, it has become apparent that engine seizure torque loads alone do not adequately define the full loading imposed on the engine mounts, pylons, and adjacent supporting airframe structure. The progression to high-bypass ratio turbofan engines of larger diameter and fewer blades with larger chords has increased the magnitude of the transient loads that can be produced during and following engine failures. As engines have grown much larger, their fans are capable of producing much higher torque loads when subjected to sudden deceleration.

Relative to the engine configurations that existed when the rule was first developed, these later generations of jet engines are sufficiently different and novel to justify amending the regulations to ensure that adequate design standards are available for the mounts and the structure supporting these newer engines. Therefore, in order to maintain the level of safety intended by FAR/CS 25.361(b), it is considered that a more comprehensive criterion is necessary - one that considers all load components when designing to address engine failure events.

Studies made by the engine and the airframe manufacturers have shown that large turbofan engines exhibit two distinct classes of sudden deceleration events:

a) The first type of event involves transient deceleration conditions involving rapid slowing of the rotating system. These events are usually associated with temporary loss of power or thrust capability, and often result in some engine distress, such as blade and/or wear strip damage. Examples are high power compressor surges, blade tip rub during manoeuvres, bird encounters, or combinations of these events. Based on the frequency of occurrence, these events are considered to be limit load conditions that require the 1.5 factor of safety prescribed in FAR/CS 25.303 to obtain ultimate loads.

b) The second type of event involves major engine failures that result in extensive engine damage and permanent loss of thrust-producing capability. Examples of these types of events are fan blade failures, bearing/bearing support failures, and shaft failures. It is evident from service history that these most severe sudden engine failure events are sufficiently infrequent to be considered ultimate load conditions. Because of the rare occurrence of these events and the conservative rational method in which the loads are to be obtained, it is proposed that these ultimate loads be applied to engine mounts and pylon structure without an additional factor of safety. At the same time, to provide additional protection for the more critical airframe structure, it is proposed that these ultimate loads be multiplied by an additional factor of 1.25 when applied to the adjacent supporting airframe structure.

Accordingly, this NPA would modify CS 25.361 and add a new CS 25.362 and a new AMC 25.362 addressing engine failure loads, thereby distinguishing between design criteria for the more common failure events (described above as the "first type of event") and design criteria for those rare events resulting from structural failures (described above as the "second type of event"). For the more rare but severe engine failure events, the proposed criteria would allow deformation in engine mounts and pylons in order to absorb the higher energy associated with high-bypass turbofan engines. At the same time, the proposed criteria would protect the adjacent supporting airframe structure in the wing and fuselage by providing an additional safety margin.

Specifically, CS 25.362 would require that the engine mounts, pylons, and adjacent supporting airframe structure be designed to withstand 1g flight loads combined with transient dynamic loads that could result from various engine structural failure conditions (i.e., the loss of any fan, compressor, or turbine blade; and, for certain designs, other engine structural failure that could result in higher loads, as defined in CS-E 520).

Although it is recognised that some engine configurations may exist in which the blade failure event is not the most critical load, it is expected that, for most conventional engines, the blade failure event will be the most severe event that needs to be investigated. Such a failure event, in which the most critical blade is assumed to fail at the maximum permissible rotational speed, is a required test under the certification standards of FAR 33.94, "Blade containment and rotor unbalance tests." See also CS-E 810 "Compressor and Turbine Blade Failure" and its associated AMC, and CS-E 520 "Strength".

In addition to these certification tests, the engine manufacturers normally conduct additional developmental tests for each engine design. These tests, taken as a whole, allow a very reliable estimate of the transient engine loads resulting from failure events. Because the loads are supported by actual tests conducted in accordance with CS-E, the proposed rule would allow the loads developed from these conditions to be used directly as ultimate loads, with no additional factor when applied to engine mounts and pylons. However, the ultimate loads would be required to be multiplied by a factor of 1.25 when applied to adjacent supporting airframe structure.

Further, the proposed CS 25.362 and its associated AMC would address only the transient engine failure load condition, since the sustained loads resulting from continued windmilling after failure currently are addressed by CS 25.901 and CS 25.903.

The proposed new conditions addressed in CS 25.362 are more rationally determined, and will be treated as dynamic conditions including all significant input and response loads. It has been determined that designing for these new conditions would achieve an improved level of safety over that provided by the existing static engine torque criterion.

With the addition of CS 25.362 and its associated AMC, the current requirements of CS 25.361 would be revised as follows:

1. CS 25.361(a)(1) would be amended to adopt, with some revisions, the current text of FAR 25.361(a).

2. CS 25.361(a)(2) would be amended to adopt most of the current text of FAR 25.361(c), except that FAR 25.361(c)(2) & (3), which refer to reciprocating engines would be deleted. Large/transport category aeroplanes have not used these engines in the past, nor are they expected to use them in the future. More importantly CS-25 is only applicable to turbine powered large aeroplanes. Therefore, the references serve no purpose in the rule.

3. CS 25.361(b) includes a sudden engine stoppage event as a limit load condition. This condition was addressed by considering only engine torque as a static load condition. This proposal would remove the sudden engine stoppage condition from these particular requirements, since new engine failure ultimate load conditions would be contained in new CS 25.362.

4. CS 25.361(a)(3) would be amended to require that engine mounts, pylons, and adjacent supporting airframe structure be designed to withstand 1g level flight loads acting simultaneously with the limit engine torque loads imposed by:
   - sudden maximum engine deceleration due to a malfunction which could result in a temporary loss of power or thrust, and
   - maximum acceleration of the engine.

5. CS 25.361(b) would be amended to contain similar design load requirements as those proposed in the amendment to CS 25.361(a)(3). However, they would apply strictly to the power unit mounts and adjacent supporting airframe structure for auxiliary power unit (APU) installations.

6. The title of CS 25.361 would be changed from the current “Engine and APU torque” to “Engine and auxiliary power unit torque.” This change would provide consistency with the title of CS 25.363 “Side load on engine and auxiliary power unit mounts”.

7. The layout of CS 25.361 is amended to clarify the applicability of the rules to different types of engines and APUs.

II) <u>Proposals</u>

The text of the amendment is arranged to show deleted text, new text or a new paragraph as shown below:

1. ~~Text to be deleted is shown with a line through it.~~
2. New text to be inserted is highlighted with grey shading.
3. ….
   Indicates that remaining text is unchanged in front of or following the reflected amendment.
   ….

<u>CS-25 BOOK 1: AIRWORTHINESS CODE</u>

<u>Proposal 1: Amend CS 25.361 to read as follows:</u>

CS 25.361 Engine and auxiliary power unit ~~APU~~ torque
(See AMC 25.361)

(a) For all engine installations:

(1) Each engine mount, pylon and ~~its~~ adjacent supporting airframe structure~~s~~ must be designed for the effects of: ~~engine torque effects combined with –~~

(i~~1~~) a limit engine torque corresponding to take-off power/thrust and, if applicable, corresponding propeller speed, acting simultaneously with 75% of the limit loads from flight condition A of CS 25.333 (b);

(ii~~2~~) a limit engine torque corresponding to the maximum continuous power/thrust and, if applicable, corresponding propeller speed, ~~as specified in sub-paragraph (c) of this paragraph~~ acting simultaneously with the limit loads from flight condition A of CS 25.333 (b); and

(iii~~3~~) for turbo-propeller installations only, in addition to the conditions specified in sub-paragraphs (a)(1)(i) and (ii)~~(2) of this paragraph~~, a limit engine torque corresponding to take-off power and propeller speed, multiplied by a factor accounting for propeller control system malfunction, including quick feathering, acting simultaneously with 1g level flight loads. In the absence of a rational analysis, a factor of 1·6 must be used.

~~(b) For turbine engines and auxiliary power unit installations, the limit torque load imposed by sudden stoppage due to malfunction or structural failure (such as a compressor jamming) must be considered in the design of engine and auxiliary power unit mounts and supporting structure. In the absence of better information a sudden stoppage must be assumed to occur in 3 seconds.~~

(2)~~(c)~~ The limit engine torque to be considered under sub-paragraph (1~~a~~) ~~(2) of this paragraph is~~ must be obtained by:

(i) for turbo-propeller installations, multiplying ~~the~~ mean engine torque for the specified power/thrust and speed by a factor of 1·25 ~~for turbo-propeller installations.~~

(ii) for other turbine engines, the limit engine torque must be equal to the maximum accelerating torque for the case considered.

(3) The engine mounts, pylons, and adjacent supporting airframe structure must be designed to withstand 1g level flight loads acting simultaneously with the limit engine torque loads imposed by each of the following conditions to be considered separately:

(i) sudden maximum engine deceleration due to a malfunction or abnormal condition; and

(ii) the maximum acceleration of the engine.

~~(d) When applying CS 25.361 (a) to turbo-jet engines, the limit engine torque must be equal to the maximum accelerating torque for the case considered. (See AMC 25.301 (b).)~~

(b) For auxiliary power unit installations:
The power unit mounts and adjacent supporting airframe structure must be designed to withstand 1g level flight loads acting simultaneously with the limit torque loads imposed by the following conditions to be considered separately:

(1) sudden maximum auxiliary power unit deceleration due to malfunction or abnormal condition or structural failure; and

(2) the maximum acceleration of the auxiliary power unit.

Proposal 2: Add a new CS 25.362 to read as follows:

CS 25.362 Engine failure loads
(See AMC 25.362.)

(a) For engine mounts, pylons and adjacent supporting airframe structure, an ultimate loading condition must be considered that combines 1g flight loads with the most critical transient dynamic loads and vibrations, as determined by dynamic analysis, resulting from the engine structural failure conditions, as defined in CS-E 520(c)(2).

(b) The ultimate loads developed from the conditions specified in paragraph (a) are to be:

(1) multiplied by a factor of 1.0 when applied to engine mounts and pylons; and

(2) multiplied by a factor of 1.25 when applied to adjacent supporting airframe structure.

CS-25 BOOK 2 - ACCEPTABLE MEANS OF COMPLIANCE (AMC)

Proposal 3: Introduce a new AMC 25.361 to read as follows:

AMC 25.361
Engine and auxiliary power unit torque

CS 25.361(a)(1) is applicable to all engine installations, including turbo-fans, turbo-jets and turbo-propellers, except CS 25.361(a)(1)(iii) which applies only to turbo-propeller installations.

CS 25.361(a)(2)(i) - "Mean engine torque" refers to the value of the torque, for the specified condition, with any dynamic oscillations removed.

CS 25.361 (a)(3)(i) - Examples are; high power compressor surges, blade tip rub during manoeuvres, small and medium bird encounters, or combinations of these events.

CS 25.361(a)(3)(ii) and (b)(2) - As an example, the term "maximum acceleration" is taken to be that torque seen by the engine mounts under a runaway of the fuel metering unit up to its maximum flow stop.

Proposal 4: Introduce a new AMC 25.362 to read as follows:

AMC 25.362
Engine Failure Loads

1. **PURPOSE**. This AMC describes an acceptable means for showing compliance with the requirements of CS 25.362 "Engine failure loads". These means are intended to provide guidance to supplement the engineering and operational judgement that must form the basis of any compliance findings relative to the design of engine mounts, pylons and adjacent supporting airframe structure, for loads developed from the engine failure conditions described in CS 25.362.

2. **RELATED CS PARAGRAPHS.**

a. CS-25:

CS 25.361 "Engine and auxiliary power unit torque"
CS 25.901 "Powerplant installation"

b. CS-E:

CS-E 520 "Strength"
CS-E 800 "Bird strike and ingestion"
CS-E 810 "Compressor and turbine blade failure"
CS-E 850 "Compressor, Fan and Turbine Shafts"

3. **DEFINITIONS**. Some new terms have been defined for the transient engine failure conditions in order to present criteria in a precise and consistent manner in the following

pages. In addition, some terms are employed from other fields and may not necessarily be in general use. For the purposes of this AMC, the following definitions should be used.

a. Adjacent supporting airframe structure: Those parts of the primary airframe that are directly affected by loads arising within the engine.

b. Ground Vibration Test: Ground resonance tests of the aeroplane normally conducted for compliance with CS 25.629, "Aeroelastic stability requirements."

c. Transient failure loads: Those loads occurring from the time of the engine structural failure, up to the time at which the engine stops rotating or achieves a steady windmilling rotational speed.

d. Windmilling engine rotational speed: The speed at which the rotating shaft systems of an unpowered engine will rotate due to the flow of air into the engine as a result of the forward motion of the aeroplane.

4. **BACKGROUND**.

a. Requirements. CS 25.362 ("Engine failure loads") requires that the engine mounts, pylons, and adjacent supporting airframe structure be designed to withstand 1g flight loads combined with the transient dynamic loads resulting from each engine structural failure condition. The aim being to ensure that the aeroplane is capable of continued safe flight and landing after sudden engine stoppage or engine structural failure, including ensuing damage to other parts of the engine.

b. Engine failure loads. Turbine engines have experienced failure conditions that have resulted in sudden engine deceleration and, in some cases, seizures. These failure conditions are usually caused by internal structural failures or ingestion of foreign objects, such as birds or ice. Whatever the source, these conditions may produce significant structural loads on the engine, engine mounts, pylon, and adjacent supporting airframe structure. With the development of larger high-bypass ratio turbine engines, it became apparent that engine seizure torque loads alone did not adequately define the full loading imposed on the engine mounts, pylons, and adjacent supporting airframe structure. The progression to high-bypass ratio turbine engines of larger diameter and fewer blades with larger chords has increased the magnitude of the transient loads that can be produced during and following engine failures. Consequently, it is considered necessary that the applicant performs a dynamic analysis to ensure that representative loads are determined during and immediately following an engine failure event.

A dynamic model of the aircraft and engine configuration should be sufficiently detailed to characterise the transient loads for the engine mounts, pylons, and adjacent supporting airframe structure during the failure event and subsequent run down.

c. Engine structural failure conditions. Of all the applicable engine structural failure conditions, design and test experience have shown that the loss of a fan blade is likely to produce the most severe loads on the engine and airframe. Therefore, CS 25.362 requires that the transient dynamic loads from these blade failure conditions be considered when evaluating structural integrity of the engine mounts, pylons and adjacent supporting airframe structure. However, service history shows examples of other severe engine structural failures where the engine thrust-producing capability was lost, and the engine experienced extensive internal damage. For each specific engine design, the applicant should consider whether these types of failures are applicable, and if they present a more critical load condition than blade loss. Examples of other engine structural failure conditions that should be considered in this respect are:

- failure of a shaft, or
- failure or loss of any bearing/bearing support, or
- a large bird ingestion.

5. EVALUATION OF TRANSIENT FAILURE CONDITIONS

a. Evaluation. The applicant's evaluation should show that, from the moment of engine structural failure and during spool-down to the time of windmilling engine rotational speed, the engine-induced loads and vibrations will not cause failure of the engine mounts, pylon, and adjacent supporting airframe structure. (*Note*: The effects of continued rotation (windmilling) are described in AMC 25-24).

Major engine structural failure events are considered as ultimate load conditions, since they occur at a sufficiently infrequent rate. For design of the engine mounts and pylon, the ultimate loads may be taken without any additional multiplying factors. At the same time, protection of the basic airframe is assured by using a multiplying factor of 1.25 on those ultimate loads for the design of the adjacent supporting airframe structure.

b. Blade loss condition. The loads on the engine mounts, pylon, and adjacent supporting airframe structure should be determined by dynamic analysis. The analysis should take into account all significant structural degrees of freedom. The transient engine loads should be determined for the blade failure condition and rotor speed approved per CS-E, and over the full range of blade release angles to allow determination of the critical loads for all affected components.

The loads to be applied to the pylon and airframe are normally determined and validated by the engine manufacturer.

The calculation of transient dynamic loads should consider:

- the effects of the engine mounting station on the aeroplane (i.e., right side, left side, inboard position, etc.); and
- the most critical aeroplane mass distribution (i.e., fuel loading for wing-mounted engines and payload distribution for fuselage-mounted engines).

For calculation of the combined ultimate airframe loads, the 1g component should be associated with typical flight conditions.

c. Other failure conditions. As identified in paragraph 4(c) above, if any other engine structural failure conditions, applicable to the specific engine design, could result in higher loads being developed than the blade loss condition, they should be evaluated by dynamic analysis to a similar standard and using similar considerations to those described in paragraph 5.b., above.

6. **ANALYSIS METHODOLOGY**.

a. Objective of the methodology. The objective of the analysis methodology is to develop acceptable analytical tools for conducting investigations of dynamic engine structural failure events. The goal of the analysis is to produce loads and accelerations suitable for evaluations of structural integrity. However, where required for compliance with CS 25.901 ("Powerplant installation"), loads and accelerations may also need to be produced for evaluating the continued function of systems related to the engine installation that are essential for immediate flight safety (for example, fire bottles and fuel shut off valves).

b. Scope of the analysis. The analysis of the aircraft and engine configuration should be sufficiently detailed to determine the transient and steady-state loads for the engine mounts, pylon, and adjacent supporting airframe structure during the engine failure event and subsequent run-down.

7. **MATHEMATICAL MODELLING AND VALIDATION**

a. Components of the integrated dynamics model The applicant should calculate airframe dynamic responses with an integrated model of the engine, engine mounts, pylon, and adjacent supporting airframe structure. The integrated dynamic model used for engine structural failure analyses should be representative of the aeroplane to the highest frequency needed to accurately represent the transient response. The integrated dynamic model consists of the following components that may be validated independently:

- Airframe structural model.
- Engine structural model.

b. Airframe Structural Model and Validation

(1) An analytical model of the airframe is necessary in order to calculate the airframe responses due to the transient forces produced by the engine failure event. The airframe manufacturers currently use reduced lumped mass finite element analytical models of the airframe for certification of aeroelastic stability (flutter) and dynamic loads. A typical model consists of relatively few lumped masses connected by weightless beams. A full aeroplane model is not usually necessary for the engine failure analysis, and it is normally not necessary to consider the whole aircraft response, the effects of automatic flight control systems, or unsteady aerodynamics.

(2) A lumped mass beam model of the airframe, similar to that normally used for flutter analysis, is acceptable for frequency response analyses due to engine structural failure conditions. However, additional detail may be needed to ensure adequate fidelity for the engine structural failure frequency range. In particular, the engine structural failure analysis requires calculating the response of the airframe at higher frequencies than are usually needed to obtain accurate results for the other loads analyses, such as dynamic gust and landing impact. The applicant should use finite element models as necessary. As far as possible, the ground vibration tests normally conducted for compliance with CS 25.629 ("Aeroelastic stability requirements") should be used to validate the analytical model.

(3) Structural dynamic models include damping properties, as well as representations of mass and stiffness distributions. In the absence of better information, it will normally be acceptable to assume a value of 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 failure loads, provided it is justified.

c. Engine Structural Model and Validation

(1) Engine manufacturers construct various types of dynamic models to determine loads and to perform dynamic analyses on the engine rotating components, static structures, mounts, and nacelle components. Dynamic engine models can range from a centreline two-dimensional (2D) model, to a centreline model with appropriate three-dimensional (3D) features, such as mount and pylon, up to a full 3D finite element model.

(2) Detailed finite element models typically include all major components of the propulsion system, such as:

- the nacelle intake,
- fan cowl doors,
- thrust reverser,
- common nozzle assembly,
- all structural casings,
- frames,
- bearing housings,
- rotors,
- gearbox, and
- a representative pylon.

Gyroscopic effects are included. The finite element models provide for representative connections at the engine-to-pylon interfaces, as well as all interfaces between components (e.g., inlet-to-engine and engine-to-thrust reverser).

(3) Features modelled specifically for blade loss analysis typically include:

- imbalance,
- component failure,
- rubs (blade-to-casing, and intershaft),
- resulting stiffness changes, and
- aerodynamic effects, such as thrust loss and engine surge.

4) The engine model will normally be validated by the Engine manufacturer under CS-E 520(c)(2) by correlation against blade-off test data obtained in showing compliance with CS-E 810. The model should be capable of accurately predicting initial blade release event loads, any rundown resonant response behaviour, frequencies, potential structural failure sequences, and general engine movements and displacements. In addition, if the Failure of a shaft, bearing or bearing support or bird strike event, as required under CS-E 800, result in higher forces being developed, such Failures and there resulting consequences should also be accurately represented.

(5) For compliance with CS 25.362, the engine model, once validated, should be modified to include the influence of representative adjacent supporting airframe structure.

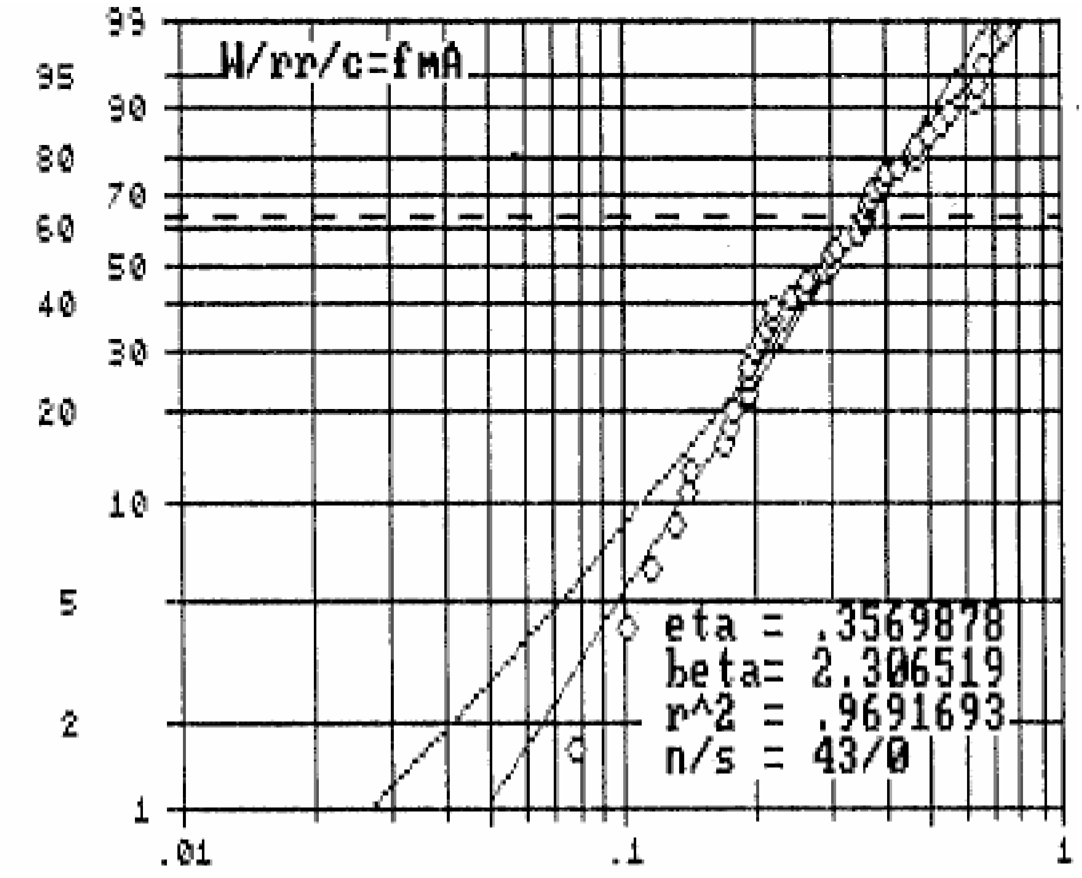
(6) The airframe and engine manufacturers should mutually agree upon the definition of the model, based on test and experience.

III) Justification for changes introduced by the Agency

1. ENGINE TORQUE LOADS

The following provides further explanation and background to the proposals contained in this NPA related to engine failure conditions.

At several LDHWG meetings in the early 1990's, data related to in-service engine failure conditions was collected, analysed and presented for discussion by General Electric (GE). The analysis included a comparison between loads experienced in-service and proposed engine failure design loads. This comparison is reproduced below as a Weibull distribution.



(Note the horizontal scale represent the severity of the in-service event relative to the proposed design conditions, whereas the vertical scale represents the relative occurrence (%).)

The graph plots 37 in-service sudden (GE) engine deceleration (partial blade-out) events. It is based on 150 x 1E6 hours of experience, and indicates that:

(a) 90% of these occurrences generate loads no greater than 60% of the proposed design level, and:
(b) no more than 75% of the proposed design load has been experienced in service.

Other engine manufacturers (like Rolls-Royce) represented at the LDHWG meetings did not offer any firm data, but confirmed that all indications were that the GE analysis was also representative of their engines.

Although it is recognised that the above data was collected and analysed more than 10 years ago, the Agency believes it is still the best and only data available on this subject (perhaps it could even be speculated that for later generation engines the occurrence rate and severity of deceleration events would be lower due to improved technology).

Given the low probability of occurrence identified above, which is comparable to other ultimate load conditions as defined in Subpart C of CS-25, and also considering the additional 1.25 factor as required by the proposed subparagraph 25.362(b), the proposals contained in this NPA are considered to provide an acceptable level of safety. Thus the above substantiation (together with the other deliberations of the LDHWG on this subject) is considered to provide sufficient justification and background to the proposals contained in this NPA relative to engine failure conditions.

2. BIRD STRIKE AND OTHER FAILURE CONDITIONS

It has generally been accepted, based on historical evidence, that the single fan-blade off condition represents the worst case failure scenario likely to be seen in service and will generate the highest loads on the engine mounts, pylon and supporting airframe structure. However, with the development of larger high-bypass ratio turbofan engines, other failure conditions, including bird strike, may represent a more severe loading condition. The large bird test, for example, simply requires safe shutdown and does not limit the material loss to a single blade. The partial loss of multiple blades may be more severe in terms of sustained imbalance than the fan-blade off test.

IV) JAA NPA 25C-305 Comment-Response Document

1. JAA NPA 25C-305 was published for consultation by the JAA on 2 April 2002.

2. By the closing date of 2 July 2002, the JAA had received 34 comments from 7 national authorities, professional organisations and private companies.

3. All comments received have been passed to the Agency and incorporated into a Comment Response Document (CRD). This CRD contains a list of all persons and/or organisations that have provided comments and the Agency's answers.

