Response to comments on NPA-E-13

1 - Justification of the NPA

1. Background

The Rotor Integrity rule is revised to ensure consistency between FAR 33 and JAR-E. In this case, the two existing rules have been found to have achieved an adequate level of safety and since no additional safety threat has been identified the process has resulted in a requirement which is generally in line with the current FAR and JAR requirements and retains elements of both.

The basic objective of the requirement then is to maintain an acceptable level of safety.

The application of the current rules have resulted in disparities in demonstration methods, and possibly different margins of safety, yet on an overall basis there has been acceptable in-service experience.

The opportunity was also taken to make minor changes to JAR-E 810(b)(1) for consistency.

2. Outline

Currently JAR-E 840 is based on a no-burst criterion whereas FAR 33.27 is based on an acceptable growth criterion. A survey of engine manufacturers shows that the majority of designs are developed to satisfy both JAR and FAR requirements and consequently it is not absolutely clear which requirement drives the current level of integrity. The harmonised requirement thus contains the basic safety standard of both current requirements and provides a clear statement of the safety objectives of (1) designing rotors with a margin to burst above certified operating conditions and above failure conditions leading to rotor overspeed and, (2) not to have a level of growth/damage which will lead to a hazardous effect.

This rule assumes that as a minimum, single failure conditions will occur, leading to overspeed conditions, and that unless sufficient margin against bursting is ensured, that hazardous failure conditions will occur.

Definitions of terms used in the requirement to assist in the unambiguous interpretation of the text are contained in the proposed ACJ E 840.

3. History

The existing JAR-E and FAR 33 standards for rotor integrity at abnormally high rotational speeds have their origins in the early 1950's versions of the now superseded British Civil Airworthiness Requirements Section C (BCAR-C) and the US Civil Aviation Requirements (US CAR).

Those early versions of the BCAR-C / US CAR standards were very simplistic statements about the need to demonstrate adequate strength margins to withstand abnormally high rotational speeds. Their lack of detail enabled considerable variations in the severity of their interpretation / application and resulted in wide variations of established strength margins. This led to difficulties between the US and British aviation authorities when either of those authorities came to validate a type certification undertaken by the other authority and there was also a need for consistency of safety levels across the various manufacturers. Those concerns resulted in the FAA producing an FAA Policy Memorandum on this subject, dated 9 February 1959 which provided a more comprehensive set of guidance material. Generally similar material was produced by the British Air Registration Board (predecessor to the UK CAA) in its 'Blue Paper' Amendment No. 320 to BCAR-C effective on 2 December 1960 but with the additional emphasis of being mainly in the form of requirements. Under both of those improved combinations of rules and guidance material, the safety level was set mainly by limiting the acceptability of permanent damage sustained by the rotors. An interesting historical point is that fully comprehensive test requirements and associated acceptable growth criteria were not incorporated into the US standards until Amendment 33-6 to FAR 33 effective October 1974 and less than two years later the UK CAA changed the BCAR-C requirements, by 'Blue Paper' Amendment No.552 effective on 16 August 1976, to address freedom from burst at abnormally high rotational speeds as the sole criterion for establishing rotor integrity.

