EASA
European Aviation Safety Agency

Rotor drive systems – Fatigue and damage tolerance

Rodrigo Martin Gomez
EASA Transmissions and Structures Expert

Rotorcraft & VTOL Structures Workshop
19-20 February 2019

Background

In the past years, a number of helicopter accidents have highlighted the vulnerability of components of the rotor drive systems with regards to fatigue. In particular, the following aspects require attention:

- Rolling contact fatigue (RCF) in bearings.
- Adequate consideration of intrinsic and extrinsic flaws in the threat assessment.
- Substantiation of approved equivalent means (means of detection).
- Verification of assumptions made at certification.

In addition, recent certification projects have highlighted the concerns regarding the scope of applicability of CS XX.571.

Process CS-29

List of candidate PSEs
- Identify parts failure of which could be catastrophic

Criticality of fatigue failure
- Evaluate if cracking of the component may lead to catastrophic consequences

Threat assessment
- Identify all representative threats for each area of each component

F&DT evaluation
- AC 29.571B Method selection

Inspections / Approved equivalent means
- Validate capability to detect crack/damage

Candidate Principal Structural Elements (PSEs)

- The 917(b) design assessment should be the starting point for establishing those elements of the rotor drive systems, whose failure may lead to catastrophic consequences.
  - This design assessment should consider the total and partial loss of each of the functions of every component.
  - Compensating provisions should not be used at this stage to reduce the severity of each failure condition analysed.

- The following step should be to assess which components from those identified in the aforementioned design assessment can actually fail by fatigue.
  - For this step bearings and cracking initiated through rolling contact fatigue (RCF) should be considered. Further guidance in the following slides.
  - Certain components or areas of components may fail by cracking, but they or their assembly may be designed in such way that any form of cracking will never lead to catastrophic consequences. Further guidance in the following slides.

Candidate PSEs – Fatigue failure

- AC 29-2C 29.571B defines Principal Structural Element (PSE) as "structural elements that contribute significantly to the carrying of flight or ground loads and **the fatigue failure of which** could result in catastrophic failure of the rotorcraft."
- Cracking may not critically affect the capability to carry load of certain components or areas of these components. This could be due to design provisions, preventing a partial or complete loss of function as a result of fatigue damage.
- Therefore, this can lead to question regarding the classification of these components as PSE. Nevertheless:
  - Although the immediate consequences of the fatigue failure of a component may not be catastrophic, if this initial failure is not detected in a timely manner, the impact on its surrounding elements may lead to a more severe failure scenario.
  - Therefore, a *fail-safe* design does not imply that the parts that form it do not need to be classed as PSEs.

Candidate PSEs – Fatigue failure

- Some examples of components/assemblies needing careful consideration:
  - Non-integrated bearing races.
  - Gear teeth: adequate selection of the gear teeth design parameters can prevent a crack initiated at a tooth surface from propagating across the rim of the gear.
  - Planetary systems designed to tolerate continued operation following cracking of a planet gear.
- The consequences of cracking should be carefully evaluated. Additionally, the capability of the damaged part and that of surrounding components to continue operation following cracking should be substantiated.
  - Impact on loads on surrounding elements.
  - Progressive degradation of the rotor drive system following fatigue failure of the component (e.g. debris released, overheating, etc).
  - Period of operation under these conditions must be substantiated.
  - Means of detection shall prevent operation beyond the substantiated period.

Bearings as candidate PSEs

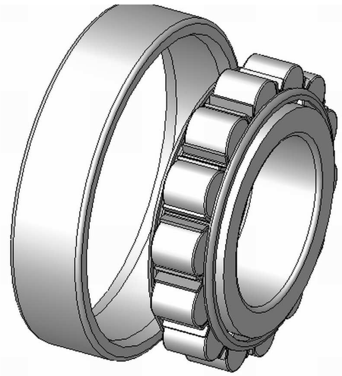
- An evaluation shall be performed for every bearing application in order to determine the need to identify it or any of its elements as a PSE.
- The effect of a propagating crack into either of the races of a bearing shall be evaluated. This may lead to its complete or partial loss of function, which may have catastrophic consequences. When this is the case, parts shall be identified as PSEs.
- This is more likely on integrated bearing races* since a crack could continuously propagate from the bearing race into the body of the component (shaft, gear or housing).