4. In responding to comments, a standard terminology has been applied to attest the Agency's acceptance of the comment. This terminology is as follows:

   - **Accepted –** The comment is agreed by the Agency and any proposed amendment is wholly transferred to the revised text.
   - **Partially Accepted –** Either the comment is only agreed in part by the Agency, or the comment is agreed by the Agency but any proposed amendment is partially transferred to the revised text.
   - **Noted –** The comment is acknowledged by the Agency but no change to the existing text is considered necessary.
   - **Not Accepted** - The comment is not shared by the Agency

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
1.		Scandinavian Airlines System	No comment.	**Noted**	(No Change)
2.		CAA NL	No comments.	**Noted**	(No Change)
3.		AECMA	No comment.	**Noted**	(No Change)
4.		Austro Control	The proposed NPA developed in the framework of the Harmonisation Work is acceptable for ACG.	**Noted**	(No Change)
5.		Embraer	No comments.	**Noted**	(No Change)
6.	General	DGAC-F	This NPA is not mature enough and should not have been circulated for comments in present state. All the rule and ACJ should be completely re-written to avoid rulemaking by AC and to ensure consistency of ACJ with the text of the rule itself. This NPA is not acceptable and should be re-worked and submitted to a second world-wide circulation for comments in an issue 2, after appropriate co-ordination with engine specialists. **Justification:** Self-explanatory.	**Accepted** Changes to the rule and AMC have been introduced to redress the balance and consistency of the Rule/AMC.	(See proposed text)
7.	Justification of the NPA	DGAC-F	The justification contains a paragraph starting with: “accordingly, this NPA would add a new	**Accepted**	2. <u>Safety Justification / Explanation</u>

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			JAR 25 … which would distinguish…". There is no such thing ("distinguish") in the proposed 25.362. What does this paragraph of the justification mean? **Justification:** Clarification is needed.		… Accordingly, this NPA would modify CS 25.361 and add a new CS 25.362 and a new AMC 25.362 addressing engine failure loads, thereby ~~which would~~ distinguishing between design criteria … …
8.	Justification of the NPA	DGAC-F	The justification of the NPA contains the following: "because the loads are supported by actual tests conducted in the most critical conditions of operation". Such statement is either not true or unknown to engine specialists. Apparently the authors of this statement ignored the conditions of JAR-E 810 and ACJ E 810. **Justification:** Clarification is needed.	**Accepted** Justification is amended to make reference to CS-E.	2. <u>Safety Justification / Explanation</u> … In addition to these certification tests, … Because the loads are supported by actual tests conducted in accordance with CS-E ~~the most critical conditions of operation~~, the proposed rule … …
9.	Justification of the NPA	DGAC-F	The justification declares that "the proposed condition addressed in JAR 25.362 are more rationally determined". If this is true, one could wonder why there is no element rationally justifying the new rule in this NPA justification. **Justification:** Clarification is needed.	**Accepted** (See Justification in Section D, III)	(No Change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
10.	25.361(a)	CAA UK	Starts "Each engine mount and its supporting structure" however, it is suggested that it should read "Each engine mount and the adjacent supporting airframe structure" to be consistent with the terminology used in the rest of the NPA. (The ACJ for 25.362 actually defines "adjacent supporting airframe structure".)	**Partially Accepted** Terminology is made consistent.	**CS 25.361 Engine and auxiliary power unit torque (See AMC 25.361)** (a) For engine installations: (1) Each engine mount, pylon and ~~its~~ adjacent supporting airframe structure must be designed for the effects of: …

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
11.	25.361(a)	DGAC-F	This paragraph is apparently applicable to all engine types (« engine » in title) but it is difficult to understand how to apply this text to turbofan engines. The wording is “power and propeller speed” in (a)(1), (a)(2) and (a)(3), and we find “turbopropeller” in (a)(3). Apparently only turbopropellers are considered in this paragraph (a): it would be difficult to define “power and propeller speed” for a turbofan. But, (a)(3) starts with “for turbopropeller installations”, obviously implicitly implying that (a)(1) and (2) are also applicable to turbofans. The use of “torque” in relation to turbofans is not usual. It should also be noted that we can find an engine limit torque in the engine data sheet for a turbopropeller but not for a turbofan. Is this wording referring to the engine wording or is it something different? This might be a means to differentiate between engine and APU installations (see the proposed 25.361(d)). But this is far from being clear, because this would imply that the word “engine” in the first sentence of (a) would also mean “APU”. **Justification:** Clarification of the applicability of this text is obviously necessary.	**Partially Accepted** Paragraph has been re-formatted to make this clear. “Power and propeller speed” is part of the original wording. While this has been retained in the rule, further guidance is provided in the AMC.	(See proposed text)
12.	25.361(a)	DGAC-F	The pass/fail criteria are not obvious for a non-	**Partially Accepted**	(See proposed text)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
	general comment		specialist. The wording of the proposed 25.361 does not fit well into the wording of 25.301/303/305 which refer to "limit load" and "ultimate load". For example, we find "limit ***engine*** torque" in 25.361 (a)(1), (a)(3) and (b), but only "limit torque" in (a)(2) or "***maximum*** limit torque ***loads***" in (c) and (d). Are these torques "limit loads" as defined in 25.301? Because the limit torque acts simultaneously with the limit loads for flight conditions (see (a)(2)), which is understood as meaning "in addition to", apparently we are above the limit loads considered in 25.301, therefore in a grey area between limit loads (25.305(a)) and ultimate loads (25.305(b)). It also appears that 25.303 is not applicable to 25.361: how could the engine torque be considered as an external load? To our knowledge, the engines are installed on the aeroplane and consequently are part of the whole aircraft. Clarification of the pass/fail criteria is necessary. Applicability of 25.305 should be clarified in an improvement of the wording of 25.361. **Justification:** Clarification of this text is obviously necessary.	Terminology is standardised throughout. "Limit torque" loads are the result of multiplying the mean torque by the relevant factors and adding the appropriate limit flight loads. This is not new to this NPA and is understood within the structures community. The engine torque loading is considered an external load with respect to the individual structural elements (e.g. engine mount, pylon and adjacent supporting airframe structure).	
13.	25.361(a)(3)	DGAC-F	It is difficult, almost impossible, to understand		(No Change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
	general comment		this paragraph. 13.1 What is the definition of "propeller control system malfunction"? is a transition for fault accommodation from one control mode to another considered as a "malfunction" (there is a "fault" or a "failure" but it is not visible in the propeller functioning)? Is any malfunction to be considered, whatever its effect on propeller functioning? 13.2 "factor accounting for propeller control system malfunction": how is this factor calculated? It appears as being totally arbitrary with no means to determine its value. See also 13.4 below. 13.3 The wording is "propeller control system malfunction, including quick feathering". Is really a quick feathering considered as being a	13.1: **Not Accepted** All propeller control system malfunctions should be considered. Historically, the 1.6 factor has been shown to cover all malfunctions. 13.2: **Not Accepted** The proposals contained in JAA NPA 25C-305 do not alter the current text of 25.361(a)(3) and are therefore outside the aims of this consultation. Notwithstanding this, the 1.6 factor of safety has a long history within the certification requirements (prior to 1965), and we are not aware of any safety issues associated with this. The ability to perform a rational analysis was introduced into JAR-25 Change 8 (November 1981) (FAR – Amendment 25-23 (May 1970)) and remains a certification option. 13.3 **Not accepted** In the context of this rule, quick feathering is seen as a result of a	

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			propeller control system malfunction? This would be very strange. 13.4 The wording “in absence of a rational analysis, a factor of 1.6 must be used”. Considering the comment 3.2 above, it is obvious that there would never be any rational analysis justifying a factor which is not defined. It would be simpler to impose the factor 1.6 in all cases. **Justification:** Clarification of the text is obviously necessary.	propeller control system malfunction. The wording is not changed by this NPA. 13.4 **Not Accepted** (see Comment #13.2)	
14.	25.361(a)(3)	CAA UK	14.1 Para 25.361(a)(3) allows a factor (of 1.6) to be applied “in the absence of a rational analysis”. This does not seem reasonable. Since the level of uncertainty will vary from installation to installation, it should be agreed with the Authority for each application. 14.2 Fan blade off (FBO) is considered as an ultimate case for the airframe (although loads are factored by 1.25). Potentially, this means that wing structure etc. will be scrapped after an FBO event. In the recent history of failures, though, we are not aware of airframe or wing structure being scrapped following FBO and this would therefore indicate a potential reduction in the overall required safety levels,	**14.1 Not Accepted** (See response to Comment #13) **14.2 Not Accepted** After a blade loss event, the airframe should be inspected to determine the amount of damage sustained and appropriate action taken prior to return to service. The safety standard is not reduced through these proposals as the loading condition is more severe than current rules require.	(No Change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			not the increase intended by the NPA.		
15.	25.361(b)	DGAC-F	15.1 The proposed paragraph 25.361(b)(2) should be deleted. JAR 25.1(a) is clear: JAR-25 applies only to turbine powered aeroplanes. 15.2 In relation to comment 3.1 above, the justification of the NPA, which states "Large/transport aeroplanes have not used these engines in the past, nor are they expected to use them in the future" should be improved. It is surprising to see this wording which does not fit with JAR 25.1(a). One could wonder why the authors apparently ignored JAR-25. 15.3 Depending on the response to a comment made on 25.361(a), the word "turbopropeller" could be deleted. 15.4 Following comment 15.1 above, the format should be improved by deleting the numbering of the sub-paragraph (1). 15.5 The wording of this paragraph (b) is extremely complex. Apparently, this text simply states the following: "***the limit engine torque considered in 25.361(a) is defined as the mean torque for the specified power and propeller speed multiplied by a factor of 1.25***". It is suggested to use this alternate wording if this interpretation is correct.	15.1 **Accepted** 15.2 **Accepted** 15.3 **Not Accepted** 15.4 **Partially Accepted** CS 25.361 has been re-formatted for clarity. 15.5 **Partially Accepted** Wording has been further improved.	**CS 25.361 Engine and auxiliary power unit torque (See AMC 25.361)** (a) For engine installations: … (2)~~(b)~~ The limit engine torque to be considered under sub-paragraph (1~~a~~) must be obtained by: (i) for turbo-propeller installations, multiplying mean engine torque for the specified power and speed by a factor of ~~(1)~~ 1·25 ~~for turbopropeller installations. (2) 1.33 for reciprocating engines.~~ (ii) for other turbine engines, the limit engine torque must be equal to the maximum accelerating torque for the case considered.

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			15.6 To be 100% clear, is the torque considered in (a)(3) equal to the mean torque multiplied by a factor of 1.25 then multiplied by a factor of 1.6? 15.7 Also for clarity, how is this "mean torque" calculated? This is not a parameter coming out of the engine certification and therefore is not known. **Justification:** For clarification of the text.	15.6 **Noted** The comment is correct. This is believed to be clear in the text. 15.7 **Accepted** Definition of mean torque is added to AMC 25.361.	
16.	25.361(b)	CAA UK	The proposed JAR 25.361(b) states that the limit engine torque to be considered under JAR 25.361(a) be obtained by multiplying the mean torque for the specified power or speed. It is suggested that the word "mean" be deleted since the torque to be considered should surely be that required to produce the rated power or speed on a fully deteriorated engine.	**Not Accepted** The term "mean engine torque" relates to the steady component as defined by new AMC 25.361 (See response to Comment 15.7). In attaining the desired engine rating, consideration would have been given to the lowest power/thrust level expected in service.	(No Change)
17.	25.361(b)(2)	CAA UK	The proposed JAR 25.361, sub para (b)(2) refers to reciprocating engines. This is at variance with the introduction to the NPA which states that other requirements relating to this type of engine have been deleted owing to the fact that this type of engine is no longer used on JAR-25 aircraft. If the requirements are to be amended such that reciprocating engines are not	**Accepted** (See also Comment #15.1)	(No Change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			addressed, it is suggested either that all references to this type of engine are deleted, or that no such references are deleted.		
18.	25.361(c)&(d)	DGAC-F	18.1 The word “turbine” in “turbine engine installation” should be deleted from (c), in relation to JAR 25.1, otherwise this would lead to confusion on applicability of JAR-25 to reciprocating engines. 18.2 The intent of (c)(1) is not clear. Could anyone imagine a “sudden engine deceleration” which would **NOT** result in a “temporary loss of power or thrust”? The wording of (d)(1) is much clearer. 18.3 The paragraph (c)(1) considers only “malfunction” when (d)(1) considers “malfunction or structural failure”. This difference should be justified: (d)(1) seems to be a better, more appropriate, safety objective. 18.4 It is therefore suggested to merge (c) and (d) into an unique paragraph based on the proposed (d). 18.5 The “maximum acceleration” referred to in (c)(2) or (d)(2) is not defined. Does this refer to the normal engine/APU operation or to failure cases? If failure cases are to be addressed, which ones are considered (extremely	**18.1 Accepted** **18.2 Accepted** Text is removed and guidance is provided in AMC 25.361. **18.3: Not Accepted** Engine structural failures are covered under 25.362. For APUs structural failures are addressed in 25.361(d)(1) (now 25.361(b)(1)), and the text is therefore appropriate. **18.4 Not Accepted** **18.5 Accepted** Definition has been added to AMC 25.361	**CS 25.361 Engine and auxiliary power unit torque (See AMC 25.361)** (a) For engine installations: … (3)~~(c) For turbine engine installations,~~ The engine mounts, pylons, and adjacent supporting airframe structure must be designed to withstand 1g level flight loads acting simultaneously with the limit engine torque loads imposed by each of the following conditions to be considered separately: (i) sudden maximum engine deceleration due to a malfunction ~~which could result in a temporary loss of power or thrust~~; and (ii) the maximum acceleration of the engine. …

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			improbable, …, remote, …)? **Justification:** For clarification of the text.		
19.	25.362(a)	DGAC-F	19.1 The proposal in (a)(1) is not consistent with the justification of the NPA which refers to failure of blade at the maximum permissible rotational speed. Therefore, the rule is not consistent with the specified intent. As a minimum, (a)(1) should be changed to read as follows: (1) the loss of any fan, compressor or turbine blade at the maximum permissible rotational speed, and 19.2 However, this would impose to the aircraft manufacturer a knowledge of the engine which would be out of its reach. Furthermore, the work is already done by the engine manufacturer under JAR-E 520(c)(2). It is then suggested to re-write the paragraph as follows: *(1) the loss of any* ***single*** *fan, compressor or turbine blade* ***determined from the data provided under JAR-E 520(c)(2)****, and* 19.3 It is important to note that JAR-E 810 does not address the "maximum permissible rotational speed": the ACJ excludes the approved over-speed limit (if any). 19.4 The proposal in 25.362, as determined	19.1: **Not Accepted** The maximum permissible rotation speed includes transient speeds above that which is applicable for this rule. (See Comment #19.3 below). Reference to CS-E 520(c)(2) added to CS 25.362(a)(1) to clarify what engine conditions are applicable. 19.2: **Partially Accepted**. Reference to CS-E added. The failure condition can result in multiple blade loss as a result of consequential damage. Text re-worded. 19.3: **Noted** 19.4: **Not Accepted**	*(Revised text in response to Comments 19&20)* **CS 25.362 Engine failure loads** (<u>See AMC 25.362</u>) (a) For engine mounts, pylons and adjacent supporting airframe structure, an ultimate loading condition must be considered that combines 1g flight loads with the most critical transient dynamic loads and vibrations, as determined by dynamic analysis, resulting from the engine structural failure conditions, as defined in CS-E 520(c)(2) ~~(1) the loss of any fan, compressor, or turbine blade; and~~ ~~(2) separately, where applicable to a specific engine design,~~ any ~~other engine structural failure that results in higher~~

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			from the declared intent in the justification for the NPA, would represent a significant change in engine certification procedures or an additional engine certification requirement without proper justification of the existence of any unsafe in-service experience. There is currently no reliable means to determine the loads induced by a blade failure in the conditions considered by this NPA (above those used for JAR-E certification) without additional tests (extrapolation in such dynamic event is not currently an acceptable tool). **Justification:** Self explanatory.	These requirements have already been complied with on individual projects over the last 10 years. (See additional justification Section B, III, 1)	~~loads.~~ (b) …
20.	25.362(a)	DGAC-F	20.1 The association side by side of the word “and” in (a)(1) with the word “separately” in (a)(2) is logically confusing for the average reader, not fully aware of an intent which is nowhere clearly specified. 20.2 In (a)(2), the “where applicable” is totally confusing. What are the criteria for application of this exemption clause? 20.3 Should we understand that the text should read as follows: (a) … With the ***highest*** transient dynamic loads resulting from ***either*** (1) The loss of ***any single*** blade, determined	**20.1: Accepted** Text has been re-worded. **20.2: Accepted** Text has been re-worded to clarify the intent. **20.3: Partially Accepted** “most critical” is introduced into sub-paragraph (a).	

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			from the data provided under JAR-E 520(c)(2), ***or*** (2) Any other engine structural failure. 20.4 What is the definition of an "engine structural failure"? Does this cover only the case of static parts? Does this cover also the case of disc failure or the case of the loss of more than one fan blade? Does this cover sudden stoppage? From paragraph 4.c of ACJ 25.362, we could understand that this only covers shaft or bearing failures. If this wording covers all engine failures (as we could also understand it), then why is there any paragraph (a)(1) at all, which in fact would only be a sub-set of (a)(2)? 20.5 The whole paragraph (a) should be re-written to be clear, understandable and logically self consistent. **Justification:** Need for understanding of the real requirement.	**20.4: Partially Accepted**. AMC 25.362(4)(c) defines the engine structural failure conditions to be considered. Large bird ingestion is added to the list. (see justification given in B, III, 2) **20.5: Accepted** Text has been amended to provide additional clarification.	
21.	25.362(b)	DGAC-F	21.1 In relation to 25.303, the proposed 25.362(b) results in no safety factor above the failure case of one fan blade. And it appears, based on the justification of the NPA and on the words "where applicable to a specific design" in (a)(2), that there is an implicit intent to avoid consideration of other cases.	**21.1/2/3 Partially Accepted** Engine failure conditions to be considered are further defined in the revised text of 25.362(a). (See Comment #18&20) The design philosophy associated with the engine requirements of E-810,	(No Change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			21.2 Therefore, it seems that this text accepts the concept of failure of the engine mounts in case of loss of two fan blades. Some sources tend to indicate that an engine separation from the aircraft would be a catastrophic event in large twin engine aircraft (without speaking of the partial separation as in the DC 10 accident) because of the dis-symmetry of thrust associated to dis-symmetry of weight. 21.3 If this is confirmed by the specialists in aircraft performance, then this failure case should be extremely improbable. 21.4 The justification of the NPA contains some vague references to the level of safety intended by JAR-25 or to studies made by the engine and aircraft manufacturers. There is no data justifying that the factor of 1.0 is adequate in relation to the intended safety level. In paragraph 5.b of ACJ 25.362 there is a statement: “they occur at sufficiently infrequent rate”, which is not supported by any data in this NPA. 21.5 There should be a review of all in service events and data and, from these data, an analysis of the risk for safety should be clearly provided in this NPA.	currently limit the need to show a single blade failure event, including subsequent damage. Multiple initial blade release is beyond existing standards. **21.4/5: Accepted** Further justification is provided in Section B, III, 1)	

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			Justification: Lack of data supporting the assumptions on safety level and lack of margin above a failure case which is likely worse than extremely remote. Similarly, the statements "based on the frequency of occurrence these events are considered to be limit loads…", "it is evident from service history that…" or "based on the rare occurrence" are not supported by any data. It is recognised that this text is an improvement of current JAR-25. However, this important safety issue should be subject to a debate in an appropriate forum with all relevant specialists.		
22.	25.362(b)(1)	CAA UK	22.1 With regard to the proposed JAR 25.362(b)(1), the factor of 1.0 is questioned. The data to support such a low factor are neither quoted nor referenced in the supporting justification for the NPA. The introduction refers to the "rare occurrence" of such [fan blade] failure events however service experience shows that such events are not as rare as the NPA seems to imply. The data used to support the proposed factors in the NPA should be identified so that it may be further reviewed. Furthermore, there have been events where multiple fan blades have been released. Whilst it is appreciated that the requirements of both JAR-E and JAR-25 do not currently address such failures, the fact that the aircraft	22.1 **Partially Accepted** (See response to Comment #14.2)	(No Change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			concerned were able to complete their respective flights safely indicates that the current requirements contain an adequate margin. It is far from clear that the "catch-all" provisions of the proposed 25.362(a)(2) are intended to cover the case of a multiple fan blade release. 22.2 On this same subject of fan blade failure, it should be noted that two of the major turbine engine manufacturers have, on their most recent products, changed the design philosophy of the engine in this respect. In view of this fundamental change, it is not appropriate to give credit to the "good past experience" in determining relevant safety factors in new requirements as is implied in the introduction to the NPA.	22.2 **Not Accepted** Any change in design philosophy will be covered by CS-E and no additional safety hazard to the airframe should be introduced.	
23.	ACJ 25.362 General	DGAC-F	The text of this ACJ does not reflect at all the currently proposed requirements of 25.362. This ACJ should be changed to become consistent with the rule it is supposed to interpret. See various other detailed comments. **Justification:** Consistency of the AC material with the rule.	**Accepted**	(See proposed text)
24.	ACJ 25.362 Paragraph 3.b	DGAC-F	It is recognised that an ACJ may create its own definitions. But in this case, to define "blade loss" so far out of the common sense is very	**Accepted** Blade loss definition is removed.	3. **DEFINITIONS**. … ~~b. Blade loss: The loss of~~

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			confusing. Furthermore, this wording is not used in the proposed 25.362 (note also that “most critical” is replaced by “any” in 25.362(a)(1)). It is suggested to delete this definition. **Justification:** Clarification.		~~the most critical fan, compressor, or turbine blade.~~ ….
25.	ACJ 25.362 Paragraph 4	CAA UK	ACJ 25.362 has a section entitled “Background” (Para 4). It is considered that the ACJ should be purely a description of a means of compliance, not an historical essay. For some reason, para 4(a)of the ACJ then summarises the requirement (JAR 25.362). The ACJ is not the correct place to list requirements. This whole section could be deleted.	**Not accepted** The background information is provided to aid understanding and is retained.	(No Change)
26.	ACJ 25.362 Paragraph 4.b	DGAC-F	26.1 The most part of the first sub-paragraph does not provide any useful additional interpretation of the rule but is trying to justify the new rule itself. This should be deleted from this ACJ which should be made consistent with the rule and limited to the necessary interpretative material. 26.2 The last sentence of the first sub-paragraph is “rulemaking by AC”: 25.362 nowhere requires the applicant to perform a dynamic analysis. The rule is currently limited to consideration of some loads. The rule should be	**26.1 Not Accepted** Background material is considered to aid understanding and is retained. **26.2 Partially accepted** The need to perform a dynamic analysis is clarified in a change to the rule.(see CS 25.362(a))	4. **<u>BACKGROUND</u>**. a. … b. <u>Engine failure loads</u>. Turbine engines have … engine failures. Consequently, ~~for engine failure events,~~ it is considered necessary that the applicant performs a dynamic analysis ~~that considers all load components~~ to ensure that representative loads are determined during and immediately following an engine

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			changed or this sentence should be deleted from the ACJ. 26.3 The second sub-paragraph refers to "a dynamic model of the aircraft and engine configuration" and uses the word "must". Again, this seems to be "rulemaking by AC" because the proposed 25.362 does not require a dynamic model. 26.4 In first sub-paragraph, last sentence, the words "all loads components" have no identifiable meaning. **Justification:** Consistency of the AC material with the rule.	 **26.3 Accepted** (See response to Comment #26.2). "Must" is changed to "should" to conform to EASA rule protocol. **26.4 Accepted** Text has been modified.	failure event. A dynamic model of the aircraft and engine configuration ~~must~~ should be sufficiently detailed to characterise the transient loads for the engine mounts, pylons, and adjacent supporting airframe structure during the failure event and subsequent run down. c. …
27.	ACJ 25.362 Paragraph 4.c	DGAC-F	27.1 This text does not provide any useful information in addition to the rule itself. Furthermore, it diverges from the rule or makes statements which are totally wrong. The statement in first sentences is totally wrong. The loss of a blade in an engine is a minor effect and there are many examples of engines having lost a blade in flight without detection by the flight crew (events discovered only on ground!). The test experience, referred to in first sentence, should be detailed. We would be interested in such data which is totally unknown to the engine specialists. To be able to make the statement which is given by this sentence, the	**27.1: Partially Accepted** While accepting that a blade loss may be a minor effect at aircraft level, in the case of a fan blade, it will often be the most severe condition. "fan" has been added to clarify the intent.	4. **BACKGROUND**. a. … b. … c. Engine structural failure conditions. Of all the applicable engine structural failure conditions, design and test experience have shown that the loss of a fan blade is likely to produce the most severe loads on the engine and airframe. Therefore, CS 25.362 requires that the transient dynamic loads

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			authors must have data based on hundreds of tests on engines of various sizes and design, comparing the various failure scenarios. If, of course, there are tests of effects of loss of a blade, no engine test is known to DGAC which would assess the effect of sudden engine stoppage or other "structural" failure. It should be noted that the wording is "loss of blade" which is not the defined word "blade loss". 27.2 When ACJ specifies "be considered when evaluating structural integrity", it diverges from the proposed 25.362 which refers only to "engine supporting structure" and nowhere refers to evaluation of the structural integrity. Furthermore, this paragraph only refers to "engine structural failure". Therefore, "evaluating structural integrity" can only refer to the integrity of the engine. This is amplified by the 4th sentence "for each specific engine design, the applicant…". 27.3 What is the real meaning of this 4th sentence? In an ACJ to JAR-25, the applicant should refer to the aircraft designer. But in a sentence like "for each specific design…" the only organisation which can assess "each specific engine design" is the engine designer. Then, it appears that this ACJ to JAR-25 is trying to impose rules to the engine designer.	27.2 **Partially Accepted** CS 25.362 and AMC 25.362 have been amended to clarify the applicable structure. 27.3 **Accepted** (See proposals & Justification to change CS-E. (Section D, II & III))	from these blade failure conditions be considered when evaluating structural integrity of the engine mounts, pylons and adjacent supporting airframe structure. However, service history shows examples of other severe engine structural failures where the engine thrust-producing capability was lost, and the engine experienced extensive internal damage. For each specific engine design, the applicant should consider whether these types of failures are applicable, and if they present a more critical load condition than blade loss. Examples of other engine structural failure conditions that should be considered in this respect are: • failure of a shaft, or • failure or loss of any ~~shaft support~~ bearing /bearing support, or • a large bird ingestion.

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			27.4 The examples of other failure conditions seem to impose the idea that the loss of two fan blades (likely to produce higher loads than the loss of a single fan blade) should not be considered. Both rule and ACJ should be re-written to be consistent. **Justification:** Consistency of the AC material with the rule.	27.4 **Not Accepted** (See response to Comment #21.2)	
28.	ACJ 25.362 Paragraph 5.a	DGAC-F	28.1 The objective specified in this paragraph is clearly "rulemaking by AC". There is no obvious rule imposing such an objective. This should be transferred into the rule itself, if a rule already exists, its reference should be added to this ACJ. 28.2 The reference to JAR-E 810 is not appropriate. It should be JAR-E 520 (c)(2). 28.3 The last sentence of the 2nd sub-paragraph is not consistent with the declared objective! What is really the objective? This should be made clear. **Justification:** Consistency of the AC material with the rule.	**28.1: Partially Accepted** The objective is moved to Section 4(a): Background. **28.2/3: Noted** Sub-paragraph 5.a is deleted.	5. **EVALUATION OF TRANSIENT FAILURE CONDITIONS** ~~a. Objective. The applicant should show, by a combination of tests and analyses, that the aeroplane is capable of continued safe flight and landing after loss of a blade, including ensuing damage to other parts of the engine.~~ ~~The primary failure condition is expected to be blade release (refer to JAR-E 810 "Compressor and Turbine Blade Failure"). However, other structural failures~~

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
					~~may need to be considered as well, depending upon the engine configuration.~~ ~~The applicant also should consider the transient loads from the time of the engine structural failure, up to the time at which the engine stops rotating or achieves a steady windmilling rotational speed. (*Note*: The effects of continued rotation (windmilling) are described in ACJ 25.901(c).)~~
29.	ACJ 25.362 Paragraph 5.b	DGAC-F	29.1 The first sub-paragraph is again “rulemaking by AC” without counterpart in the proposed 25.362: the rule does not require to determine if the mounts would fail because of vibrations. 29.2 The second sub-paragraph is only “blahblah” trying, again, to justify the NPA. It should be deleted as not being relevant. In addition, the association of “major failure” with “ultimate loads” does not seem to be consistent with the concepts used in 25.1309 or in JAR-E 510. The “sufficiently infrequent rate” is not justified. **Justification:**	**29.1: Accepted** “Vibration” is added to CS 25.362(a). **29.2: Partially Accepted** Further justification is provided in Section B, III, 1)	(See proposed text)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			Consistency of the AC material with the rule.		
30.	ACJ 25.362 Paragraph 5.c	DGAC-F	30.1 The requirement for “dynamic analysis” is again “rulemaking by AC”: the rule requires only to design the mounts to withstand some loads. 30.2 This paragraph is also trying to replace JAR-E 520 (c)(2). An ACJ to JAR-25 should not be used to dictate what the engine certification should be. All of this paragraph should be changed to make use of the existence of JAR-E and to limit itself to activities of the aircraft manufacturer. 30.3 It is noted that the text refers to “critical flight conditions” (in second sub-paragraph). This is surprising when the rule specifies “1g flight loads” and when the ACJ in 4th sub-paragraph refers to “typical flight conditions”. This is totally confusing. 30.4 This paragraph contains, in its 3rd sub-paragraph, the following: “the analysis of incremental transient airframe loads”: this is rulemaking by AC because this is not required by the proposed rule. It is also noted that there is no provision in the proposed 25.362 to consider “the most critical aeroplane mass distribution”.	**30.1: Partially Accepted** CS 25.362(a) is amended to necessitate the need for a dynamic analysis. **30.2: Partially Accepted** (See proposals & Justification to change CS-E. (Section D, II & III)) **30.3: Accepted** Second part of sentence is removed to clarity the required flight condition. During the deceleration immediately following the blade-off event, material variability and temperature will not affect the loads generated and reference is removed from the text. **30.4: Partially Accepted**. The need for a dynamic analysis is now included in 25.362(a). The text of 5.b. is amended accordingly. The use of the most critical mass distribution is seen as providing guidance relating to a critical loading condition, as defined in CS	5. **EVALUATION OF TRANSIENT FAILURE CONDITIONS** … b~~e~~. Blade loss condition. The ~~applicant should determine~~ loads on the engine mounts, pylon, and adjacent supporting airframe structure should be determined by dynamic analysis. The analysis should take into account all significant structural degrees of freedom. The transient engine loads should be determined for the ~~fan~~ blade failure condition and rotor speed approved per CS-E, ~~as specified in JAR-E 810,~~ and over the full range of blade release angles to allow determination of the critical loads for all affected components. ~~The amount of engine damage that develops during the failure event and, consequently, the loads produced, depends on material properties and temperature. Therefore, the analysis of transient engine loads should consider the effects of variations in engine material~~

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			Justification: Consistency of the AC with the rule.	25.321.	~~properties and temperature. This step in the analysis may be satisfied by analysing the engine stiffness characteristics at typical flight temperatures, and the engine strength and deflection characteristics at maximum design temperatures.~~ The loads~~forcing function~~ to be applied to the pylon and airframe are normally determined~~generated~~ and validated by the engine manufacturer~~, including those changes needed to represent the critical flight conditions.~~ The calculation ~~analysis~~ of ~~airframe incremental~~ transient dynamic loads should consider: … For calculation of the combined ultimate airframe loads, the 1g component should~~may~~ be associated with typical flight conditions.
31.	ACJ 25.362 Paragraph 5.d	DGAC-F	31.1 The wording "more critical load condition" is not consistent with 25.362 which only refers to "higher loads". The wording in the rule and	**31.1: Accepted**	5. **EVALUATION OF TRANSIENT FAILURE CONDITIONS**

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			the ACJ should be consistent. 31.2 "Should be evaluated by dynamic analysis" is again rulemaking by AC, because the rule does not require a dynamic analysis. 31.3 What are these "assumptions"? Although supposed to be "described in paragraph 5.c", they cannot be identified in paragraph 5.c. Are they the same as the assumptions in JAR 21.101 (CPR rules)? **Justification:** Clarification is needed.	**31.2: Noted** CS 25.362(a) is amended to necessitate the need for a dynamic analysis. **31.3: Partially Accepted** Text changed. The same considerations should be given in the analysis of other failure conditions, if more critical, as are given to the blade loss condition.	… c~~d~~. Other failure conditions. As identified in paragraph 4(c) above, if any other engine structural failure conditions, applicable to the specific engine design, could result in higher loads being developed ~~are identified that present a more critical load condition~~ than the blade loss condition, they should be evaluated by dynamic analysis to a similar standard and using similar considerations ~~assumptions~~ to those described in paragraph 5.b~~c~~., above.
32.	ACJ 25.362 Paragraph 7.a	DGAC-F	32.1 "Calculate airframe dynamic response with an integrated model" is rulemaking by AC. The rule addresses "engine supporting structure", not the "airframe". There is no requirement for an integrated model. There is no rule for consideration of "dynamic response". 32.2 Similarly, to require an "engine structural model" is again rulemaking by AC but is also a new rule against JAR-E, which is not consistent with current JAR-E 520 (c)(2) which refers only to data. Again, an ACJ to JAR-25 should not be used to impose new requirements onto the	**32.1: Partially Accepted** CS 25.362(a) is amended to necessitate the need for a dynamic analysis. Text of AMC 25.362 7.a. is amended to clarify the model required and the extent of the analysis. **32.2: Partially Accepted** (See proposals & Justification to change CS-E. (Section D, II & III))	7. **MATHEMATICAL MODELLING AND VALIDATION** a. Components of the integrated dynamics model The applicant should calculate airframe dynamic responses with an integrated model of the engine, engine mount, pylon, and adjacent supporting airframe structure. The integrated dynamic

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			engine. **Justification:** Clarification is needed.		model …
33.	ACJ 25.362 Paragraph 7.b (1)	DGAC-F	The first sentence is rulemaking by AC ("necessary" is rule wording; "to calculate the airframe responses": no rule requires that). **Justification:** Consistency of ACJ with the rule should be ensured.	**Partially Accepted** CS 25.362(a) is amended to necessitate the need for a dynamic analysis.	(See CS 25.362(a))
34.	ACJ 25.362 Paragraph 7.c	DGAC-F	This is clearly an interference with engine certification. In particular, paragraph 7.c (4) which makes references to vibration tests (those of JAR-E 650 ??) and to JAR-E 810, but does not refer to JAR-E 520 (c)(2). All engine activity should disappear from this ACJ and JAR-E 520 should be taken into account. Paragraph 7.c (4) states:"for compliance with JAR 25.362, the engine model…". There is no such requirement in the proposed 25.362. With regard to the current state of the art, it is very unlikely that a dynamic engine model would ever be validated as being able to comply	**Accepted**	(See new proposals to AMC 25.362 (Paragraph 7) and new AMC E 520.)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			with the "rules" of 7.c (6) ("accurately predicts"). If JAR-E 520 (c)(2) is not adequate, this should be officially declared and notified to the ESG. A change could be considered. It is totally abnormal to try to impose something onto the engine by means of this ACJ to JAR-25. **Justification:** Consistency of JAR codes.		
35.	ACJ 25.362 Paragraph 7c	CAA UK	Para 7c of ACJ 25.362 covers validation of the engine structural model. There seems to be an assumption in parts of this para that the engine is a fan design, but this is not always the case. "First stage rotor" would be a better term to use.	**Partially Accepted** "fan" is removed from AMC 25.362 paragraph 7.c (3).	7. **MATHEMATICAL MODELLING AND VALIDATION** … c. Engine Structural Model and Validation … (3) Features modelled specifically for blade loss analysis typically include: • ~~fan~~ imbalance, • component failure, …

C. JAA NPA 25E-306: Sustained Engine Imbalance

I) Explanatory Note

(See also "A.I: General Explanatory Note")

1. General

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). Under the auspices of ARAC, a working group of industry and government structural specialists of Europe, the U.S., and Canada has developed recommendations regarding design criteria and analytical methodology for assessing the engine imbalance event. These recommendations are contained in the report "Engine Windmilling Imbalance Loads - Final Report " dated July 1, 1997. The proposals contained in this JAA NPA 25C-306 are derived from the recommendations in that report.

