COMMENT RESPONSE DOCUMENT (CRD) TO NOTICE OF PROPOSED AMENDMENT (NPA) 2007-15

for amending the Executive Director Decision No. 2003/02/RM of 17 October 2003 on certification specifications, including airworthiness codes and acceptable means of compliance, for large aeroplanes (« CS-25 »)

And

for amending the Executive Director Decision No. 2003/09/RM of 24 October 2003 on certification specifications, including airworthiness codes and acceptable means of compliance, for engines (« CS-E »)

"Engine & APU Failure Loads and Sustained Engine Windmilling"

Explanatory Note

I. General

1. The purpose of the Notice of Proposed Amendment (NPA) 2007-15, dated 24 October 2007 was to propose an amendment to Decision N° 2003/02/RM of the Executive Director of the European Aviation Safety Agency of 17 October 2003 on certification specifications, including airworthiness codes and acceptable means of compliance, for large aeroplanes (« CS-25 ») and to propose an amendment to Executive Director Decision No. 2003/09/RM of 24 October 2003 on certification specifications, including airworthiness codes and acceptable means of compliance, for engines (« CS-E »).

II. Consultation

2. The draft Executive Director Decision amending Decision N° 2003/02/RM and Decision N° 2003/09/RM was published on the web site (http://www.easa.europa.eu) on 24 October 2007.

3. By the closing date of 24 January 2008, the European Aviation Safety Agency ("the Agency") had received 35 comments from 7 National Aviation Authorities, professional organisations and private companies.

III. Publication of the CRD

3. All comments received have been acknowledged and incorporated into this Comment Response Document (CRD) with the responses of the Agency.

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 or proposed amendment is not shared by the Agency

   The resulting text highlights the changes as compared to the current rule.

5. The Agency's Decision will be issued at least two months after the publication of this CRD to allow for any possible reactions of stakeholders regarding possible misunderstandings of the comments received and answers provided.

6. Such reactions should be received by the Agency not later than 23 August 2009 and should be submitted using the Comment-Response Tool at http://hub.easa.europa.eu/crt.

IV. CRD table of comments, responses and resulting text

A. EXPLANATORY NOTE - IV. Content of the draft Decision p. 5-6

comment | 1 | comment by: *Francis Fagegaltier Services*

It is correct to say, in paragraph IV.10, that the interfaces between aircraft and engine are better addressed in a group having both engine and aircraft expertise.

However, cancellation of the task E.002 may be questionned.

Indeed, as shown in other comments, the "CS-E" rulemaking has not been addressed adequately. Only CS-E 520 is addressed when other texts are related to the subject : in particular, CS-E 650 deals also with engine - aircraft interface with regard to vibration.

It is then suggested resurrecting the task E.002 to determine all effects on CS-E of this "aircraft" rulemaking and eventually to correct / change any part of CS-E as necessary for consistency.

response | *Partially accepted*

In terms of process, addressing engine and airframe interface issues within a single group is still considered to be an efficient way of working. The review group was supplemented with an additional engine specialist specifically to ensure that engine issues were correctly addressed. The Agency therefore has no plans to resurrect task E.002.

A reference to CS-E 650 has been included in AMC E 520(c)(2).

comment | 4 | comment by: *Francis Fagegaltier Services*

General comment
The sharing of texts between CS-25 and CS-E according to respective design responsibilities of aircraft and engine designers has been greatly improved when compared to JAA NPAs.

However, this goal has not been totally achieved in these proposals. Indeed, the “engine” model is addressed in three different places : AMC 25.362, AMC 25-24 and AMC E 520(c)(2). The words are similar but not identical in these texts.

This raises questions on the rationale behind such differences when one can assume that aircraft / engine designers will define only one model and not three different models.

CS-E is very clear on the definition of what constitutes the engine and asks for the identification of interfaces with the aircraft (CS-E 20). During engine certification, only the engine parts would be addressed under CS-E 520. Therefore, the engine model, which must be validated during engine certification, cannot address parts which are not under the engine type certificate.

