Federal Aviation Administration
Aviation Rulemaking Advisory Committee

Transport Airplane and Engine Issue Area
Engine Harmonization Working Group

**Task 8 – 14 CFR 35 JAR-P**

# Task Assignment

**DEPARTMENT OF TRANSPORTATION**

**Federal Aviation Administration**

## Aviation Rulemaking Advisory Committee (ARAC); Engine Harmonization Working Group

**AGENCY:** Federal Aviation Administration (FAA), DOT.

**ACTION:** Notice of new task assignments for the Aviation Rulemaking Advisory Committee.

**SUMMARY:** Notice is given of new task assignments for the Engine Harmonization Working Group of the Aviation Rulemaking Advisory Committee (ARAC). This notice informs the public of the activities of the ARAC.

**FOR FURTHER INFORMATION CONTACT:** Mr. Michael Borfitz, Assistant Executive Director for Transport Airplane and Engine Issues, Aviation Rulemaking Advisory Committee, FAA Engine & Propeller Directorate, 12 New England Executive Park, Burlington, Massachusetts 01803; telephone (617) 238–7110, fax (617) 238–7199.

**SUPPLEMENTARY INFORMATION:** On January 22, 1991 (56 FR 2190), the Federal Aviation Administration (FAA) established the Aviation Rulemaking Advisory Committee (ARAC). The committee provides advice and recommendations to the FAA Administrator, through the Associate Administrator for Regulation and Certification, on the full range of the FAA's rulemaking activities with respect to aviation-related issues.

In order to develop such advice and recommendations, the ARAC may choose to establish working groups to which specific tasks are assigned. Such working groups are comprised of experts from those organizations having an interest in the assigned tasks. A working group member need not be a representative of a member of the full committee. One of the working groups established by the ARAC is the Engine Harmonization Working Group.

The FAA announced at the Joint Aviation Authorities (JAA)—Federal Aviation Administration (FAA) Harmonization Conference in Toronto, Canada, (June 2–5, 1992), that it would consolidate within the ARAC structure an ongoing objective to "harmonize" the Joint Aviation Requirements (JAR) and the Federal Aviation Regulations (FAR).

### Tasks

The Engine Harmonization Working Group new tasks are as follows:

*Task 1, Fire Pervention*—Review FAR and JAR requirements and create one set of common requirements (FAR 33.17; JAR–E–530).

*Task 2, FAR 35*—Conduct a comparison of FAR Park 35 and JAR–P requirements and advisory material and identify significant differences. This comparison should clarify and redefine existing requirements to include new standards to reflect recent advancements in design and construction of composite material propellers, propeller control systems (such as dual acting control systems) and electronic controls.

### Reports

For each task listed, the Engine Harmonization Working Group should develop and present to the ARAC:

1. A recommended work plan for completion of the tasks, including the rationale supporting such as a plan, for consideration at the meeting of the ARAC to consider transport airplane and engine issues held following publication of this notice;
2. A detailed conceptual presentation on the proposed recommendation(s), prior to proceeding with the work stated in item 3. below;
3. A draft Notice of Proposed Rulemaking, with supporting economic and other required analyses, and/or any other related guidance material or collateral documents the working group determines to be appropriate; or, if new or revised requirements or compliance methods are not recommended, a draft report stating the rationale for not making such recommendations; and
4. A status report at each meeting of the ARAC held to consider transport airplane and engine issues.

### Participation in Working Group Task

An individual who has expertise in the subject matter and wishes to become a member of the working group should write to the person listed under the caption **FOR FURTHER INFORMATION CONTACT** expressing that desire, describing his or her interest in the task(s), and stating the expertise he or she would bring to the working group. The request will be reviewed with the assistant chair and working group chair, and the individual will be advised whether or not the request can be accommodated.

The Secretary of Transportation has determined that the formation and use of the Aviation Rulemaking Advisory Committee are necessary in the public interest in connection with the performance of duties imposed on the FAA by law.

Meetings of the Aviation Rulemaking Advisory Committee will be open to the public, except as authorized by section 10(d) of the Federal Advisory Committee Act. Meetings of the working group will not be open to the public, except to the extent that individuals with an interest and expertise are selected to participate. No public announcement of working group meetings will be made.

Issued in Washington, DC, on August 10, 1994.

**Chris A. Christie,**

*Executive Director, Aviation Rulemaking Advisory Committee.*

[FR Doc. 94–20151 Filed 8–6–94; 8:45 am]

**BILLING CODE 4910–13–M**

Mr. Craig R. Bolt
Manager, Product Development and Validation
Pratt & Whitney
Mail Stop 162-12
East Hartford, CT 06108

Dear Mr. Bolt:

In an effort to clean up pending Aviation Rulemaking Advisory Committee (ARAC) recommendations on Transport Airplane and Engine Issues, the recommendations from the following working groups have been forwarded to the proper Federal Aviation Administration offices for review and decision. We consider your submittal of these recommendations as completion of the ARAC tasks. Therefore, we have closed the tasks and placed the recommendations on the ARAC website at http://www.faa.gov/avr/arm/arac/index.cfm

| Date | Task | Working Group |
|---|---|---|
| December 1999 | Interaction of Systems and Structure<br>Part 33 Static Parts | Loads and Dynamics Harmonization Working Group |
| March 2000 | Part 35/JARP: Airworthiness Standards Propellers | Engine Harmonization Working Group #9 |
| April 2000 | Flight Characteristics in Icing conditions | Flight Test Harmonization Working Group |
| May 2000 | Thrust Reversing Systems | Powerplant Installation Harmonization Working Group |
| September 2000 | Lightning Protection Requirements | Electromagnetic Effects Harmonization Working Group |
| July 2001 | Main Deck Class B Cargo Compartments | Cargo Standards Harmonization Working Group |
| April 2002 | Design Standard for Flight Guidance | Flight/Guidance Systems Harmonization Working Group |
| | | |

I wish to thank the ARAC and the working groups for the resources they spent in developing these recommendations. We will continue to keep you apprised of our efforts on the ARAC recommendations at the regular ARAC meetings.

Sincerely,

Anthony F. Fazio
Executive Director, Aviation Rulemaking
Advisory Committee

# Recommendation

**DRAFT -- version 8 -- 12/21/99**

**(This document does not represent final agency action on this matter and should not be viewed as a guarantee that any final action will follow in this or any other form.)**

**[4910-13]**

**DEPARTMENT OF TRANSPORTATION**

**Federal Aviation Administration**

**14 CFR Parts 23, 25, 33, 35**

**[Docket No. XXXXX; Notice No. 9X-XXXX]**

**RIN 2120-XXXX** [obtain from AGC]

**Airworthiness Standards; Propellers**

**AGENCY:** Federal Aviation Administration (FAA), DOT.

**ACTION:** Notice of proposed rulemaking (NPRM).

**SUMMARY:** The Federal Aviation Administration (FAA) proposes to revise the airworthiness standards for the issuance of original and amended type certificates (TC) for aircraft propellers. The existing propeller requirements do not adequately address the technological advances of the past twenty years. The proposed standards would address the current advances in technology and would harmonize the FAA requirements with those being drafted by the European Joint Aviation Authorities (JAA). This proposal would establish nearly uniform standards for aircraft propellers certified by the United States under FAA standards and by the JAA countries under JAA standards, thereby simplifying airworthiness approvals for import and export products.

**DATE:** Comments must be received on or before [INSERT DATE 60 DAYS AFTER

DATE OF PUBLICATION IN THE FEDERAL REGISTER.]

**ADDRESSES:** Comments on this notice should be mailed or delivered, in duplicate, to: U.S. Department of Transportation Dockets, Docket No. [ ], 400 Seventh Street SW., Room Plaza 401, Washington, DC 20590. Comments submitted must be marked: "Docket No. [ ]." Comments may also be sent electronically to the following Internet address: 9-NPRM-CMTS@faa.gov. Comments may be filed and examined in Room Plaza 401 between 10 a.m. and 5 p.m. weekdays, except Federal holidays.

**FOR FURTHER INFORMATION CONTACT:** Jay Turnberg, Engine and Propeller Standards Staff, ANE-110, Federal Aviation Administration, 12 New England Executive Park, Burlington, Massachusetts, 01803-5299; telephone (781) 238-7116; facsimile (781) 238-7199.

**SUPPLEMENTARY INFORMATION:**

**Comments Invited**

Interested persons are invited to participate in the making of the proposed rule by submitting such written data, views, or arguments as they may desire. Comments relating to the environmental, energy, federalism, or economic impact that might result from adopting the proposals in this notice are also invited. Substantive comments should be accompanied by cost estimates. Comments must identify the regulatory docket and be submitted in triplicate to the Rules Docket address specified above.

All comments received, as well as a report summarizing each substantive public contact with FAA personnel on this rulemaking, will be filed in the docket. The docket is available for public inspection before and after the comment closing date.

All comments received on or before the closing date will be considered by the

Administrator before taking action on this proposed rulemaking. Late-filed comments will be considered to the extent practicable. The proposals contained in this notice may be changed in light of the comments received.

Commenters wishing the FAA to acknowledge receipt of their comments submitted in response to this notice must include a pre-addressed, stamped postcard with those comments on which the following statement is made: "Comments to Docket No. XXXXX." The postcard will be date stamped and mailed to the commenter.

**Availability of NPRMs**

An electronic copy of this document may be downloaded using a modem and suitable communications software from the FAA regulations section of the Fedworld electronic bulletin board service (telephone: 703-321-3339), the Federal Register's electronic bulletin board service (telephone: 202-512-1661), or the FAA's Aviation Rulemaking Advisory Committee Bulletin Board service (telephone: 800-322-2722 or 202-267-5948).

Internet users may reach the FAA's web page at http://www.faa.gov/avr/arm/nprm/nprm.htm or the Federal Register's web page at http://www.access.gpo.gov/su_docs/aces/aces140.html for access to recently published rulemaking documents.

Any person may obtain a copy of this NPRM by submitting a request to the Federal Aviation Administration, Office of Rulemaking, ARM-1, 800 Independence Avenue, SW., Washington, DC 20591, or by calling 202- 267-9680. Communications must identify the notice number or docket number of this NPRM.

Persons interested in being placed on the mailing list for future NPRMs should request from the above office a copy of Advisory Circular No. 11-2A, Notice of Proposed Rulemaking Distribution System, which describes the application procedure.

**Background**

Statement of the Problem

Technology has advanced to the extent that most propeller certification programs over the past decade have required numerous applications of special conditions or special tests. The existing propeller requirements do not adequately address today's advances in technology. In addition to technological advances, the need to demonstrate compliance with both the FAA and the JAA requirements has placed additional burdens on the propeller manufacturers in order to obtain foreign certification. Therefore, the FAA has concluded that part 35 should reflect the above considerations and be substantially revised. This effort has been adopted as a part 35 and Joint Aviation Regulations for Propellers harmonization project and was selected as an Aviation Rulemaking Advisory Committee project.

Aviation Rulemaking Advisory Committee (ARAC) Project

Part 35 prescribes airworthiness standards for the issuance of type certificates and amendments to those type certificates for aircraft propellers. The Joint Aviation Requirements-Propellers (JAR-P) prescribe corresponding airworthiness standards for the European Joint Aviation Authorities (JAA).

On August 17, 1994, the FAA gave public notice of a new task assignment for the ARAC Engine Harmonization Working Group (EHWG) of the Transport Airplane and Engine Issues Group (TAEIG). The task is to conduct a comparison of part 35 and JAR-

P requirements and advisory material and identify significant differences. The purpose of this comparison is to clarify and redefine existing requirements to include new standards to reflect recent advancements in the design and construction of composite material propellers, propeller control systems (such as dual acting control systems) and electronic controls for propellers.

For the task, the EHWG was to develop and present the following components to the ARAC:

1. A recommended work plan for completion of the tasks, including the rationale supporting the plan, for consideration at the ARAC meeting for transport airplane and engine issues held following publication of this notice;

2. A detailed conceptual presentation on the proposed recommendation(s), prior to proceeding with the work stated in item 3 below;

3. A draft NPRM, with supporting economic and other required analyses, and/or any other related guidance material or collateral documents the working group determines to be appropriate; or, if new or revised requirements or compliance methods are not recommended, a draft report stating the rationale for not making such recommendations; and

4. A status report at each ARAC meeting for transport airplane and engine issues.

To complete this task the EHWG established the Propeller Harmonization Working Group (PHWG). The PHWG includes regulatory and industry representatives from Canada, France, Germany, United Kingdom, and the United States. The basis for the comparison is part 35, as amended through Amendment 35-7, and JAR-P, as amended through Change 7. The initial PHWG effort was focused on identifying the differences between part 35 and JAR-P. The comparison categorized the requirements into the following six areas:

1. Those requirements that are in part 35, but not in JAR-P;
2. Those requirements that are in both part 35 and JAR-P, but are not accepted as equivalent for both part 35 and JAR-P;
3. Those requirements that are accepted as equivalent for both part 35 and JAR-P;
4. Those requirements in which the intent is not clear;
5. Those requirements that may be simplified or deleted; and
6. Those requirements that are not in either part 35 or in JAR-P.

The PHWG identified the initial set of part 35 requirements to be developed, clarified, and harmonized with JAR-P. From this identification, it became evident that both part 35 and JAR-P should be substantially amended. The proposed amendment of part 35 would accomplish the following:

1. Eliminate deficiencies in the existing requirements;
2. Clarify the intent of the requirements;
3. Standardize compliance findings;
4. Improve certification efficiency;
5. Standardize advisory material; and
6. Facilitate harmonization of future changes.

<u>History</u>

Propeller designs have advanced over the past twenty years with little change in certification requirements. The following significant events and technological advances that have occurred over the past twenty years have led to this proposal.

1. Free turbine engines have become common, resulting in low engine-induced propeller loads.

2. Flange-mounted high horsepower propellers have become common, resulting in new propeller hub fatigue interface issues.

3. Composite blades and spinners using materials not covered by the regulations have been certificated.

4. The JAA was formed, resulting in additional standards for certification of import and export propellers.

5. Airline de-regulation has created a surge in the production of commuter airplanes, resulting in the increased use of propellers for public transportation.

6. Airlines have implemented the feeder/hub operational structure, resulting in the increased use of propellers for public transportation.

7. Digital electronic propeller controls which use technologies not covered by the regulations have been certificated.

8. Full authority digital electronic controls (FADEC) have been certificated, introducing new interface issues with the engine.

**Reference Material**

The following reference material was used as the basis for this proposed rule:

1. Special Conditions No. 35-ANE-01, Hamilton Standard Model 247F Propeller, Docket No. 94-ANE-50.

2. Special Conditions No. 35-ANE-02, Hamilton Standard Model 568F Propeller, Docket No. 94-ANE-60.

3. Special Conditions No. 35-ANE-03, Hamilton Standard Model 568F Propeller, Docket No. 94-ANE-61.

4. Special Conditions SC-92-03-NE, Hartzell Propeller, Inc. Model HD-E6C-3( )/E13482K Dual Acting Propeller, Docket No. 92-ANE-47.

5. Joint Airworthiness Requirements - Propellers, JAR-P, Change 7, October 22, 1987.

6. 14 CFR Part 21, Certification Procedures for Products and Parts, Amendment 21-75, 2/23/98.

7. 14 CFR Part 23, Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes, Amendment 23-53, 4/30/98.

8. 14 CFR Part 25, Airworthiness Standards: Transport Category Airplanes, Amendment 25-98, 3/10/99.

9. 14 CFR Part 33, Airworthiness Standards: Engines, Amendment 33-19, 4/30/98.

10. 14 CFR Part 35 Airworthiness Standards: Propellers, Amendment 35-7, 12/29/95.

**General Discussion of the Proposals**

<u>§§23.905 and 25.905 Propellers and §33.19 Durability</u>.

This proposal would require that propeller controls included in the aircraft or engine type design meet the same requirements as propeller controls that are included in the propeller type design.

§§23.907 and 25.907 Propeller vibration.

This proposal would revise the technical requirements of §§23.907 and 25.907 to make them identical. The technical requirements provide specific requirements to determine that a propeller demonstrates safe vibration compatibility with the airplane. The vibration evaluation of a propeller on an airplane involves both vibration and fatigue requirements. These requirements are the same for propellers installed on part 25 transport category airplanes and smaller part 23 category airplanes. The vibration evaluation of the propeller is dependent on the airplane and engine installation; the proposed requirements would show this dependency.

The current requirements are different for part 23 and 25 airplanes. The requirements do not address fatigue evaluation, do not require comparison to the fatigue limits and other structural data established in part 35, do not require a revision of the propeller operating and airworthiness limitations, do not address the flutter requirements of JAR-P and, in the case of §23.907, permit the use of service experience to show compliance. The use of service experience is an unsatisfactory method to show compliance with this requirement. The proposed revision addresses these issues.

The proposed paragraph (a) would add that the stresses are to be determined throughout the declared operational envelope of the airplane. The paragraph would permit the determination of stresses by analysis based on direct testing to permit interpolation and extrapolation of the measured data if it is not feasible to test the entire declared operational envelope of the airplane. The paragraph would permit the determination of stress by comparison with a similar airplane for which these measurements were made. The proposed requirement would not permit the use of service experience as a method to determine stresses.

The proposed paragraph (a) would harmonize with the JAR-P by adding the requirement from the current JAR-P 190 (a) (1) (i) to investigate stress peaks or resonant conditions and by adding the requirement from the current JAR-P 180 to address flutter to the proposed paragraph (b).

The proposed paragraph (c) would add a requirement to conduct a fatigue evaluation on the propeller for the airplane. This section would add requirements to revise the airplane and propeller operating and airworthiness limitations sections as needed to show compliance with the fatigue requirements. Prior to the propeller vibration and fatigue evaluation on the airplane, the propeller would undergo a substantial amount of structural evaluation during the certification program to show compliance with part 35. The proposal would require that this data be used.

The proposed revisions would rename §§23.907 and 25.907 "Propeller vibration and fatigue" to reflect the intent of the requirements.

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§25.901 Installation.

This proposal would revise §25.901 to add a reference to the propeller installation instructions provided under §35.3.

Part 35 -- Airworthiness Standards: Propellers.

The structure of this section will mirror the structure of part 35 for the convenience of the reader. Partial redesignation of the requirements has been proposed to harmonize part 35with the proposed JAR-P redesignation. The harmonization proposal accommodates the current CFR and JAR-P designation schemes. The part 35 designation will differ from the JAR-P designation by a zero. For example, the proposed §35.35 Centrifugal load tests will be equivalent to the JAR-P 350 Centrifugal load tests.

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Subpart A - General

This subpart addresses the requirements for the issuance of TCs and amended TCs for propellers. The proposed revisions to the subpart clarify the propeller configuration to be certificated; list the requirements for installing and operating the propeller; specify ratings and operating limitations.

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§35.1 Applicability.

No change is proposed for current paragraphs (a) and (b). Paragraph (c) would be added to establish the relationship between propeller and airplane certification. As under the current requirements, a propeller TC is issued after showing compliance with subparts A, B, and C of this part. Compliance with the proposed §§23.907 and 25.907 would require adequate coordination between the propeller manufacturers, aircraft manufacturers, FAA Aircraft Certification Offices, and FAA Propeller Certification Offices, promoting safer propeller installation.

Paragraph (d) would be added to refine the propeller definition in §1.1 for the purposes of this part. A propeller and propeller system would be defined for certification purposes; these terms are referenced throughout the proposed part 35 revision.

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§35.2 Propeller configuration and identification.

The new §35.2(a) would add a requirement for the applicant to provide a list of all the components and parts, including references to the relevant drawings and software design data, that define the type design of the propeller to be approved. This requirement would improve the documentation regarding the propeller components that are included within the propeller type design. The new §35.2(b) would reinforce the link between parts 35 and 45 and harmonize with JAR-P. The proposed requirement does not add requirements that are not already included in part 45 or JAR-21.

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§35.3 Instruction manual for installing and operating the propeller.

Section 35.3 currently specifies a requirement for the applicant to prepare and make available a manual(s) containing instructions for installing and operating the propeller. This proposal would revise the current requirement by providing the applicant with specific requirements regarding the content of the propeller installation and operation instructions. The revision would require the applicant to prepare instructions containing the data required by the aircraft manufacturer to install and operate the propeller within the limitations of the propeller type design.

The proposed revision would rename §35.3 "Instructions for propeller installation and operation" to reflect the intent of the requirements.

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§35.4 Instructions for Continued Airworthiness.

No changes would be made to §35.4.

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§35.5 Propeller operating limitations.

Section 35.5 currently specifies requirements for the establishment and documentation of propeller operating limitations. The operating limitations are to be established by the Administrator, included directly or by reference in the TC data sheet, and include limitations based on the operating conditions demonstrated during the tests required by this part and any other information found necessary for the safe operation of the propeller.

The proposed revision would modify the requirements regarding the establishment of the ratings and operating limitations. The ratings and operating limitations would be established by the applicant and approved by the Administrator. This change to the requirement reflects the process used to establish the limitations and ratings for the propeller. The process involves an applicant proposal to the FAA for approval. The modified requirement would be designated paragraph (a).

The proposed revision would add paragraph (b), which lists specific ratings and limits to be addressed. The list would document ratings for takeoff power and rotational speed, maximum continuous power and rotational speed, and maximum torque. These ratings are referenced within other requirements in this part. The proposed revision would also document transient overspeed and overtorque limits that would not require maintenance. The overspeed and overtorque limits are intended for inadvertent or maintenance use.

The list of ratings and operating limits does not represent all the ratings and operating limits that may be required for safe operation of the propeller. Paragraph (a) would state that the ratings and operating limitations must include limitations based on the operating conditions demonstrated during the tests required by this part and any other information necessary for the safe operation of the propeller.

The proposed revision would rename §35.5 "Propeller ratings and operating limitations" to reflect the intent of the requirements.

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§35.7 Features and characteristics.

The new §35.7(a) would harmonize with JAA requirements, incorporate features from §35.15, and add to the requirements of §21.21(b)(2). JAR 21.21 and §21.21 differ in that §21.21(b)(2) is written for the aircraft, and the corresponding JAR 21.21 requirement is written for the product and therefore includes the propeller. In JAR 21.21 the JAA requires a statement from the applicant reflecting that the applicant does not know of any features or characteristics that make the propeller unsafe for the uses for which certification is requested. The addition of §35.7(a) would incorporate this requirement.

Section 35.45(b) currently requires the following post-inspection requirements: "After the inspection the applicant must make any changes to the design or any additional tests that the Administrator finds necessary to establish the airworthiness of the propeller." These requirements would be revised and incorporated in the proposed §35.7(b).

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Subpart B – Design and construction

Subpart B currently addresses design and construction requirements for propellers. This proposed revision would maintain the intent of the current subpart, eliminate sections that are redundant or no longer applicable, and revise or add sections that address existing and future design and construction technology that is not adequately covered by the current requirements.

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§35.11 Applicability.

Section 35.11 is a descriptive statement about subpart B compliance that is fully addressed within §35.1. Therefore, it is proposed that §35.11 be removed and reserved.

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§35.13 General.

Section 35.13 is a descriptive statement about subpart B compliance that is fully addressed within §35.1. Therefore, it is proposed that §35.13 be removed and reserved.

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§35.15 Design features.

This proposal would revise and rename this section. Currently, §35.15 specifies that the propeller may not have design features that experience has shown to be hazardous or unreliable and also specifies that the suitability of each questionable design detail or part must be established by tests. Compliance to this section has taken many forms, ranging from a comparison to an existing design to a comprehensive safety assessment conducted on the propeller design.

The proposed revision would require that a safety analysis of the propeller be conducted. Safety analysis has been used to show compliance with the current requirement for the majority of new propeller certification programs during the past decade. The ultimate objective of the safety analysis requirement is to ensure that the collective risk from all propeller failure conditions is acceptably low. The basis is the concept that an acceptable total propeller design risk is achievable by managing the individual risks to acceptable levels. This concept emphasizes reducing the risk of an event proportionally with the severity of the hazard it represents.

The proposed revision would be written at the propeller level. Showing compliance with this requirement would not mean that a propeller is suitable for use on all or any aircraft applications. For example, a part 25 aircraft may require different failure effects and probabilities of failure than would be required by a part 23 aircraft. The proposed revision would define hazardous and major propeller effects, based on JAR-P requirements and the propeller special conditions listed under "Reference Material." These definitions would be used throughout the part and would only be applicable to this part.

The proposed revision would rename §35.15 "Safety analysis" to reflect the intent of the requirements.

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§35.17 Materials.

This proposal would revise and rename this section. Currently, §35.17 requires that the suitability and durability of the materials used in the propeller design must be established on the basis of experience, test, or both and must conform to approved specifications (e.g., industry or military specifications or Technical Standard Orders) that ensure the materials used have the strength and other properties assumed in the design data.

The proposed revision would require that both materials specifications and manufacturing methods be acceptable to the Administrator. This proposed revision would remove the list of examples of approved specifications and change the word "approved" to "acceptable." This change would reflect the level of review of the specifications by the Administrator.

The proposed revision would also require that the suitability and durability of materials must take into account the effects of environmental conditions expected in service. Consideration for environmental effects would be included in this proposed section because many materials used in the propeller design are dependent on the environment in which the propeller operates. This is especially relevant for composite materials which have age-dependent properties, as well as properties that are affected by humidity and temperature.

The proposed section would harmonize with the JAR-P requirements by requiring that design values consider the minimum properties stated in the accepted specifications. This clarification would prevent misinterpretations regarding the application of material properties to the propeller design.

The proposed revision would rename §35.17 "Materials and manufacturing methods" to reflect the intent of the requirements.

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§35.19 Durability.

Section 35.19 is redundant since compliance is fully addressed by showing compliance with §§35.4, 35.15, 35.17 and 35.37. Therefore, it is proposed that §35.19 be removed and reserved.

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§35.21  Reversible propellers.

This proposal would revise and rename this section.  The revision would modify the wording of the existing section and would incorporate the current pitch control and indication requirements of §35.23(c).

The proposed revision would expand the current §35.23(c) requirement to include all aircraft installations with reversible propellers.  The rule would be expanded to include reciprocating engine aircraft because the flight safety aspect of this rule applies regardless of engine type.

The revision would rename §35.21 "Variable and reversible pitch propellers" to reflect the intent of the requirements.

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§35.22  Feathering propellers.

The proposed revision would redesignate §35.23(b) as the new §35.22.  The text of the feathering requirement of the current §35.23(b) would be revised, but the intent would remain the same.

The proposed revision would harmonize with the JAR-P by adding two requirements from the current JAR-P.  The requirements of JAR-P 100 would be incorporated into paragraph (a), which would require feathering propellers to feather from all normal and emergency conditions in flight, taking into account likely wear and leakage.  The feathering characteristics and limitations must also be documented in the appropriate manuals.  The requirements of the current JAR-P 220 (b)(5) would be incorporated into paragraph (c), which would require that the propeller be designed to be capable of unfeathering at the minimum declared outside air temperature after stabilization to a steady-state temperature.

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§35.23 Pitch control and indication.

The proposed revision would revise and rename §35.23. Currently, this section consists of three paragraphs. Paragraph (a) addresses loss of pitch control, paragraph (b) requires backup oil systems for feathering propellers, and paragraph (c) incorporates low-pitch indicators. The proposed revision would retain and revise the current paragraph (a), redesignate and revise the current paragraph (c) as §35.21(b), and redesignate and revise the current paragraph (b) as §35.22(b).

The revised §35.23 would add requirements that address control system validation, control system design, software design, and control system description for all types of propeller mechanical, hydraulic, and electronic control systems and would retain the requirements of the current §35.23(a). The current part 35 propeller control design requirements, §§35.21 and 35.23(a) and (b), address specific design issues. Section 35.21 addresses single failure conditions on reversible propellers, and §35.23 addresses loss of normal control that may cause hazardous overspeeding and an alternative means to override or bypass the engine oil system for propellers that use engine oil to feather. This revision to part 35 would retain the specific reversible propeller requirements in §35.21 and would add §35.22 to include specific feathering propeller requirements. All other propeller control requirements would be incorporated into the revised §35.23.

The proposed §35.23(a) would add design, construction, and validation requirements for the control system.

The proposed §35.23(a)(1) would ensure that the control system, operating in normal and alternative modes and transitions between operating modes, performs the intended functions throughout the declared operating conditions and flight envelope. The validation of the control system operation is currently a flight testing requirement of JAR-P 220, Functional Tests. To harmonize JAR-P and part 35, the operational validation of JAR-P 220 would be added to part 35. The specific JAR-P requirement to mandate flight test on an aircraft would be removed from the requirement. Substantiation by propeller tests, rig tests, aircraft tests, analysis or a combination of these would be acceptable.

The proposed §35.23(a)(2) would ensure that the control system functionality is not adversely affected by declared environmental conditions. This requirement is not contained in the current part 35 or JAR-P.

The proposed §35.23(a)(3) would ensure that methods are provided to indicate to the flight crew, if crew action is required, that a mode change has occurred.

The proposed §35.23(b) would propose system safety requirements in addition to those in §35.15. The proposed new paragraph (b) would consist of five paragraphs. Paragraph (b)(1) would propose a level of integrity consistent with the intended aircraft application. Paragraph (b)(2) would propose that no single failure or malfunction of electronic or electrical components would result in hazardous propeller effects. Paragraph (b)(3) would address the relationship between failures of the linkages from the aircraft to the propeller control, and the effects that aircraft fires and overheating have on the propeller control. Paragraph (b)(4) would adopt the requirements of the current §35.23(a). Paragraph (b)(5) would address the effect of isolation between propellers on an aircraft.

The proposed §35.23(c) would add a requirement that all software must be designed and implemented by a method approved by the Administrator and that the software design must be consistent with the criticality of the performed functions to minimize the existence of software errors.

The proposed §35.23(d) would add requirements for aircraft-supplied data so that no single failure or malfunction of aircraft-supplied data would result in hazardous propeller effects.

The proposed §35.23(e) would add requirements for aircraft-supplied electrical power so that abnormalities of the power supply would not result in hazardous effects and would not require a declaration of the validated power supply characteristics.

The proposed revision would rename §35.23 "Propeller control system" to reflect the intent of the requirements.

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§35.24 Strength.

The current part 35 does not have specific design strength requirements. The current JAR-P 60 requires that the strength of the propeller must be such as to ensure safe operation up to the maximum speed and powers quoted in the declaration. To harmonize, the new §35.24 establishes strength requirements that are consistent with satisfactory practice as currently required by JAR-E 100 for aircraft engines.

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Subpart C – Tests and inspections

Subpart C currently addresses test and inspection requirements for the propeller. This proposed revision would maintain the intent of the current test and inspection requirements; however, the revision would eliminate regulations that are redundant or no longer applicable and would modify or add sections that reflect existing industry and FAA standard practices. Since subpart C applies to both test and analysis, the subpart heading would be changed to "Type Substantiation."

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§35.31 Applicability.

Section 35.31 is a descriptive statement about subpart C and is not a requirement. It is proposed that §35.31 be removed and reserved.

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§35.33 General.

This proposal would revise this section. The current §35.33(a) requires that the applicant demonstrate that the propeller and its essential accessories complete the tests and inspections of this subpart without evidence of failure. This requirement does not adequately address certification requirements. Many tests for certification are conducted on components and sub-assemblies. The propeller is tested as an assembly for the endurance and functional. The proposed revision would remove §35.33(a). The pass-fail criteria are defined in the requirements, as applicable.

The current §35.33(b) would be revised to identify that the testing conducted in this subpart is also governed by the test requirements established in part 21. The paragraph would be re-numbered as §35.33(a).

JAR-P 150 requires automatic controls be in operation during tests. The proposed new §35.33(b) would adopt this requirement and clarify that it also applies to propeller safety systems. In addition the proposal clarifies the conditions under which some tests may be conducted without the automatic controls or safety systems. For example, a primary system may have to be disabled to test a backup system.

This proposed revision would adopt a requirement for the evaluation of propeller components that cannot be adequately tested by the requirements of this part. This requirement would be adopted as §35.33(c) to address potential safety issues that may occur if it is identified during certification of the propeller that the required certification tests do not adequately test a component. This is currently a requirement of JAR-P 30.

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§35.34 Inspections, adjustments, and repairs.

The new §35.34 would add requirements to part 35 by revising and incorporating requirements that address inspection, adjustment, and repairs that are applicable to all tests from §§35.45 and 35.47.

The existing §35.45, Teardown inspection, is limited to post-test inspection. The current JAR-P 160 requires inspection prior to starting the test. The proposed §35.34(a) would adopt the JAR-P requirement for pre- and post-test inspections. Pre-test inspection establishes the condition of the test article prior to testing. This is particularly important for composite structures in which damage may be internal and not visible. Internal damage may be present prior to the start of the test, and the post-test inspection may not be valid without knowing the pre-test condition of the test article.

Section 35.47 currently limits the service, adjustments, and repairs of the test article. This paragraph would be revised and incorporated in the proposed §35.34(b).

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§35.35 Blade retention test.

This proposal would revise and rename §35.35. The section currently requires that the hub and blade retention for propellers with detachable blades be tested to a centrifugal load of twice the maximum centrifugal force to which the propeller would be subjected during operation. The revised requirement would be limited to the blade and hub retention and would not address the entire propeller assembly or changes in materials due to environmental factors.

This proposed revision would define requirements for the entire propeller and would include consideration of material degradation expected in service. Material degradation considerations apply to all types of construction, but would be specifically added to address composite materials, which may absorb moisture or show some evidence of delamination in service prior to retirement from service.

The proposed §35.35(a) would require the hub, blade retention, and counterweights be tested to twice the centrifugal load for one hour. This test is designed to assure a suitable static strength margin above the maximum rated rotational speed.

The proposed §35.35(b) would require the transition in a composite blade from the composite material to the metallic retention to be tested to twice the centrifugal load for one hour. This requirement would also apply to other types of construction in which a blade to the retention transition occurs.

The proposed §35.35(c) would address lower energy debris for the entire propeller. The propeller is evaluated at 159 percent of the maximum centrifugal load. This evaluation is currently required by JAR-P 170, Centrifugal Load Tests, and thus would be adopted for harmonization with JAR-P. The revised requirement would address spinners, de-icing equipment, blade erosion shields, and other assemblies used with or attached to the propeller.

The proposed revision would rename §35.35 "Centrifugal load tests" to reflect the intent of the requirements.

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§35.36 Bird impact.

This proposal would add requirements to part 35 that address bird impact with the propeller. This new §35.36 would maintain the level of safety that has been established by the use of special conditions for propellers with composite blades and would extend the bird impact certification requirement to all propeller designs, with the exception of fixed-pitch wood propellers of conventional design.

Currently there are no bird impact requirements under part 35 or JAR-P. The need for bird impact requirements was recognized when composite blades were introduced in the 1970s. The safety issues have been addressed by special tests and special conditions for composite blade certifications. These special conditions were unique for each propeller and effectively stated that the propeller must withstand a four pound bird impact without contributing to a major or hazardous propeller effect. The special tests and special conditions have been effective for over four million flight hours, and no accidents have been attributed to bird impact against composite propellers. The selection of a four-pound bird is based on the extensive service history of blades that have been designed using the four pound bird criteria.

The new §35.36 would exclude conventional fixed-pitch wood propellers because of their satisfactory experience. The new requirement would apply to metallic blades but allow compliance by experience on similar designs. The intent of this proposed section is to address designs that will be affected by bird impact.

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§35.37 Fatigue limit tests.

This proposal would revise and rename §35.37. The existing §35.37 requires that a fatigue evaluation be made and the fatigue limits be determined for each metallic hub and blade and each primary load-carrying metal component of nonmetallic blades. The current requirement does not adequately address composite materials and is limited to hubs, blades, and primary load-carrying metal components of nonmetallic blades. The proposed revision would expand the requirements to all materials and components whose failure would cause a hazardous propeller effect (including control system components, if applicable), and include environmental effects.

The proposed revision would retain the fatigue evaluation requirement in paragraph (b). The proposed revision would require that the fatigue evaluation be conducted on the intended aircraft in accordance with §§23.907 or 25.907 or on a typical aircraft. The typical aircraft may be a configuration used to develop design criteria for the propeller in those instances when the intended aircraft installation is not available or is unknown at the time of propeller type certification.

The proposal would rename §35.37 "Fatigue limits and evaluation" to reflect the intent of the requirements.

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§35.38 Lightning strike.

This proposal would add requirements to part 35 that address lightning strikes to the propeller system. Currently there are no lightning strike requirements in part 35 or

JAR-P. The need for lightning strike requirements was recognized when composite blades were first introduced in the 1970s. At that time special tests and special conditions were issued for each design that uses composite blades. The special tests and special conditions, which were unique for each propeller, effectively stated that the propeller must be able to withstand a lightning strike without contributing to a major or hazardous propeller effect.

The new §35.38 would exclude conventional fixed-pitch wood propellers because of their satisfactory experience. This new requirement would apply to metallic blades but allow compliance by experience on similar designs. The intent of this proposed section is to address designs that would be affected by lightning strike.

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§35.39 Endurance test.

The proposal would revise §35.39 to adopt a modified version of the JAR-P 210 requirements. The existing 10-hour endurance block test would be eliminated from the section because testing one propeller at the greatest pitch and diameter for ten hours is not adequate for a family of propellers. All current fixed-pitch propellers are being tested in accordance with the current 50-hour test requirement, which provides an adequate test.

The proposed revision would delete the requirement of testing a propeller of the greatest diameter for which certification is requested. This change would be introduced because testing of the greatest diameter is restrictive and does not necessarily result in an increase in airworthiness.

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§35.40 Functional test.

The proposed revision would redesignate the current §35.41 as §35.40. The new §35.40 would revise the redesignated text to change the requirement from operating for 30 seconds at maximum power and rotational speed selected by the applicant for maximum reverse pitch to stabilized operation at maximum power and rotational speed selected by the applicant for maximum reverse pitch.

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§35.41 Functional test.

The proposed revision would redesignate the §35.41 requirement as §35.40 to correspond with the JAR-P numbering. Section 35.41 would be used to add requirements to part 35 that address propeller overspeed and overtorque limits. Part 35 currently does not have requirements to verify the declared transient overspeed and overtorque limits of the propeller. JAR-P 210 (b)(3) has an overspeed requirement. The proposed §35.41 would require verification of declared transient overspeed and overtorque limits, harmonizing with JAR-P.

Section 35.41 would be renamed "Overspeed and overtorque" to reflect the intent of the requirements.

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§35.42 Blade pitch control system component test.

The proposed revision would combine the current §35.42 (a) and (b) into a single paragraph (b). The 1000-hour operation requirement would be expanded to the initially-declared inspection interval or a minimum of 1000 hours.

The proposed revision would rename §35.42 "Components of the propeller control system" to reflect the intent of the requirements.

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§35.43  Special tests.

The existing §35.43 Special tests states that "The Administrator may require any additional tests he finds necessary to substantiate the use of any unconventional features of design, material, or construction."  This statement is also included in §21.16 Special conditions.  Sections 35.43 and 21.16 perform the same function, with the exception that the requirements of §35.43 are not made available to the public, as is the case with special conditions issued under §21.16.

