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# Defect-caused alteration of a composite unit modal parameters

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ABSTRACT

This paper presents research on diagnostic parameters for monitoring conditions of a light aircraft engine blade made of composite materials (CM) in flight. This study covers the modal parameters investigation of the blades in the frequency range of 30–60 Hz. Using the Doppler Effect the vibration response between the used blades and a new blade was compared. The used blades demonstrated a fourfold increase in amplitude of resonant vibration in the first bending mode. The amplitude growth of the first bending mode resonant vibration can be used as a diagnostic sign of emerging defects. The ease of amplitude and frequency analysis of a blade resonant vibration in flight conditions will allow researchers to develop an express-control device for technical condition analysis of CM blades while in air.

## 1. Introduction

The composite materials (CM) are widely used in aircraft products. Any discontinuity in a CM structure may lead to dramatic growth of binder fractures, causing the possible crash of the aircraft, while an ordinary metal structure could sustain small fractures without causing severe damage. Therefore, it is important to evaluate the integrity of the critical aircraft CM parts in a timely manner during the flight. However, existing methods of CM inspection make it possible to only diagnose units in an airfield laboratory. As a result, the development of an express-test device for aircraft CM is an important task.

In order to implement the diagnostic device system on aircraft, it is required to solve two major problems. First of all, a parameter measurement system, which could indicate the defect manifestation, has to be developed. One of the possible solutions is a system of sensors, integrated into the structure of a CM detail [3]. The simple installation of piezo-electric or micro strip resonators is inacceptable, because it reduces the unit strength by an average of 27% [1,2]. This is why it is stated, that the carbon nanotubes, arranged between the layers of CM fibers in the manufacturing process could be used for the measurement of material properties. The same use of ferroelectric ceramic composites in polymer matrix was depicted in article [4]. Second, it is necessary to define the construction properties that could cause the defect to appear. Finally, the parameters corresponding to the said properties must be measurable in flight.

According to Swedirski [5], the composite material can suffer from different kinds of discontinuities, such as reinforcing wire breakage, binder fractures, fiber separation from the wire net, microdiscontinuities and micropores. Moreover, the composite structure is not homogeneous and therefore it is easy to mistake the undamaged CM structure for a cracked one. The process of defect detection and identification, as well as assessment of the overall design impact remains complex and unevident, thus explaining the wide range of composite material inspection methods.

Acoustic methods are the most common for composite structure investigation. There are two ways to detect a fault in composite material. In the first case, a critical force is applied to the unit, causing microdiscontinuities in the material structure. The exact localization points of cracks are registered using the acoustic emission method [6,7]. This method allows researchers to determine the maximum loads for the given structural element. The critical disadvantage of this method is that it renders the unit inoperable. In the second case, the tested unit is exposed to a high-frequency acoustic impact. The articles [8,9] describe the composite surface defects survey using the optical coherence tomography, where vibration response is analyzed in ultrasonic frequency range (up to 28 kHz). In order to find internal CM failures, such as large material cracks and gaps at the depth of first five to seven layers, the Lamb waves are registered in frequencies up to 300 kHz. The piezoelectric element was used as an excitation source [10,11]. The excitation frequency has to be increased up to megahertz level in order to further enhance the method accuracy to detect micro-breaks and micropores [12]. Karabutov et al. [12] depict that laser optoacoustic excitation method has to be applied in order to obtain the

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required power of a stable excitation signal. In this case, the diagnosis was carried out according to the change in the acoustic attenuation coefficient. The test equipment demonstrated its high sensitivity to noise, therefore, this testing method requires a controlled area and is not suitable for use in an aircraft.

To further increase accuracy in an in-depth material defect diagnosis, it is necessary to increase the test frequency range up to terahertz level [13]. Kolodii and Lyaschuk investigate the defect impact on electromagnetic waves reflectance coefficient in their article [14]. X-ray analysis techniques were used in article [15]. However, this kind of analysis is not safe for equipment in close proximity to a test crew unit and is also inapplicable in flight conditions.

