Guidance on exclusion of a High Pressure Turbine shaft element, section, or system from failure consideration in determining the terminal High Pressure Turbine rotor speed in the event of a complete loss of load event

AIA CARS Committee
Propulsion Subcommittee
Advisory Working Group
Loss of Load and Overspeed (14 CFR §33.27)

Summary

This report details the recommendations of the AIA advisory working group for assessing areas of the shaft system that can be excluded from the overspeed rule when considering a loss of load event. This guidance does not apply to the areas of the shaft system that are not being excluded.

The objective of the overspeed rule is to ensure that an applicant's rotor is designed with sufficient strength to avoid a hazardous condition at speeds above the certified operating conditions and the terminal speed that would be attained in the event of a loss of load condition due to a failure of the shaft system.

The latest amendments to FAA regulation 14 CFR §33.27 and EASA regulation CS-E 850 permit exclusion of sections of the shaft from the overspeed requirements. Exclusion is permitted if the applicant:

(1) Identifies the shaft as an engine life-limited-part and complies with §33.70 and CS-E 515.

(2) Uses material and design features that are well understood and that can be analyzed by well-established and validated stress analysis techniques.

(3) Determines, based on an assessment of the environment surrounding the shaft section, that environmental influences are unlikely to cause a shaft failure. This assessment must include complexity of design, corrosion, wear, vibration, fire, contact with adjacent components or structure, overheating, and secondary effects from other failures or combination of failures.

(4) Identifies and declares, in accordance with §33.5, any assumptions regarding the engine installation in making the assessment described above in paragraph (3).

(5) Assesses, and considers as appropriate, experience with shaft sections of similar design.

(6) Does not exclude the entire shaft.

Under CS-E 850, meeting these requirements enables exclusion of elements of the shaft as failure of these sections can be accepted as Extremely Remote (i.e., as defined within the Safety Rules such as 14 CFR §33.75 and generally associated with a life limited part failure rate). However, from the FAA perspective, the failure rate embodied by 14 CFR §33.27 requires a more stringent failure rate than Extremely Remote.

The FAA intent was that the exclusion only applied to the cold fan section forward of the thrust bearing, where there have been no known field events. This team looked specifically at the requirements for High Pressure Turbine (HPT) shaft systems and

whether the HPT shafts should allow exclusions like the fan shafts. The Intermediate Power Turbine (IPT) and Low Pressure Turbine (LPT) shaft field history suggests that there are multiple failures of these shafts and this team does not recommend a change to the historical treatment of those shaft sections. This guidance document applies to High Pressure Turbine shafts only. Appendix 1 includes the request from the FAA to the AIA to form an advisory group on overspeed.

The team collected data on loss of load events (Appendix 4), specifically looking at the failure modes for the HPT shaft system. These failure modes were included with the failure modes from the existing guidance material from the FAA and EASA (AC33.27-1 and AMC E-850).

Based on the outcome of the data collection effort, the team recommends allowing exclusions of elements, including a complete shaft, of HPT shaft systems. This report defines the assessments to be completed to substantiate an exclusion of elements of a HPT shaft to present to the certifying agencies.

These assessments should be completed at certification and should be re-evaluated as part of any life extension activity (or as part of a modification package that either changes the part configuration or changes the environment in which the part operates).

The guidance provided is not mandatory. The guidance outlines a means of compliance, but it is not the only means of compliance. This document also provides guidance on a large list of potential failure modes. This list may not be exhaustive. A Failure Modes and Effects Critical Analysis (FMECA), or similar methodology, should be the starting point when assessing any shaft system that will have excluded shaft sections. All potential failure modes (including the failure modes listed herein) that are identified in the FMECA need to be addressed when an applicant is considering exclusion of shaft elements or sections.

Definition of a Shaft System

For the purposes of this document, the following describes the shaft system that transmits torque from the turbine to the compression system

- The shaft system comprises any component that is essential to transmitting torque between the turbine and the compression system, or between either stage of a two stage HPT rotor. Those may include, but are not limited to:
    - Shafts, both long and stub
    - Tie-bolts that maintain torque carrying capability
    - Disks in the torque path (see Appendix 5, example 1)
    - Mechanical system component(s) that can carry sufficient torque through a secondary load path(s) to preclude a hazardous engine condition (see appendix 5, example 8)

Appendix 5 has examples of shaft systems for different rotor architectures. In this document, a failure of the shaft system is a failure that prevents transmission of torque that would result in a loss of load condition of the turbine. Reference to a failure of an element of the shaft or a section of the shaft is used interchangeably in this document. Any failures of an element or section of the shaft that would result in a loss of torque transmission is considered a failure of the shaft system.

