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**Evaluation method for the resonance  
frequency of the multi-copter UA  
(unmanned aircraft) by measurement  
of rotor and body frequencies**

*Méthode d'évaluation de la fréquence de résonance du multicoptère  
télépiloté par mesure des fréquences du rotor et du corps*

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ISO copyright office  
CP 401 • Ch. de Blandonnet 8  
CH-1214 Vernier, Geneva  
Phone: +41 22 749 01 11  
Email: [copyright@iso.org](mailto:copyright@iso.org)  
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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 16, *Unmanned aircraft systems*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

This document defines the correlation between the excitation frequency caused by rotor rotation and the resonance frequency of the main body in the design of the multi-copter UA (unmanned aircraft), and suggests the evaluation method to define the design requirements of the multi-copter UA to prevent damage due to resonance.

Typical applications for evaluation of resonance of the UA are:

- a) measuring the natural frequency of the UA;
- b) measuring the thrust forces and the rotational frequency of the rotor;
- c) determining the modal properties of the UA (natural frequency, damping and mode shape);
- d) checking the resonance between the natural frequency of main body and the rotational frequency of the rotor.

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# Evaluation method for the resonance frequency of the multi-copter UA (unmanned aircraft) by measurement of rotor and body frequencies

## 1 Scope

This document provides a method for evaluating the resonance vibration frequency of the multi-copter unmanned aircraft (UA). This document specifies a method of designing the UA so as to avoid the resonance generated by the coincidence of the natural frequency of the UA body and the rotational frequency of the rotor.

This document is applicable to multi-copter UA weighing less than 150 kg.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068-2-6, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-64, *Environmental testing – Part 2-64: Tests – Test Fh: Vibration, broadband random and guidance*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

### 3.1

#### **operating frequency range**

rotation frequency span between the lowest frequency to the highest frequency of an unmanned aircraft (UA) to fly

### 3.2

#### **natural frequency**

frequency or rate at which an unmanned aircraft (UA) vibrates naturally when disturbed

Note 1 to entry: The natural frequency changes when the mass distribution (e.g. adding a payload) changes, it is measured with the added payload.

### 3.3

#### **resonant frequency**

phenomenon in which an external force or a vibrating system forces another system around it to vibrate with greater amplitude at a specified frequency of operation

**3.4**  
**frequency response function**

function that represents the relationship between an input signal and an output signal in the frequency domain

**3.5**  
**FFT**

fast Fourier transform  
algorithm that computes the discrete Fourier transform (DFT) of a sequence

Note 1 to entry: Fourier analysis converts a signal from its original domain (often time or space) to a representation in the frequency domain and vice versa.

**3.6**  
**arming frequency**

rotating frequency of the propeller before take-off

**4 Test method**

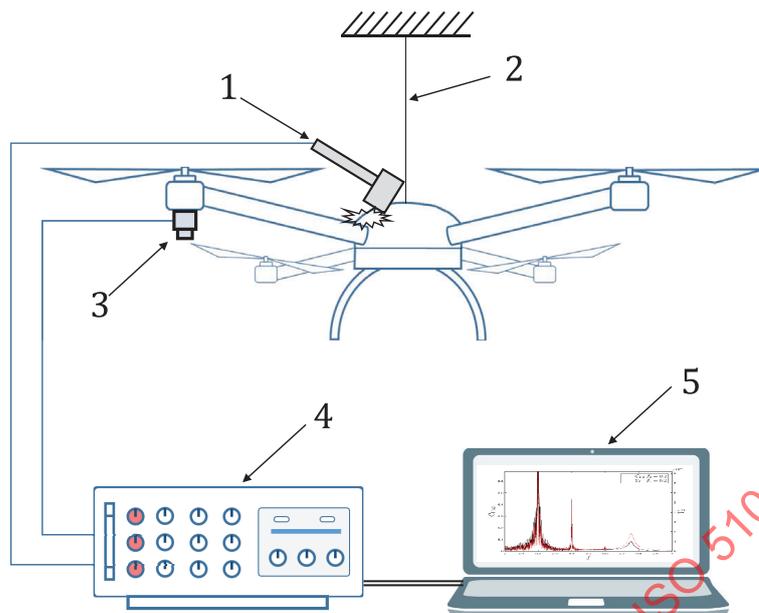
**4.1 Test setup**

**4.1.1 General**

In the case of a small-sized UA, the impact hammering method is simple; it has good cost-effectiveness and is often used to measure the natural frequency of small structures. In the case of a large-sized UA, if an impact hammer is used, the energy transfer is small and accurate measurement may not be possible. In such a case, the natural frequency and the natural mode shape can be measured using an exciter. The method to use depends on the size, shape, and material of the UA; so it is determined by previous experiences. It may also be possible to measure the vibration profiles for the larger UA, depending on the size of the test article, by using the hammering excitation method.