Prior to amendment 3, JAR-E was essentially similar to the then existing FAR 33 regarding rotor integrity tests. At amendment 3 of JAR-E (via Blue Paper C552) the requirements for "Rotor Integrity Tests" were changed, from a criterion of acceptable permanent growth on typical strength rotors after test at 120% overspeed, to a criterion of no-burst by minimum strength rotors when tested at an increased overspeed of 125%. The criteria for the single and double failure caused overspeed conditions were also changed to minimum strength no-burst with 5 percentage point increases in speed factors. Those changes were not arbitrary; considerable investigation showed the changed criteria were equivalent to the original criteria for the majority of cases, and they were aimed at giving a clear "yes/no" acceptance standard without increasing or decreasing the severity. However, because the original and the changed criteria are not related in a unique way, in certain cases the changed criteria could be more severe than the originals. This difficulty was accommodated by including means for the acceptance of minimum strength rotors which had not burst at, for example, 120% speed but could not achieve 125% speed without bursting. There were also other provisions for the no-burst criteria to be met by extrapolation from the permanent growth measurements of rotors after tests at speeds which could be lower by as much as 5 percentage points. As a result of these various alleviating provisions, the intended clarity of the "no-burst" standard was diminished and problems of interpretation/application arose. Further similar and new problems also arose from the further changes made at Amendment 7 of JAR-E, via Blue Paper C798 and NPA-E-2. (One of the changes resulting from NPA-E-2 was subsequently recognised as being an unintentional increase in severity. Problems of interpretation/application have occurred from the changes made by Paper C798, whereby OEI/Contingency speed limits need not be considered in the 125% overspeed no-burst case and need only to be treated as being a form of overspeed condition resulting from a failure.)

4. Proposed Requirement

The requirement is based on the premise that the rotor needs to demonstrate its integrity to meet the demands of its rated operating conditions and any overspeed failure condition.

The proposed requirement has been produced in four parts: JAR-E 840(a)& (d) are statements of the safety objectives while JAR-E 840 (b) defines the overspeed factors that must be applied for the conditions stated. JAR-E 840(a) requires the design of rotors to contain a margin to burst above certified operating conditions and above failure conditions leading to rotor overspeed. JAR-E 840(d) states the second safety objective which is to assure that a rotor, subjected to failure case speeds, will not (1) demonstrate a level of growth/damage which will lead to a hazardous condition. and (2), exhibit any condition which precludes the safe operation of the engine for the duration of the event or during any likely continued operation following the event. JAR-E 840(c) provides requirements that must be followed when determining the failure case conditions of (b)(3) and (b)(4)

It should be noted that OEI ratings are no longer addressed as failure conditions as in the previous rule. This is therefore an increased requirement for such engines.

JAR-E 840 (b)(1) & (2) address the non-failure cases and require a no-burst demonstration in excess of the maximum permissible speed
For ratings of 2.5minutes and above, a factor of 120% of the maximum permissible speed is required. It should be noted that the previous requirement was based only on maximum steady state speed and thus did not consider transient overspeeds. Since these are now addressed within the maximum permissible speed it is considered acceptable to reduce the overspeed factor to 120%. This condition is deemed largely equivalent to 125% of maximum steady state speed. This approach was already adopted in FAR 33.27 and now forms an important part of the harmonised rule.

Recognising their likely rate of usage, a factor of 115% of maximum permissible speed is considered to provide an adequate margin of safety for the high speed ratings of less than 2.5minutes.

JAR-E 840 (b)(3) and (b)(4) define the speed factors for failure cases. Currently FAR 33.27 has two cases addressing failure, namely: 105% of a single failure and 100% of a combination of failures. Current JAR-E 840 has 110% of a single failure and 105% for a combination of failures. The acceptance criteria are acceptable growth (FAR) and no burst (JAR-E) . It is clear that single and multiple failure events demand the same margin of safety and as such it is considered that no distinction should be drawn between them – the same overspeed factor should be applied to both. Adoption of a factor of 105% for both single and multiple failures for ratings of 2 minute and above formalises a position agreed with the JAA and at least two European manufacturers under previous rules. For ratings of less than 2minutes, a test speed factor of 100% is considered sufficient. This recognises that the worst combination of material properties, tolerances, temperature and flight envelope position determine the conditions to be addressed and that the probability of an event occurring under such an extreme combination of circumstances is considered to be Extremely Remote or better. Thus, an additional factor is not warranted.