* Integrated bearing races are areas of gears, pinions, shafts and housings specifically designed and manufactured to perform the function of the bearing inner or outer race.

Bearings as candidate PSEs

- For non-integrated bearing races, due to their configuration, cracking may not have a critical effect on their capability to carry load. As a result fatigue damage may not result directly in catastrophic failure. Based on this, traditionally, compliance with CS 29.571 has not been shown for many bearing applications.
- The typical arrangement – non-integrated bearing race supported by an external element (shaft, gear or housing) and the rolling elements – can be sufficient to ensure the support and location functions of the bearing.
- Nevertheless, a cracked bearing race may degrade rapidly, leading to wear and/or spalling. Therefore, this condition must be detectable prior to the partial or complete loss of the bearing function (see note below).

<u>Note:</u> *Regardless of the classification in accordance with CS 29.571, any bearing application, failure of which could be catastrophic, shall be provided with means of detection.*



Threat assessment

- All components identified as PSEs should be submitted to a threat assessment as per CS 29.571(e)(4).
- This shall evaluate the necessary threats to be considered at each area of each PSE taking into consideration experience from previous designs, manufacturing techniques, expected operating environment, overhaul reports, rejection criteria, etc.
- Additional testing may be needed to develop an adequate understanding of the level of threat to be considered for new designs, materials, manufacturing methods, etc.
- Any assumptions made at the time of certification with regards to the threats to be faced by any PSE during its life should be continuously verified in service (more on this during the next presentation).

Fatigue tolerance evaluation

- As per CS 29.571(e)(5), a determination of the fatigue tolerance characteristics of each PSE shall be carried out. This shall take into consideration the relevant threats identified and support the inspections and retirement times, or approved equivalent means.
- Figure AC 29.571B-1 describes the acceptable methods for compliance with this requirement (described in one of the previous presentations). Some considerations are provided on the next slide.
- Subsequently, the maximum damage size determined during the fatigue tolerance evaluation shall be used for demonstrating the residual strength capability of the design, as per CS 29.571(f).
  - For *fail-safe* designs, the capability to withstand the resulting loads following failure of one element until this condition is detected shall be demonstrated.

Fatigue tolerance evaluation

Challenges

- Accurate modelling of the loads on certain components.
- Combination of contact, residual and body stresses in gears and bearings races.
- Rolling and sliding contact fatigue: large initiation scatter and difficulty to adequately understand propagation mechanisms.