**4.1.2 Hammering method**

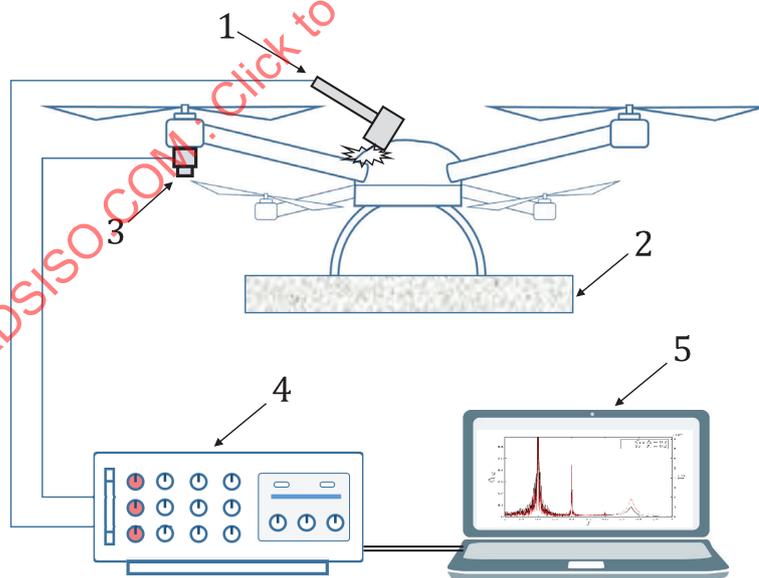
[Figure 1](#) and [Figure 2](#) show the concept of the test device for measuring the natural frequency and the natural-mode shape. To measure the natural frequency, the UA is typically suspended in the air using a wire or placed on a sponge. At this time, in order not to affect the natural frequency of the wire's stiffness, it is enough to have the minimum strength to hang UA. The sponge should also be soft, if possible, in order not to affect the natural frequency. A previous analysis shall be done so as to determine the natural frequencies, which should be far away in order not to affect the natural frequencies of the UA (estimated previously). Since the stiffness of the blade is very small compared to the stiffness of the frame, the direction of the blade is not so important in small UA. However, it is better placing the blades in such that direction of them is perpendicular to each arm.



**Key**

- |   |                 |   |           |
|---|-----------------|---|-----------|
| 1 | impact hammer   | 2 | wire      |
| 3 | accelerometer   | 4 | amplifier |
| 5 | signal analyser |   |           |

**Figure 1 — Schematic diagram of measuring the natural frequency using a wire (small-sized UA)**



**Key**

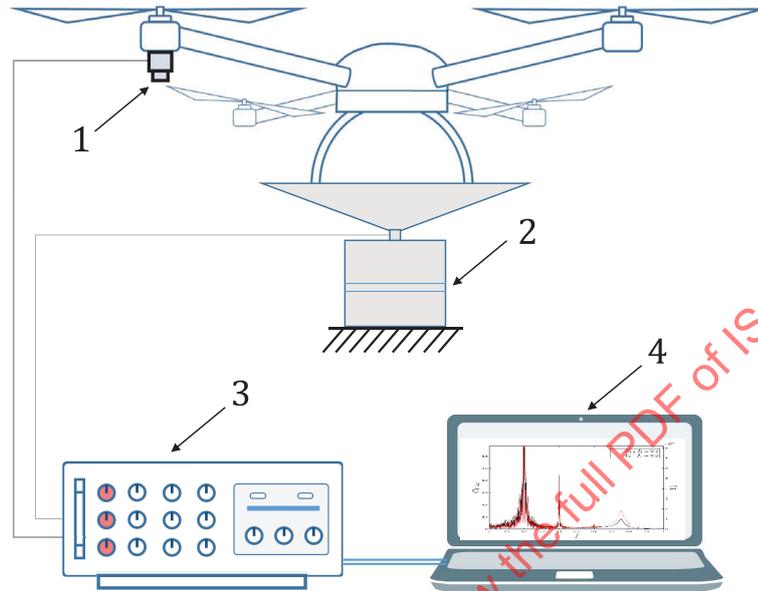
- |   |                 |   |           |
|---|-----------------|---|-----------|
| 1 | impact hammer   | 2 | sponge    |
| 3 | accelerometer   | 4 | amplifier |
| 5 | signal analyser |   |           |

