U.S. Department of Transportation
Federal Aviation Administration

Memorandum

Subject: **INFORMATION**: Policy for Propeller Safety Analysis
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From: Manager, Engine and Propeller Directorate,
Aircraft Certification Service

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Manager, Atlanta Aircraft Certification Office, ACE-115A
Manager, Airframe and Propulsion Branch, ACE-117A
Manager, Chicago Aircraft Certification Office, ACE-115C
Manager, Propulsion Branch, ACE-118C
Manager, Wichita Aircraft Certification Office, ACE-115W
Manager, Systems and Propulsion Branch, ACE-116W
Manager, Anchorage Aircraft Certification Office, ACE-115N
Manager, Transport Airplane Directorate, ANM-100
Manager, Transport Standards Staff, ANM-110
Manager, Airframe and Propulsion Branch, ANM-112
Manager, Seattle Aircraft Certification Office, ANM-100S
Manager, Propulsion Branch, ANM-140S
Manager, Denver Aircraft Certification Office, ANM-100D
Manager, Los Angeles Aircraft Certification Office, ANM-100L
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1. Purpose. The FAA has developed this policy to provide guidance for conducting a propeller safety analysis. Although 14 CFR part 35 does not explicitly require a safety analysis, safety analyses are frequently conducted to support the following:

a. Section 35.15, Design features.

b. Section 35.21, Reversible propellers.

c. Section 35.23, Pitch control and indication.

d. Section 21.16, Special conditions.

e. Aircraft manufacturer certification requirements.

2. Related Regulations.

a. Section 23.933(b), Reversing systems.

b. Section 23.937, Turbopropeller-drag limiting systems

c. Section 23.1309, Equipment, systems, and installations.

d. Section 25.933(b), Reversing systems.

e. Section 25.937, Turbopropeller-drag limiting systems

f. Section 25.1309, Equipment, systems, and installations.

3. Related Documents.

a. Policy Number ANE-2001-35.13-R0, "Policy for Propeller-Level Failure Effects," dated March 12, 2003.

b. Policy Number 1999-33/35-R0, Policy for Rule and Advisory Material Development under Title 14 of the Code of Federal Regulations (14 CFR) Parts 33 and 35, dated 5/24/99.

c. Advisory Circular (AC) 25.1309-1A, System Design and Analysis, dated 6/21/88.

d. AC 23.1309-1C, Equipment, Systems, and Installations in Part 23 Airplanes, dated 3/12/99.

e. Society of Automotive Engineers (SAE) Document No. ARP 926B, Fault/Failure Analysis Procedure, issued June 1997.

f. SAE Document No. ARP 4754, Certification Considerations for Highly Integrated or Complex Aircraft Systems, issued November 1996.

g. SAE Document No. ARP 4761, Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment, issued December 1996.

h. Carter, A.D.S., *Mechanical Reliability*, 2nd edition. Macmillan, 1986.

4. Definitions. The following definitions apply to this policy:

a. Analysis and assessment. The terms "analysis" and "assessment" are used throughout this policy. Each term has a broad definition and the two terms are, to some extent, interchangeable. However, the term "analysis" generally implies a more specific and more detailed evaluation, while "assessment" implies a more general or broader evaluation that may include one or more types of analysis. In practice, the distinction comes from the specific application (for example, Functional Hazard Analysis (FHA), Fault Tree Analysis (FTA), Markov Analysis, Preliminary System Safety Assessment (PSSA), etc.).

b. Check. A check is an examination, inspection, or test that determines physical integrity, functional capability, or both.

c. Critical component. A critical component is a component whose failure could have a hazardous propeller effect, and for which critical characteristics have been identified that are controlled to ensure the required level of integrity.

d. Error. An error refers to an omission or incorrect action by crew members or maintenance personnel or a mistake in requirements, design, or implementation. An error may result in a failure but is not considered a failure itself.

e. External event. An external event is an occurrence that originates separately from the propeller system or aircraft. Examples of external events include lightning strikes and bird strikes.

f. Failure condition. A failure condition is a condition that directly results in a propeller-level effect and is caused or contributed to by one or more failures. Examples of failure conditions include loss of hydraulic pressure and loss of primary governor.

g. Failure mode. The failure mode is the manner in which a part or function can fail. Examples of failure modes include corrosion, fatigue, and jamming.

h. Redundancy. Redundancy refers to multiple independent methods that are incorporated to perform a given function when each method alone is capable of performing the function.

i. System. System refers to a combination of inter-related parts that are arranged to perform a specific function(s).