Since the PHWG has determined that it is in the best interest of the public to require special conditions to be issued and made available to the public when testing is required for unconventional features of design, material, or construction, it is proposed that the special tests requirement of §35.43 be removed.  The section would be retained and would incorporate requirements for propeller hydraulic components.

The proposed §35.43 would add requirements for testing of propeller components that contain hydraulic pressure.  These tests have been previously required by special condition or special tests under the current §35.43.  This proposal adopts the test procedures that are currently being conducted on applicable components.  The proposed §35.43 would be renamed "Propeller hydraulic components" to reflect the intent of the requirements.

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§35.45  Teardown inspection.

Since this proposal would move the teardown inspection requirements to §35.34, it is proposed that §35.45 be removed and reserved.  [See the discussion under §35.34.]

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§35.47 Propeller adjustments and parts replacements.

Since this proposal would move the propeller adjustment and repair requirements to §35.34, it is proposed that §35.47 be removed and reserved.

APPENDIX A TO PART 35 - INSTRUCTIONS FOR CONTINUED AIRWORTHINESS

No changes would be made to Appendix A to Part 35 - Instructions for Continued Airworthiness.

**Paperwork Reduction Act**

**[To be developed]**

**International Compatibility**

**[To be developed]**

**Regulatory Evaluation Summary**

**[TO BE DEVELOPED BY APO]**

**Initial Regulatory Flexibility Determination**

**[TO BE DEVELOPED BY APO]**

**International Trade Impact Analysis**

**[TO BE DEVELOPED BY APO]**

**Federalism Implications**

**[To be developed]**

**Unfunded Mandates Reform Act**

**[TO BE DEVELOPED BY APO]**

**Environmental Analysis**

**[To be developed]**

**Energy Impact**

**[To be developed]**

**List of Subjects in 14 CFR Part 23**

Air transportation, Aircraft, Aviation safety, Safety.

**List of Subjects in 14 CFR Part 25**

Air transportation, Aircraft, Aviation safety, Safety.

**List of Subjects in 14 CFR Part 33**

Air transportation, Aircraft, Aviation safety, Safety.

**List of Subjects in 14 CFR Part 35**

Air transportation, Aircraft, Aviation safety, Safety.

**The Proposed Amendment**

In consideration of the foregoing, the Federal Aviation Administration proposes to amend parts 23, 25, 33, and 35 of Chapter I, Title 14 of the Code of Federal Regulations as follows:

**PART 23—AIRWORTHINESS STANDARDS: NORMAL, UTILITY, ACROBATIC, AND COMMUTER CATEGORY AIRPLANES**

1. The authority citation for part 23 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701-44702, 44704

2. Revise §23.905(d) to read as follows:

**§ 23.905 Propellers.**

*          *          *          *          *

(d)  The propeller blade pitch control system must meet the requirements of §§35.27, 35.42 and 35.44 of this chapter.

*          *          *          *          *

3.  Revise §23.907 to read as follows:

**§23.907  Propeller vibration and fatigue.**

Sections 23.907(a), (b), and (c) do not apply to fixed-pitch wood propellers of conventional design.

(a)  Determine the magnitude of the propeller vibration stresses or loads, including any stress peaks and resonant conditions, throughout the operational envelope of the airplane by either:

(1)  Measurement of stresses or loads through direct testing or analysis based on direct testing of the propeller on the airplane and engine installation for which approval is sought; or

(2)  Comparison of the propeller to similar propellers installed on similar airplane installations for which these measurements have been made.

(b)  Demonstrate by tests, analysis based on tests, or previous experience on similar designs that the propeller does not experience harmful effects of flutter throughout the operational envelope of the airplane.

(c)  Perform an evaluation of the propeller to show that failure due to fatigue will be avoided throughout the operational life of the propeller using the fatigue and structural data obtained in accordance with part 35 and the vibration data obtained from compliance with paragraph (a) of this section.  For the purpose of this paragraph, the propeller includes the hub, blades, blade retention component and any other propeller component whose failure due to fatigue could be catastrophic to the airplane.  This evaluation must include:

(1)  The intended loading spectra including all reasonably foreseeable propeller vibration and cyclic load patterns, identified emergency conditions, allowable overspeeds and overtorques, and the effects of temperatures and humidity expected in service.

(2)  The effects of airplane and propeller operating and airworthiness limitations.

**PART 25—AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES**

4.  The authority citation for part 25 continues to read as follows:

Authority:  49 U.S.C. 106(g), 40113, 44701-44702, 44704

5.  Revise §25.901(b)(1)(i) to read as follows:

**§25.901  Installation.**

*     *     *     *     *

(b)  *   *   *

(1)  *   *   *

(i)  The installation instructions provided under §§33.5 and 35.3 of this chapter; and

*     *     *     *     *

6.  Revise §25.905(c) to read as follows:

**§25.905 Propellers.**

*     *     *     *     *

(c) The propeller blade pitch control system must meet the requirements of §§35.23, 35.42 and 35.43 of this chapter.

*     *     *     *     *

7. Revise §25.907 to read as follows:

**§25.907 Propeller vibration.**

Sections 25.907(a), (b), and (c) do not apply to fixed-pitch wood propellers of conventional design.

(a) Determine the magnitude of the propeller vibration stresses or loads, including any stress peaks and resonant conditions, throughout the operational envelope of the airplane by either:

(1) Measurement of stresses or loads through direct testing or analysis based on direct testing of the propeller on the airplane and engine installation for which approval is sought; or

(2) Comparison of the propeller to similar propellers installed on similar airplane installations for which these measurements have been made.

(b) Demonstrate by tests, analysis based on tests, or previous experience on similar designs that the propeller does not experience harmful effects of flutter throughout the operational envelope of the airplane.

(c) Perform an evaluation of the propeller to show that failure due to fatigue will be avoided throughout the operational life of the propeller using the fatigue and structural data obtained in accordance with part 35 and the vibration data obtained from compliance with paragraph (a) of this section. For the purpose of this paragraph, the propeller includes the hub, blades, blade retention component and any other propeller component whose failure due to fatigue could be catastrophic to the airplane. This evaluation must include:

(1) The intended loading spectra including all reasonably foreseeable propeller vibration and cyclic load patterns, identified emergency conditions, allowable overspeeds and overtorques, and the effects of temperatures and humidity expected in service.

(2) The effects of airplane and propeller operating and airworthiness limitations.

**PART 33 – AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES**

8. The authority citation for part 33 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701-44702, 44704

9. Revise §33.19(b) to read as follows:

**§33.19 Durability.**

* * * * *

(b) Each component of the propeller blade pitch control system which is a part of the engine type design must meet the requirements of §§35.23, 35.42 and 35.43 of this chapter.

* * * * *

10. Revise part 35 to read as follows:

**PART 35—AIRWORTHINESS STANDARDS: PROPELLERS**
**Subpart A—General**

Sec.

AUTHORITY: 49 U.S.C. 106(g), 40113, 44701-44702, 44704

**Subpart A—General**

**§35.1 Applicability.**

* * * * *

(c) The applicant is eligible for a propeller type certificate when compliance with subparts A, B and C has been demonstrated. However, the propeller may not be installed on an airplane unless compliance with either §§23.907 or 25.907, as applicable, has been shown or is not required for installation on that airplane.

(d) For the purposes of this part, the propeller consists of those components listed in the type design, and the propeller system consists of the propeller plus all the components necessary for its functioning, but not necessarily included in the propeller type design.

**§35.2 Propeller configuration and identification.**

(a) The applicant must provide a list of all the components, including references to the relevant drawings and software design data, that define the type design of the propeller to be approved under §21.31.

(b) The propeller identification must comply with §§45.11 and 45.14.

**§35.3 Instructions for propeller installation and operation.**

The applicant must provide instructions that are approved by the Administrator and that will contain:

(a) Instructions for installing the propeller, which must:

(1) Specify the physical and functional interfaces with the aircraft, aircraft

equipment and engine.

(2) Define the limiting conditions on the interfaces from paragraph (a)(1) of this section.

(3) Include a description of the operational modes of the propeller control system and functional interface of the control system with the aircraft and engine systems.

(4) List the limitations established under §35.5.

(5) Define the hydraulic fluids approved for use with the propeller, including grade and specification, related operating pressure and filtration levels.

(6) State the assumptions made to comply with the requirements of this part.

(b) Instructions for operating the propeller which must specify all procedures necessary for operating the propeller within the limitations of the propeller type design.

**§35.4 Instructions for continued airworthiness.**

* * * * *

**§35.5 Propeller ratings and operating limitations.**

(a) Propeller ratings and operating limitations must:

(1) Be established by the applicant and approved by the Administrator.

(2) Be included directly or by reference in the propeller type certificate data sheet, as specified in §21.41 of this chapter.

(3) Be based on the operating conditions demonstrated during the tests required by this part as well as any other information necessary for the safe operation of the propeller.

(b) Ratings and operating limitations must be established for the following, as applicable:

(1) Power and rotational speed for:

(i) Takeoff.

(ii) Maximum continuous.

(2) Maximum torque.

(3) Overspeed and overtorque limits.

**§35.7 Features and characteristics.**

(a) The propeller must not have features or characteristics, revealed by any test or analysis or known to the applicant, that make it unsafe for the uses for which certification is requested.

(b) If a failure occurs during a certification test, the cause must be determined, and the effect on the airworthiness of the propeller must be assessed. The applicant must make changes to the design or conduct additional tests, or both, that the Administrator finds necessary to establish the airworthiness of the propeller.

**Subpart B—Design and Construction**

**§35.11 [Reserved.]**

**§35.13 [Reserved.]**

**§35.15 Safety analysis.**

(a) (1) An analysis of the propeller system must be carried out in order to assess the likely consequence of all failures that can reasonably be expected to occur. This analysis must consider the following:

(i) The propeller system in a typical installation. When the analysis depends on representative components, assumed interfaces, or assumed installed conditions, the assumptions must be stated in the analysis.

(ii) Consequential secondary failures and latent failures.

(iii) Multiple failures referred to in paragraph (d) of this section or that result in the hazardous propeller effects defined in paragraph (g)(1) of this section.

(2) A summary must be made of those failures that could result in major propeller effects or hazardous propeller effects, together with an estimate of the probability of occurrence of those effects.

(3) It must be shown 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 total rate for hazardous propeller effects to be assessed. For propeller certification, it is acceptable to consider that the intent of this paragraph has been achieved if the probability of a hazardous propeller effect arising from an individual failure can be predicted to be not greater than $10^{-8}$ per propeller flight hour. It will also be accepted that, in dealing with probabilities of this low order of magnitude, absolute proof is not possible and reliance must be placed on engineering judgment and previous experience combined with sound design and test philosophies.

(4) It must be shown that major propeller effects are not predicted to occur at a rate in excess of that defined as remote (probability of $10^{-5}$ or less per propeller flight hour).

(b) If significant doubt exists as to the effects of failures or likely combination of failures, any assumption of the effect may be required to be verified by test.

(c) It is recognized that 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 must be placed on meeting the prescribed integrity requirements of this part. These instances must be stated in the safety analysis.

(d) If reliance is placed on a system or device, such as safety devices, feathering and overspeed systems, instrumentation, early warning devices, maintenance checks, and similar equipment or procedures, to prevent a failure progressing to hazardous propeller effects, the possibility of a safety system failure in combination with a basic propeller failure must be covered. If items of a safety system are outside the control of the propeller manufacturer, the assumptions of the safety analysis with respect to the reliability of these parts must be clearly stated in the analysis and identified in the propeller installation and operation instructions required under §35.3.

(e) If the acceptability of the safety analysis is dependent on one or more of the following, it must be identified in the analysis and appropriately substantiated.

(1) Performance of mandatory maintenance actions at stated intervals required for certification and other maintenance actions. This includes the verification of the serviceability of items which could fail in a latent manner. These maintenance intervals must be published in the appropriate manuals. Additionally, if errors in maintenance of the propeller system could lead to hazardous propeller effects, the appropriate procedures must be published in the appropriate manuals.

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

(3) The provisions of specific instrumentation not otherwise required.

(4) A fatigue assessment.

(f) If applicable, the safety analysis must include assessment of indicating equipment, manual and automatic controls, governors and propeller control systems, synchrophasers, synchronizers, and propeller thrust reversal systems.

(g) Unless otherwise approved by the Administrator and stated in the safety analysis, for compliance with part 35, the following failure definitions apply to the propeller:

(1) The following are regarded as hazardous propeller effects:

(i) A significant overspeed of the propeller.

(ii) The development of excessive drag.

(iii) Thrust in the opposite direction to that commanded by the pilot.

(iv) A release of the propeller or any major portion of the propeller.

(v) A failure that results in excessive unbalance.

(vi) The unintended movement of the propeller blades below the established minimum in-flight low-pitch position.

(2) The following are regarded as major propeller effects for variable pitch propellers:

(i) An inability to feather the propeller for feathering propellers.

(ii) An inability to command a change in propeller pitch.

(iii) A significant uncommanded change in pitch.

(iv) A significant uncontrollable torque or speed fluctuation.

**§35.17 Materials and manufacturing methods.**

(a) The suitability and durability of materials used in the propeller must:

(1) Be established on the basis of experience, tests, or both.

(2) Account for environmental conditions expected in service.

(b) All materials and manufacturing methods must conform to acceptable specifications.

(c) The design values of properties of materials must be suitably related to the minimum properties stated in the material specification.

**§35.19 [Reserved.]**

**§35.21 Variable and reversible pitch propellers.**

(a) No single failure or malfunction in the propeller system during normal or emergency operation will result in unintended travel of the propeller blades to a position below the in-flight low-pitch position. The extent of any intended travel below the in-flight low-pitch position must be documented in the appropriate manuals. Failure of structural elements need not be considered if the occurrence of such a failure is shown to be extremely remote under §35.15(c).

(b) For propellers incorporating a method to select blade pitch below the in-flight low pitch position, provisions must be made to sense and indicate to the flight crew that the blades are below that position by an amount defined in the installation manual. The method for sensing and indicating the propeller blade must be such that its failure does not affect the control of the propeller.

**§35.22 Feathering propellers.**

(a) Feathering propellers must be designed to feather from all normal and emergency conditions in flight, taking into account likely wear and leakage. Feathering and unfeathering limitations must be documented in the appropriate manuals.

(b) Propeller pitch control systems that use engine oil to feather must incorporate a method to allow the propeller to feather if the engine oil system fails.

(c) Feathering propellers must be designed to be capable of unfeathering at the minimum declared outside air temperature after stabilization to a steady-state temperature.

**§35.23 Propeller control systems.**

The requirements of this section are applicable to any system or component that controls, limits or monitors propeller functions.

(a) The propeller control system must be designed, constructed and validated to show that:

(1) The propeller control system, operating in normal and alternative operating modes and transition between operating modes, performs the intended functions throughout the declared operating conditions and flight envelope.

(2) The propeller control system functionality is not adversely affected by the declared environmental conditions, including temperature, electromagnetic interference

(EMI), high intensity radiated fields (HIRF) and lightning. The environmental limits to which the system has been satisfactorily validated must be documented in the appropriate propeller manuals.

(3) A method is provided to indicate that an operating mode change has occurred if flight crew action is required. In such an event, operating instructions must be provided in the appropriate manuals.

(b) The propeller control system must be designed and constructed so that, in addition to compliance with §35.15:

(1) A level of integrity consistent with the intended aircraft is achieved.

(2) No single failure or malfunction of electrical or electronic components in the control system results in a hazardous propeller effect.

(3) Failures or malfunctions directly affecting the propeller control system in a typical aircraft, such as structural failures of attachments to the control, fire, or overheat, do not lead to a hazardous propeller effect.

(4) The loss of normal propeller pitch control does not cause a hazardous propeller effect under the intended operating conditions.

(5) The failure or corruption of data or signals shared across propellers does not cause a major or hazardous propeller effect.

(c) Electronic propeller control system imbedded software must be designed and implemented by a method approved by the Administrator that is consistent with the criticality of the performed functions and minimizes the existence of software errors.

(d) The propeller control system must be designed and constructed so that the failure or corruption of aircraft-supplied data does not result in hazardous propeller effects.

(e) The propeller control system must be designed and constructed so that the loss, interruption or abnormal characteristic of aircraft supplied electrical power does not result in hazardous propeller effects. The power quality requirements must be described in the appropriate manuals

**§35.24 Strength.**

The maximum stresses developed in the propeller must not exceed values conforming to those established by satisfactory practice for the material involved. Due account should be taken of the particular form of construction and the most severe operating conditions. If a new type of material is involved, evidence must be available to substantiate the assumed material characteristics.

**Subpart C—Type Substantiation**

**§35.31 [Reserved.]**

**§35.33 General.**

(a) Each applicant must furnish test article(s) and suitable testing facilities, including equipment and competent personnel, and conduct the required tests in accordance with part 21.

(b) All automatic controls and safety systems must be in operation unless it is accepted that this is not possible or that they are not required because of the nature of the test. If needed for substantiation, the applicant may test a different propeller configuration if this does not constitute a less severe test.

(c) For those systems or components which cannot be adequately substantiated by the requirements of this part, additional tests or analysis must be made to demonstrate that the systems or components are able to perform their intended functions in all declared environmental and operating conditions.

**§35.34 Inspections, adjustments and repairs.**

(a) Before and after conducting the tests prescribed in this part, the test article must be subjected to an inspection, and a record must be made of all the relevant parameters, calibrations and settings.

(b) During all tests, only servicing and minor repairs are permitted. Major repairs or replacement of parts may be allowed, provided that the parts in question are subjected to an agreed level of additional testing. Any unscheduled repair or action on the test article must be recorded and reported.

**§35.35 Centrifugal load tests.**

Except for fixed-pitch wood or fixed-pitch metal propellers of conventional design, it must be demonstrated that a propeller accounting for environmental degradation expected in service complies with paragraphs (a), (b) and (c) of this section without evidence of failure, malfunction, or permanent deformation that would result in a major or hazardous propeller effect. Environmental degradation may be accounted for by adjustment of the loads during the tests.

(a) The hub, blade retention system, and counterweights must be tested for a period of one hour to a load equivalent to twice the maximum centrifugal load to which the propeller would be subjected during operation at the maximum rated rotational speed.

(b) If appropriate, blade features associated with transitions to the retention system (for example a composite blade bonded to a metallic retention) may be tested either during the test of §35.35(a) or in a separate component test.

(c) Components used with or attached to the propeller (for example, spinners, de-icing equipment, and blade erosion shields) must be subjected to a load equivalent to 159 percent of the maximum centrifugal load to which the component would be subjected during operation at the maximum rated rotational speed. This must be performed by either:

(1) Testing at the required load for a period of 30 minutes; or

(2) Analysis based on test.

**§35.36 Bird Impact.**

It must be demonstrated, by tests or analysis based on tests or experience on similar designs, that the propeller is capable of withstanding the impact of a four-pound bird at the critical location(s) and critical flight condition(s) of a typical installation without causing a major or hazardous propeller effect. This section does not apply to fixed-pitch wood propellers of conventional design.

**§35.37 Fatigue limits and evaluation.**

This section does not apply to fixed-pitch wood propellers of conventional design.

(a) Fatigue limits must be established by tests, or analysis based on tests, for propeller:

(1) Hubs.

(2) Blades.

(3) Blade retention components.

(4) Other components which are affected by fatigue loads and which are shown under §35.15 as having a fatigue failure mode leading to hazardous propeller effects.

(b) The fatigue limits must take into account:

(1) All known and reasonably foreseeable vibration and cyclic load patterns that are expected in service; and

(2) Expected service deterioration, variations in material properties, manufacturing variations, and environmental effects.

(c) A fatigue evaluation of the propeller must be conducted to show that hazardous propeller effects due to fatigue will be avoided throughout the intended operational life of the propeller on either:

(1) The intended aircraft by complying with §§23.907 or 25.907, as applicable; or

(2) A typical aircraft.

**§35.38 Lightning strike.**

It must be demonstrated, by tests or analysis based on tests or experience on similar designs, that the propeller is capable of withstanding a lightning strike without causing a major or hazardous propeller effect. This section does not apply to fixed-pitch wood propellers of conventional design. The limit to which the propeller has been qualified shall be documented in the appropriate manuals.

**§35.39  Endurance test.**

Endurance tests on a propeller system must be made on a representative engine in accordance with paragraph (a) or (b) of this section, as applicable, without evidence of failure or malfunction.

(a)  Fixed-pitch and ground adjustable-pitch propellers must be subjected to one of the following tests:

(1)  A 50-hour flight test in level flight or in climb.  The propeller must be operated at takeoff power and rated rotational speed during at least five hours of this flight test, and at not less than 90 percent of the rated rotational speed for the remainder of the 50 hours.

(2)  A 50-hour ground test at takeoff power and rated rotational speed.

(b)  Variable-pitch propellers must be subjected to one of the following tests:

(1)  A 110-hour endurance test that must include the following conditions:

(i)  Five hours at takeoff power and rotational speed and thirty 10-minute cycles composed of:

(A)  Acceleration from idle,

(B)  Five minutes at takeoff power and rotational speed,

(C)  Deceleration, and

(D)  Five minutes at idle.

(ii)  Fifty hours at maximum continuous power and rotational speed,

(iii)  Fifty hours, consisting of ten 5-hour cycles composed of:

(A)  Five accelerations and decelerations between idle and takeoff power and rotational speed,

(B) Four and one half hours at approximately even incremental conditions from idle up to, but not including, maximum continuous power and rotational speed, and

(C) Thirty minutes at idle.

(2) The operation of the propeller throughout the engine endurance tests prescribed in part 33 of this chapter.

**§35.40 Functional test.**

The variable-pitch propeller system must be subjected to the applicable functional tests of this section. The same propeller used in the endurance test (§35.39) must be used in the functional tests and must be driven by a representative engine on a test stand or on an aircraft. The propeller must complete these tests without evidence of failure or malfunction. This test may be combined with the endurance test for accumulation of cycles.

(a) Manually-controllable propellers. Five hundred representative flight cycles must be made across the range of pitch and rotational speed.

(b) Governing propellers. Fifteen hundred complete cycles must be made across the range of pitch and rotational speed.

(c) Feathering propellers. Fifty cycles of feather and unfeather operation must be made.

(d) Reversible-pitch propellers. Two hundred complete cycles must be made from lowest normal pitch to maximum reverse pitch selected by the applicant and while at maximum reverse pitch must reach stable power and rotational speed.

### §35.41 Overspeed and overtorque.

(a) When approval of a transient maximum propeller overspeed is sought, it must be shown that the propeller is capable of further operation without maintenance action at the maximum propeller overspeed condition. This may be accomplished by either:

(1) Performance of 20 runs, each of 30 seconds duration, at the maximum propeller overspeed condition; or

(2) Analysis based on test or service experience.

(b) When approval of a transient maximum propeller overtorque is sought, it must be shown that the propeller is capable of further operation without maintenance action at the maximum propeller overtorque condition. This may be accomplished by either:

(1) Performance of 20 runs, each of 30 seconds duration, at the maximum propeller overtorque condition; or

(2) Analysis based on test or service experience.

### §35.42 Components of the propeller control system.

It must be demonstrated, by tests or analysis based on tests or service experience on similar components, that each propeller blade pitch control system component, including governors, pitch change assemblies, pitch locks, mechanical stops, and feathering system components, can withstand cyclic operation that simulates the normal load and pitch change travel to which the component would be subjected during the initially declared overhaul period, or a minimum of 1000 hours of typical operation in service.

**§35.43 Propeller hydraulic components.**

Propeller components that contain hydraulic pressure and whose structural failure or leakage from a structural failure could cause a hazardous propeller effect must demonstrate structural integrity by performing:

(a) A proof pressure test to 1.5 times the maximum operating pressure without permanent deformation or leakage that would prevent performance of the intended function.

(b) A burst pressure test to 2.0 times the maximum operating pressure without failure. Leakage is permitted and seals may be excluded from the test.

**§35.45 [Reserved.]**

**§35.47 [Reserved.]**

**APPENDIX A TO PART 35 – INSTRUCTIONS FOR CONTINUED AIRWORTHINESS**

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that any final action will follow in this or any other form.)**

**Advisory**

**Circular**

| | | | |
|---|---|---|---|
| **Subject: VIBRATION AND FATIGUE EVALUATION OF AIRCRAFT PROPELLERS.** | **Date:**12/21/99 | | **AC No:** 20-66-xx |
| | **Initiated By:** | Jay Turnberg<br>ANE-110 | **Change:** A2066v9 |

**1. PURPOSE.** This advisory circular (AC) provides guidance and describes acceptable methods, but not the only methods, for demonstrating compliance with provisions of the requirements of Title 14 of the Code of Federal Regulations (14CFR) §§23.907 and 25.907 pertaining to the vibration and fatigue evaluation of propellers installed on airplanes. Like all AC material, this AC is not, in itself, mandatory and does not constitute a regulation. While these guidelines are not mandatory, they are derived from extensive Federal Aviation Administration (FAA) and industry experience in determining compliance with the pertinent regulations.

**2. CANCELLATION**. AC 20-66 Vibration Evaluation of Aircraft Propellers, 1/29/70, is canceled.

**3. RELATED DOCUMENTS.**

a. Related Regulations.

(1) Title 14 Code of Federal Regulations (CFR)

(a) §35.4 Instructions for Continued Airworthiness

(b) §35.15 Safety analysis

(c) §35.37 Fatigue limits and evaluation

(c) §23.907 Propeller vibration and fatigue

(d) §25.907 Propeller vibration and fatigue

(2) Joint Airworthiness Authority (JAA) Requirements:

(a) JAR-P 370 Fatigue Limits and Evaluation.

(b) JAR-P Sub-Section D, Propeller Vibration and Fatigue Evaluation.

b. Advisory Circulars.

(1) AC 35-37-xx, Guidance Material for 14 CFR 35.37 Fatigue Limits and Evaluation, dated xx/xx/xx.

(2) AC 20-107A, Composite Aircraft Structure, dated 4/25/84.

(3) AC 21-26, Quality Control for the Manufacture of Composite Structures, dated 6/26/89.

(4) AC 25.571-1C, Damage Tolerance and Fatigue Evaluation of Structure, Dated 4/29/98.

(5) AC 20-95, Fatigue Evaluation of Rotorcraft Structure, Dated 5/18/76.

c. <u>Joint Airworthiness Authority (JAA) Advisory Circulars</u>.

(1) ACJ P-370, Fatigue limits and evaluation, dated xx/xx/xx.

(2) ACJ P-550, Fatigue verification, dated xx/xx/xx.

d. <u>Related Reading Material</u>.

(1) Report No. NADC-87042-60(DOT/FAA/CT-86/39), "Certification Testing Methodology for Composite Structure Volume I – Data Analysis & Volume II – Methodology Development", R.S. Whitehead, H.P. Kan, R. Cordero, E.S. Saether, Northrop Corporation Aircraft Division, Naval Air Development Center, October 1986.

(2) Den Hartog, J. P., <u>Mechanical Vibrations</u>, McGraw-Hill Book Company, 1956

**4. <u>DEFINITIONS</u>**. For the purposes of this AC, the following definitions are provided.

a. <u>Damage tolerance</u> is the attribute of the structure that permits it to retain its required residual strength for a period of use after the structure has sustained a given level of fatigue, corrosion, accidental or discrete source damage.

b. <u>End of life condition</u>. The physical condition of the component defined during certification when it will be considered to have the maximum extent of damage while still while still maintaining sufficient residual strength to meet all airworthiness loading requirements.

c. <u>Fail-safe</u> is the attribute of the structure that permits it to retain its required residual strength for a period of unrepaired use after the failure or partial failure of a principal structural elements.

d. <u>Limit loads</u> are the maximum loads expected in service.

e. <u>Hazardous propeller effects</u>. The following are regarded as hazardous propeller effects:

(1) A significant overspeed of the propeller.

(2) The development of excessive drag.

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

(4) A release of the propeller or any major portion of the propeller.

(5) A failure that results in excessive unbalance.

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

f. Principal structural element is an element that contributes significantly to the carrying of propeller loads, and whose integrity is essential in maintaining the overall structural integrity of the propeller.

g. Safe-life of a structure is that number of events such as flights, landings, or flight hours, during which there is a low probability that the strength will degrade below its design value due to fatigue cracking.

h. Scatter factor. A life reduction factor used in the interpretation of fatigue analysis and test results.

**5. DISCUSSION.** The vibration evaluation of a propellers on an aircraft involves the determination of propeller vibratory stresses on the aircraft and a fatigue evaluation to show that the propeller can be operated safely within the structural limitations of the propeller. The regulations and process to show compliance is the same for propellers installed on part 25, transport category airplanes as it is for part 23 normal, utility, acrobatic, and commuter category airplanes. The regulations are §§23.907 and 25.907 Propeller vibration and fatigue. The regulatory text is:

**Sections 23/25.907(a), (b), and (c) do not apply to fixed pitch wood propellers of conventional design.**

**(a) Determine the magnitude of the propeller vibration stresses or loads, including any stress peaks and resonant conditions, throughout the operational envelope of the airplane by either:**

**(1) Measurement of stresses or loads through direct testing or analysis based on direct testing of the propeller on the airplane and engine installation for which approval is sought; or**

**(2) Comparison of the propeller to similar propellers installed on similar airplane installations for which these measurements have been made.**

**(b) Demonstrate by tests, analysis based on tests, or previous experience on similar designs that the propeller does not experience harmful effects of flutter throughout the operational envelope of the airplane.**

**(c) Perform an evaluation of the propeller to show that failure due to fatigue will be avoided throughout the operational life of the propeller using the fatigue and structural data obtained in accordance with part 35 and the vibration data obtained from compliance with paragraph (a) of this section. For the purpose of this paragraph, the propeller includes the hub, blades, blade retention component and any other propeller component whose failure due to fatigue could be catastrophic to the airplane. This evaluation must include:**

**(1) The intended loading spectra including all reasonably foreseeable propeller vibration and cyclic load patterns, identified emergency conditions, allowable overspeeds and overtorques, and the effects of temperatures and humidity expected in service.**

**(2) The effects of airplane and propeller operating and airworthiness limitations.**

a. Coordination. The vibration evaluation of the propeller is dependent on the propeller, airplane and engine. Because of this dependency the airplane applicant (Airplane company/modifier), Aircraft Certification Office working with the airplane applicant (Airplane ACO), propeller type certificate holder (Propeller manufacturer), and the ACO that certified the propeller (Propeller ACO) should coordinate activities. The role of each participant in the propeller vibration and fatigue evaluation should be established early in the airplane certification program. The roles may vary depending on the type of program and the expertise of the participants. The roles may be quite different for a single engine tractor aircraft than for a large transport aircraft.

(1) Imported Propellers. The vibration evaluation of import propeller with FAA type certificates generally requires coordination with the foreign certification authority that issued the propeller type certificate in the country of origin and the propeller manufacturer that exported the propeller. The coordination is needed to obtain the information and documentation to show compliance with the requirements of §23.907 or §25.907. This coordination should be established early in the airplane certification program as above in paragraph a.

(2) Aircraft listed on the propeller type certificate data sheet. For most propellers imported from Joint Airworthiness Authority (JAA) countries, the propeller is shown to meet similar Joint Airworthiness Requirements (JAR), JAR 23.907 and JAR 25.907 for an airplane installation when the propeller is issued a type certificate. These airplanes may be listed on both the foreign propeller type certificate data sheet and the corresponding FAA propeller type certificate data sheet. It should be noted that the detailed regulatory requirements for JAR 23.907 and JAR 25.907 are contained in JAR-P Sub-Section D. The airplanes listed on the propeller type certificate data sheet of an imported propeller does not automatically grant compliance to §23.907 or §25.907 for that airplane. Additional documentation is required for the propeller to show acceptability to the Airplane ACO. Coordination of this documentation should be established early in the airplane certification program as, above in paragraph a.

b. Applicable Projects. The following are some of the airplane projects that generally require a re-evaluation or review of propeller vibration and fatigue:

- TC or STC programs that install or change a propeller.
- Increase in propeller RPM and/or power including increased thermodynamic capability or flat rating the engine.
- Installation of a new engine or engine model.
- Installation of floats.
- Multi-engine airplane increase in maximum gross weight, decrease in minimum gross weight, modification airplane nacelle tilt or toe, modifications affecting wing lift, and increase in Vmo, Vne, and Vd.
- Adding a new TC category to an aircraft such as acrobatic or commuter.

c. Propeller Structural Data. Prior to the propeller vibration and fatigue evaluation on the aircraft the propeller has undergone a substantial amount of structural evaluation during the propeller certification program. Much of the propeller certification program involves generating the structural data used to support the vibration tests and fatigue evaluation on the airplane. This data is generated under part 35. An outline of the process is shown in Figure 1. The structural data required to conduct a propeller fatigue evaluation on the airplane generally resides with the propeller manufacturer. If the propeller structural data is unavailable through the propeller manufacturer it may be generated in accordance with the part 35. Reference 3b(1) provides guidance to generate propeller fatigue limits.

d.  Fixed Pitch Wood Propellers of Conventional Design**.**  A fixed pitch wood propeller of conventional design is a propeller that has the following physical properties:

- One piece laminated wood construction.
- Two or four blades.
- The surface coating does not contribute to the propeller strength.
- The surface coatings only provides environmental protection.

A fixed pitch propeller that has a composite shell over a wood core would not qualify as conventional construction when the composite shell contributes to the strength and frequency response of the propeller.  A fixed pitch wooden propeller with a fabric or composite covering, that does not alter the structure, for environmental protection would be considered to be of conventional design.

e.  Background.  Additional background information is provided in the Appendices to this advisory circular.  Appendix A provides a basic information regarding propeller excitation sources and aircraft and propeller interactions which may be useful to guide the process of planning and implementing the propeller vibration and fatigue evaluation program.  Appendix B provides considerations for planning a vibration test for propellers on reciprocating and turbine engine installations.

## 6.  VIBRATION TESTS.

a.  Vibration Measurement.

(1)  Propeller vibration survey.  Propeller loads are measured on the aircraft during the propeller vibration survey. Typically electric resistance strain gage coupled with a electronic signal processing system and a recording device are used to measure the loads on a propeller.  The strain gage signals are recorded during the test at flight and ground operating conditions suitable to evaluate the propeller loads throughout the aircraft operational envelope.  The strain gages signals and other applicable information are processed following the flight test for evaluation.

(2) Strain gages. There are many varieties of strain gages varying in size, resistance, material, construction, etc. The type of strain gage is selected by understanding the required result, operating environment, and system instrumentation requirements. The strain gage manufacturers provide complete application guides and installation instructions for the transducers they produce.

(a) Strain gages should be located on the propeller to measure surface strain which can be converted to stress or to load with proper calibration. There are many considerations when locating strain gages on the propeller for the flight stress survey. Consideration should be given to the fatigue tests conducted for §35.37 since the measured flight test data will be used in conjunction with the fatigue test data. The location and quantity of strain gages used during the vibration survey is governed by the requirements of the evaluation. If the strain gages do not provide an accurate picture of the propeller loading the subsequent evaluations will not provide useful results.

(b) It is not always possible to locate a strain gage where the maximum strain or stress occurs. In these cases, reference strain gages may be used. Strain gage readings from one location may be related to other locations on the propeller based on previous analysis or test data. Strain gages are typically installed on the propeller blades along the camber side at the point of maximum thickness which is the point farthest from the blade neutral axis. Propeller blades should have sufficient strain gages installed to define the load distribution along the blade to identify peak load locations and at reference locations needed to relate the data to applicable fatigue limits. Additionally, strain gages should be located on other areas as dictated by the specific blade design as well as other propeller parts such as the hub unit, pitch change components, engine shaft, or any other components for which dynamic load information is required. For the evaluation of flutter conditions, 45° gages (shear stress gages) should be installed.

(c) In some cases, strain gages should be installed on the engine shaft. Data from these gages can be used to determine the torsional forcing frequencies output by the engine and bending loads due to aerodynamic and gyroscopic loads. Sometimes these data are required to evaluate the bending moment that must be withstood to conduct a propeller hub flange evaluation. In other cases, the engine shaft data and the propeller data are acquired concurrently, and the engine data are passed along to the engine manufacturer for their own fatigue evaluation.

(3) Instrumentation systems. The strain gage signals along with some flight and ground aircraft operating conditions are recorded for subsequent data reduction and analysis. There are many instrumentation options available to record the stress survey data. The fundamental system design may be analog or digital, may use frequency modulation or amplitude modulation, and etc. The instrumentation should include the following considerations:

- Data calibration to assure that the signals being recorded are accurate.
- Verification of adequate system frequency response, including sampling rates for digital systems.
- Verification that the data amplitudes are not over loading the system causing data to be clipped or otherwise distorted.
- On line monitoring of the data for flight safety and signal quality verification.
- Adequate sensitivity so that the recorded data is above the system noise level.
- Time correlation to relate the strain gage data to the aircraft data.

(a) Common problems with data recording systems come from a lack of understanding of the capabilities of the components within the data recording system. Each electronic component has a range of frequency capability. If the strain gage signals of importance are higher than the capability of the equipment than the strain gage results will not be accurate. This is also true with respect to the amplitude of the strain gage signals. A system designed for a large diameter propeller on a turbine engine transport aircraft many not be adequate for a small diameter propeller on a general aviation aircraft and vice versa. The system requirements may also be different for a metallic blade and a composite blade. Each installation should be reviewed to determine if the instrumentation system is adequate to record propeller stresses.

(b) Instrumentation systems may not have the capability to measure steady stress as well as vibratory stress. When steady stress is not measured appropriate analysis should be conducted to determine the steady stress levels.

(4) Test data. The strain gage signals are recorded during the stress survey along with certain aircraft parameters. In addition data is logged during the stress survey. The combination of recorded and logged data is established to fit the needs of the fatigue

evaluation. Consideration should be given to recording or logging the following test parameters:

| | |
|---|---|
| Voice | Pitch angle |
| Strain gage signals | Altitude |
| 1P speed phase pulse | Blade angle |
| Propeller RPM | Aircraft gross weight & CG |
| Engine torque | Flap setting |
| Airspeed | Ground wind speed |
| Aircraft vertical acceleration | Ground wind direction |
| Yaw angle | Weather conditions |

The list of test parameters is more extensive than needed for many flight and ground test programs. The parameters that are recorded is based on an evaluation of the overall test program requirements.

(5) Data reduction. The extent of data reduction is related to the overall fatigue evaluation. Data reduction involves determination of the magnitude of vibratory stresses at each test condition and where applicable the determination of the propeller response frequency content to assess that the propeller response is as expected.

(a) The flight and ground test data being evaluated has continuously varying steady and vibratory amplitudes and frequency content. The evaluation of a test condition may be in the form of a mean stress and a peak vibratory stress or a statistically sampled vibratory stress. When values other than the peak vibratory stress is used an evaluation should be conducted to show the significance of higher stresses that are excluded from the fatigue evaluation.