Data Collection

A set of data on shaft loss of load events was collected (Appendix 4) from each of the engine manufacturers on the team. The intent of the data gathering was to have a better understanding of the types of shaft system failures that have occurred in the industry. Each of the failure types was included in the guidance material to be considered as part of a Loss of Load (LoL) scenario. The following table summarizes the causes of the failures in the data set. The “Quantity of Unique Occurrences” means the total number of unique events reported. As an example, if there were 10 occurrences of a failure for a particular part number, that would count as one unique occurrence in the data set. Those occurrences are then broken down into Events and Findings. Events are occurrences where the shaft or portion of the shaft system failed. Findings are occurrences where the shaft or portion of the shaft system was found cracked, but not failed. Each of the failure modes was addressed in the guidance material as potential failure modes to consider when assessing shaft failures for exclusion from the overspeed rule for loss of load.

Cause	Quantity of unique occurrences in the Database	Events	Findings
Fatigue	16	7	9
HP or LP Imbalance	9	8	1
Rub on Adjacent Structure	7	6	1
Corrosion	6	1	5
Improper Assembly	6	3	3
Bearing Failure	5	5	0
Manufacturing	5	0	5
Oil Fire	5	5	0
Failure of disk in load path	3	2	1
Coked Oil Between Shafts	2	2	0
Nick, Dent, Scratch	2	0	2

Guidance for assessing shafts for exclusion from the Loss of Load Condition for Overspeed per §33.27 (f) and CS-E 850 (b)(2)

Failure of a HPT shaft or section of a shaft may be excluded from consideration in determining the highest overspeed that would result from a complete loss of load on a turbine rotor if the applicant can show compliance with all of the following items 1-5:

1. Identifies the components within the shaft system that could result in a loss of load event as being life-limited-parts and complying with 14 CFR §33.70 and CS-E 515.
2. Shows that the shaft components use material and design features that are well understood and that can be analyzed by well-established and validated stress analysis techniques. This should be validated by testing and/or service experience with parts of similar design
3. Determines, based on an assessment of the environment surrounding the shaft section, that environmental influences are appropriately addressed when assessing a shaft failure. This assessment should address the complexity of the design, the entire list shown in the following table, and secondary effects from other failures or combination of failures.

Potential Mechanisms for Loss of Load in a Torque Carrying Section of a Shaft System
Assessed as part of the Engineering Plan
Fatigue and Damage Tolerance
Additional Guidance on Fatigue and Damage Tolerance Assessments
Low Pressure or High Pressure spool imbalance
Rub/contact with adjacent components
Shaft overload conditions – Torsional, Axial, and Bending
Bearing failures
Overtemperature (Overheating)
Internal oil leaks and fires
Failure of Combustion Systems
Oscillatory loading from fuel flow instability or other aero-mechanical and vibratory resonant interactions
Loss of spline lubrication
Assessed as part of the Manufacturing Plan
Improper assembly of the shaft system or damage to the shaft from the assembly process (both assembled at new make or assembled after overhaul at the MRO)
Manufacturing tolerances
Assessed as part of the Service Management Plan
In service and environmental assessments

4. Identifies and declares, in accordance with 14 CFR §33.5, any assumptions regarding the engine installation in making the assessment described in paragraph 14 CFR §33.5 (f)(3).
5. Assesses, as appropriate, experience with shaft sections of similar design.

If all elements or sections of the shaft system comply with the assessments, then the whole shaft system may be excluded from consideration in determining the highest overspeed that would result from a complete loss of load on a HPT rotor. If not, only the elements or sections of the shaft system that comply may be excluded.

The applicant would then determine the maximum terminal rotor speed from the failure of the remaining shaft system elements.

Engineering Plan

Fatigue and Damage Tolerance

To be considered for exclusion from the requirements of 14 CFR §33.27 or CS-E 840/850, the following requirements shall be met.