As a result of this consultation, the JAA received 50 comments, many of which were critical of the proposals and were seen as impacting on traditional engine/airframe interfaces. These comments were not resolved prior to the creation of the Agency. However, the task was identified in the transition inventory and placed on the Agency's rulemaking programme, together with the related task on Engine and APU Load Conditions, (Tasks 25.016 and 25.015, respectively).

In March 2006, an EASA rulemaking group was formed to progress tasks 25.015 and 25.016. The group was composed of representative from EASA, NAAs and the airframe and engine manufactures. This NPA is the output from this group.

2. Safety Justification / Explanation

Refer to the background section of the proposed AMC 25-24 and the LDHWG final report on "Engine Windmilling Imballance Loads" contained in the Appendix to this NPA.

II) Proposal

The text of the amendment is arranged to show deleted text, new text or a new paragraph as shown below:

1. ~~Text to be deleted is shown with a line through it.~~
2. New text to be inserted is highlighted with grey shading.
3. ….
   Indicates that remaining text is unchanged in front of or following the reflected amendment.
   ….

CS-25 BOOK 1: AIRWORTHINESS CODE

Proposal 1: Add reference to a new AMC in CS 25.901(c):

CS 25.901 Installation

(a) …

(b) …

(c) The powerplant installation must comply with CS 25.1309, except that the effects of the following need not comply with CS 25.1309(b):

(1) Engine case burn through or rupture;

(2) Uncontained engine rotor failure; and

(3) Propeller debris release.

(See AMC 25.901(c) Safety Assessment of Powerplant Installations and AMC 25-24: Sustained Engine Imbalance)

Proposal 2: Add a new AMC 25-24 to the General section of CS-25 Book 2 to read as follows:

AMC 25-24
Sustained Engine Imbalance

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 the aircraft design for sustained engine rotor imbalance conditions.

2. RELATED CS PARAGRAPHS

a. CS-25:

CS 25.571 “Damage tolerance and fatigue evaluation of structure”
CS 25.629 “Aeroelastic stability requirements”
CS 25.901 “Installation”
CS 25.903 “Engines”

b. CS-E:

CS-E 520 "Strength"
CS-E 525 "Continued Rotation"
CS-E 810 "Compressor and Turbine Blade Failure"
CS-E 850 "Compressor, Fan and Turbine Shafts**"**

3. DEFINITIONS. Some new terms have been defined for the imbalance condition in order to present criteria in a precise and consistent manner. In addition, some terms are employed from other fields and may not be in general use as defined below. The following definitions apply in this AMC:

a. Airborne Vibration Monitor (AVM). A device used for monitoring the operational engine vibration levels that are unrelated to the failure conditions considered by this AMC.

b. Design Service Goal (DSG). The design service goal is a period of time (in flight cycles/hours) established by the applicant at the time of design and/or certification and used in showing compliance with CS 25.571.

c. Diversion Flight. The segment of the flight between the point where deviation from the planned route is initiated in order to land at an en route alternate airport and the point of such landing.

d. Ground Vibration Test (GVT). Ground resonance tests of the aeroplane normally conducted in compliance with CS 25.629.

e. Imbalance Design Fraction (IDF). The ratio of the design imbalance to the imbalance (including all collateral damage) resulting from release of a single turbine, compressor, or fan blade at the maximum rotational speed to be approved, in accordance with CS-E 810.

f. Low Pressure (LP) Rotor. The rotating system, which includes the low pressure turbine and compressor components and a connecting shaft.

g. Well Phase. The flight hours accumulated on an aeroplane or component before the failure event.

4. BACKGROUND

a. Requirements. CS 25.901(c) requires the powerplant installation to comply with CS 25.1309. In addition, CS 25.903(c) requires means of stopping the rotation of an engine where continued rotation could jeopardise the safety of the aeroplane, and CS 25.903(d) requires that design precautions be taken to minimise the hazards to the aeroplane in the event of an engine rotor failure. CS-E 520(c)(2) requires that data shall be established and provided for the purpose of enabling each aircraft constructor to ascertain the forces that could be imposed on the aircraft structure and systems as a consequence of out-of-balance running and during any continued rotation with rotor unbalance after shutdown of the engine following the occurrence of blade failure, as demonstrated in compliance with CS-E 810.

b. Blade Failure. The failure of a fan blade and the subsequent damage to other rotating parts of the fan and engine may induce significant structural loads and vibration throughout the airframe that may damage the nacelles, equipment necessary for continued safe flight and landing, engine mounts, and airframe primary structure. Also, the effect of flight deck vibration on displays and equipment is of significance to the crew's ability to make critical decisions regarding the shut down of the damaged engine and their ability to carry out other operations during the remainder of the flight. The vibratory loads resulting from the failure of a fan blade have traditionally been regarded as insignificant relative to other portions of the design load spectrum for the aeroplane. However, the progression to larger fan diameters and fewer blades with larger chords has changed the significance of engine structural failures that result in an imbalanced rotating assembly. This condition is further exacerbated by the fact that fans will continue to windmill in the imbalance condition following engine shut down. Current rules require provisions to stop the windmilling rotor where continued rotation could jeopardise the safety of the aeroplane. However, it may be impractical or undesirable to stop the windmilling rotation of large high bypass ratio engines in flight.

c. Bearing/Bearing Support Failure. Service experience has shown that failures of bearings/bearing supports have also resulted in sustained high vibratory loads.

d. Imbalance Conditions. There are two sustained imbalance conditions that may affect safe flight: the windmilling condition and a separate high power condition.

(1) Windmilling Condition. The windmilling condition results after the engine is shut down but continues to rotate under aerodynamic forces. The windmilling imbalance condition results from bearing/bearing support failure or loss of a fan blade along with collateral damage. This condition may last until the aeroplane completes its diversion flight, which could be several hours.

(2) High Power Condition. The high power imbalance condition occurs immediately after blade failure but before the engine is shut down or otherwise spools down. This condition addresses losing less than a full fan blade which may not be sufficient to cause the engine to spool down on its own. This condition may last from several seconds to a few minutes. In some cases it has hampered the crew's ability to read instruments that may have aided in determining which engine was damaged.

e. The information provided in this AMC is derived from the recommendations in the report "Engine Windmilling Imbalance Loads - Final Report," dated July 1, 1997, which is appended to this NPA for information.

f. The criteria presented in this AMC are based on a statistical analysis of 25 years of service history of high by-pass ratio engines with fan diameters of 1.52 metres (60 inches) or greater. Although the study was limited to these larger engines, the criteria and methodology are also acceptable for use on smaller engines.

5. EVALUATION OF THE WINDMILLING IMBALANCE CONDITIONS

a. Objective. It should be shown by a combination of tests and analyses that after:
i) partial or complete loss of an engine fan blade, or
ii) after bearing/bearing support failure, or
iii) any other failure condition that could result in higher induced vibrations
including collateral damage, the aeroplane is capable of continued safe flight and landing.

b. Evaluation. The evaluation should show that during continued operation at windmilling engine rotational speeds, the induced vibrations will not cause damage that would jeopardise continued safe flight and landing. The degree of flight deck vibration[1] should not prevent the flight crew from operating the aeroplane in a safe manner. This includes the ability to read and accomplish checklist procedures.

This evaluation should consider:

(1) The damage to airframe primary structure including, but not limited to, engine mounts and flight control surfaces,

(2) The damage to nacelle components, and

(3) The effects on equipment necessary for continued safe flight and landing (including connectors) mounted on the engine or airframe.

c. Blade Loss Imbalance Conditions

(1) Windmilling Blade Loss Conditions. The duration of the windmilling event should cover the expected diversion time of the aeroplane. An evaluation of service experience indicates that the probability of the combination of a 1.0 IDF and a 60 minute diversion is on the order of 10^{-7} to 10^{-8} while the probability of the combination of a 1.0 IDF and a 180 minute diversion is 10^{-9} or less. Therefore, with an IDF of 1.0, it would not be necessary to consider diversion times greater than 180 minutes. In addition, the 180 minute diversion should be evaluated using nominal and realistic flight conditions and parameters. The following two separate conditions with an IDF of 1.0 are prescribed for application of the subsequent criteria which are developed consistent with the probability of occurrence:

(a) A 60 minute diversion flight.

(b) If the maximum diversion time established for the aeroplane exceeds 60 minutes, a diversion flight of a duration equal to the maximum diversion time, but not exceeding 180 minutes.

(2) Aeroplane Flight Loads and Phases

(a) Loads on the aeroplane components should be determined by dynamic analysis. At the start of the windmill event, the aeroplane is assumed to be in level flight with a typical payload and realistic fuel loading. The speeds, altitudes, and flap configurations considered may be established according to the Aeroplane Flight Manual (AFM) procedures. The analysis should take into account unsteady aerodynamic characteristics and all significant structural degrees of freedom including rigid body modes. The vibration loads should be determined for the significant phases of the diversion profiles described in paragraphs 5c(1)(a) and (b) above.

(b) The significant phases are:

1 The initial phase during which the pilot establishes a cruise condition;

[1] An acceptable level of cockpit vibration in terms of vibration frequency, acceleration magnitude, exposure time and direction may be found in ISO 2631/1 “International Standard, Evaluation of Human Exposure to Whole-Body Vibration, Part I: General Requirements”, 1985.

2 The cruise phase;
3 The descent phase; and
4 The approach to landing phase.

(c) The flight phases may be further divided to account for variation in aerodynamic and other parameters. The calculated loads parameters should include the accelerations needed to define the vibration environment for the systems and flight deck evaluations. A range of windmilling frequencies to account for variation in engine damage and ambient temperature should be considered.

(3) Strength Criteria

(a) The primary airframe structure should be designed to withstand the flight and windmilling vibration load combinations defined in paragraphs 1, 2, and 3 below.

1 The peak vibration loads for the flight phases in paragraphs 5c(2)(b)1 and 3 above, combined with appropriate 1g flight loads. These loads should be considered limit loads, and a factor of safety of 1.375 should be applied to obtain ultimate load.

2 The peak vibration loads for the approach to landing phase in paragraph 5c(2)(b)4 above, combined with appropriate loads resulting from a positive symmetrical balanced manoeuvring load factor of 1.15g. These loads should be considered as limit loads, and a factor of safety of 1.375 should be applied to obtain ultimate load.

3 The vibration loads for the cruise phase in paragraph 5c(2)(b)2 above, combined with appropriate 1g flight loads and 70 percent of the flight manoeuvre loads up to the maximum likely operational speed of the aeroplane. These loads are considered to be ultimate loads.

4 The vibration loads for the cruise phase in paragraph 5c(2)(b)2 above, combined with appropriate 1g flight loads and 40 percent of the limit gust velocity of CS 25.341 as specified at V_C (design cruising speed) up to the maximum likely operational speed of the aeroplane. These loads are considered to be ultimate loads.

(b) In selecting material strength properties for the static strength analyses, the requirements of CS 25.613 apply.

(4) Assessment of Structural Endurance

(a) Criteria for fatigue and damage tolerance evaluations of primary structure are summarised in Table 1 below. Both of the conditions described in paragraphs 5c(1)(a) and (b) above should be evaluated. Different levels of structural endurance capability are provided for these conditions. The criteria for the condition in paragraph 5c(1)(b) are set to ensure at least a 50 percent probability of preventing a structural component failure. The criteria for the condition in paragraph 5c(1)(a) are set to ensure at least a 95 percent probability of preventing a structural component failure. These criteria are consistent with the probability of occurrences for these events discussed in paragraph 5(c)(1) above.

(b) For multiple load path and crack arrest "fail-safe" structure, either a fatigue analysis per paragraph 1 below, or damage tolerance analysis per paragraph 2 below, may be performed to demonstrate structural endurance capability. For all other structure, the structural endurance capability should be demonstrated using only the damage tolerance approach of paragraph 2 below. The definitions of multiple load path and crack arrest "fail-safe" structure are the same as defined for use in showing compliance with CS 25.571, "Damage tolerance and fatigue evaluation of structure."

1 Fatigue Analysis. Where a fatigue analysis is used for substantiation of multiple load path "fail-safe" structure, the total fatigue damage accrued during the well phase and the windmilling phase should be considered. The analysis should be conducted considering the following:

(aa) For the well phase, the fatigue damage should be calculated using an approved load spectrum (such as used in satisfying the requirements of CS 25.571) for the durations specified in Table 1. Average material properties may be used.

(bb) For the windmilling phase, fatigue damage should be calculated for the diversion profiles using a diversion profile consistent with the AFM recommended operations, accounting for transient exposure to peak vibrations, as well as the more sustained exposures to vibrations. Average material properties may be used.

(cc) For each component, the accumulated fatigue damage specified in Table 1 should be shown to be less than or equal to the fatigue damage to failure of the component.

2 Damage Tolerance Analysis. Where a damage tolerance approach is used to establish the structural endurance, the aeroplane should be shown to have adequate residual strength during the specified diversion time. The extent of damage for residual strength should be established, considering growth from an initial flaw assumed present since the aeroplane was manufactured. Total flaw growth will be that occurring during the well phase, followed by growth during the windmilling phase. The analysis should be conducted considering the following:

(aa) The size of the initial flaw should be equivalent to a manufacturing quality flaw associated with a 95 percent probability of existence with 95 percent confidence (95/95).

(bb) For the well phase, crack growth should be calculated starting from the initial flaw defined in paragraph 5c(4)(b)2(aa) above, using an approved load spectrum (such as used in satisfying the requirements of CS 25.571) for the duration specified in Table 1. Average material properties may be used.

(cc) For the windmilling phase, crack growth should be calculated for the diversion profile starting from the crack length calculated in paragraph 5c(4)(b)2(bb) above. The diversion profile should be consistent with the AFM recommended operation accounting for transient exposure to peak vibrations as well as the more sustained exposures to vibrations. Average material properties may be used.

(dd) The residual strength for the structure with damage equal to the crack length calculated in paragraph 5c(4)(b)2(cc) above should be shown capable of sustaining the combined loading conditions defined in paragraph 5c(3)(a) above with a factor of safety of 1.0.

TABLE 1 - Fatigue and Damage Tolerance

	Condition	Paragraph 5c(1)(a)	Paragraph 5c(1)(b)
	Imbalance Design Fraction (IDF)	1.0	1.0
	Diversion time	A 60-minute diversion	The maximum expected diversion[6]
Fatigue Analysis[1,2] (average material properties)	Well phase	Damage for 1 DSG	Damage for 1 DSG
	Windmilling phase	Damage due to 60 minute diversion under a 1.0 IDF imbalance condition.	Damage due to the maximum expected diversion time[6] under a 1.0 IDF imbalance condition
	Criteria	Demonstrate no failure[7] under twice the total damage due to the well phase and the windmilling phase.	Demonstrate no failure[7] under the total damage (unfactored) due to the well phase and the windmilling phase.
Damage Tolerance[1,2] (average material properties)	Well phase	Manufacturing quality flaw[5] (MQF) grown for 1 DSG	Manufacturing quality flaw[5] (MQF) grown for 1/2 DSG
	Windmilling phase[3,4]	Additional crack growth for 60 minute diversion with an IDF = 1.0	Additional crack growth for the maximum diversion[6] with an IDF = 1.0
	Criteria	Positive margin of safety with residual strength loads specified in 5c(3)(a) for the final crack length	Positive margin of safety with residual strength loads specified in 5c(3)(a) for the final crack length

Notes:

1 *The analysis method that may be used is described in paragraph 5 (Evaluation of the Windmilling Imbalance Conditions) of this AMC.*

2 *Load spectrum to be used for the analysis is the same load spectrum qualified for use in showing compliance with CS 25.571, augmented with windmilling loads as appropriate.*

3 *Windmilling phase is to be demonstrated following application of the well phase spectrum loads.*

4 *The initial flaw for damage tolerance analysis of the windmilling phase need not be greater than the flaw size determined as the detectable flaw size plus growth under well phase spectrum loads for one inspection period for mandated inspections.*

5 *MQF is the manufacturing quality flaw associated with 95/95 probability of existence. (Reference - 'Verification of Methods For Damage Tolerance*

Evaluation of Aircraft Structures to FAA Requirements', Tom Swift FAA, 12th International Committee on Aeronautical Fatigue, 25 May 1983, Figures 42, and 43.)

6 *Maximum diversion time for condition 5c(1)(b) is the maximum diversion time established for the aeroplane, but need not exceed 180 minutes. This condition should only be investigated if the diversion time established for the aeroplane exceeds 60 minutes.*

7 *The allowable cycles to failure may be used in the damage calculations.*

(5) Systems Integrity

(a) It should be shown that systems required for continued safe flight and landing after a blade-out event will withstand the vibratory environment defined for the windmilling conditions and diversion times described above. For this evaluation, the aeroplane is assumed to be dispatched in its normal configuration and condition. Additional conditions associated with the Master Minimum Equipment List (MMEL) need not be considered in combination with the blade-out event.

(b) The initial flight environmental conditions are assumed to be night, instrument meteorological conditions (IMC) en route to nearest alternate airport, and approach landing minimum of 300 feet and 3/4 mile or runway visual range (RVR) 4000m or better.

(6) Flight crew Response. For the windmilling condition described above, the degree of flight deck vibration shall not inhibit the flight crew's ability to continue to operate the aeroplane in a safe manner during all phases of flight.

d. Bearing/Bearing Support Failure. To evaluate these conditions, the low pressure (LP) rotor system should be analysed with each bearing removed, one at a time, with the initial imbalance consistent with the airborne vibration monitor (AVM) advisory level. The analysis should include the maximum operating LP rotor speed (assumed bearing failure speed), spool down, and windmilling speed regions. The effect of gravity, inlet steady air load, and significant rotor to stator rubs and gaps should be included. If the analysis or experience indicates that secondary damage such as additional mass loss, secondary bearing overload, permanent shaft deformation, or other structural changes affecting the system dynamics occur during the event, the model should be revised to account for these additional effects. The objective of the analyses is to show that the loads and vibrations produced by the bearing/bearing support failure event are less than those produced by the blade loss event across the same frequency range.

An alternative means of compliance is to conduct an assessment of the design by analogy with previous engines to demonstrate this type of failure is unlikely to occur. Previous engines should be of similar design and have accumulated a significant amount of flight hours with no adverse service experience.

e. Other failure conditions. If any other engine structural failure conditions applicable to the specific engine design could result in more severe induced vibrations than the blade loss or bearing/bearing support failure condition, they should be evaluated. Examples of other engine structural failure conditions that should be considered in this respect are:

- failure of a shaft, or

- a large bird ingestion.

6. ANALYSIS METHODOLOGY

a. Objective of the Methodology. The aeroplane response analysis for engine windmilling imbalance is a structural dynamic problem. The objective of the methodology is to develop acceptable analytical tools for conducting dynamic investigations of imbalance events. The goal of the windmilling analyses is to produce loads and accelerations suitable for structural, systems, and flight deck evaluations.

b. Scope of the Analysis. The analysis of the aeroplane and engine configuration should be sufficiently detailed to determine the windmilling loads and accelerations on the aeroplane. For aeroplane configurations where the windmilling loads and accelerations are shown not to be significant, the extent and depth of the analysis may be reduced accordingly.

c. Results of the Analysis. The windmilling analyses should provide loads and accelerations for all parts of the primary structure. The evaluation of equipment and human factors may require additional analyses or tests. For example, the analysis may need to produce floor vibration levels, and the human factors evaluation may require a test (or analysis) to subject the seat and the human subject to floor vibration.

7. MATHEMATICAL MODELLING

a. Components of the Integrated Dynamic Model. Aeroplane dynamic responses should be calculated with a complete integrated airframe and engine analytical model. The aeroplane model should be to a similar level of detail to that used for certification flutter and dynamic gust analyses, except that it should also be capable of representing asymmetric responses. The dynamic model used for windmilling analyses should be representative of the aeroplane to the highest windmilling frequency expected. The integrated dynamic model consists of the following components:

(1) Airframe structural model,
(2) Engine structural model,
(3) Control system model,
(4) Aerodynamic model, and
(5) Forcing function and gyroscopic effects.

b. Airframe Structural Model. An airframe structural model is necessary in order to calculate the response at any point on the airframe due to the rotating imbalance of a windmilling engine. The airframe structural model should include the mass, stiffness, and damping of the complete airframe. A lumped mass and finite element beam representation is considered adequate to model the airframe. This type of modelling represents each airframe component, such as fuselage, empennage, and wings, as distributed lumped masses rigidly connected to weightless beams that incorporate the stiffness properties of the component. A full aeroplane model capable of representing asymmetric responses is necessary for the windmilling imbalance analyses. Appropriate detail should be included to ensure fidelity of the model at windmilling frequencies. A more detailed finite element model of the airframe may also be acceptable. Structural damping used in the windmilling analysis may be based on Ground Vibration Test (GVT) measured damping.

c. Engine Structural Model.

(1) Engine manufacturers construct various types of dynamic models to determine loads and to perform dynamic analyses on the engine rotating components, its static structures, mounts, and nacelle components. Dynamic engine models can range from a centreline two-dimensional (2D) model, to a centreline model with appropriate three-dimensional (3D) features such as mount and pylon, up to a full 3D finite element model (3D FEM). Any of these models can be run for either transient or steady state conditions.

(2) These models typically include all major components of the propulsion system, such as the nacelle intake, fan cowl doors, thrust reverser, common nozzle assembly, all structural casings, frames, bearing housings, rotors, and a representative pylon. Gyroscopic effects are included. The models provide for representative connections at the engine-to-pylon interfaces as well as all interfaces between components (e.g., inlet-to-engine and engine-to-thrust reverser). The engine that is generating the imbalance forces should be modelled in this level of detail, while the undamaged engines that are operating normally need only to be modelled to represent their sympathetic response to the aeroplane windmilling condition.

(3) Features modelled specifically for blade loss windmilling analysis typically include fan imbalance, component failure and wear, rubs (blade to casing, and intershaft), and resulting stiffness changes. Manufacturers whose engines fail the rotor support structure by design during the blade loss event should also evaluate the effect of the loss of support on engine structural response during windmilling.

(4) Features that should be modelled specifically for bearing/bearing support failure windmilling events include the effects of gravity, inlet steady air loads, rotor to stator structure friction and gaps, and rotor eccentricity. Secondary damage should be accounted for, such as additional mass loss, overload of other bearings, permanent shaft deformation, or other structural changes affecting the system dynamics, occurring during rundown from maximum LP rotor speed and subsequent windmilling.

d. Control System Model. The automatic flight control system should be included in the analysis unless it can be shown to have an insignificant effect on the aeroplane response due to engine imbalance.

e. Aerodynamic Model. The aerodynamic forces can have a significant effect on the structural response characteristics of the airframe. While analysis with no aerodynamic forces may be conservative at most frequencies, this is not always the case. Therefore, a validated aerodynamic model should be used. The use of unsteady three-dimensional panel theory methods for incompressible or compressible flow, as appropriate, is recommended for modelling of the windmilling event. Interaction between aerodynamic surfaces and main surface aerodynamic loading due to control surface deflection should be considered where significant. The level of detail of the aerodynamic model should be supported by tests or previous experience with applications to similar configurations. Main and control surface aerodynamic derivatives should be adjusted by weighting factors in the aeroelastic response solutions. The weighting factors for steady flow (k=0) are usually obtained by comparing wind tunnel test results with theoretical data.

f. Forcing Function and Gyroscopic Forces. Engine gyroscopic forces and imbalance forcing function inputs should be considered. The imbalance forcing function should be calibrated to the results of the test performed under CS-E 810.

8. VALIDATION.

a. Range of Validation. The analytical model should be valid to the highest windmilling frequency expected.

b. Aeroplane Structural Dynamic Model. The measured ground vibration tests (GVT) normally conducted for compliance with CS 25.629 may be used to validate the analytical model throughout the windmilling range. These tests consist of a complete airframe and engine configuration subjected to vibratory forces imparted by electro-dynamic shakers.

(1) Although the forces applied in the ground vibration test are small compared to the windmilling forces, these tests yield reliable linear dynamic characteristics (structural modes) of the airframe and engine combination. Furthermore, the windmilling forces are far less than would be required to induce non-linear behaviour of the structural material (i.e. yielding). Therefore, a structural dynamic model that is validated by ground vibration test is considered appropriate for the windmilling analysis.

(2) The ground vibration test of the aeroplane may not necessarily provide sufficient information to assure that the transfer of the windmilling imbalance loads from the engine is accounted for correctly. The load transfer characteristics of the engine to airframe interface via the pylon should be validated by test and analysis correlation. In particular, the effect of the point of application of the load on the dynamic characteristics of the integrated model should be investigated in the ground vibration test by using multiple shaker locations.

(3) Structural damping values obtained in the ground vibration tests are considered conservative for application to windmilling dynamic response analysis. Application of higher values of damping consistent with the larger amplitudes associated with windmilling analysis should be justified.

c. Aerodynamic Model. The dynamic behaviour of the whole aeroplane in air at the structural frequency range associated with windmilling is normally validated by the flight flutter tests performed under CS 25.629.

d. Engine Model. The engine model will normally be validated by the Engine manufacturer under CS-E 520(c)(2) by correlation against blade-off test data obtained in showing compliance with CS-E 810. This is aimed at ensuring that the model accurately predicts initial blade release event loads, any rundown resonant response behaviour, frequencies, potential structural failure sequences, and general engine movements and displacements. In addition, if the Failure of a shaft, bearing or bearing support or bird strike event, as required under CS-E 800, result in higher forces being developed, such Failures and there resulting consequences should also be accurately represented.

9. HIGH POWER IMBALANCE CONDITION.

An imbalance condition equivalent to 50 percent of one blade at cruise rotor speed considered to last for 20 seconds may be assumed unless it is shown that the engine will respond automatically and spool down in a shorter period. It should be shown that attitude, airspeed, and altimeter indications will withstand the vibratory environment of the high power condition and operate accurately in that environment. Adequate cues should be available to determine which engine is damaged. Strength and structural endurance need not be considered for this condition.

III) <u>Justification for changes introduced by the Agency</u>

1. PLACEMENT OF AMC

As a result of the JAA NPA, a number of comments were received regarding the placement of this AMC (ACJ) within the regulatory framework. As a result of these comments, the following options were considered:

- i) Retain as AMC 25.901(c)
- ii) Move to AMC-20
- iii) Split the AMC into various AMCs.
- iv) Rename as AMC 25-24

Having considered the merits of each option, the Agency concluded that renaming the AMC as AMC 25-24 offered the best solution. This would retain commonality with FARs, would ensure that the rule was limited in scope to Part 25 and would retain all related material in one location. The only exclusion to this, was in removing AMC material related to the validation of the engine model, which was seen as an engine manufacturer's task and would best be placed in Book 2 of CS-E.

2. DISTRIBUTION OF TEXT BETWEEN CS-E AND CS-25

(See justification in Section D.III)

IV) JAA NPA 25E-306 Comment Response Document

1. JAA NPA 25E-306 was published for consultation by the JAA on 1 February 2002.

2. By the closing date of 1 May 2002, the JAA had received 50 comments from 8 national authorities, professional organisations and private companies.