(b) Other techniques may be employed to process the cyclic content of the measured data to assess the cumulative exposure to the loads. A “rainflow” load cycle accumulation methodology is suitable to describe load cycle content of a load history for fatigue evaluation.

b. Vibration Test Conditions. The test conditions that need to be evaluated during the propeller vibration test can vary significantly with each installation. As previously mentioned, the type of engine, reciprocating or turbine, will be a primary determining factor in identifying the conditions that should be evaluated. The other significant factors are the type of aircraft and the maneuvers included in the aircraft operating envelope. Appendix B provides an example of test conditions evaluated during propeller vibration testing on part 23 category reciprocating and turbine engine installations.

(1) Reciprocating engine installations. The propeller vibration testing on reciprocating engine installations should focus primarily on evaluating the possible combinations of engine power and RPM during ground operations and in flight. Propellers installed on normal category single reciprocating engine tractor type installations is generally based on engine power and RPM combinations. Propellers installed on other types of reciprocating engine installations such as twin engine aircraft, pusher aircraft, aerobatics aircraft, etc. will require additional testing to evaluate the contribution of aerodynamic loading to the propeller vibratory load amplitudes.

(a) There are a number of other factors that can influence the propeller vibration characteristics and load amplitudes during testing and when evaluating propeller installations based on similarity to others that have been tested.

1 When comparing identical engines with and without fuel injection, the fuel injected engines will tend to be smoother running engines due to more uniform fuel distribution and cylinder pressures. Propellers installed on the fuel injected engines will therefore tend to exhibit slightly lower vibratory load amplitudes.

2 When comparing identical engines with different compression ratios the engine with the higher compression ratio will tend to produce higher propeller vibratory load amplitudes due to the increase in cylinder pressures.

3 Engine crankshaft torsional damper configurations and crankshafts can differ between otherwise identical engines listed on the same engine TCDS. Any change to the damper configuration or crankshaft will change the propeller vibration characteristics and load amplitudes.

4  Propeller indexing relative to the crankshaft can effect propeller vibration characteristics and stress amplitudes.  Some installations provide the option of multiple indexing positions for the propeller and some propellers will exhibit unequal blade to blade vibratory load amplitudes.  These variables should be considered during the evaluation.

5  Turbocharged and supercharged engines will produce rated power at higher altitudes and operate at higher manifold pressures than normally aspirated engines.  Evaluation of propellers on turbocharged and supercharged engines should include testing at the maximum altitude at which maximum power can be maintained and incremental combinations of manifold pressure and RPM.

(2)  Turbine engine installations.  The propeller vibration evaluation on turbine engine installations should focus on evaluating the installation characteristics and flight conditions that effect the aerodynamic loading of the propeller.  The magnitude of the 1P aerodynamic loading will be significantly influenced by the thrust alignment of the engine as it is installed in the aircraft.  This is a parameter that is typically not subject to change based on results of the propeller vibration evaluation.  Therefore, it is to the advantage of the aircraft manufacturer or modifier to work with the propeller manufacturer to optimize the engine thrust alignment to best satisfy the requirements of both aircraft handling qualities and propeller loading, and not optimize one without regard to the implications to the other.

(a)  There are a number of other factors that can influence the propeller vibration characteristics and load amplitudes during testing and when evaluating propeller installations based on similarity to others that have been tested.

1  Changes in aircraft weight can have a significant influence on the propeller load amplitudes so the propeller vibration evaluation needs to consider both the maximum gross weight and minimum flying weight, which would be the weight with minimum crew and fuel.  If the aircraft cannot be tested at these weights the propeller load evaluation needs to provide an analytical projection of the propeller loads for these conditions.

2  Takeoff rotation on many turbine powered installations produces propeller vibratory load amplitudes that can be at or near the applicable limits.  The use of flaps during

takeoff will tend to reduce the propeller vibratory loading due to the reduction in angle of attack. Many aircraft flight manuals specify a specific flap position for takeoff but do not prohibit takeoffs with the flaps retracted. Therefore, all possible flap positions should be evaluated including the fully retracted position.

3 Turbine engine installations should be evaluated at more than one altitude to identify any adverse effects on propeller loading due to altitude. This should include the maximum altitude at which maximum power can be maintained. This is particularly significant for engines that are flat rated, or have thermodynamic capabilities that allow the engine to produce rated power at altitudes that are significantly higher than equivalent engines that are not flat rated.

c. Similarity. Propeller vibratory stress amplitudes may be analytically derived for an installation using test data from a sufficiently similar installation. The objective is to show the operating environment is similar between the aircraft, so the measured vibratory stresses and the fatigue evaluation conducted on baseline aircraft are applicable to a target aircraft. Similarity is generally not used to determine propeller vibration stresses on large multi-engine aircraft or acrobatic aircraft because of inaccuracies associated with evaluating the aerodynamic environment.

(1) Overview. The process to show propeller stresses by similarity involves a review of the vibration stress survey from the baseline aircraft to identify trends in stress variation and the conditions that cause the maximum stresses during ground and flight operation and to conduct an evaluation of the target aircraft to identify the probable source of stresses. The vibratory stresses may be due to engine excitations or aerodynamic excitations. The evaluation to show that the operating environments between installations varies considerably in complexity in going from single reciprocating engine installations to multi-engine turbine installations.

(2) Aerodynamic environment. The propeller aerodynamic environment is evaluated using a substantiated analysis to compute the flow into the propeller from the baseline aircraft to the target aircraft. AQ analysis has been shown to be suitable for the evaluation of some installations. The parameter AQ is the product of angle of flow (A) into the propeller multiplied by the aircraft dynamic pressure (Q):

$AQ = y \times 1/2rV^2$

where: y - total inflow angle into the propeller, degrees r - air density, lb-sec$^2$/ft$^4$

V - air speed, ft/sec

The AQ is proportional to the propeller vibratory stresses in flight due to angular inflow, therefore, the name AQ analysis. Aerodynamic excitations are discussed further in Appendix A.

(3) General considerations. The following paragraphs provide some general considerations;

(a) An approved propeller vibration stress survey and evaluation showing compliance with §§23.907 or 25.907 should have been conducted on the baseline aircraft to form the basis for the target aircraft.

(b) The vibratory stresses measured in flight on baseline aircraft associated with aerodynamic excitation should be below the endurance limits of the propeller for normal flight conditions. Similarity is generally not used when the stresses measured in flight on the baseline aircraft are close to the endurance limits of the propeller. The accuracy of analyses and measurement to show similarity are generally insufficient when stress margins are close to the endurance limits of the propeller.

(c) The vibratory stresses measured on the ground and in flight for the baseline aircraft that exceed the endurance limits of the propeller should be shown to be independent of the aircraft installation.

(d) The baseline aircraft and target aircraft should have propellers that are vibrationwise equivalent and the basic engine should be equivalent. Reciprocating engine model differences may cause significant variations in propeller stresses. Therefore, the baseline reciprocating engine model and ratings should be identical unless it can be shown that engine model number variations associated with component differences do not affect the vibration characteristics.

(e) The engine and propeller control systems should be rigged the same or such that the propeller loading on the target aircraft is shown to be less than that of baseline aircraft in reverse thrust, feather, taxi, ground and flight operation.

(f) The power and rpm ratings for the target aircraft should not exceed that of the baseline aircraft. Limitations and placards should be the same or shown to be more restrictive.

(g) Similarity is generally not applicable to acrobatic aircraft due to potentially significant differences in gyroscopic and aerodynamic propeller loading between installations.

(h) Similarity is generally not applicable when there are service life limits associated with the propeller on the baseline aircraft.

(i) The target aircraft should be of the same category (normal, utility, agricultural use) or one that is shown to have a less severe operating environment.

(j) All propeller airworthiness limitations from the baseline aircraft should be applied to target aircraft.

(k) The engine mounts and the flexibility of the support structure should be the equivalent.

d. Stress Peaks and Resonant Conditions. Stress peaks are generally due to resonant conditions. Resonant conditions are discussed in Appendix A. When a stress peak is found within the propeller operating range, further testing may be required to determine if rpm restrictions will be needed to avoid the resonant conditions. The test program should be modified to obtain further detail regarding the extent of the stress peak. When testing indicates that a stress peak is just beyond the propeller operating range, testing should be conducted sufficiently above the operating range to determine the maximum stresses that could occur due to potential overspeed conditions. Overspeed conditions may be due to such items as overspeed governor checks, transients or tachometers that are not properly calibrated.

e. Propeller Flutter. The propeller may be shown to be free from the harmful effects of flutter by evaluating the measured vibratory response and showing that flutter does not exist within the operational envelope of the propeller. The harmful effects are high blade stresses that result in unacceptable fatigue life. If flutter is found within the operational envelope of the propeller, further testing and fatigue evaluation may be required to show that the flutter conditions will not cause harmful effects within the operational life of the propeller. Limitations may be needed to avoid flutter or to limit the exposure to flutter.

**7. PROPELLER FATIGUE EVALUATION.** The propeller fatigue evaluation establishes for the propeller, the fatigue life, mandatory replacement times (life limits), and in some cases mandatory inspections for components due to fatigue. Additionally, aircraft and propeller operating and airworthiness limitations may be required for safe operation of the propeller. Although a uniform approach to fatigue evaluation is desirable, it is recognized that in such a complex problem, new design features, methods of fabrication, new approaches to fatigue evaluation and new configurations may require deviation from the procedures described here. In addition it is recognized that there are many different phenomena influencing the fatigue life of the propeller and that assessing and assuring the fatigue life should begin at the earliest stages of the propeller design and ending with the fatigue evaluation on the airplane.

Since the rate of accumulation of stress cycles for propeller blades, hubs and other propeller components is very high the design goal is typically to show that stresses are below the component or material endurance limit, whenever possible. However, not all materials have a well defined endurance limit and the stresses that are developed during maneuvers, ground operation, ground air ground (GAG) cycles and at other areas of the aircraft operating envelope may cause damage. The accumulation of this damage must be taken into account to determine if propeller components are life limited require mandatory inspections or to determine if the propeller is suitable for use on an aircraft.

a. Common Elements. There are a number of different approaches to fatigue evaluation. The approaches discussed in this advisory circular are safe-life and damage tolerance. The method used for the fatigue evaluation is also affected by the material and failure mode. The approaches presented for evaluation are suitable to both metallic structure and composite structure. Independent of the approach selected the fatigue evaluation should include the following elements:

(1)  Applicable Components.  A fatigue evaluation is performed on the hub, blades, blade retention components and any other propeller component whose failure due to fatigue could be catastrophic to the airplane.  The propeller components identified in §35.15, Safety analysis as causing a hazardous propeller effect should be assessed to determine if their fatigue failure could be catastrophic to the airplane.  Examples of components that may be identified by a safety analysis are the piston cylinder (dome), counterweights and pitch control components.

(2)  Identification of locations to be evaluated.  In this examination, consideration should be given, as necessary to the results of stress analyses, static tests, fatigue tests, strain gage surveys, test of similar structural configuration, and service experience.  Service experience has shown that special attention should be focused on the design details of important discontinuities such as composite blade metallic blade root bond joints, hub mounting faces, bolt holes, dowel pin holes, and blade bearing retention.  Areas prone to probable damage such as corrosion, denting, gouging, wear, erosion, bird impact, and other foreign object damage should also be considered.

(3)  The effects of material variability and environmental conditions on the strength and durability properties of materials.

(4)  The identification of fracture modes for the structural components.  Components should be assessed to establish appropriate damage criteria in relation to the ability to be inspected and damage characteristics from initial detectability to fracture.

(5)  Damage Accumulation.  Appropriate and substantiated damage accumulation algorithms such as Miners rule for safe life calculations or a crack or damage growth algorithm for damage tolerance calculations should be selected.  The damage accumulation algorithm may be verified by previous testing, past experience and acceptable published literature when available.

(6)  Each determined mandatory replacement period and inspection interval must be included in the Airworthiness Limitation Section of the Instruction of Continued Airworthiness.  If, as a result of the vibration survey and the fatigue evaluation it is determined that certain operating conditions, or ranges, need to be limited, installation

and operating limitation shall be included in the Instructions for Propeller Installation and operation and in the appropriate airplane manuals.

b. Aircraft Load Spectrum. The aircraft load spectrum depends on the category and operation of the aircraft. The elements of the spectrum should include normal flight conditions that occur with each flight (take-off, climb, cruise, descent, approach, and landing), as well as transient aircraft flight conditions associated with maneuvers (banked turns, side-slip, pull-ups, push-overs, and etc.), gusts, special flight conditions specific to a mission (fire-fighting, acrobatic, and etc.), emergency conditions, aircraft limit load conditions, and training maneuvers. The load spectrum should also include ground operating conditions such a taxi, operation in cross winds, maintenance checks, and etc. The overall aircraft flight spectrum involves the combination of all ground and flight conditions that will be included in the operation of the aircraft throughout it's life. The flight spectrum loads should be determined from the aircraftground and flight test data performed on the intended aircraft and engine combination with the installed propeller

(1) The aircraft operating spectrum is obtained from the aircraft applicant for the intended application. Additional flight spectrum information may be developed by the propeller manufacturer to supplement the aircraft data. Portions of the flight spectrum may not be directly measurable such as some severe gust conditions, limit load conditions, and some emergency conditions that may threaten the safety of the aircraft. These conditions may be extrapolated or derived based on the available test data. When the aircraft operating spectrum is not available the spectrum information may be based on the design assumptions and design and service experience regarding the intended aircraft and engine application.

(2) The aircraft applicant has the definition of the aircraft operating environment and the flight spectrum. The definition of the flight spectrum includes the number of occurrences of each flight condition along with the duration of the flight condition. Elements of a load spectrum are given in Table 1 for a transport category aircraft. As shown most of the flight conditions occur within a day to day normal flight operation of the aircraft. In the extreme are once in the life of the aircraft load conditions such as an extreme yaw or extreme high "g" maneuver. All of these load conditions are taken into account for the propeller fatigue evaluation.

(3) The flight spectrum loads should include low cycle fatigue ground air ground cycles (GAG) that occur with each flight. Within each flight there is a maximum and minimum load. Each GAG cycle is capable of causing fatigue damage and should be taken into

account with the test planning, data acquisition, and fatigue evaluation. Figure 2 illustrates the load variation and the GAG cycle of a normal flight.

(4) The aircraft flight spectrum should be defined to the extent required to thoroughly evaluate the propeller loading throughout the intended flight envelope and conduct a fatigue evaluation. Some installations may have substantial load margin so that only the maximum and minimum load levels are needed to conduct the fatigue evaluation. Other installations may have operating conditions that produce load amplitudes that are life limiting for the propeller blades or other load bearing propeller components. When life limiting conditions are identified an extensive aircraft flight spectrum may be required as shown in Table 1.

(5) After the load spectrum is identified, the stress or load levels at each of the load conditions are determined using the measured vibratory stress data.

(6) The determination of the propeller stress and load should include the likely service deterioration expected in service. Examples of likely service deterioration are as follows: The frequency of an aluminum blade may change as the blade width and thickness decrease with erosion. The frequency of composite blades may also change due to added material when the blade is repaired or due to the absorption of moisture.

c. Safe-Life Evaluation. The safe-life approach is based on the principle that the repeated loads can be sustained through out the intended life of the propeller during which there is a low probability that the strength will degrade below its design value due to fatigue.

(1) The data used to conduct a safe-life evaluation is generally S-N diagrams and Goodman diagrams developed from an appropriate combination of coupon tests and full scale component tests as required by §35.37 and described in reference 3b(1).

(2) The safe-life is the component fatigue life reduced by an appropriate scatter factor that accounts for the variability of the fatigue evaluation process. The fatigue life is determined by combining the aircraft loading spectrum with the fatigue data using a damage summation algorithm (safe-life evaluation). Unless substantially justified for

metallic structure a scatter factor of three or greater should be used. Mandatory replacement times are established for parts with safe-lives. Mandatory replacement times are included in the propeller Airworthiness Limitations Section of the propeller Instructions for Continued Airworthiness.

(3) When the propeller loads are below the endurance limits as defined in the Goodman diagram, no fatigue damage is accumulated and damage summation is not needed. This generally does not occur. The loads generated during extreme and emergency maneuvers, and GAG may result in stresses that are above the fatigue limit and fatigue damage is accumulated. In these cases, summation procedures such as Miner's rule may be employed, if properly substantiated. Small deviations in the flight loads spectrum may have appreciable influence on the calculated fatigue life. Therefore, care should be taken with the establishment of the safe-life, and a life sensitivity to the loads spectrum should be performed. The scatter factor applied to the fatigue life to determine the safe-life should account for sensitivity to the load.

(a) JAA reference 3.(c.)(2), ACJ P-550, provides a method to evaluate aluminum propeller blades and hubs using Goodman diagrams. This approach assumes that no damage will be accumulated over the life of the propeller.

(4) Unlimited Life. When it is shown that all stressed are be below the endurance limits established for the component the component is said to have unlimited life. These components will be removed from service for reasons other than fatigue. In addition, when the safe-life of a component is shown to be greater then 70,000 hours and it is shown that the component will be retired from service for reasons other than fatigue prior to 70,000 hours the component may be said to have unlimited life.

(5) Composite materials. Miner's rule may be applied to composite materials when sufficiently substantiated. Since the application of Miner's rule to composites may be highly unconservative, the safe-life should be established using a substantiated scatter factor. Unless substantially justified for composite structure a scatter factor of ten or greater should be used. The applicability of Miner’s linear damage summation rule for composites should be verified by spectrum loading for the full scale structure using loads established from the flight test. Spectrum load testing is discussed in reference 3b(1). Reference 3d(1) contains a method of assuring proper confidence levels are attained when running the test by consideration of material statistical scatter.

d. Damage Tolerant Evaluation. Damage tolerance is the attribute of the structure that permits it to retain its required residual strength for a period of use after the structure has sustained a given level of fatigue, corrosion, accidental or discrete source damage. Fail safe is the attribute of the structure that permits it to retain its required residual strength for a period of unrepaired use after the failure or partial failure of a principal structural element. This AC assumes that when damage tolerance methods are applied the component has been designed using these principles. The damage tolerant approach is based on the principle that damage is inherent in the structure or inflicted in service and may grow with the repeated application of loads, and that the propeller or propeller components will be inspected at intervals to assess the extent of damage. When damage reaches the maximum permissible flaw size the propeller or propeller component is retired.

(1) Inspection Interval. For damage tolerance methods the inspection interval is related to the time the damage reaches maximum permissible flaw size as defined during certification (detectable damage) to the end of life condition (the extent of damage for residual strength evaluation). The maximum permissible flaw size is established during certification by considering the inspection method, the inspection interval and the end of life condition. The inspection interval is established to permit multiple opportunities, typically three opportunities, to find the damage prior to reaching the end of life condition. The inspection method should also be evaluated to determine the probability of detection (POD). Inspection methods are typically shown to have a POD of 90% probability with 90% confidence. When the POD is less than 90% probability with 90% confidence the inspection frequency may be increased. The component is removed from service when damage is detected at the maximum permissible flaw size. These inspections when mandatory are defined in the Airworthiness Limitations section of the Instructions for Continued Airworthiness, §35.4.

(2) Damage Growth Data. Damage tolerant evaluation can be applied to both metallic and composite materials. With metallic materials the damage is generally a crack and the damage growth is characterized by da/dN curves where the crack growth rate is plotted against a stress intensity factor. The da/dN curves have been characterized for a wide variety of metallic materials used for propeller structure. With composite the damage growth is characterized by delamination growth rate curves that are developed for each unique full scale composite structure as shown in Figure (3). An approach to the development of delamination growth rate curves is found in reference 3b(1). The damage tolerant data and evaluation should include:

- Structural details, elements, and sub-components of critical structural areas tested in accordance with §35.37 to define the sensitivity of the structure to damage growth.

· Effects of the environment on the flaw growth characteristics should be assessed. The environment assumed should be appropriate to the expected service usage.

· Repeated loading representative of anticipated service usage.

· Repeated load testing including damage levels (including impact damage) typical of those that may occur during fabrication, assembly, and in-service, consistent with the inspection techniques employed.

· Test articles fabricated and assembled in accordance with production specifications and processes so that the test articles are representative of production structure.

(3) Verification. The applicability of the damage tolerant assessment should be verified by spectrum loading for the full scale structure using loads established from the flight test. Spectrum load testing is discussed in reference 3b(1). The detectable damage size and location should be established and be consistent with the inspection techniques employed during manufacture and in service. Flaw/damage growth data should be obtained by repeated load cycling of intrinsic flaws or mechanically introduced damage. The damage growth model should be validated by tests of full scale components.

(4) Residual Strength. The residual strength of the component should be demonstrated on full scale damaged components at the end of life condition. The end of life condition is the physical condition of the component defined during propeller certification when it will be considered to have the maximum extent of damage while still while still maintaining sufficient residual strength to meet all airworthiness loading requirements. The end of life condition is established in conjunction with the service life. Therefore, the component in its end of life condition is still safe. The end of life condition should be well before structural failure.

**8. AIRCRAFT AND PROPELLER operating and airworthiness limitations.** Each propeller or airplane operating and airworthiness limitation necessary for safe operation of the airplane and propeller must be appropriately documented. Documentation includes but are not limited to;

a. The Airworthiness Limitations Section, Airplane Instructions for Continued Airworthiness,, for life limits and mandatory inspections,

b. The Airplane Instructions for Continued Airworthiness.

c. The Airplane Flight Manual

d. Placards.

e. The Propeller Instructions for Continued Airworthiness, Airworthiness Limitations Section, for life limits and mandatory inspections,

f. The Propeller Instructions for Continued Airworthiness.

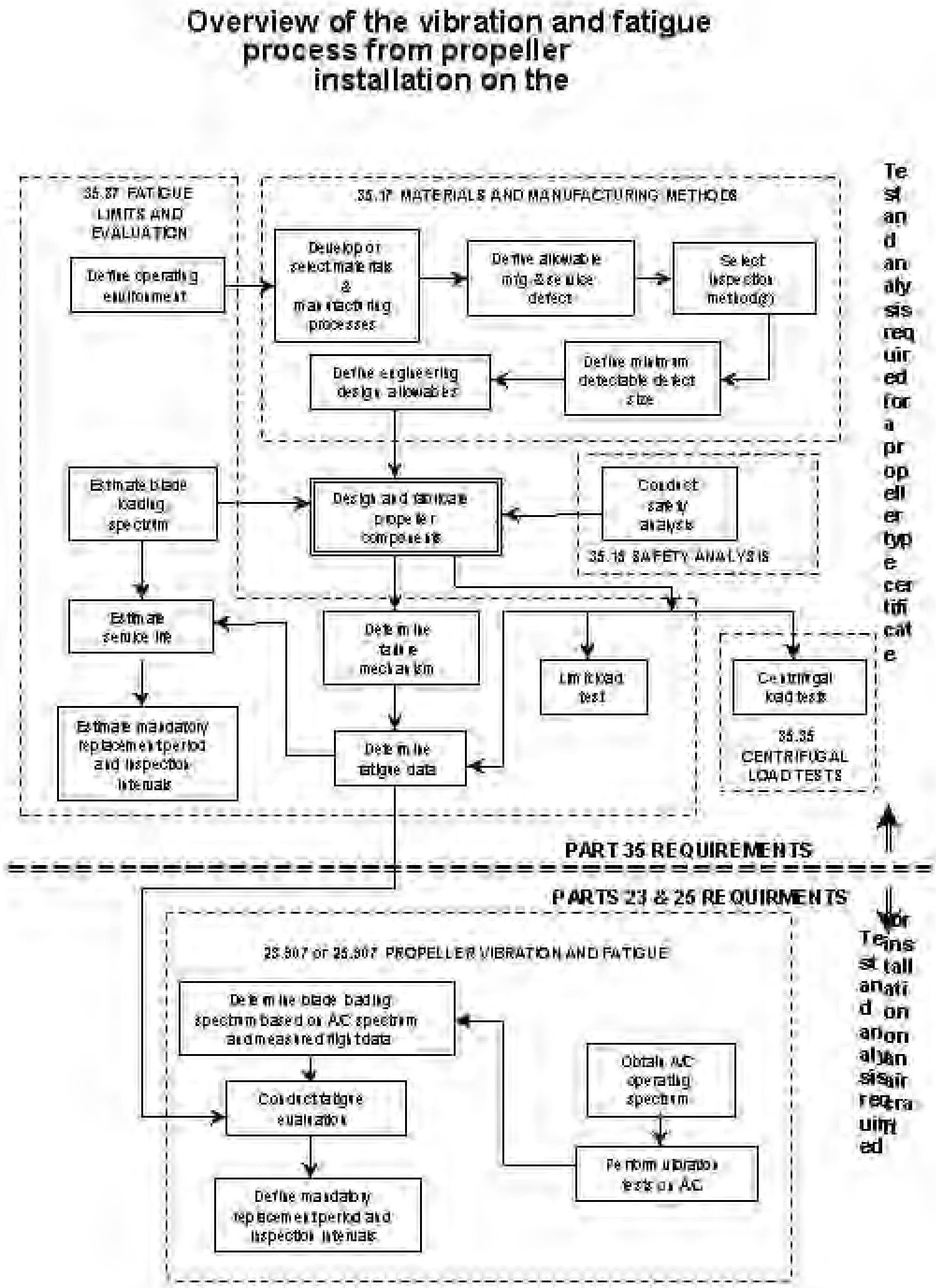
g. The Instructions for Propeller Installation and Operation.

**TABLE 1**

# EXAMPLE AIRCRAFT LOAD SPECTRUM

| No. | Condition | GW | Yaw deg. | Bank deg. | Flaps deg. | Load g's | RPM % | Torque % | V KCAS | Time Event sec. | Events per 70k hrs | Cycles per 70k hrs | Cycles per Flight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Typical Flight | | | | | | | | | | | | | |
| 1 | Taxi no crosswind | 1 | 0 | 0 | 0 | 1 | 70 | GI | 0 | 100 | 35000 | 4.90E+07 | 466.66667 |
| 2 | Taxi 15kt crwind | 1 | 0 | 0 | 0 | 1 | 70 | GI | 0 | 100 | 35000 | 4.90E+07 | 466.66667 |
| 3 | Taxi 25kt crwind | 1 | 0 | 0 | 0 | 1 | 70 | GI | 0 | 100 | 35000 | 4.90E+07 | 466.66667 |
| 4 | TO roll | 1 | 0 | 0 | 0 | 1 | 100 | 100 | 0-100 | 40 | 105000 | 8.40E+07 | 800 |
| 5 | TO rotation | 1 | 0 | 0 | 15 | 1 | 100 | 100 | 110 | 2 | 105000 | 4.20E+06 | 40 |
| 6 | Climb A | 1 | 0 | 0 | 15 | 1 | 100 | 100 | 110 | 30 | 105000 | 6.30E+07 | 600 |
| 7 | Climb B | 1 | 0 | 0 | 15 | 1 | 100 | 100 | 130 | 40 | 105000 | 8.40E+07 | 800 |
| 8 | Climb Spectrum | Contained in spectrum data below | | | | | | | | | | | |
| 10 | Cruise Spectrum | Contained in spectrum data below | | | | | | | | | | | |
| 13 | Descent Spec. | Contained in spectrum data below | | | | | | | | | | | |
| 15 | Approach Spec. | Contained in spectrum data below | | | | | | | | | | | |
| 17 | Reverse max | 1 | 0 | 0 | 20 | 1 | 100 | 70 | 120 | 10 | 35000 | 7.00E+06 | 66.666667 |
| 18 | Reverse 1/2 | 1 | 0 | 0 | 20 | 1 | 100 | 35 | 120 | 10 | 35000 | 7.00E+06 | 66.666667 |
| Vertical Maneuver Spectrum | | | | | | | | | | | | | |
| 19 | Vertical Maneuver | 2 | 0 | 0 | 0 | 2.6 | 100 | 70 | 180 | 15 | 5.6 | 1.68E+03 | 0.016 |
| 20 | Vertical Maneuver | 2 | 0 | 0 | 0 | 2.2 | 100 | 70 | 180 | 18 | 47 | 1.69E+04 | 0.1611429 |
| 21 | Vertical Maneuver | 2 | 0 | 0 | 0 | 1.8 | 100 | 70 | 180 | 22 | 576 | 2.53E+05 | 2.4137143 |
| 22 | Vertical Maneuver | 2 | 0 | 0 | 0 | 1.4 | 100 | 70 | 180 | 25 | 23838 | 1.19E+07 | 113.51429 |
| 23 | Vertical Maneuver | 2 | 0 | 0 | 0 | 1 | 100 | 70 | 180 | 30 | 122354 | 7.34E+07 | 699.16571 |
| 24 | Vertical Maneuver | 2 | 0 | 0 | 0 | -1.4 | 100 | 70 | 180 | 25 | 23838 | 1.19E+07 | 113.51429 |
| 25 | Vertical Maneuver | 2 | 0 | 0 | 0 | -1.8 | 100 | 70 | 180 | 22 | 576 | 2.53E+05 | 2.4137143 |
| 26 | Vertical Maneuver | 2 | 0 | 0 | 0 | -2.2 | 100 | 70 | 180 | 18 | 47 | 1.69E+04 | 0.1611429 |
| 27 | Vertical Maneuver | 2 | 0 | 0 | 0 | -2.8 | 100 | 70 | 180 | 15 | 5.6 | 1.68E+03 | 0.016 |
| 28 | Vertical Maneuver | 2 | 0 | 0 | 0 | 2.6 | 80 | 70 | 200 | 15 | 5.6 | 1.34E+03 | 0.0128 |
| 29 | Vertical Maneuver | 2 | 0 | 0 | 0 | 2.2 | 80 | 70 | 200 | 18 | 47 | 1.35E+04 | 0.1289143 |
| 30 | Vertical Maneuver | 2 | 0 | 0 | 0 | 1.8 | 80 | 70 | 200 | 22 | 576 | 2.03E+05 | 1.9309714 |
| 31 | Vertical Maneuver | 2 | 0 | 0 | 0 | 1.4 | 80 | 70 | 200 | 25 | 23838 | 9.54E+06 | 90.811429 |
| | etc. | | | | | | | | | | | | |
| Lateral Gust - Yaw Spectrum | | | | | | | | | | | | | |
| 72 | Lateral Gust - Yaw | 2 | 9.12 | 0 | 0 | 1 | 100 | 70 | 180 | 0.5 | 34 | 3.40E+02 | 0.0032381 |
| 73 | Lateral Gust - Yaw | 2 | 7.46 | 0 | 0 | 1 | 100 | 70 | 180 | 0.5 | 364 | 3.64E+03 | 0.0346667 |
| 74 | Lateral Gust - Yaw | 2 | 5.23 | 0 | 0 | 1 | 100 | 70 | 180 | 0.5 | 7324 | 7.32E+04 | 0.6975238 |
| 75 | Lateral Gust - Yaw | 2 | 3.12 | 0 | 0 | 1 | 100 | 70 | 180 | 0.5 | 56398 | 5.64E+05 | 5.3712381 |
| 76 | Lateral Gust - Yaw | 2 | 0 | 0 | 0 | 1 | 100 | 70 | 180 | 0.5 | 345626 | 3.46E+06 | 32.916762 |
| 77 | Lateral Gust - Yaw | 2 | -3.12 | 0 | 0 | 1 | 100 | 70 | 180 | 0.5 | 56398 | 5.64E+05 | 5.3712381 |
| 78 | Lateral Gust - Yaw | 2 | -5.23 | 0 | 0 | 1 | 100 | 70 | 180 | 0.5 | 7324 | 7.32E+04 | 0.6975238 |
| 79 | Lateral Gust - Yaw | 2 | -7.46 | 0 | 0 | 1 | 100 | 70 | 180 | 0.5 | 364 | 3.64E+03 | 0.0346667 |
| 80 | Lateral Gust - Yaw | 2 | -9.12 | 0 | 0 | 1 | 100 | 70 | 180 | 0.5 | 34 | 3.40E+02 | 0.0032381 |
| | etc. | | | | | | | | | | | | |
| Vertical Gusts | | | | | | | | | | | | | |
| | etc. | | | | | | | | | | | | |
| Extreme Maneuvers | | | | | | | | | | | | | |
| 213 | Limit Yaw | 1 | 32 | 0 | 0 | 1 | 100 | 100 | 170 | 3.3 | 1 | 6.60E+01 | 0.0006286 |
| 214 | Limit Pull out | 1 | 0 | 0 | 0 | 3 | 100 | 100 | 150 | 3.2 | 1 | 6.40E+01 | 0.0006095 |
| 215 | Rudder kick | 1 | 21 | 0 | 0 | 1 | 100 | 100 | 150 | 2.3 | 4 | 1.84E+02 | 0.0017524 |
| | etc. | | | | | | | | | | | | |

**FIGURE 1**



Overview of the vibration and fatigue process from propeller installation on the
35.37 FATIGUE LIMITS AND EVALUATION
Define operating environment
35.17 MATERIALS AND MANUFACTURING METHODS
Develop or select materials & manufacturing processes
Define allowable mfg & service defect
Select inspection method(s)
Define minimum detectable defect size
Define engineering design allowables
Estimate blade loading spectrum
Design and fabricate propeller components
Conduct safety analysis
35.15 SAFETY ANALYSIS
Estimate service life
Determine failure mechanism
Limit load test
Centrifugal load tests
35.35 CENTRIFUGAL LOAD TESTS
Estimate mandatory replacement period and inspection intervals
Determine fatigue data
Test and analysis required for a propeller type certificate
PART 35 REQUIREMENTS
PARTS 23 & 25 REQUIRMENTS
Test and analysis required for installation on an aircraft
23.907 or 25.907 PROPELLER VIBRATION AND FATIGUE
Determine blade loading spectrum based on A/C spectrum and measured flight data
Obtain A/C operating spectrum
Conduct fatigue evaluation
Perform vibration tests on A/C
Define mandatory replacement period and inspection intervals

FIGURE 2

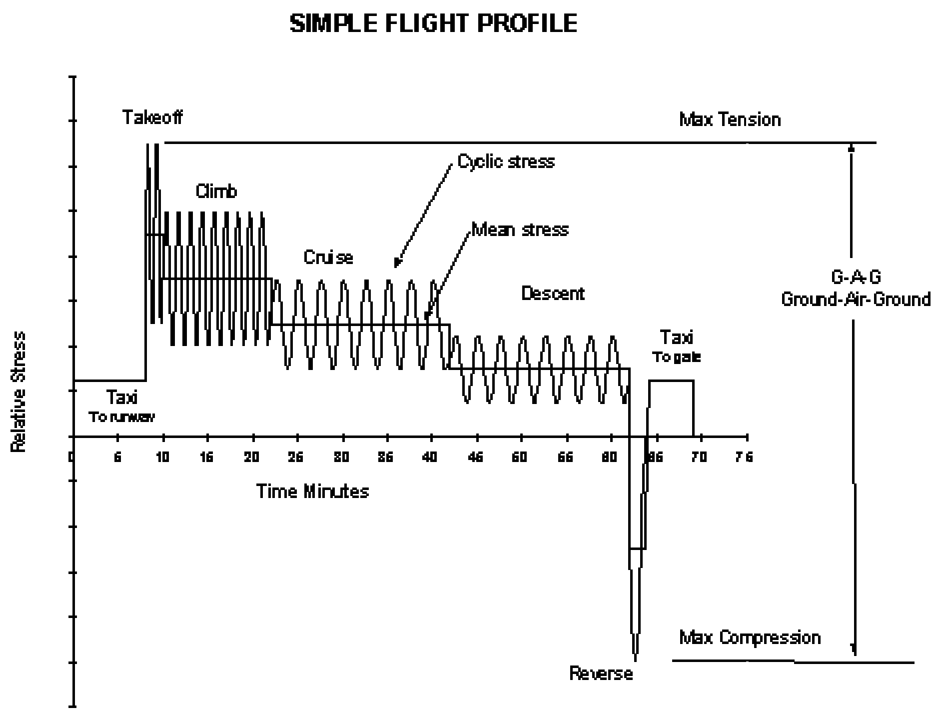
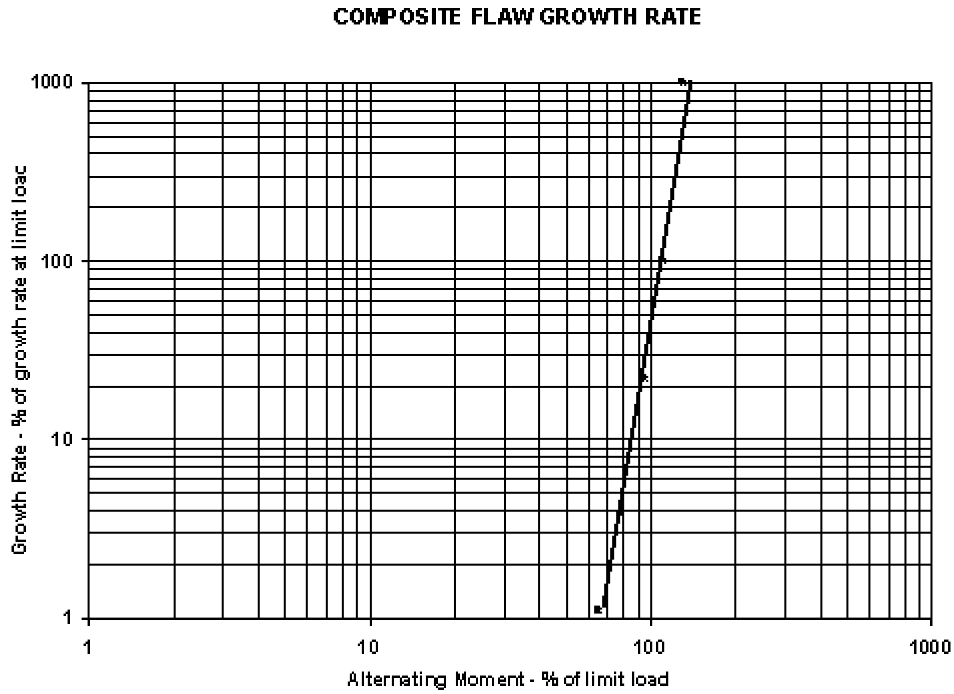



FIGURE 3




# APPENDIX A

## PROPELLER VIBRATION

## BACKGROUND INFORMATION

**A1. <u>INTRODUCTION</u>.** Propeller vibration as it applies to propeller certification refers to the dynamic loading that a propeller is subjected to during operation on an aircraft. The loads include a combination of cyclic or vibratory loads and steady or zero frequency loads and can be defined in terms of stress in pounds per square inch (psi), moment in inch-pounds (in-lbs), microstrain in µin/in, or any other appropriate engineering unit. The loads are either mechanically or aerodynamically induced or a combination thereof and can vary greatly in both amplitude and frequency throughout the intended operating envelope of the aircraft. The purpose of propeller vibration evaluation is to quantify the dynamic loads to which the propeller is subjected throughout the intended operating envelope of the aircraft to insure the loads will remain within predetermined limits and to establish appropriate operating limitations and restrictions when needed to insure continued safe operation of the propeller.