- All components which include an excluded shaft element or section must be a Life Limited Part (LLP) subject to 14 CFR §33.70 and/or CS-E 515. If the entire shaft system is excluded, then each component of the shaft system must be a LLP subject to 14 CFR §33.70 and/or CS-E 515.

- The fatigue life and crack growth life model(s) should comply with the applicant's approved lifing methodology for the rotor component material across the range of temperatures and stresses applicable to the shaft operating environment of 14 CFR §33.70 and/or CS-E-515 aircraft flight profile(s).

- Limits for all excluded shaft components defined in the Airworthiness Limitations Section (ALS) of the Time Limits Manual (TLM) shall be based on an assessment that includes an additional level of safety for the excluded shaft component elements or sections. The minimum calculated life of features in any excluded component element or section is based on the lifing process described below. The life of features in the component elements or sections not excluded shall be assessed using the applicant's certifying agency approved lifing methodology. The ALS of the TLM limit of any component containing excluded elements or sections is based on the lowest life feature of the component regardless of whether the feature exists or does not exist within the excluded element or section.

- Damage tolerance assessments, such as those to address surface or material anomalies, shall be completed per 14 CFR §33.70 and/or CS-E 515 and any associated Advisory Circulars (AC) or EASA AMC material.

- The beneficial impact of surface compressive residual stress (e.g., from peening) can be diminished during high temperature exposure in engine operation and should not be included unless validated by test or service experience on the material and in a similar thermal and stress environment, including the impact of hot ambient temperature day usage.

- The life assessment described below should assess both hoop and axial/radial plane stresses at all surface locations on each excluded shaft element, section, or system except for those identified in the next section, “Additional Guidance on Fatigue and Damage Tolerance Assessments”.

- Temperature uncertainty should be included within the life assessment described below. For locations sensitive to predicted temperature uncertainty which may adversely impact material strength, fatigue, or crack growth capability, the life analysis is adjusted based on the fidelity of the temperature validation. Full temperature validation means the part temperature used in the design analysis of the aircraft flight profile(s) are consistent with the requirements of the applicant’s approved lifing method without deviation. Partial temperature validation means all situations other than full temperature validation.
    - Partial temperature validation of an excluded component or an excluded component element or section:
      f_T = ½ maximum for use in the equation below.
    - Full temperature validation of an excluded component or an excluded component element or section:
      f_T = 1 maximum for use in the equation below.
    - Temperature data gathering within the engine environment supports a value of f_T up to the maximum value.

- The equation and parameters depicted below are based on a Monte Carlo evaluation of various fatigue and crack growth capabilities that address the 14 CFR §33.70 rule for static parts. The static part comparison was made because the 14 CFR §33.70 rule allows the life to be set based on a combination of Low Cycle Fatigue (LCF) and a portion of the Crack Growth (CG) life. The outcome supports a $1\text{x}10^{-9}$ per Engine Flight Hour (EFH) fracture rate. The life calculation equation assumes the minimum crack growth life is lower than the minimum LCF life.

$$N = f_T f_B [N_{LCF}] \left[1 + \left(\frac{N_{CG}}{N_{LCF}} \right)^2 \right]$$

Where
f_T = Temperature uncertainty life margin factor
f_B = Base life margin factor
N_{LCF} = Feature minimum (-3 sigma or B.1) LCF Life
N_{CG} = Feature minimum (-3 sigma or B.1) crack growth life (defined below)
$\frac{N_{CG}}{N_{LCF}}$ ≤ 1.0 (i.e., maximum value = 1)

- The Monte Carlo process indicated f_B = 2/3 will satisfy the 14 CFR §33.70 Extremely Remote (ER) requirement. To set a more stringent failure rate than Extremely Remote (ER) for the 14 CFR §33.27 exclusion process, the value of f_B is fixed at ½.

- The crack growth life, N_{CG}, is determined using an applicant’s approved crack growth method modified, if necessary, to include the following:

- The crack growth calculation should include a method to capture Thermal Mechanical Fatigue (TMF) crack growth such as the non-isothermal method of FAA AC 33.70-2
    - The crack growth calculation includes a High Cycle Fatigue (HCF) threshold check such that the crack growth calculation is terminated when the HCF cycle can grow the crack.
    - The crack growth calculation should capture the major and minor cycles within the applicant's approved lifing method aircraft flight profile(s).
    - Three-dimensional stress intensity prediction methods have the capability to predict the general direction of the crack path and can be used to predict whether the crack will turn. But the resulting stress intensities should not be relied upon to calculate the crack growth life capability without test or service experience validation to ensure the interaction of the fracture modes is appropriately captured.