It is assumed that this engine model, defined by the engine designer, would be

	integrated, by the aircraft designer, in a "powerplant" model (powerplant = engine + aircraft parts of the nacelle). CS-25 and CS-E texts should be consistent with the respective responsibilities of the type certificate holders. CS-25 should be limited to certification specifications necessary for obtaining an aircraft type certificate and CS-E should be limited to certification specifications necessary for obtaining an engine type certificate. The engine is defined by its type design. The sharing of work between designers should not interfere with the writing of CS-25 and CS-E. Indeed, many times the engine TC holder is also in charge of providing some nacelle elements or even the complete nacelle. But, in such cases, the engine company is acting as a supplier to the aircraft TC holder and not as the engine TC holder Then, it is suggested a further improvement of the package by clearly separating responsibilities of the engine designer and of the aircraft designer. AMC to CS-E should address the engine model, when AMCs to CS-25 should address integration of this engine model into a powerplant and / or aircraft model. This re-writing work is too much important for giving a detailed counter-proposal as part of this comment : this should be done within the NPA writing group.
response	*Accepted* The distribution of text relating to models has been further reviewed and simplified. In particular, reference to the "engine structural model" has been replaced by "propulsion structural model" in CS-25, to reflect the fact that it may include elements not required by the engine type-design. The engine model is identified as a sub-part of the propulsion structural model and detailed engine model validation is addressed only in CS-E 520(c)(2). Furthermore, reference to the propulsion structural model in AMC 25.362 is removed and replaced with a reference to AMC 25-24 to avoid duplication.

comment	*15* comment by: *Francis Fagegaltier Services* CS-25 is not limited to aircraft powered by turbofan engines. Why is the case of propellers not addressed ?
response	*Not accepted* The effects of propeller blade failure or release are already covered under CS 25.905.

comment	*16* comment by: *Turbomeca* Either it should be clarified that incorporation of these new additional requirements in CS-E is only applicable to turbofan engines or it should be added justification for the need of incorporation of additional requirement in CS-E for engines (e.g engine for rotorcraft) other than turbofan. **Justification:** the origin of this rulemaking task based on ARAC LDHWG report and JAA NPA25C-305/25E-306 is **only** related to Large aeroplanes and engines for large aeroplanes i.e **turbofan** engines. There is no study showing that service experience showed current CS-E is not appropriate for engines for

	rotorcraft. By the way, CS-23,27 and 29 are not proposed to be modified (no safety issue has been identified).
response	*Not accepted* The proposed addition to CS-E 520 reflects the philosophy that consideration must be given to all identified failures that are likely to result in high out-of-balance forces, including those associated with the existing requirements of CS-E 800 and CS-E 810. This is equally applicable to all engines.

A. EXPLANATORY NOTE - V. RIA - 1. Purpose and intended effect p. 6-7

comment	*17* comment by: *Turbomeca* Either it should be clarified that incorporation of these new additional requirements in CS-E is only applicable to turbofan engines or it should be added justification for the need of incorporation of additional requirement in CS-E for engines (e.g engine for rotorcraft) other than turbofan. **justification:** the origin of this rulemaking task based on ARAC LDHWG report and JAA NPA25C-305/25E-306 is **only** related to Large aeroplanes and engines for large aeroplanes i.e **turbofan** engines. There is no study showing that service experience showed current CS-E is not appropriate for engines for rotorcraft. By the way, CS-23,27 and 29 are not proposed to be modified (no safety issue has been identified). It is never justified why new requirement is necessary for engines for CS-23/27/29 installations. The only justification related to safety is for turbofan engines.
response	*Not accepted* (See response to Comment #16)

A. EXPLANATORY NOTE - V. RIA - 2. Options p. 7-8

comment	*18* comment by: *Turbomeca* Option2 (i): it is said: " In addition, amend CS-E 520(c)(2) concerning Engine Imbalance Loads to ensure the correct airframe/engine interface. " . This may be right and necessary for airframe/engine interface related to CS-25 installations but not the case for airframe/engine interface related to CS-23/27/29 installations . Therefore either it should be clarified that incorporation of these new additional requirements in CS-E is only applicable to turbofan engines or it should be added justification for the need of incorporation of additional requirement in CS-E for engines (e.g engine for rotorcraft) other than turbofan.
response	*Not accepted* (See response to Comment #16)

A. EXPLANATORY NOTE - V. RIA - 4. Impacts p. 8-9

comment	*19* comment by: *Turbomeca*
	ai) safety: this paragraph justifies safety improvement for large aeroplanes only. It does not provide any justification for need to increase safety level for other aircrafts (CS-23,27,29) and associated engines. aii) and avi) Economic and Foreign comparable regulatory requirements: CS-E changes as proposed by this NPA 2007-15 leads to an additional difference between CS-E and FAR 33 in particular for engines other than turbofan if proposed CS-E changes remain applicable to all engines. Therefore this may lead to duplicate certification activities. Has EASA the intent to consider this difference as a SRD?(Significant Regulatory Difference). b) equity and Fairness issues: regarding engines other than turbofan, CS-E changes will lead to smaller harmonisation and therefore will reduce the equity and Fairness.
response	*Not accepted* The change to CS-E 520(c)(2) is intended to clarify existing certification practice and will not create an additional Significant Standard Difference (SSD).