5. Background.

a. The objective of a safety analysis is to ensure that the risk to the aircraft from all propeller failure conditions is within a historically acceptable range. The objective is based on the concept that an acceptable total propeller design risk can be achieved by managing the individual major and hazardous risks to acceptable levels. This concept emphasizes reducing the likelihood or probability of an event in proportion to the severity of the hazard it represents. The safety analysis should support the propeller design goals, so that major or hazardous propeller effects would not exceed an established probability of occurrence.

b. The depth and scope of an acceptable safety assessment depend on the following elements:

(1) The complexity and criticality of the functions performed by the system(s);

(2) The components or assemblies under consideration;

(3) The severity of related failure conditions;

(4) The uniqueness of the design and extent of relevant service experience;

(5) The number and complexity of the identified causal failure scenarios; and

(6) The ability to detect contributing failures.

c. The "Policy for Rule and Advisory Material Development under Title 14 of the Code of Federal Regulations (14 CFR) Parts 33 and 35" establishes that the part 35 certification procedures address a single propeller and that the effects of failures should be assessed at the propeller level. Once the propeller passes into the certification environment of the aircraft, specifics of the particular installation are used to address the issues of powerplant redundancy or the effects of various failure conditions. Offices with aircraft certification authority (under parts 23, 25, 27 or 29) regulate the aircraft-level effects of all parts of the aircraft, including the propellers.

6. Propeller-Level Failure Effects. For the purpose of this policy the following terms, as defined in Policy Statement Number ANE-2001-35.13-R0, apply to the propeller:

a. Hazardous propeller effects. The following are considered hazardous propeller effects:

(1) Significant overspeed of the propeller.

(2) Development of excessive drag.

(3) Significant thrust in the direction opposite to that commanded by the pilot.

(4) Release of the propeller or any major portion of the propeller.

(5) Failure that results in excessive unbalance.

(6) Unintended movement of the propeller blades below the established minimum in-flight low-pitch position.

b. Major propeller effects. The following are considered major propeller effects for variable pitch propellers:

(1) Inability to feather the propeller (for feathering propellers).

(2) Inability to change propeller pitch.

(3) Significant uncommanded change in pitch.

(4) Significant uncontrollable torque or speed fluctuation.

7. Aircraft-Level Considerations.

a. Aircraft-level failure classifications do not directly apply to propeller safety assessments because the aircraft may have features that could decrease or increase the consequences of a propeller failure effect. Additionally, the same type-certificated propeller may be used in a variety of installations, each with different aircraft-level failure classifications.

b. Due to installation differences, aircraft-level requirements for individual failure conditions may be more severe than the propeller-level requirements. Therefore, the propeller manufacturer and the aircraft manufacturer should coordinate with each other, as well as with the appropriate FAA certification offices, to ensure that the propeller installation is acceptable. The FAA strives to ensure that the propeller applicant is aware of the possibility of more restrictive regulations in the installed condition.

8. Objectives for the Safety Analysis.

a. Scope of the analysis.

(1) Consequence of failures. The analysis of the propeller system should assess the likely consequence of all failures that could reasonably be expected to occur. The analysis should consider the following:

(a) The propeller system in a typical installation. When the analysis depends on representative components, assumed interfaces, or assumed installed conditions, the analysis should state those assumptions.

(b) Substantial secondary failures and latent failures.

(c) Multiple failures as discussed in paragraph 8.d. of this policy or that result in hazardous propeller effects.

(2) Failure summary. The analysis should include a summary of those failures that could result in major propeller effects and hazardous propeller effects and provide an estimate of the probability of occurrence of those effects.

(3) Probability of failures. The analysis should show that hazardous propeller effects are not predicted to occur at a rate in excess of that defined as extremely remote (probability of 10^{-7} or less per propeller flight hour). The estimated probability for individual failures may be insufficiently precise to enable the assessment of the total rate for hazardous propeller effects. Therefore, this probability can be achieved if the probability of a hazardous propeller effect resulting from an individual failure can be predicted to be less than or equal to 10^{-8} per propeller flight hour. When dealing with probabilities of this low order of magnitude, absolute proof is not possible. Therefore, reliance should be placed on engineering judgment and previous experience, combined with sound design and test philosophies.

b. Verification of assumptions. If there is significant doubt as to the effects of failures or likely combination of failures, any assumption of the effect should be verified by test.

c. Single elements. The probability of primary failures of certain single elements (for example, blades) cannot be sensibly estimated in numerical terms. If the failure of such elements is likely to result in hazardous propeller effects, reliance should be placed on meeting the integrity requirements of part 35 or other integrity requirements developed by special conditions under §21.16. The safety analysis should state these instances.

d. Safety systems or devices. If reliance is placed on a system or device to prevent a failure from progressing to hazardous propeller effects, the analysis should include the possibility of a safety system failure in combination with a basic propeller failure. If parts of a safety system are outside the control of the propeller manufacturer, the analysis should state the assumptions regarding the reliability of these parts. Systems or devices include the following:

(1) Safety devices;

(2) Feathering and overspeed systems;

(3) Instrumentation;

(4) Early warning devices;

(5) Maintenance checks;

(6) Similar equipment or procedures; and

(7) Propeller deicing and anti-icing systems.

e. Additional considerations. If the acceptability of the safety analysis depends on one or more of the following, the analysis should identify and substantiate this:

(1) Performance of maintenance actions at stated intervals required for certification and other maintenance actions. This includes the verification of the serviceability of items that could fail in a latent manner. These maintenance intervals should be published in the appropriate manual.