- Per instructions in AC33.4-2, life limited parts are required to be inspected at each piece part opportunity. For shaft elements excluded from 14 CFR §33.27, detailed inspection processes and rejection criteria should be included in Section 5-21 of the airworthiness limitations section.

Additional Guidance on Fatigue and Damage Tolerance Assessments

Cracks at a feature in the loadpath are assumed to result in a loss of load condition, unless experience to the contrary is available either from service or from a component test run under service-representative loading conditions.

It may be possible, however, to exempt certain starting crack locations from the requirement for enhanced fatigue/damage tolerance capability if the debris associated with the loss of load failure sequence can be shown to cause sufficient damage to the engine such that a hazardous loss of load event will not occur (e.g. a sufficiently sized penetration hole in the outer casing). When assessing the consequences of the failure sequence with respect to engine damage and its effect on turbine terminal speed, the assumptions noted below for a separate loadpath component apply. It will be necessary, however, to justify the debris fragment sizes used, the assumed damage progression and the subsequent engine and turbine component behavior.

It may also be possible to exempt axial crack starting locations from the requirement for enhanced fatigue/damage tolerance if it can be shown the presence of the crack can be reliably determined by engine monitoring equipment and appropriate action is mandated to prevent the failure progression before a loss of load event occurs. If the action includes crew action an appropriate time for this to occur should be agreed with the authorities.

Some examples of scenarios where cracking may not result in a hazardous loss of load condition and their associated considerations are listed below.

- Axial crack starter locations close to a main disc body

  If the starter location for an axial crack is sufficiently close to the main body of a disc, for example on a turbine disc front drive arm close to the fillet with the disc web, the crack is likely to remain axial as it grows. Supporting evidence for this scenario could, for example, be provided by examining crack trajectories in component-representative rig components.

- A separate loadpath component

  If part of the shaft loadpath includes a separate component with significant hoop stresses, for example a mini disk between the compressor rear flange and the turbine front flange, it may be possible to exclude the separate component of the shaft system from the requirement to meet the more stringent fatigue and damage tolerance conditions provided above.

  The separate loadpath component to be considered exempt from enhanced hoop-stress-related fatigue and damage tolerance conditions should be defined as a critical part as per 14 CFR §33.70 and CS-E 515. If a hoop-stress-driven burst originating in this component can be demonstrated to rupture the outer casing of the engine, allowing the core gases to escape to atmospheric conditions, the resulting terminal speed may be assumed not to lead to burst of the turbine disk/s.

  This requires either a demonstration by test or past experience of similar design construction or application of a validated containment assessment methodology. A validated containment assessment methodology means it a) has been correlated to past service experience or rig test results of contained and non-contained events or b) incorporates assumptions which minimize the likelihood of containment assessment error. The assessment method should err conservatively which means having a higher likelihood of debris containment within the outer casing. The containment assessment method should include:

  1) Appropriate conservative assumptions about the size of the released fragments should be made, including whether the part is likely to fragment or simply unwrap and engage the surrounding static hardware increasing the likelihood of containment. For example, in the case of a cast-wrought nickel or powder nickel material disk-like separate component (see example 1 in Appendix 5) such as a mini disk, the hoop burst may be assumed to result in the component breaking into two sectors, one containing one-third of the circumference and the other two-thirds. Based on its higher translational energy, the one-third piece should be used for the containment calculations.
  2) Nominal geometry should be assumed both for the failed separate component and any parts through which it needs to pass to escape through the engine outer casing.
  3) Typical material properties at the relevant temperatures should be used for all components. More capable (+1σ; plus one standard deviation) component measured material properties should be used if the containment assessment method is not correlated to contained and non-contained events or data.