**A2. <u>PROPELLER EXCITATION SOURCES</u>.** Propellers operate in an environment where the loads are composed of a complex combination of vibratory and steady loads. The loads arise from many sources and are dependent on both the aircraft installation and the type of engine. Each propeller is evaluated to determine if it has acceptable strength and dynamic characteristics to operate in the complex load environment on the aircraft. Since there are many sources of excitation it is best not to over generalize or over simplify the testing that will be required. Each installation should be evaluated to determine the extent of testing and evaluation required.

a. <u>Mechanical Excitation</u>. The mechanical excitation of propellers is primarily associated with reciprocating engine installations. The reciprocating engine introduces a whole series of vibrational impulses to the propeller that are generated by the engine rotating system. The frequencies of these impulses are generally in multiples of the engine RPM and produce a combination of both forced and resonant frequency propeller loading. The piston impulses from normal four cycle reciprocating engines will excite the propeller at two impulses per revolution for a four cylinder engine, three per revolution for a six cylinder engine, four per revolution for an eight cylinder engine, etc. These piston impulses comprise only one component of the exciting frequencies generated by the engine rotating system.

(1) The crankshaft in a reciprocating engine, like any flexible body, has a series of natural frequencies in both torsion and bending. These natural frequencies are excited by engine power impulses and inertia forces from the engine rotating system. The free end of the crankshaft, to which the propeller is attached on direct drive engines or indirectly through a gearbox on geared engines, is forced to vibrate due to the various mechanical inputs. The propeller, which is attached to the free end of the crankshaft or gearbox output shaft, has a high level of inertia and acts as a flywheel which rotates with a minimum of angular acceleration and responds to the various mechanical inputs from the engine with varying frequencies and amplitudes of vibratory loads.

(2) Each propeller model has unique natural frequencies for each of the modes of vibration. When a natural frequency of the propeller in any one mode coincides with a frequency of the engine rotating system, resonance occurs and the propeller load amplitudes increase to a peak value. Most modern reciprocating aircraft engines are equipped with some form of mechanical damping to reduce the amplitude of specific frequencies. Most commonly used are pendulum type dampers installed on the crankshaft and tuned to specific frequencies, with some engines using other methods such as flexible couplings to reduce reciprocating engine frequency output amplitudes.

Further information on engine vibration can be found in reference 3d(2) (Den Hartog, J. P., Mechanical Vibrations, McGraw-Hill Book Company, 1956).

(3) Reciprocating engines generally have a few dominant excitations with multiples of those excitations that become less severe with increasing harmonics. The excitation frequencies can be plotted on a critical speed diagram with the blade natural frequencies to identify rotational speeds of potential high response and the cause of the high response as shown in Figure (A1). When critical speeds exist, placards or other operating restrictions may be required.

(4) Other factors should be taken into account when assessing continued airworthiness of reciprocating engine installations.

(a) Many engines use dampers to reduce the transmitted excitation forces. Over time dampers if not properly maintained will wear and lose their ability to reduce the transmitted excitations. When this occurs the propeller stresses may increase to a level that is unacceptable. Engine dampers should be maintained through an engine and/or aircraft continued airworthiness program to maintain acceptable propeller stress levels.

(b) One cylinder not firing can have a major effect on propeller vibration stresses. Therefore, when the operator should seek corrective action prior to the next flight upon detection of a cylinder not firing. A cylinder not firing is typically detected as a loss of power, RPM or both and in larger engines equipped with a CHT probe by an abnormal temperature reading for the cylinder not firing.

(5) The frequency of turbine engine mechanical excitations is in general too high to contribute to the excitation of the propeller.

b. Aerodynamic Excitation. The aerodynamic excitation of propellers is typically associated with turbine engine installations because the mechanical vibrations are lower in amplitude. Aerodynamic excitation is the primary exciting force on turbine engine installations, but in some cases can be a major contributing factor to the propeller loads on reciprocating engine installations.

(1)  A propeller is an open rotor and is subjected to a non-uniform inflow that results in aerodynamic excitation.  The major contributor in flight is due to angular inflow into the propeller.  The propeller thrust axis is generally not aligned with the direction of flight of the aircraft and is usually pointed some combination of up, down, left, or right a few degrees.  When the flow into the propeller is at an angle relative to the thrust axis, the local blade angle of attack changes as a sinusoid with each revolution of the propeller.  This causes a once-per-revolution (1P) sinusoidal loading of the propeller.  The magnitude of the 1P loads is directly related to the inflow angle and the dynamic pressure which changes with airspeed, flap setting, gross weight, maneuvers, etc.  The 1P aerodynamic excitation of the propeller is a forced loading and is not associated with any of the propeller natural frequencies.

(2)  The aerodynamic effects are generally greater on wing mounted multi-engine aircraft because the wing upwash magnifies the flow angularity and more opportunity exists to angle the propeller installation up and down (tilt) and left and right (toe in or toe out).  Other factors such as the proximity of the propeller to the fuselage may contribute to the flight 1P loads.

(3)  Experience has shown that propeller resonant frequencies are not excited by 1P loading although the 1P loading may be magnified by the proximity of the first mode natural frequency to the 1P frequency.  In flight excitations at orders greater than 1P are caused by disturbances to the airflow into the propeller disc such as from the flow around the aircraft.  Pusher installations and swept wing installations may cause 2P, 3P, 4P, etc. excitation of both major and minor axis modes due to the disturbances to the airflow into the propeller disc.  These higher order excitations may become dominant if a propeller critical speed exists in the operating range.

(4)  One of the worst operating environments for a propeller exists on the ground when the aircraft is not moving and the wind is blowing from behind the propeller disc.  Under this type of condition the flow into the propeller is constantly changing and many excitation orders exist; 1P, 2P, 3P, 4P, etc.  The amplitude of the excitations tends to decrease with increasing order, but the high number of excitation frequencies increase the likelihood of a critical speed in the propeller operating range.  When a critical speed exists a placard or other operating restriction may be required to prevent high propeller loads.

(5) In addition to aerodynamic 1P loads a propeller may be subjected to gyroscopic 1P loads due to maneuvers which force the propeller out of its normal plane of rotation and can significantly increase the propeller vibratory loads. This is of particular significance on acrobatic aircraft equipped with either turbine or reciprocating engines. The rapid pitch and yaw changes of the rotating propeller during aerobatic maneuvers result in 1P aerodynamic loads being further amplified by the out of plane gyroscopic 1P loads. This type of 1P loading can be significantly greater than any of the mechanically induced loads when these maneuvers are performed by aircraft with reciprocating engines.

c. Propeller Flutter. Propeller blade flutter is indicated by a self excited vibration and can generate extremely high propeller load amplitudes in the blade tip area and in the pitch change mechanism. Blade flutter is most likely to occur during high power static operation or during landing when flat or reverse pitch blade angles are selected at high forward speeds. All other propeller vibratory response is cause by an external force and is related to the rotational speed of the propeller, engine, or gearbox. By contrast, the susceptibility of a propeller blade to flutter can be influenced by surface wind speed and relative direction to the propeller, atmospheric conditions such as temperature and relative humidity and airspeed when flat or reverse pitch blade angles are selected. The load amplitudes may change dramatically with minor changes in operating conditions. In addition to generating potentially fatigue damaging loads in the propeller blades and pitch change components, flutter can usually be identified by a high frequency airframe vibration and significant change in propeller noise levels. Although some installations have been approved with operating restrictions to prevent the occurrence of blade flutter, it is usually simpler to redesign the propeller blade when a susceptibility to flutter has been demonstrated.

**A3. PROPELLER RESPONSE.** Propeller response to the various exciting forces is related to the propeller natural resonant frequencies, blade strength, and damping. The propeller response is magnified when the excitation frequency is at or near a natural resonant frequency of the propeller blades. These resonant frequencies are generally classified as flatwise (minor axis), edgewise (major axis), and torsional frequencies and can be excited as either symmetrical or unsymmetrical (whirl) modes and reactionless modes of vibration. Figure (A2) and Table (A1) illustrate these modes of vibration.

a. General. Due to the complex loading and geometry of propellers, there are multiple areas of the propeller that are subjected to varying amplitudes and frequencies of loads. The propeller blade loads are typically identified as tip area, mid-blade area, and blade shank/retention area loads that are usually evaluated against allowable fatigue limits that are unique for those specific areas of the propeller blades. In addition the propeller hub and other load bearing components in the propeller pitch change system may require evaluation against specific fatigue allowables for those components. The type of response the propeller exhibits in these various load bearing areas is greatly influenced by the type of excitation. Propeller response to mechanical excitation from reciprocating engines is typically characterized by maximum minor axis vibratory loads occurring in the blade tip and major axis loads in the blade shank area. Propeller response to aerodynamic excitation is typically characterized by minor axis vibratory loads occurring on the mid-blade and blade shank areas. More complex combinations of response will occur when resonant frequencies are excited or combinations of mechanical and aerodynamic loads are being reacted.

b. Reactionless Mode. Propellers with four or more blades will also have a minor axis resonant frequency known as the reactionless mode of vibration. The primary characteristic of this mode is a 2P or 3P frequency with all loads canceled in the hub. This mode of vibration is excited primarily on the ground when surface winds are from behind the propeller disc and can generate high loads in the mid-blade and blade shank/retention area. Surface winds from behind the propeller disc can also excite the major axis edgewise mode at frequencies of 2P, 3P, or 4P which can generate high loads in the blade shank/retention area. Most installations exhibiting these characteristics are subject to operating restrictions to prevent continuous operation within the RPM range where these modes can be excited.

c. Centrifugal Stiffening. The propeller blade minor axis natural frequencies change with the effects of rotational speed and blade angle due to changes in centrifugal stiffening. Major axis and torsional frequencies are not effected as much by changes in blade angle and centrifugal stiffening. The blade frequencies and excitation frequencies can be shown graphically on a critical speed diagram which provides a method to assess rotational speeds where the vibratory loads may be magnified. Critical speeds should be calculated prior to vibration testing and verified during the test. Reference 3d(2) (Den Hartog, J. P., Mechanical Vibrations, McGraw-Hill Book Company, 1956) provides a general discussion of response magnification at and near natural frequencies.

d. Flight response. In flight the propeller response is dominated by engine mechanical excitation on reciprocating engine installations and 1P aerodynamic excitation on turbine engine installations. The 1P aerodynamic excitation is always present, but the propeller response to the 1P aerodynamic excitation may be masked by a higher dominant reciprocating engine excitation.

e. GAG Cycle. Propellers also experience a maximum and minimum load cycle during each flight, commonly called the ground air ground (GAG) cycle. This maximum and minimum load is due to centrifugal loads varying from zero to maximum with each flight and maximum and minimum vibratory bending loads. These peak vibratory bending loads may occur at maximum thrust at take-off and at maximum reverse during landing for reversible propellers.

**A4. CATEGORY OF AIRCRAFT.** The type of vibration loading the propeller receives is dependent on the type of engine and the aircraft configuration. There are two major categories of engine; reciprocating and turbine while there are three major aircraft configurations; single engine tractor, wing mounted multiengine tractor, and pusher aircraft. The various combinations of engine category and aircraft configuration result in unique sources of propeller excitation. Reciprocating engines generate mechanical excitation whereas wing mounted multiengine tractor configurations and pusher configurations can contribute additional aerodynamic excitation to the propeller. The propeller vibratory load evaluation should be tailored to the type of engine and category of aircraft.

**A5. AIRCRAFT OPERATION.** The type of operation for which the aircraft is intended will also influence the propeller vibratory load evaluation. These may include; commuter, transport, utility, acrobatic, amphibious, fire fighting, agricultural, etc. The type of operation has a major influence on the loading environment. Propeller test data acquired on one type of aircraft may not provide adequate substantiation to allow use of the same propeller on an aircraft with a different operating envelope.

**TABLE A1**

**TYPES OF PROPELLER MODES**

Types of propeller modes

**Number of Blades**

**P order**

| **3** | **4** | **5** | **6** | **8** | **10** | |
|---|---|---|---|---|---|---|
| 1 | W | W | W | W | W | W |
| 2 | W | R | R | R | R | R |
| 3 | S | W | R | R | R | R |
| 4 | W | S | W | R | R | R |
| 5 | W | W | S | W | R | R |
| 6 | S | R | W | S | R | R |
| 7 | W | W | R | W | W | R |
| 8 | W | S | R | R | S | R |

W - Whirl or unsymmetrical

S - Symmetrical (all blades in phase)

R - Reactionless (blade reactions cancel at hub)

**Figure A1**

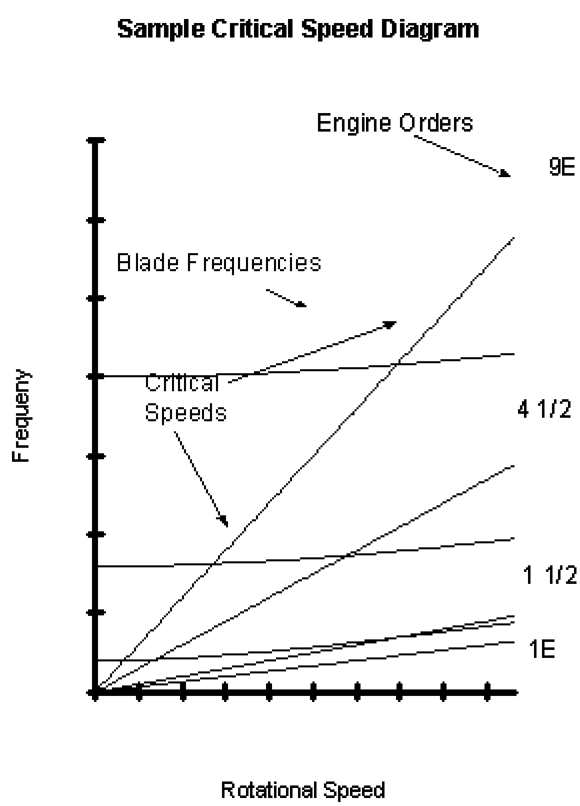
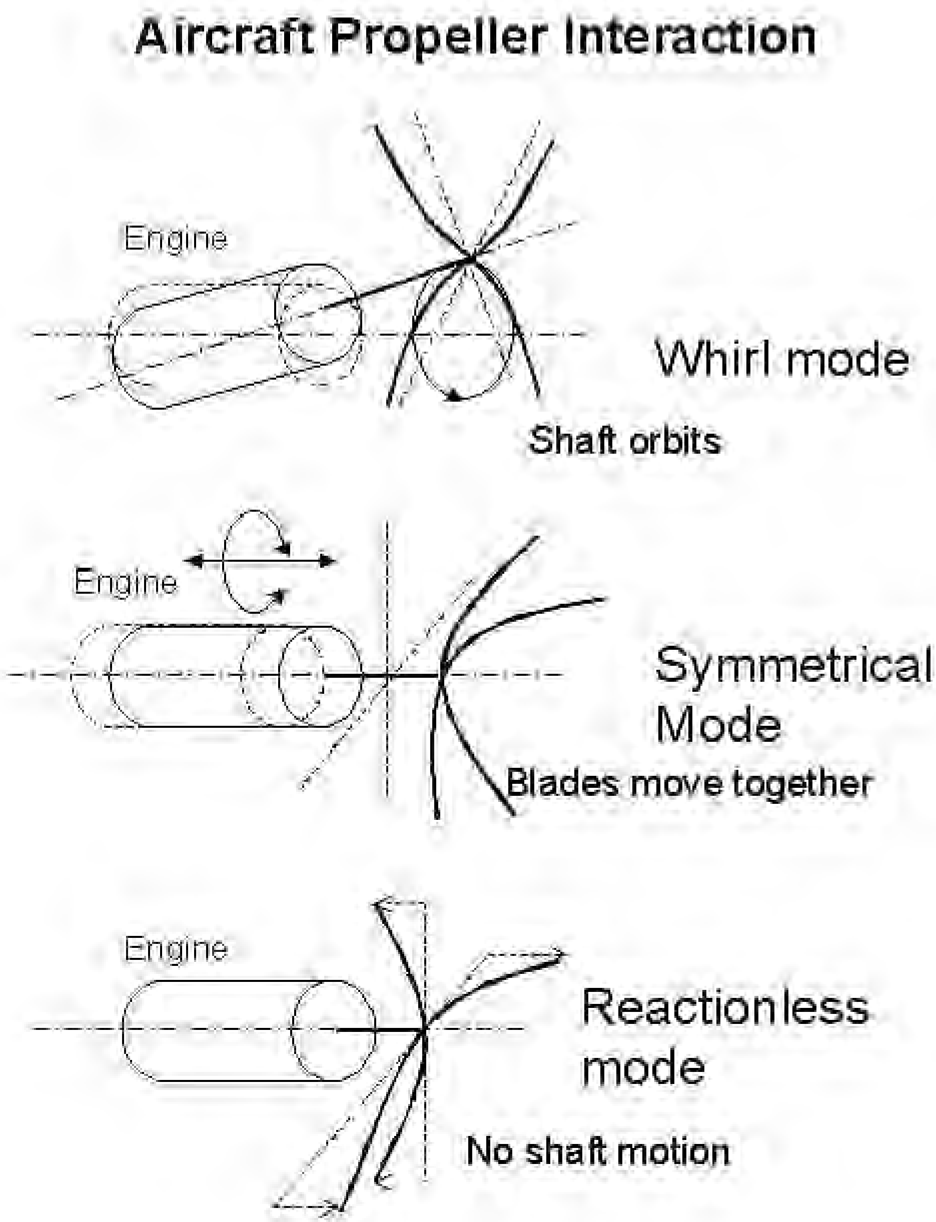


**Figure A2**


Aircraft Propeller Interaction
Engine
Whirl mode
Shaft orbits
Engine
Symmetrical
Mode
Blades move together
Engine
Reactionless
mode
No shaft motion

# APPENDIX B

## PROPELLER VIBRATION EVALUATION

## TEST CONDITIONS

**B1 INTRODUCTION.** This appendix contains a listing of the typical propeller vibration test conditions for installations with reciprocating and turbine engines. These lists are provided as guidance for developing the specific test points to be considered when preparing a test plan. When testing propellers on aircraft that are designed for operation outside of the standard normal and utility category type of operations the testing will need to evaluate the specific maneuver envelope associated with the installation. This would apply to agricultural aircraft, aerobatic aircraft, STOL aircraft, or any other special mission type of installation.

**B2 TEST CONDITIONS FOR PROPELLER VIBRATION TESTING ON RECIPROCATING ENGINE INSTALLATIONS.**

a. General Comments.

(1) The intended operating envelope and maneuver spectrum will need to be evaluated for each installation and test conditions added, deleted, or changed as necessary to fully evaluate propeller loads.

(2) It may be necessary to revise test conditions as data is reviewed during the test.

(3) Multiengine installations may require testing on more than one engine depending on aircraft configuration and previous test experience.

(4)  Testing may be required at reduced diameters to verify repair allowances.

(5)  The maximum governing RPM should be set to a minimum of 103% of maximum rated RPM.

(6)  Maximum power will be the maximum manifold pressure permitted at the RPM and altitude of the test point.

(7)  These test conditions are based on conventional reciprocating aircraft engines with separate throttle and propeller controls and the use of a conventional constant speed propeller.  Installations which deviate from this standard will require modifications to the test conditions as appropriate to fully evaluate propeller vibration characteristics.

-

b.  Test Conditions.

-

(1)  Ground testing with the aircraft static into the wind.

(a)  Increase the RPM from idle to maximum in 50 increments.

(b)  Accelerate and decelerate between idle and maximum RPM.

(c)  Conduct normal engine and propeller preflight functional checks.

(d)  Maintain maximum power and reduce RPM from maximum to minimum governing RPM.

(2) Ground testing with the aircraft static in a 45° cross-tail wind of not less than 15 knots. Required for propellers with four or more blades.

(a) Increase the RPM from idle to maximum in increments.

(b) Accelerate and decelerate between idle and maximum RPM.

(c) Record wind velocity at beginning and end of test.

(3) Flight Testing.

(a) Takeoff rotation and initial climb with maximum power. All possible flap positions should be considered.

(b) Maintain climb airspeed and maximum power and reduce RPM from maximum to minimum climb RPM in increments.

(c) Maintain level flight and maximum power and reduce RPM from maximum to minimum governing RPM in increments. This test should be conducted at low altitude (at or below approximately 5000 ft. MSL), and at approximately 10,000 ft. MSL. Higher altitudes should be considered for turbocharged installations.

(d) Repeat B2b(3)(c) as necessary at reduced manifold pressure settings.

(e) With the throttle closed increase the airspeed to achieve maximum RPM, then begin a continuous reduction in airspeed to the minimum airspeed prior to stall. The resulting RPM reduction will be recorded.

(f) For multiengine installations reduce power to idle on engine without instrumented propeller and record data with maximum power and RPM during single engine climb and level flight.

(g) For multiengine installations record feathering and unfeathering of the instrumented propeller during engine shutdown and restart in flight.

(h) Any unusual engine operating conditions or maneuvers associated with the intended aircraft mission profile.

(i) For aerobatic installations all maneuvers that will be approved for the aircraft need to be tested. All maneuvers should be tested to the left and right and at varying entry speeds where applicable. The testing may include but is not limited to the following maneuvers.

| | |
|---|---|
| Chandelle | Rolling 360° Turn |
| Immelmann | Cuban 8 - Inside and outside. |
| Loop | Knife Edge |
| Slow Roll | Hammerhead |
| Barrel Roll | Tail Slide - Forward and aft pitch. |
| Hesitation Roll | Upright Spin - Six turns with power off. |
| Vertical Roll | Upright Spin - Six turns with maximum power for first turn then reduced to idle. |
| Torque Roll | Inverted Spin - Six turns with power off |
| Snap Roll | Inverted Spin - Six turns with maximum power for first turn then reduced to idle. |
| Shoulder Roll | Lomcevak |

**B3 <u>TEST CONDITIONS FOR PROPELLER VIBRATION TESTING ON TURBINE ENGINE INSTALLATIONS</u>.**

a. General Comments.

(1) The intended operating envelope and maneuver spectrum will need to be evaluated for each installation and test conditions added, deleted, or changed as necessary to fully evaluate propeller loads.

(2) It may be necessary to revise test conditions as data is reviewed during the test.

(3) Multiengine installations may require testing on more than one engine depending on aircraft configuration and previous test experience.

(4) Testing may be required at reduced diameters to verify repair allowances.

(5) Maximum power will be the first limit of torque or ITT.

(6) Flight testing should be conducted at the maximum aircraft gross weight for certification and the minimum weight of the aircraft in the test configuration.

(7) These test conditions are based on conventional turbine aircraft engines with separate power and propeller controls and the use of a conventional constant speed propeller. Installations which deviate from this standard will require modifications to the test conditions as appropriate to fully evaluate propeller vibration characteristics.

b. Test Conditions

(1) Ground testing with the aircraft static into the wind.

(a) Using power lever, increase propeller RPM from idle to maximum RPM in increments.

(b) Accelerate and decelerate between idle and maximum RPM.

(c) Maintain maximum power and reduce RPM from maximum to minimum governing RPM in increments.

(d) Maximum Reverse

(2) Ground testing with the aircraft static in a 45° cross tail wind of not less than 15 knots. Required for propellers with four or more blades.

(a) Repeat B3b(1)(a)

(b) Repeat B3b(1)(b)

(c) Propeller feather/unfeather or engine start/shutdown as applicable.

(d) Record wind velocity at beginning and end of test.

(3) Flight testing at or below approximately 8000 ft MSL.

(a) Takeoff rotation and initial climb with maximum power and RPM. All possible flap positions should be considered.

(b) Maintain maximum power and RPM and increase airspeed from minimum to $V_{MO}/V_{NE}$ in increments.

(c) Repeat B3b(3)(b) with 70% torque.

(d) Maintain level flight and reduce torque from 100% to 40% in increments of approximately 10%.

(e) Left and right banks at 30°, 45°, and 60° during climbing and level flight.

(f) Incremental left and right rudder skids to the first limit of rudder travel or pedal force during climbing and level flight.

(g) Stalls with flight idle power and approximately 60% torque.

(h) Flight idle descent at incremental airspeeds.

(i) Selection of maximum and partial reverse at incremental speeds up to the maximum landing airspeed.

(j) For multiengine installations record propeller feather/unfeather and/or engine shutdown/restart as applicable.

(k) For multiengine installations reduce power to idle on engine without instrumented propeller and record data with maximum power and RPM during single engine climb and level flight.

(4) Flight testing above approximately 12,000 ft MSL. Higher altitudes should be considered for engines with significant thermodynamic capability.

(a) Maintain maximum power and maximum RPM and increase airspeed from minimum to $V_{MO}$ /$V_{NE}$ in increments.

(b) Maintain maximum power and reduce from maximum RPM to minimum governing RPM in increments.

(5) Any unusual engine operating conditions or maneuvers associated with the intended aircraft mission profile.

(6) For aerobatic installations all maneuvers that will be approved for the aircraft need to be tested. All maneuvers should be tested to the left and right and at varying entry speeds where applicable. The testing may include but is not limited to the following maneuvers.

| | |
|---|---|
| Chandelle | Rolling 360° Turn |
| Immelmann | Cuban 8 - Inside and outside. |
| Loop | Knife Edge |
| Slow Roll | Hammerhead |
| Barrel Roll | Tail Slide - Forward and aft pitch. |
| Hesitation Roll | Upright Spin - Six turns with power off. |
| Vertical Roll | Upright Spin - Six turns with maximum power for first turn then reduced to idle. |
| Torque Roll | Inverted Spin - Six turns with power off |
| Snap Roll | Inverted Spin - Six turns with maximum power for first turn then reduced to idle. |
| Shoulder Roll | Lomcevak |

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**(This document does not represent final agency action on this matter and should not be viewed as a guarantee that any final action will follow in this or any other form.)**

# Advisory Circular

| | | | |
|---|---|---|---|
| **Subject: GUIDANCE MATERIAL FOR 14 CFR 35.15 SAFETY ANALYSIS.** | **Date:** 12/21/99 | | **AC No:** 35-15-xx |
| | **Initiated By:** | Jay Turnberg ANE-110 | **Change:** A3515v4 |

**1. PURPOSE.** This advisory circular (AC) provides guidance and describes acceptable methods, but not the only methods, for demonstrating compliance with provisions of the requirements of Title 14 of the Code of Federal Regulations (14CFR) §35 pertaining to safety analysis for propellers. Like all AC material, this AC is not, in itself, mandatory and does not constitute a regulation. While these guidelines are not mandatory, they are derived from extensive Federal Aviation Administration (FAA) and industry experience in determining compliance with the pertinent regulations.

**2. RELATED DOCUMENTS.**

a. Related Regulations.

(1) Title 14 Code of Federal Regulations (CFR):

(a) §23.1309 Equipment, systems, and installations.

(b) §25.1309 Equipment, systems, and installations.

(c) §35.23 Propeller control system

(d) §35.36 Bird impact

(e) §35.37 Fatigue limits and evaluation

(f) §35.38 Lightning strike

(g) §35.43 Propeller hydraulic components

(2) Joint Airworthiness Requirements (JAR):

(a) JAR 23.1309 Equipment, systems, and installations.

(b) JAR 25.1309 Equipment, systems, and installations.

(c) JAR-P 230 Propeller control system

(d) JAR-P 360 Bird impact

(e) JAR-P 370 Fatigue limits and evaluation

(f) JAR-P 380 Lightning strike

(g) JAR-P 430 Propeller hydraulic components

(h) JAR-P Sub-Section D, Propeller Vibration and Fatigue Evaluation.

b. Advisory Circulars.

(1) AC 25.1309-1A, "System Design and Analysis", 6/21/88

(2) AC23.1309-1C, "Equipment, Systems, and Installations in Part 23 Airplanes", 3/12/99

c. Joint Airworthiness Authority (JAA) Advisory Circulars.

(1) AMJ 25.1309, "System Design and Analysis", xx/xx/xx.

d. Related Reading Material.

(1) Society of Automotive Engineers (SAE), Document No. ARP4754, Certification Considerations for Highly Integrated or Complex Aircraft Systems.

(2) SAE Document No. ARP 926A, Fault/Failure Analysis Procedure.

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

(4) Carter, A.D.S., Mechanical Reliability (2nd ed.). Macmillan, 1986.

**3. DEFINITIONS**. For the purposes of this AC, the following definitions are provided.

a. Analysis. A specific and detailed qualitative and/or quantitative evaluation of the propeller system offered for certification to determine compliance with §35.15. Examples are Fault Tree Analysis (FTA), Failure Mode and Effects Analysis (FMEA) and Markov Analysis.

b. Assessment. A more general or broad evaluation of the engine which may include the results of the analysis completed, as well as any other information, to support compliance with §35.15.

c. Check. An examination, inspection and/or test to determine the physical integrity and/or the functional capability of an item.

d. Critical component. A component, the failure of which could have a hazardous propeller effect, and for which critical characteristics have been identified which must be controlled to ensure the required level of integrity.

e. Error. An omission or incorrect action by a crew member or maintainer or a mistake in requirements, design or implementation. An error may result in a failure but is not a failure in and of itself.

f. External event. An occurrence originating apart from the propeller system or airplane including but not limited to icing, lightning strikes, or bird strikes.

g. Failure condition. A condition with a direct, consequential propeller-level effect, caused or contributed to by one or more failures. Examples include loss of hydraulic pressure or loss of primary governor.

h. Failure mode. The manner in which an item or function can fail. Examples include corrosion, fatigue, or jamming.

i. Redundancy. Multiple independent methods incorporated to accomplish a given function, each one of which is sufficient to accomplish the function.

j. System. A combination of inter-related items arranged to perform a specific function(s).

**4. BACKGROUND.**

a. The ultimate 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 basis is the concept that an acceptable total propeller design risk is achievable by managing the individual major and hazardous risks to acceptable levels. This concept emphasizes reducing the likelihood or probability of an event proportionally with the severity of the hazard it represents. The safety analysis should support the propeller design goals, such that there would not be major or hazardous propeller effects occurring as a result of propeller failure modes that exceeded the required probability of occurrence.

b. Compliance with §35.15 should be shown by a safety analysis substantiated, if possible, by appropriate testing and/or comparable service experience. An assessment may range from a simple report that offers descriptive details associated with a failure condition, an interpretation of test results, a comparison of two similar components or assemblies, other qualitative information, to a detailed safety analysis.

c. The depth and scope of an acceptable safety assessment depend on the following: the complexity and criticality of the functions performed by the system(s), components or assemblies under consideration; the severity of related failure conditions; the uniqueness of the design and extent of relevant service experience; the number and complexity of the identified causal failure scenarios; and the detectability of contributing failures.

## 5. SECTION 35.15 - GENERAL.

a. Section 35.15 defines the propeller-level failure conditions and presumed severity levels. Aircraft-level failure classifications are not directly applicable to propeller safety assessments since the aircraft may have features that could reduce or increase the consequences of a propeller failure condition. Additionally, the same type-certificated propeller may be used in a variety of installations, each with different aircraft-level failure classifications.

b. Since aircraft-level requirements for individual failure conditions may be more severe, due to installation effects, than the propeller-level requirements, there should be early coordination between the propeller manufacturer and the aircraft manufacturer, as well as the relevant FAA certification offices, to ensure an installable propeller. It is the aim of the FAA to help ensure the propeller applicant is aware of possibly more restrictive regulations in the installed condition.

## 6. SECTION 35.15(a)(1).

a. Rule Text. The regulation in §35.15(a)(1) reads as follows: "**An analysis of the propeller system must be carried out in order to assess the likely consequence of all failures that can reasonably be expected to occur. This analysis must consider the following:**

**(i) The propeller system in a typical installation. When the analysis depends on representative components, assumed interfaces, or assumed installed conditions, the assumptions must be stated in the analysis.**

**(ii) Consequential secondary failures and latent failures.**
**(iii) Multiple failures referred to in paragraph (d) of this section or that result in the hazardous propeller effects defined in paragraph (g)(1) of this section."**

b. Guidance.

(1) The propeller is defined by the components declared in the type design and the propeller system is 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 have included hydraulic controls, electronic controls, overspeed governors, spinners, deicing boots, and deicing components. When components are not included in propeller type design they are not under the design control of the propeller type certificate holder. These components are controlled by the aircraft or engine type certificate holders. Even though these components are not within the scope of the propeller type design, compliance with §35.15 requires that representative components be assumed to assess the system safety.

(2) The phrase "typical installation" does not imply that the aircraft-level effects are known, but that assumptions of typical aircraft or engine devices, such as governors, annunciation devices, etc., are clearly stated in the analysis. The typical installation does not necessarily imply the average installation. A typical installation may be the intended installation or one that requires a higher level of safety.

(3) Regulations within the aircraft paragraphs of 14CFR (Parts 23 and 25) contain aircraft-level device requirements.

(4) A component level safety analysis may be an auditable part of the design process or may be conducted specifically for demonstration of compliance with §35.15(a)(1).

(5) The possible latency period of failures is included in the probabilistic calculations of failure rates.

**7. SECTION 35.15(a)(2).**

a. Rule Text for §35.15(a)(2). The regulation in §35.15(a)(2) reads as follows: "**A summary must be made of those failures that could result in major propeller effects or hazardous propeller effects, together with an estimate of the probability of occurrence of those effects."**

b. Guidance. No guidance available.

**8. SECTION 35.15(a)(3).**

a. Rule Text for §35.15(a)(3). The regulation in §35.15(a)(3) reads as follows**: "It**

**must be shown 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 total rate for hazardous propeller effects to be assessed. For propeller certification, it is acceptable to consider that the intent of this paragraph has been achieved if the probability of a hazardous propeller effect arising from an individual failure can be predicted to be not greater than $10^{-8}$ per propeller flight hour. It will also be accepted that, in dealing with probabilities of this low order of magnitude, absolute proof is not possible and reliance must be placed on engineering judgment and previous experience combined with sound design and test philosophies."**

b. Guidance.

(1) The occurrence rate of hazardous propeller effects applies to each individual effect. The $10^{-7}$ to $10^{-9}$ range of probabilities for each hazardous propeller effect applies to the summation of the probabilities of this hazardous propeller effect arising from individual failure modes or combination of failure modes other than failure of critical components (blades, hubs, counter weights). For example, the total rate of occurrence of reverse pitch in flight when adding up the individual failure modes and combination of failure modes leading to reverse pitch in flight, should not exceed $10^{-7}$.

(2) When considering primary failures of certain single elements such as critical components, the numerical failure rate cannot be sensibly estimated. Where the failure of such elements is likely to result in hazardous propeller effects, reliance must be placed on their meeting the prescribed integrity requirements such as §§35.17, 35.35, and 35.37, among others. These requirements are considered to support a design goal that among other goals, primary fatigue failure of the component should be extremely improbable throughout its operational life. There is no requirement to include the estimated primary failure rates of such single elements in the summation of failures for each hazardous effect, due to the difficulty in producing and substantiating such an estimate.

## 9. SECTION 35.15(a)(4).

a. Rule Text for §35.15(a)(4). The regulation in §35.15(a)(4) reads as follows: **"It must be shown that major propeller effects are not predicted to occur at a rate in excess of that defined as remote (probability of $10^{-5}$ or less per propeller flight hour)."**

b. Guidance. No guidance available.

## 10. SECTION 35.15(b).

a. Rule Text for §35.15(b). The regulation in §35.15(b) reads as follows: "**If significant doubt exists as to the effects of failures or likely combination of failures,**

**any assumption of the effect may be required to be verified by test."**

b. Guidance. Prediction of the likely progression of some propeller failures may rely extensively upon engineering judgment and is not susceptible to absolute proof. Where there is some question over the validity of such engineering judgment, to the extent that the conclusions of the analysis could be invalid, additional substantiation may be required. Additional substantiation may consist of reference to previous relevant service experience, engineering analysis, material, component, rig or engine test or a combination of the above. Where significant doubt exists over the validity of the substantiation so provided, additional testing or other validation may be required.

**11. SECTION 35.15(c).**

a. Rule Text for §35.15(c). The regulation in §35.15(c) reads as follows: **"It is recognized that 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 must be placed on meeting the prescribed integrity requirements of this part. These instances must be stated in the safety analysis."**

b. Guidance. Prescribed integrity requirements include structural testing as required by §35.35, §35.37 and §35.42, among others.

**12. SECTION 35.15(d).**

a. Rule Text for §35.15(d). The regulation in §35.15(d) reads as follows: **"If reliance is placed on a system or device, such as safety devices, feathering and overspeed systems, instrumentation, early warning devices, maintenance checks, and similar equipment or procedures, to prevent a failure progressing to hazardous propeller effects, the possibility of a safety system failure in combination with a basic propeller failure must be covered. If items of a safety system are outside the control of the propeller manufacturer, the assumptions of the safety analysis with respect to the reliability of these parts must be clearly stated in the analysis and identified in the propeller installation and operation instructions required under §35.3."**

b. Guidance. The safety system failure may be present as a latent failure, occur simultaneously with the basic propeller failure, or occur subsequent to the propeller failure.

**13. SECTION 35.15(e) and 35.15(e)(1).**

a. Rule Text for §35.15(e). The regulation in §35.15(e) reads as follows: "**If the acceptability of the safety analysis is dependent on one or more of the following, it must be identified in the analysis and appropriately substantiated."**

b. Rule Text for §35.15(e)(1). The regulation in §35.15(e)(1) reads as follows: **"Performance of mandatory maintenance actions at stated intervals required for certification and other maintenance actions. This includes the verification of the serviceability of items which could fail in a latent manner. These maintenance intervals must be published in the appropriate manuals. Additionally, if errors in maintenance of the propeller system could lead to hazardous propeller effects, the appropriate procedures must be published in the appropriate manuals."**

c. Guidance.

(1) There should be general statements in the analysis summary that refer to regular maintenance in a shop as well as on the line. It is expected that, whenever specific failure rates rely on special or unique maintenance checks those shall be explicitly stated in the analysis.

(2) The propeller maintenance manual, overhaul manual, or other relevant manuals may serve as the appropriate substantiation for (e)(1) above. A listing of all possible incorrect maintenance actions is not required.

(d). Maintenance error lessons learned. Maintenance errors have contributed to hazardous or catastrophic effects at the aircraft level. Many of these events have arisen due to similar maintenance actions being performed on multiple propellers during the same maintenance availability by one maintenance crew, and are thus primarily an aircraft-level concern. Where appropriate, consideration should be given to communicating strategies against performing contemporaneous maintenance of multiple propellers. Consideration should be given to mitigating the effects of maintenance errors in the design phase. Components undergoing frequent maintenance should designed to facilitate the maintenance and correct re-assembly. However, completely eliminating sources of maintenance error during design is not possible.

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

- • Omitting to torque, under-torquing, over-torquing nuts or failure to install.
- • Incorrect/omitted application of lockwire.
- • Servicing with incorrect fluids.

(2) Improper maintenance on parts such as blades, hubs, counterweights, and spacers has led to failures resulting in hazardous propeller effects. Examples of this which have occurred in service are overlooking existing cracks, corrosion or damage during inspection, and failure to apply or incorrect application of protective coatings (e.g. anti-gallant, anti-corrosive), and failure to apply or incorrect application of cold working (e.g. shot peen, cold rolling).

**14. SECTION 35.15(e)(2).**

a. Rule Text for §35.15(e)(2). The regulation in §35.15(e)(2) reads as follows: **"Verification of the satisfactory functioning of safety or other devices at pre-flight or other stated periods. The details of this satisfactory functioning must be published in the appropriate manual."**

b. Guidance. If specific failure rates rely on special or unique maintenance checks for protective devices, those should be explicitly stated in the analysis.