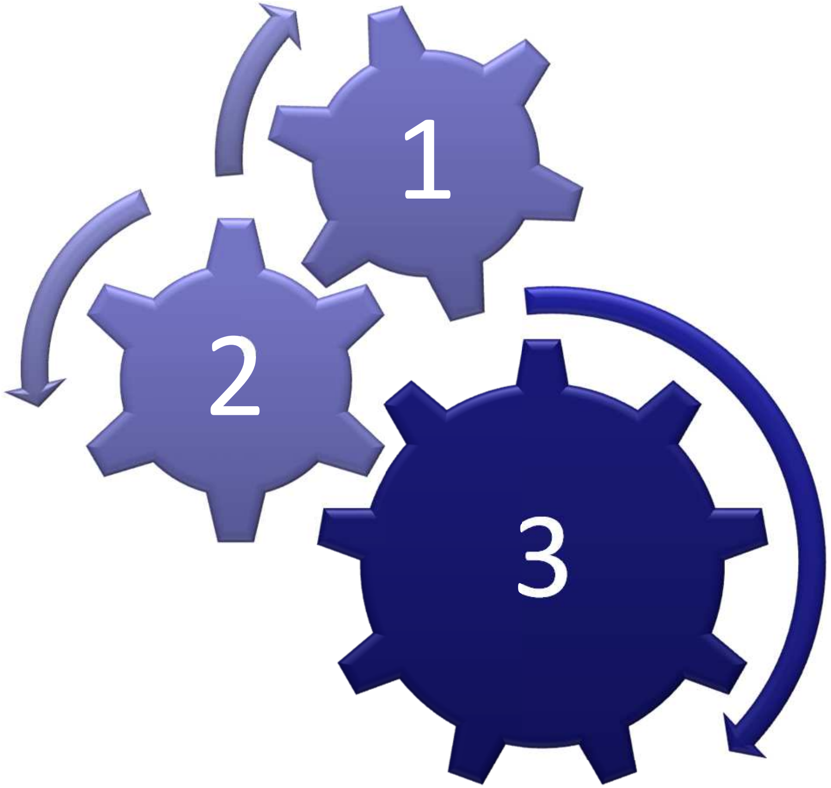
Recommendations

- Testing shall always be considered in support of any analysis.
- Ensure tests are as representative as possible, especially when dealing with rolling and/or sliding contact fatigue.
- Use fail-safe design whenever possible.
- When not possible, ensure slow crack growth and reduce probability of initiation.

Approved equivalent means

- Appropriate inspections and retirement time or approved equivalent means must be established to avoid Catastrophic Failure, in accordance with the results from the fatigue tolerance evaluation.
- Due to the nature of rotor drive systems configurations, many parts are not easily accessible for regular inspections, leading to these being only inspected during overhaul.
- In addition, it may not be feasible to design these components to align their damage tolerant life with the planned time between overhaul (TBO).
- For such elements approved equivalent means (chip detection, oil analysis, VHM, etc) can be used to detect the condition of the part prior to the damage reaching its critical size. The capability of the approved equivalent means to ensure timely intervention shall also be demonstrated.

Approved equivalent means



Compliance demonstration for the approved equivalent means:

1. Justification of the adequacy of the selected method to directly or indirectly monitor the condition of the part.
2. Determination of the interval between the damage or monitored condition becoming detectable and the time of failure.
3. Demonstration of the effectiveness and reliability of the approved equivalent means considering the time to failure.

Process CS-27

List of candidate "PSEs"
- Identify parts failure of which could be catastrophic

Criticality of fatigue failure
- Evaluate if cracking of the component may lead to catastrophic consequences

~~Threat sment~~
- Identify all representative threats for each areas of each component

Fatigue evaluation
- CS 27.571 Method selection

Use of Approved equivalent means
- Support against rolling contact fatigue.
- Detection of failed elements.

CS-27 fatigue evaluation

- When feasible, a *fail-safe evaluation* is considered the most appropriate method for most rotor drive system components. This method ensures that, should fatigue cracks initiate, the remaining structure will withstand service loads without failure until the cracks are detected.
- Conducting structural tests and analysis to substantiate that the fail-safe design objective has been achieved, including residual strength demonstration, is considered needed.
- Means of detection (approved equivalent means) must be provided for those elements that cannot be directly inspected and whose failure need to be detected to support a *fail-safe evaluation*.

CS-27 fatigue evaluation

- When applying methods of compliance such as *safe life*, it can be complicated to account for rolling and sliding contact fatigue.
- As it has been mentioned, the large scatter of these phenomena means that a large amount of testing would be needed to support the development of representative fatigue curves.
- Additionally, simplification of tests and read-across of previous experimental results is complex due to the number of parameters affecting these phenomena.
- Means of detection (approved equivalent means) can be used to ensure that any crack initiated by such mechanism will be detected prior to having any impact on the fatigue substantiation performed.
  - This shall be used in combination with other design parameters that reduce the likelihood of rolling/sliding contact fatigue initiation.
  - For example: maintain stress levels below values for which experience shows the risk of RCF is negligible.

EASA
European Aviation Safety Agency

Thank you for your attention!

Any questions....?

Your safety is our mission.

An agency of the European Union