A. EXPLANATORY NOTE - V. RIA - 5. Summary and Final Assessment p. 9

comment	*20* comment by: *Turbomeca*
	Safety improvement is only justified for large aeroplanes. There is no justification for need to increase safety level for other aircrafts (CS-23,27,29) and associated engines. CS-E changes as proposed by this NPA 2007-15 leads to an additional difference between CS-E and FAR 33 in particular for engines other than turbofan if proposed CS-E changes remain applicable to all engines. Therefore this may lead to duplicate certification activities. CS-E changes will lead to smaller harmonisation and therefore will reduce the equity and Fairnessin particular for engines other than turbofan. Therefore it should be clarified that incorporation of these new additional requirements in CS-E is only applicable to turbofan engines or it should be added justification for the need of incorporation of additional requirement in CS-E for engines (e.g engine for rotorcraft) other than turbofan.
response	*Not accepted* The change to CS-E 520(c)(2) is intended to clarify existing certification practice and will not create an additional SSD.

B. JAA NPA 25C-305: Engine & APU Load Conditions - II) Proposals - CS-25 BOOK 1: AIRWORTHINESS CODE - Proposal 1 (CS 25.361) p. 14-15

comment | *28* comment by: *Dassault Aviation*

In CS 25.361 (b) concerning APU, only 1g level flight loads are asked to be coupled with limit acceleration torque loads.
It seems that in case of an APU used in flight, 75% limit loads or limit load factor from condition A of CS 25.333 (b) has to be combined with limit APU torque as it is asked in 25.361 (a) for the engines.
Comment from G. Ménard
Dassault- Aviation DGT/DTAS

response | *Not accepted*

CS 25.361(b) is fully consistent with CS 25.361(a)(3).

comment | *29* comment by: *FAA*

Comment: We recommend re-wording the introduction of CS 25.361(a) to "For all engine installations (not including auxiliary power units)."
Rationale: CS 25.361(a) refers to "engines," which is not intended to include APUs. Only CS 25.361(b) is intended to address APUs. Since it's possible that someone could consider an auxiliary power unit to be an "engine," and therefore subject to CS 25.361(a), a clear distinction should be made between "engine" and "APU."

response | *Not accepted*

The implication of this comment is that all references to "engine" would need to be so annotated. CS-Definitions define's both "*Engine*" and "*Auxiliary Power Unit*". Furthermore, the distinction is clearly highlighted in the title to CS 25.361.

The word "all" in sub-paragraph (a) is removed as this may be causing some confusion.

resulting text |

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

(a) For ~~all~~ engine installations:
(1) Each engine mount,...

B. JAA NPA 25C-305: Engine & APU Load Conditions - II) Proposals - CS-25 BOOK 1: AIRWORTHINESS CODE - Proposal 2 (CS 25.362) p. 15

comment | *11* comment by: *Francis Fagegaltier Services*

CS-25.362 (a)
The words "as defined in CS-E 520 (c)(2)" cannot be easily linked to the appropriate noun. There are three grammatical possibilities for finding this noun. It may be one of the following:
(1) loads and vibration
(2) dynamic analysis

	(3) failure conditions. However, none of them is consistent with CS-E 520 (c)(2) : (1) CS-E 520 addresses “forces”, not “loads and vibration” (2) CS-E 520 requires “validated data”, not “dynamic analysis”, (3) CS-E 520 does not use the wording “engine structural failure”. Therefore, it is not easy to determine who, aircraft designer or engine designer, is in charge of (1) determining the most critical transient dynamic loads and vibrations, (2) making the dynamic analysis. Was the intent to simply say : ...... failure conditions, using the validated data required in CS-E 520 (c)(2) ? With this counter-proposal, CS-25.362 (a) would be clearer and both CS-25 and CS-E would be consistent.
response	*Partially accepted* Text is re-written. (See response to comment #31)

comment	*30* comment by: *FAA* **Comment:** We recommend adding a sentence to the bottom of CS 25.362(a) that states, "This requirement does not apply to auxiliary power units." **Rationale:** CS 25.362 refers to "engines," which is not intended to include APUs. Since it's possible that someone could consider an auxiliary power unit to be an "engine," and therefore subject to CS 25.362, a clear distinction should be made between "engine" and "APU."
response	*Not accepted* (See response to comment #29)

comment	*31* comment by: *FAA* **Comment:** The text of CS 25.362(a) should be changed back to that originally proposed in JAA NPA 25C-305. **Rationale:** The original JAA NPA included the following: "(a) For engine supporting structure, an ultimate loading condition must be considered that combines 1g flight loads with the transient dynamic loads resulting from: (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 loads." The justification for this EASA NPA is consistent with the original JAA NPA, but the proposed rule text is not. The justification includes: "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)."