**15. SECTION 35.15(e)(3).**

a. Rule Text for §35.15(e)(3). The regulation in §35.15(e)(3) reads as follows: **"The provisions of specific instrumentation not otherwise required."**

b. Guidance. No guidance is available.

**16. SECTION 35.15(e)(4).**

a. Rule Text for §35.15(e)(4). The regulation in §35.15(e)(4) reads as follows: **"A fatigue assessment."**

b. Guidance. No guidance is available.

**17. SECTION 35.15(f).**

a. Rule Text for §35.15(f). The regulation in §35.15(f) reads as follows: **"If applicable, the safety analysis must include assessment of indicating equipment, manual and automatic controls, governors and propeller control systems, synchrophasers, synchronizers, and propeller thrust reversal systems."**

b. Guidance. The safety analysis is not limited to the items listed.

**18. SECTION 35.15(g) and 35.15(g)(1).**

a. Rule Text for §35.15(g). The regulation in §35.15(g) reads as follows: **"Unless otherwise approved by the Administrator and stated in the safety analysis or not applicable for the propeller, for compliance with part 35, the following failure definitions apply to the propeller:"**

b. Rule Text for §35.15(g)(1). The regulation in §35.15(g)(1) reads as follows: **"The following are regarded as hazardous propeller effects:"**

c. Guidance. As discussed previously, early coordination with the aircraft manufacturer is needed to assure that the propeller is installable. The level of safety provided by the evaluation of hazardous propeller effects may not be sufficient for the level of safety required for the intended aircraft. The aircraft advisory circulars in references 2b(1) and (2) should be reviewed. Some of the hazardous propeller effects listed below have been known to prevent continued safe flight and landing of some aircraft.

(1) From an airplane perspective, in reference 2b(2), the following are considered hazardous and catastrophic failure conditions:

> "Hazardous: Failure conditions that would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be the following:
>
> (i) A large reduction in safety margins or functional capabilities;
>
> (ii) Physical distress or higher workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely; or
>
> (iii) Serious or fatal injury to an occupant other than the flight crew.
>
> Catastrophic: Failure conditions that are expected to result in multiple fatalities of the occupants, or incapacitation or fatal injury to a flight crewmember normally with the loss of the airplane. Notes: (1) The phrase "are expected to result" is not intended to require 100 percent certainty that the effects will always be catastrophic. Conversely, just because the effects of a given failure, or combination of failures, could conceivably be catastrophic in extreme circumstances, it is not intended to imply that the failure condition will necessarily be considered catastrophic. (2) The term "Catastrophic" was defined in previous versions of the rule and the advisory material as a Failure Condition that would prevent continued safe flight and landing.

(2) For the safety analysis it is acceptable to classify and evaluate as a more severe failure condition that stated in the rule. This may be needed for the propeller to be installed on some aircraft."

**19. <u>SECTION 35.15(g)(1)(i)</u>.**

a. <u>Rule Text for §35.15(g)(1)(i)</u>. The regulation in §35.15(g)(1)(i) reads as follows: **"A significant overspeed of the propeller.**

b. <u>Guidance</u>. Propeller failures resulting in significant overspeed, depending on the flight phase, could result in a hazardous condition related to aircraft controllability and engine damage. Overspeeds are generally caused by unwanted low propeller pitch in-flight.

**20. <u>SECTION 35.15(g)(1)(ii) and (iii)</u>.**

a. <u>Rule Text for §35.15(g)(1)(ii)</u>. The regulation in §35.15(g)(1)(ii) reads as follows: **"The development of excessive drag."**

b. <u>Rule Text for §35.15(g)(1)(ii)</u>. The regulation in §35.15(g)(1)(ii) reads as follows:

**"Thrust in the opposite direction to that commanded by the pilot."**

c. Guidance. Propeller failures resulting in excessive drag or thrust in the opposite direction to that commanded by the pilot can, depending on the flight phase, result in a hazardous condition related to aircraft controllability. Those failures, where applicable to part 35 certification that could be classified as hazardous events include; unwanted low or reverse propeller pitch in flight and high forward thrust when reverse thrust is commanded.

**21. SECTION 35.15(g)(1)(iv).**

a. Rule Text for §35.15(g)(1)(iv). The regulation in §35.15(g)(1)(iv) reads as follows: **"A release of the propeller or any major portion thereof."**

b. Guidance. The propeller, blades, hubs, counterweights, erosion shields, and other similar large rotating components with sufficient energy to penetrate a fuselage should therefore always be considered.

**22. SECTION 35.15(g)(1)(v).**

a. Rule Text for §35.15(g)(1)(v). The regulation in §35.15(g)(1)(v) reads as follows: **"A failure that results in excessive unbalance."**

b. Guidance. Propeller failures resulting in excessive unbalance result in a hazardous condition related to aircraft and engine damage. Those failures, where applicable to part 35 certification that could be classified as hazardous events include; release of a blade, major portion of a blade, or counterweight, uncommanded pitch change of individual blades. The propeller may have mitigating features that reduce the unbalance effect of uncommanded pitch change of individual blades such as counter weights and the ability to feather. Mitigating features may be taken into account in the analysis.

**23 SECTION 35.15(g)(1)(vi).**

a. Rule Text for §35.15(g)(1)(vi) The regulation in §35.15(g)(1)(vi) reads as follows**: "The unintended movement of the propeller blades below the established minimum in-flight low-pitch position."**

b. Guidance. This type of failure could disrupt the airflow over the wing and stall an airplane.

**24 SECTION 35.15(g)(2).**

a. Rule Text for §35.15(g)(2) The regulation in §35.15(g)(2) reads as follows: **"The following are regarded as major propeller effects for variable pitch propellers:"**

b. Guidance. From an airplane perspective, in reference 3b(2); "Major: Failure

Conditions that would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be a significant reduction in safety margins or functional capabilities; a significant increase in crew workload or in conditions impairing crew efficiency; or a discomfort to the flight crew or physical distress to passengers or cabin crew, possibly including injuries."

**25 SECTION 35.15(g)(2)(i), (ii), (iii), and (iv).**

a. Rule Text for §35.15(g)(2)(i) The regulation in §35.15(g)(1)(i) reads as follows: **"An inability to feather the propeller for feathering propellers."**

b. Guidance. No guidance available.

c. Rule Text for §35.15(g)(2)(ii) The regulation in §35.15(g)(1)(i) reads as follows: **"An inability to command a change in propeller pitch."**

d. Guidance. No guidance available.

e. Rule Text for §35.15(g)(2)(iii) The regulation in §35.15(g)(1)(iii) reads as follows: **"A significant uncommanded change in pitch."**

f. Significant uncommanded change in pitch. To facilitate propeller system safety analysis, design and certification in the absence of a application specific definition; a significant uncommanded change in pitch should be considered as that equivalent to a change that would result in more than a 10% change in thrust at the rated speed condition at any operating condition. However, final determination of the installation requirement is based on aircraft controllability requirements and must be evaluated during aircraft certification.

g. Rule Text for §35.15(g)(2)(iv) The regulation in §35.15(g)(1)(iv) reads as follows: **"A significant uncontrollable torque or speed fluctuation."**

h. Significant uncontrollable speed fluctuation. To facilitate propeller system safety analysis, design and certification in the absence of an application specific definition; significant uncontrollable speed fluctuation is defined as the loss of capability to modulate and maintain rotational speed within 3% of reference speed at all normal operating conditions.

**26. OTHER CONSIDERATIONS.**

a. Improper operation. Errors in operation of the propeller have resulted in hazardous or catastrophic effects at the aircraft level which otherwise would have been less serious. Consideration should be given to mitigating the effects of improper operation or to providing operating instructions that reduce the likelihood of improper operation. In particular, abnormal propeller symptoms and their desired response or appropriate procedures for trouble shooting for these symptoms should be communicated to the installer (reference §35.3).

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

## 27. ANALYTICAL TECHNIQUES.

a. The depth and scope of an acceptable safety assessment depends on the complexity and criticality of the functions performed by the system(s), components or assemblies under consideration, the severity of related failure conditions, the uniqueness of the design and extent of relevant service experience, the number and complexity of the identified causal failure scenarios, and the detectability of contributing failures.

b. This section describes various techniques for performing a safety analysis. Other comparable techniques exist and may be proposed by an applicant for use in any certification program. Variations and/or combinations of these techniques are also acceptable. For derivative propellers it is acceptable to limit the scope of the analysis to modified components or operating conditions and their effects on the rest of the propeller. Early agreement between the applicant and the propeller certification office should be reached on the scope and methods of assessment to be used.

c. Various methods for assessing the causes, severity levels, and likelihood of potential failure conditions are available to support experienced engineering judgment. The various types of analysis are based on either inductive or deductive approaches. Brief descriptions of typical types of analyses are provided below. More detailed descriptions of analytical techniques may be found in the paragraph 2d, Related Reading.

(1) Failure Modes and Effects Analysis. A structured, inductive, bottom-up analysis which is used to evaluate the effects on the engine system of each possible element or component failure. When properly formatted, it will aid in identifying latent failures and the possible causes of each failure mode.

(2) Fault tree or Dependence Diagram (Reliability Block Diagram) Analyses. Structured, deductive, top-down analyses which are used to identify the conditions, failures, and events that would cause each defined failure condition. These are graphical methods of identifying the logical relationship between each particular failure condition and the primary element or component failures, other events, or their combinations 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.

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**(This document does not represent final agency action on this matter and should not be viewed as a guarantee**
**that any final action will follow in this or any other form.)**

**Advisory**

**Circular**

| | | |
|---|---|---|
| **Subject: PROPELLER TYPE CERTIFICATE HANDBOOK** | **Date:** 12/21/99 | **AC No:** 35-1-xx |
| | **Initiated By:** Jay Turnberg<br>ANE-110 | **Change:** A351v9 |

**1. PURPOSE.** This advisory circular (AC) provides guidance and describes acceptable methods, but not the only methods, for demonstrating compliance with provisions of the requirements of Title 14 of the Code of Federal Regulations (14CFR) §35. Like all AC material, this AC is not, in itself, mandatory and does not constitute a regulation. While these guidelines are not mandatory, they are derived from extensive Federal Aviation Administration (FAA) and industry experience in determining compliance with the pertinent regulations.

**2. RELATED DOCUMENTS.**

a. Related Regulations.

(1) Title 14 Code of Federal Regulations (CFR):

(a) Part 21, Certification procedures for products and parts

(b)  Part 23, Airworthiness standards: normal, utility, acrobatic, and commuter category airplanes.

(c)  Part 33, Airworthiness standards: transport category airplanes

(d)  Part 45, Identification and registration marking

(2)  Joint Airworthiness Authority (JAA) Requirements:

(a)  JAR-P, Joint Aviation Requirements-Propellers.

b.  Advisory Circulars.

(1)  AC 35-37-xx, Guidance Material for 14 CFR 35.37 Fatigue Limits and Evaluation, dated xx/xx/xx.

(2)  AC 20-66-xx, Vibration Evaluation of Propellers, dated xx/xx/xx.

(3)  AC 35-15-xx, Guidance Material for 14 CFR 35.15 Safety Analysis, dated xx/xx/xx.

(4)  AC 35-23-xx, Guidance Material for 14 CFR 35.23 Propeller Control System, dated xx/xx/xx.

(4)  AC 20-107A, Composite Aircraft Structure, dated 4/25/84.

d. Orders and Notices.

(1) N8110.80 "FAA and Industry Guide to the Product Certification Process", February 26, 1999

(2) FAA Order 8100.5, "Aircraft Certification Directorate Procedures", dated October 1, 1982

(3) FAA Order 8110.4A, "Type Certification", dated March 2, 1995

**3. BACKGROUND.** The "Propeller Type Certification Handbook" was developed in conjunction with the Federal Aviation Administration (FAA) revision to the airworthiness standards for the issuance of original and amended type certificates (TC) for airplane propellers. The previous amendment, amendment 7, of propeller requirements did not adequately address the technological advances of the past twenty years. The new standards, amendment 8, addresses the current advances in technology and harmonize the FAA requirements with the European Joint Aviation Authorities (JAA). The current amendment establishes nearly uniform standards for airplane propellers certified by the United States under FAA standards and by the JAA countries under JAA standards, thereby simplifying airworthiness approvals for import and export products.

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Manager, Engine and Propeller Directorate

Aircraft Certification Service

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# CHAPTER 1

## -

## INTRODUCTION

**1.1 GENERAL.** This advisory circular (AC) provides procedural and guidance material for the type certification of propellers. This AC will be amended on an as-needed basis to maintain currency, such as with the issuance of FAR Part 35 rules changes, or the development of substantive new guidance material. It is important that persons using this advisory material verify that it corresponds to the current amendment of Part 35. The advisory material corresponds to Part 35, as amended through Amendment 8.

**1.2 DEFINITIONS.** The following definitions apply to the propeller certification guidance provided in this AC. They should not be assumed to apply to the same or similar terms used in other regulations or AC's.

a. Conventional. An attribute of a system is considered to be conventional if it is the same as, or closely similar to, that of previously-approved systems that are commonly used.

b. Feather. The pitch setting of the propeller when not rotating in flight such that the propeller will produce net zero torque on the engine. This angle may not result in minimum drag for an airplane.

c. Flight idle. Typically, the lowest power lever and associated minimum blade pitch position permitted in flight. (In-flight low pitch position.)

d. Ground idle. Typically, the power lever position which results in zero or nearly zero thrust while the aircraft is on the ground and not moving.

e. Hazardous propeller effects. The following are regarded as hazardous propeller effects:

(1) A significant overspeed of the propeller.

(2) The development of excessive drag.

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

(4) A release of the propeller or any major portion of the propeller.

(5) A failure that results in excessive unbalance.

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

f. In-flight low pitch position. Minimum blade pitch position permitted in flight. See flight idle 1.2c.

g. Major propeller effects. The following are regarded as major propeller effects for variable pitch propellers:

(1) An inability to feather the propeller for feathering propellers.

(2) An inability to command a change in propeller pitch.

(3) A significant uncommanded change in pitch.

(4) A significant uncontrollable torque or speed fluctuation.

h. Normal operation. Operation with a fully functional propeller system with no faults or failures.

i. Pitch control system. The components of the propeller system that functions to control blade pitch position, including but not limited to governors, pitch change assemblies, pitch locks, mechanical stops and feathering system components.

j. Propeller. Those components listed in the type design.

k. Propeller system. The propeller system consists of the propeller plus all the components necessary for its functioning, but not necessarily included in the propeller type design

l. Reverse pitch. Reverse pitch is any blade angle below ground idle blade angle.

m. Reversible propeller. A propeller in which blades can be rotated to a reverse pitch blade angle.

## CHAPTER 2

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## GENERAL TYPE CERTIFICATION PROCEDURES

**2.1. PURPOSE.** This chapter provides information and guidance material on the certification procedures which may be employed for propeller type certification projects.

**2.2. PROPELLER SYSTEM AND PROPELLER TYPE DESIGN.** For the purposes of this AC, the propeller consists of those components listed in the type design and the propeller system consists of the propeller plus all the components necessary for its functioning, but not necessarily included in the propeller type design. The distinction is needed because components required to operate the propeller may not be included in the propeller type design. These components have typically been, hydraulic controls, electronic controls, overspeed governors, spinners, deicing boots, and deicing components. When components are not included in propeller type design they are not under the design control of the propeller type certificate holder. These components are controlled by the aircraft or engine type certificate holders. Even though these components are not within the scope of the propeller type design, compliance with some regulations in part 35 requires that representative or typical components be included and to some extent evaluated during certification design and test.

The components, typically controls and accessories, that are substantiated by the applicant to operate with the propeller system and are approved for use with the propeller by the Certificate Management Aircraft Certification Office (CMACO) but are not included in the propeller type design are referenced on the propeller type certificate data sheet as, approved components not included in the propeller type design, under the applicable notes, see paragraph 2.4 Type Certificate Data Sheets. Components that are not included in the propeller type design are under the design control of the aircraft or engine type certificate holder and must be shown by the aircraft or engine type certificate holder to meet the applicable aircraft or engine airworthiness requirements.

**2.3. TYPE CERTIFICATION PROCESS.** The "FAA and Industry Guide to the Product Certification Process", reference 2d(1), describes how to plan, manage, and document an effective, efficient product certification program and describes the working relationship between the Aircraft Certification Service of the Federal Aviation Administration (FAA) and an Applicant. The Guide should be used by the FAA and Applicants for Type Certification, significant Supplemental Type Certification, significant amendments to either TC or STC, and for Production Approval. The type certification process is contained in Orders 8110.4A and 8100.5, references 2d(2) and 2d(3).

## 2.4. TYPE CERTIFICATE DATA SHEETS.

General guidance for the type certificate data sheet is provided in Order 8110.4A. Additional guidance on the notes is provided below.

a. General Propeller TCDS.

(1) Type Certificate Holder. Name and address.

(2) Type. A brief description of the propeller, e.g., ground adjustable; manually controllable; mechanical; two position hydraulic; constant speed; electrical; etc. Pitch control is covered in Note 3 and feathering and reversing in Note 4. Reference should be made to these notes when applicable.

(3) Engine Shaft or Flange. Describe the type of engine mounting necessary for the propeller, e.g., SAE No. 50, SAE No. 60, SAE No. 2 flange, Special flange 6.75” bolt circle, etc. Reference should be made to Note 1 when applicable.

(3) Hub Material. Describe the basic material used for fabrication of the hub, e.g., Aluminum alloy.

(4) Blade Material. Describe the basic material for fabrication of the blades, e.g., Composite fiberglass shell and carbon fiber spar.

(5) Number of Blades. List the number of blades

(6) Hub Models, Propeller Model Designations, or Design series. List hub model, propeller model, or designations and reference notes when applicable, typically NOTE 1, NOTE 4, or NOTE 12.

(7) Blade table.

(a) The blades approved for use are shown on the data sheet in tabular form, as follows:

| Blades (See Note 2) | | Maximum Continuous HP RPM | | Takeoff HP RPM | | Diameter Limits (See Note 2) | | Approximate Propeller Weight |
|---|---|---|---|---|---|---|---|---|

(b) In cases where the blades listed have been approved at different ratings in more than one hub model, separate tabulations should be made under each pertinent hub model. The information that should be tabulated under each of the headings follows:

1. List the approved propeller blade in the column marked "Blades." The model designation of the blade which will result in a propeller of the largest diameter approved with that particular blade will be listed first. Next list the model designation of the blade which will result in a propeller of the smallest diameter approved with that particular blade. The preposition "to" will be inserted in between. The method used by the applicant to denote a reduction in diameter is explained in Note 2, therefore, this note is referenced by placing "(See Note 2)" below "Blades."

2. List the maximum continuous horsepower and revolutions per minute ratings for which the propeller is approved under the appropriate headings.

3. List the takeoff ratings under the appropriate headings.

4. List the diameter limits which represent the maximum and minimum propeller diameters as indicated by the corresponding blade model designations. An applicant may use the same blade model in several propeller models, but, in each case the resulting propeller diameter should be checked since it cannot be assumed that the resulting propeller diameters are identical. This is because the blade socket of one hub may be further from the hub center line than the blade socket of another hub. The diameter limits are nominal limits as explained in Note 2, therefore, Note 2 will be referenced under the heading of "Diameter Limits." when applicable.

5. List the total weight of the propeller under the column headed “Approximate Propeller Weight”. Include hub, blade, and other type certificated components and reference appropriate Notes.

(8) Certification Basis. List the following:

(a) Federal Aviation Regulations Part number including latest amendment at the time the application was submitted below is an example of wording:

1 Part 35, as amended through Amendment 8.

(b) Any special conditions, equivalent level of safety findings, or exemptions;

(c) The foreign certification basis for imported propellers;

(9) TC Application date.

(10) TC issued date.

(11) Import Requirements. Information for the airworthiness acceptance of aircraft propellers manufactured outside the U.S. for which a U.S. TC has been issued is found in § 21.500. Additional guidance is contained in AC 21-23, Airworthiness Certification of Civil Aircraft Engines, Propellers, and Related Products, Imported into the United States. Each propeller exported to the U.S. shall be accompanied by a certificate of airworthiness for export or a certifying statement endorsed by the exporting cognizant civil airworthiness authority which contains the following language included on the type certificate data sheet:

To be considered eligible for installation on U.S. registered aircraft, each propeller to be exported to the United States shall be accompanied by a certificate of airworthiness for export or certifying statement endorsed by the exporting cognizant civil airworthiness authority which contains the following language:

(1) This propeller conforms to its United States type design (Type Certificate Number _____) and is in a condition for safe operation.

(2) This propeller has been subjected by the manufacturer to a final operational check and is in a proper state of airworthiness.

Reference FAR Section 21.500 which provides for the airworthiness acceptance of aircraft engines or propellers manufactured outside the U.S. for which a U.S. type certificate has been issued.

Additional guidance is contained in FAA Advisory Circular 21-23, Airworthiness Certification of Civil Aircraft, Engines, Propellers and Related Products, Imported into the United States.

(12) Production Basis. List the PC number.

(13)  Notes.  The same numbering system and subject heading should be used for Notes on all propeller data sheets, for Notes 1 through 12.  Insert opposite the number of the note involved "not applicable," when one of a series of notes is not pertinent.  The explanation for Notes from 1 to 12 follow:

(a)  NOTE 1.  Hub Model Designation or Propeller Model Designation.  Describe the hub or propeller model designation, whichever is pertinent.  Numerals or letters composing the hub or propeller model designation usually identify such features as basic design, number of blades, blade shank size, size for engine flange or spline required for mounting the propeller.  A series of suffixes may be used to denote minor changes not affecting eligibility and/or major design features such as feathering.  The use of a diagram has been found suitable to indicate the significance of each numeral or letter appearing in the model designation.

(b)  NOTE 2.  Blade Model Designation.  Use a diagram similar to that used for the hub model designation to indicate the significance of any numerals or letters and to describe the system used to denote propeller diameter reductions.  Include, when pertinent, a description below the diagram to outline the system used by the applicant to identify blade details such as round or square tip shapes.

(c)  NOTE 3.  Pitch Control.  Describe the pitch control components approved for use with the propeller.  Indicate if the approved pitch control components are not included in the propeller type design.  The pitch control components should be identified by name as well as model designation.

1.  For control systems integrated into the engine controls the following statement is added to establish relationship between the propeller and engine manufacturer.  The engine type certificate data sheet should have a similar statement.

The propeller model xxx complies with the propeller airworthiness requirements when used with yyy engine only.  Any change to the engine, including its control system, which effects or may affect the propeller approval must be substantiated to demonstrate that the propeller as integrated with the changed engine, including its control system, still complies with the propeller certification basis.  Also, any change to the engine resulting from a change to the propeller must be substantiated to demonstrate that the engine still complies with the engine certification basis.

(d) NOTE 4. Feathering and Reversing. Identify any models that feather and/or reverse and indicate any special type of control that is approved.

(e) NOTE 5. Left-Hand Models. Indicate the approval status of the left-hand blade model of an approved right-hand blade model. When applicable, reference Note 5 in the "Blade". The following note is used rather than repeating the ratings, diameter limits, etc., for the left-hand model:

The left-hand version of an approved propeller model is eligible at the same rating and diameter limitations as listed for the right-hand model.

(f) NOTE 6. Interchangeable Blades. Include all relevant information regarding limitations associated with interchangeability such as interchangeability in one direction only, aerodynamic similarity, structural similarity.

(g) NOTE 7. Accessories. Describe the accessories such as spinners, governors, deicing and anti-icing equipment approved for use with the propeller. Indicate if the approved accessories are not included in the propeller type design.

(h) NOTE 8. Shank Fairings. Indicate when a blade has been modified to incorporate shank fairings or cuffs. If the blade model includes shank fairings or cuffs when originally certificated, Note 8 is not required because the blade model designation will be sufficient identification in this respect.

(i) NOTE 9. Special Limits. List or include by appropriate reference operational and airworthiness limitations.

1. Normal Category Single Reciprocating Engine Tractor Aircraft. List the propeller-engine combinations approved considering vibration for use on normal category single-reciprocating engine tractor aircraft or approved installations of §21.29 propellers.

(aa) A conventional aluminum bladed propeller model is eligible vibrationwise in any normal category single-reciprocating engine tractor aircraft when it is installed on the same engine model used for the vibration approval of the particular propeller-engine combination. If the propeller vibration stress survey was conducted on a multi-engine or pusher aircraft, any placard found applicable in such a survey will be applied to the single-reciprocating engine tractor installation until a vibration re-survey shows that the placard is not required on the single-reciprocating engine tractor application. Approvals of this type should be listed under NOTE 9 as follows:

Table of Propeller-Engine Combinations
Approved Vibrationwise for Use on Normal Category
Single-Reciprocating Engine Tractor Aircraft

The maximum and minimum propeller diameters that can be used from a vibration standpoint are shown below. No reduction below the minimum diameter listed is permissible, since this figure includes the diameter reduction allowable for repair purposes.

| Hub Model | Blade Model | Engine Model | Max. Dia. (Inches) | Min. Dia. (Inches) | Placards |
|---|---|---|---|---|---|

2. The approval of most import propellers (§21.29) includes the vibration and performance approval of the propeller for use on a particular engine-airplane combination. These approvals should be listed under Note 9 in a format appropriate to the data on the type certificate from the country of origin or as follows:

Approved Installations

Propellers listed in this data sheet are approved only for use in the engine-aircraft combinations shown below:

| Propeller Model | Aircraft Model | Engine Model | Maximum Takeoff Weight | FAA Data Sheet Aircraft Engine |
|---|---|---|---|---|

(j) NOTE 10. Special Note. The following note should be added to the propeller type certificate data sheet.

The propeller installation must be approved as part of the aircraft type certificate to demonstrate compliance with the applicable aircraft airworthiness requirements.

The propeller Airworthiness Limitations must be evaluated by the propeller Aircraft Certification Office responsible for the propeller type certificate management for each new aircraft installation to assess possible changes to the propeller Airworthiness Limitations.

(k) NOTE 11. Life-Limited Parts. List or include by appropriate reference all propeller life limited parts. Include the following statement.

(l) NOTE 12. Use when additional notes are applicable. For example, the TC may occasionally be granted before the applicant has completed the required service manual. Note 12 will be used in such an instance to indicate that the propeller is not eligible for installation until the manual becomes available. After approval of the manual, Note 12 would be deleted from the data sheet.

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b. <u>Data Sheet for Fixed-Pitch Propellers</u>. Data sheets for fixed-pitch propellers will be similar to those for propellers with detachable blades except as follows:

(1) Type Certificate Holder. Name and address.

(2) Type - Fixed-Pitch (Single-Piece);

(3) Engine Shaft - Omit;

(4) Material – Describe the basic material and fabrication of the propeller;

(5) Number of Blades;

(6) Hub Models Applicable - Omit;

(7) In lieu of the table of "blades," the following table of models will be used:

| Data sheet for fixed-pitch propellers | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | **Takeoff Max. Cont.** | | | | | | | | | |
| | **Hub Drilling** | | | **Hub Dimensions** | | **Weight (lb.)** | | | | |
| **Model (See NOTE 2)** | | | | | | | | | | |
| **HP** | **RPM** | **Diameter** | **Standard Pitch** | **No. holes** | **Dia. holes** | **Dia. Bolt circle** | **Diameter Pilot Hole** | **Dia.** | **Thickness** | **(Max. Dia.)** |

(8) Notes. The following notes will be used:

(a) NOTE 1. Installation. A typical note follows: "These models are for installation on flanged propeller shaft ends (See NOTE 2). The front plate supplied by the engine manufacturer is not to be used. Installation is to be made with special steel bolts which are either furnished or specified by the propeller manufacturer."

(b) NOTE 2. Model Designation. A diagram will be used to indicate the significance of the digits and letters in the propeller model designation. This diagram encompasses the data given in Notes 1 and 2 for detachable blade propellers.

(c) NOTES 3, 4, 5, and 6. Not applicable. (So marked on data sheet.)

(d) NOTES 7. Accessories. Describe the accessories such as spinners and spacers approved for use with the propeller. Indicate if the approved accessories are not included in the propeller type design.

(e) NOTE 8. Not applicable. (So marked on data sheet.)

(f) NOTE 9. Special Limits. In the table of propeller-engine combinations, the "hub model" and "blade model" columns are replaced by a "propeller model" column. The table applies only to fixed-pitch metal propellers.

<u>Table of Propeller-Engine Combinations</u>
<u>Approved Vibrationwise for Use on Normal Category</u>
<u>Single-Reciprocating Engine Tractor Aircraft</u>

The maximum and minimum propeller diameters that can be used from a vibration standpoint are shown below. No reduction below the minimum diameter listed is permissible, since this figure includes the diameter reduction allowable for repair purposes.

| Propeller Model | Engine Model | Max. Dia. (Inches) | Min. Dia. (Inches) | Placards |
|---|---|---|---|---|

(g) NOTE 10. Special Note. The following note should be added to the propeller type certificate data sheet.

The propeller installation must be approved as part of the aircraft type certificate to demonstrate compliance with the applicable aircraft airworthiness requirements.

The propeller Airworthiness Limitations must be evaluated by the propeller Aircraft Certification Office responsible for the propeller type certificate management for each new aircraft installation to assess possible changes to the propeller Airworthiness Limitations.

(k) NOTE 11. Life-Limited Parts. List or include by appropriate reference all propeller life limited parts. Include the following statement.

(l) NOTE 12. Use when additional notes are applicable.

**2.5. <u>PROPELLER DEICING COMPONENTS</u>.** The propeller type certification does not approve ice protection equipment for flight into known icing. Aircraft icing is demonstrated on the aircraft under the airworthiness requirements of parts 23 and 25.

# CHAPTER 3.

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# GUIDANCE MATERIAL FOR SUBPART A - GENERAL

## 3.1. 35.1 APPLICABILITY.

a. Rule Text. The regulation in §35.1 reads as follows:

**(a) This part prescribes airworthiness standards for the issue of type certificates and changes to those certificates for propellers.**

**(b) Each person who applies under part 21 for such a certificate or change must show compliance with the applicable requirements of this part.**

**(c) The applicant is eligible for a propeller type certificate when compliance with subparts A, B and C has been demonstrated. However, the propeller may not be installed on an airplane unless compliance with either §§23.907 or 25.907, as applicable, has been shown or is not required for installation on that airplane.**

**(d) For the purposes of this part, the propeller consists of those components listed in the type design and the propeller system consists of the propeller plus all the components necessary for its functioning, but not necessarily included in the propeller type design.**

b. Guidance. No guidance available.

## 3.2 35.2 PROPELLER CONFIGURATION AND IDENTIFICATION.

a. Rule Text. The regulation in §35.2 reads as follows:

**(a) The applicant must provide a list of all the components, including references to the relevant drawings and software design data, that define the type design of the propeller to be approved under §21.31.**

**(b) The propeller identification must comply with §§45.11 and 45.14.**

b. Guidance. No guidance available.

## 3.3. 35.3 INSTRUCTIONS FOR PROPELLER INSTALLATION AND OPERATION.

a. Rule Text. The regulation in §35.3 reads as follows:

**The applicant must provide instructions that are approved by the Administrator and that will contain:**

**(a) Instructions for installing the propeller, which must:**

**(1) Specify the physical and functional interfaces with the aircraft, aircraft equipment and the engine.**

**(2) Define the limiting conditions on those interfaces from paragraph (a)(1) or this section.**

**(3) Include a description of the operational modes of the propeller control system and its functional interface with the aircraft and engine systems.**

**(4) List the limitations established under §35.5.**

**(5) Define the hydraulic fluids approved for use with the propeller, including grade and specification, related operating pressure and filtration levels.**

**(6) State the assumptions made to comply with the requirements of this part.**

**(b) Instructions for operating the propeller which must specify all procedures necessary for operating the propeller within the limitations of the propeller type design.**

b. Guidance. The installation manual may reference other documents such as maintenance and overhaul manuals as applicable.

(1) The following warning should be added when applicable: Do not command the propeller blades to move below the flight idle position in flight. To do so will result in a command to low blade angle, which will result in either a propeller overspeed and/or a high drag condition.

(2) The manual should include control system characteristics, authority in both normal operation and failure conditions, and the range of control of other controlled functions.

c. Sample contents of an installation manual for a constant speed, feathering, and reversing propeller are as follows:

(1) Drawings - List of top level propeller drawing titles and numbers.

(2) Propeller type data and description - Reference Type Certificate Data Sheet and supplemental documents.

(3) Components and accessories - List of components and suppliers.

(4) System description - Description of the overall system.

(5) Control system description. See AC 35-23 for specific guidance.

(6) Propeller properties and limitations

- Diameter
- Number of blades
- Power and rpm limits, §35.5
- Torque limits, §35.5
- Overspeed and overtorque limits, §35.5
- Propeller shaft loads
- Propeller system mounting instructions and bolt torque's
- Propeller balance (as delivered)
- Vibration environment.
- Altitude versus ambient temperature limitations
- Ground deicing limitations

(7) Propeller system component weights

- Moments of inertia
- Center of gravity
- List weights

(8) Pitch change

- Settings
- Slew rates
- Beta sensor position, §35.21(b).
- Limits on intended movement below the in-flight low-pitch-position, §35.21(a).
- Feathering limitations, §35.25.

(9) Recommended operating procedures including:

· Ground operation

- Starting

- Propeller brake operating

- Overspeed governor check

- Secondary low pitch stop check

- Limitations and restrictions.

· Deicing operation

· Flight operation

· Emergency operations

- Loss of hydraulic pressure

- Loss of electrical power

· Fault detection, isolation and accommodation

(10) Ice protection system - System description

(11) Electrical - System description

· Power requirements

· Loss of aircraft electrical power effects

(12) EMI/Lightning protection

· System description

- Qualification results
- Limitations

(13) Actuation and lubrication system

- Actuating/lubrication fluids
- Propeller pump fluid requirements
- Fluid filtration
- Lubricating fluid
- Hub lubricating fluid
- Auxiliary motor and pump

(14) Propeller performance

(15) Safety Analysis Assumptions, §35.15

- Assumed component reliability
- Required safety checks
- Maintenance actions

**3.4. 35.4 INSTRUCTIONS FOR CONTINUED AIRWORTHINESS.**

a. Rule Text. The regulation in §35.4 reads as follows:

**The applicant must prepare Instructions for Continued Airworthiness in accordance with Appendix A to this part that are acceptable to the Administrator.**

**The instructions may be incomplete at type certification if a program exists to ensure their completion prior to delivery of the first aircraft with the propeller installed, or upon issuance of a standard certificate of airworthiness for an aircraft with the propeller installed, whichever occurs later.**

b. Guidance. No guidance available.

## 3.5. 35.5 PROPELLER RATINGS AND OPERATING LIMITATIONS.

a. Rule Text. The regulation in §35.5 reads as follows:

**(a) Propeller ratings and operating limitations must:**

**(1) Be established by the applicant and approved by the Administrator.**

**(2) Be included directly or by reference in the propeller type certificate data sheet, as specified in §21.41 of this chapter.**

**(3) Be based on the operating conditions demonstrated during the tests required by this part as well as any other information necessary for the safe operation of the propeller.**

**(b) Ratings and operating limitations must be established for the following, as applicable:**

**(1) Power and rotational speed for:**

**(i) Takeoff.**

**(ii) Maximum continuous.**

**(2) Maximum torque.**

**(3) Overspeed and overtorque limits.**

b. Guidance. The rated power, rotational speed and torque are those values declared by the applicant and substantiated by the requirements of this part. The applicant may elect to conduct certification tests, analysis, and evaluation at values greater than the declared rated values. There no requirement for the takeoff power and rpm to be greater than the maximum continuous power and rpm although takeoff power and rpm is typically greater.

(1) The propeller maximum continuous power and rpm are validated during the endurance test in §35.39.

(2) The power and rpm ratings that are declared on the propeller Type Certificate Data Sheet are not applicable to any given airplane installation. They are only applicable to the propeller. The propeller may only be suitable for operation on some aircraft at a lower power or rpm. The appropriate aircraft installation limitations are established by parts 23 or 25.

(3) The overspeed and overtorque limits are established in §35.53. These limits are independent of the maximum power and rotational speeds. The overspeed and overtorque limits are not intended to be used in a routine manner. These are for occasional service issues, service checks, and inadvertent excursions in torque and speed.

## 3.6. 35.7 FEATURES AND CHARACTERISTICS.

a. Rule Text. The regulation in §35.7 reads as follows:

**(a) The propeller may not have features or characteristics, revealed by any test or analysis or known to the applicant, that makes it unsafe for the uses for which certification is requested.**

**(b) If a failure occurs during a certification test, the cause must be determined, and the effect on the airworthiness of the propeller must be assessed. The applicant must make changes to the design or conduct additional tests, or both that the Administrator finds necessary to establish the airworthiness of the propeller.**

b. Guidance.

(1) Compliance with (a) may be accomplished with a letter from the applicant.

(2) No guidance available for paragraph (b).

# CHAPTER 4.

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# GUIDANCE MATERIAL FOR SUBPART B - DESIGN AND CONSTRUCTION

## 4.1. 35.15 SAFETY ANALYSIS.

a. Rule Text. The regulation in §35.15 reads as follows:

**(a) (1) An analysis of the propeller system must be carried out in order to assess the likely consequence of all failures that can reasonably be expected to occur. This analysis must consider the following:**

**(i) The propeller system in a typical installation. When the analysis depends on representative components, assumed interfaces, or assumed installed conditions, the assumptions must be stated in the analysis.**

**(ii) Consequential secondary failures and latent failures.**

**(iii) Multiple failures referred to in paragraph (d) of this section or that result in the hazardous propeller effects defined in paragraph (g)(1) of this section.**

**(2) A summary must be made of those failures that could result in major propeller effects or hazardous propeller effects, together with an estimate of the probability of occurrence of those effects.**

**(3) It must be shown 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 total rate for hazardous propeller effects to be assessed. For propeller certification, it is acceptable to consider that the intent of this paragraph has been achieved if the probability of a hazardous propeller effect arising from an individual failure can be predicted to be not greater than $10^{-8}$ per propeller flight hour. It will also be accepted that, in dealing with probabilities of this low order of magnitude, absolute proof is not possible and reliance must be placed on engineering judgment and previous experience combined with sound design and test philosophies.**

**(4) It must be shown that major propeller effects are not predicted to occur at a rate in excess of that defined as remote (probability of $10^{-5}$ or less per propeller flight hour).**

**(b) If significant doubt exists as to the effects of failures or likely combination of failures, any assumption of the effect may be required to be verified by test.**

**(c) It is recognized that 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 must be placed on meeting the prescribed integrity requirements of this part. These instances must be stated in the safety analysis.**

**(d) If reliance is placed on a system or device, such as safety devices, feathering and overspeed systems, instrumentation, early warning devices, maintenance checks, and similar equipment or procedures, to prevent a failure progressing to hazardous propeller effects, the possibility of a safety system failure in combination with a basic propeller failure must be covered. If items of a safety system are outside the control of the propeller manufacturer, the assumptions of the safety analysis with respect to the reliability of these parts must be clearly stated in the analysis and identified in the propeller installation and operation instructions required under §35.3.**

**(e) If the acceptability of the safety analysis is dependent on one or more of the following, it must be identified in the analysis and appropriately substantiated.**

**(1) Performance of mandatory maintenance actions at stated intervals required for certification and other maintenance actions. This includes the verification of the serviceability of items which could fail in a latent manner. These maintenance intervals must be published in the appropriate manuals. Additionally, if errors in**

**maintenance of the propeller systemcould lead to hazardous propeller effects, the appropriate procedures must be published in the appropriate manuals.**

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

**(3) The provisions of specific instrumentation not otherwise required.**

**(4) A fatigue assessment.**

**(f) If applicable, the safety analysis must include assessment of indicating equipment, manual and automatic controls, governors and propeller control systems, synchrophasers, synchronizers, and propeller thrust reversal systems.**

**(g) Unless otherwise approved by the Administrator and stated in the safety analysis, for compliance with part 35, the following failure definitions apply to the propeller:**

**(1) The following are regarded as hazardous propeller effects:**

**(i) A significant overspeed of the propeller.**

**(ii) The development of excessive drag.**

**(iii) Thrust in the opposite direction to that commanded by the pilot.**

**(iv) A release of the propeller or any major portion of the propeller.**

**(v) A failure that results in excessive unbalance.**

**(vi) The unintended movement of the propeller blades below the established minimum in-flight low-pitch position.**

**(2) The following are regarded as major propeller effects for variable pitch propellers:**

**(i) An inability to feather the propeller for feathering propellers.**

**(ii) An inability to command a change in propeller pitch.**

**(iii) A significant uncommanded change in pitch.**

**(iv) A significant uncontrollable torque or speed fluctuation.**

b. Guidance. Guidance is found in reference 2b(3) AC 35-15-xx, Guidance Material for 14 CFR 35.15 Safety Analysis, dated xx/xx/xx.