The test time requirement for the transient, short duration failure cases is established as being equal to the time period of the failure condition. Typically, for turbine rotors, the

failure case speed requirement is determined by the loss of load failure case. These peak speeds exist for very short periods of time (usually for less than one second). For some rotor designs the environmental conditions are best duplicated by utilising an engine test, but these environment conditions cannot be sustained at realistic levels for five minutes in an engine. It is felt that utilising an engine test for less than five minutes for these cases is valid because it demonstrates that the rotor will not burst due to a one time failure that is of short duration.

The 30 second and 2 minute ratings are permitted a 5% alleviation in the rotor integrity demonstration speed. These ratings have been established to enhance rotorcraft safety after an engine failure or precautionary shutdown. These new ratings rely on the usage of existing design demonstration margins to enable engines designed and sized for efficient normal twin engine operations to be used briefly at higher power levels, achieved by the use of higher turbine temperatures, during an emergency. Mandatory maintenance actions are required following each usage of this rating. The margin required by a number of other certification requirements (endurance test, overtemperature test, tear down inspection) are being revised to make the rating feasible.

To ensure that maximum possible overspeed conditions will meet the safety criteria of JAR-E840(d), actual (100%) speeds associated with failure conditions must also be assessed for those rotors which are subjected to the speed requirements of JAR-E 840 (b) (1), or (b)(2). The requirements of JAR-E 840(a) relative to adverse combination of tolerances and material properties, etc. are equally applicable.

5. Advisory material

The methods of compliance outlined in the advisory material are largely in line with those defined currently in both FAR 33.27 and JAR-E-840. Additionally, where an acceptable data base can be demonstrated, there is the option of complying with the regulation by analytical methods. These methods are based upon existing experimental and certification rotor testing and have to be approved by the Authority.

Additionally, to assist in the interpretation of the requirement, other factors to be considered when determining the test conditions are included. The required temperatures to be considered for each of the conditions specified in JAR-E840(b) are defined. Also advisory material is included with respect to material properties and the requirement to demonstrate compliance for the minimum specification properties rotor.

There is no longer a requirement that prohibits cracking of the rotor material during a demonstration. This is largely based on the absence of evidence in these demonstrations that such cracks that may have formed would have progressed to catastrophic rupture of the body of the rotor within a purely centrifugal stress field (no fatigue or creep consideration). It was also noted that there is currently no standard inspection technique specified to determine the existence of cracks. However the new rule and advisory material state that "the rotor must not exhibit conditions such as cracking or distortion which preclude the safe operation of the engine during any likely continued operation following such an overspeed event in service".

Testing to failure following demonstration of the capability of the rotor to meet the integrity requirements is allowed for a better understanding of design capability. Understanding how to conduct tests and correctly relate them to engine conditions, as well as validating failure predictions and relating these to physical examination of the failed rotors yields valuable engineering information.

The advisory material allows testing to be conducted in an engine at 96% of the required test speeds for the non-failure cases as a satisfactory means of compliance. Difficulty is often encountered when trying to achieve the required speed when testing in an engine. However, it is recognised that testing in an engine allows the conditions surrounding the rotor to be more realistic than that which can be achieved in a rig. For this reason, it is allowable to only test to 96% of the required integrity demonstration and to then show from a validated speed/growth curve that burst would not have occurred at 100% speed.

For some rotors, usually smaller or cast, it is impossible to incorporate a test ring that accurately represents the properties of the actual rotor. In these cases, manufacturers rely on process controls to maintain the required material properties. These process controls normally include the periodic destructive sampling of castings or forgings. Samples are normally taken from each manufacturing process lot in a manner that assures that the quality standards are being maintained. The use of the data base obtained from this sampling plan, in combination with the properties from a rotor from the same manufacturing process lot as the test article, should provide an accurate estimate of the material properties of the test article.

With respect to combinations of failures, it is considered that if the likelihood of a combination is Extremely Remote the case need not be considered. This does not introduce an unacceptable risk to achieving the overall safety objective.