	However, the rule text deletes the specific failure conditions that must be considered, that is "the loss of any fan, compressor, or turbine blade; and, for certain designs, other engine structural failure that could result in higher loads." Instead, it refers to engine structural failure conditions, as defined in CS-E 520(c)(2). This reference is inadequate. One objective of this EASA NPA is to improve the engine / airframe interface issues, because much of the data required for compliance to CS 25.361 and 25.362 is developed by or with the engine manufacturer. The NPA states that "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." While we agree with the objective of improving the link between the engine and airframe requirements, we do not agree with the proposed rule text. The first concern is that the specific failure conditions are deleted. The second and larger concern is that an engine requirement is included within an airframe requirement. We believe this could present administrative problems and potentially result in the necessary work not being completed. We believe the original JAA NPA text should be used and reference to CS-E 520 should be made in AMC 25.362. We would also support putting identical language in both requirements to improve the link between the two.
response	*Partially accepted* The rule is amended to include specific failures and the reference to AMC E.520(c)(2) is moved to AMC. The original JAA text required separate analysis of blade failure and any other engine structural failure. This is considered unnecessary as only the most severe condition need be analysed.

comment	*32* comment by: *FAA* **Comment:** We recommend adding the following text to the end of CS 25.362(a): "The engine supporting structure must be able to support these ultimate load conditions without failure. In addition, the airplane must be capable of continued safe flight considering the aerodynamic effects on controllability due to any permanent deformation that results from these ultimate load conditions." **Rationale:** CS 25.362 only prescribes "ultimate load conditions" for which the absence of structural failures must be shown. The requirement does not include any "limit load conditions," which would require consideration of permanent deformations that do not result in failure. The added text would make it clear that both deformations and failures must be considered. The FAA received a similar comment when proposing the engine failure loads special condition on a recent airplane program. We have since added similar language to our special condition and plan to apply it to all airplane programs until new rulemaking is completed.
response	*Partially accepted* First part is not necessary as it is already required under CS 25.305. Second part – Intent is accepted. Proposed text is re-worded to read as a structural rule.

resulting text

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 <u>failure of a blade, shaft, bearing or bearing support, or bird strike event.</u> ~~the engine structural failure conditions, as defined in CS-E 520(c)(2).~~ <u>Any permanent deformation from these ultimate load conditions should not prevent continued safe flight and landing.</u>

(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.

B. JAA NPA 25C-305: Engine & APU Load Conditions - II) Proposals - CS-25 BOOK 2: AMC - Proposal 4 (AMC 25.362) - 2. RELATED PARAGRAPHS p. 16

comment *34* comment by: *Gulfstream Aerospace Corp*

AMC 25-24, paragraph 2 a "Related CS paragraphs CS-25:" -
CS 25.302 "Interaction of systems and structures" should be included in the list of related CS paragraphs. This regulation was still being developed at the time the Loads & Dynamics Harmonization Working Group (LDHWG) was developing its report on sustained engine imbalance so it was not directly referenced, but the then proposed interaction of systems and structures rule was used as the basis for setting the factors of safety and structural criteria in the report. Now that CS 25.302 is part of the EASA regulations, it is appropriate to reference it in connection with AMC 25-24. Note that FAR 25.302 is still pending, and so AC 25-24 does not have a reference to it.

response *Accepted*

For resulting text see Appendix 2.

B. JAA NPA 25C-305: Engine & APU Load Conditions - II) Proposals - CS-25 BOOK 2: AMC - Proposal 4 (AMC 25.362) - 5. EVALUATION OF TRANSIENT FAILURE CONDITIONS p. 18

comment *12* comment by: *Francis Fagegaltier Services*

AMC 25.362 paragraph 5 (b)
The issues to be addressed are correctly identified. But why is this AMC demanding more on the engine than the dedicated AMC E 520 (c)(2) ? (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.)

The fact that the engine model is addressed in triplicate (see general comment), with different wording each time, is not adequate. Everything affecting the engine and the work of the engine designer should be eliminated from CS-25 documents and placed in CS-E documents.

Note that the word “normally” in the sentence “The loads to be applied to the pylon and airframe are normally determined and validated by the engine manufacturer » does not reflect the new wording of CS-E 520 (c)(2) which requires validated data from the engine designer.

response *Partially accepted*

AMC 25.362 requires more conditions to be considered for the airframe than CS-E requires for the engine. Clarification is added that the airframe manufacturer is normally responsible for determining the loading conditions based on the integrated model.