(2) Verification of the satisfactory functioning of safety or other devices at pre-flight or other stated periods. The details of this satisfactory functioning should be published in the appropriate manual.

(3) Provisions of specific instrumentation not otherwise required.

(4) Fatigue assessment.

(5) Airworthiness limitations established in part 35.

f. Other components. If applicable, the safety analysis should include the assessment of the following:

(1) Indicating equipment;

(2) Manual and automatic controls;

(3) Governors and propeller control systems;

(4) Synchrophasers;

(5) Synchronizers; and

(6) Propeller thrust reversal systems.

9. Guidance on Safety Assessment Objectives.

a. Scope of the analysis.

(1) The propeller is defined by the components declared in the type design. The propeller system consists of the propeller and all other components required to operate the propeller on a typical installation. Some components may not be included in the propeller type design. These components may include the following:

- Hydraulic controls;
- Electronic controls;
- Overspeed governors;
- Spinners;
- Deicing boots;
- Deicing components; and
- Lightning protection devices.

When components are not included in propeller type design, they are not under the design control of the propeller type certificate (TC) holder; they are controlled by the aircraft or engine TC holders. Although these components are not within the scope of the propeller type design, the safety analysis should assume representative components to assess the system safety.

(2) The phrase "typical installation" does not imply that the aircraft-level effects are known. It implies that assumptions of typical aircraft or engine devices, such as governors or annunciation devices, are stated in the analysis. The typical installation does not imply an average installation. A typical installation may be the initial aircraft installation or one that requires a higher level of safety if the initial aircraft installation requires a lower level of safety than other potential aircraft applications.

(3) Parts 23 and 25 provide requirements for aircraft-level devices.

(4) A component level safety analysis may be a part of the design process that may be audited or may be conducted specifically for the safety analysis.

(5) The probabilistic calculations of failure rates include the possible latency period of failures.

(6) The failure summary may be formatted as a list or table.

(7) Probability of failures.

(a) The occurrence rate of hazardous propeller effects applies to each individual effect. The 10^{-7} or less per propeller flight hour range of probabilities for each hazardous propeller effect applies to the sum of the probabilities of this hazardous propeller effect arising from individual failures and combinations of failures other than failure of critical components. For example, if the fatigue failure of a connector combined with the failure of a pump could lead to reverse pitch in flight, then the total rate of occurrence is the failure rate of the connector multiplied by the failure rate of the pump failure. This combination should not exceed 10^{-7}. Some rates may not be as well understood as others. In this example, the pump failure rate may be well known from past reliability data, but the individual failure rate of the connector due to fatigue may not be well known. In this case, engineering judgment or analysis would be used to estimate the probability of connector failure. Some aircraft may require a rate of occurrence of reverse pitch in flight that does not exceed 10^{-9}.

(b) When considering primary failures of certain single elements such as critical components, the numerical failure rate cannot be estimated. When the failure of such elements is likely to result in hazardous propeller effects, reliance should be placed on meeting integrity requirements, such as §§35.35 and 35.37. There is no requirement to include the estimated primary failure rates of such single elements in the summary of failures for each hazardous effect due to the difficulty of producing and substantiating such an estimate.

b. Verification of assumptions. Prediction of the likely progression of some propeller failures may rely extensively upon engineering judgment. When the validity of such engineering judgment is questioned, to the extent that the conclusions of the analysis could be invalid, the judgment should be substantiated. Additional substantiation may consist of previous relevant service experience, engineering analysis, material, component, rig or engine test, or a combination of these. When there is significant doubt of the validity of the substantiation, additional testing or other validation should be considered.

c. Single elements. The integrity requirements include structural testing such as the tests required by §§35.35 and 35.37. When appropriate, additional integrity requirements may be developed under §35.43 Special Tests or §21.16 Special Conditions.

d. Safety devices. The safety system failure may be present as a latent failure, occur with the basic propeller failure, or occur after the propeller failure.

e. Additional considerations. The analysis summary should include general statements when the safety analysis depends on the elements listed in paragraphs 8.e.(1) through (4) of this policy.

(1) The general statements in the analysis summary should refer to regular maintenance in a shop as well as maintenance on the line, as applicable. When specific failure rates rely on special or unique maintenance checks, the analysis should state this.