4) The fracture event containment should be assessed throughout the entire engine operation envelope, including the impact of fully rated and de-rated conditions (example: takeoff, climb, cruise, etc).
   a. If the fractured disk penetrates the outer casing, then it may be assumed that the disk will not overspeed, due to escape of the core gases. Without the core gases, the disk will not overspeed to burst and the engine will shut down safely. This would be an acceptable condition
   b. If the fractured disk does not penetrate the outer casing, then the applicant must calculate the HPT disk terminal velocity and burst speed for the most limiting flight condition where there is no case penetration. This calculation should be made assuming no secondary engine damage from the burst disk. The burst speed of the HPT disk at that flight condition shall be greater than or equal to 105% of the calculated terminal velocity.
   c. If the applicant cannot comply with items 1 or 2, it may still be possible to exempt a separate loadpath component from satisfying the above fatigue and damage tolerance conditions, even if the debris from a hoop burst does not penetrate the case. This will, however, require an assessment to be made of the level of secondary engine damage resulting from the separate component burst and its effect on the resulting turbine disk terminal speed following an assumed loss of load event. Validation of the assumptions should be part of the assessment. The burst speed of the HPT disk at that flight condition shall be greater than or equal to 105% of the calculated terminal velocity.

- <u>Axial cracks that turn and grow circumferentially</u>

  A long axial crack in a drive cone, assumed to turn circumferentially when it reaches a change in section, may produce either one or two triangles of unsupported material at the top of the cone bounded by the axial and circumferential cracks. As the crack grows further circumferentially, at some point the triangle(s) of unsupported material will break off under centrifugal load and impact the surrounding casing. When assessing the consequences of this failure with respect to engine damage and its effect on turbine disk terminal speed, the same assumptions as in the section for “A separate loadpath component” relating to flight profile speed, material properties and tolerances should be made. It will be necessary, however, to justify the debris fragment sizes used, the assumed damage progression and the subsequent engine and turbine disk behavior. The associated turbine disk integrity should be assessed assuming minimum material properties and most adverse geometrical tolerances at 105% speed margin above the predicted terminal speed from the resulting loss of load event.

LP or HP Spool Imbalance

The vibration stresses of the shaft system, including torsional and bending modes, may not exceed the endurance limit stress of the material of the shaft anywhere in the flight envelope of the engine application. In particular:

- o Design features in the excluded shaft elements must have HCF life margin at the maximum allowable field operating imbalance which precludes a failure by HCF.

- o For imbalances less than ultimate, the excluded shaft elements shall be able to withstand the loading conditions for a time period that, as a minimum, allows the engine to operate without a shaft failure until the cause of the imbalance is removed.

- o For imbalances considered ultimate, the excluded shaft elements should not fail during the shutdown of the engine and subsequent windmilling. A failure of the excluded shaft elements after shutdown maybe allowable, provided a hazardous engine effect does not occur and the plane can safely land.

- o Field data should be provided to support the assessment, if available. This requires showing similarity of the field experience to the excluded shaft elements and substantiation of how the field experience is applicable.

Rub/contact with adjacent components

A loss of load event due to contact between a shaft element and another component can be caused by cutting, by a part to part contact rub-initiated crack, or by a loss of structural integrity due to increased temperatures resulting from the contact.

For a specific rub failure to be considered acceptable, it shall be demonstrated that the rub will not result in a hazardous loss of load event. This may be done either by demonstrating that rubs will not occur, that the amount of rubbing will be small and will not affect the mechanical structural integrity of the contact region, or that the failure mode associated with the rub will not result in a hazardous loss of load event.

Axial or radial rubs on adjacent parts have been caused by mechanisms which include, but may not be limited to:

- Failure of the adjacent part.
- Unexpected relative movement of the adjacent parts in ‘normal’ operation, including all engine maneuvers and flight loads. The relative movement could include movement because of deformation arising from nonlinear material behavior such as creep or plasticity.
- Movement of the rotor/adjacent parts under a failure condition where it can’t be demonstrated that the engine will cease to operate. This includes loss of radial and/or axial location following bearing failures.
- Improper assembly of adjacent parts which is not detected prior to or during engine acceptance testing.
- Excessive rotational vibration of the shaft in question (or an adjacent/concentric shaft). This vibration can be from either an unintended as-assembled out of balance condition or an out of balance condition caused by a failure of the rotor or a component mounted on the rotor such as a blade.

- Fluid leaking into enclosed rotating cavities, such as the inside of a shaft or compressor/turbine rotor, may exert excessive loads on the component at high speed resulting in rubbing against adjacent parts. This type of issue should be addressed with drain holes or similar features to mitigate collection of fluid.

Note:

Rubbing contact may be intermittent and it may be a cumulative effect of intermittent rubs that cause a failure. An intermittent rub may add heat to a component at a rate greater than it can be dissipated, thus increasing local temperature.