Repetition of engine models is addressed (see response to comment #4)

Last part is addressed by clarification of the text in AMC 25.362 paragraph 5(b).

For resulting text see Appendix 1.

B. JAA NPA 25C-305: Engine & APU Load Conditions - II) Proposals - CS-25 BOOK 2: AMC - Proposal 4 (AMC 25.362) - 7. MATHEMATICAL MODELLING AND VALIDATION p. 19-21

comment *13* comment by: *Francis Fagegaltier Services*

AMC 25.362 paragraph 7 (a)
The words « may be » in the sentence « The integrated dynamic model consists of the following components that may be validated independently:
o Airframe structural model.
o Engine structural model. »
is not consistent with the new wording of CS-E 520 (c)(2) which requires validated data from the engine designer. Unless this “engine structural model” is not the one supposed to be provided by the engine designer according to CS-E. Once again the general comment on the triplication of texts is valid here.

response *Accepted*

Text amended to provide greater clarity.

For resulting text see Appendix 1.

comment *14* comment by: *Francis Fagegaltier Services*

AMC 25.362 paragraph 7 (c)
The difficulty in differentiating the “engine structural model” and the “engine model” is illustrated here. The whole paragraph addresses the first one (according to its title) when the sub-paragraph 7 (c)(4) addresses the second. Components listed in paragraph 7 (c)(2) are not all “engine” components and therefore out of the responsibility of the engine type certificate holder. Once again the general comment on the triplication of texts is valid here.

response *Accepted*

The term “propulsion structure model” is introduced to clarify.

For resulting text see Appendix 1.

comment | *33* | comment by: *FAA*

Comment: The section addressing "Engine Structural Model and Validation" should be changed back to that originally proposed in JAA NPA 25C-305, and the proposed new AMC E 520(c)(2) should be deleted.
Rationale: Some of the text addressing engine model validation was extracted from AMC 25.362 and used to create the new AMC E 520(c)(2). As noted above, while we recognize the importance of the interface between engine and airframe manufacturers, CS 25.362 remains an airframe requirement. Therefore, we think this text belongs in AMC 25.362 as originally proposed in JAA NPA 25C-305.

response *Not accepted*

Creating AMC E 520(c)(2) is believed to clarify the responsibilities between engine and airframe manufacturer.

C. JAA NPA 25E-306: Sustained Engine Imbalance - II) Proposal - CS-25 BOOK 1: AIRWORTHINESS CODE - Proposal 2 - AMC 25-24) - 2. RELATED PARAGRAPHS p. 52-53

comment | *3* | comment by: *Francis Fagegaltier Services*

AMC 25-24, paragraph 4 (b)
The last but one sentence correctly reflects the text of CS-25 : the rotor must be stopped when continued rotation could jeopardise the safety. The legal implications of the last sentence, which bluntly states that this “safety” rule may be forgotten simply because it would be “undesirable”, should be carefully analysed, in view of possible law suits following an accident resulting from engine continued rotation.

It is suggested adding an explanation of the “undesirable” aspect : may be this is because the drag of a stopped rotor would more affect the aircraft safety than a windmilling rotor.

Nevertheless, it remains that this AMC is suggesting that one CS-25 certification specification cannot be or should not be complied with : this is not adequate. A change to CS 25.903 (c) should be proposed or a strong explanation be given for keeping a “safety” specification which would be either “impractical” or “undesirable”.

response *Accepted*

Last two sentences are deleted.

For resulting text see Appendix 2.

C. JAA NPA 25E-306: Sustained Engine Imbalance - II) Proposal - CS-25 BOOK 1: AIRWORTHINESS CODE - Proposal 2 - AMC 25-24) - 4. BACKGROUND p. 53-54

comment	2 comment by: *Francis Fagegaltier Services*
	AMC 25-24, paragraph 4 (a) The description of what is required in CS-E 520 (c)(2) does not apply to the new wording proposed for this paragraph in this NPA, but refers to the old CS-E text. It is then suggested changing the paragraph 4 (a) for consistency, for example by adapting or copying the last sentence of paragraph 8 (d) of this AMC 25-24.
response	*Accepted* Text is amended. For resulting text see Appendix 2.