3. All comments received have been passed to the Agency and incorporated into a Comment Response Document (CRD). This CRD contains a list of all persons and/or organisations that have provided comments and the Agency's answers.

4. In responding to comments, a standard terminology has been applied to attest the Agency's acceptance of the comment. This terminology is as follows:

   - **Accepted –** The comment is agreed by the Agency and any proposed amendment is wholly transferred to the revised text.
   - **Partially Accepted –** Either the comment is only agreed in part by the Agency, or the comment is agreed by the Agency but any proposed amendment is partially transferred to the revised text.
   - **Noted –** The comment is acknowledged by the Agency but no change to the existing text is considered necessary.
   - **Not Accepted** - The comment is not shared by the Agency

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
1.	General	CAA DK	Agreement without comment.	**Noted**	(No Change)
2.	General	Austro Control	NPA 25E-306 is acceptable for ACG.	**Noted**	(No Change)
3.	General	Transport Canada	TC agrees with the NPA	**Noted**	(No Change)
4.	General	Rolls Royce	The NPA, although itself acknowledging that it is purely advisory material and is 'not the only means' of compliance, goes on to read more like a requirement and appears to provide little flexibility in compliance. Further, it appears to create additional engine requirements without the direct input of the Engine Study Group.	**Noted** This EASA NPA is a further development of the original JAA NPA 25E-306 and was developed by a dedicated rulemaking group, which included representatives from the engine community.	(See proposals)
5.	General	DGAC France	The format of all NPAs should be harmonised throughout the JAA system (JAR 11.060 (d)). Furthermore, we note that the numbering system of the proposed ACJ is not complying with the guidelines of ACJ 11.050 (there is a paragraph numbered: "5 c 4 (a) (1) (aa)"!). The numbering of our JAR-E texts might also be slightly out of the guidelines but they are not as bad as in this ACJ.	**Noted** The formatting of the NPA has been addressed in this revision. Paragraph numbering is retained to align with FAA AC 25-24.	(Editorial Changes)
6.	General	DGAC France	The ACJ seems to set requirements by means of interpretative material (see §5 a, which is almost: "It *must* be shown by a combination of tests and analyses that after partial or complete loss of an engine fan blade, including collateral damage, or after shaft support failure, the airplane is capable of continued safe flight and	**Accepted** The use of words such as "must" and "should" has been reviewed for this NPA.	(Editorial Change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			landing": it seems, when reading this ACJ, that the "should" is in reality a "must").		
7.	General	F. Fagegaltier, chairman JAA engine study group	The proposal is an ACJ to 25.901(c). Then, this could be understood as indicating that the only concern behind 25.901(c) is a concern with the aircraft structure or the flight crew ability to fly the aircraft in a continued engine imbalance situation. The link with 25.1309 (which is the basic requirement of 25.901(c)) is not obvious. It would be interesting to know if this very limited applicability of 25.901(c) is supported by the PPSG.	**Accepted** To indicate that this AMC is not specific to CS 25.901(c), and in line with the FAA designation, the AMC is moved to the General section of Book 2 and renamed AMC 25-24. (See also justification given in Section C.III)	**~~ACJ 25.901(c)~~AMC 25-24** **Sustained Engine Imbalance**
8.	General	F. Fagegaltier, chairman JAA engine study group	It is also surprising to see an ACJ to 25.901(c) and not to 25.903(c) which would appear as being more appropriate, at least from the content of the rule itself (continued rotation should not jeopardise continued safe flight and landing).	**Noted** (See response to Comment #7.)	(No Change)
9.	General	F. Fagegaltier, chairman JAA engine study group	It seems strange to see, in a draft response to comments document, that no response is necessary to the ESG comment on the fact that this ACJ constitutes "rulemaking by advisory material" when this is now formally forbidden.	**Noted** The proposed changes have been reviewed and proposals changed or moved to better reflect their rule status.	(See proposal)
10.	General	F. Fagegaltier, chairman JAA engine study group	It seems that the appropriate co-ordination between the structure study group, the powerplant study group and the engine study group (other groups?) has not taken place before issuance of this NPA for comments. According to JAR-11.060(e)(4), this should not occur: the	**Noted** The engine community has been fully involved in the development of these EASA proposals.	(No Change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			consistency of JAR-E requirements and JAR-25 "advisory material" should be discussed in co-ordination with all appropriate people.		
11.	General	F. Fegagaltier, chairman JAA engine study group	JAR-E contains rules for engine continued rotation (JAR-E 525) and for providing data to aircraft manufacturer (JAR-E 520(c)(2)). By means of this package, we ensure the safe behaviour of the engine and we deal with the interface with the aircraft by providing information.	**Noted** Interface issues between CS-25 and CS-E have been addressed in this EASA NPA.	(See proposals)
12.	General	F. Fegagaltier, chairman JAA engine study group	The proposed ACJ imposes "rules" for aircraft certification without assessing the compatibility and appropriateness of the engine rules (the authors obviously ignored the requirements of JAR-E 520(c)(2); the simple addition of a reference to this paragraph in the ACJ at last minute because ESG made a comment is not an appropriate response to the concern).	**Noted** As part of this rulemaking task, EASA set up a rulemaking group with representatives from both the airframe and engine manufacturers to review the JAA NPA.	(See proposals)
13.	General	F. Fegagaltier, chairman JAA engine study group	If the data required by JAR-E 520(c)(2) are not adequate for aircraft certification, this should be explained and discussed to determine how JAR-E should be modified. There is no point in asking for some data which would not be used!	**Noted** (See comment #12) (See also proposed changes to CS-E 520(c)(2) in Section D of this NPA).	(No Change)
14.	General	DGAC France	It must be remembered that the result of the blade off test may indeed be the worst case scenario in terms of initial engine reaction and containment on the release of a single complete blade, however the large bird test simply requires safe shutdown and does not limit the	**Accepted** The structural failure scenarios in AMC 25-24 have been expanded to consider other failure conditions.	5. <u>EVALUATION OF THE WINDMILLING IMBALANCE CONDITIONS</u> a. <u>Objective</u>. It should be shown by a combination of tests and

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			material loss to a single blade. The partial loss of multiple blades may be more severe in terms of sustained imbalance than the blade off test. Other engine effects, such as the loss of multiple blades due to fan flutter could also happen.		analyses that after: i) partial or complete loss of an engine fan blade, or ii) after bearing/bearing support failure, or iii) any other failure condition that could result in higher induced vibrations including collateral damage, the aeroplane is capable of continued safe flight and landing. … e. <u>Other failure conditions</u>. If any other engine structural failure conditions applicable to the specific engine design could result in more severe induced vibrations than the blade loss or bearing/bearing support failure condition, they should be evaluated. Examples of other engine structural failure conditions that should be considered in this respect are: • failure of a shaft, or • a large bird ingestion.
15.	Paragraph 2	DGAC France	There is no detailed justification of the proposal in this NPA. This is abnormal. There should be a summary of in-service data (or any other source of data), a definition of a safety goal and a demonstration that the	**Accepted** A more expanded justification and background is given in the Appendix to this NPA	(No change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			proposals are adequate in relation to the goal and are supported by the provided data. **Justification:** This NPA should be re-issued for comments after consideration of all comments and should incorporate clear, precise and detailed justification.		
16.	ACJ 25.901 (c) Paragraph 1	DGAC France	This paragraph refers to undetermined JAR-25 provisions "related to the aircraft design for sustained engine rotor imbalance conditions". Although this ACJ is supposed to interpret 25.901 (c), this cannot be 25.901 (c) which simply refers to 1309. It would be useful to clearly identify the JAR-25 rules which are used to impose the "requirements" of this ACJ. This 25.901(c) is of very high level, even much higher than the essential rules which are considered for EASA. Even 25.903(c) is of high level ("continued rotation (should not) jeopardise the safety of the aeroplane"). Therefore, all this ACJ is really certification specifications and the main elements should be part of section 1 of JAR-25. **Justification:** This NPA should be re-assessed in view of	**Partially Accepted** .(See response to Comment #7) The associated rules are already identified in Section 2 "Related CS Paragraphs".	(No change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			splitting the material of the ACJ into rules in section 1 of JAR and interpretative material in a new ACJ.		
17.	ACJ 25.901(c) Paragraph 2	CAA UK	Related JAR paragraphs. Under the proposed paragraph 2 of the ACJ, the list of related JAR paragraphs could be expanded to include JAR-E 525 (Continued rotation) and JAR-E 710 (Rotor locking tests). Both of these, together with their associated ACJ material, are directly relevant to the subject of this NPA 25E-306.	**Partially Accepted** Reference to CS-E 525 and CS-E 850 are added. Reference to CS-E 710 is not directly related to this subject and is not included. Reference to CS 25.901 is added for consistency with FAR AC 25-24.	**AMC 25-24** **Sustained Engine Imbalance** … 2. <u>RELATED CS PARAGRAPHS</u> a. <u>CS-25</u>: CS 25.571 "Damage tolerance and fatigue evaluation of structure" CS 25.629 "Aeroelastic stability requirements" CS 25.901 "Installation" CS 25.903 "Engines" b. <u>CS-E</u>: CS-E 520 "Strength" CS-E 525 "Continued Rotation" CS-E 810 "Compressor and Turbine Blade Failure" CS-E 850 "Compressor, Fan and Turbine Shafts"
18.	General	F. Fagegaltier, chairman JAA engine study group	It is not clear that the new FAR 33 / JAR-E harmonised texts on engine continued rotation have been taken into account when preparing this NPA 25E-306. There is no cross-reference to engine rules on the subject (JAR-E 525). As a minimum, we would expect some words on this interface subject to ensure that our engine rules (found in section 1 of JAR-E) are compatible with the aircraft "rules" (only found in ACJ!!).	**Accepted** Cross references to CS-E 525 has been added.	
19.		DGAC France	We note that there is no reference to JAR-E 520 (c)(2) which is much more relevant than the JAR-E 810 which is noted in this NPA.	**Not Accepted** Reference to CS-E 520 is already included.	
20.	ACJ 25.901(c) Paragraph 3	DGAC France	The ACJ defines an 'Imbalance Design Fraction' (IDF), which would appear to be a safety factor on the information supplied by the engine constructor following the blade out test. However, this factor is set to 1.0 throughout the rest of the ACJ. It would be necessary to	**Partially Accepted** IDF has historically been used to define the level of damage relative to the testing conducted under CS-E 810. Statistically it can be shown that with an IDF=1 and specified diversion times, an	

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			confirm the purpose of this factor and also that setting the value to 1.0 means that in effect no safety factor is applied.	acceptable level of safety can be achieved. (Ref LDHWG final report in Appendix)	
21.	ACJ 25.901(c) Para 3(e)	CAA UK	It is not always simply the results of tests that determine the level of imbalance; further analysis may be required to ensure all factors are taken into account. In the proposed paragraph 3e, "Imbalance Design Fraction (IDF)", it is therefore suggested that the text be changed to read: *"The ration of the design imbalance to the imbalance (including all collateral damage) resulting from a single release of a turbine, compressor, or fan blade at redline speed (as established when demonstrating compliance with JAR-E 810)"*.	**Partially Accepted** Definition of IDF has been amended.	3. DEFINITIONS … e. Imbalance Design Fraction (IDF). The ratio of the design imbalance to the imbalance (including all collateral damage) resulting from ~~tests of~~ release of a single ~~release of a~~ turbine, compressor, or fan blade at the maximum rotational speed to be approved, in accordance ~~redline speed (as usually conducted for compliance~~ with CS-E 810.
22.	ACJ 25.901 (c), paragraph 3e general comment	DGAC France	The definition of IDF is not precise enough. "Redline speed" is not defined. We have "red lines" for various ratings: which one is considered here? (note: "red line" usually means "certified limit") It should also be noted that JAR-E 810 does not test the engine to the highest red line (see ACJ E 810 which excludes any approved transient over-speed). Why is there such a definition when everywhere in this ACJ this factor is set to one? Apparently there is no safety margin above a failure case	**Partially Accepted** (See response to Comment #14 & #21)	

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			which is severe but may be not the most severe one. Multiple fan blade failures due to bird ingestion of flutter might induce higher loads.		
23.	ACJ 25.901(c) Para 3(f)	CAA UK	For clarity it is suggested that the proposed paragraph 3f be amended to include the words “of an engine” at the end of the sentence.	**Not Accepted** The text is believed to be clear without any further addition.	(No change)
24.	ACJ 25.901(c) Para 4(a)	DGAC France	We suggest as a minimum to add, in §4 a, the following: “JAR-E 520 (c)(2) requires that data … (see current text of JAR-E)”.	**Accepted**	
25.	ACJ 25.901 (c) Para 4(b)	DGAC France	What is a “critical equipment”? (third line) **Justification:** Clarification of wording. An undefined wording makes difficult the application of the text.	**Accepted** The words “critical equipment” in paragraph 4.b. of the proposed advisory material will be replaced by “equipment necessary for continued safe flight and landing”. (Also in paragraph 5.b.3)	4. BACKGROUND … b. Blade Failure. The failure of a fan blade …throughout the airframe that may damage the nacelles, ~~critical equipment~~, equipment necessary for continued safe flight and landing, engine mounts, and airframe primary structure. Also, …
26.	ACJ 25.901(c) Para 4(b) general comment	CAA UK	In paragraph 4b the final sentence states that, “However, large high bypass ratio engines are practically impossible to stop in flight.” This may not necessarily be true. There may however be other reasons why it may be undesirable to stop such engines from rotating in flight, such as the large amount of drag that such an action may produce. It is therefore suggested that this sentence be changed to read,	**Accepted**	4. BACKGROUND … b. Blade Failure. The failure of a fan blade …could jeopardise the safety of the aeroplane. ~~However, large high bypass ratio fans are practically impossible to stop in flight.~~ However, it may be impractical or undesirable to stop the windmilling

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			"However, it may be impractical or undesirable to stop the windmilling rotation of large high bypass ration engines in flight."		rotation of large high bypass ratio engines in flight. …
27.	ACJ 25.901 (c) Para 4(b)	Dassault	The vibratory loads resulting from the failure of a fan blade have traditionally been regarded as insignificant relative to other portions of the design load spectrum for the aeroplane. However, the progression to larger fan diameters and fewer blades with larger chords has changed the significance of engine structural failures that result in an imbalanced rotating assembly. **Justification:** Engine location is also a driving parameter and windmilling on fuselage mounted engines with small fans do not result in significant loads.	**Not Accepted** Although it is recognised that engine imbalance loads may depend on the aircraft configuration, as stated in paragraph 4.f. of the proposed advisory material, this NPA is deemed applicable to small and large engines, regardless of location (wing or airframe mounted).	(No change)
28.	ACJ 25.901(c) Para 4(c)	CAA UK	The statement in paragraph 4c is not accepted. Unless the supporting evidence can be presented that shaft support failures have indeed resulted in levels of imbalance comparable to that resulting from the loss of a fan blade, it is suggested that this paragraph be withdrawn.	**Partially Accepted** Last part of sentence is deleted.	4. BACKGROUND … c. ~~Shaft~~ Bearing/Bearing Support Failure. Service experience has shown that failures of ~~shaft~~ bearings/bearing supports ~~and shaft support structure~~ have also resulted in sustained high vibratory loads. ~~similar to the sustained imbalance loads resulting from fan blade loss.~~
29.	ACJ	DGAC	"After the engine is spooled down": this does	**Accepted**	4. BACKGROUND

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
	25.901 (c) Para 4(d)(1)	France	not mean that the engine is shut down. The usual understanding of windmilling implies that the engine is shut down. Why is this different here?	The words "spooled down" in paragraph 4.d.(1) of the proposed advisory material is replaced by "shut down".	… d. Imbalance Conditions … (1) Windmilling Condition. The windmilling condition results after the engine is ~~spooled~~ shut down but continues to rotate under aerodynamic forces. The …
30.	ACJ 25.901 (c) Para 4(e)	DGAC France	Who is the author of this report? Where can it be found? Why is there no "summary" of the supporting data in the justification of the NPA? This paragraph 4e should be deleted and replaced by a detailed justification of the proposals in the "justification" of the NPA. **Justification:** Clarification. This ACJ should not be used to try to justify the proposal (see 4e and 4f).	**Accepted** The final report on Engine Windmilling Imbalance Loads produced by the ARAC LDHWG is contained in the Appendix to this NPA	(No change)
31.	ACJ 25.901 (c) Para 4(f)	DGAC France	Where are these data? How can we find them for checking? Are they related to the report referenced in 4 e? **Justification:** Clarification of reference. Again, a lack of justification of the adequacy of the proposals.	**Accepted** (See response to Comment #30)	(No change)
32.	ACJ	DGAC	32.1 To be sure that this is not rulemaking by	**32.1 Partially Accepted**	

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
	25.901 (c) Para 5(a)	France	advisory material the reference of the applicable rule imposing this objective should be given (is it 25.903(c)?). 32.2 It should be clearly spelled out that the worst case is not addressed and that therefore the aeroplane is not expected to continue safe flight and landing in these more severe cases. This should be justified in relation to the overall safety objective intended in JAR-25 and supported by data.	The AMC is renamed AMC 25-24 and moved to the general section of Book 2. References to applicable rules are identified in Section 2 of the AMC. **32.2 Noted** Historically the fan blade loss condition generates the most severe conditions on the airframe. However, other failure conditions, currently part of engine certification under CS-E, could theoretically result in more severe conditions. While recognising that even more severe blade-off events are possible, their occurrence are considered to be so improbable that they go beyond the intended safety level. (See response to Comment #14)	
33.	ACJ 25.901 (c) Para 5(b)	Goodrich Corp.	What is the acceptable level of cockpit vibration that will permit the crew to perform their functions to read instruments and check lists? This vibration level should be defined?	**Accepted** A reference to ISO 2631/1 is added to paragraph 5.b of the AMC.	*(Footnote to Section 5 (b))* An acceptable level of cockpit vibration in terms of vibration frequency, acceleration magnitude, exposure time and direction may be found in ISO 2631/1 "International Standard, Evaluation of Human Exposure to Whole-Body Vibration, Part I: General Requirements", 1985.
34.	ACJ 25.901 (c) Para 5(c)(1)	DGAC France	34.1 "An evaluation of service experience": these data should be presented in the justification of the NPA so that the pertinence of	**34.1 Accepted** (See response to Comment #15)	(No change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
	general comment		the statement could be assessed. 34.2 The 1.0 value for the IDF factor should be similarly explained in the justification: as defined the IDF is not the most severe case. **Justification:** Clarification.	**34.2 Partially Accepted** (See response to Comment 21 & 32.2)	
35.	ACJ 25.901(c) Para 5(c)(1)	CAA UK	Paragraph 5c(1) refers to service experience and sets acceptable conditions for compliance based on this service experience. Given the work of the JAA´s LROPS working group, this service experience may not be representative of expected future operations. The work of the LROPS working group should be taken into account in setting acceptable means of compliance criteria.	**Not Accepted** The service experience reviewed when preparing this NPA is considered to be still valid when looking at expected future operations. In addition, as explained in the proposed advisory material, paragraph 5.c.(1), diversion times greater than 180 minutes need not be considered.	(No change)
36.	ACJ 25.901(c) Para 5c(2)(a)	Dassault	The analysis should take into account unsteady aerodynamic characteristics and all significant structural degrees of freedom including rigid body modes. **Justification:** On fuselage mounted small fan engines vibration levels are independent on aerodynamics. Accounting for unsteady aerodynamics in a time dependent phenomenon is a heavy unnecessary work.	**Not Accepted** (See response to Comment #27) Note that under 6.b. provision is made to allow a reduction in the scope of the analysis, both in terms of extent and depth, for aeroplane configurations where the windmilling loads and accelerations are shown not to be significant.	(No change)
37.	ACJ	DGAC	37.1 Consistency with JAR 25.301(a) is not	**37.1 Noted**	(No change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
	25.901(c) Para 5c(3)(a) 1 and 2	France	obvious. The limit loads are supposed to be the maximum loads to be expected in service: is this really the case here? Does this mean that this ACJ deviates from the published rules? This would not be acceptable: no rulemaking by ACJ. 37.2 In 25.303, the safety factor above limit loads is set to 1.5 and the safety factor above ultimate loads is set to 1. How is the proposed 1.375 factor justified?	(See comment 32.2). **37.2 Not Accepted** The safety factor is linked to the probability of being in the failure condition. For the derivation of the factor 1.375 see CS 25.302.	
38.	ACJ 25.901 (c), Para 5c(3)(a) 3 and 4	DGAC France	Consistency with JAR 25.301(a) is not obvious. The limit loads are supposed to be the maximum loads to be expected in service. It is not easy to determine if the loads which are considered here are under or above the maximum to be expected in service (there is no justification of the proposals in this NPA). Then it is even more difficult to determine if they are really "ultimate" loads! Does this mean that this ACJ deviates from the published rules? This would not be acceptable: no rulemaking by ACJ.	**Noted** (See comment #32.2).	(No change)
39.	ACJ 25.901 (c) Para 5c(4)(a)	DGAC France	The wording is "the criteria for the condition in paragraph 5c(1)(a) are set…". This is a very complex way of stating the following: "The 1-hour diversion flight is set…".	**Not Accepted** The text as proposed is deemed to be sufficiently clear.	(No change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			This second wording is proposed to replace the text of the ACJ (if this is what the authors wanted to say).		
40.	ACJ 25.901 (c) table 1 general comment	DGAC France	It is interesting to note that the "1-hour diversion flight" suddenly becomes a "60-minute diversion". Although it is the same duration, the change in wording should be avoided. **Justification:** Consistency of vocabulary.	**Accepted** For consistency, diversion times will be quoted in minutes throughout.	(Editorial Change)
41.	ACJ 25.901 (c) Para 5d	DGAC France	This looks like a new requirement for engine certification, in addition to JAR-E 520 (c)(2). Rulemaking by advisory material should not occur, especially when an ACJ to JAR-25 tries to impose a new JAR-E requirement. **Justification:** Consistency of JAR codes should be ensured, with the engine requirements in engine code and aircraft requirements in aircraft code. This NPA should be sent back to an ad hoc group involving engine specialists to ensure that codes are consistent.	**Partially Accepted** (See proposals & Justification to change CS-E. (Section D, II & III))	
42.	ACJ 25.901(c)	Rolls Royce	**Shaft Support Failure** We have a significant concern over the ability to	**Accepted** Text added to AMC 25-24 paragraph 5	5. <u>EVALUATION OF THE WINDMILLING IMBALANCE</u>

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
	Para 5.d		perform a meaningful analysis of the imbalance effects caused simply by a failure of a bearing support. Unlike the fan blade-off condition, there is little test or service experience to validate any such analysis and consequently it may prove difficult to demonstrate conclusively that the loads and vibrations produced in this case are less than those produced by the blade off event. There appears to be some recognition of this in the NPA (Section 8 – Validation) by the lack of any mention in this section of the shaft support failure condition. While we believe that this failure type would not give rise to conditions worse than the fan blade off condition, the lack of in-service examples suggest that this issue would be better addressed via the safety analysis and claiming that such an event is sufficiently remote. We therefore propose that 5.d recognizes that an alternative approach would be to address such a condition in the safety analysis.	(d).	CONDITIONS … d. ~~Shaft~~ Bearing/bearing Support Failure. … An alternative means of compliance is to conduct an assessment of the design by analogy with previous engines to demonstrate this type of failure is unlikely to occur. Previous engines should be of similar design and have accumulated a significant amount of flight hours with no adverse service experience.
43.	ACJ 25.901(c) Para 6(c)	Dassault	The evaluation of equipment and human factors may require additional analyses or tests. For example, the analysis may need to produce floor vibration levels, and the human factors evaluation may require a test (or analysis) to subject the seat and the human subject to floor	**Partially Accepted** For acceptable vibration levels - See response to Comment #33 This AMC is applicable to all engine and types and mounting positions. (See	(No change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			vibration. **Justification:** There is a need for JAA provision regarding the acceptable vibration level as a function of frequency in order to help manufacturers. **Dassault conclusion:** it should be mentioned that part of this NPA is only applicable to a/c equipped with wing mounted large fan engines.	also response to Comment #36)	
44.	ACJ 25.901 (c) Para 7(c)	DGAC France	Again, this looks like a new requirement for engine certification. Rulemaking by advisory material should not occur, especially when an ACJ to JAR-25 tries to impose a new JAR-E requirement. This is obvious for example from the wording in 7 c (3):"manufacturers whose engines fail… Should also evaluate…". This ACJ imposes some additional requirement onto the engine manufacturers!! **Justification:** Consistency of JAR codes should be ensured, with the engine requirements in engine code and aircraft requirements in aircraft code. This NPA should be sent back to an ad hoc group involving engine specialists to ensure that codes are consistent.	**Not Accepted** Section 7 .c. is intended to offer advice to the airframe manufacturer to enable an integrated model of sufficient fidelity to be assembled and which contains the required engine features.	
45.	ACJ	DGAC	Again, this looks like a new requirement for	**Partially Accepted**	

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
	25.901 (c) Para 7(f)	France	engine certification, in addition to existing JAR-E 520 (c)(2). Currently there is no requirement to establish a calibrated engine structural model. Rulemaking by advisory material should not occur, especially when an ACJ to JAR-25 tries to impose a new JAR-E requirement. **Justification:** Consistency of JAR codes should be ensured, with the engine requirements in engine code and aircraft requirements in aircraft code. This NPA should be sent back to an ad hoc group involving engine specialists to ensure that codes are consistent.	(See proposals & Justification to change CS-E. (Section D, II & III))	
46.	ACJ 25.901(c) Para 8(b)(3)	Goodrich Corp.	Is it permitted to use measured damping values obtained from max fan out-of-balance ground vibration tests? Suggest "… in the ground vibration tests…" be changed to "…in any ground vibration tests…". **Justification:** It is not clear what tests can be included as part of ground vibration test.	**Not Accepted** The wording of the NPA as proposed is sufficiently general to allow the (substantiated) use of damping evaluations from e.g. engine tests.	(No change)
47.	ACJ 25.901 (c) Para 8(d)	DGAC France	The wording is strictly a new rule: "the engine model **<u>is</u>** validated on **<u>dedicated</u>** vibration tests"!! (underline added)	**Partially Accepted** (See proposals & Justification to change CS-E. (Section D, II & III))	

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			Rulemaking by advisory material should not occur, especially when an ACJ to JAR-25 tries to impose a new JAR-E requirement (dedicated vibrations tests). It should be noted that the direct reference to JAR-E 810 is also an interference with engine certification. The requirements is in JAR-E 20 (c)(2) to provide data to the aircraft manufacturer. **Justification:** Consistency of JAR codes should be ensured, with the engine requirements in engine code and aircraft requirements in aircraft code. This NPA should be sent back to an ad hoc group involving engine specialists to ensure that codes are consistent.		
48.	ACJ 25.901 (c) Para 8d(2)	DGAC France	48.1 It is very unlikely, in the current state of the art, that there could be any **validated** means for prediction of the loads, frequencies, etc. in case of the very dynamic fan blade loss event. It is not possible to impose a new requirement which cannot be complied with. 48.2 Furthermore, this NPA seems to rely on a precise model to use reduced safety factor above a case which is not the most severe one. It would appear that this NPA plays dangerously	**48.1 Not Accepted** This is standard practice in compliance demonstration. **48.2 Accepted** (See response to Comment #14)	(No change)

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
			with risk without proper margins. Or, at least, without any justification that the margins are adequate in relation to the overall safety objective (which is not stated). **Justification:** The proposals should be clearly justified in the "justification" of the NPA. This NPA should be sent back to an ad hoc group involving engine specialists to ensure that codes are consistent.		
49.	ACJ 25.901(c) Para. 9	Rolls Royce	High Power Imbalance Condition It needs to be recognised that some engine designs will respond very quickly to such a failure condition and will immediately surge and spool down. The 20 sec. imbalance condition then becomes irrelevant. Therefore we propose that para. 9 should be amended as follows: 9. High Power Imbalance Condition (a) An imbalance condition equivalent to 50% of one blade at cruise rotor speed considered to last for 20 sec. may be assumed unless it is shown that the engine will respond automatically and spool down in a shorter period. It should be shown...	**Accepted**	9. HIGH POWER IMBALANCE CONDITION. ~~a.~~ An imbalance condition equivalent to 50 percent of one blade at cruise rotor speed considered to last for 20 seconds may be assumed unless it is shown that the engine will respond automatically and spool down in a shorter period. It should be shown that attitude, airspeed, and altimeter indications will withstand the vibratory environment of the high power condition and operate accurately in that environment. Adequate cues should be available to determine which engine is damaged. Strength and structural endurance

Ref.	Related Paragraph	Comment provider	Comment/Justification	EASA Response	Resulting text
50.	ACJ 25.901 (c) Para 9a	DGAC France	49.1 Note that there is apparently no sub-paragraph b: is it missing or is it a numbering mistake? 49.2 This paragraph 9a is not explained: what is the probability of occurrence of such an event? Is this a limit or ultimate load condition? The condition considered in this paragraph 9a is apparently not consistent with the conditions which were supposed to be addressed if we rely on paragraph 4d(2) ["which may not be sufficient to cause the engine to spool down on its own"]: on a large fan engine, the loss of half a fan blade would very likely result in a spool down, if not a complete shut down. Should we understand the last sentence of 9a as meaning that it is acceptable to break the engine mounts or the aircraft structure in such an event? ("strength…need not be considered"). **Justification:** The proposals should be clearly justified in the "justification" of the NPA. And the text should be clarified to be fully understandable.	**50.1 Accepted** **50.2 Not Accepted** The high power imbalance condition is intended to define a vibratory condition, and it must be shown that certain indications are able to withstand, and operate accurately in, this condition. It is not intended to create a new limit or ultimate load condition, and it is assumed that the vibratory loads are limited (20 seconds) in duration. Strength and structural endurance need therefore not be considered for this condition.	need not be considered for this condition.