## 4.2. 35.17 MATERIALS AND MANUFACTURING METHODS.

a. Rule Text. The regulation in §35.17 reads as follows:

**(a) The suitability and durability of materials used in the propeller must:**

**(1) Be established on the basis of experience, tests, or both.**

**(2) Account for environmental conditions expected in service.**

**(b) All materials and manufacturing methods must conform to acceptable specifications.**

**(c) The design values of properties of materials must be suitably related to the minimum properties stated in the material specification.**

b. Guidance.

(1) Metallic Materials and Processes for Propellers. The metallic materials used in propeller production and the fabrication processes employed should be established on the basis of experience and/or tests. Materials should adhere to the following guidelines.

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(a) Material selection. Selected materials should be suitable for their intended mechanical and/or physical function and be resistant to degradation by atmospheric corrosion and by the chemical environment to be encountered in the specific application. When the use of inherently resistant materials is not practical, the use of adequate coating systems should be considered. Alloy-temper combinations that are susceptible to stress corrosion cracking (SCC) should be avoided. Coatings may delay, but not prevent, the onset of SCC. Designs that involve active galvanic coupling of dissimilar metals/alloys should be avoided as much as possible. When such coupling becomes the logical deign choice, the use of coatings, films or sealants should be considered.

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(b)  Specifications.  Materials should be procured to adequately detailed specifications. Such specifications should be acceptable to the Administrator, either specifically, or by having been prepared by an organization which the Administrator accepts as having the necessary credentials to do so.  The detail of the specification should be related to the criticality of the application.

(c)  Design values.  The assumed design values of properties of materials should be suitably related to the minimum (conservative) properties stated in the material specification or some other recognized document.

(d)  Process Specifications.  Manufacturing processes should be performed according to detailed process specifications.  Such specifications should be acceptable to the Administrator either specifically or by having been prepared by an organization which the Administrator accepts as having the necessary credentials to do so.  The detail of the process specification is related to the criticality of the application.

(e)  Special Manufacturing Methods.  Casting, forging, welding and brazing should be considered as custom manufacturing methods, requiring precautions not ordinarily applicable to manufacture from mill products (bar, sheet, plate and the like). The following should be observed:

1.  Classification:  Materials requiring special manufacturing methods should be classified according to their functional criticality.  This classification becomes the basis for establishing the nondestructive inspection and testing requirements to be listed on the drawing.

2.  Testing: Materials requiring special manufacturing methods should have provisions for testing the material.  A reasonable plan for testing should be developed for these materials.  The purpose of the test material would be to verify mechanical properties, microstructure and the like.

3.  Inspection.  Materials requiring special manufacturing methods should be subjected to a suitable nondestructive and destructive inspection process at an appropriate stage and with an appropriate sampling rate.

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(2) Composite Materials and Processes for Propellers. Guidance material is found in AC 20-107A, Composite Aircraft Structure.

**4.3. <u>35.21 VARIABLE AND REVERSIBLE PITCH PROPELLERS</u>.**

a. <u>Rule Text</u>. The regulation in §35.21 reads as follows:

**(a) No single failure or malfunction in the propeller system during normal or emergency operation will result in unintended travel of the propeller blades to a position below the in-flight low-pitch position. The extent of any intended travel below the in-flight low-pitch position must be documented in the appropriate manuals. Failure of structural elements need not be considered if the occurrence of such a failure is shown to be extremely remote under §35.15(c).**

**(b) For propellers incorporating a method to select blade pitch below the in-flight low pitch position, provisions must be made to sense and indicate to the flight crew that the blades are below that position by an amount defined in the installation manual. The method for sensing and indicating the propeller blade must be such that its failure does not affect the control of the propeller.**

b. <u>Guidance</u>.

(1) Intended travel accounts for backlash, tolerances, secondary stop, and etc. For example a hydraulic failure of a dual acting propeller system with pitch lock operating at the in-flight low-pitch positions could permit a small decrease in blade angle due to system backlash. The pitch lock may require a degree or two of blade angle change before it engages. This value is documented in the Instructions for Propeller Installation and Operation.

(2) The sensor may be anywhere along the hydro-mechanical or mechanical path used to actuate the propeller pitch change.

**4.5. <u>35.22 FEATHERING PROPELLERS</u>.**

a. Rule Text. The regulation in §35.22 reads as follows:

**(a) Feathering propellers must be designed to feather from all normal and emergency conditions in flight, taking into account likely wear and leakage. Feathering and unfeathering limitations must be documented in the appropriate manuals.**

**(b) Propeller pitch control systems that use engine oil to feather must incorporate a method to allow the propeller to feather if the engine oil system fails.**

**(c) Feathering propellers must be designed to be capable of unfeathering at the minimum declared outside air temperature after stabilization to a steady-state temperature.**

b. Guidance.

(1) The feathering and unfeathering characteristics and limitations may include such as the feather angle, rate pitch change, and airspeed limits above which the propeller may not feather completely of at a slower rate. These should be listed in the Manual for Propeller Installation and Operation.

(2) Evaluation at the minimum declared outside temperature may be verified in a cold chamber or by flight test.

## 4.8. 35.23 PROPELLER CONTROL SYSTEM.

a. Rule Text. The regulation in §35.23 reads as follows:

**The requirements of this section are applicable to any system or component that controls, limits or monitors propeller functions.**

**(a) The propeller control system must be designed, constructed and validated to show that:**

**(1) The propeller control system, operating in normal and alternative operating modes and transition between operating modes, performs the intended functions throughout the declared operating conditions and flight envelope.**

**(2) The propeller control system functionality is not adversely affected by the declared environmental conditions, including temperature, electromagnetic interference (EMI), high intensity radiated fields (HIRF) and lightning. The environmental limits to which the system has been satisfactorily validated must be documented in the appropriate propeller manuals.**

**(3) A method is provided to indicate that an operating mode change has occurred if flight crew action is required. In such an event, operating instructions must be provided in the appropriate manuals.**

**(b) The propeller control system must be designed and constructed so that, in addition to compliance with §35.15:**

**(1) A level of integrity consistent with the intended aircraft is achieved.**

**(2) No single failure or malfunction of electrical or electronic components in the control system results in a hazardous propeller effect.**

**(3) Failures or malfunctions directly affecting the propeller control system in a typical aircraft, such as structural failures of attachments to the control, fire, or overheat, do not lead to a hazardous propeller effect.**

**(4) The loss of normal propeller pitch control does not cause a hazardous propeller effect under the intended operating conditions.**

**(5) The failure or corruption of data or signals shared across propellers does not cause a major or hazardous propeller effect.**

**(c) Electronic propeller control system imbedded software must be designed and implemented by a method approved by the Administrator that is consistent with the criticality of the performed functions and minimizes the existence of software errors.**

**(d) The propeller control system must be designed and constructed so that the failure or corruption of aircraft-supplied data does not result in hazardous propeller effects.**

**(e) The propeller control system must be designed and constructed so that the loss, interruption or abnormal characteristic of aircraft supplied electrical power does not result in hazardous propeller effects. The power quality requirements must be described in the appropriate manuals**

b. Guidance. Guidance material is found in reference 2b(4) (4), AC 35-23-xx, Guidance Material for 14 CFR 35.23 Propeller Control System, dated xx/xx/xx.

## 4.9. 35.24 STRENGTH.

a. Rule Text. The regulation in §35.24 reads as follows:

**The maximum stresses developed in the propeller must not exceed values conforming to those established by satisfactory practice for the material involved. Due account should be taken of the particular form of construction and the most severe operating conditions. If a new type of material is involved, evidence must be available to substantiate the assumed material characteristics.**

b. Guidance. Compliance may be shown by an auditable part of the design process provided that the following is established for the propeller.

· Design definition.

· Design requirements.

· Design loads.

· Stress analysis.

· Test results.

· Material specifications.

· Verification that the component tested and/or analyzed represents the type design

· A process that reviews this requirement for each design change.

# CHAPTER 5

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## GUIDANCE MATERIAL FOR SUBPART C - TYPE SUBSTANTIATION

### 5.1. 35.33 GENERAL.

a. Rule Text. The regulation in §35.33 reads as follows:

**(a) Each applicant must furnish test article(s) and suitable testing facilities, including equipment and competent personnel, and conduct the required tests in accordance with part 21.**

**(b) All automatic controls and safety systems must be in operation unless it is accepted that this is not possible or that they are not required because of the nature of the test. If needed for substantiation, the applicant may test a different propeller configuration if this does not constitute a less severe test.**

**(c) For those systems or components which cannot be adequately substantiated by the requirements of this part, additional tests or analysis must be made to demonstrate that the systems or components are able to perform their intended functions in all declared environmental and operating conditions.**

b. Guidance.

(1) Paragraph (a): No guidance available.

(2) Paragraph (b): Some tests may be run without automatic controls or safety systems. For example, a primary system may have to be disabled to test a backup system or a governing function may need to be disabled to test an overspeed condition.

(3) Paragraph (c): No guidance available.

### 5.2 35.34 INSPECTION, ADJUSTMENTS AND REPAIRS.

a. Rule Text. The regulation in §35.34 reads as follows:

**(a) Before and after conducting the tests prescribed in this part, the test article must be subjected to an inspection, and a record must be made of all the relevant parameters, calibrations and settings.**

**(b) During all tests, only servicing and minor repairs shall be permitted. Major repairs or replacement of parts may be allowed, provided that the parts in question are subjected to an agreed level of additional testing. Any unscheduled repair or action on the test article must be recorded and reported.**

b. Guidance. No guidance available.

## 5.3 35.35 CENTRIFUGAL LOAD TESTS.

a. Rule Text. The regulation in §35.35 reads as follows:

**Except for fixed pitch wood or fixed pitch metal propellers of conventional design, it must be demonstrated that a propeller accounting for environmental degradation expected in service complies with paragraphs (a), (b) and (c) of this section without evidence of failure, malfunction, or permanent deformation that would result in a major or hazardous propeller effect. Environmental degradation may be accounted for by adjustment of the loads during the tests.**

**(a) The hub, the blade retention system, and the counterweights must be tested for a period of one hour to a load equivalent to twice the maximum centrifugal load to which the propeller would be subjected during operation at the maximum rated rotational speed.**

**(b) If appropriate, blade features associated with transitions to the retention system, (for example a composite blade bonded to a metallic retention) may be tested either during the test of §35.35(a) or in a separate component test.**

**(c) Components used with or attached to the propeller (for example, spinners, de-icing equipment, and blade erosion shields) must be subjected to a load equivalent to 159 percent of the maximum centrifugal load to which the component would be**

**subjected during operation at the maximum rated rotational speed. This may be performed by either:**

**(1) Testing at the required load for a period of 30 minutes.**

**(2) Analysis based on test.**

b. Conventional Fixed Pitch Propellers.

(1) Fixed Pitch Wood Propellers of Conventional Design**.** A fixed pitch wood propeller of conventional design is a propeller that has the following physical properties:

- One piece laminated wood construction.
- Two or four blades.
- The surface coating does not contribute to the propeller strength.
- The surface coatings only provides environmental protection.

A fixed pitch propeller that has a composite shell over a wood core would not qualify as conventional construction when the composite shell contributes to the strength and frequency response of the propeller. A fixed pitch wooden propeller with a fabric or composite covering, that does not alter the structure, for environmental protection would be considered to be of conventional design.

(2) Fixed Pitch Metal Propellers of Conventional Design**.** A fixed pitch metal propeller of conventional design is a propeller that has the following physical properties:

- One piece construction.
- Two or four blades.

c. Hub and retention test. Guidance for paragraph (a)

(1) The maximum centrifugal load to which the propeller would be subjected during operation within the limitations established for the propeller is based on the maximum rated rpm declared in the Type Certificate Data Sheet. Overspeed limits and overspeeds such as would occur at the overspeed governor setting are not considered normal and do not constitute the maximum rpm to be used for establishing test conditions.

(2) The hub, blade retention, and counter weights may be tested as an assembly either by whirl testing to 141% rpm, where twice centrifugal load occurs, or by applying twice centrifugal load to the assembled components to simulate the centrifugal load ,as appropriate.

(3) The blade retention is that area of the blade that transmits blade centrifugal and bending loads to the hub. Included in the retention are bearing races and other associated components used for the transmission of loads to the hub.

(4) This test does not need to include the complete blade. Stub blades, with weights to establish the correct centrifugal load during whirl tests, can be utilized. The stub blades should have the same blade retention so that similarity to the full blade retention is maintained.

d. Blade Features. Guidance for paragraph (b). Blade features associated such as those associated with transitions from composite blade to the metallic retention can be tested during the hub and retention test or with a separate component test. The blade features are typically associated with the transition from a composite blade to a metallic retention. But other applicable configuration may exist such as the transition associated with a configuration where the blade of any material construction is bonded or otherwise attached to the portion of the blade that is retained in the hub.

e. Propeller Components. Guidance for paragraph (c). Propeller components not requiring twice centrifugal load tests should be subjected to test or analysis equivalent to the centrifugal load equivalent to 126% rotational speed for a period of 30 minutes. These components may also be shown to be acceptable by similarity to existing components with applicable service history. Testing can involve whirl testing, static testing with the assembly or on a component or sub-component level. Analysis methods used to demonstrate compliance for these components should be accepted by the Administrator.

**5.4 35.36 BIRD IMPACT.**

a. Rule Text. The regulation in §35.36 reads as follows:

**It must be demonstrated, by tests or analysis based on tests or experience on similar designs, that the propeller is capable of withstanding the impact of a four-pound bird at the critical location(s) and critical flight condition(s) of a typical installation without causing a major or hazardous propeller effect. This section does not apply to fixed pitch wood propellers of conventional design.**

b. Guidance. Compliance may be based on similarity and service history to existing propeller installations, bird impact testing, or analysis combined with similarity and testing. Both static and rotating tests are acceptable. Both natural and simulated birds are acceptable for use in testing.

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(1) Selection of critical operating conditions. The selection of critical operating conditions is based on an evaluation of the intended use of the propeller, the operating conditions when the propeller will most likely encounter bird populations, and the impact geometry of the propeller. Typical this condition occurs at takeoff when the airspeed is low and the power is high. The result of low airspeed and high power is high impact angle on the propeller. Also, most bird impacts occur close to the ground. The bird population decreases with altitude

(2) Selection of impact site. The field experience with bird impacts shows that the entire span of the blade is capable to receive bird strikes. Therefore, an impact site is chosen to produce maximum blade retention loads to show that the entire blade will not separate and at the same time test for local structural integrity to show any local or tip blade damage. A major contributor to both the resultant retention loads and local damage is the dynamic impact force and the dynamic blade response. Considerations for local structure may also play a role in the final determination of the impact site. Discontinuities in the structure such as ply drops in composite blades may factor into the critical impact location selection. It is recommended that foreign object analyses be used to guide the selection of the impact site when ever possible. Multiple impact tests may be required to determine the critical impact site when other information is unavailable or insufficient.

(3) Selection of the bird. The bird is defined to weigh be four pounds. Natural birds or simulated birds may be used for testing. Although, the composition and geometry of the simulated birds should be acceptable to the Administrator. Care should be taken to assure that the bird or simulated bird has been stored properly so that the physical characteristics are similar to those that exist in nature. Improper storage can change the density and fluid properties of the natural bird or simulated bird. Also, the bird temperature should be appropriate for the test, since temperature has an effect on the properties.

(4) Static or rotating testing. Either static or rotating testing is acceptable. The objective is to simulate a bird strike in controlled manner to assess the resulting blade response and damage. The response of the blade is needed to assess any damage that the bird strike may have on the propeller components were not included in the test. Where ever possible, for static testing, blade hub, retention, and pitch change hardware should be included as part of the test set-up.

(a) Test set up. The test set up should include a method to verify the bird impact velocity, geometry, and the blade response to the impact. This may be accomplished with high speed cameras and instrumentation to record blade strain and load during and following the impact

(b) Damage evaluation. Blade damage evaluation involves pre and post test evaluation of the blades The evaluation for composite blades typically include a combination of:

- Visual examination
- Frequency response tests.
- Blade tap tests for delamination evaluation of composite components.
- Ultrasonic inspection for delamination and internal damage of composite components.
- X-ray inspection for internal damage
- Fluorescent penetrant inspection or magnetic particle inspection of metallic components.

The inspection and evaluation is to determine the changes in the blade for interpretation regarding the structural adequacy of the blade following a bird strike.

(c) Strike Verification. Verification of a successful bird strike should be accomplished. A successful strike should have no more than 10% of the bird is sliced off by the leading edge and passing by the camber side of the blade. The material passing by the camber side of the blade does not contribute to the impact. The bird should also be oriented no more than 10 degrees off axis in any direction.

(5) Any limitations determined from the test results should be entered into the Instructions for Propeller Installation and Operation or in other manuals as appropriate.

**5.5. 35.37 FATIGUE LIMITS AND EVALUATION.**

a. Rule Text. The regulation in §35.37 reads as follows:

**This section does not apply to fixed-pitch wood propellers of conventional design.**

**(a) Fatigue limits must be established by tests, or analysis based on tests, for propeller:**

**(1) Hubs.**

**(2) Blades.**

**(3) Blade retention components.**

**(4) Other components which are affected by fatigue loads and which are shown under §35.15 as having a fatigue failure mode leading to hazardous propeller effects.**

**(b) The fatigue limits must take into account:**

**(1) All known and reasonably foreseeable vibration and cyclic load patterns that are expected in service; and**

**(2) Expected service deterioration, variations in material properties, manufacturing variations, and environmental effects.**

**(c) A fatigue evaluation of the propeller must be conducted to show that hazardous propeller effects due to fatigue will be avoided throughout the intended operational life of the propeller on either:**

**(1) The intended aircraft by complying with §§23.907 or 25.907, as applicable; or**

**(2) A typical aircraft.**

b. Guidance. Guidance material is found in reference 2b(1) AC 35-37-xx, Guidance Material for 14 CFR 35.37 Fatigue Limits and Evaluation, dated xx/xx/xx.

## 5.6 35.38 LIGHTNING STRIKE.

a. Rule Text. The regulation in §35.38 reads as follows:

**It must be demonstrated, by tests or analysis based on tests or experience on similar designs, that the propeller is capable of withstanding a lightning strike without causing a major or hazardous propeller effect. This section does not apply to fixed-pitch wooden propellers of conventional design. The limit to which the propeller has been qualified shall be documented in the appropriate manuals.**

b. Guidance. This guidance provides a brief overview of test methodology used to determine the effect of a lightning on a propeller. Detailed methods, test set-up information on voltage waveforms, current waveforms, or data collection are provided in the reference documents. Advisory circular AC 35-23-xx, Propeller Control Systems, addresses the effects of lightning on electronic controls.

(1) Consideration should be given to all components of the propeller assembly that could be in the lightning path these include but are not limited to the spinner, blade, hub, blade bearings, and possibly the pitch change mechanism. Additional consideration should be given to electrical/electronic components that could be influenced by the indirect effects, these include propeller blade and spinner de-icing system components as well as any other propeller mounted electrical or electronic components.

(2) The damage caused by lightning is characterized into two categories, direct and indirect. The direct effects associated with lightning depend on the structural component involved, the attachment point and current path through the structure. The indirect effects are classified as damage to electrical equipment by the current or voltages either by the associated electromagnetic field, surges, or by current directly injected into the electrical wires.

(a) Indirect effects testing determines the conducted currents, surge voltages, and induced voltages entering the aircraft electrical system through systems such as the propeller de-icing system. Testing involves measurement of voltages at the terminals of the de-icing system or other electrical/electronic systems where they connect to the aircraft electrical system.

(b) The direct effect of lightning is to cause physical damage. The damage caused by lightning is dependent on the strength of the strike and on the construction of the propeller races and bearings.

(3) The information found in the references below provide information regarding test setup, simulated lightning wave forms, other general procedures to conduct a lightning strike test.

(a) AC 20-136, "Protection of Aircraft Electrical. Electronic Systems Against the Indirect Effects of Lightning", March 5, 1990.

(b) AC 20-53A, "Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning", April 12, 1985.

(c) RTCA Document DO-160D, "Environmental Conditions and Test Procedures for Airborne Equipment", July 19, 1997.

(d) Report of SAE Committee AE4L-98-5, “Aircraft Lightning Zoning Standard,” May 1998.

(e) Report of SAE Committee AE4L-97-4, “Aircraft Lightning Environment and Related Test Waveforms Standard,” July 1997.

(f) Report of SAE Committee AE4L, “Lightning Test Waveforms and Techniques for Aerospace Vehicles and Hardware”, June 20, 1978.

(g) Report of SAE Committee AE4L-87-3 Rev. C, “Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning,” Revision C, September 1996.

**5.7 35.39 ENDURANCE TESTS.**

a. Rule Text. The regulation in §35.39 reads as follows:

**Endurance tests on the propeller system must be made on a representative engine in accordance with paragraph (a) or (b) of this section, as applicable, without evidence of failure or malfunction.**

**(a) Fixed-pitch and ground adjustable-pitch propellers must be subjected to one of the following tests:**

**(1) A 50-hour flight test in level flight or in climb. The propeller must be operated at take-off power and rated rotational speed during at least five hours of this flight test, and at not less than 90 percent of the rated rotational speed for the remainder of the 50 hours.**

**(2) A 50-hour ground test at take-off power and rated rotational speed.**

**(b) Variable-pitch propellers must be subjected to one of the following tests:**

**(1) A 110-hour endurance test that must include the following conditions:**

**(i)  Five hours at takeoff power and rotational speed and thirty 10-minute cycles composed of;**

**- acceleration from idle,**

**- five minutes at takeoff power and rotational speed,**

**- deceleration, and**

**- five minutes at idle.**

**(ii)  Fifty hours at maximum continuous power and rotational speed,**

**(iii)  Fifty hours, consisting of ten 5-hour cycles composed of;**

**- five accelerations and decelerations  between idle and takeoff power and rotational speed,**

**- four and one half hours at approximately even incremental conditions from idle up to, but not including, maximum continuous power and rotational speed, and**

**- 30 minutes at idle.**

**(2)  Operation of the propeller throughout the engine endurance tests prescribed in part 33 of this chapter.**

b.  Guidance.  The following definitions and discussions are.

(1)  Test Configuration.  Testing should be conducted with the propeller and all other components required to operate the propeller on an aircraft.  Some components may not be included in the propeller type design.  The engine power output should be at least equal to the propeller take-off and maximum continuous power ratings.  Spinner and de-ice components should be installed during the endurance test.  However, in lieu of this, conduct of a spin-rig test or similarity to a previously tested configuration may be acceptable.

(2)  Propeller diameter.  When the propeller being certified includes more than one acceptable blade design, the diameter of the propeller tested need not be the blades that give maximum propeller diameter.  The blades tested should be ones for which certification is sought and the applicant should show that testing with these blades will represent all other similar blades to be included in the type design.  The blades shall representative of the loading and vibrational characteristics of the propeller for use with

the blade. It is the responsibility of the applicant to supply engineering data to show that the blades utilized during the endurance test will result in the same test conclusions if the blade design differs from the design that the endurance test results will be applicable. In addition testing with blades of different construction than blades for which certification is sought may not be acceptable. For example if both composite and aluminum blade options are to be included the type design both the composite and aluminum blades should be tested.

(3) Representative engine. The engine should be capable of developing the power and speed for which certification of the propeller is sought. The engine vibration should be similar to the intended application for the propeller. For example testing conducted on a turbine engine may not be applicable to show that the propeller is acceptable on a piston engine.

(4) Continuity of test. The endurance test may be continuous or in increments agreed upon between the propeller applicant and the Administrator.

(5) Controls should be operated in accordance with the applicant's instructions (with such minor alterations as the Administrator may permit). The applicant's instructions should be those which are proposed to be incorporated in the propeller manuals.

(6) Stops. The test should be run in accordance with the approved test plan unless agreed to by the authority.

## 5.8. <u>35.40 FUNCTIONAL TEST</u>.

a. <u>Rule Text</u>. The regulation in §35.40 reads as follows:

**The variable-pitch propeller system must be subjected to the applicable functional tests of this section. The same propeller used in the endurance test (§35.39) must be used in the functional tests and must be driven by a representative engine on a test stand or on an aircraft. The propeller must complete these tests without evidence of**

**failure or malfunction.  This test may be combined with the endurance test for accumulation of cycles.**

**(a)  Manually-controllable propellers.  Five hundred  representative flight cycles must be made across the range of pitch and rotational speed.**

**(b)  Governing propellers.  Fifteen hundred complete cycles must be made across the range of pitch and rotational speed.**

**(c)  Feathering propellers.  Fifty cycles of feather and unfeather operation must be made.**

**(d)  Reversible-pitch propellers.  200 complete cycles must be made from lowest normal pitch to maximum reverse pitch selected by the applicant and while at maximum reverse pitch must reach stable power and rotational speed.**

b.  Guidance.  Definitions for the §35.39, Endurance test, are applicable.  The functional tests are intended to substantiate the control function in the propeller system.  This test can be performed in conjunction with the §35.39, Endurance test and §35.42, Components of the propeller control system.

c.  Governing propellers.  The following is an example of a simulated flight cycle that may be used for §35.40 (b) and would be a representative flight cycle for §35.42:

- Ground idle (GI) - stabilize
- Acceleration from GI to takeoff power - transition
- Takeoff power - stabilize
- Takeoff power to maximum continuous power - transition
- Maximum continuos power - stabilize
- Maximum continuous power to cruise power - transition
- Cruise power - stabilize
- Cruise power to descent power - transition
- Descent power - stabilize

· Descent power to reverse power - transition

· Reverse power - stabilize

· Reverse power to GI - transition

c. Feather cycle. The following is an example of a feather cycle that may be used for §35.40 (c):

· GI - stabilize

· GI to feather - transition

· Feather - stop rotation

· Unfeather to GI - transition

e. Reverse cycle. The following is an example of a reverse cycle that may be used for §35.40 (d):

· GI - stabilize

· GI to maximum reverse power - transition

· Maximum reverse power - stabilize

· Maximum power to GI - transition

## 5.9 35.41 OVERSPEED AND OVERTORQUE.

a. Rule Text. The regulation in §35.41 reads as follows:

**(a) When approval of a transient maximum propeller overspeed is sought, it must be shown that the propeller is capable of further operation without maintenance action at the maximum propeller overspeed condition. This may be accomplished by either:**

**(1) Performance of 20 runs, each of 30 seconds duration, at the maximum propeller overspeed condition; or**

**(2) Analysis based on test or service experience.**

**(b) When approval of a transient maximum propeller overtorque is sought, it must be shown that the propeller is capable of further operation without maintenance action at the maximum propeller overtorque condition. This may be accomplished by either:**

**(1) Performance of 20 runs, each of 30 seconds duration, at the maximum propeller overtorque condition; or**

**(2) Analysis based on test or service experience.**

b. Guidance. No guidance available.

## 5.10 35.42 COMPONENTS OF THE PROPELLER CONTROL SYSTEM.

a. Rule Text. The regulation in §35.42 reads as follows:

**It must be demonstrated, by tests or analysis based on tests or service experience on similar components, that each propeller blade pitch control system component, including governors, pitch change assemblies, pitch locks, mechanical stops, and feathering system components, can withstand cyclic operation that simulates the normal load and pitch change travel to which the component would be subjected during the initially declared overhaul period, or a minimum of 1000 hours of typical operation in service.**

b. Guidance. Tests conducted explore all the operating conditions applicable to items of propeller components used in the control (including governors, pitch change assemblies, pitch locks, mechanical stops, and feathering system components, beta control and reverse thrust) of the propeller. The tests may be carried out on suitable rigs or in conjunction with the Endurance tests, §35.39, and Functional tests, §35.40. This test is to identify functionality and wear of the propeller pitch control systems components for the purpose of establishing appropriate instructions for continued airworthiness. The tests should represent the amount of operation which would arise within the initially declared overhaul period, but not less than 1000 hours of operation. Compliance with this section may be shown by a rational analysis based on the results of tests or service experience on similar components.

## 5.11 35.43 PROPELLER HYDRAULIC COMPONENTS.

a. Rule Text. The regulation in §35.43 reads as follows:

**Propeller components that contain hydraulic pressure, and whose structural failure or leakage from a structural failure could cause a hazardous propeller effect must demonstrate structural integrity by performing :**

**(a) A proof pressure test to 1.5 times the maximum operating pressure without permanent deformation or leakage that would prevent performance of the intended function.**

**(b) A burst pressure test to 2.0 times the maximum operating pressures without failure. Leakage is permitted and seals may be excluded from the test.**

b. Guidance. Tests are to be conducted to verify the structural adequacy of the hydraulic components in the event of over pressurization of the system. For the burst pressure test testing should demonstrate structural integrity with no significant fracture. Verification that unacceptable permanent deformation did not take place may be shown by comparing dimensional part measurements before and after test.

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**(This document does not represent final agency action on this matter and should not be viewed as a guarantee that any final action will follow in this or any other form.)**

# Advisory Circular

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|---|---|---|---|
| **Subject: GUIDANCE MATERIAL FOR 14 CFR 35.23 PROPELLER CONTROL SYSTEM.** | **Date:** 12/21/99 | | **AC No:** 35-23-xx |
| | **Initiated By:** | Jay Turnberg ANE-110 | **Change:** A3523v4 |

**1. PURPOSE.** This advisory circular (AC) provides guidance and describes acceptable methods, but not the only methods, for demonstrating compliance with provisions of the requirements of Title 14 of the Code of Federal Regulations (14CFR) §35 pertaining to propeller control systems. Like all AC material, this AC is not, in itself, mandatory and does not constitute a regulation. While these guidelines are not mandatory, they are derived from extensive Federal Aviation Administration (FAA) and industry experience in determining compliance with the pertinent regulations.

**2. RELATED DOCUMENTS.**

a. Related Regulations.

(1) Title 14 Code of Federal Regulations (CFR):

(a) §25.901 Installation.

(b) §23.905 Propellers.

(c) §23.1309 Equipment, systems, and installations.

(d) §25.901 Installation.

(e) §25.905 Propellers.

(f) §25.1309 Equipment, systems, and installations.

(g) §35.3 Instructions for propeller installation and operation.

(h) §35.4 Instructions for Continued Airworthiness.

(i) §35.15 Safety analysis.

(j) §35.42 Components of the propeller control system.

(k) §35.43 Propeller hydraulic components.

b. Advisory Circulars, Notices and Policy Letters/Memoranda.

(1) AC 20-53B, Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning, dated April, 22, 1991.

(2) AC 20-115B, Radio Technical Commission for Aeronautics, Inc. RTCA/DO-178B dated January 11, 1993. RTCA, Inc. Document RTCA/DO-178B, dated January 11, 1993. (Calls attention to RTCA Document No. DO-178B, "Software Considerations in Airborne Systems and Equipment Certification" issued December 1992).

(3) AC 20-136, Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning, dated May 3, 1990.

(4) AC 21-16D, RTCA Document No. DO-160D, dated July 21, 1998. (Calls attention to RTCA Document No. DO-160D, "Environmental Conditions and Test Procedures for Airborne Equipment, dated July 29, 1997.)

(4) AC 23.1309-1C, "Equipment, Systems, and Installations in Part 23 Airplanes", 3/12/99

(5) AC 25.1309-1A, "System Design and Analysis", 6/21/88

(6) Federal Aviation Administration (FAA) Notice N8110.71, Guidance For The Certification of Aircraft Operating in High Intensity Radiated Field (HIRF) Environments, issued April 2, 1998.

(7) Policy Memorandum, - "Federal Aviation Administration (FAA) Engine and Propeller Directorate Policy Regarding Time Limited Dispatch (TLD) Of Engines Fitted With Full Authority Digital Engine Control (FADEC) Systems" dated October 28, 1993

(8) Policy Memorandum, - Federal Aviation Administration (FAA) Engine and Propeller Directorate Policy Regarding Integrated Full Authority Digital Engine Control (FADEC) and Electronic Propeller Control (EPC) Systems, dated Jan. 30 1995.

c. Joint Airworthiness Authority (JAA) Advisory Documents.

(1) ACJ P-230, Propeller Control Systems, dated xx/xx/xx.

d. Industry Documents.

(1) RTCA Document No. DO-160D (EUROCAE ED14D), Environmental Conditions and Test Procedures for Airborne Equipment, dated July 29, 1997.

(2) RTCA Document No. DO-178B (EUROCAE ED12D), Software Considerations in Airborne Systems and Equipment Certification, dated December 1, 1992.

(3) SAE AE4L-87-3 Revision C, Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning, Dated September 1996.

(4) SAE AE4L-97-4, Aircraft Lightning Environment and Related Test Waveforms Standard, Dated July 1997.

(5) SAE AE4L-98-5, Aircraft Lightning Zoning Standard, Dated May 1998.

(6) SAE APR 4754, Certification Considerations for Highly-Integrated or Complex Aircraft Systems, issued November 1996.

(7) SAE ARP 4761, Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems, issued December 1996.

(8) SAE ARP 4874 Electronic Propulsion Control/Aircraft Interface Control Documents.

e. Military Specifications.

(1) MIL-STD-461D, Requirements For the Control of Electromagnetic Interference Emissions and Susceptibility, dated January 11, 1993.

(2) MIL STD-462D, Measurement of Electromagnetic Interference Characteristics, Test Standard For, dated February 5, 1996.

(3) MIL-STD-810E, Environmental Test Methods and Engineering Guidelines, dated July 31, 1995.

(4) MIL-HDBK-217F, Reliability Prediction of Electronic Equipment, dated February 28, 1995.

(5) MIL-HDBK-179A, Microcircuit Acquisition Handbook, dated July 20, 1995.

**3. DEFINITIONS.**

a. Alternate Control or Operating Mode(s). For the purposes of this AC, an alternate control or operating mode is one where the operating characteristics or capabilities are sufficiently different from the "normal mode" such that the operating characteristics or capabilities of the aircraft, crew workload, or what constitutes appropriate crew procedures may be significantly affected.

b. Detected Faults or Failures. Detected faults are component functional failures that are detected by the pilot, or are announced to the pilot, or are recorded by the system for subsequent accommodation.

c. Electronic Propeller Control System (EPCS). This is a general term that encompasses electronic propeller controls of all levels of authority, including full authority digital electronic controls and electrical/electronic sub-systems that control a specific propeller function, e.g. syncrophasing, autofeather or overspeed.

d. Failure Conditions. A condition having an effect on either the airplane or its occupants, or both, either direct or consequential, which is caused or contributed to by one or more failures or errors considering the flight phase and relevant adverse operational or environmental conditions or external events. Failure Conditions, as defined in AC 23.1309-1C (reference 2b4) may be classified according to their severity as follows:

(1) No safety effect. Failure conditions that would have no affect on safety (that is, Failure Conditions that would not affect the operational capability of the airplane or increase crew workload).

(2) Minor. Failure conditions that would not significantly reduce airplane safety and involve crew actions that are well within their capabilities. Minor failure conditions may include a slight reduction in safety margins or functional capabilities, a slight increase in crew workload (such as routine flight plan changes), or some physical discomfort to passengers or cabin crew.

(3) Major. Failure conditions that would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be a significant reduction in safety margins or functional capabilities; a significant increase in crew workload or in conditions impairing crew efficiency; or a discomfort to

the flight crew or physical distress to passengers or cabin crew, possibly including injuries.

(4) Hazardous. Failure conditions that would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be the following:

(a) A large reduction in safety margins or functional capabilities;

(b) Physical distress or higher workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely; or

(c) Serious or fatal injury to an occupant other than the flight crew.

(5) Catastrophic: Failure Conditions that are expected to result in multiple fatalities of the occupants, or incapacitation or fatal injury to a flight crewmember normally with the loss of the airplane.

e. Hazardous propeller effects. The following are regarded as hazardous propeller effects:

(1) A significant overspeed of the propeller.

(2) The development of excessive drag.

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

(4) A release of the propeller or any major portion of the propeller.

(5) A failure that results in excessive unbalance.

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

f. Local Events. Local events are failures of aircraft systems and components, other than the propeller and its control, that may affect the installed environment of the propeller control system.

g. Major propeller effects. The following are regarded as major propeller effects for variable pitch propellers:

(1) An inability to feather the propeller for feathering propellers.

(2) An inability to command a change in propeller pitch.

(3) A significant uncommanded change in pitch.

(4) A significant uncontrollable torque or speed fluctuation.

h. Normal operation. Operation with a fully functional propeller system with no faults or failures.

i. Significant uncommanded change in pitch. To facilitate propeller system safety analysis, design and certification in the absence of a application specific definition; a significant uncommanded change in pitch should be considered as that equivalent to a change that would result in more than a 10% change in thrust at the rated speed condition at any operating condition. However, final determination of the installation requirement is based on aircraft controllability requirements and must be evaluated during aircraft certification.

j. Significant uncontrollable speed fluctuation. To facilitate propeller system safety analysis, design and certification in the absence of an application specific definition; significant uncontrollable speed fluctuation is defined as the loss of capability to modulate and maintain rotational speed within 3% of reference speed at all normal operating conditions.