C. JAA NPA 25E-306: Sustained Engine Imbalance - II) Proposal - CS-25 BOOK 1: AIRWORTHINESS CODE - Proposal 2 - AMC 25-24) - 5. EVALUATION OF THE WINDMILLING IMBALANCE CONDITIONS (1) Windmilling Blade Loss Conditions p. 55

comment	5 comment by: *Francis Fagegaltier Services*
	AMC 25-24, paragraph 5 (c) (1) The response to a comment (n°35) on LROPS and implicitly on the limit to 180 minutes, made at time of the JAA NPA, states that the explanation can be found in this AMC. This is not correct : the justification of the EASA NPA should explain why the 270 minutes or 300 minutes diversion times are not considered. One observer could think that an aircraft flying with one engine in windmilling after a blade out event would be more likely to be in trouble when flying 300 minutes than when flying 60 minutes.
response	*Noted* There is currently no data to support extending the 180 minutes ETOPS limit combined with the 1 IDF condition. This is an area which may require future research.

C. JAA NPA 25E-306: Sustained Engine Imbalance - II) Proposal - CS-25 BOOK 1: AIRWORTHINESS CODE - Proposal 2 - AMC 25-24) - 5. EVALUATION OF THE WINDMILLING IMBALANCE CONDITIONS - (5) Systems Integrity p. 59-60

comment	26 comment by: *Airbus*
	In paragraph <u>e. Other failure conditions</u> (bottom of page 59 & top of page 60), delete the example of a large bird ingestion (second bullet). The addition of bird strike is not justified, as: • The Loads & Dynamics Harmonisation Working Group retained criteria (IDF=1.00 together with the one hour/three hours diversion times) that were based on a statistical review of in-service imbalance data. In this review, all sources of engine imbalance (bird strike included) were

accounted for, as explained in chapter 3 - Service History of the Group's report, page 97 in NPA 2007-15. So there is no need to make a special case with large bird ingestion, since all imbalance causes were considered in the definition of the criteria.

- Bird strike events generally occur during Take-Off and Landing phases, so not relevant for a combination with a one or three hours diversion time.

FAA Advisory Circular 25-24, that was developed using the a.m. report, does not make a special case with large bird ingestion. As explained above, there is no reason to introduce this case into AMC 25-24, which would result in disharmonisation with the FAA.

response *Accepted*

Bird ingestion is removed from AMC 25-24.

For resulting text see Appendix 2.

comment *27* comment by: *UK CAA*

The existing statement is generally satisfactory if all systems are shown to survive the blade out event, although, as indicated above, it is not only the windmilling condition that should be considered. If the compliance approach is that only a minimum number of systems will be shown to survive, it is important that no MMEL relief is permitted for those systems necessary for CSF&L.

Proposed Text:
(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 *imbalance* conditions and diversion times described above. For this evaluation, the aeroplane is assumed to be dispatched in its normal configuration and condition. *If it is shown that all the systems withstand the transitory and sustained imbalance conditions, the combination of additional conditions associated with the Master Minimum Equipment List (MMEL) need not be considered. However, if it is shown that only the minimum number of systems required for continued safe flight and landing withstand the imbalance conditions, no degradation of these systems by the MMEL is permitted. These essential systems must be clearly identified such that they are excluded from MMEL relief for the life of the aircraft*

Justification:
Aircraft typically fly under MMEL/MEL relief therefore it is necessary to ensure that continued safe flight and landing is not compromised by the MMEL in event of SEI, even though such events are rare. SEI is a specific event and dispensation under the MMEL is an existing pre-flight condition, therefore quantitative analysis of the probability of the failure condition is inappropriate.

response *Not accepted*

The probability of having an imbalance event combined with the defined diversion times is already low ($<10^{-9}$/flight hour). Consideration of additional system failures is therefore unnecessary.

comment	35 comment by: *Gulfstream Aerospace Corp*
	AMC 25-24 paragraph 5 e "Other failure conditions" - The structural criteria for the blade out wind-milling events were developed based on the statistical probability of the occurrence of a 1.0 IDF blade loss event. It is inappropriate to apply the same criteria to more severe, but less probable events. Paragraph 5 e should refer to CS 25.302 to direct the manufacturer to set structural criteria based on probability of occurrence for any other failure conditions evaluated. It is recommended that the following sentence be added: " . . . could result in more severe induced vibrations than the blade loss or bearing/bearing support failure condition, they should be evaluated. **Factors of Safety should be set based on the probability of occurrence per the criteria in CS 25.302.** Examples of other . . . **"**
response	*Not accepted* Probability of failure was addressed in the statistical analysis for other failure conditions, including shaft and bearing failures.

comment	36 comment by: *Gulfstream Aerospace Corp*
	AMC 25-24 paragraph 5 e "other failure conditions" - Failures which can be linked to a particular flight segment should not necessarily require a 3 hour diversion. Specifically the bird strike criteria are linked to takeoff and approach and landing segments. Birds are found at low altitudes near land, not at cruise altitudes in the middle of the ocean, so a bird strike would only occur relatively close to an airport and would not involve a long diversion.
response	*Accepted* (See response to comment #26) For resulting text see Appendix 2.

