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Rotors and Transmissions Design Assessment: Experience and the Regulators Viewpoint

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Content

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- Rotor and Drive System Failures: Contributory Causal Factors
- A Philosophy of Risk
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The Challenge of Rotor and Rotor System Safety

- Many single load path components / no obvious economic design alternatives to duplicate function of critical components.
- Loss of main rotor drive or pitch control is catastrophic.
- Loss of tail rotor drive or pitch control is potentially catastrophic.
- Objective of existing Part 29 requirement is to minimise the likelihood of occurrence of these critical components by identifying suitable design, maintenance and monitoring compensating provisions.

Accident Rate

Part 29 Fatal CAT Airworthiness Accident Rate

Insert Graph

- Part 29 fatal airworthiness accident rate has reduced from X to Y over Z years.
- Currently the Part 29 fatal airworthiness accident rate remains in the order of 1 / 10 million flying hours.
- This is > 10 greater than comparable fixed wing accident rate.

A Philosophy of Risk (1)

"there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – the ones we don't know we don't know. And if one looks throughout the history of our country and other free countries, *it is the latter category that tend to be the difficult ones*."

- Donald Rumsfeld, United States Secretary of Defense, February 12, 2002.

Can the same approach be applied to rotor and rotor drive systems and would the final conclusion be the same?

A Philosophy of Risk (2)

- Known Knowns: Logic and fully understood physical phenomena with a quantifiable risk. (the only risk in this category are design mistakes)
- Known Unknowns: Expected or foreseeable risks, which can be reasonably anticipated but not quantified based on past experience. (e.g. POA/MOA quality issues)
- Unknown Unknowns: Unforeseeable risks, such as complex common cause failures or physical phenomena that are not fully understood. These cannot be anticipated based on past experience or investigation. (Black Swan)
- Unknown Knowns: Known risk which is falsely believed to be acceptable i.e. false assumption

Review of Accidents

12 potentially fatal accidents (occurring since 1996) resulting from rotor or rotor drive system failure have been analysed to assess;

- Known Known, Known Unknown or Unknown Unknown
- Failure Analysis could have identified adequate provisions?
- Involving Critical Part?
- Considered to be preventable?
- Influence of POA / MOA quality issues
- Preventable by improved health monitoring

Review of Accidents

- Known Knowns: 4 accidents involved contributory causal factors which can be considered as know knowns. These include;
  - Misclassification of failure hazard severity
  - Inaccurate finite element model results
  - Design did not allow effective health monitoring (ODM)
- Known Unknowns: 6 accidents involved contributory causal factors which can be considered as know knowns which include;
  - Tail rotor blade capability to withstand lightning strike.
  - POA / MOA operation non-compliance with procedures.
  - ICA inadequate as failure cause was not anticipated.
  - RFM emergency procedures not followed as intended.

Review of Accidents

- Unknown Unknowns: 6 accidents involved contributory causal factors which can be considered as know knowns. These include;
  - complex combination failures that are not foreseeable through Common Cause Analysis (2 accidents)
  - Physical characteristics / metallurgical behaviour not previously experienced (4 accidents)
- Failure Analysis identified adequate provisions?
  - Only one case where Failure Analysis was incorrect regarding identification of failure hazard severity of
  - Some examples where ICA provisions identified did not prevent the failure, however, certain events of wear of fretting may have been difficult to foresee.

Review of Findings

- Few accidents result Known Known risks i.e. from design mistakes. Lessons learned would be to improve integrity of FEM data and to verify capability of health monitoring when identified as a design provision.
- Half the accidents where influenced by Known Unknown risks. The main causes were MOA / POA error and ICA not anticipating the failure mode and
- Around half the accidents involved Unknown Unknown risks including phenomena not previously experienced and unforeseeable complex common cause failures.

Review of Findings

- Inadequacy of failure analysis is not an issue.
- 9 of the 12 accidents involved Critical Parts.
- 10 are preventable by improved design and ICA
- Approximately half the accidents had potential for prevention by health monitoring. ODM is as at least as important as VHM.

Conclusions (1)

- There is significant potential to reduce the future accident rate due to rotor and rotor drive system failures.
- Most accidents involve failure of a Critical Part.
- Current failure analysis methods seem to work well. The only observation is that strengthening the design review of ICA provisions preventing catastrophic failure may be worthwhile. Alternatively maybe the MRB could assist in this assessment of ICA provisions identified for compliance with 29.917(b)

Conclusions (2)

- For many accidents either POA / MOA, inadequate ICA to prevent unforeseen failure modes, complex common cause failures or previously unseen phenomena / behaviour were identified as contributory causal factors.
- With lessons learned, most accidents can be prevented from repeating on existing designs. The challenge is to prevent them from occurring on new designs?

Recommendations (1)

- Focus on improving integrity of Critical Parts
  - Application of higher safety margins for fatigue strength? This may be a consequence of new flaw tolerant requirements (29.571)
  - Design of Critical Parts is normally subject to independent review. However, for critical avionic systems, different systems can be designed and tested by independent teams. Should Critical Parts be designed twice by independent designers?
  - Stick to known materials and processes for critical applications until extensive industry knowledge is available.
  - Improve monitoring of Critical Parts in-service. EASA CM-S-007 Post Certification Actions to Verify the Continued Integrity of Rotorcraft Critical Parts has been published to help address this issue.

Recommendations (2)

- Design of Critical Parts so that the need for maintenance is minimised and verification that maintenance tasks are straight forward.
- Design of Critical Parts should make provision for a means of health monitoring when this is possible? This should then be verified.
- System design should minimise the need for Critical Parts. Complexity of design is not addressed in Part 29.
- Some accidents could be prevented by improved ODM. The amount of resource allocated to VHM maybe disproportionate to that spent on ODM when considering the potential safety benefit.

Questions to Industry

- What options are available for designers to consider for improving rotor and drive system architecture, with respect to reliability and failure conditions?
- Should there be a limit on number of Critical Parts used on a transmission design?
- Is there a way to maximise the benefit of design review during the design process?
- Should operators' experience be sought during the design phase of future helicopter transmission design?
- What are the future possibilities for health monitoring?
- Are there immediate opportunities for industry standards, regulations, and the safety regulation process to improve future safety standards?

Any Questions ?