D. Proposed Change to CS-E

I) Explanatory Note

(See also “A.I: General Explanatory Note”)

Comments received on JAA NPA 25C-305 and 25E.306, highlighted issues relating to the interface issues between CS-25 and CS-E, and that further re-organisation and clarification was necessary to ensure that responsibilities were clearly established. The EASA rulemaking group reviewed these comments, and largely concurred with the need to re-organise the proposals. As a result a change to CS-E 520 (c)(2) is proposed.

II) Proposals

The text of the amendment is arranged to show deleted text, new text or a new paragraph as shown below:

1. ~~Text to be deleted is shown with a line through it.~~
2. New text to be inserted is highlighted with grey shading.
3. ….
   Indicates that remaining text is unchanged in front of or following the reflected amendment.
   ….

CS-E BOOK 1: AIRWORTHINESS CODE

Amend CS-E 520(c)(2) as follows:

CS-E 520 Strength

(a) …

(b) …

(c) (1) …

(2) Validated data (from analysis or test or both) must be established and provided for the purpose of enabling each aircraft constructor to ascertain the forces that could be imposed on the aircraft structure and systems as a consequence of out-of-balance running and during any continued rotation with rotor unbalance after shutdown of the Engine following the occurrence of blade Failure as demonstrated in compliance with CS-E 810. If the Failure of a shaft, bearing or bearing support or bird strike event, as required under CS-E 800, result in higher forces being developed, such Failures must also be considered. The data must include, but is not limited to, the relevant out-of-balance forces and Engine stiffnesses, together with the expected variations with time of the rotational speed(s) of the Engine’s main rotating system(s) after ~~blade~~ Failure. (See AMC E 520(c)(2))

(d) …

Create a new AMC 520(c)(2) to CS-E as follows:

AMC E 520(c)(2) Engine Model Validation

(1) Finite element models are typically produced to provide representative connections at the engine-to-pylon interfaces, as well as all interfaces between components (e.g., inlet-to-engine and engine-to-thrust reverser).

(2) Features modelled specifically for blade loss analysis typically include:

- imbalance,
- component failure,
- rubs (blade-to-casing, and intershaft),
- resulting stiffness changes, and
- aerodynamic effects, such as thrust loss and engine surge.

(3) Manufacturers whose engines fail the rotor support structure by design during the blade loss event should also evaluate the effect of the loss of support on engine structural response.

(4) The model should be validated based on vibration tests and results of the blade loss test required for compliance with CS-E 810, giving due allowance for the effects of the test mount structure. The model should be capable of accurately predicting the transient loads from blade release through run-down to steady state. In cases where compliance with CS-E 810 is granted by similarity instead of test, the model should be correlated to prior experience.

(5) Validation of the engine model static structure including the pylon is achieved by a combination of engine and component tests, which include structural tests on major load path components. The adequacy of the engine model to predict rotor critical speeds and forced response behaviour is verified by measuring engine vibratory response when imbalances are added to the fan and other rotors. Vibration data are routinely monitored on a number of engines during the engine development cycle, thereby providing a solid basis for model correlation.

(6) Correlation of the model against the CS-E 810 blade loss engine test is a demonstration that the model accurately predicts:

- initial blade release event loads,
- any rundown resonant response behaviour,
- frequencies,
- potential structural failure sequences, and
- general engine movements and displacements.

(7) To enable this correlation to be performed, instrumentation of the blade loss engine test should be used (e.g., use of high-speed cinema and video cameras, accelerometers, strain gauges, continuity wires, and shaft speed tachometers). This instrumentation should be capable of measuring loads on the engine attachment structure.

(8) The airframe and engine manufacturers should mutually agree upon the definition of the model, based on test and experience.

III) Justification

A significant issue which arose in comments submitted in reply to the public consultation of both JAA NPAs 25C-305 and 25E-306, was the need to redistribute the text developed by the LDHWG between codes (i.e. CS-25 or CS-E) to reflect existing product responsibilities.

CS-E 520(c)(2) currently requires the engine manufacturer to provide the necessary data in order for the airframe manufacturer to determine the forces on aircraft structure and systems as a result of engine out-of-balance forces. While this rule goes a long way towards the intent of the two NPA's, some differences are obvious. What seems to be missing are engine structural failures other than blade failure, more extensive engine modelling (instead of just engine stiffnesses), and model/data validation.

The EASA WG therefore concluded that the following actions were necessary:

- to modify the text of CS-E 520(c)(2) to include consideration of other engine failure conditions required by CS-25.

- to move elements of AMC 25.362 and AMC 25-24 related to engine model validation into a new AMC to CS-E 520(c)(2).

APPENDIX

“Engine Windmilling Imbalance Loads”, July 1997, prepared by a subgroup of the Loads & Dynamics Harmonisation Working Group.

Engine Windmilling Imbalance Loads

Final Report - July 1, 1997

Aviation Rulemaking Advisory Committee

Loads and Dynamics Harmonization Working Group

Engine Imbalance Loads Sub Group

Executive Summary

This report is submitted to complete the task published in the Federal Register (Vol. 61, Number 129) on July 3, 1996 assigned to the Aviation rulemaking Advisory Committee (ARAC) entitled "Engine Windmilling Imbalance Loads." This report details the work performed in establishing an acceptable criteria and methodology for determining the dynamic airplane loads and accelerations resulting from an imbalanced windmilling engine. The conclusions and recommendations of this report represent the fully agreed position of the Loads and Dynamics Harmonization Working Group.

This report addresses fan blade failure events as well as other likely causes of significant engine vibratory loads such as loss of centerline support.

Thorough examination of all known events indicates that none resulted in significant airplane damage and all resulted in continued safe flight and landing. However, an examination of the existing criteria did not identify any specific requirements that would continue to guarantee the positive outcome experienced in the known events. Therefore, the working group developed recommended criteria to assure safety of flight in all future airplanes in the event of windmilling under engine imbalance.

The criteria recommended in this report are applicable to high bypass ratio engines with fan diameters greater than 60 inches. In the absence of evidence justifying an alternative approach providing an equivalent level of safety, these criteria should also be assumed to apply equally to airplanes with smaller diameter engines.

Based on statistical analysis of the service history data of large high bypass ratio engines under windmilling imbalance condition, design evaluation criteria have been developed to ensure continued safe flight and landing following a fan blade loss event.

This is accomplished by establishing the maximum level of engine imbalance and associated diversion times to be used for analytical determination of the airplane loads and accelerations.

Recommendations are included addressing the level of detail required for engine and airframe modelling to adequately describe the dynamic characteristics needed to provide valid loads and accelerations. The working group reviewed the traditional ground vibration tests, flight flutter tests, and tests performed under Sec. 33.94 of 14 CFR and concluded that no further demonstrative ground or flight test programs would be needed in order to achieve the objective of establishing confidence in the proposed methodology.

The working group recommends that a harmonized FAR Part 25 Advisory Circular and an ACJ to JAR 25 be developed based on the technical information contained in this report.

1. Contents

2. Introduction

The gradual evolution of the turbofan engines has led to the introduction of engines with increasing bypass ratio to achieve high fuel efficiency. These engines have the same propulsion principle as the earlier generation high bypass ratio engines. A gas turbine drives a multi-bladed fan that accelerates the oncoming airmass, generating thrust for propelling the aircraft. A small amount of jet thrust is also provided from the engine core. Need for higher efficiency and greater robustness has resulted in fan design consisting of fewer blades of larger mass than previously used.

In the service experience of the existing high bypass ratio engines there had been instances, though very rare, of blade loss and even more rarely, fan shaft support loss. In most cases the fan continues to rotate producing an imbalance load even after the engine combustor has been extinguished. This phenomenon is called imbalance load under engine windmilling. In all cases the airplane safely landed with no other significant damage to the airplane, and without any injury to the passengers or crew.

With the advent of heavier fan blades, the FAA became concerned whether the past design practice that resulted in safe designs will continue to produce safe design for the new engine–airframe combinations. To address this concern the FAA is requiring detailed evaluation of airplanes by means of Issue Papers on new certification programs. In these Issue Papers, the FAA has cited existing sections of the FAR Part 25 as the basis for compliance. The Issue Paper process does not afford sufficient sharing of knowledge with the industry as a whole and the FAA. Therefore, to address the issue the Aviation Rulemaking Advisory Committee (ARAC) has assigned a task to the Loads and Dynamics Harmonization Working Group that consists of experts in this field. The task has been published on July 3, 1996 in the Federal Register, Vol. 61, Number 129, and is reproduced below.

"The Task—This notice is to inform the public that the FAA has asked ARAC to provide advice and recommendation on the following harmonization task:"

"Engine Windmilling Imbalance Loads. Define criteria for establishing the maximum level of engine imbalance that should be considered, taking into account fan blade failures and other likely causes of engine imbalance. Develop an acceptable methodology for determining the dynamic airframe loads and accelerations resulting from an imbalanced windmilling engine. Validate the proposed methodology with a demonstrative ground or flight test program (as deemed appropriate by ARAC) that has the objective of establishing confidence in the proposed methodology. The validation process should answer the following questions; (1) What are the parameters to consider in determining the minimum degree of dynamic structural modeling needed to properly represent the imbalanced condition; (2) Is the proposed analytical methodology taken in conjunction with the traditional ground vibration tests, flight flutter tests, and tests performed under Sec. 33.94 of 14 CFR sufficient, or are there additional tests measurements that need to be made to address this condition."

"Within 12 months from the date of the published notice of new task in the Federal Register, complete the above task and submit a report to the FAA with recommendations detailing the criteria and methodology."

In this report a thorough review of the service history of high bypass ratio engines under windmilling imbalance condition is presented. The service history data have been examined by the engine companies, the aircraft manufacturers, and the FAA and JAA specialists. Based on the evaluation of the service history data, recommendations have been made on design evaluation criteria.

Extensive industry experience of ground and flight testing pertaining to dynamic behavior of the airframe–engine combination has been reviewed. Analytical results have been correlated with the test results. Appropriate methodology for determining airframe loads and accelerations are presented. The methodology has been essentially validated by ground and flight tests currently performed to satisfy various sections of the 14 CFR.

Where additional tests can contribute to further increase confidence, they have been identified.

This report completes the above mentioned task assigned to the Loads and Dynamics Harmonization Working Group.

3. Service History

The service history of large high bypass ratio turbofan engines from entry into service up to May 1996 is comprised of 426 million engine flight hours. During this period 152 notable events have occurred. A notable event represents either a condition where an imbalance equivalent to one fourth of a fan blade or greater is experienced, or a condition resulting from the failure of a support element of the rotor. (Large is defined as engines with a fan diameter of 60 inches or greater. Engine flight hours are defined as the time period from the start of takeoff roll to touchdown.) While events involving loss of fan blade material equivalent to less than one fourth of a blade have occurred in service, these have not caused significant vibrations. The fan blade loss events are more common than fan rotor support loss events; 146 vs. 6. In this chapter the service history data for both of these imbalance conditions are analyzed.

Fan Blade Loss

Fan blade loss has occurred in service for various reasons; for example, bird strike, foreign object ingestion and high and low cycle fatigue. Service history data indicates a gradual improvement in the robustness of the fan blades as a result of the industry's effort to improve all aspects of fan blade design, manufacture, and maintenance. Though significant improvement has been achieved over time, to be conservative, the entire service history is considered as a single set.

The available service history data consist of blade–out material release fractions and subsequent windmilling time for large modern high by-pass ratio fan engines. The database includes events occurring from entry into service through May 1996, a period of approximately three decades. A total of 146 events in the resulting database are used for statistical analysis.

The primary parameters used in the statistical analysis are imbalance design fraction (IDF) and the windmilling time . Windmilling time is defined as the time in minutes from blade release to landing. An IDF of 1.0 is defined as the mass imbalance that would result from failure of the most critical turbine, compressor, or fan blade under the conditions specified for the blade containment and rotor imbalance tests in section 33.94 of 14 CFR. Blade fraction is defined as the vector sum of the mass moments of the lost rotor material divided by the mass imbalance of one blade removed at the dovetail fillet. Mathematically this value is expressed as:

$$Blade\ Fraction = \frac{\sqrt{\left(\sum_{i=1}^{n} m_i \cdot r_i \cdot \cos\theta_i\right)^2 + \left(\sum_{i=1}^{n} m_i \cdot r_i \cdot \sin\theta_i\right)^2}}{m_b \cdot r_b}$$

Where,

m = a missing rotor mass

r = the radius from the rotor center to the center of gravity of m

θ = an angle measured from a fixed axis (normal to the axis of rotation) to the radial line, r

And subscripts are,

i identifies the ith missing mass of n items

b identifies a removed blade

The statistical analysis is used to derive exceedance curves, and thus to determine exceedance rates over a wide range of IDF and windmilling time values. In order to accomplish this task, the cumulative distribution functions (CDF) for the IDF and windmilling times were generated. At least two methods could be used to generate the CDF's for the two distributions. The first would be to use the ranked raw data, and the second would be to use continuous distributions. There are good reasons for considering both approaches. The raw data is the historical record with all of the events included, even those that may be considered anomalous. The perspective provided may be useful in bounding the issues considered in this document. However, the continuous distributions may be more realistic for predicting the behavior of future events since they are weighted by the bulk of the data. Thus, the effect of potentially anomalous data at the extreme end of the sample is damped which reduces overly conservative estimates of events.

Histograms of design fraction and windmill time are shown in Figures 3.1 and 3.2 together with the actual numbers of events. The histograms are included in modified form in other figures for comparison with the distribution fits.

The data were tested for fit using three different statistical distributions: gamma, Weibull and lognormal. These distributions were chosen because they do not have negative values and they can be shaped to minimize the effect of the lack of data between 0 and 0.1 IDF (0.25 blade fraction) where data was not collected.

The parameters for the gamma, Weibull, and lognormal distributions are obtained by finding the maximum likelihood estimators (MLE) for each of the distributions based on the data sets. Once the parameters are determined, the data are compared graphically to the distribution in two ways.

The first comparison is of the three distributions to a normalized histogram of the data. The area under the normalized histogram is one. This allows comparison against a probability density function (pdf) and is shown in Figure 3.3a. All three of the distributions follow the same trend, but the gamma pdf and the lognormal pdf follow the shape of the histogram more closely. The peak of the lognormal pdf is slightly closer to the peak of the histogram than the gamma pdf.

The second graphical method compares the MLE distributions against the ranked data for the CDF and 1 – CDF. This is accomplished by ordering the data and assigning an order number, i. The CDF is estimated as follows:

$$CDF(i) = \frac{i - 0.3}{N + 0.4}$$

where:
N = total data points that occurred in flight
i = order number

The comparisons of the MLE distributions against the ranked data for design fraction are shown in Figures 3.3b and 3.3c.

A correlation coefficient (R^2) estimate of the fitted distributions has been determined. These are seen in Figure 3.3c, along with plots of the CDF. The lognormal distribution has a greater value of R^2 than the other two distributions.

The parameter estimates are listed in Figure 3.3b and shows 1 - CDF, which is the probability of that event or greater occurring. The tails of the distributions in Figure 3.3b shows that the lognormal distribution will give the highest probability for a given event or larger, making the lognormal distribution the most conservative at the high end of the distribution.

Since the lognormal distribution gives the best representation of the data and is the most conservative for extreme values, it is used to represent the IDF distribution in the rest of the analyses.

The statistics for windmilling event duration after blade loss are also fitted with the three types of distributions. Similar comparisons that are shown in Figure 3.3 for imbalance design fraction are shown in Figure 3.4 for the windmilling duration. The reporting of windmill times is typically split into 10 minute increments, causing difficulty in fitting a continuous distribution. In addition there are three notable clusters at twenty, thirty, and fifty minutes. These times are typical of events which occur early in climb and top of climb without fuel dump, and any event which occurs up to top of climb with a fuel dump before return, respectively. The Weibull distribution appeared to fit slightly better than the other two distributions but the lognormal distribution is chosen for further analyses since it is most conservative at the high end of the distribution.

Figure 3.5 shows a scatter plot of windmill time versus design fraction. The correlation coefficient (R^2) between blade fraction and windmill time was computed for a linear fit to be 0.05. Based on R^2, IDF and windmill time are statistically independent of one another. Thus, the joint probability function is defined as follows:

$$P(x,w) = (1 - F_X(x))(1 - F_W(w))$$

where:

P = probability of an event with $X \geq x$ and $W \geq w$.
x = imbalance design fraction
w = windmill time (minutes)
F_X = CDF for imbalance design fraction
F_W = CDF for windmill time (minutes)

The joint probability function is used to calculate the probability of having an event with an IDF of x or greater, and a windmill time of w or greater.

The exceedance rate curves are generated using the previously defined joint probability function with the number of reported fan blade separation incidents which occurred in flight and the corresponding total number of hours accumulated by all large high bypass ratio engines. The formula used to calculate the exceedance rate is:

$$Exceedance\ Rate = \frac{N_I \cdot P(x,w)}{C_T}$$

where:

C_T = total number of engine flight hours in database
N_I = number of reported incidents in database above V_1

Note that the exceedance rates are based on the number of fan blade loss events that occurred during the flight phase; i.e., at speeds greater than decision speed (V_1). If one were to include all blade loss events from start of takeoff roll to airplane stop after landing, the exceedance rate would be approximately thirty percent greater than that computed for the 124 in flight events. However, the resulting probabilities would then require scaling by the probability that the blade release event occurred in flight (about 0.76), bringing the result back to the one in the above equation. The engine hour exceedance rates for various design fractions and windmill times are shown in Figure 3.6. The joint probability function used in this calculation was generated using the lognormal distributions for IDF and windmilling time. The reader may substitute the actual data CDF's to obtain an actual data estimate of the exceedance curves if desired.

Exceedance rates in airplane hours may be obtained from Figure 3.6 by multiplying the ordinate by the number of engines used on the airplane.

A conservative estimate of the impact of including the loss of centerline support events in the analysis showed that the exceedance values at 1.0 IDF and windmilling times greater than zero, 60 and 180 minutes increased to 3.5×10^{-8}, 6.3×10^{-9} and 1×10^{-10} per engine flight hour, respectively. These changes to the exceedance estimates would not alter the conclusions drawn in this report.

Engine Rundown and Shutdown Experience

Service experience indicates that rundowns occur at all levels of blade fraction within the database. Engines which have experienced a full blade loss or more have always rundown to idle or below within a few seconds after blade release All were shut down by the flight crew within a few seconds after rundown.

Rundown experience is less clear for blade fractions less than one. The consensus of the engine manufacturers is that 20 seconds run–on for self shutdown or crew intervention is a reasonable time for blade fractions greater than 0.50 but less than 1.0 Some events between 0.25 and less than 0.5 blade fraction may run on indefinitely unless the crew takes action to shut down the engine. Although these events cause higher frequency vibration than windmilling events and are not a threat to the airplane structure they have caused crew confusion as to which engine should be shut down. Engine secondary damage resulting from the run on at power has in some cases caused engine conditions which could be hazardous to the airplane (for example through an engine fire). Consideration should be given to ensure that on future airplane designs the crew members are able to make the decision to shut down the appropriate engine in a timely manner.

Fan Rotor Support Loss

Service history database contains six events where fan rotor support loss has resulted in moderate to heavy vibration as characterized by crew comments. These events are shown in Table 3.1. In all cases the crew were able to fly the airplane to complete a safe flight and landing. There were no reports of airplane damage beyond loss of some small access panels and minor structural element cracks (which were not substantiated as being caused by the event) for any of the support loss events. There are six fan rotor support loss events, giving an estimated cumulative probability of 1.41 x 10^{-8} per engine flight hour. However, five of the events have occurred since 1995 leaving a twenty year gap between the first event. When this data is viewed from a three year rolling rate perspective the rates are about three times greater. A cumulative rate comparison of FBO and loss of support events is shown in Figure 3.7

In loss of support events, the induced vibration results from the displacement of the center of the mass of the fan or turbine from the geometric center of the rotating system. The rotor displacement is controlled by a combination of gaps in the shaft support system and shaft deflection due to the elastic and (sometimes) plastic deformation of the rotor shaft.

As seen in Table 3.1, loss of a bearing support can result in crew reports of high vibration. However, even in these cases the airplanes were landed safely. Investigation of these airplanes showed that the primary structure sustained no damage. From this service experience, it is concluded that current airplanes should have adequate strength to meet this condition. However, this may not always be the case, especially if new airplane designs are significantly different from conventional configurations in vertical and longitudinal mass distributions of fuel, payload, engine location, etc. and operational roles. Without a specific "loss of centerline support" condition, the current engine failure requirements do not guarantee that the necessary static and fatigue strength will always be present. Therefore, consideration has been given to the introduction of a specific "loss of centerline support" condition in addition to the fan blade imbalance condition. Recommended criteria for both of these conditions are given in Chapter 4.

Table 3.1 Fan Rotor Support Loss

Date	**1/5/96**	**8/17/74**	**12/5/95**	**3/6/96**	**8/14/95**	**7/21/95**
Landed Safely	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Vibration[1]	**Moderate /High**	**Hi**	**Hi**	**Hi**	**Hi**	**Hi**
Rubbing	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Permanent Shaft Deflection	**No**	**Yes**	**No**	**---**	**No**	**No**
Bearings on Shaft[2]	**1-1-0-0**	**0-1**	**0-1**	**0-1**	**1-0**	**0-1-1**
CAAM Hazard Level[3]	**0**	**1d**	**1d**	**0**	**0**	**0**

1 Based on crew comment

2 The designations in this row represent the bearing configuration on the low rotor of the engine type represented in the event.

A "0" indicates a loss of centerline at that station (a bearing failure or a decoupled bearing support or both).

A "1" indicates a sound bearing and support.

3 CAAM (Continued Airworthiness Assessment Methodology) hazard level 1d signifies minor damage to the airplane. In these cases it was the loss of access panels, or wing tip antennae, or minor strut secondary structure cracking.

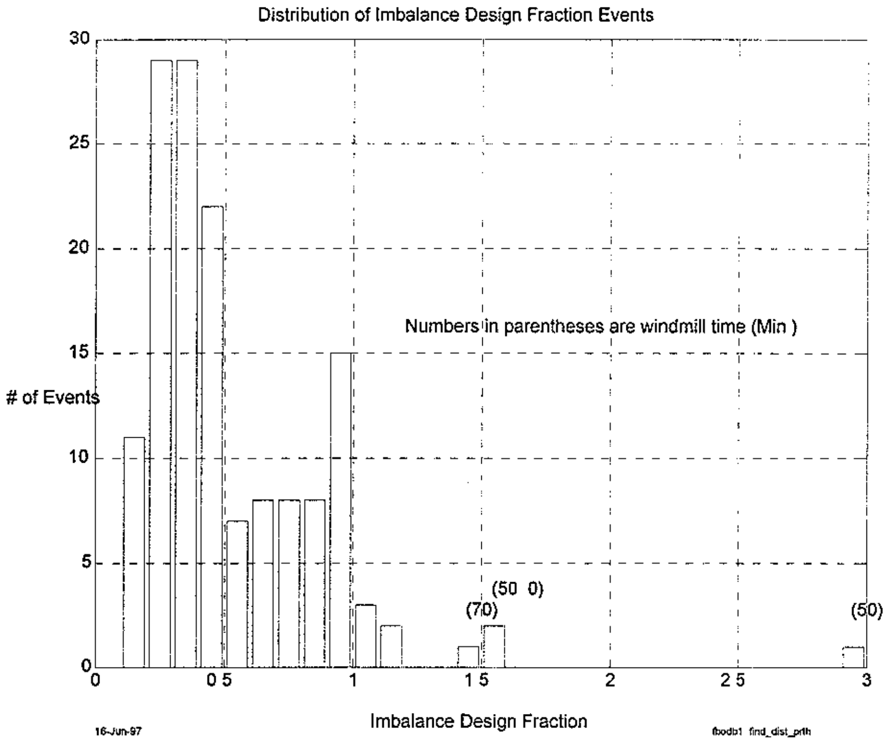


Figure 3 1

3-10

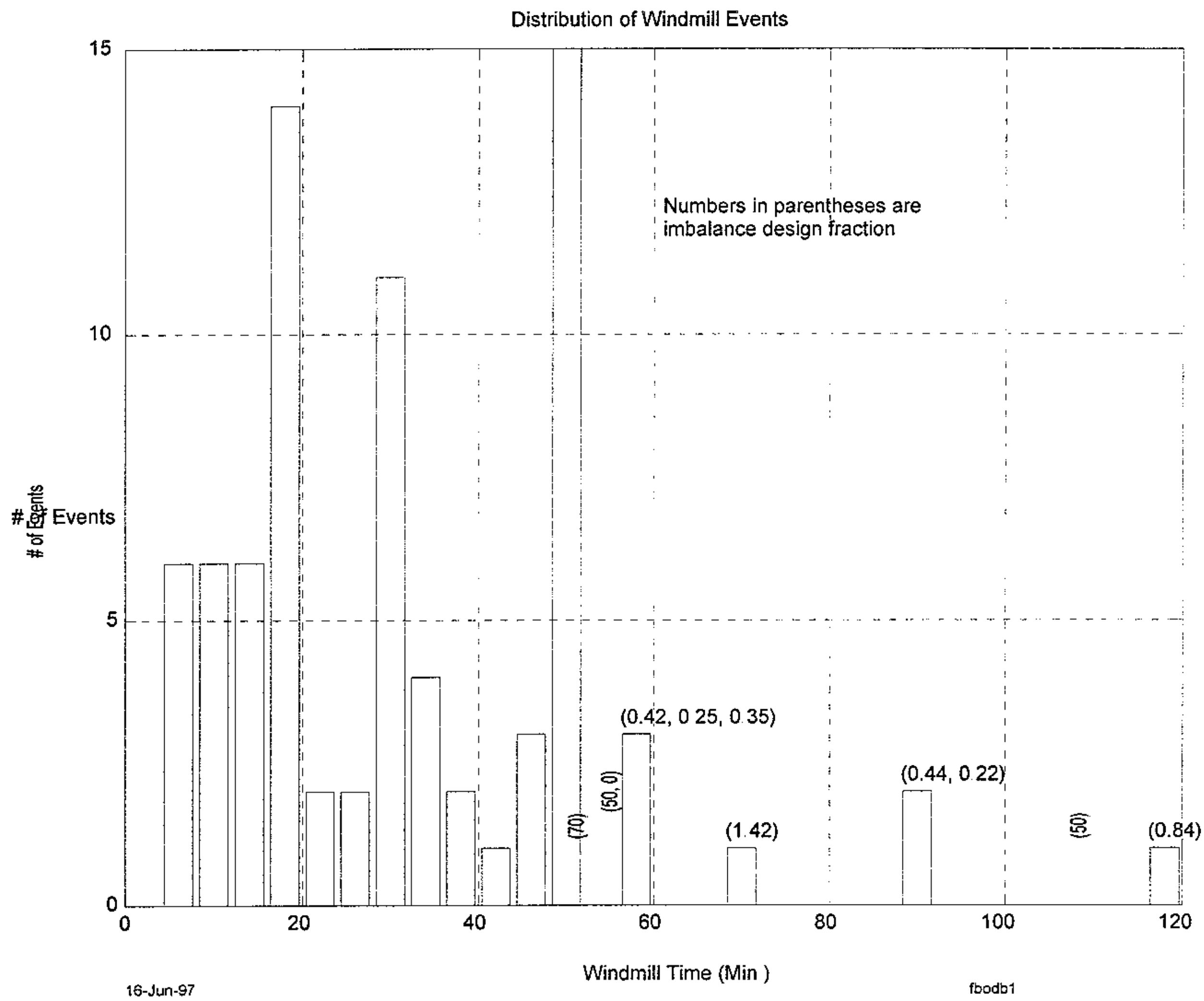


Figure 3 2

3-11

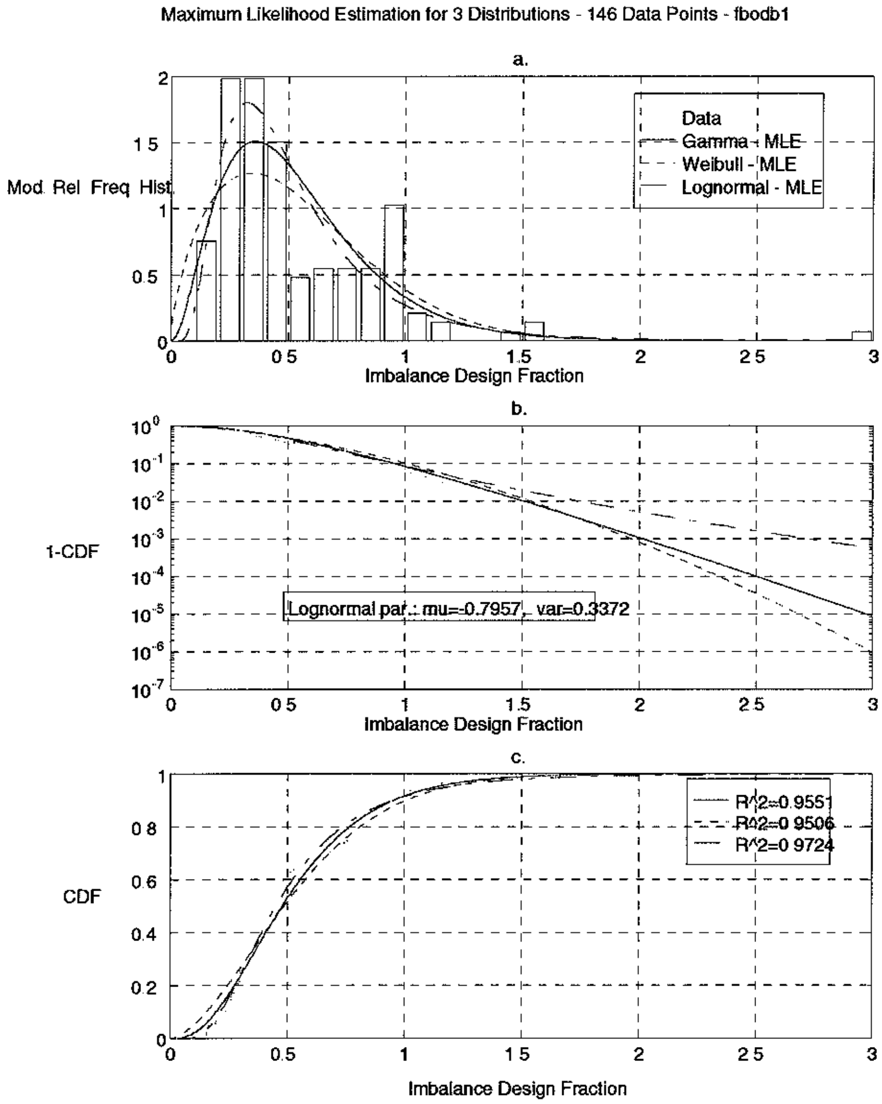

Maximum Likelihood Estimation for 3 Distributions - 146 Data Points - fbodb1
a.
Mod. Rel. Freq. Hist.
Data
Gamma - MLE
Weibull - MLE
Lognormal - MLE
Imbalance Design Fraction
b.
1-CDF
Lognormal par.: mu=-0.7957, var=0.3372
Imbalance Design Fraction
c.
CDF
R^2=0.9551
R^2=0.9506
R^2=0.9724
Imbalance Design Fraction
16-Jun-97
fbodb1 find_dist