C. JAA NPA 25E-306: Sustained Engine Imbalance - II) Proposal - CS-25 BOOK 1: AIRWORTHINESS CODE - Proposal 2 - AMC 25-24) - 8. VALIDATION p. 62

comment	6 comment by: *Francis Fagegaltier Services*
	AMC 25-24, paragraph 8 (d) In line with a general comment made on this NPA 2007-15, the sentence found in this paragraph 8 (d) : “The engine model will normally be validated by the Engine manufacturer under CS-E 520(c)(2) » is not true if this « engine model » is the one addressed in paragraph 7 (c) of this same AMC 25-24. CS-E addresses only the parts which are declared as constituting the engine type design. Therefore, nacelle components, which are not part of the engine type design, would not be addressed during engine certification.
response	*Accepted* (See response to comment #4) For resulting text see Appendix 2.

D. Proposed Change to CS-E - I) Explanatory Note p. 86

comment | *21* comment by: *Turbomeca*

Explanation only shows interface issue between CS-25 and CS-E for engines for large aeroplanes. There is no explanation related to engines for other installations and interface issues between CS-E and CS23/27/29.

Therefore it should be clarified that incorporation of these new additional requirements in CS-E is only applicable to turbofan engines or it should be added justification for the need of incorporation of additional requirement in CS-E for engines (e.g engine for rotorcraft) other than turbofan.

response | *Not accepted*

(See response to Comment #16)

D. Proposed Change to CS-E - II) Proposals - CS-E BOOK 1: AIRWORTHINESS CODE - CS-E-520 p. 86

comment | *7* comment by: *Francis Fagegaltier Services*

CS-E 520 (c)(2), general
The last sentence is not changed when compared to current CS-E (except one deleted word). Therefore, the word “engine stiffnesses” is still here when the justification contains the following : “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. ». It seems that the intent shown in the justification is not implemented in the change to CS-E 520.

This appears as being some sort of rulemaking by advisory material (if this concept is still valid because the legal structure of texts is not the same in USA and in Europe) : AMC E 520 (c)(2) is being used to change CS-E 520 by requesting more.

It is suggested putting the certification specifications in CS-E 520 (c)(2) and the acceptable means of compliance in AMC E 520 (c)(2), to remain within the current structure of CS-E.

response | *Partially accepted*

Text is deleted from CS-E 520(c)(2) and paragraph 2 of AMC E 520(c)(2) is amended.

For resulting text see Appendix 3.

D. Proposed Change to CS-E - II) Proposals - CS-E BOOK 1: AIRWORTHINESS CODE - AMC 520(c)(2) p. 87

comment | *8* comment by: *Francis Fagegaltier Services*

AMC 520 (c)(2), general

	Notwithstanding the previous comment on rulemaking by advisory material, it should be remembered that CS-E 520 is applicable to other engines than those installed on CS-25 aircraft. It is then suggested to start this AMC by something like this : "In case an engine model is being developed in cooperation with the aircraft designers, in particular those required to comply with CS-25 and associated AMC 25-24 and AMC 25.362, as a means to provide the "validated data" required by CS-E 520 (c)(2), this AMC E 520 (c)(2) provides guidance and acceptable means of compliance for the development of an engine model."
response	*Not accepted* (See response to Comment #16)

comment	*9* comment by: *Francis Fagegaltier Services* AMC 520 (c)(2), paragraph (5) The wording in this AMC ("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"), by considering only tests, is going much farther than what is found in CS-E 520 (c)(2) which allows to provide validated data on the basis of analysis. The certification specifications and the means of compliance should be consistent. Rulemaking by advisory material should be avoided.
response	*Accepted* Text is revised. For resulting text see Appendix 3.

comment	*10* comment by: *Francis Fagegaltier Services* AMC 520 (c)(2), paragraph (5) The wording in this AMC ("Vibration data are routinely monitored on a number of engines during the engine development cycle, thereby providing a solid basis for model correlation") has likely been transferred from the JAA "aircraft" texts without consideration to existing CS-E texts. It would be appropriate, in an AMC in CS-E, to refer to CS-E 650 Vibration surveys, which imposes a thorough analysis of the engine behaviour, including, in particular, out of balance cases. This CS-E 650 also addresses the interface with aircraft vibration analysis and therefore would have been relevant to this EASA rulemaking task. It is suggested a review within the EASA task group, may be completed by people having a detailed knowledge of CS-E, or a resurrection of the task E.002, to ensure that all effects on CS-E of this rulemaking are appropriately considered.
response	*Partially accepted* (see response to Comment #1) For resulting text see Appendix 3.