## 4. BACKGROUND.

a. The purpose of §35.23 is to set objectives for the general design and functioning of the propeller control system. These requirements do not replace or supersede other requirements. Therefore, individual components of the control system, such as pumps, sensors, actuators, should be covered additionally in other paragraphs of part 35, as appropriate.

b. The requirements of §35.23 are also applicable to the propeller control when it is incorporated into the aircraft or engine type design. When the propeller control is included in the propeller type design these requirements are applicable to the propeller applicant. Alternatively, if the propeller control is not included in the propeller type design but is included in either the aircraft or engine type design these requirements are applicable to the aircraft or engine applicant as specified in §§23.905, 25.905, and 33.5. This provides a uniform standard for propeller control systems.

c. One of the objectives for a propeller certification program is to show that the certificated propeller is “installable” in a particular aircraft or aircraft type. In the case where the application is unknown at the time of propeller certification, to achieve this objective the applicant should make reasonable installation and operational assumptions for the target application.

d. It is recognized that propeller system compliance with applicable aircraft certification regulations (e.g., §§ 23/25.33, 23/25.905, 23/25.933, 23/25.937, 25.1027, 23/25.1309 and others) is determined by the cognizant aircraft certification office. However, to support the objective to have an installable propeller, there should be early coordination between the applicant and the installer, as well as the relevant Federal

Aviation Administration (FAA) certification offices, to ensure an installable propeller. It is the aim of the FAA to help ensure the propeller applicant is aware of possibly more restrictive regulations in the installed condition. It should be noted that installation limitations or operational issues will be noted in the Instructions for propeller installation and operation.

**1. SECTION 35.23 - GENERAL.**

a. Rule Text. The regulation §35.23 reads as follows: **"The requirements of this section are applicable to any system or component that controls, limits or monitors propeller functions."**

b. Guidance. The regulation is applicable to all types of propeller control systems. These might be mechanical, hydro-mechanical, hydro-mechanical with a limited authority electronic supervisor, single channel full authority propeller control with hydro-mechanical back-up or dual channel full authority electronic propeller control or any other combination. The electronic technology can be analog or digital.

**2. SECTION 35.23(a).**

a. Rule Text. The regulation §35.23(a) reads as follows: **"The propeller control system must be designed, constructed and validated to show that:"**

b. Guidance. Validation may be accomplished by propeller tests, rig tests, bench tests, analysis, similarity or any combination thereof.

**3. SECTION 35.23(a)(1).**

a. Rule Text. The regulation §35.23(a)(1) reads as follows: **"The propeller control system, operating in normal and alternative operating modes and transition between operating modes, performs the intended functions throughout the declared operating conditions and flight envelope."**

b. Guidance. The intent of this rule is to ensure that all control modes including those which occur as a result of control failure or fault accommodation strategies, are implemented in a manner which continues to be compliant with part 35 requirements Coordination should take place with the installer to assure that control failure or fault accommodation strategies are consistent with the aircraft requirements.

(1) Descriptions of the functioning of the control system operating in its normal (primary) and any alternative modes are provided in the Instructions for propeller installation and operation. As a minimum the control should consider the following capability in all operating modes and transitions between modes:

(a) A means to control rotational speed within declared limits over the required range of propeller operating conditions.

(b) The avoidance of pitch change fluctuations of sufficient magnitude to impact satisfactory control of the aircraft.

(c) Where protective functions are required to satisfy the requirements of §§35.15, 35.21, and 35.22 these should be provided for all control modes including any alternative or back-up modes.

(d) All control modes, including alternative or back-up modes, should be capable of operating in the environmental conditions, including high intensity radiated fields (HIRF) and lightning, declared in the Instructions for propeller installation and operation.

(3) It is acceptable to use the propeller endurance test and functional tests defined in §35.39 and §35.40 using the primary full-up control system. However it must be demonstrated by test or analysis based on test that the propeller can meet the defined criteria when operating in any alternative or back-up control mode. Adding some portion to the propeller endurance test and functional test in the alternate or back-up mode(s), including transition between modes, can be used as part of system validation, if desired. The durability of the control system is addressed by the component testing of §§35.42 and 35.43.

(4) If the applicant seeks to take credit for Time Limited Dispatch (TLD) potentially provided by a redundant system configuration, the intent of the Policy Memorandum on TLD (reference 2b(7)) should be satisfied.

**4. SECTION 33.23(a)(2).**

a. Rule Text. The regulation in §35.23(a)(2) reads as follows: **"The propeller control system functionality is not adversely affected by the declared environmental conditions, including temperature, electromagnetic interference (EMI), high intensity radiated fields (HIRF) and lightning. The environmental limits to which the system has been satisfactorily validated must be documented in the appropriate propeller manuals."**

b. Objective. The objective of this requirement is to demonstrate that the control system can function in it's installed environment and declare those environmental limitations as part of the type design characteristics in the instructions for propeller installation and operation.

(1) When the installer specifies the environmental conditions of the installation, compliance with this requirement can be demonstrated by environmental testing meeting the specified installation requirements.

(2) When the installation requirements are not specified, environmental testing should be conducted to demonstrate that the control system can be installed in a typical installation for which the control system is designed.

(3) Electronics may be sensitive to lightning and other electromagnetic interference. Therefore, electronic controls are designed with protections to compensate for this sensitivity. For compliance, the system design must demonstrate the functional integrity of the control system should be demonstrated when subjected to designated levels of electromagnetic disturbances.

(4) Hydro-mechanical and mechanical control systems have not been sensitive to lightning and other electromagnetic interference. Compliance may be shown by similarity to existing designs with service experience.

c. <u>Environmental Testing</u>. All components of the control system, including all electronics units, sensors, harnesses, hydro-mechanical elements, and any other relevant elements/units, are required to be tested to establish that they will operate properly in their declared environment. Where applicable, tests defined in RTCA DO-160D (reference 2d(1)) to agreed category levels have been accepted. Environmental tests in accordance with military standards, e.g. MIL-STD-810E and MIL-STD-461D / 462D (references 2e(3) and 2e1 / 2e(2)), will be accepted in lieu of RTCA DO-160D tests where the MIL tests are equal to or more rigorous than those defined in RTCA DO-160D. FAA approval of environmental test plans should be obtained prior to the commencement of the tests. Although the FAA does not specify the environmental test limits, environmental tests are required to be representative of the environments that are expected to be encountered in the propeller installation.

(1) The applicant should prepare an environmental test plan that is summarized in an environmental test matrix that defines the method to be used to qualify each component for each of it's environments. The components may be qualified by test, similarity, analysis and combinations thereof.

(2) Environmental tests, such as those for electromagnetic effects including high intensity radiated fields (HIRF) and lightning, that are discussed in this section.

(3) In some cases, the testing required for the propeller tests under endurance and functional tests, §§35.39 and 35.41, may be adequate to qualify components for some or all of the environmental requirements. Otherwise, additional tests are required.

c. <u>Validated Environmental Qualification Levels</u>. The environment to which the component is qualified should be entered into the Instructions for propeller installation and operation, and is considered to be an installation limitation for the installer. For aircraft certification, the installer should substantiate that these levels are adequate. Validation that the component qualification limits are adequate for installation will be required prior to aircraft certification.

f. System Test Configuration Considerations. HIRF, lightning, and EMI tests have generally been conducted as system tests on closed loop real time simulation laboratory setups provided with hydraulic pressure to move actuators to close the actuating loops. A simplified engine simulation may be used to close the engine loop.

(1) The tests should be conducted with the control system controlling the propeller at the most sensitive operating points. (These may be different operating point for the three different tests, HIRF, lightning, and EMI.) The system should be exposed to the HIRF, lightning, and EMI environmental threats while operating at the selected condition.

(2) The criteria for HIRF and lightning should be established prior to testing. The "no effect" or "system upsets" on the operation or operational characteristics of the system should be defined. The following results are examples of test failures:

(a) Transfers to alternate channels, backup hydro-mechanical systems, or reversionary modes.

(b) Component damage.

(c) Spurious fault codes recorded in fault memory.

(d) False fault annunciation to the flight crew.

(e) Erroneous operation of a control mode that would require corrective action, increased crew workload or create a potentially hazardous condition.

(f) Erroneous operation of a protective function; e.g. overspeed or auto-feather circuits.

g. Open Loop Laboratory Tests. If the applicant elects to conduct tests in open loop setups, the following factors should also be considered:

(1) The test software should be developed and implemented by guidelines defined for appropriate software levels of at least equal to the Level, in RTCA DO-178B (reference 2d(2)) that the control system is to be qualified to.

(2) The system test setup should be instrumented to monitor both the output drive signals and the input signals.

(3) All results should be analyzed on a validated propeller system simulation.

h. HIRF Test Requirements. When the installation is known, coordination is recommended between the applicant and the installer to establish appropriate test levels.

It should be noted that the agreed upon test levels may prevent the propeller from being installed on other installations without additional testing.

(1) If for this particular reason or because the aircraft application is not known or defined at the time of the propeller certification, the applicant may use the HIRF threat defined at the aircraft level in FAA Notice, N8110.71, "Guidance for the Certification of Aircraft Operating in High Intensity Radiated Fields (HIRF) Environments" (reference 2b(6)).

(2) The applicant should use the test guidelines provided in Section 20 of RTCA DO-160D for category "W".

j. Lightning Test Requirements. Lightning tests should follow the guidelines of AC 20-136 (reference 2b(3)) and Section 22 of RTCA DO-160D. Multiple Stroke (MS) and Multiple Burst (MB) tests may be conducted on the system connected on the test bench.

(1) MS Lightning Tests. Low level lightning test(s) should be conducted to establish propeller cable shield current levels. Low level tests have been used to establish the waveforms and current levels coupled on to the cables for the MS tests. The shield current level has been on the order of 1000 to 2000 amperes. These levels are typically determined by low current level lightning tests on the propeller without the full benefit of nacelle attenuation and, therefore, should be conservative. Although the FAA does not mandate the shield current level to be used in an MS lightning test, the applicant should demonstrate that the level is a realistic level for the category of propeller and its application.

(2) MB Lightning Tests. MB tests using Waveform 3 or Component H defined in AC 20-136 are an accepted test standard.

(3) Pin Injection Tests (PIT). PITs are normally conducted on the components at levels and test waveforms selected as appropriate from the tables of Section 22 of RTCA DO-160D. Systems satisfactorily tested to waveform set designation B4E4 have in general been found to satisfy the specific established aircraft environment.

(4) Aircraft/Propeller Certification Lightning Tests. The applicant should note that each installer installing a propeller must determine the levels to which the installed propeller and control system will be exposed for the particular aircraft, and demonstrate that these levels are equal to or less than the levels that were used for propeller certification testing. If this is not the case, additional control system lightning tests may be needed to show compliance with aircraft certification requirements.

k. Maintenance Requirements. Section 35.4 and Appendix A to part 35 require that the applicant prepare Instructions for Continued Airworthiness (ICA) for the propeller. As part of the ICA a maintenance plan must be provided. Therefore, those features required by the system to meet the qualified levels of HIRF and lightning, requires that a maintenance plan be provided to ensure the continued airworthiness of the installed systems.

l. Time Limited Dispatch (TLD) Environmental Tests. Where TLD is declared for certification, HIRF and lightning tests at the worst case for TLD configuration are usually conducted for certification. For these conditions on a redundant dual channel system, applicants have usually determined that the single channel dispatch configuration is the worst case dispatch configuration and have conducted HIRF and lightning tests with one channel inoperative to demonstrate compliance. For other environments, the applicants have complied by analysis and statements of compliance.

**5. SECTION 33.23(a)(3).**

a. Rule Text. The regulation in §35.23(a)(3) reads as follows: **"A method is provided to indicate that an operating mode change has occurred if flight crew action is required. In such an event, operating instructions must be provided in the appropriate manuals."**

b. Guidance. In general, transition to an alternative mode should be accomplished automatically by the control system. However, systems have been found to be acceptable wherein pilot action is required to engage the back-up mode providing the process did not result in excessive workload or loss of capability to cope with adverse operating conditions. For instance, a fault in the primary system may result in a "failed-fixed" and some action is required by the pilot to engage the back-up system in order to modulate propeller speed or blade angle.

**6. SECTION 33.23(b).**

a. Rule Text. The regulation in §35.23(b) reads as follows: "**The propeller control system must be designed and constructed so that, in addition to compliance with §35.15:**

b. Guidance. None available.

**7. SECTION 33.23(b)(1).**

a. Rule Text. The regulation in §35.23(b)(1) reads as follows: **"A level of integrity consistent with the intended aircraft is achieved."**

b. Guidance. The level of integrity is defined as that of maintaining an upper bound on the rate of control system failure that is consistent with the intended aircraft requirements. Early coordination with the installer is recommended to assure the level of integrity has been achieved. Acceptable system reliability rate may be achieved by using alternate or backup modes that may have reduced functionality.

**8. SECTION 33.23(b)(2).**

a. Rule Text. The regulation in §35.23(b)(2) reads as follows: **"No single failure or malfunction of electrical or electronic components in the control system results in a hazardous propeller effect.**

b. Guidance. Compliance with the single failure requirements should be demonstrated by the system safety assessment. A functional hazards assessment of the control system considering the propeller system and the intended application, should be conducted to identify the hazards to be included in the system safety assessment. These hazards may be in addition to those identified in §35.15. If the intended application is not known the failure conditions identified in §35.15 establish a minimum. The applicant should complete and submit for approval a safety analysis for the control system, addressing all declared dispatchable control configurations. Data used in the safety analysis should be capable of being substantiated.

**9. SECTION 33.23(b)(3).**

a. Rule Text. The regulation in §35.23(b)(3) reads as follows: **"Failures or malfunctions directly affecting the propeller control system in a typical aircraft, such as structural failures of attachments to the control, fire, or overheat, do lead to a hazardous propeller effect.**

b. Guidance. This requirement considers local events.

(1) Whatever the local event, the behavior of the propeller control system must not cause a hazardous propeller effect.

(2) An overheat condition exists when the temperature of the propeller control is greater than the maximum operating temperature declared by the applicant in the instructions for propeller installation and operation. The propeller control system should not cause a hazardous propeller effect when the control is exposed to a continuous overheat or over-temperature condition. Specific design features or analysis methods may be used to show compliance with respect to the prevention of hazardous propeller effects. Where this is not possible, for example, due to the variability or the complexity of the failure sequence, then testing may be required.

(3) The applicant should demonstrate by analysis or test that when any EPC system component input or output electrical connection is open circuited or shorted to ground, the system behaves in a safe and predictable manner. In addition, it should be shown that any EPC system component connector that becomes disconnected while the propeller is operating does not cause a hazardous propeller effect.

(4) The applicant should demonstrate by analysis or test that hydraulic or lubricating leaks do not result in a hazardous propeller effect.

(6) The applicant should demonstrate by test or analysis that mechanical disruptions that could sever connections or impact and damage propeller control system components do not result in hazardous propeller effects. It is recognized that evaluation of this design feature is installation dependent in many cases, and that the evaluation of the considerations in the design for mechanical disruptions may have to be considered on a case-by-case basis.

## 9. SECTION 33.23(b)(4).

a. Rule Text. The regulation in §35.23(b)(4) reads as follows: **"The loss of normal propeller pitch control does not cause a hazardous propeller effect under the intended operating conditions."**

b. Guidance. This requires that the propeller have a protection system or back-up device such as an overspeed governor, counter weights, pitch lock, low pitch stop and etc.

c. Protection System Requirements. This section applies to propeller designs requiring a dedicated protection control function to prevent a hazardous failure condition. Two categories of malfunction need to be considered: those resulting from external causes such as engine failures and aircraft flight conditions and those caused by propeller control system failures. If a control system protection function is necessary, the protection system should be evaluated with regard to functionality and reliability as part of the propeller control system.

(1) For compliance with §35.21 and §35.23 the overspeed protection system should meet the following requirements:

(a) The combined normal or primary propeller control and protection system must be at least two faults or failures removed from a potential hazardous propeller effect, where one of the failures can be considered to be that causing the failure condition e.g., a single failure mode shall not result in unintended movement below the in-flight low pitch position. In this case, a potential overspeed or high drag condition will only be possible as a result of a first fault causing a low pitch command and an independent fault preventing the protection system from operating.

(b) The analysis should show that the probability per flight hour of a control system failure condition from any cause in combination with failures of the appropriate protection system is less than extremely improbable, $10^{-7}$ or less per flight hour. The overall probability should be established for the intended installation to assure that the propeller is installable. Some installations require $10^{-9}$ or less per flight hour to be shown for unintended movement below the in-flight low pitch position.

(c) The probability of the protection system, failing to operate when required, should be on the order of $10^{-4}$ or less per flight hour.

(d) The probability of an inadvertent operation of the protection system should be commensurate with the failure consequences.

(e) Dedicated protection systems, where they are provided to prevent a hazardous propeller effects, are a necessary function for dispatch. Therefore, the protection system should be tested in a manner commensurate with the intended installation and the reliability of the protection system.

**10. SECTION 33.23(b)(5).**

a. Rule Text. The regulation in §35.23(b)(5) reads as follows: **"The failure or corruption of data or signals shared across propellers does not cause a major or hazardous propeller effect."**

b. Common Mode Faults. In the exchange of data with the aircraft, consideration should be given to elimination of unacceptable common mode faults affecting the operation of more than one engine or propeller. Common faults that affect propeller protection limit systems or could hazard the aircraft would generally be unacceptable. In particular, the following cases should be considered:

(1) Erroneous data received from the aircraft or engine by the propeller control system, if the data source is common to more than one propeller (e.g., air data sources, synchronizing controls).

(2) Control system operating faults propagating via data links between propellers (e.g., maintenance recording, common bus, cross-talk, auto-feathering, automatic power reserve (APR)system.).

(3) Loss or interruption of aircraft data or electrical power used by the propeller control, when that loss or interruption is caused by the failure of another propeller system.

(4) Exchange of data between propellers to implement control functions, (e.g synchrophasing) should be shown to incorporate authority limits in order to prevent unacceptable common mode loss of control.

(5) Logic included in the control system to accommodate the faults considered in items (1) to (4) above should be demonstrated. Any precautions needed to address common effects may be taken either through the aircraft system architecture or by logic internal to the propeller control system. These precautions should be described in the instructions for propeller installation and operation. This may be demonstrated as part of the EPC system validation test program.

**11. SECTION 33.23(c).**

a. Rule Text. The regulation in §35.23(c) reads as follows: **"Electronic propeller control system imbedded software must be designed and implemented by a method approved by the Administrator that is consistent with the criticality of the performed functions and minimizes the existence of software errors."**

b. Intent of Rule. The intent of §35.23(c) is that EPC system software undergo a sufficient level of design assurance testing to ensure, with a high level of confidence, such that errors in the software are prevented, and that the FAA approve the method used to design and implement the software.

c. Guidance. The following paragraphs provide guidance material for a method of compliance with §35.23(c), but should not be considered to be the only method of compliance for this particular regulation. Compliance with this subparagraph should be accomplished by software design and implementation in accordance with an approved method, such as RTCA DO-178B, in combination with system validation testing.

(1) Software Level Requirement. The level of confidence relative to error prevention in the software is directly related to the extent of effort of the design assurance activity. These design assurance levels of effort have been defined in terms of software levels. These levels have been correlated to EPC functional criticality. The FAA has accepted EPC software validation and verification to a specified software level as substantiation of the error prevention requirement. The following is provided for determination of software level:

(a) The RTCA DO-178B documents represents an acceptable method of software validation and verification.

1 The required software level should be a function of the failure condition criticality of EPC functions and should be determined from the safety analysis.

2 RTCA DO-178B software level A should be used for EPCs on part 25 and part 23 commuter category aircraft.

3 RTCA DO-178B software level B or greater should be used for EPCs on part 23 aircraft, subject to confirmation by the safety analysis. It should be noted that for reversible propellers unintended movement of the propeller blades below the established minimum in-flight low-pitch position has been known to prevent continued safe flight and landing on some aircraft. Therefore, the software level should be addressed accordingly.

4 For either part 25 or part 23 aircraft lower levels of software can be used as an exception under some circumstances as acceptable to the aircraft certification requirements, such as:

(aa) EPCs equipped with a electromechanical, hydro-mechanical, or mechanical backup system, subject to confirmation by the safety analysis.

(bb) EPCs on non-reversing and non-feathering propellers, subject to confirmation by the safety analysis.

(2) All software changes to EPCs are defined as major (class 1) changes unless specifically exempted for certification.

**12. SECTION 33.23(d).**

a. Rule Text. The regulation in §35.23(d) reads as follows: **"The propeller control system must be designed and constructed so that the failure or corruption of aircraft-supplied data does not result in hazardous propeller effects."**

b. Failure of Aircraft-Supplied Data. "Aircraft Data", in this context, includes all analog, discrete and digital data provided by the aircraft systems to the EPC. The applicant should define in the instructions for propeller installation and operation the impact of the failure of aircraft data on the propeller characteristic throughout the flight envelope. The above data should be provided for all allowable propeller control and aircraft dispatch configurations where loss of aircraft power or data in that dispatch configuration would result in a different control system response.

**13. SECTION 33.23(e).**

a. Rule Text. The regulation in §35.23(e) reads as follows: **"The propeller control system must be designed and constructed so that the loss, interruption or abnormal characteristic of aircraft supplied electrical power does not result in hazardous propeller effects. The power quality requirements must be described in the appropriate manuals."**

b. Failure of Aircraft-Supplied Power. The applicant should provide an analysis, based on testing, that substantiates the function of EPC system with the failure or interruption of aircraft-supplied power at any point within the declared propeller-operating envelope.

**14. PROPELLER INSTALLATION AND OPERATION MANUAL §35.3.**

a. The following information regarding the propeller control system description, characteristics and authority, in both normal operation and failure conditions, and the range of control of other controlled functions, should be specified in the instructions for installing and operating the propeller submitted in compliance with §35.3.

(1) Control System Description. The applicant should include a brief control system description and may reference a more detailed system description document.

(2) Interface Description. The description should specify all of the physical, electrical, and functional interface requirements of the control system. The following are examples of the types of information that should be included for EPCs:

(a) EPC power requirements and quality, including interrupt limitations, should be defined.

(b) Impedance and buffering limitations for the signals provided by the EPC system for display and instrumentation should be specified.

(c) Signals used by the EPC, such as air data information, should be specified to ensure that the EPC system is adequately isolated and unaffected by other systems using these signals.

(d) Subtle interface requirements, such as power interrupt tolerance of the EPC, should be clearly defined.

(3) Operational Description. The instructions for installing and operating the propeller should contain a description of the control system operating characteristics in both the normal and alternate control or operating modes.

(a) Restrictions in the flight envelope or unusual operating characteristics in these alternate modes should be clearly defined.

(b) Abnormal control characteristics that could have an impact on crew procedures, training, workload, or any other aspects of aircraft performance and/or operating characteristics should be identified for evaluation during aircraft certification.

(c) Control system "output information" to the cockpit, indicating faults, should be described.

(4) Substantiation Data. Data from safety analyses, environmental testing, and software level determinations that will assist the installer to safely install the propeller should be included or referenced in the instructions for installing and operating the propeller. Specific data that should be included, but is not limited to, is as follows:

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(5) System Safety Analysis. The estimated reliability of, or the failure rates for, safety significant failure conditions and the other control system associated events as determined from the system safety analysis.

(6) Environmental Testing. The types and levels of environmental exposure for which the control system has been successfully qualified (e.g. vibration, temperature, HIRF, lightning, etc.) should be stated. For the HIRF, lightning and EMI qualification tests, the interfacing aircraft cables used for the tests.

(7) Software Validation and Verification. The documentation submitted in support of the software certification should be stated.

**DRAFT -- version 4.0 -- 12/21/99**

**(This document does not represent final agency action on this matter and should not be viewed as a guarantee that any final action will follow in this or any other form.)**

# Advisory Circular

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|---|---|---|---|
| **Subject: GUIDANCE MATERIAL FOR 14 CFR 35.37 FATIGUE LIMITS AND EVALUATION.** | **Date:** 12/21/99 | | **AC No:** 35-37-xx |
| | **Initiated By:** | Jay Turnberg ANE-110 | **Change:** A3537v5 |

**1. PURPOSE.** This advisory circular (AC) provides guidance and describes acceptable methods, but not the only methods, for demonstrating compliance with provisions of the requirements of Title 14 of the Code of Federal Regulations (14CFR) §35 pertaining to fatigue limits and fatigue evaluation of propellers. Like all AC material, this AC is not, in itself, mandatory and does not constitute a regulation. While these guidelines are not mandatory, they are derived from extensive Federal Aviation Administration (FAA) and industry experience in determining compliance with the pertinent regulations.

**2. CANCELLATION.** AC 35.37-1 Composite Propeller Blade Fatigue Substantiation, May 11, 1983, is canceled.

**3. RELATED DOCUMENTS.**

a. Related Regulations.

(1) Title 14 Code of Federal Regulations (CFR):

(a) §35.4 Instructions for Continued Airworthiness

(b) §35.15 Safety analysis

(c) §23.907 Propeller vibration and fatigue

(d) §25.907 Propeller vibration and fatigue

(2) Joint Airworthiness Authority (JAA) Requirements:

(a) JAR-P 370 Fatigue Limits and Evaluation.

(b) JAR-P Sub-Section D, Propeller Vibration and Fatigue Evaluation.

b. Advisory Circulars.

(1) AC 20-107A, Composite Aircraft Structure, dated 4/25/84.

(2) AC 20-66-xx, Vibration and Fatigue Evaluation of Propellers, dated xx/xx/xx.

(3) AC 21-26, Quality Control for the Manufacture of Composite Structures, dated 6/26/89.

(4) AC 25.571-1C, Damage Tolerance and Fatigue Evaluation of Structure, Dated 4/29/98.

c. Joint Airworthiness Authority (JAA) Advisory Circulars.

(1) ACJ P-370, Fatigue limits and evaluation, dated xx/xx/xx.

(2) ACJ P-550, Fatigue verification, dated xx/xx/xx.

d. Related Reading Material.

(1) Report No. NADC-87042-60(DOT/FAA/CT-86/39), "Certification Testing Methodology for Composite Structure Volume I – Data Analysis & Volume II – Methodology Development", R.S. Whitehead, H.P. Kan, R. Cordero, E.S. Saether, Northrop Corporation Aircraft Division, Naval Air Development Center, October 1986.

**4. DEFINITIONS**. For the purposes of this AC, the following definitions are provided.

a. Damage tolerance is the attribute of the structure that permits it to retain its required residual strength for a period of use after the structure has sustained a given level of fatigue, corrosion, accidental or discrete source damage.

b. End of life condition. The physical condition of the component defined during certification when it will be considered to have the maximum extent of damage while still maintaining sufficient residual strength to meet all airworthiness loading requirements.

c. Fail-safe is the attribute of the structure that permits it to retain its required residual strength for a period of unrepaired use after the failure or partial failure of a principal structural elements.

d. Hazardous propeller effects. The following are regarded as hazardous propeller effects:

(1) A significant overspeed of the propeller.

(2) The development of excessive drag.

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

(4) A release of the propeller or any major portion of the propeller.

(5) A failure that results in excessive unbalance.

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

e. Load factor is a factor applied to decrease the load or stress level on an S-N diagram as appropriate, (Figure 2).

f. Life factor is a factor applied to decrease the number of cycles on an S-N diagram as appropriate, (Figure 2).

g. Limit loads are the maximum loads expected in service.

h. Principal structural element is an element that contributes significantly to the carrying of propeller loads, and whose integrity is essential in maintaining the overall structural integrity of the propeller.

i. Safe-life of a structure is that number of events such as flights, landings, or flight hours, during which there is a low probability that the strength will degrade below its design value due to fatigue cracking.

j. Scatter factor. A life reduction factor used in the interpretation of fatigue analysis and test results.

k. Stress ratio (R). For repeated stress cycles this is the ratio of the minimum stress to the maximum stress, $R = \sigma_{min} / \sigma_{max}$.

**5. DISCUSSION.** Propellers are continuously subjected to steady and vibratory stresses under many different operating conditions on an aircraft while in flight and on the ground. Therefore, fatigue limits must be determined and a fatigue evaluation must be conducted to show compliance with §35.37 and to provide data that supports installation of the propeller on an aircraft. Section 35.37, shown below, requires fatigue limits to be developed in paragraph (b) and requires that a fatigue evaluation be conducted in paragraph (c). Paragraph (a) establishes that these requirements are not needed for fixed pitch wooden propellers of conventional design.

The regulation in §35.37 reads as follows:

> **This section does not apply to fixed-pitch wood propellers of conventional design.**
>
> **(a) Fatigue limits must be established by tests, or analysis based on tests, for propeller:**
>
> > **(1) Hubs.**
> > **(2) Blades.**
> > **(3) Blade retention components.**
> > **(4) Other components which are affected by fatigue loads and which are shown under §35.15 as having a fatigue failure mode leading to hazardous propeller effects.**
>
> **(b) The fatigue limits must take into account:**
>
> > **(1) All known and reasonably foreseeable vibration and cyclic load patterns that are expected in service, and**
> > **(2) Expected service deterioration, variations in material properties, manufacturing variations, and environmental effects.**
>
> **(c) A fatigue evaluation of the propeller must be conducted to show that hazardous propeller effects due to fatigue will be avoided throughout the intended operational life of the propeller on either:**
>
> > **(1) The intended aircraft by complying with §§23.907 or 25.907 as applicable, or**
> > **(2) A typical aircraft.**

Since the rate of accumulation of stress cycles for propeller blades, hubs and other propeller components is very high the design goal is typically to show that stresses are below the component or material endurance limit, whenever possible. However, not all materials have a well defined endurance limit and the stresses that are developed during maneuvers, ground operation, ground air ground (GAG) cycles and at other areas of the aircraft operating envelope may cause damage. The accumulation of this damage must be taken into account to determine if propeller components are life limited require mandatory inspections or to determine if the propeller is suitable for use on an aircraft.

a. Fixed Pitch Wood Propellers of Conventional Design. A fixed pitch wood propeller of conventional design is a propeller that has the following physical properties:

- One piece laminated wood construction.
- Two or four blades.
- The surface coating does not contribute to the propeller strength.

- The surface coatings only provides environmental protection.

A fixed pitch propeller that has a composite shell over a wood core would not qualify as conventional construction when the composite shell contributes to the strength and frequency response of the propeller. A fixed pitch wooden propeller with a fabric or composite covering, that does not alter the structure, for environmental protection would be considered to be of conventional design.

b. Fatigue Limits. The development of fatigue limits associated with §35.37 is one step in the overall process for the structural evaluation of a propeller for certification and approval for use on an aircraft. Figure 1 provides a flow overview of process. Fatigue limits is a general term referring to the data base used to support the fatigue evaluation of the propeller. Fatigue limits may take many forms such as a Goodman diagrams to assess whether or not stresses are below the endurance limit, S-N curves for safe life evaluations, and crack growth curves (da/dN curves) and delamination growth curves used for damage tolerant evaluations. The fatigue limits are generated with an understanding of the propeller component, material, failure mechanism, and loading. Because of the complex nature of propeller fatigue the development of fatigue limits for §35.37(b) are generally conducted in association with §§35.37(c), 23.907 and 25.907. These regulations are dependent on each other since the data used to show compliance with one regulation may provide information that will be used for compliance with another regulation. The development of fatigue limits may be supported by previous testing, past experience and acceptable published test data when available.

c. Damage Accumulation. The fatigue limits are developed to support a damage accumulation algorithm such as Miners rule for safe life calculations or a crack or damage growth algorithm for damage tolerance calculations. The damage accumulation algorithm is used to conduct the fatigue evaluation required by §§35.37(b) 23.907 and 25.907. Associated with the development of fatigue limits is the verification of the damage accumulation algorithm. The spectrum tests discussed in this advisory circular provide a method for verification of a damage accumulation algorithm. The damage accumulation algorithm may be verified by previous testing, past experience and acceptable published literature when available.

When the propeller stresses are below the Goodman line on a Goodman diagram it is assumed that no damage is accumulated. JAA reference 3.(c.)(1), ACJ P-370, provides a method to evaluate aluminum propeller blades and hubs using Goodman diagrams. This approach assumes that no damage will be accumulated over the life of the propeller.

d. Applicable Components. For propeller certification, fatigue limits are established for the propeller hub, blades, and blade retention and those components whose fatigue failure would cause a hazardous propeller effect. The components whose fatigue failure would cause a hazardous propeller effect are identified by the propeller safety analysis conducted for §35.15. Examples of components that may be identified by a safety analysis are the piston cylinder (dome), counterweights and pitch control components. For items such as bearings which are typically part of the hub assembly, the fatigue limits are generally established for the assembly, not for the individual components.

Each applicable component should be assessed to determine if it has multiple critical regions or requires different limits for different regions. Aluminium blades are a typical example of a component that has different limits for different regions. The blade steady stresses vary substantially from the blade root to the blade tip, therefore blades typically have fatigue limits established for each of the stress regions. Also, aluminium blades may have differing material limits to account for local working effects due to shot peening or cold rolling.

e. <u>Propeller Loads</u>. The loads applied during the fatigue limit tests are derived from the consideration of the steady and vibratory propeller loading conditions that occur on the intended airplane and engine installation throughout it's life or on a typical airplane. The loads applied during fatigue limit tests reflect the fatigue data to be generated. For example the loads establish the stress ratios (R) for coupon specimen tests and set the amplitude and direction for full scale testing. Also, the load magnitude and direction should be established in a manner that represents the loading the propeller will experience in service.

The applied loads are derived from a spectrum of aircraft and engine operating conditions that depend on the category and operation of the aircraft. The elements of operation should include flight, ground, and engine load conditions. Flight conditions may include normal conditions that occur with each flight (take-off, climb, cruise, descent, approach, landing, and reverse thrust), transient aircraft flight conditions associated with maneuvers (banked turns, side-slip, pull-ups, push-overs, and etc.), gusts, special flight conditions specific to a mission (fire-fighting, acrobatic, and etc.), emergency conditions, acrobatic maneuvers when applicable, and training maneuvers. Ground conditions include taxi, operation in cross winds, maintenance checks, and etc. Engine load conditions include the loads generated by the engine and transmitted to the propeller. Typically engine loads are associated with piston firing in reciprocating engines. The loads are the combination of all ground, flight, and engine conditions that will be included in the operation of the aircraft throughout it's life. From these loads the limit loads are determined.

The loads are verified using the aircraft ground and flight test data obtained on the intended aircraft and engine combination with the installed propeller to show compliance with §§23.907 or 25.907. The measured loads verify the applicability of the fatigue limit data for fatigue evaluation to show compliance with §§23.907 or 25.907.

The aircraft operating spectrum, when available, may be obtained from the aircraft company for the intended application. When the aircraft operating spectrum is not available the spectrum may be based on the design assumptions and design experience on a typical or on the intended aircraft.

f. <u>Component Degradation</u>. The fatigue limits should account for likely service deterioration, variations in material properties, manufacturing anomalies, and environmental effects.  There are many methods available to account for component degradation.  Reductions in fatigue limits may be applied as life or load factors based on the manufacturers service experience and test data base with the components, as shown in Figure 2.  The reductions may also be developed by appropriate specimen tests or by testing intentionally degraded full scale components.

(1)  Manufacturing Anomaly.  Propellers manufactured to a process specification have limits to control manufacturing variables.  Accordingly, these limits, such as, surface finish, and machining marks in metals and fiber misalignment, resin content, and delaminations in composites, should be considered for their impact on structural integrity.

(2)  Service Damage.  Propellers are exposed to, and experience a certain amount of service damage from corrosion, erosion, stone strikes, handling damage, and in addition for composites small bird strikes and hail impact.  The damage to a composite should consider both visible surface damage and hidden internal damage, such as delaminations.  The extent of tolerance to such damage and the method of demonstration should be considered.

(3)  Environmental Degradation.  Aircraft may spend their entire operational life in a severe climatic zone.  Accordingly the strength degradation of the material system should be established.  When assessing operational environments the following should be considered as appropriate:

- • High Temperature and Humidity.
- • Low Temperature.
- • Thermal Cycling
- • Ultraviolet Light.
- • Aviation Chemicals.

g.  Repairs.  Repairs alter the as manufactured condition of the propeller.  Therefore, the manufacturer should consider the impact of planned repairs on structural integrity of the propeller.

h.  Coupon Tests.  Establishing an S-N curve from coupon tests is recommended for determining its fatigue strength and statistical strength distribution.  It is important to develop the S-N curve for both the low cycle and high cycle fatigue regimes.  The S-N curve should be representative of the propeller's material system.  For metals this may include effects such as surface finish, cold rolling, shot peening and corrosion inhibitors.  For composites this may include effects such as resin systems, ply stacking sequence, ply orientation, and manufacturing processes.  In addition, the propeller's station-to-station variance between metallic to composite bond regions, shank sections, mid-blade section, and tip regions may warrant the testing of coupons representative of each.  S-N curves may be developed using acceptable published data when available or may be developed by testing a sufficient number of specimens that are representative of the propeller's material system manufacturing processes.

When conducting coupon tests the coupons should be tested to failure under a combination of steady and vibratory loads. The steady loading should be representative of that anticipated in service for the propeller. The vibratory loading component should be selected to facilitate the generation of an S-N curve, over a broad range of stress cycles, so that an endurance limit can be defined. The endurance limit for composites is normally projected to 500 million cycles and for aluminum is normally considered projected to 100 million cycles. The frequency of the vibratory loading may be at any frequency, provided representative failure modes are realized. Attempts to compress testing time by resorting to high-frequency vibratory loading should be approached with caution, to preclude the introduction of unrepresentative temperatures, failure modes, and fatigue lives. Accelerated testing should include some form of temperature monitoring to preclude overheating the specimen.

i. <u>Full Scale Testing</u>.

(1) Test Specimen. Full-scale components should be manufactured to represent the type design and should be fatigue tested at combinations of steady and vibratory loads as needed to support subsequent evaluations. Also, to address the issues of safe life, damage tolerance and continued airworthiness, the specimens may be manufactured to include specific manufacturing anomalies and likely service damage. The extent of such defects/damage should be consistent with inspection techniques employed in service.

(2) Failure Criteria. A rational failure criteria should be established. This will be different for various types of construction and materials. For composites, as shown in Figure 3, material failure is markedly progressive, starting at initiation (Region I) through a damage growth or delamination growth phase (Region II) to an advanced damage state where large delamination and secondary failure modes and locations form throughout the component (Region III). Failure criteria's such as a specific loss of stiffness in the structure, visible damage, and delamination area have been applied to composites. For metallic components the failure criteria may be the initiation of a crack or a specific crack length. The selected failure criteria will be a factor in establishing the component life, since the component should maintain sufficient residual strength throughout its life. When using stiffness loss as failure criteria, the effect on component resonant frequency placement should be addressed since this may impact the continued airworthiness of the component.

(3) Component Monitoring. Components should be strain gauged and have load cells to monitor the loads and stress distribution. When a test rig applies load by means of an amplitude actuator the input amplitude may require adjustment to account for test rig and/or component wear in or degradation to assure that the test load is maintained. The specimen should be examined regularly for cracks, delamination, or other degradation. The stiffness of each specimen should be measured at the outset of each test, and periodically monitored throughout the test when stiffness is being used as the failure criteria. The frequency of monitoring should be closer during the failure process. When appropriate, testing should be continued after the component has failed according to the failure criteria to demonstrate damage growth characteristics and residual strength capacity.

j. <u>Data Reliability</u>.