Figure 3.3

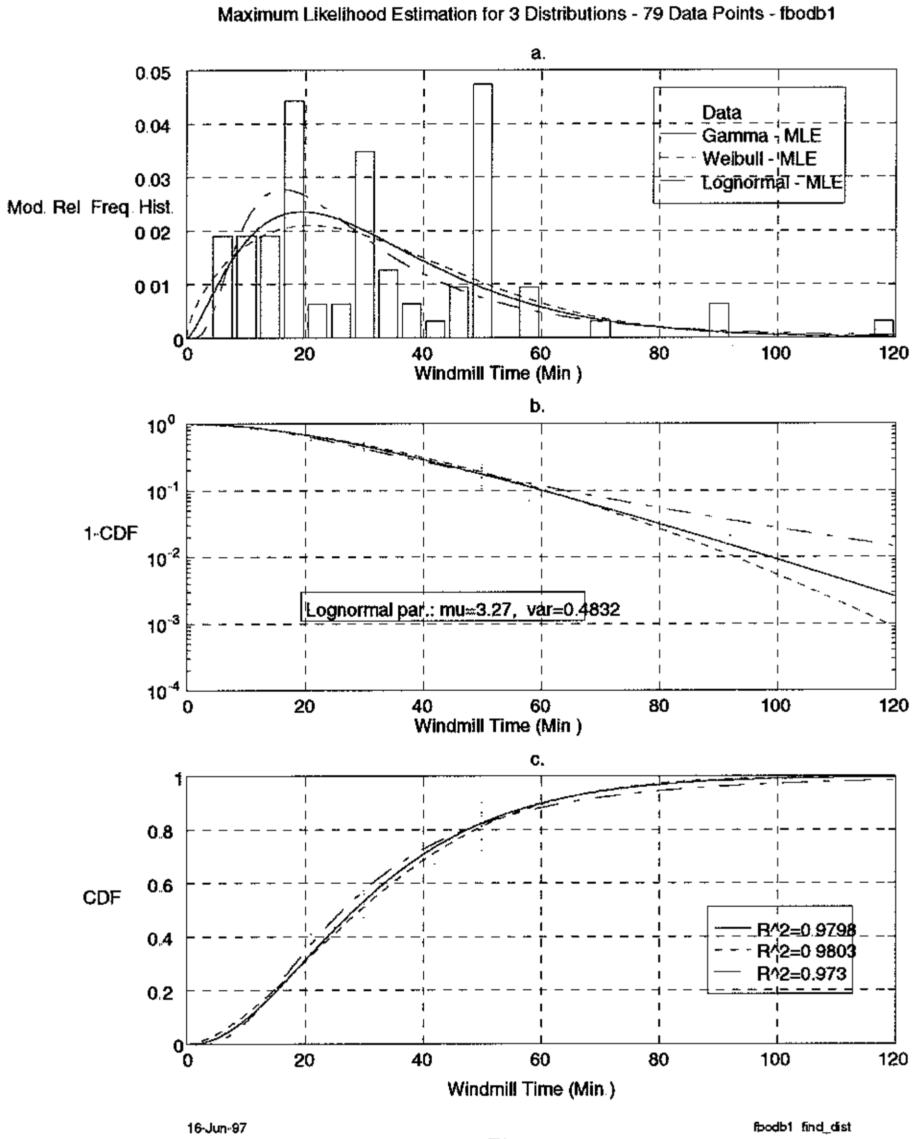

Maximum Likelihood Estimation for 3 Distributions - 79 Data Points - fbodb1
a.
Mod. Rel Freq. Hist.
Data
Gamma - MLE
Weibull - MLE
Lognormal - MLE
Windmill Time (Min)
b.
1-CDF
Lognormal par.: mu=3.27, var=0.4832
Windmill Time (Min)
c.
CDF
R^2=0.9798
R^2=0 9803
R^2=0.973
Windmill Time (Min.)
16-Jun-97
fbodb1 find_dist

Figure 3.4

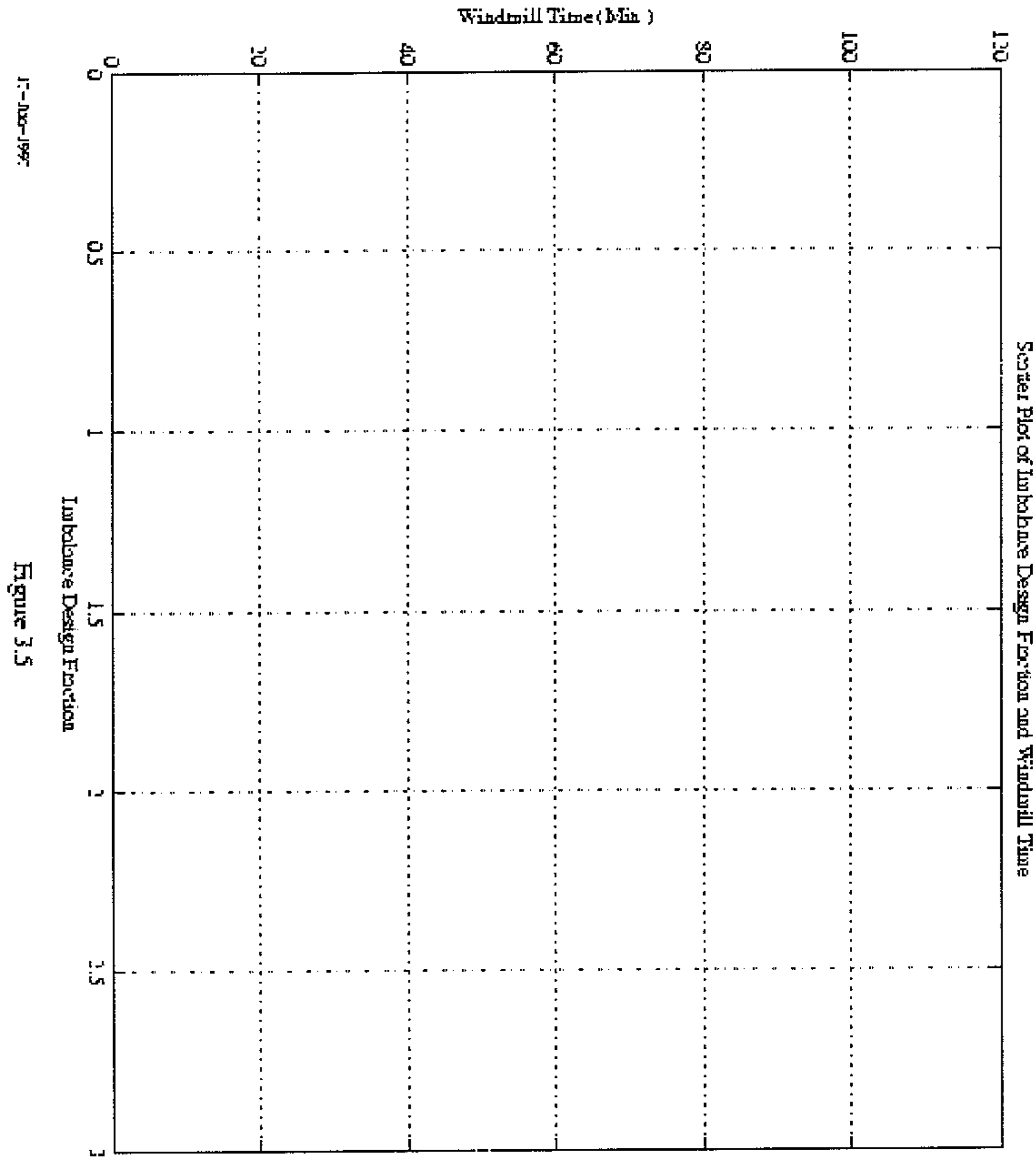


Figure 3.5

3-14

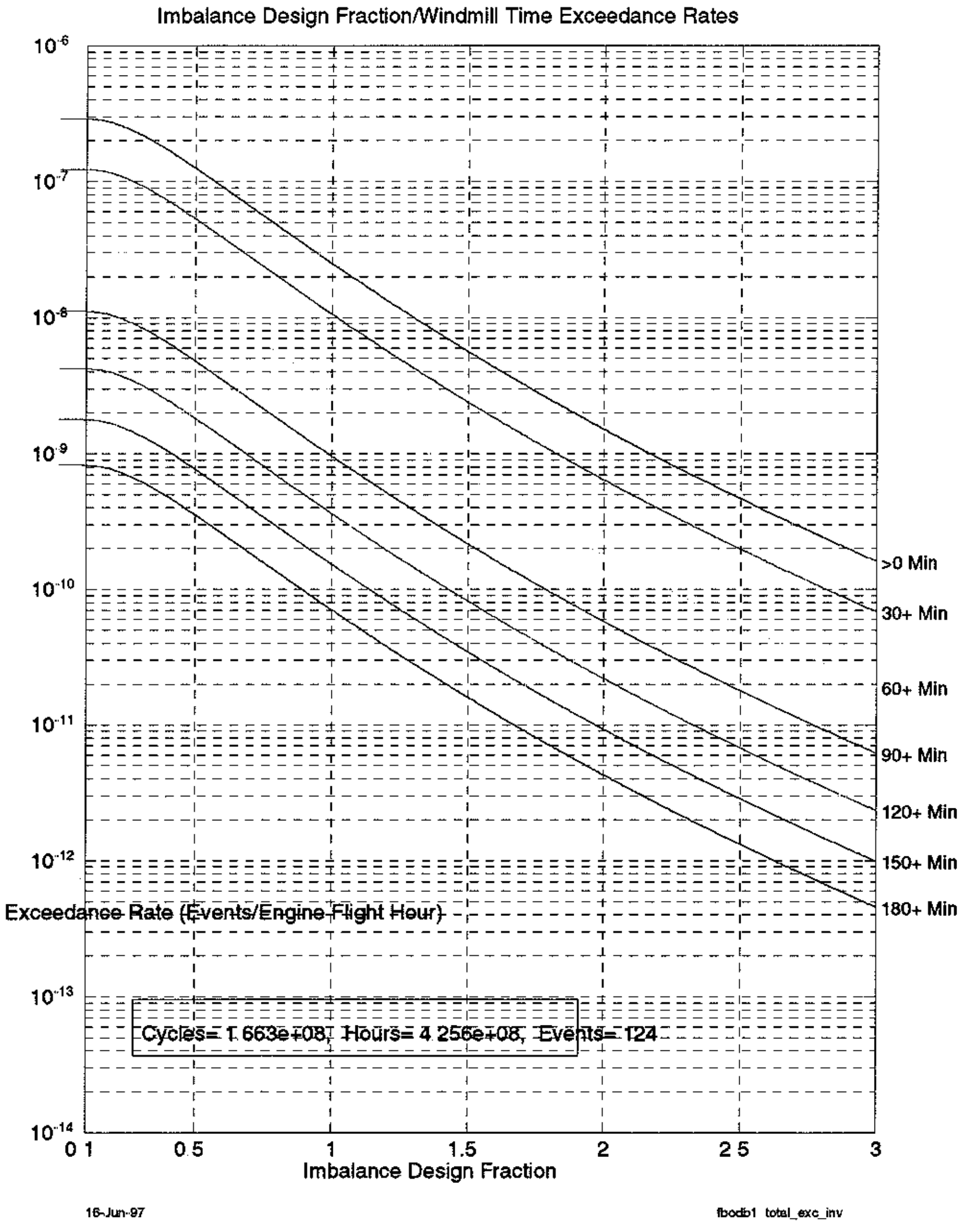
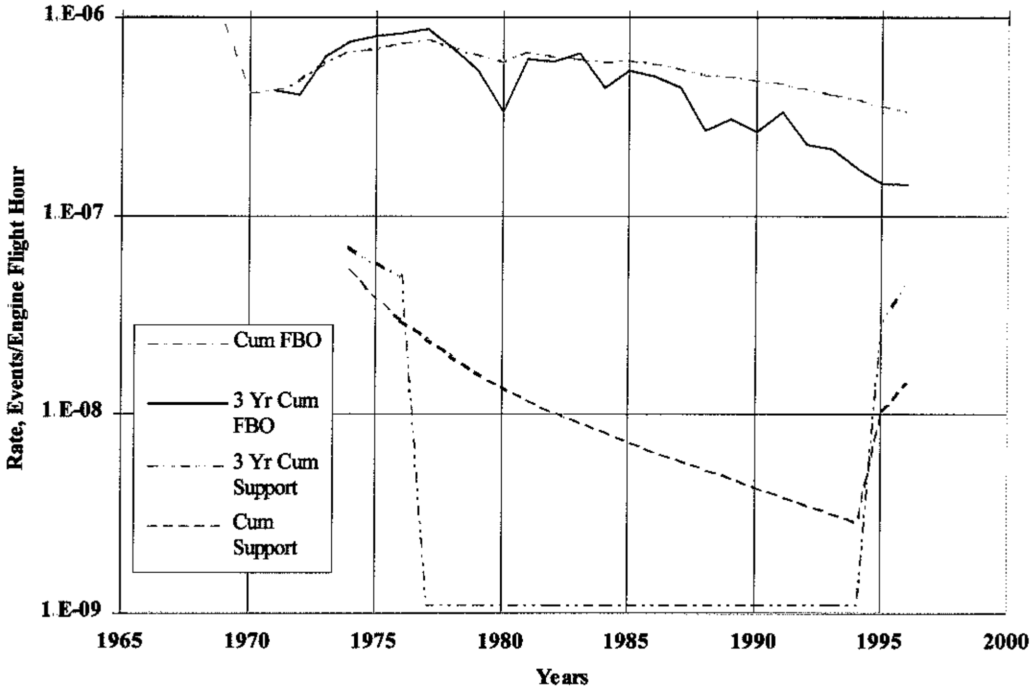

Imbalance Design Fraction/Windmill Time Exceedance Rates
10-6
10-7
10-8
10-9
10-10
10-11
10-12
10-13
10-14
Exceedance Rate (Events/Engine-Flight Hour)
>0 Min
30+ Min
60+ Min
90+ Min
120+ Min
150+ Min
180+ Min
Cycles= 1 663e+08, Hours= 4 256e+08, Events= 124
0 1
0 5
1
1.5
2
2 5
3
Imbalance Design Fraction
16-Jun-97
fbodb1 total_exc_inv

Figure 3 6

Figure 3.7 Fan Rotor Blade and Support Loss Rate Trends



4. Recommended Criteria

In this chapter the recommended criteria for engine windmilling imbalance load are presented. These criteria apply to airplanes with high bypass ratio engines with fan diameters greater than 60 inches. In the absence of evidence justifying an alternative approach providing an equivalent level of safety this criteria should also be assumed to apply equally to airplanes with smaller diameter engines. The requirements are intended to ensure continued safe flight and landing following a blade out event. This is accomplished by defining windmilling conditions for evaluation of structure, systems including operating engine(s), and flight crew performance under the vibratory loads resulting from engine windmilling with imbalance. The level of imbalance recommended is an imbalance design fraction (IDF) of 1.0. An IDF of 1.0 is equal to the level of mass imbalance that would result from engine tests required under section 33.94 of 14 CFR. The windmilling duration required for evaluation should account for the maximum diversion profile appropriate to the airplane model, but not exceeding 180 minutes for all engine and airframe configurations. The fleet service data presented in Chapter 3 show that the combined probability of having an IDF of 1.0 along with a 180 minutes diversion is less than 10^{-9} per airplane flight hour. In light of this, it is recommended that this condition should be evaluated using nominal and realistic flight conditions and parameters.

A recommended methodology is presented for the structural evaluation that consists of static strength, fatigue, and damage tolerance analyses. Additional evaluations for other factors such as systems and flight crew performance should also be considered. These additional evaluations, while out of the scope of this task, should use criteria recommended here for definition of the windmilling conditions.

The criteria presented pertain to sustained imbalance due to fan blade out events. The criteria do not specifically address situations where the engine does not shut down immediately following the fan blade out event. Recommendations are also proposed for the loss of rotor support condition discussed earlier in Chapter 3.

1. Windmilling Condition Definition

The airplane is assumed to be in level flight with typical payload and realistic fuel loading. The speeds, altitudes, and flap configurations considered may be established in accordance with airplane flight manual (AFM) procedures. Unless it can be shown otherwise, the engine fan shaft is assumed to be windmilling with a rotating imbalance resulting from the loss of fan blade material. An IDF of 1.0 shall correspond to the mass imbalance that would result from failure of the most critical turbine, compressor, or fan blade under the conditions specified for the blade containment and rotor imbalance tests in section 33.94 of 14 CFR. Significant changes in structural stiffness and geometry within the engine that would result from the specified blade failure conditions should be accounted for.

The following conditions should be evaluated using assumptions consistent with the probability of occurrence (Reference Chapter 3):

(a) 1.0 IDF in conjunction with the maximum diversion time of the airplane, but limited to a maximum of 180 minutes.

(b) 1.0 IDF in conjunction with a 60 minute diversion.

2. Windmilling Vibration Loads

Loads on the airplane components should be determined by dynamic analysis. The analysis should take into account unsteady aerodynamic characteristics and all significant structural degrees of freedom including rigid body modes. The vibration loads should be determined for the significant phases of the diversion profiles described in 1(a) and 1(b). The significant phases are:

(a) an initial phase during which the pilot establishes a cruise condition,
(b) the cruise condition,
(c) the descent phase, and
(d) the approach to landing phase

The flight phases may be further subdivided to account for variation in aerodynamic and other parameters.

The calculated loads parameters should include the accelerations needed to define the vibration environment for the systems and flight deck evaluations.

3. Static Strength Analysis

(a) The primary airframe structure should be shown capable of sustaining the flight and windmilling vibration loads combinations defined in (i), (ii), and (iii) below.

(i) The peak vibration loads for the flight phases described in (2)(a) and 2(c) combined with appropriate 1g flight loads. These loads are to be considered limit loads, and a factor of safety of 1.375 shall be applied.

(ii) The peak vibration loads for the approach to landing phase described in (2)(d) combined with appropriate 1g flight loads and incremental loads corresponding to a limit positive symmetric balanced maneuvering load factor of 0.15g. These loads are to be considered limit loads, and a factor of safety of 1.375 shall be applied.

(iii) The vibration loads for the cruise phase described in (2)(b) combined with the appropriate 1g flight loads and 70% of the flight maneuver loads and, separately, 40% of the limit gust velocity (vertical or lateral) as specified at V_C up to the maximum likely operational speed following the event. These loads are to be considered ultimate loads.

(b) In selecting material strength properties for the static strength analysis, the requirements of section 25.613 apply.

Note: The factor of safety (1.375) was chosen using the criterion that has been applied as a special condition for the interaction of systems and structure. That criterion allows the factor of safety to vary from 1.5 at a rate of occurrence of 10^{-5} per hour to 1.25 at 10^{-9} per hour. The database has been conservatively interpreted as justifying a rate of occurrence of 10^{-7} per hour for the 1.0 IDF event resulting in the 1.375 factor of safety. This conservatism is justified for the sustained imbalance condition because of the many applications of the load as the resonant peak is traversed.

4. Assessment of Structural Durability

Requirements for fatigue and damage tolerance evaluations are summarized in Table 4-1. Both Conditions 1(a) and 1(b) should be evaluated. The specific conditions listed represent two different targets for structural durability based on the overall probability of the event occurring. Condition 1(a) is established at a 50% probability and condition 1(b) is established at a 95% probability.

For multiple load path "fail-safe" structure, where it can be shown by observation, analysis, and/or test that a load path failure, or partial failure in crack arrest structure, will be detected by general visual inspection prior to the failure of the remaining structure, either a fatigue analysis or damage tolerance analysis may be performed to demonstrate structural capability. All other structure should be shown to have capability using only the damage tolerance approach.

(a) Fatigue Analysis

If a fatigue analysis is used for substantiation of a multiple load path "fail-safe" structure then the total fatigue damage accrued during the well phase and the windmilling phase should be considered. The analysis should be conducted considering the following:

(i) For the well phase, the fatigue damage should be calculated using an approved load spectrum (such as used in satisfying the requirements of FAR(JAR) 25.571)) for the duration specified in Table 4.1. Average material properties may be used.

(ii) For the windmilling phase, fatigue damage should be calculated for the diversion profiles using a mission that envelopes the AFM recommended operation accounting for transient exposure to peak vibrations as well as the more sustained exposures to vibrations (ref. 2(a) through 2(d)). Average material properties may be used.

(iii) For each component the accumulated fatigue damage due to 4(a)(i) and 4(a)(ii) multiplied by the appropriate factor (if any) specified in Table 4.1 should be shown to be less than or equal to the fatigue damage to failure.

4-5

(b) Damage Tolerance Analysis

Where a damage tolerance analysis is used for substantiation the airplane should be shown to have adequate residual strength. The extent of damage for residual strength should be established taking into account growth from an initial flaw during the well phase followed by growth during the windmilling phase. The analysis should be conducted considering the following:

(i) The size of the initial flaw should be equivalent to a manufacturing quality flaw associated with a 95% probability of existence with 95% confidence (95/95).

(ii) For the well phase, crack growth should be calculated starting from the initial flaw defined in 4(b)(i) using an approved load spectrum (such as used in satisfying the requirements of FAR(JAR) 25.571)) for the duration specified in Table 4.1. Average material properties may be used.

(iii) For the windmilling phase, crack growth should be calculated for the diversion profile starting from the crack length calculated in 4(b)(ii) using a mission that envelopes the AFM recommended operation accounting for transient exposure to peak vibrations as well as the more sustained exposures to vibrations (Ref. 2(a) through 2(d)). Average material properties may be used.

(iv) The residual strength for the structure with damage equal to the crack length calculated in 4(b)(iii) should be shown capable of sustaining the combined loading conditions defined in 3(a) of this section with a factor of safety of 1.0.

Table 4.1 - Fatigue and Damage Tolerance Criteria for Windmilling Event

		Fatigue[1,2] (average material properties)			Damage Tolerance[1,2] (average material properties)		
Cond	**Desc**	**Well Phase**	**Wind-milling Phase[3]**	**Criteria**	**Well Phase**	**Wind-milling Phase[3,4]**	**Criteria**
1a	1-IDF 180 Min. Max[6]	Damage[7] due to 1 DSG	Damage[7] due to 180 minute max[6] diversion with an IDF =1 0	The total damage[7] due to the well case and the windmill phase ² 1 0	MQF[5] grown for 1/2 DSG	Additional crack growth for a 180 minute max[6] diversion with an IDF = 1 0	Positive M S. wrt residual strength due to the limit loads specified in 3(a) for the final crack length
1b	1-IDF 60 Min	Damage[7] due to 1 DSG	Damage[7] due to 60 minute diversion with an IDF = 1 0	2 times the total damage[7] due to the well phase and windmill phase	MQF[5] grown for 1 DSG	Additional crack growth due to a 60 minute diversion with an IDF = 1 0	Positive M S. wrt residual strength due to the limit loads specified in 3(a) for the final crack length

Notes:

1 The analysis method that may be used is defined in section 4 0.

2 Load spectrum to be used for the analysis is the same load spectrum qualified for use in showing compliance to FAR(JAR) 25 571 augmented with windmilling loads as appropriate.

3 Windmilling phase is to be demonstrated following application of well phase spectrum loads.

4 The initial flaw for damage tolerance analysis of the windmilling phase need not be greater than the flaw size determined as the detectable flaw size plus growth under well phase spectrum loads for one inspection period for mandated inspections.

5 MQF is the manufacturing quality flaw associated with 95,95 probability of existence.(Reference - 'Verification of Methods For Damage Tolerance Evaluation of Aircraft Structures to FAA Requirements', Tom Swift FAA, 12th International Committee on Aeronautical Fatigue, 25 May 1983, Figures 42, and 43)

6 Maximum diversion time for Condition 1a is the maximum diversion time established for the airplane, not to exceed 180 minutes.

7. The allowable cycles to failure may be used in the damage calculation where DSG equals Design Service Goal.

4-7

5. Loss Of Centerline Analysis

The above recommendations pertain to sustained imbalance due to fan blade out and do not include loss of centerline support events except those that are designed to occur as an intentional result of the fan blade out event. The following approach is recommended to address the loss of centerline condition with no fan blade loss.

Once the fan blade out windmilling loads are determined, the design should be evaluated to determine if a loss of centerline event produces a more severe dynamic condition to the airplane. If the dynamic loads are greater for the loss of centerline event than those resulting from the fan blade out imbalance in the windmilling range they should be evaluated as a design condition for the airplane in a manner approved by the authorities.

To evaluate the loss of centerline condition, the LP rotor system should be analyzed with each bearing removed, one at a time, with the imbalance consistent with the AVM advisory level.

The windmilling analysis should account for secondary damage occurring during rundown from the maximum LP rotor speed (assumed centerline support loss speed).

5. Objective of Analysis

The airplane response analysis for engine windmill imbalance is a structural dynamic problem. The task is to develop acceptable analysis methodology for conducting dynamic investigations of imbalance events. The task further requires that the proposed methodology be validated. The objectives of the analysis methodology are to obtain representative or conservative airplane response characteristics. The goal of the windmilling analysis is to produce loads and accelerations suitable for the following evaluations:

(1) Structural

(2) Systems

(3) Flight deck and human factors

The analytical model should be valid to the highest windmilling frequency expected. The validation of the analytical model discussed in subsequent sections of this report will address the following aspects:

(1) Modeling details necessary to represent airframe structural dynamic characteristics

(2) Engine model detail for the windmilling engine

(3) Aerodynamic representation

The normal output of the windmilling analysis would be expected to yield loads and accelerations for all parts of the primary structure. The evaluation of equipment and human factors may require additional analysis or test. For example, the analysis may need to produce floor vibration levels, and the human factors evaluation may require a test where the seat and the human subject is subjected to floor vibration.

6. Integrated Model

Airplane dynamic responses should be calculated with a complete integrated airframe and engine analytical model. The airplane model should be to a similar level of detail to that used for certification flutter and dynamic gust analyses, except that it must also be capable of representing asymmetric responses. The dynamic model used for windmilling analyses should be representative of the airplane to the highest windmilling frequency expected. The integrated dynamic model consists of the following components:

(1) Structural Model
  (A) Airframe
  (B) Engine

(2) Control System Model

(3) Aerodynamic Model

(4) Forcing Function

(5) Gyroscopics

In the following sections of this chapter, the recommended level of model details are presented. These model parameters have been selected using ground and flight test based validation experience. In subsequent chapters, the test data is compared with analysis results to demonstrate the validation. Most of the test data utilized for this purpose are presently performed to satisfy various requirements of 14 CFR.

Airframe Structural Model

The structural model should include the mass, stiffness, and damping of the complete airframe. A lumped mass and finite element beam representation is recommended to model the airframe. This type of modeling represents each airframe component, such as fuselage, empennage and wings, as distributed lumped masses rigidly connected to weightless finite element beams that incorporate the stiffness properties of the component. Appropriate detail should be included to ensure fidelity of the model at windmilling frequencies. More detailed finite element modeling of the airframe is also acceptable.

Structural damping used in the windmilling analysis may be based on Ground Vibration Test (GVT) measured damping.

Engine Structural Model

The engine structural model consists of the engine, strut, and nacelle. Engine and nacelle models at the same level of detail as the models used for FAR §33.94 test simulation are acceptable for windmilling analysis. Optionally, a simplified engine model may be used in the windmilling analysis if shown to be valid. Engine models typically include the following:

(1) Structural mass distribution and stiffness of static components

(2) Each major rotor mass and rotor stiffness

(3) Each shaft support

(4) Engine mounts and additional load paths

(5) Strut

The airplane model should use the modes and frequencies in the windmilling range extracted from the engine model described above. The engine subjected to the imbalance forces is recommended to be modeled in this level of detail.

Undamaged engines that are operating normally need only be modeled to represent their sympathetic response to the airplane windmilling conditions.

Control System Model

The automatic flight control system should be included in the analysis unless it can be shown to have an insignificant effect on the airplane response due to engine imbalance.

Aerodynamic Model

The use of unsteady three-dimensional panel theory methods for incompressible or compressible flow, as appropriate, is recommended for modeling of the windmilling event. Interaction between aerodynamic surfaces and main surface aerodynamic loading due to control surface deflection should be considered where significant. The level of detail of the aerodynamic model should be supported by tests or previous experience with applications to similar configurations. Main and control surface aerodynamic data are commonly adjusted by weighting factors in the aeroelastic response solutions. The weighting factor for steady flow (k=0) are usually obtained by comparing wind tunnel test results with theoretical data.