**Figure 2 — Schematic diagram of measuring the natural frequency using a sponge (small-sized UA)**

NOTE Details of support systems are given in Section 7.5 of ASTM E1876-01.

4.1.3 Excitation table method

For a large UA, it should be placed on the vibrator during the measurement. The resonance frequency of the UA using the vibrator shall be measured according to IEC 60068-2-6 or IEC 60068-2-64. Figure 3 shows the measurement on the vibrator. In this test, the natural frequency and natural mode shape of the UA are measured. In order to measure the natural frequency of the UA, the accelerometer shall be attached to the UA and the measurement shall be taken in several places. A 3-axis accelerometer should be used.

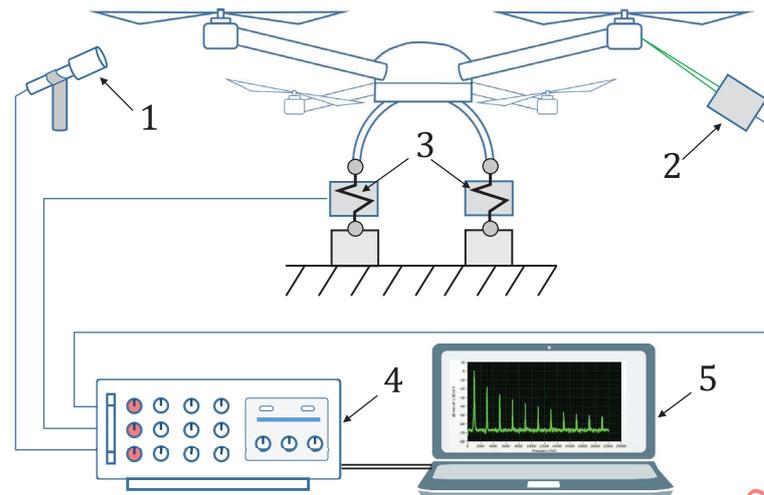


- Key**
- 1 accelerometer
  - 2 vibrator
  - 3 amplifier
  - 4 signal analyser

Figure 3 — Schematic diagram of measuring the natural frequency (large-sized UA)

4.2 Concept of an operation frequency

Figure 4 shows the schematic diagram of the device for measuring the rotor speed and the thrust force. The purpose of this test is to measure the thrust force caused by the rotational speed of the UA rotor. For a small-sized UA, it is difficult to take the measurement with a tachometer as the motor rotates at a high speed; a microphone should be used in this case. For a large-sized UA, a tachometer should be used.



### Key

- |   |                 |   |            |
|---|-----------------|---|------------|
| 1 | microphone      | 2 | tachometer |
| 3 | load cell       | 4 | amplifier  |
| 5 | signal analyser |   |            |

Figure 4 — Schematic diagram of the device for measuring the rotor speed and the thrust force

## 5 Analysis of natural frequency and operation frequency

### 5.1 Natural frequency

#### 5.1.1 General

Because the rotor that generates the thrust force of the UA is located at the end of an arm, it can be modelled to a form with a fixed cantilever and a concentrated mass at the end. The natural frequency of a multi-copter UA is governed by [Formula \(1\)](#) of four main design factors. The main design factors related to natural frequency are the Young's modulus of the cantilever arm, the 2nd moment of inertia, the mass of the cantilever arm and the length of the cantilever arm. [Formula \(1\)](#) can be used by the UA designer to assess the impact of each design factor on the resonant frequency, to ensure that the final design will avoid resonance under operating conditions.