Contacting or non-contacting seals should not be on the direct torque path. Examples include seal teeth, knife edges, seal fins, air flow discouragers, or other features intended to have a tight clearance between static and rotating hardware.

If seals are implemented on the torque path, it shall be demonstrated that the seal is tolerant of rubbing conditions. There should be an adequate heat sink in the surrounding material to prevent loss of material properties following a rub, including during non-detected failures that may have increased the normal operating temperature. It shall also be demonstrated that a rub will not cause a thermal runaway (or unstable rub) where the friction heats both the static and rotating seal components and results in a larger rub. It shall also be demonstrated that the rub does not result in any unacceptable seal fin cracking that could lead to a hazardous loss of load event.

Shaft overload conditions – Torsional, Axial, and Bending

The excluded area of the shaft system must be designed to withstand the imbalance loads generated during a limit or an ultimate HP or LP blade-out event without causing a shaft system failure that could lead to a hazardous loss of load event. The axial loads, radial shear loads, bending moments, and torsional loads must be included, in addition to the normal axisymmetric loading.

If available, historical field and factory experience should be provided to support the assessment.

Bearing Failures

There are three mechanisms that can result in a shaft failure following a bearing failure:

1. Axial or radial rub (see above),
2. Axial or radial movement causing a bearing chamber lubricant leak, or
3. Axial or radial movement causing a fire within a bearing chamber containing the shaft in question.

For item 2, it shall be demonstrated that the leaking bearing lubricant cannot auto-ignite near the shaft and/or that any bearing lubricant leaked outside of the normal bearing sump cannot cause an additional load on the rotor that results in excessive growth at normal operating conditions. If this cannot be fully demonstrated, then the criteria for internal oil leaks and fires (in the following sections) may be used to address the concern.

If the failure of the bearing can be detected and the engine prevented from operating (either automatically or by crew intervention) prior to any hazardous loss of load failure, then this mode can be discounted.

The primary bearing failure cannot be claimed to occur at a rate that is less than Remote (1 x10^{-6}).

Over-temperature (Overheating)

The secondary flows that create the thermal environment for the excluded portion of the shaft should be evaluated for all failure scenarios that could lead to an over-temperature of the shaft. If engine operation can continue with an undetected failure of the secondary airflow circuits, then it shall be shown that the shaft can operate without failure for an unlimited service interval, or until the planned inspection of the system where the airflow circuit failure would be detected and fixed. Other appropriate actions may be needed when the failed secondary airflow circuit is detected, such as replacement of the shaft, for example. If there is a negative effect on the shaft life capability, then the life should be debited, or there must be a mandatory inspection of the shaft if the impact on the shaft is significant.

Internal oil leaks and fires

Internal fires from combustible fluids (such as oil, fuel, hydraulic fluid, etc.) are known to be a cause of shaft failures. Therefore, to allow them to be dismissed as a cause of shaft failures it will need to be shown that either internal fires are not possible or that the excluded shaft or shaft section is not affected.

It is acceptable to demonstrate that any internal fire, which may lead to a hazardous loss of load event, is detected and that engine operation is ceased or reduced to a non-fire supporting level (either automatically or by crew action) prior to the fire causing a failure that would result in a hazardous loss of load event. If the mitigation is crew action an appropriate time for this to occur should be agreed with the authorities.

The starting point for this analysis is a FMECA (or similar methodology) that include, but may not be limited to, the following assessments:

- All the possible locations on the shaft where a fire could cause a shaft failure.
- The causes of combustible fluid leaks and ignition sources, e.g. seal failures
- Failures that affect the surrounding environment, e.g. secondary air system failures including blockage and partial blockage of air flow holes.
- Failures of the combustible fluid delivery systems, e.g. jet failures or failures that increase/decrease the intended combustible fluid flow.
- Failures of the oil scavenge system that result in higher than expected oil levels in bearing cavities.
- Failures that affect the ignition properties of the oil such as degradation or oil contaminated by fuel due to a leaking heat exchanger.
- Locations where oil could pool and that are not adequately drained.
- Consideration should be given to the possible effects on oil delivery, scavenge and air distribution due to oil coking in the pipework, chambers and air system passages.

The following activities can then be used to address each identified failure mode and fire location.