Forcing Function and Gyroscopics

Engine gyroscopic forces and imbalance forcing function inputs should be considered. The forcing function should be calibrated to the results of tests performed under Sec. 33.94 of 14 CFR.

7. Airframe Structural Model

An analytical model of the airframe is required to calculate the response at any point on the airframe due to the rotating imbalance of a windmilling engine that has lost some portion of its fan blades. The airframe manufacturers currently use a reduced lumped mass finite element analytical model of the airframe for certification of aeroelastic stability (flutter) and dynamic loads including gust and dynamic landing. A typical model as shown in Figure 7.1 consists of a relatively few lumped masses connected by massless beams. As stated previously in Chapter 6, a full airplane model capable of representing asymmetric responses is necessary for windmilling.

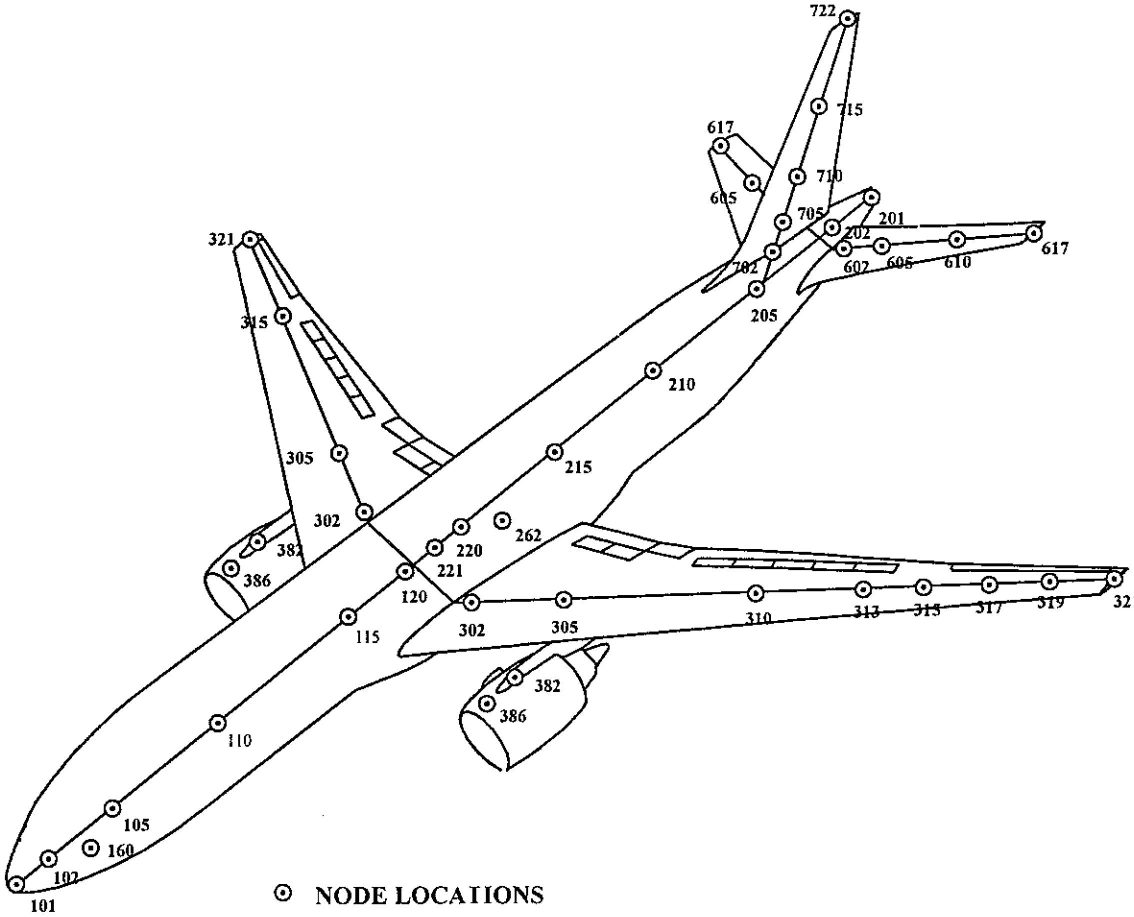
Windmilling, dynamic gust, and landing analyses are based on calculating the dynamic response of the airframe due to a force input. The windmilling analysis should require calculating the response of the airframe at higher frequencies than are usually required to obtain accurate results for the other analyses mentioned above. Flutter analyses normally include frequencies exceeding the nominal engine windmilling frequencies.

In order to verify that the lumped mass model of the airframe gives an accurate representation of the response of the airframe in the windmilling range a comparison was made between analysis and test data for representative commercial airplanes. Six airframe manufacturers submitted data comparing analysis modal frequencies to measured Ground Vibration Test (GVT) frequencies for eighteen different airplanes. These airplanes included two, three, and four engine airplanes with wing, fuselage, and tail mounted engines. A sample of the data submitted, as shown in Figure 7.2, define the airplane and the typical engine fan windmilling frequencies. Also included is a description of each of the natural modes of the airplane along with their test frequency, analysis frequency, percent difference, and test damping.

A plot of the analysis frequencies versus the GVT frequencies is shown in Figure 7.3 and a plot of the difference of analysis and GVT is shown in Figure 7.4. Most of the typical windmilling frequencies reported are within the range from 15 to 25 hertz. Figure 7.3 and 7.4 indicate that the analytical model is as accurate for the windmilling range as for lower frequencies. The histogram in Figure 7.5 shows that for all the reported data the vast majority of differences are within ± 10%, which is considered adequate for windmilling analysis.

Structural damping used in the windmilling analysis may be based on Ground Vibration Test (GVT) measured damping.

A lumped mass beam model is currently accepted for certification analysis including: dynamic gust, dynamic landing, and flutter. The measured GVT data has validated the analytical model through the windmilling range. Therefore, a lumped mass beam model of the airframe is acceptable for frequency response analyses due to engine fan blade out windmilling. Additional detail may be needed to insure adequate fidelity for windmilling frequencies. Finite element models should be used as necessary.



NOT DRAWN TO SCALE

Figure 7.1 Typical Airframe Structural Model

7-3

Modal Frequencies Comparison

(WINDMILLING FREQUENCY: TYPICAL=20 HZ.)

DESCRIPTION	GVT FREQUENCY (HZ)	ANALYSIS FREQUENCY (HZ)	DIFFERENCE (%)	TEST DAMPING (%critical)
SYMMETRIC:				
RIGID BODY PITCH	0.27	0.279	3.33	
RIGID BODY FORE & AFT	0.78	0.825	5.77	
RIGID BODY PLUNGE	1.6	1.54	-3.75	1.48%
WING 1ST BENDING	1.79	1.759	-1.73	0.45%
WING ENGINE YAW	2.07	2.097	1.30	1.72%
FUSE BEND / WENG PITCH	3.22	3.204	-0.50	0.62%
WING INNER PANEL TORSION	4.1	4.117	0.41	0.69%
AFT ENGINE PITCH	4.8	4.775	-0.52	0.30%
HORIZ STAB 1ST BENDING	5.39	5.565	3.25	0.52%
WING 2ND BENDING	5.5	5.225	-5.00	
WING 1ST FORE & AFT	6.01	6.09	1.33	0.96%
WING ENGINE ROLL	6.48	6.509	0.45	0.78%
WING 3RD BENDING	8.81	8.459	-3.98	
MAIN LANDING GEAR YAW	9.62	9.618	-0.02	2.04%
WING 2ND TORSION	11.87	11.187	-5.75	2.22%
WING OUTER PANEL TORSION	12.5	12.497	-0.02	1.76%
HORIZ STAB 1ST FORE & AFT	14.4	14.432	0.22	1.41%
VERT STAB 1ST FORE & AFT	15.75	15.763	0.08	
HORIZ STAB 2ND BENDING	17.19	17.381	1.11	
HORIZ STAB 1ST TORSION	25.69	26.295	2.36	
ANTI-SYMMETRIC:				
RIGID BODY YAW	0.43	0.408	-5.12	
RIGID BODY LATERAL	0.89	0.769	-13.60	
RIGID BODY ROLL	1.29	1.306	1.24	1.04%
WING 1ST BENDING	2.13	2.129	-0.05	0.81%
WING ENGINE YAW	2.35	2.385	1.49	1.27%
FUSE/WING/VS CPLD	2.78	2.698	-2.95	0.43%
VERT STAB 1ST BENDING	3.95	3.667	-7.16	0.57%
WING ENGINE PITCH	4.15	4.005	-3.49	0.49%
HORIZ STAB 1ST BENDING	4.5	4.235	-5.89	0.82%
FWD FUSE BEND/WG F & A	4.95	4.97	0.40	0.57%
AFT ENGINE ROLL	5.57	5.506	-1.15	1.32%
WING ENGINE ROLL	6.37	6.481	1.74	0.88%
WING 2ND BENDING	7.16	6.656	-7.04	1.48%
HORIZ STAB YAW	7.36	7.279	-1.10	0.99%
MAIN LANDING GEAR CPLD	8.32	8.662	4.11	2.78%
VERT STAB 2ND BENDING	8.76	9.267	5.79	1.38%
MAIN LANDING GEAR YAW	9.94	10.065	1.26	
WING OUTER PANEL TORSION	11.66	11.84	1.54	
HORIZ STAB 2ND BENDING	15.41	16.681	8.25	
UPPER WINGLET 1ST BENDING	21.59	22.922	6.17	
HORIZ STAB 1ST TORSION	25.69	26.154	1.81	
WING 3RD BENDING				

Figure 7.2

7-4

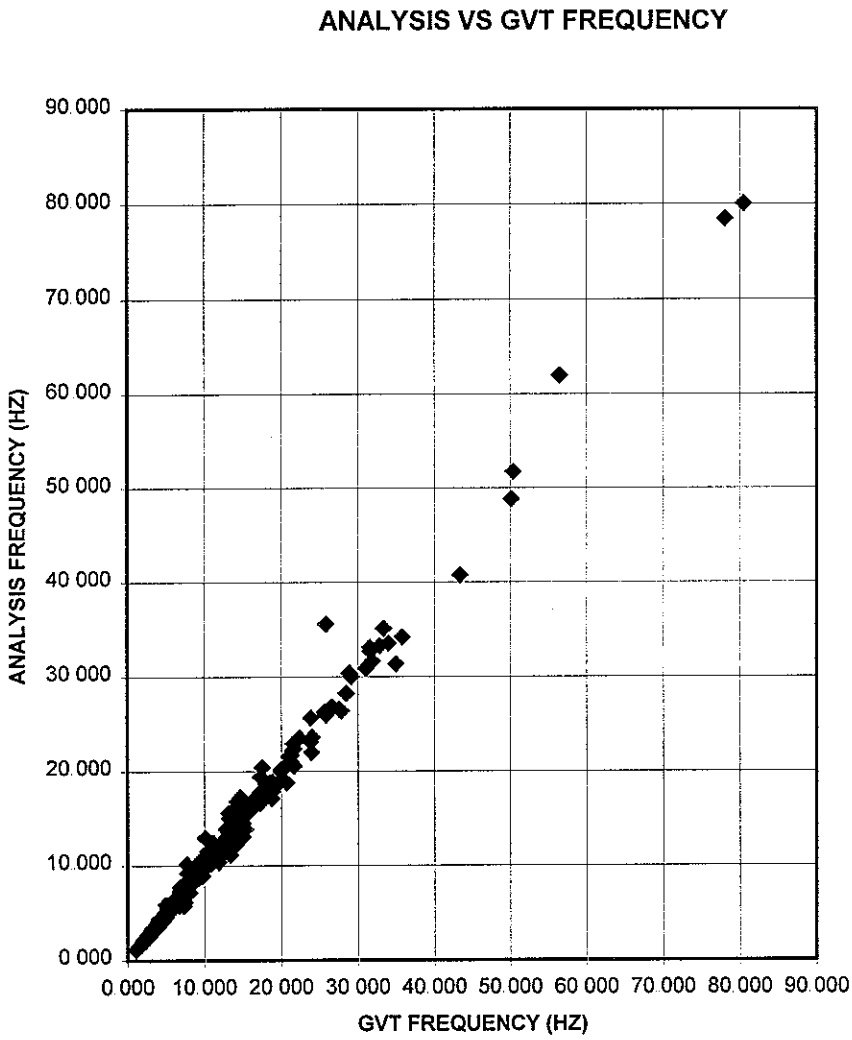
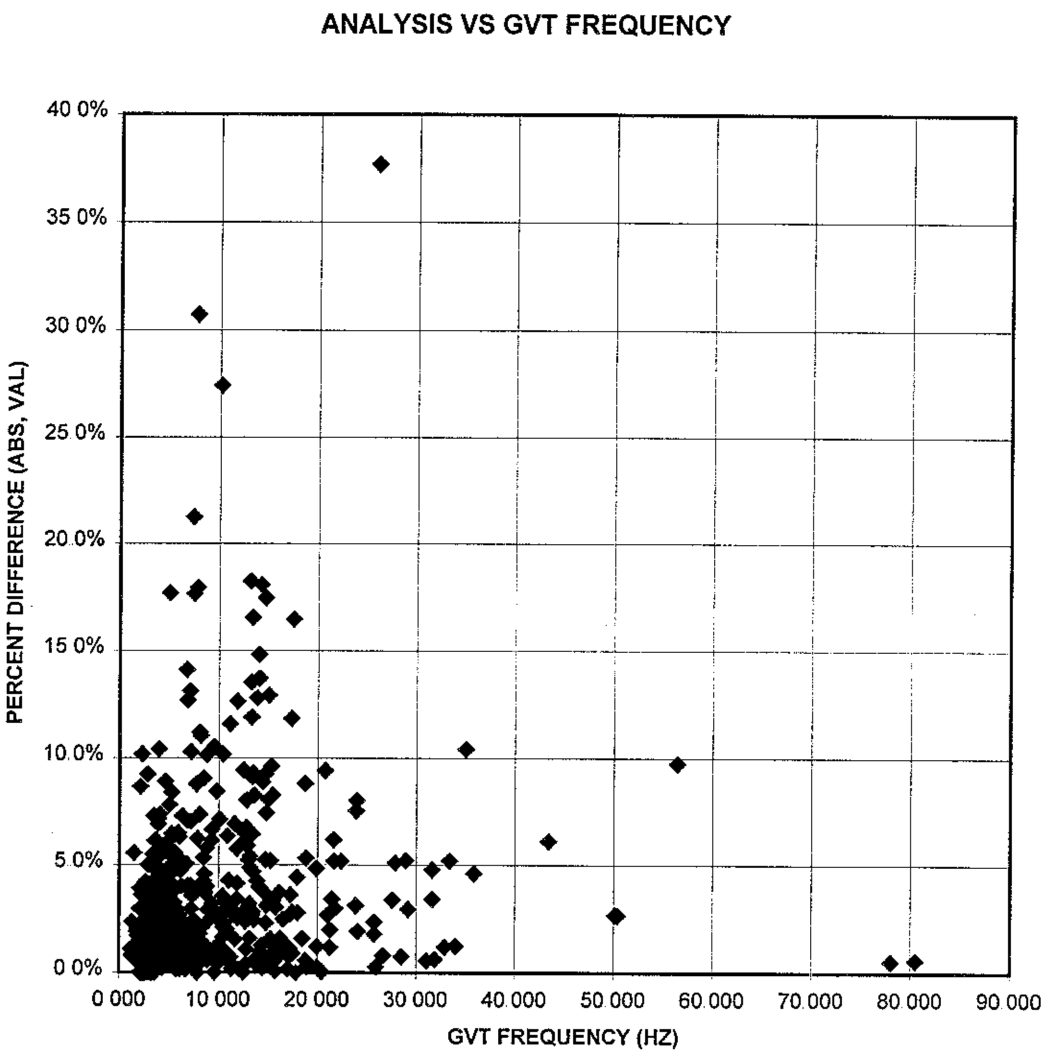

ANALYSIS VS GVT FREQUENCY
ANALYSIS FREQUENCY (HZ)
90.000
80.000
70.000
60.000
50.000
40.000
30.000
20.000
10.000
0.000
0.000 10.000 20.000 30.000 40.000 50.000 60.000 70.000 80.000 90.000
GVT FREQUENCY (HZ)

Figure 7.3


ANALYSIS VS GVT FREQUENCY
PERCENT DIFFERENCE (ABS, VAL)
40 0%
35 0%
30 0%
25.0%
20.0%
15 0%
10.0%
5.0%
0 0%
0 000
10 000
20 000
30 000
40.000
50.000
60.000
70.000
80.000
90.000
GVT FREQUENCY (HZ)
Figure 7.4

7-6

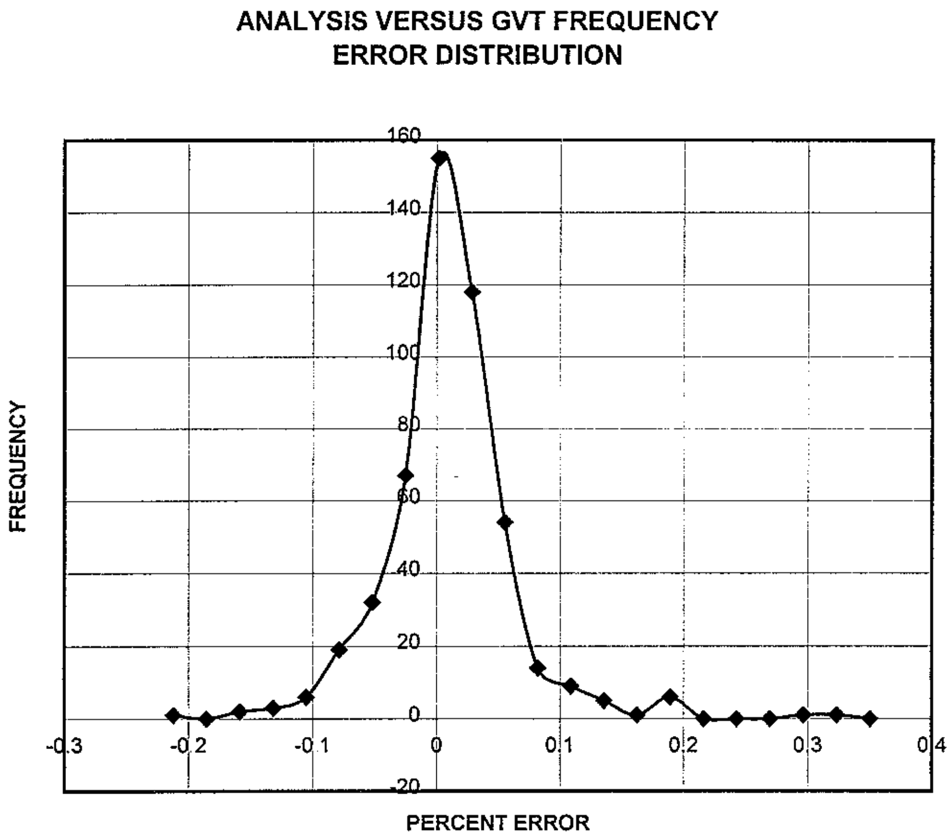

ANALYSIS VERSUS GVT FREQUENCY
ERROR DISTRIBUTION
FREQUENCY
160
140
120
100
80
60
40
20
0
-20
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
PERCENT ERROR

Figure 7.5

7-7

8. Engine Structural Model

The purpose of this chapter is the definition of an engine structural model which adequately describes the dynamic characteristics needed to accomplish the objectives of the windmilling loads analysis.

Engine manufacturers construct various types of dynamic models to determine loads and to perform dynamic analyses on the engine rotating components, its static structures, mounts and nacelle components. Dynamic engine models can range from a centerline two-dimensional (2D) model, to a centerline model with appropriate three-dimensional (3D) features such as mount and strut, up to a full 3D finite element model (3D FEM). Any of these models can be run for either transient or steady state conditions. A typical 3D FEM engine model is shown in Figure 8.1.

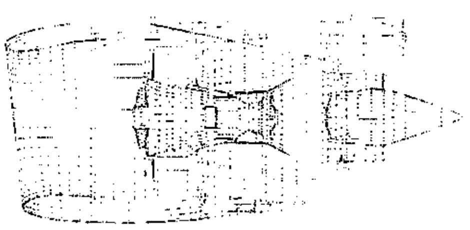


Figure 8.1 Typical Engine

These models typically include all major components of the propulsion system, such as the nacelle intake, fan cowl doors, thrust reverser, common nozzle assembly, all structural casings, frames, bearing housings, rotors and a representative strut. Gyroscopic effects are included. The models provide for representative connections at the engine-to-pylon interfaces as well as all interfaces between components (e.g., inlet-to-engine and engine-to-thrust reverser).

Features modeled specifically for blade loss windmilling analysis typically include fan imbalance, component failure and wear, rubs, (blade to casing, and intershaft), and resulting stiffness changes. Manufacturers whose engines fail the rotor support structure by design during the blade out event should also evaluate the effect of the loss of support on engine structural response during windmilling.

Features which should be modeled specifically for loss of centerline windmilling events include the effects of gravity, inlet steady air loads, rotor to static structure friction and gaps, and rotor eccentricity. Secondary damage, such as additional mass loss, overload of other bearings, permanent shaft deformation, or other structural changes affecting the system dynamics, occurring during rundown from maximum LP rotor speed and subsequent windmilling should be accounted for.

The definition of the model should be mutually agreed upon between the airframer and engine manufacturer based on test and experience. The model is validated based on dedicated vibration tests and results of FAR 33.94 fan blade out test. In cases where compliance to FAR 33.94 is granted by similarity instead of test, the windmill model should be correlated to prior experience.

Validation of the engine model static structure including the strut is achieved by a combination of engine and component tests which include structural tests on major load path components. The adequacy of the engine model to predict rotor critical speeds and forced response behavior is verified by measuring engine vibratory response when imbalances are added to the fan, LPC (or IPC), HPC, HPT, (IPT if for a three shaft engine) and LPT rotors. Vibration data are routinely monitored on a number of engines during the engine development cycle, thereby providing a solid basis for model correlation.

While the validation aspects listed above are important for representation of the windmilling loads, the fan blade loss correlation is also pertinent to the windmill event because the event involves predicting the response of the entire propulsion system under a high level imbalance load. Correlation of the model against the FAR 33.94 fan blade out engine test is a demonstration that the model accurately predicts initial blade release event loads, any rundown resonant response behavior, frequencies, potential structural failure sequences, and general engine movements and displacements. To enable this correlation to be performed, instrumentation of the blade out engine test is used, for example high speed cine and video cameras, accelerometers, strain gauges, continuity wires, and shaft speed tachometers.

9. Aerodynamic Model

The airframe manufacturers currently use an aerodynamic model of their airframes for calculation of dynamic gust loads and flutter analyses that generally cover all of the significant frequencies required for windmilling analyses.

Flight test results have been collected by the aircraft manufacturers in order to provide a basis for validation of aerodynamic forces which will be used for dynamic analysis in windmilling conditions. Available flight test data for control surface sweep inputs were reviewed indicating good correlation between calculated and measured response. Figures 9.1 through 9.3 are representative results showing the response of the fuselage due to aileron, elevator, and rudder sweep inputs respectively. All the comparisons of analysis predictions versus flight test data showed good correlation up to approximately 8Hz. Reliable flight test data above 8Hz is difficult to obtain with control surface sweeps since the actuators roll off at these frequencies giving a low signal versus noise ratio.

The airframe manufacturers have evaluated the sensitivity of the windmilling analysis to the accuracy of the unsteady aerodynamic model. Responses at several different locations on the airplane were calculated for an engine fan imbalance at frequencies from zero through the maximum expected windmilling frequency. The airplane configurations analyzed consisted of a wing mounted twin, a wing mounted four engine airplane, and a fuselage mounted twin. The frequency response analyses were performed for the following aerodynamic variations:

(1) Nominal aerodynamics.

(2) ±10% applied to all unsteady aerodynamic forces.

(3) ±20% applied to nacelle unsteady aerodynamic forces.

Figure 9.4 is a plot of the acceleration response of the cockpit versus frequency for one of the airplanes analyzed with the aerodynamic variations listed above. The small magnitude of differences shown in the Figure is representative of all of the results reviewed. This magnitude of difference indicates that the engine imbalance response analyses are not sensitive to reasonable variation in aerodynamics.

Analyses were also performed with no aerodynamics and the results indicated in general a significant effect on the response of the airplane. The analysis with no aerodynamics was generally conservative at most frequencies, but not always.

Validation of Aerodynamic Model

Available flight test data covers frequencies up to 8Hz. In this range of frequencies, flight test and analysis shows good agreement. Flight flutter tests demonstrate that currently employed aerodynamic modeling is reliable for frequencies within the windmilling range. These methods are accepted for flutter analysis which is more sensitive to aerodynamic variation than response to windmilling imbalance.

Generalized aerodynamic forces for all modes up through the windmilling range behave smoothly and do not exhibit large variations versus reduced frequencies in the flight regime (subsonic and low transonic) involved in windmilling diversions. Based on the above observations, it is concluded that aerodynamic modeling currently used in certification flutter analyses is adequate for windmilling analysis.

Generally, airplane response data from flight test shows good correlation compared to analysis up to approximately 8 Hz. Correlated analysis to test data generally are not available above 8 Hz. Airplane response data are usually obtained by control surface sweep inputs. These data are normally limited to approximately 8 Hz because of the frequency response characteristics of the control surface actuators, which are incapable of exciting the airplane at higher frequencies. During flight flutter testing, wing and stabilizer vanes are sometimes used to excite the aeroelastic modes of the airplane at frequencies up to 30 Hz. These tests have shown that analytically predicted stability characteristics are acceptable for all significant structural modes.

Flight flutter tests demonstrate that currently employed aerodynamic modeling is reliable for frequencies of windmilling. These methods are accepted for certification flutter analyses that are more sensitive to aerodynamic variations than airplane response due to windmilling imbalance. Aerodynamic forces are well behaved and are continuous functions in the flight regime involved in windmilling diversions (subsonic and low transonic).