The formula for calculating the natural frequency of the cantilever arm is:

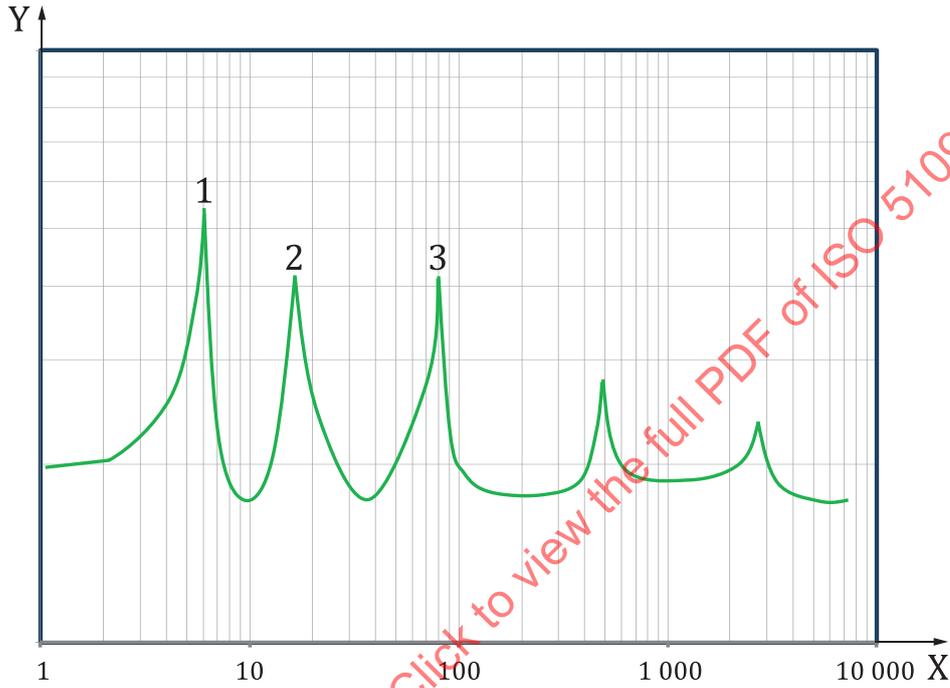
$$f_n = \frac{1}{2\pi} \sqrt{\frac{3EI_n}{Ml^3}} \quad (1)$$

where

- $f_n$  is the natural frequency of  $I_n$  direction;
- $E$  is the Young's modulus of the cantilever arm;
- $I_n$  is the 2nd moment of inertia (maximum  $I_1$ , minimum  $I_2$ );
- $M$  is the mass of the cantilever arm;
- $l$  is the length of the cantilever arm.

5.1.2 Natural frequency measurement

The natural frequency of a small-sized UA shall be measured by applying an impact using an impact hammer or sound wave or other dispersed load and receiving a signal using an accelerometer to perform FFT analysis; or the calculation result shall be applied to the natural frequency. This is a very common method and the natural frequency can be measured using a relatively simple experimental tool. However, it is difficult to measure the natural frequency and the natural mode of a large-sized UA in this manner because the transmission power is too weak to excite it using an impact hammer. For a large-sized UA, the natural frequency shall be measured by placing it on a vibrator and sweeping the frequency. Figure 5 shows the frequency response function of UA and natural frequencies.



- Key
- 1 1st natural frequency
  - 2 2nd natural frequency
  - 3 3rd natural frequency

Figure 5 — Frequency response function of UA and natural frequencies

5.2 Operation frequency

5.2.1 Operation frequency measurement

In order for the UA to fly, the thrust force caused by the rotor must be greater than its own weight before it takes off. The thrust force of the rotor shall be measured by attaching a load cell to the skid of the UA and fixing it securely to the ground. The rotational frequency of the rotor shall be measured by counting the number of revolutions of the motor using a tachometer. For a small-sized UA, it is easier and simpler to measure sound waves using a microphone because the motor rotates at a high speed. The operating frequency should be measured under different working conditions.

5.2.2 Thrust force measurement

The thrust force,  $N$ , shall be obtained by measuring of the load cell attached to the UA skid or rotor measuring stand while increasing the motor speed. Here, the arming frequency refers to the frequency of motor revolutions that the UA starts up before taking off. The operating frequency range refers to the