U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

FAR GUIDANCE MATERIAL

Subject: COMPOSITE PROPELLER BLADE FATIGUE SUBSTANTIATION
Date: 05/11/93
Initiated by: ANE-110
AC No: 35.37-1
Change:

1. PURPOSE. This advisory circular (AC) provides guidance and an acceptable method, but not the only method, by which composite propeller blades can be fatigue evaluated for determination of safe vibratory loadings, as required by Federal Aviation Regulations (FAR) 35.37.

2. RELATED FAR SECTIONS. FAR Sections 35.37, 35.43, 25.907, and 23.907.

3. RELATED REFERENCE MATERIAL.

a. AC 20-107A, Composite Aircraft Structure.

b. AC 21-26, Quality Control for the Manufacture of Composite Structures.

c. MIL-HDBK-17B, Polymer Matrix Composites, Volume 1, Guidelines.

d. MIL-HDBK-5E, Military Standardization Handbook.

4. BACKGROUND. Propeller's operating steady and vibratory stresses are recorded for an installation on an aircraft equipped with a given engine during the propeller's flight strain survey. In order to determine the significance of the data, knowledge of the fatigue strength of the critical areas of the propeller is needed. Based on the fatigue strength, the allowable stress limits, or "endurance limits," are determined for each critical area. These limits are then compared with the data recorded during the propeller flight strain survey. Accordingly, an assessment of the propeller fatigue life can be made, assisting decisions regarding the life-limiting of propeller components and the necessity for placards.

5. DISCUSSION. Development of fatigue strength characteristics of new composite propeller blades to be certificated can be accomplished in a two-phased approach. These are: (1) Coupon tests to establish the fatigue (S-N) curve shape, standard deviation, and statistical distribution; and (2) Full-scale shank, mid-blade, and tip specimens that are fatigue tested to establish

the strength level, failure location, and failure mode/mechanism for the material system and geometry of the propeller.

a. Coupon Tests.

(1) S-N Curve Development. Establishing an S-N curve for each fiber-resin system to be used in a composite propeller is necessary for determining its fatigue strength. Unlike metal propellers, there may be insufficient data upon which to assess the fatigue characteristics of the anticipated material systems to be used in composite propellers.

(i) Essential Characteristics. Essential characteristics undefined or poorly understood are: The fatigue (S-N) curve shape, the statistical distribution of fatigue strength for such systems, and the standard deviation. Additional insight is needed with respect to strength degradation as a result of manufacturing defects, service damage, and adverse environments.

(ii) Representative Specimens. Establishing an S-N curve involves the testing of specimens that are representative of the propeller's material system, stacking sequence, and manufacturing processes.

(A) In addition, the propeller's station-to-station variance between root/shank sections, mid-blade section, and tip regions may warrant the testing of coupons representative of each.

(B) A sufficiently large number of coupons should be tested to define the S-N curve shape. A minimum of thirty (30) coupons, all exhibiting the same failure mode, should be tested.

(C) Coupons should be tested to failure under a combination of steady and vibratory loads. The loading may be tension-tension or tension-bending. The steady loading should be representative of that anticipated in service for the propeller. The vibratory loading component should be arbitrarily selected to facilitate the generation of an S-N curve, over a broad range of stress cycles, so that the endurance limit can be defined. This is normally considered to be at 500×10^6 cycles. The frequency of the vibratory loading, although preferably at the propeller's 1-P, may be at any frequency the manufacturer chooses, 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.

(2) Strength/Life Degradation. In addition to the inherent fatigue characteristics of a propeller's material system, an evaluation of strength degradation, as a result of manufacturing defects, service damage, and adverse environments, needs to be made. Further, although propeller design reflects the safe-life philosophy, evaluation of the structural degradation of these defects can provide valuable information regarding their fail safety/damage tolerance qualities. Existing test data may be used to establish strength degradation factors where it can be shown to be directly applicable to the material system.

(i) Manufacturing Defects. Propellers manufactured to a process specification have quality control limits, with respect to manufacturing defects or flaws. Accordingly, these quality limits, such as, fiber misalignment, variances in resin content, and delaminations, should be considered for their impact on structural integrity. To some extent, coupon testing is appropriate for this purpose.

(ii) Service Damage. Propellers are exposed to, and experience a certain amount of service damage from, stone nicks, small bird strikes, hail impact, and handling. The extent of such damage tolerance and the method of demonstration can be the choice of the manufacturer. Although full-scale testing is ideally suited for this purpose, coupon testing, or the analyses of existing data, may identify the scope of full-scale testing necessary.