Flight Test vs Analysis
Fuselage Response due to Aileron Sweeps

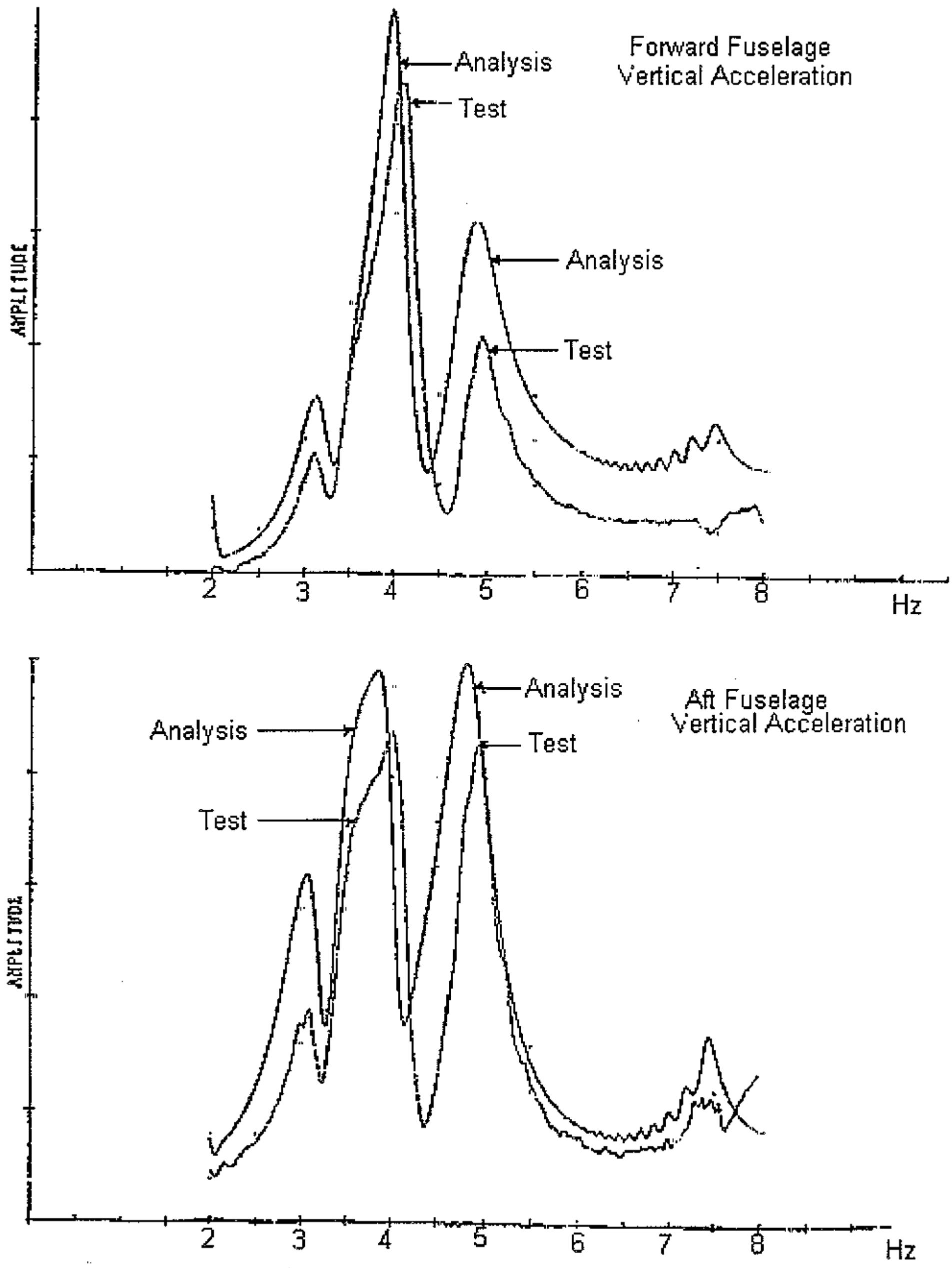
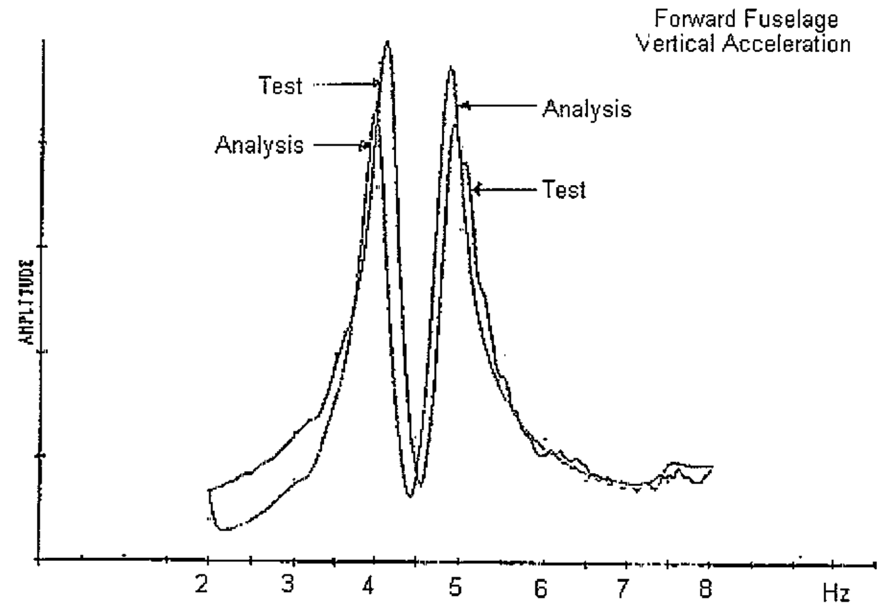


Figure 9.1
9-4

Flight Test vs Analysis
Fuselage Response due to Elevator Sweeps



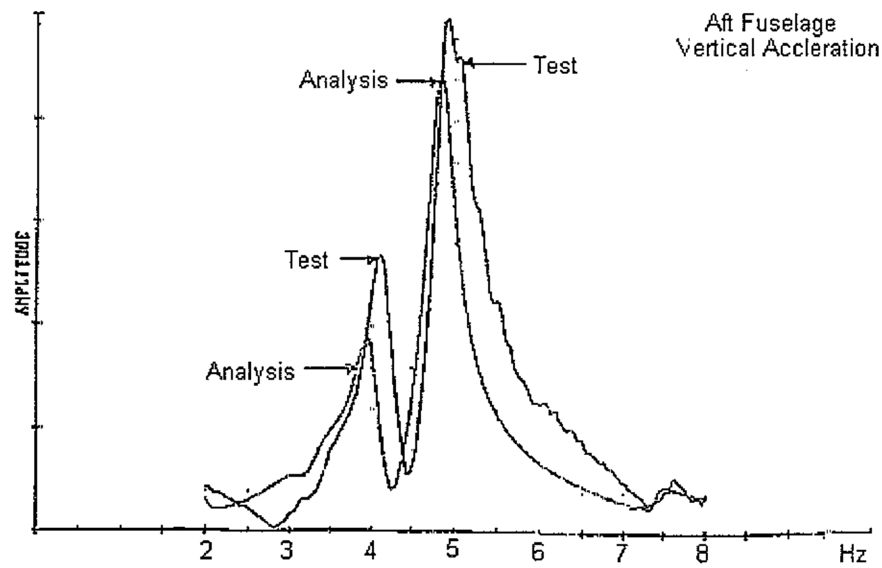


Figure 9.2

9-5

Flight Test vs Analysis
Fuselage Response due to Rudder Sweeps

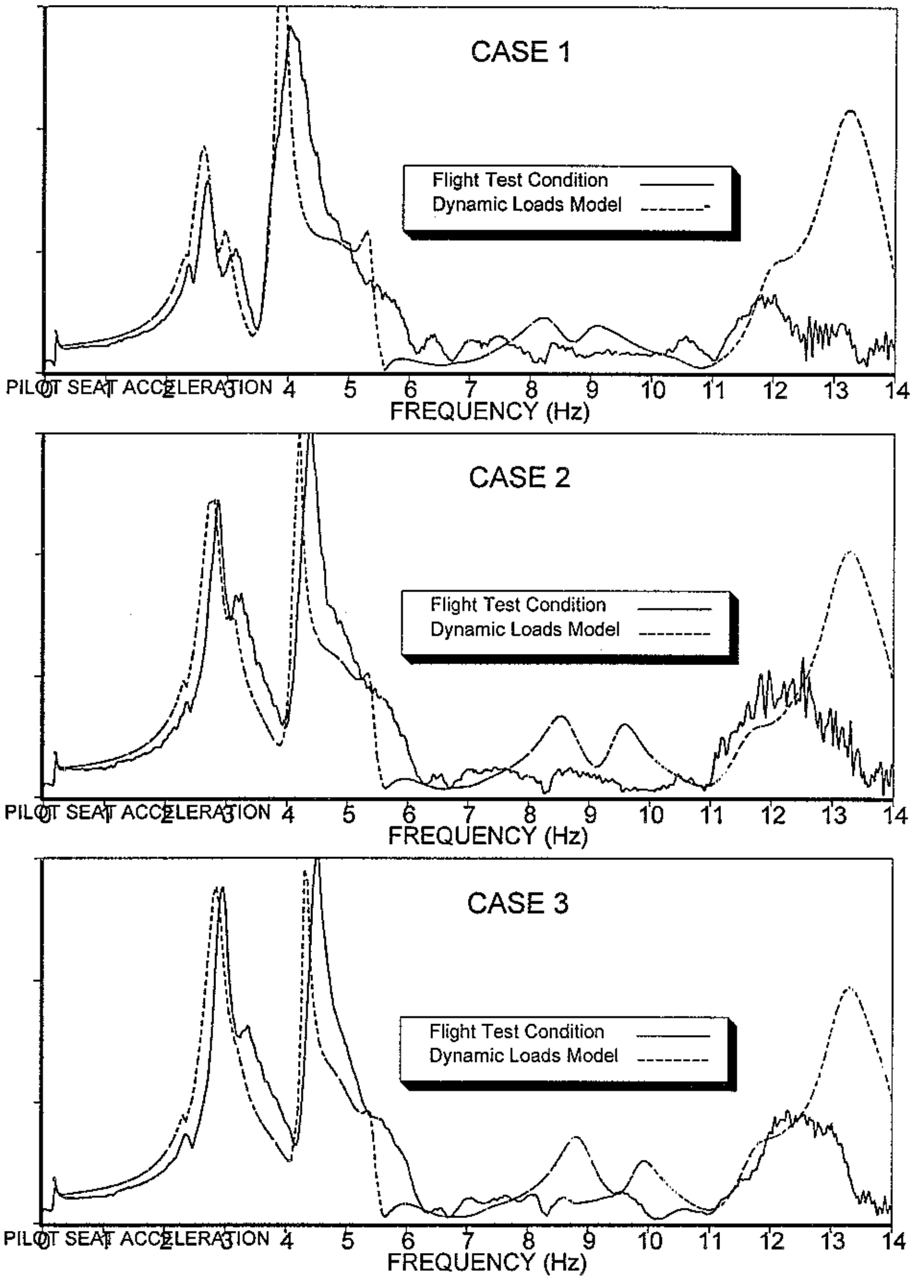


Figure 9.3

9-6

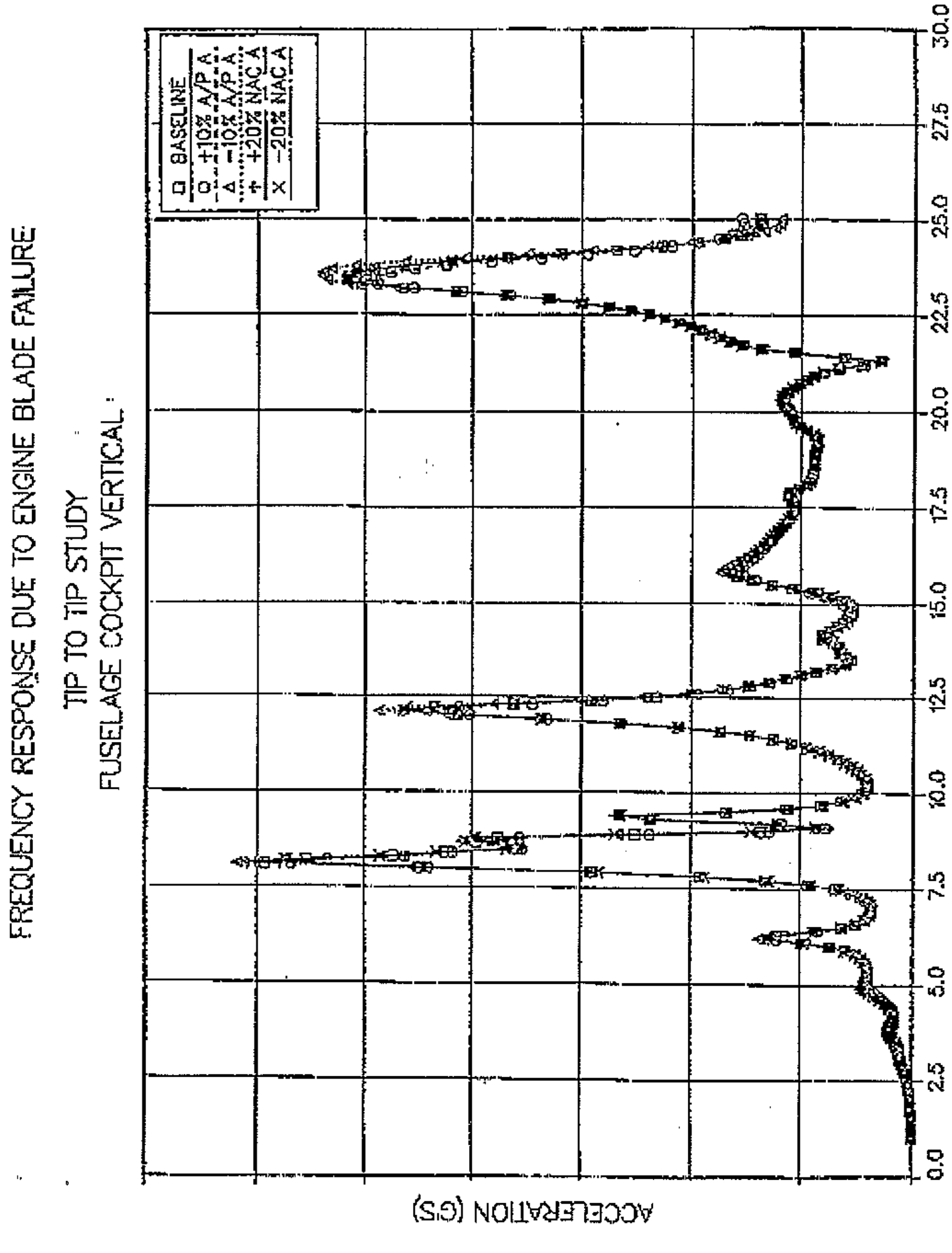

FREQUENCY RESPONSE DUE TO ENGINE BLADE FAILURE
TIP TO TIP STUDY
FUSELAGE COCKPIT VERTICAL
BASELINE
+10% A/P A
-10% A/P A
+20% NAC A
-20% NAC A
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
FREQUENCY (HZ)
ACCELERATION (G'S)

Figure 9.4

9-7

10. Validation of Integrated Model

The model parameters recommended in Chapter 6 are based on analysis methods that are well understood and represent present industry practice for demonstrating compliance with various sections of 14 CFR. The analysis techniques have a long history of ground and flight test based validation.

The airframe model is validated by ground vibration tests that typically consist of a complete airframe and engine configuration subjected to vibratory forces imparted by electro-dynamic shakers. Although the forces applied are small compared to windmilling forces, these tests yield reliable dynamic characteristics (structural modes) of the airframe engine combination. Structural damping values obtained in these tests are conservative for application to windmill analysis. Application of higher values of damping appropriate for the larger amplitudes on the windmill analysis, need to be justified.

These characteristics are valid within the linear range of structural material properties. The windmilling forces, though greater than test shaker forces, are far less than forces required to induce nonlinear behavior of the structural material; i.e. yielding. Thus, a structural dynamic model that is validated by ground vibration test is considered appropriate for the windmilling analysis.

However, the ground vibration test of the aircraft does not necessarily provide sufficient information to assure that the transfer of the windmilling imbalance loads from engine is correctly accounted for as described in Chapter 8. The load transfer characteristics of the engine to airframe interface via the strut should be validated by test and analysis correlation. In particular, the effect of the point of application of the load on the dynamic characteristics of the integrated model needs to be understood. To this end, the modes and frequencies of several airplanes have been determined by tests where the point of application of the loads is changed; e.g., at the wing, at the fuselage, tail surfaces, and at the engine. The results are presented in Tables 10.1 to 10.3. The results show that to completely identify all of the aircraft modes necessary for windmilling analysis, multiple shaker locations are needed, including locations on the engine.

The dynamic behavior of the whole airplane in the structural frequency range associated with windmilling is normally validated by the flight flutter tests performed under 25.629 14 CFR. Some typical results are presented in Chapter 9.

Table 10.1
777-200 GVT Multiple Shaker Configurations

Run	Shaker Location (Direction)	Freq. Range (Hz)
1	Both wing tips vert, LH stab vert, fin lateral	0 to 6.25
2	Both wing tips vert, LH stab vert, fin lateral	0 to 25
3	LH wing vert, LH stab vert, both nacs lat	0 to 6.25
4	LH wing vert, LH stab vert, both nacs lat	0 to 25
5	Rudder, elevator, aileron	0 to 25
6	Left and right nac vertical and lateral	0 to 25

Table 10.2
GVT Multiple Shaker Configurations
Test Frequencies and Modeshapes

Mode Description	Run 2	Run 4	Run 6
Rigid Body Yaw	0.389	0.379	0.379
Rigid Body Lat Trans w/Roll	0.451	0.452	0.453
Rigid Body F/A Trans w/Pitch	0.548	0.546	0.552
Rigid Body Roll	0.713	0.712	0.717
Rigid Body Pitch w/Roll	0.783	0.779	0.788
Rigid Body Vert Trans w/Roll	0.970	0.968	0.975
Sym 1st Wing Vert Bend	1.620	1.622	1.620
Antisym 1st Wing Vert Bend	2.008	2.010	2.009
Sym Nac SB	2.479	2.370	2.224
Antisym Nac SB	2.666	2.623	2.613
Antisym Aft Body Tor/Wing VB	2.981	2.979	2.985
Sym Wing VB/Nac VB/Body VB	3.005	3.042	3.028
Antisym Wing VB/H Stab Opp Phase/Body Tor/Nac VB	3.319	3.316	3.316
Sym Wing VB/Nac VB/Body VB	3.404	3.405	3.406
Antisym Wing VB/Body Tor/Nac VB	3.661	3.642	3.705
Antisym H Stab Roll	3.794	3.817	3.862
Sym Wing VB/Stab VB Opp Phase	4.089	4.090	4.127
Antisym Wing VB/Stab VB in Phase/Fin B	4.269	4.263	4.296
Sym Wing VB/Antisym Stab VB/Fin B	4.343	4.340	4.376
Sym Wing VB/Stab VB Opp Phase/Fin LB/NLG Lat	4.528	4.436	4.446
Sym Wing VB/Fin LB		4.531	4.550
Sym Wing VB/Fin LB(Fin & Stab Phase Change)	4.578		4.580
Antisym Wing VB/Stab VB Opp Phase/Fin LB/NLG Lat/Body LB	4.964	4.921	4.921
Sym Stab VB/Antisym Wing CW	5.159	5.129	5.126
Sym Stab VB/Sym Wing VB	5.182	5.165	5.205
NLG Lat/Antisym Wing VB/Antisym Stab CW	5.557	5.586	5.594
Sym Wing CW	5.621	5.616	5.631
Sym Wing CW	5.723	5.710	5.739
Antisym Wing VB/Nonsym H Stab/Fin LB	5.939	5.997	6.011
Sym Wing VB/Stab VB/Nac Tor RH Dominate/Fin CW	6.333	6.276	6.123
Antisym H Stab CW/Fin CW	6.422	6.406	6.638
LH Nac Tor	6.894	6.740	6.694
Antisym Wing VB/Stab CW/NLG FA/MLG FA	7.263	7.113	7.189
Antisym Wing/Stab CW/Fin & Body Lat	7.388	7.362	
Antisym Wing/Stab CW/MLG FA/Nac Tor/Body Lat	7.696	7.795	7.596
Nonsym Wing VB/Stab VB/MLG FA/Fin CW	8.113		
Sym Wing VB/MLG FA	8.244	8.243	8.250
Sym Wing VB/MLG FA/NLG FA/Fin CW	8.481	8.483	8.453
Antisym Wing CW/MLG FA/Sym H Stab VB/Body Tor	8.683		
Antisym Wing CW/H Stab CW Opp Phase/Fin LB/Body LB	8.902	8.917	8.945

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Table 10.2 (continued)
AIRPLANE GVT MODESHAPES AND FREQUENCIES (HZ)
PRELIMINARY TEST FREQUENCIES

Mode Description	Run 2	Run 4	Run 6
Nonsym Wing VB/Antisym Wing CW/Stab CW Opp Phase/Fin LB	9.134	9.121	9.171
Antisym Wing VB/Sym H Stab VB Opp Phase/Fin CW/Body VB	9.229	9.371	
Antisym Wing VB/Stab CW/Body Tor	9.511	9.501	9.536
Antisym Wing VB/H Stab VB/Fin LB/Body Tor	10.250		
Antisym Wing VB/H Stab VB/Fin LB/Body Tor	10.269		10.190
Sym Wing VB/H Stab VB in/Body VB	10.325	10.322	10.369
Sym Wing Tor+VB/H Stab VB Opp/Body VB	10.773	10.776	
Sym Wing VB/H Stab VB Opp/Body VB	10.840		
Antisym Wing CW/H Stab CW in Phase/Fin LB/Body LB			10.919
Antisym Wing Tor/H Stab VB/Fin Rudder LB/MLG L	11.282	11.294	11.195
Antisym Wing VB/H Stab VB/Fin LB		11.348	11.348
Antisym Wing VB/H Stab VB/Fin LB Opp Phase			11.445
Sym Wing VB/Nonsym H Stab VB/Fin Rudder LB	11.874		
Antisym Wing Tor/H Stab VB/Fin Rudder LB/F Body L	12.063	12.055	12.077
Antisym Wing Tor/H Stab VB/Fin Rudder LB	12.081		
H Stab Elev/Fin Rudder 2nd VB	12.598		
Sym Wing VB/Nonsym H Stab VB	12.671	12.611	
Sym Wing VB/Nonsym H Stab VB/Rud&Fin LB	12.730	12.801	
Sym Wing Tor/Asym H Stab&Elev VB & Rot/Rud&Fin LB	13.341		12.993
Sym Wing Tor/Antisym H Stab VB/Rud&Fin LB	13.376	13.694	13.526
Antisym Wing Tor/H Stab VB/Fin Rudder LB			14.027
LH Asym Elev Rot	14.215	14.477	
Sym Wing Tor/Asym H Stab&Elev VB & Rot/Rud&Fin LB			14.667
Antisym Wing VB/LH Stab VB/Elev Rot/Rud&Fin LB	14.638		
Antisym Wing VB/Fin Rudder LB/L H Stab Tor/R H Stab VB	14.725		
Sym Wing Tor+VB/H Stab VB Opp/Body VB			14.870
Asym Wing VB RH Dominate/Sym H Stab&Elev VB/Rudder LB	15.054		
Sym Wing CW/Nac Tor/Rudder Opp Fin LB			15.343
Asym Wing VB -90LH to RH	15.955	15.967	15.715
Sym Wing Tip VB	16.033		
Antisym Wing Tip VB	16.044	16.492	16.283
Antisym Wing VB/H Stab Tor/Rudder LB	16.539	16.563	16.593
Antisym Wing Tip VB/Fin&Rudder LB/Rud-Tab Rot/H Stab in Phase w/Wing		16.613	
LH Elev Tor	18.156		
Antisym Wing Tor/H Stab VB/Rudder LB	18.882	18.779	18.950
Antisym Wing Tip VB/Fin&Rudder LB/Rud-Tab Rot/H Stab Opp Phase w/Wing			19.07
Antisym Wing Tip VB/Nac LB/Rudder Tor/H Stab Opp Phase w/Wing			19.601
Sym Wing Tip Tor	19.931		
Sym Wing Tip Tor/H Stab Tip VB/Elev Tor	20.030	20.014	
Antisym Wing Tip VB/H Stab VB/Rudder Bending	20.314		
H Stab Tip VB/Elev Tor	20.647	20.538	
Fin Tip LB/Rudder Tor/Rud-Tab Rot	22.861		20.953
Asym Wing Tip Tor CW/Nac Diag @ 45/Rudder Tor			21.194
Antisym Wing Tip VB/Rudder Tor/Rud-Tab Rot	24.121		

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Table 10.3
GVT Multiple Shaker Positions
Analysis and test Comparison

Anal. Freq. (Hz)	Mode No.	Test Freq. (Hz)	Damping g	Description	Run No
1.65	1	1.62	0.007	Symmetric, 1st Wing Bending	1
2.04	2	2.01	0.006	Antisymmetric, 1st Wing Bending	1
2.45	3	2.32	0.041	Symmetric, Nacelle Lateral	3
2.60	4	2.65	0.022	Antisymmetric, Nacelle Lateral	1
2.90	5	2.98	0.011	Antisymmetric, 1st Body Lateral Bending/Aft body Torsion/2nd Wing Bending/1st Wing Chordwise	1 1
3.02	6	3.02	0.108	Symmetric, 1st Body Vertical Bending/Nacelle Vertical/2nd Wing Bending	1
3.33	7	3.31	0.013	Antisymmetric, Nacelle Vertical/Aft Body Torsion/2nd Wing Bending	1
3.34	8	3.40	0.018	Symmetric, Nacelle Vertical/2nd Wing Bending/1st Body Vertical Bending	1
	9	3.63	0.034	Antisymmetric, Main Gear+Platform Fore-Aft	1
3.84	10	3.78	0.024	Antisymmetric, Aft Body Torsion/1st Stabilizer Bending	1
4.36	11	4.08	0.028	Symmetric, Main Gear+Platform Lateral	1
4.33	12	4.26	0.023	Antisymmetric, 1st Fin Bending/2nd Wing Bending (Wing and Stab Tips in Phase)	1
4.44	13	4.33	0.022	Antisymmetric, 1st Fin Bending/2nd Wing Bending (Wing and Stab Tips Out of Phase)	1
	14	4.45	0.030	Antisymmetric, Nose Gear+Platform Lateral	6
5.04	15	4.51	0.028	Symmetric, 3rd Wing Bending	3
	16	4.98	0.048	Antisymmetric, Wing Chordwise/1st Body Lateral Bending/Nose Gear Lateral	1
	17	5.15	0.029	Antisymmetric, Main gear Lateral/Wing Chordwise	1
5.10	18	5.18	0.020	Symmetric, 1st Stab. Bending/1st Fin Chordwise	2
5.27	19	5.27	0.054	Antisymmetric, Wing Chordwise	5
5.53	20	5.56	0.017	Antisymmetric, 3rd Wing Bending/Stabilizer Chordwise/Nose Gear Lateral	2
5.57	21	5.72	0.025	Symmetric, Wing Chordwise/Fin Chordwise	2
6.92	22	6.01	0.038	Right Nacelle Torsion	6
6.18	23	6.41	0.046	Antisymmetric, Stabilizer Chordwise/Body Ovalizing	4

Table 10.3 (continued)
GVT Multiple Shaker Positions
Analysis and test Comparison

Anal Freq. (Hz)	Mode No.	Test Freq. (Hz)	Damping g	Description	Run No
	24	6.64	0.023	Fin Chordwise	6
6.94	25	6.69	0.038	Left Nacelle Torsion	6
6.33	26	7.36	0.040	Antisymmetric, Body Ovalizing/Body Roll/Stab Chordwise/Nose Gear Lateral	4
	27	7.69	0.031	Antisymmetric, 3rd Wing Bending/Nacelle Vertical/Body Ovalizing/Main Gear Vertical	2
7.85	28	7.85	0.043	Symmetric, Nose Gear Vertical/Main Gear Fore-Aft/Fin Chordwise/Stabilizer 1st Bending/Nacelle Vertical/Body 1st Vertical Bending/Wing 3rd Bending	6
	29	8.24	0.023	Symmetric, 3rd Wing Bending/Main Gear Fore-aft	2
	30	8.68	0.023	Antisymmetric, Fore Body Ovalizing out of Phase with Aft Body Ovalizing/Wing 2nd Chordwise	2
8.80	31	8.90	0.022	Antisymmetric, Fore Body Ovalizing in Phase with Aft Body ovalizing/Body Roll/Main Gear Vertical/ Fin 1st Bending/Stabilizer 1st Bending/Stabilizer 1st Chordwise	2
	32	9.13	0.025	Antisymmetric, Aft Body Ovalizing in Phase with 1st Bending/Wing 2nd Chordwise out of Phase with Stabilizer 1st Chordwise/Stabilizer 1st Bending/Wing 3rd Bending/Main Gear Vertical	2
8.92	33	9.23	0.006	Symmetric, Body 2nd Vertical Bending/Fin Chordwise/Stabilizer 1st Bending/Nacelle Vertical Bending	[illegible]
9.81	34	9.51	0.035	Antisymmetric, Wing 3rd Bending/Fore Body	2
9.85				Ovalizing in Phase with Aft Body Ovalizing/Wing 1st Chordwise out of Phase with Stabilizer Chordwise/Rudder Rotation	2
9.33	35	10.19	0.025	Symmetric, Wing 1st Torsion out of Phase Nacelle Vertical Bending/Wing 3rd Bending	6
	36	10.27	0.027	Antisymmetric, Aft Body Ovalizing out of Phase with Fin 1st Bending/Stabilizer 1st Bending/Wing 3rd Bending/Stabilizer Chordwise	2

11. CONCLUSIONS AND RECOMMENDATIONS

This report is submitted to complete the task published in the Federal Register (Vol. 61, Number 129) on July 3, 1996 assigned to the Aviation Rulemaking Advisory Committee (ARAC) entitled "Engine Windmilling Imbalance Loads." This report details the work performed in establishing an acceptable criteria and methodology for determining the dynamic airplane loads and accelerations resulting from an imbalanced windmilling engine. It addresses fan blade failure events as well as other likely causes of significant engine vibratory loads such as loss of centerline support.

The service history data of high by-pass ratio engines under windmilling imbalance condition was reviewed. The review concluded that current airplanes have demonstrated adequate capability to withstand loss of fan blade and loss of centerline support. However, this may not always be the case, especially if new airplane and engine designs are significantly different from past conventional configurations. An examination of the existing criteria did not identify any specific requirements that would continue to guarantee the positive outcome experienced in the known events. Therefore, the working group developed recommended criteria to be used in assuring safety of flight in all future airplanes in the event of windmilling under engine imbalance. These criteria include the windmilling condition definition which should be used in evaluating structure, systems including operating engine(s), and flight crew performance. Specific criteria for evaluating structure have been developed.

The criteria recommended in this report are applicable to high bypass ratio engines with fan diameters greater than 60 inches. In the absence of evidence justifying an alternative approach providing an equivalent level of safety, these criteria may be applicable to airplanes with smaller diameter engines.

For the blade loss event, design evaluation criteria for future airplanes have been developed and are presented in Chapter 4. These establish the maximum level of engine imbalance and associated diversion times to be used for analytical determination of the airplane loads and accelerations. The maximum level of engine imbalance for blade loss is recommended to be 1.0 imbalance design fraction, which is the mass imbalance resulting from the FAR 33.94 blade containment and rotor imbalance test. The two recommended diversion times are 60 minutes and the maximum diversion time up to 180 minutes. In addition, an approach for evaluating the loss of centerline support condition has been recommended in Chapter 4.

Service experience indicates that engine rundowns occur at all levels of blade fraction. Engines which have experienced a full blade loss or more have always rundown to idle or below within a few seconds after blade release. All were shut down by the flight crew within a few seconds after rundown. Some events between 0.25 and less than 0.5 blade fraction may run on indefinitely unless the crew takes action to shut down the engine. These events cause higher frequency vibration than windmilling events but are concluded not to be a threat to the airplane structure. However, they have caused crew confusion as to which engine should be shut down. Consideration should be given to ensure that on future airplane designs the crew members are able to make the decision to shut down the appropriate engine in a timely manner.

Recommendations are included addressing the level of detail required for engine and airframe modelling to adequately describe the dynamic characteristics needed to provide valid loads and accelerations. Airplane dynamic responses should be calculated with a complete integrated airframe and engine analytical model. The airplane model should be comparable to those used for certification flutter and dynamic gust analyses. The engine and nacelle model would normally be to the same level of detail as the model used for FAR 33.94 test simulation. Optionally a simplified engine model may be used in the windmilling analysis if shown to be valid for the airplane/engine configuration and the frequencies of interest.

The working group reviewed the traditional ground vibration tests, flight flutter tests, and tests performed under Sec. 33.94 of 14 CFR and concluded that no further demonstrative ground or flight test programs would be needed in order to achieve the objective of establishing confidence in the proposed methodology. However, it is recommended that the GVT conducted to validate the structural dynamic model should include multiple shaker locations, including locations on the engine.

The working group recommends that a harmonized FAR Part 25 Advisory Circular and an ACJ to JAR 25 be developed based on the technical information contained in this report.