Another group of methods for CM monitoring is based on the analysis of heat fluxes, emitted by the composite material structure. The alternate measurement techniques include the infrared thermography, which is presented in articles [16,17], and a synchronous phase thermography (lock-in thermography), presented in article [5]. Unfortunately, the reflected heat flux does not always allow researchers to make a decision on material defect. In some cases, the receiving chamber must be installed behind the measuring panel, which is not possible in a real flight.

As it was noted in the material inspection methods review, all these techniques are unsuitable for flight conditions. A specific diagnostic feature, which would appear in the normal aircraft operation during flight, needs to be found. Pilots have claimed to feel an increased vibration during flight whenever the defects in material appeared. This kind of disturbance could possibly be the increased resonant vibration at one of the modal propeller frequencies. It is possible to suggest that the increase in amplitude of vibration at modal frequency might be the defect diagnostic sign.

There are a number of studies about frequency range of composite structures, including the mechanical oscillations natural frequencies [18–22]. The modal frequencies are characterized by the changes in the amplitude of the surface vibration. The change of structure response in the frequency range up to 20 kHz was determined by means of scanning vibrometer, thus detecting the fiber separation in composite structure [19]. In the later papers [20–22], it was concluded that fiber separation can be diagnosed by the general growth of RMS vibration values in the high frequency range. Still, there are no known studies on impact of the defect on the modal frequencies and shapes of the tested element. Therefore, the study of composite material modal characteristics in continuous operation, and especially their comparison with reference models remains an important task.

## 2. Experiment conditions

The probability of CM components failure is increased dramatically by the end of the working period. The fatigue life of a light aircraft airframe ranges within 2000 and 6000 h, whereas the blade life is less than 300 h. Apparently blade replacement takes place from seven to twenty times during aircraft life. Moreover, the probability of airplane accidents will rise sharply with blade replacement time coming closer. Accidents may arise from time to time during airplane landing, taking off and climbing as well as high-speed and high-angle-of-attack maneuvering when the level-flight lift is not sufficient for gliding. Therefore, the blades of a small-engine propeller aircraft (Fig. 1) were chosen to study the changes in the modal parameters that are caused by composite material cracking and delamination. Table 1 represents the main characteristics of the blades under study. The new blade, which never was in operation, was used as a reference unit (Fig. 2a). The blades (Fig. 2b–d) that exceeded suggested running time (more than 1.4 times the assigned resource) were examined for the visible defects. In manufacturing composite blades, their weight tolerance can exceed 50 g. This is due to the technological features of manufacturing composite items. The difference in blade mass (represented in Table 2) can lead to blade natural frequency variation up to 2 Hz.

The study of natural frequencies and modal shapes was carried out using a rigid console-term blade support in the holding device with the mass of 28 kg or so (see Fig. 3(a)). The holding device was fixing the blade hub with clamps, as shown in Fig. 3(b). The support was excited by means of vibration in nonparallel and

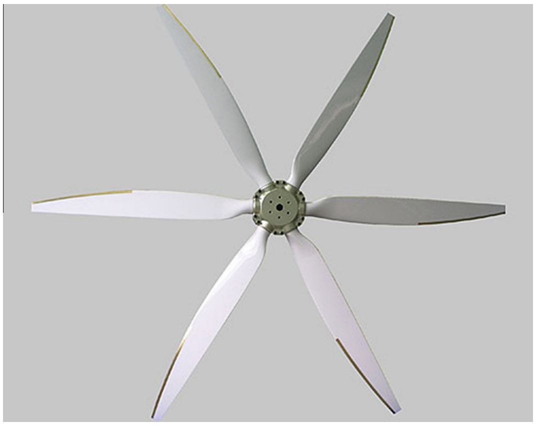

**Fig. 1.** Propeller of small-engine aircraft.

**Table 1**
Parameter values of the blades.

| Main particulars | Value |
|---|---|
| Blade length L, (mm) | 800 |
| Blade chord at radius R = 0.9 L, (mm) | 64 |
| Blade thickness ratio at radius R = 0.9 L | 0.125 |
| Hub-to-diameter ratio | 0.086 |
| Blade section | Clark Y |

**Fig. 2.** Blades used during testing.