To allow an internal fire to be dismissed as not possible it should be shown that either of the following is not available:

1) It may be demonstrated that an ignition source is not available in the area of the excluded shaft. This may include an evaluation of the surrounding air temperature to assure it is below the Auto Ignition (AI) temperature of the combustible fluid throughout the engine design intended flight envelope. Also, it should be shown that there are no rubs (either seals or metal to metal) that can generate an ignition source. Ignition sources can't be dismissed if they are a result of the failure that caused the fluid leak.

2) It may be demonstrated that the local air flow velocity cannot support flame stabilization in the sump. Each applicant may use their own recognized sump fire methodologies to demonstrate this condition. This assessment should include the various conditions which can likely occur throughout the engine design intended flight envelope.

The position of internal fires must not be mitigated only by a statement that the fluid cannot reach an area of concern, as it has been shown in service that the secondary air system can transport the fluid to areas of the engine away from the source of a leak.

It may be claimed that an internal fire does not affect the exempted shaft (or section of a shaft) and that a secondary component fails prior to the shaft in question and prevents continued engine operation. In this case, justification shall be provided and, where available, actual failures should be used to validate this justification.

Oil leaks may also occur in a fault-free engine under abnormal (but possible) operating conditions, such as those seen during engine troubleshooting. Then, this leaked oil can result in a fire during later operation. This should be mitigated by either indicating that the abnormal operation is not acceptable or that the oil is removed in a safe way prior to the engine returning to operational service.

Oil leaks into enclosed rotating cavities such as the inside of a shaft or compressor / turbine rotor may exert excess loads on the component at high speed that results in failure or rubbing against adjacent parts. These issues should be addressed with drain holes or similar features to mitigate collection of fluid.

Failures of combustion systems

Where the exempt shaft passes close to the combustion system it shall be demonstrated that a combustion system failure (that allows the engine to maintain operation) cannot result in a hazardous loss of load event.

Oscillatory loading from fuel flow instability or other aero-mechanical and vibratory resonant interactions

Vibratory resonances of shaft systems with fuel system control natural frequencies and fuel flow control instability frequencies have caused shaft failures in service. The fuel system frequencies shall be assessed. The shaft system natural frequencies must be shown to have sufficient frequency margin or HCF margin to the fuel flow system to preclude HCF failures of the shaft system.

Likewise, the shaft system natural frequencies shall have sufficient frequency margin or HCF margin to known aero-mechanical or other vibratory excitations to preclude HCF failures of the excluded shaft system.

Loss of spline lubrication

For splines, or other mechanical torque coupling features, in the excluded portion of the shaft system that require lubrication for proper operation, it must be shown that a failure of the feature will not occur due to loss of lubrication. This can be done by showing that an undetected loss of lubrication cannot occur or that the problem will be detected, and actions taken to preclude a hazardous loss of load event. If crew action is involved, then an appropriate time for crew action to occur should be agreed with the authorities. Alternatively, it is acceptable to show that the feature can operate to the minimum critical part or inspection interval life of the shaft without lubrication.

Manufacturing Plan

Improper assembly of the shaft system or damage to the shaft from the Assembly Process (both newly made and after overhaul at the MRO)

The rotor assembly processes and tooling shall be reviewed and shown to be a robust process. It shall be shown that the assembly tooling and process is error-proofed such that damage to the shaft or misassembly of the shaft (or hardware that is adjacent to the shaft, which might cause an unintended contact or rub on the shaft) is not possible. Post assembly verification through dimensional checks or equivalent methods should be included as part of the assembly process.

Historical field and factory experience should be provided to support the assessment.

Manufacturing Tolerances

Studies shall be performed on the shafts system to assess the sensitivity to manufacturing tolerances. Manufacturing tolerances should be assumed to consist of part geometric allowance (minimum fillet radii, minimum/maximum hole size, allowed machining mismatches, etc.) and manufacturing process tolerance. The impact of these allowed tolerances on part operating stresses and the resulting LCF capability shall be evaluated and shown to have small and acceptable effects. Evaluation of any shaft excluded feature should be consistent with the section on Fatigue and Damage Tolerance.

Service Management Plan

In service and environmental assessments

As part of showing compliance to § 33.70 and CS-E 515, all LLPs have service limits determined by a process approved by the administrator. In general, this type of surface damage includes impact damage (nicks, dents, and scratches), wear (fretting, galling, etc.), and environmental attack such as corrosion. Service limits should be set to prevent an engineering crack from forming in the life of the part.