comment	*22* comment by: *Turbomeca*
	In the title add: " (Turbine engines for large aeroplanes)" **Justification:** the origin of this rulemaking task based on ARAC LDHWG report and JAA NPA25C-305/25E-306 is **only** related to Large aeroplanes and engines for large aeroplanes i.e **turbofan** engines. There is no study showing that service experience showed current CS-E is not appropriate for engines for rotorcraft. By the way, CS-23,27 and 29 are not proposed to be modified.
response	*Not accepted* (See response to Comment #16)

comment	*24* comment by: *Turbomeca*
	the text of this AMC is not applicable to engines for rotorcraft: e.g terms in bold letters in the extract below are not applicable to engine/rotorcraft. (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)**.
response	*Accepted* Text is deleted as it does not aid understanding and could be misleading. For resulting text see Appendix 3.

D. Proposed Change to CS-E - III) Justification p. 88

comment	*23* comment by: *Turbomeca*
	Explanation only shows necessity of redistribution between CS-25 and CS-E .There is no explanation related to necessity between CS-E and CS23/27/29. Therefore it should be clarified that incorporation of these new additional requirements in CS-E is only applicable to turbofan engines or it should be added justification for the need of incorporation of additional requirement in CS-E for engines (e.g engine for rotorcraft) other than turbofan.
response	*Not accepted* (See response to Comment #16)

resulting text

Appendix 1: Revised text of AMC 25.362

AMC 25.362
Engine Failure Loads

...

4. **BACKGROUND**.

...

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~~ In accordance with CS-E 520 (c)(2), other 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**

...

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 by the applicant based on the ~~and validated~~ integrated model, which includes the validated engine model supplied 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.

...

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 aircraft systems, including those 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 model should 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). 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 must ~~may~~ be validated ~~independently~~:

- Airframe structural model.
- Propulsion~~Engine~~ structural model. (including the engine model, representing the engine type-design).

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. PropulsionEngine 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.

For propulsion structural model and validation, see AMC 25-24.

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

Appendix 2: Revised text of AMC 25-24

AMC 25-24
Sustained Engine Imbalance

...

2. RELATED CS PARAGRAPHS

a. CS-25:

CS 25.302 “Interaction of systems and structures”
CS 25.571 “Damage tolerance and fatigue evaluation of structure”
CS 25.629 “Aeroelastic stability requirements”
CS 25.901 “Installation”
CS 25.903 “Engines”

...

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, or a shaft, bearing or bearing support, if this results in higher loads.

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. ...

...

5. EVALUATION OF THE WINDMILLING IMBALANCE CONDITIONS

...

e. Other failure conditions. If any other engine structural failure conditions

applicable to the specific engine design, e.g. failure of a shaft, 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.~~
...

7. MATHEMATICAL MODELLING

a. Components of the Integrated Dynamic Model. Aeroplane dynamic responses should be calculated with a complete integrated airframe and propulsion ~~engine~~ analytical model. The model should 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). 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) Propulsion ~~Engine~~ structural model (including the engine model, representing the engine type-design),
(3) Control system model,
(4) Aerodynamic model, and
(5) Forcing function and gyroscopic effects.

The airframe and engine manufacturers should mutually agree upon the definition of the integrated structural model, based on test and experience.

b. Airframe Structural Model. ...

c. Propulsion ~~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 and 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) Propulsion structural ~~These~~ models typically include the engine and 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) ...

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 propulsion system ~~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 propulsion system ~~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) ...

...

d. Engine Model. The engine model covering the engine type-design, 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 their~~there~~ resulting consequences should also be accurately represented.

...

Appendix 3: Revised text of CS-E 520 and AMC E 520(c)(2)

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, except for bird strike in relation to continued out-of-balance running. ~~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) ...

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) Validated data ~~Features modelled~~ specifically for blade loss analysis typically include:

- Finite element model
- Out-of-~~im~~balance,
- component failure,
- rubs (blade-to-casing, and intershaft),
- resulting stiffness changes, ~~and~~
- aerodynamic effects, such as thrust loss and engine surge, and
- variations with time of the rotational speed(s) of the Engine's main rotating system(s) after failure.

(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, or by analysis, or both. 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 (See CS-E 650). 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 represents~~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.