6. Changes to JAR-E 50 and JAR-E 810

The proposed JAR-E 50 (e) is a copy of current FAR 33.27 (b) which is kept in the new proposed FAR 33 rules under this harmonisation effort. It is possible that changes to this text might result from the electronic engine control harmonisation effort.

The proposed change to JAR-E 810 is intended to ensure compatibility between JAR-E 810 and JAR-E 840. In the current JAR-E 810 (b) the requirement calls for a margin above an overspeed condition. This margin is in fact dictated by JAR-E 840.

2 - Economic impact analysis

This proposal does not have a cost impact on the applicants as the means of compliance are largely identical to that required by the existing regulation. The proposed changes are generally in respect of the level of overspeed required to be demonstrated in certain cases and the acceptance criteria following the test.

3 - Comments received during the circulation of the NPA

Comments were received from the following organisations :

- Authority of United Kingdom
- AECMA, AIA, Rolls Royce
- A member of the JAA Regulation Advisory Panel.

4 - Response to comments

Two commenters questioned the term « reasonable » used in JAR-E 50 (e) and JAR-E 810 (b)(1)(i) and proposed alternative wording. The changes to JAR-E 50 (e) were rejected as being outside the scope of this NPA which copied the current text of FAR 33.27 (b). Harmonisation of JAR-E 50 with FAR 33.28 will consider the comments. The change to JAR-E 810 was accepted.

One commenter proposed to add the words « includes changes caused by in service deterioration » into JAR-E 840 (a). This was rejected because, according to JAR 21.33, the certification are performed on parts conforming to the type design. Instructions for continued airworthiness should be used to control appropriately the service deterioration. A new harmonisation effort will consider disk lifing methodology and potential for damage tolerance, therefore addressing the concern of the commenter.

One commenter proposed to add the words « provided the speed margins are maintained » at the end of the second sentence of JAR-E 840 (a). The principle was agreed but different wording was used.

In JAR-E 840 (b), one commenter proposed to delete the words « and also in accordance with the provisions of JAR-E 840 » as not being clear enough and, may be, unnecessary. This was agreed in principle ; an editorial improvement was introduced.

One commenter proposed clarification of text of JAR-E 840 (b)(3)(ii) by adding « light operation that is the most critical with respect to overspeeding ». This was agreed.

One commenter proposed to maintain a positive margin in JAR-E 840 (b)(4). This was rejected. The rationale provided in the justification of this NPA was considered as being appropriate.

Four commenters questioned the rule of JAR-E 840 (c) and proposed to exclude extremely remote cases and to replace extremely improbable by extremely remote. They quoted unconsistencies with JAR-E 510 and JAR-E 850. This was agreed and the text was modified.

One commenter thought that JAR-E 840 (d) should make reference to JAR-E 840 (b)(1) and (b)(2). This was not agreed. JAR-E 840 (d) is addressing the rotor growth resulting from an actual overspeed. JAR-E 840 (b)(1) and (b)(2) are not failure conditions.

One commenter suggested that the implementation of the second paragraph of ACJ E 50 for the mechanical part of the protection system would be difficult. The comment was agreed in principle : the sentence was clarified.

One commenter suggested to include the « Maximum Engine Overspeed » in paragraph (1) (d) of ACJ E 840 in addition to transients. This was agreed for clarity: according to JAR-1 definition, the « Maximum Engine Overspeed » is a transient.

One commenter suggested to add advisory material on « dimensional tolerances » in the ACJ E 840. This was agreed.

One commenter suggested clarification of the text of paragraphs (d)(i) and (ii) in ACJ E 840. This was agreed.

One commenter questioned paragraph (1)(c) of ACJ E 840. The comment was agreed. The definition of « extremely improbable » was deleted since it is no longer necessary in relation to the changes made to JAR-E 840 (c) in response to another comment.

One commenter requested a better justification of the changes made to the current rules for ensuring that the new rules proposed adequate safety margins. Other commenters requested other improvements in the justification. This was agreed : the text was modified accordingly.