Areas of a shafting system exempted from the regulation should be subject to a Service Damage Monitoring plan, with close attention to the areas of the shaft that are being excluded from the overspeed rule. Early field data should be gathered, and the observed surface anomaly data catalogued and assessed relative to the life limits. The applicant will assess the impact of the observed surface anomalies on the part life and disposition parts and update the engine manual accordingly. Where practical, root cause analysis should be used to eliminate the cause of the damage.

Any interface to an adjacent part within the excluded sections of the shaft system should be reviewed for the potential of wear and fretting. Shaft wear data from field or factory hardware on the same hardware (or similar hardware) should be characterized. Using an approved methodology, the impact of the wear should be assessed relative to the durability of the part. It must be shown that the expected wear areas, and the amount of wear, on the shafts will not limit the life of the shaft, reduce the overspeed capability, or result in a premature failure of the shaft system.

Any environmental influences on the excluded elements of the shaft system must be assessed. If possible, it should be shown that the material (or material/coating system) is resistant to corrosion effects at the operating temperatures and the operating environment of the proposed shaft. Otherwise, service limits based on material testing may be used to set corrosion pit depth limits. It shall be shown that a shaft failure due to corrosion attack is sufficiently managed through serviceable limits and repairs. If a life debit due to corrosion is needed, then the debited life shall be used in the life equation provided previously in the section on fatigue and damage tolerance.

Flowdown of requirements

When a shaft or portion of the shaft system is excluded from the overspeed rule, there are limitations identified in the assessments. Any limitation (e.g. LCF life limitation per the Fatigue and Damage Tolerance assessment section of this guidance material) must be flowed down through the Engineering, Manufacturing, and Service Management plans that are required by § 33.70 and CS-E 515.

Appendix 1 Request from FAA

Letter to AIA for
Overspeed Requirer

U.S. Department
of Transportation
**Federal Aviation
Administration**

Engine and Propeller Directorate

Aircraft Certification Service
12 New England Executive Park
Burlington, MA 01803
(781) 238-7100, Fax (781) 238-7199

March 18, 2015

Attn: Ali Bahrami
Vice President, Civil Aviation
Aerospace Industries Association

Dear Mr. Bahrami:

Recently, two applicants for an engine type certificate proposed to exclude the shaft system from failure consideration in determining the terminal rotor speed in the event of a complete loss of load. The proposals asked to exclude either the entire shaft or significant parts of the shaft in the turbine section of the engine. Exclusion of the entire shaft is not allowed under § 33.27 (f)(6). Additionally, exclusion of significant parts of the shaft in the turbine section of the engine is not consistent with past practice or the original intent of the regulation.

The FAA would like to request the Aerospace Industries Association (AIA), Civil Aviation Regulatory & Safety Committee (CARS), Propulsion Sub-Committee (PC) form an advisory group to the FAA. The scope of this group would be:

> a) to determine whether there is a need for the FAA to change the overspeed standards or guidance material related to shaft-system failure in or around the turbine section of the engine, and
>
> b) if changes are necessary, to provide recommendations for changes to the overspeed standards and guidance material.

We are particularly interested in evaluating the high-pressure rotor in these respects.

We would appreciate the AIA's consideration of our request to form an advisory group and look forward to hearing from you.

Sincerely,

Ann C. Mollica
Acting Manager, Engine and Propeller Directorate
Aircraft Certification Service

CC: Tim Mouzakis, ANE-111
Anthony Murphy, AIA-CARS Chair
Keith Morgan, AIA-PC Chair

Appendix 2 Glossary of Terms

Tie bolt or tie rod - a single centrally located tension member that maintains axially clamping of a series of disks or spools in an assembly. Examples are shown in Appendix 5, examples 5 and 7.

Appendix 3 List of Participating companies

Boeing
EASA
FAA
FAA - Consultant
General Electric Aviation
Honeywell
Pratt and Whitney
Pratt and Whitney – Canada
Rolls Royce
Safran Aircraft Engines
Safran Helicopter Engines
TCCA (Transport Canada Civil Aviation)

Appendix 4 Data Collection Summary

AIA HP Shaft LOL events Final Data.xls

Appendix 5 Shaft System Examples

Shaft Definition