(2) The propeller maintenance manual, overhaul manual, or other relevant manuals may provide the appropriate documentation.

(3) The Airworthiness Limitations include mandatory replacement times, inspection intervals, and related procedures required for type certification.

(4) Maintenance errors have contributed to hazardous or catastrophic conditions at the aircraft level. Errors have resulted from similar maintenance actions being performed on multiple powerplants during the same maintenance interval by one maintenance crew; thus, these are primarily an aircraft-level concern. When appropriate, the applicant should consider communicating strategies that prevent simultaneous maintenance of multiple propellers. When designing the propeller, the applicant should also consider methods for mitigating the effects of maintenance errors. Components that will undergo frequent maintenance should be designed to facilitate the maintenance and correct reassembly of the component. However, completely eliminating sources of maintenance error during design is not possible.

(a) The following list of propeller maintenance errors was developed from situations that have repeatedly occurred in service and have caused one or more serious events:

- Failure to properly torque or properly install nuts and bolts;
- Incorrect/omitted application of lockwire; and
- Servicing with incorrect fluids.

(b) Improper maintenance on parts such as blades, hubs, counterweights, and spacers has led to failures that resulted in hazardous propeller effects. Examples of improper maintenance that have occurred in service include the following:

- Overlooking existing cracks, corrosion, or damage during inspection;
- Failure to apply or incorrect application of protective coatings (for example, anti-gallant, anti-corrosive); and
- Failure to apply or incorrect application of cold working (for example, shot peen, cold rolling).

(5) If specific failure rates rely on special or unique maintenance checks for protective devices, those maintenance checks should be stated in the analysis.

10. Other Considerations.

a. Improper operation. Errors in operation of the propeller have resulted in hazardous or catastrophic conditions at the aircraft level that would have been less serious at the propeller level. The applicant should consider mitigating the effects of improper operation or provide operating instructions that reduce the likelihood of improper operation.

b. Assembly. If the incorrect assembly of parts could result in hazardous propeller effects, the parts should be designed to minimize the risk of incorrect assembly or, if this is not practical, should be permanently marked to indicate their correct position when assembled.

11. Analytical Techniques.

a. This section describes various techniques for performing a safety analysis. Other techniques are comparable; the applicant may propose their use in any certification program. Variations or combinations of these techniques are also acceptable. For derivative propellers, the scope of the analysis may be limited to modified components or operating conditions and their effects on the rest of the propeller. The applicant and the project manager from the aircraft certification office that manages the original propeller TC should agree early in the certification program on the scope of the analysis and the methods of assessment.

b. Various methods for assessing the causes, severity levels, and likelihood of potential failures are available to support experienced engineering judgment. The various types of analysis are based on either inductive or deductive approaches. For more detailed descriptions of analytical techniques, refer to SAE Document numbers ARP 4754 and 4761.

(1) Functional Hazard Analysis (FHA). Functional Hazard Analysis is a systematic, comprehensive examination of the propeller system to identify potential major and hazardous propeller effects that may arise, not only as a result of malfunctions or failure to function, but also as a result of normal responses to unusual or abnormal external factors. FHA is concerned with the operational vulnerabilities of systems instead of a detailed analysis of the actual implementation. The FHA is an engineering tool that should be used early in the design and updated as necessary.

(2) Failure Modes and Effects Analysis (FMEA). An FMEA is a structured, inductive, bottom-up analysis that evaluates the effects of each possible element or component failure on the propeller system. When properly formatted, the FMEA aids in identifying latent failures and the possible causes of each failure mode.

(3) Fault Tree or Dependence Diagram (Reliability Block Diagram) Analyses. These analyses are structured, deductive, top-down analyses that identify the conditions, failures, and events that would cause each defined failure condition. These analyses are graphical methods of identifying the logical relationship between each particular failure condition and the primary element or component failures, other events, or combinations of these that can cause the failure condition. A Fault Tree Analysis is failure-oriented and is conducted from the perspective of which failures must occur to cause a defined failure condition. A Dependence Diagram Analysis is success-oriented and is conducted from the perspective of which failures must not occur to preclude a defined failure condition.

12. Effect of Policy.

a. The general policy stated in this document does not constitute a new regulation or create what the courts refer to as a "binding norm." The office that implements policy should follow this policy when applicable to the specific project. Whenever an applicant's proposed method of compliance is outside this established policy, it must be coordinated with the policy issuing office, e.g., through the issue paper process or equivalent. Similarly, if the implementing office becomes aware of reasons that an applicant's proposal that meets this policy should not be approved, the office must coordinate its response with the policy issuing office.

b. Applicants should expect certificating officials to consider this information when making findings of compliance relevant to new certificate actions. Also, as with all advisory material, this policy statement identifies one means, but not the only means, of compliance.

[*Original signed 10/30/03 by F.A.F.*]

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