(iii) Environmental Degradation. General aviation aircraft, unlike transport category aircraft, are unable to average out the effects of a number of climates, but may spend their entire operational life in a severe climatic zone. Accordingly, depending on the propeller's intended usage, coupon tests and/or applicable existing data are required to establish the strength degradation of the material system. For those tests set out in paragraphs (iii)(A) through (iii)(E) below, the coupons may be soaked without their protective coating system, to shorten the soak period to a minimum. Operational environments that should be addressed are:

(A) High Temperature and Humidity. Coupons should be conditioned, in accordance with the recommendations in MIL-HDBK-17B, until their weight gain has stabilized. Fatigue testing should be conducted under the controlled temperature-humidity environment.

(B) Low Temperature. Coupons should be soaked and fatigue tested in a controlled atmosphere of -65 $^{\circ}$F.

(C) Thermal Cycling. Coupons should be exposed to 50 thermal cycles from -65 to 160 $^{\circ}$F, then fatigue tested at ambient temperature.

(D) Ultraviolet Light. Coupons should be exposed to an artificial light source, such as, per Mil-Std-810D, Method 505, dated July 19, 1983, and then fatigue tested. Existing data of the propeller's protective coating system may justify dispensing with this test.

(E) Aviation Chemicals. Coupon tests should be conducted to establish the structural degradation, if any, of the composite material/protective coating system, as a result of exposure to such aviation chemicals as fuel, oil, glycol, hydraulic fluid, solvents, etc.

b. Full-Scale Tests.

(1) Specimen Selection.

(i) Full-scale shank, mid-blade, and tip specimens, or combinations of these, should be fatigue tested at combinations of steady and vibratory loads. Depending on the blade design, mean stress distribution and expected first-order and higher-order vibratory loading, consideration may be given to combining tip and mid-blade, or mid-blade and retention testing into one series of tests.

(ii) To obtain realistic values for the fatigue strength, and to address the issues of damage tolerance and continued airworthiness, the specimens should be airworthy, yet have representative, if not "worst case," manufacturing defects and service damage due to stone nicks, small bird strikes, hail impact and handling. The extent of such defects/damage must be consistent with inspection techniques employed and the airworthiness must be demonstrated.

(2) Loading.

(i) Include all of the steady and vibratory loads in order to obtain a realistic value for the fatigue strength.

(ii) The vibratory loads should be imposed at the propeller's 1-P, or higher-order, frequency. Higher-order excitation can be significant for mid-blade and tip regions.

(iii) The majority of propeller fatigue problems concern high-cycle fatigue strength. Therefore, it is necessary that most of the fatigue test data (failures) be generated at a relatively high number of cycles, preferably in the 10^7 to 10^8 cycle range. To induce failures in this preferred cycle range, it may be necessary to increase the vibratory component of the load(s).

(3) Specimen Monitoring.

(i) Each specimen should be strain gauged and have load cells to monitor the loads and stress distribution.

(ii) The propeller blade should be examined regularly for delamination or cracks.

(iii) The bending and torsional stiffness of each specimen should be measured at the outset of each test, and periodically monitored throughout the test. The frequency of stiffness monitoring should be closer during the failure process.

(iv) Testing should be continued after the initiation of failure to demonstrate damage growth characteristics.

c. Reliability and Service Life.

(1) Mean Endurance Limit. The mean endurance limit of each critical section is defined as: the mean steady and vibratory stress at which all samples tested would have failed had they all been tested to 500×10^6 cycles, or an asymptote representing the endurance limit. Customarily, this is established by: (1) "fitting" the coupon-derived S-N curve shape through each failure point, thereby extrapolating each failure to 500×10^6 cycles; and (2) computing the mean of these extrapolated failure points.

(2) Reliability. Being dynamically loaded components, the structural integrity of propellers may be 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, must 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.

(i) For a prescribed reliability, the mean endurance limit (E_{50}) will be reduced by a factor (k), governed by the selected sample size (n) and the coupon-derived statistical strength distribution, and the standard deviation ( ) of the full scale data. More specifically, the 99 percentile endurance limit (E_{99}) may be expressed: $E_{99} = E_{50} - k$; where (k) is a function of the sample size (number of full-scale specimens tested).

(ii) For the normal strength distribution, (k) varies with sample size as follows:

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	

Note: Use of available in-house, development data and analytic expertise, along with limited full-scale testing, may be used as an alternative in substantiating the required reliability.

(4) <u>Service Life</u>. For the purposes of establishing service life and granting vibration approvals, a final S-N curve will be drawn. It will bear the shape of the coupon-developed S-N curve, with an endurance limit at 500 x 10^6 cycles, including an appropriate service damage/environmental degradation factor. All anticipated operating steady and vibratory stresses should be below the 99 percentile endurance limit.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1993 - 343-120/85920

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