(1) Mean S-N diagram. The mean S-N diagram for each critical location is defined from the mean steady and vibratory stress for all coupons/components tested extrapolated out to an asymptote representing the high cycle fatigue endurance limit and extrapolated back to a low number of cycles. The coupon-derived S-N curve shape may be used to supplement extrapolation through the failure points when the failure mechanism has been duplicated by the coupon tests.

(2) Reliability. Being dynamically loaded components, the structural integrity of propellers is generally governed by their fatigue, rather than their static strength. Accordingly, a reliability, at least as good as the "A" basis for static strength allowables of a normal distribution, should be demonstrated. That is, a reliability of 99 percent, with a 95 percent confidence level, should be demonstrated.

(3) Number of Test Specimens. The number of full-scale test specimens to be fatigue tested for each critical propeller section is optional, provided the required reliability is satisfied.

(a) For a prescribed reliability, the mean endurance limit ($E_{50}$) should be reduced by a factor (k), governed by the selected sample size (n) and the standard deviation ($\sigma$) data. More specifically, the 99 percentile endurance limit ($E_{99}$) may be expressed: $E_{99} = E_{50} - k\,\sigma$; where (k) is a function of the sample size (number of specimens tested).

(b) For the normal strength distribution, (k) varies with sample size as follows:

Sample size and normal distribution reduction factor

| **Sample size** | **Normal distribution reduction factor** |
|---|---|
| n | k |
| 2 | 37.094 |
| 3 | 10.553 |
| 4 | 7.042 |
| 5 | 5.741 |
| 6 | 5.062 |
| 7 | 4.642 |
| 8 | 4.354 |
| 9 | 4.143 |
| 10 | 3.981 |
| **REF. Table 9.6.4.1, Mil-hdbk-5e, June 1, 1987** | |

(c) Notes:

- • Use of the manufactures in-house methodology, development data and analytic expertise, along with limited full-scale testing, may be used as an alternative in substantiating the required reliability.
- • The "A" basis for reliability provides for similar reductions for scatter as the methods described in JAA reference 3c(1), ACJ P-370, for a sample size of seven or greater.

(4) Working data. The working data is developed from the "A" basis curve by dividing by an appropriately justified load or life factor to account for the variations discussed in paragraph 5f. Factors for composite materials should be developed for each new composite system (fiber, resin, coating, adhesives and etc.).

## 6. COMPOSITE COMPONENT FATIGUE LIMITS.

a. Composites Discussion. An increasing number of propeller blades are constructed of composite materials. Due to the anisotropic characteristics of composite materials, composite component design and verification of design differs significantly from metal structure, and propeller blade fatigue loading differs significantly from most other structure. Past practices employed for metal structure or employed for other composite structure may not be adequate when dealing with composite propeller structure and fatigue loading. Although this discussion focuses on propeller blades the principles may be applied to any composite structure.

With the added flexibility of composite component design, effort should be made to include damage tolerant and fail safe principles wherever possible. Damage tolerance is the attribute of the structure that permits it to retain its required residual strength for a period of use after the structure has sustained a given level of fatigue, corrosion, accidental or discrete source damage. Fail safe is the attribute of the structure that permits it to retain its required residual strength for a period of unrepaired use after the failure or partial failure of a principal structural element. This AC assumes that when damage tolerance methods are applied the component has been designed using these principles.

Figure 3 illustrates the typical progression of fatigue failure, degradation of fatigue life, and reduction in residual strength of a typical composite component. Region I is the damage initiation phase. Region II is the damage growth or delamination growth phase. This is the region where delamination growth propagates steadily and predictably, and region III is an advanced damage state where large delamination and secondary failure modes and locations form throughout the laminate. Region III is where component stiffness and residual strength degrade rapidly. This AC provides guidance for the development of fatigue limits for a fatigue evaluation to assure region III is not reached in service.

Fatigue limits are generally developed to support a fatigue evaluation based on a safe life approach or a damage tolerant approach. This AC will provide guidance for these two approaches.

b. Safe Life Fatigue Limits for Composite Components. Development of fatigue strength characteristics of composite components to be used for a safe life fatigue evaluation can be accomplished in a two-phased approach. The phases are (1) coupon tests for both static properties and fatigue properties to supplement the fatigue (S-N) curve shape, standard deviation, and statistical distribution; and (2) full-scale testing to establish the strength level, statistical distribution, failure location, and failure mode and mechanism for the material system and geometry of the propeller. For blades this may involve testing of metallic to composite bonds, shank, mid-blade, and tip specimens. Figure 4 illustrates some types of test rigs that have been utilized to assess various areas of a blade. The development of the fatigue properties may be supported by previous testing, past experience and published material data when available.

(1) Loading.

(a) Testing of full scale composite structure may require two types of testing. Constant loading to define the S-N curve and spectrum loading to address cumulative loading effects since damage is dependent on both low and high cycle fatigue loads. These loads include ground-air-ground (GAG) cycles, low occurrence high amplitude maneuver limit loads, and high occurrence take-off, climb, and cruise loads. The fatigue characteristics may also be dependent on the order in which the loads are applied and should be considered when establishing the test load spectrum. Typically this effect is addressed by performing many sets of load blocks.

(b) The vibratory loads should be imposed at a frequency that will provide representative failure modes. Attempts to compress testing time by resorting to high-frequency vibratory loading should be approached with caution, to preclude the introduction of unrepresentative temperatures, failure modes, and fatigue lives. Accelerated testing should include some form of temperature monitoring to preclude overheating the specimen. Cooling may be required to preclude overheating the component.

(c) Low and high cycle fatigue are closely related and both need to be addressed. Because composite S-N diagrams have a shallow slope the initial emphasis of full-scale testing is usually low cycle fatigue (LCF). Coupon tests have limited value in areas with complex geometry or with metallic to composite bonds unless the coupons duplicate the mode of damage.

(d) Constant amplitude high cycle fatigue failures are generated in the $10^6$ to $10^8$ cycle range. To induce failures in this cycle range, the alternating component of the load(s) is generally increased (load factor) from design or operating values. The steady component of load is generally not increased to induce failures. If no failure occurs a no failure point (run out) is generated. When using data to determine S-N curve shape or statistical distribution, a new specimen should be used for testing at a higher load level to generate a failure point.

(e) Constant amplitude low cycle fatigue failures are generated in less than $10^6$ cycle range. Failures may be induced by increasing the number of cycles (life factor) of the applied load expected in service or expected to reach failure or increasing the vibratory component of the load (load factor), or combination thereof. The steady component of load is not increased to induce failures. Subsequent data evaluation should account for the cycle or load increase required to generate the failures. Care should be taken when using load factor because the failure mode may change.

(f) Spectrum load testing is a method often used to verify the damage accumulation algorithm to be used for subsequent fatigue evaluations. Miner's rule with appropriate consideration for scatter has been shown to be suitable to calculate component life. A load spectrum includes operating conditions representative of the intended operation for the propeller. For blades, the load spectrum may include a typical flight consisting of start-up, taxi out, run-up to take-off thrust and maximum 1P vibratory load, climb, cruise, descent, landing, reverse thrust, taxi back, and shut-down. Within this spectrum a high amplitude low cycle maneuver load would be periodically applied. Life factors to account for scatter per reference 3d(1) are preferred to load factors, which may alter the failure mode.

(2) Data Reliability. The data should be developed as in paragraph 5j above.

c. <u>Damage Tolerant Data for Composite Components</u>. Development of fatigue strength characteristics of composite propeller components to be used for a damage tolerant fatigue evaluation is generally accomplished using full scale test specimens to establish the damage growth, strength, failure location, and failure mode and mechanism. Unlike the safe life approach the damage tolerant approach is based on the principle that damage is inherent in the structure or inflicted in service and may grow with the repeated application of loads, and that the propeller or propeller components will be inspected at intervals to assess the extent of damage. When damage reaches the maximum permissible flaw size the propeller or propeller component is retired. The damage tolerant discussion will focus on propeller blades, but may be applied to any composite propeller component.

(1) Tests to Determine Failure Mechanism. Utilizing knowledge of the propeller blade loading spectrum and blade design, a test is conducted to determine the failure mechanism. This preliminary step in the fatigue verification cycle is used as a verification of the failure mechanism determined in the blade design phase. It will also confirm the location of critical defects that will be used in subsequent fatigue tests.

(a) Test specimen. The specimen should be constructed to represent actual type design. The purpose of this test is to verify the critical stress locations and failure mechanism determined during the blade design process. No artificial defects should be incorporated and naturally occurring flaws should be located well away from the predicted high stress (failure initiation) point.

(b) Loading. The blade should be loaded to accurately simulate the predicted critical loading environment. Note: this may not be the highest steady load condition. For example, a low RPM condition with a high vibratory bending load may be more damaging due to increased transverse stress and increased compressive stress.

(1) Most composite designs are more sensitive to the low cycle fatigue part of the spectrum. Therefore, particular attention should be paid to conditions that produce high fatigue loads but not necessarily high cycles. Some examples of these conditions are high power, high yaw, high g loading due to maneuver or gust loading, ground air ground, and resonant vibration loads occurring during initial run-up or run-down in a cross-wind environment. Thermally induced stresses should also be considered. Loads induced during these and other conditions can be substantially higher than normally occurring high load conditions such as take off rotation. To expedite testing, alternating bending loads may be increased above the actually occurring loads to initiate and propagate damage.

(c) Monitoring of Failure Mechanism. The initiation and growth of damage should be monitored utilizing non-destructive inspection (NDI) techniques. During the test the NDI techniques to be used on the type certificated product and defined in the Instructions for Continued Airworthiness, §35.4 should be evaluated. Since the purpose of this test is to determine failure mechanism, the test should be run to structural failure. The definition of this failure should be the point at which the stiffness of the specimen has begun to rapidly degrade, and if possible, the component should be taken to total separation.

(2) Test to Determine Flaw Growth. This portion of the testing process determines the rate of flaw growth as a function of loading. The purpose is to determine the load that will propagate a flaw and the rate of flaw growth vs. loading.

(a) Test Specimens. Test specimens should be manufactured with the allowable manufacturing anomaly(s) located in the most critical location. The most critical location should be the location determined in the design analysis and confirmed in the failure mechanism test in paragraph 6c(1) above. If more than one critical defect has been identified, all should be evaluated. If all defects result in the propagation of the same type flaw, only the propagating flaw needs to be analyzed for propagation. For example, if voids, resin pockets, and delaminations are possible manufacturing anomalies, and all defects result in the initiation and growth of delamination, then only delamination growth needs to be analyzed for propagation.

(b) Loading. As above in paragraph 6c(1)(b), steady loads should be representative of normally occurring loads, and alternating loads should be applied to produce flaw growth. If flaw growth can not be obtained within the foreseen loading conditions, elevated loads should be used to produce flaw growth. Constant amplitude testing should be conducted at several different alternating load conditions.

(c) Monitoring of Failure Mechanism. As above, flaw growth should be monitored using NDI techniques. During the test the NDI techniques to be used on the type certificated product and defined in the Instructions for Continued Airworthiness, §35.4 should be evaluated. Since the purpose of this test is to determine flaw growth data, the test should be run until sufficient data have been collected to accurately model flaw growth.

(1) During flaw growth testing, the failure mode should remain the same as the shown in the failure mechanism test. If this is not the case, the test and the design should be evaluated to determine the reason for the inconsistency. If a second failure mode is also present, it will either need to be addressed through design or have an independent test.

(d) Define End of Life Condition. The physical condition of the component when it will be considered to have the maximum extent of damage while still maintaining sufficient residual strength to meet all airworthiness loading requirements. The loading requirements should account for resonant conditions when applicable. Resonant conditions may be applicable when the stiffness of the component changes sufficiently to change the natural frequency. The end of life condition is established in conjunction with the service life. Therefore, the component in its end of life condition is still safe. The end of life condition should be well before structural failure.

(e) Assign Growth Rate. A rate should be assigned to the flaw growth data. For simplicity, a linear rate may be assigned. Figure 3 shows the progression of a typical composite blade failure. The point of the fatigue analysis is to provide data that will be used to determine component life and inspection intervals as required for the loading environment. It is conservative to assign a linear value to the growth data as long as the linear value predicts flaw growth to the fail safe condition prior to the actual function. All components should be treated equally when assigning flaw rates.

(1) Figure 5 shows test data from a flaw growth test. Note the test began with a known defect size and was ended prior to the fail safe condition. This practice is acceptable as long as the failure mode and its progression are known. For this practice to be acceptable, the initial failure test should show ample margin between the point when the assigned flaw rate predicts the end of life condition and when the actual end of life condition occurs.

(3) Develop Flaw Growth Curve. The assigned flaw growth data is then used to produce a flaw growth curve as shown in Figure 6.

(4) Spectrum Load Testing. Spectrum load testing is conducted to verify the flaw growth accumulation algorithm used for subsequent flaw growth evaluations. A load spectrum includes operating conditions representative of the intended operation for the propeller. The load spectrum may include a typical flight consisting of no load, increase to take-off thrust and maximum 1P vibratory load, reduce to a climb conditions, reduce to cruise conditions, increase to maximum reverse conditions and return to no load. Within this spectrum a high amplitude low cycle limit maneuver load would be periodically applied.

## 7. **METALLIC COMPONENT FATIGUE LIMITS**.

a. Metallic Discussion. The fatigue limits for metallic components are determined by developing fatigue data through coupon and full scale testing, previous testing, past experience and acceptable published data. to develop S-N diagrams and Goodman diagrams suitable for a safe life propeller fatigue evaluation and da/dn diagrams for damage tolerant evaluation of the applicable propeller components. Specifically those components listed in paragraph 5d.

b. Safe Life Fatigue Limits Metallic Components. Development of fatigue strength characteristics for metallic components follows the basic format presented in paragraph 6b. A two-phased approach is used. The phases are (1) coupon tests for both static properties and fatigue properties to supplement the fatigue (S-N) curve shape, standard deviation, and statistical distribution; and (2) full-scale specimens that are fatigue tested to establish the strength level, statistical distribution, failure location, and failure mode and mechanism for the material system and geometry of the propeller. The development of the fatigue properties may be supported by previous testing, past experience and published material data when available.

(1) Loading. Steady loads should be representative of normally occurring loads, and alternating loads should be applied to produce the desired failure results. Testing may be conducted in steps with constant amplitude alternating loads. If the alternating load level that is selected is below the endurance limit failure will not occur within the number of cycles considered acceptable to verify the endurance limit. This is considered a run out condition. The alternating load should be increased and the test should be resumed at ever increasing load level until failure occurs. Low cycle fatigue also needs to be addressed. Because of the shape of metallic S-N diagrams the initial emphasis of full-scale testing of metallic components is usually high cycle fatigue (HCF). Coupon tests have limited value in areas with complex geometry.

(2) Data Reliability. The data should be developed as in paragraph 5j above.

c. Damage Tolerant Data for Metallic Components. Classical fracture mechanics techniques are generally employed when conducting a damage tolerance evaluation of metallic components. There are alternate methodologies such as a safe life approach coupled with experimental assessment of the effect of damage utilizing coupons or full scale components. Additionally, equating damage to a crack may be extremely conservative for some materials and hence an alternate method for quantifying the effect of the damage on life may be used in these cases. This AC assumes that when damage tolerant methods are applied the components have been designed using damage tolerance and fail-safe principles.

(1) Tests to Determine Failure Mechanism. The full scale tests are used to define the fracture location for an undamaged component. When including the effects of

damage, the damage will be assumed to occur at the fracture site.

(2) Test to Determine Flaw Growth Crack growth data for the material of interest may be obtained from acceptable published data. If not available, then it will be necessary to experimentally obtain this data using appropriate coupon configurations and taking into account the effects of stress ratio (R).

(a) Develop Flaw growth Curve. The experimental data should be used to produce a crack growth curve in the form of da/dn (amount of crack extension per cycle) versus ΔK (stress intensity range) as a function of stress ratio (R). Figure 7 is a schematic of such a curve. It is noted that the curve shape is sigmoidal when presented on a log-log plot. In the mid-region the growth is linear with a slope of "m". In the initial region called "near threshold", the plot exhibits curvature and becomes asymptotic to the threshold stress intensity range (ΔKth). In the final region, the plot exhibits opposite curvature and becomes asymptotic to critical stress intensity range (Kic).

(b) Spectrum Load Considerations. It has been shown that for metals that commercial and government computer programs such NASA/FLAGROW, NASGRO and FASTRAN contain analytical crack growth algorithms that sufficiently account for growth under spectrums anticipated in service. Hence, these techniques may be used when performing crack growth calculations from the initial detectable crack to the critical crack length. The loading should include all of the segments of the spectrum unless an analytical damage assessment shows the spectrum can be truncated i.e. Specific segments produce negligible damage. Consideration should be given to material statistical scatter. Generally this is accomplished by using typical growth data and applying scatter factors on inspection intervals.

**8. METALLIC HUB AND RETENTION FATIGUE TESTS.** The complex nature of the hub and retention structure with bolted joints and bearings makes measurement of critical stress locations difficult if not impossible. Therefore, the fatigue test should be conducted on full scale components in a test rig that simulates the orientation of operating loads so that applied test loads result in the stresses that match or exceed operating stresses in critical areas. Hub and retention testing is conducted to develop S-N curve fatigue data or to show that the hub has a sufficient life through run out testing at an appropriate load or spectrum loading. Run out testing should be supported by previous testing, past experience and published material data.

The centrifugal load, thrust, torque, cyclic aerodynamic loads and engine cyclic loads for reciprocating engines should be applied simultaneously during fatigue testing. A test rig such as the one illustrated in Figure 8 is one type of test rig that has been shown to be suitable for testing with simultaneously applied loads for high power installations (1500 shp or greater) with high once-per-revolution loading. This type of rig has been useful to assess the interface between the hub and propeller shaft flange. The hub is mounted to the actual propeller flange and shaft unit that has been adapted to the test rig. The blade loads are input by means of actuators that are aligned in the direction of the applicable steady and vibratory blade loads. Centrifugal loads are also be applied to load the blade retention. Since the hub loading is complex, sound judgement is required to approximate the complete loading pattern for the hub. The test rig shown in Figure 8 approximates that the blade vibratory and steady loads are in the same direction. A determination of the suitability of a test rig of this type, or any other type of test rig should be made prior to fatigue testing.

**9. <u>FATIGUE EVALUATION</u>.** Section 35.37(c) requires fatigue evaluation to be conducted on a typical or on the intended aircraft. The intended aircraft may be the aircraft used during aircraft certification to conduct the vibration tests and evaluation required by either §§ 23.907 or 25.907. The typical aircraft may be one used to develop design criteria for the propeller or another appropriate aircraft.

The propeller fatigue evaluation establishes the propeller mandatory replacement times (life limits), and in some cases mandatory inspections. When compliance is shown for §35.37(c)(2) the results are preliminary since propeller vibratory stress on the aircraft has not yet been measured. The evaluation is a design evaluation on a typical aircraft. The intent of §35.37(c)(2) is to provide an acceptable level of assurance that the propeller will be structurally acceptable for use on an aircraft prior to installation on an aircraft. When compliance is shown for §35.37(c)(1) it may be conducted for the intended aircraft by complying with §§ 23.907 or 25.907. In either case airworthiness limitations should be identified and appropriately documented in the Airworthiness Limitations section of the Instructions for Continued Airworthiness. It should be noted that for each new aircraft installation the applicability of the Airworthiness Limitations should be re-evaluated.

There are a number of different approaches to fatigue evaluation. The fatigue limits discussed in this advisory circular were developed to support safe-life, and damage tolerant evaluations. Methods to conduct a fatigue evaluation are found in reference 3b(2), AC 20-66-xx, Vibration and Fatigue Evaluation of Propellers. Some of the concepts to consider when conducting the fatigue evaluation are shown below.

a. <u>Unlimited Life</u>. When it is shown that all stresses are be below the endurance limits established for the component the component is said to have unlimited life. These components will be removed from service for reasons other than fatigue. In addition, when the safe life of a component is shown to be greater then 70,000 hours and it is shown that the component will be safely retired from service for reasons other than fatigue prior to its safe life the component may be said to have unlimited life.

b. <u>Safe-Life</u>. Safe-life is the component fatigue life reduced by an appropriate scatter factor that accounts for the variability of the fatigue evaluation process. The fatigue life is determined by combining the aircraft loading spectrum with the fatigue data using a damage summation algorithm (safe-life evaluation). Unless substantially justified a scatter factor of three or greater should be used for metallic components and a scatter factor of 10 or greater for composite components. Mandatory replacement times are established for parts with safe-lives.

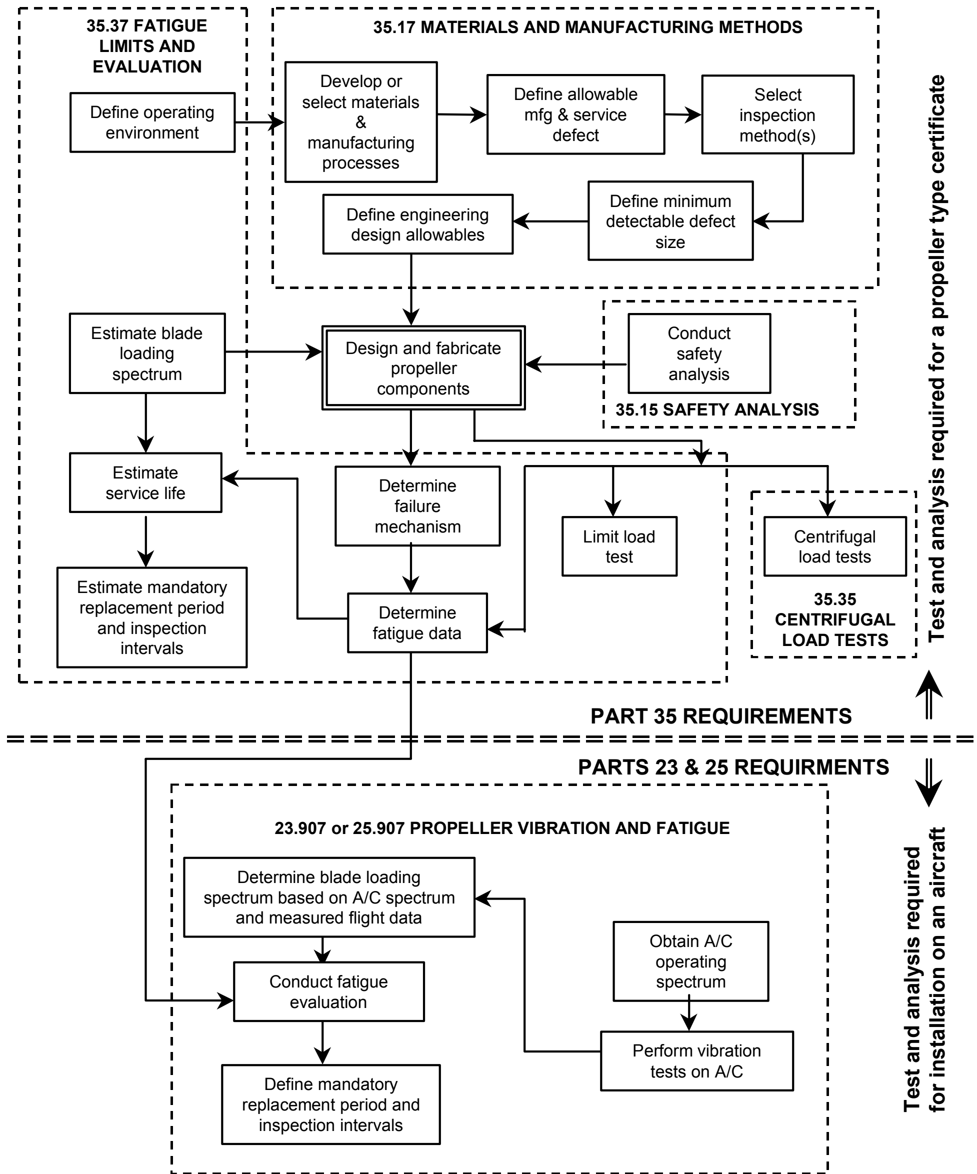
c. <u>Damage Tolerance Inspection Interval</u>. For damage tolerance methods the inspection interval is related to the time the damage reaches maximum permissible flaw size as defined during certification (detectable damage) to the end of life condition (the extent of damage for residual strength evaluation). The maximum permissible flaw size is established during certification by considering the inspection method, the inspection interval and the end of life condition. The inspection interval is established to permit multiple opportunities, typically three opportunities, to find the damage prior to reaching the end of life condition. The inspection method should also be evaluated to determine the probability of detection (POD). Inspection methods are typically shown to have a POD of 90% probability with 90% confidence. When the POD is less than 90% probability with 90% confidence the inspection frequency may be increased. The component is removed from service when damage is detected. These inspections when mandatory are defined in the Airworthiness Limitations section of the Instructions for Continued Airworthiness., §35.4.

d. <u>Limit Load Fatigue Test</u>. The propeller blade should be able to withstand limit loads without detrimental permanent deformation or deformation that would result in a hazardous propeller effect. Since the propeller is a rotating device this is a fatigue test. Appropriate life factors should be applied during the test. The test should be performed on a blade considered its end of life condition.

## FIGURE 1

[if gte vml 1]>

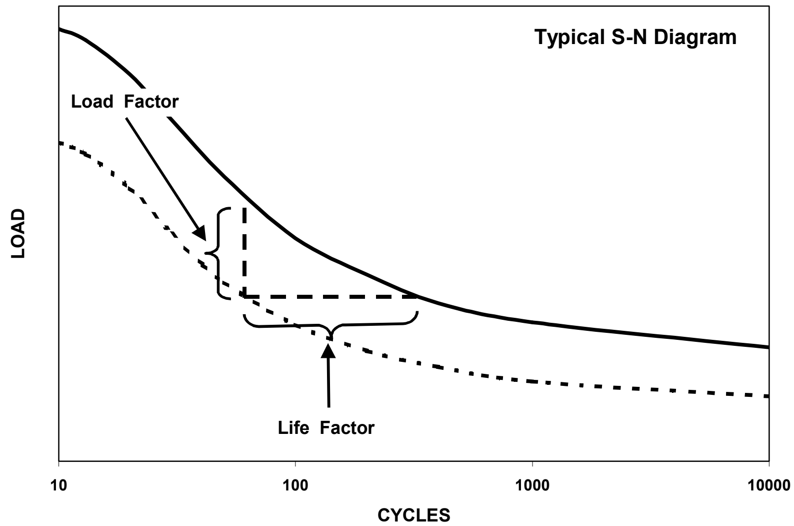
**Overview of the vibration and fatigue evaluation process from propeller certification to installation on the aircraft**




<![endif]

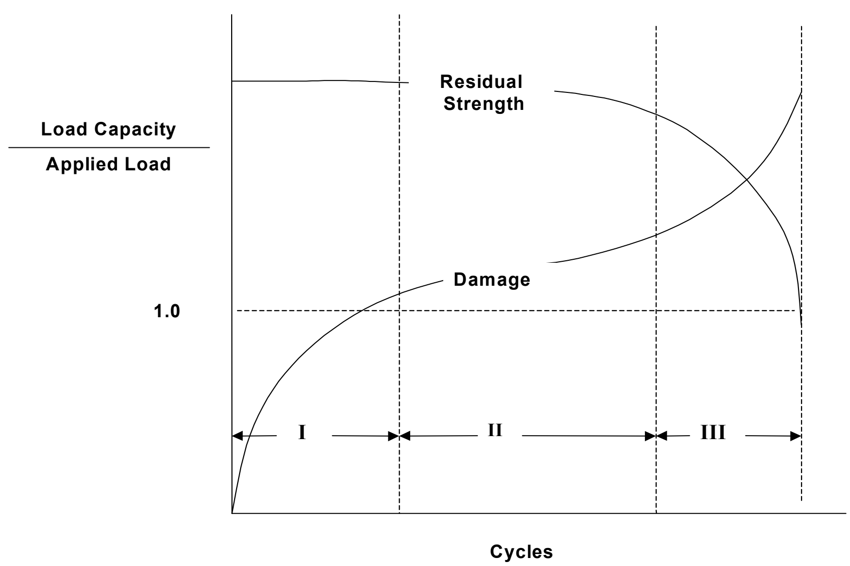
## FIGURE 2

### LOAD AND LIFE FACTORS




## FIGURE 3

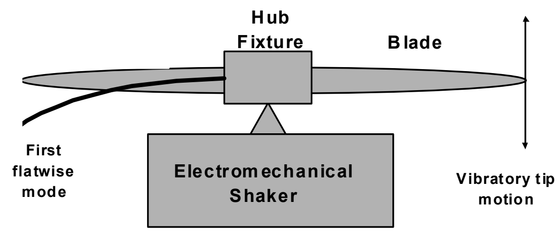
### COMPOSITE BLADE DAMAGE DEVELOPMENT



## FIGURE 4

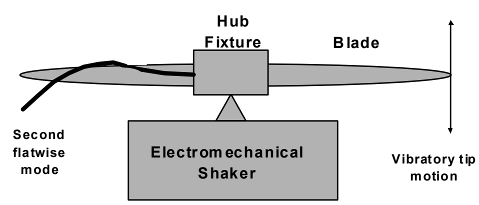
# EXAMPLES OF BLADE TEST RIGS

### ROOT ZERO MEAN STRESS TEST



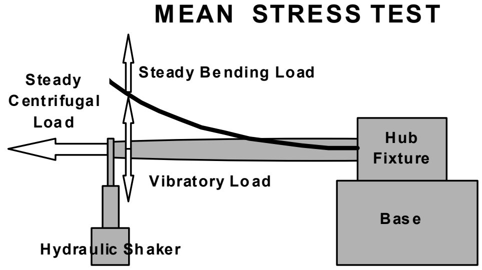

- Peak stress near the blade root
- R ratio equal zero, does not match flight loads for blade root
- Resonant test

### TIP ZERO MEAN STRESS TEST



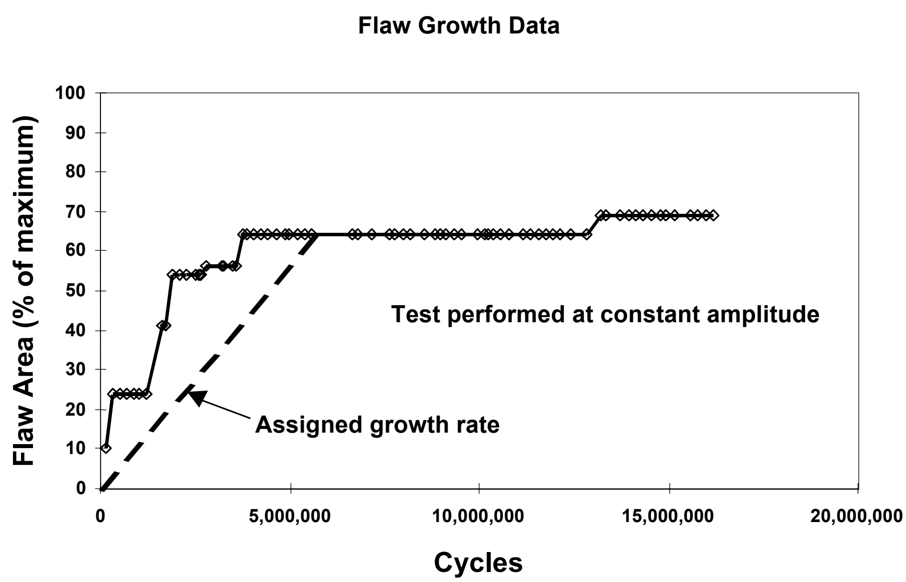

- Peak stress near the blade tip
- R ratio equal zero
- Resonant test

### MEAN STRESS TEST

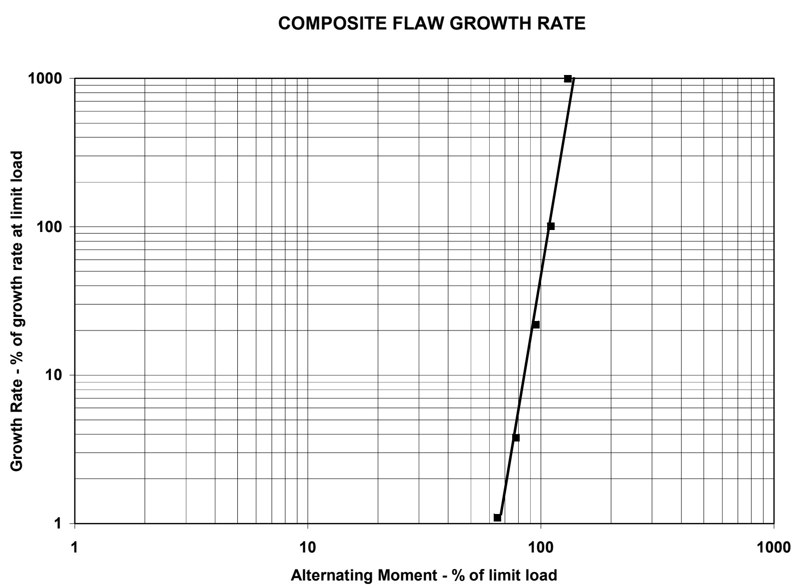



- Peak stress near the blade root
- R ratio adjusted for flight condition simulated
- Forced response test

## FIGURE 5




## FIGURE 6



# FIGURE 7

**Typical Crack Growth Curve Shape**

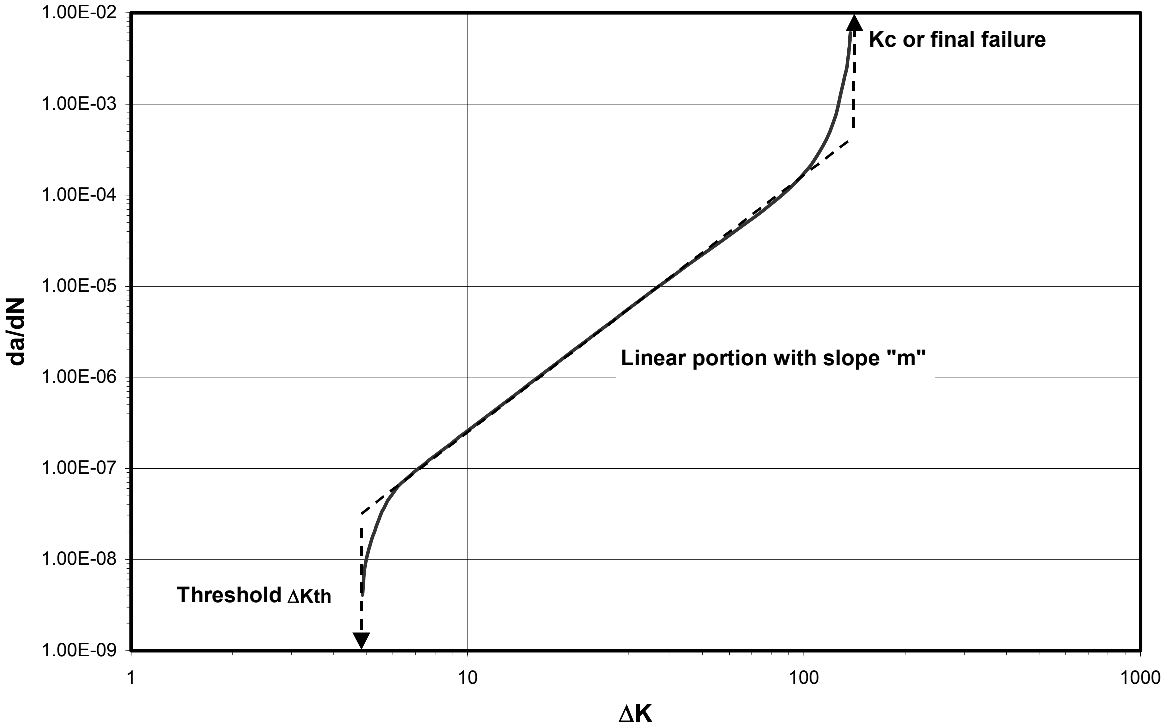
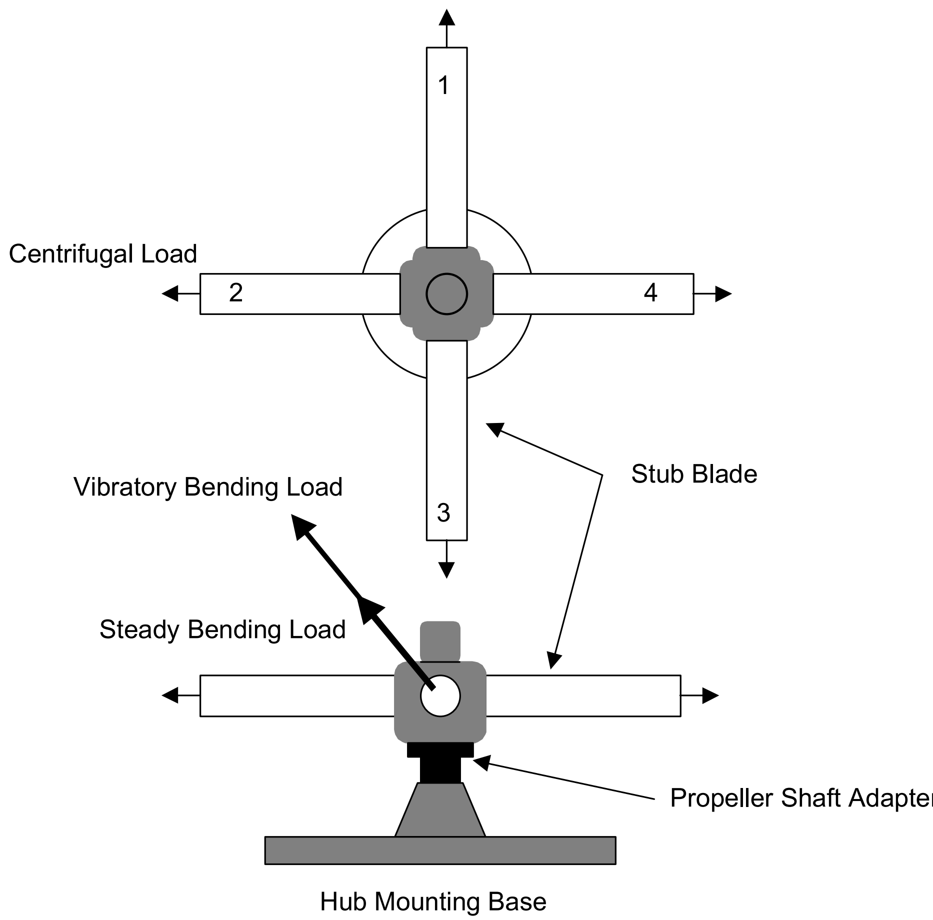


FIGURE 8

**HUB AND BLADE RETENTION TEST RIG**




Notes:

Loads are applied to each blade stub

Vibratory bending is simple harmonic loading and 90 degrees out of phase from blade stub to blade stub

Steady bending is maintained at all times

Centrifugal loading is maintained at all times