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VIBROACOUSTIC SYSTEM FOR MEASUREMENT OF THE TOUCHDOWN OF A LIGHT AIRCRAFT

Summary. Aircraft touchdown is one of the most difficult and dangerous phases of a flight. The paper presents an aerial light aircraft, prepared and produced by vibroacoustic tests, using an aircraft landing and landing monitoring system (AVI). The concept is based on the use of an ultrasonic transceiver head and vibration transducer, together with an appropriate signal processing and analysis system. The system measures the touchdown speed and altitude of the aircraft in the final phase of the flight and determines the level of load transmitted to the aircraft during the landing. Thanks to data archiving, it allows for better estimation of the wear rate of the structure, which is important in determining the causes of possible malfunction. It can be used with light and ultralight aircraft and, after adaptation, in unmanned aircraft. It can also be used to evaluate the art of piloting during landing.

Keywords: aircraft landing; landing monitoring system; ultrasonic measures

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1. AVI SYSTEM

The ultrasonic measuring system consists of a transmitter head, receiver head, signal processing circuitry and controller.

The method of measurement is based on the detection of wave propagation time along the path from the transmitting head, through the ground surface, to the receiving head. This time depends on the distance of the aircraft from the landing. A schematic view of the AVI system operating principle is shown in Fig 1. Working in the 40-kHz band, the interfering signal generated by the aircraft when in flight can be significantly reduced

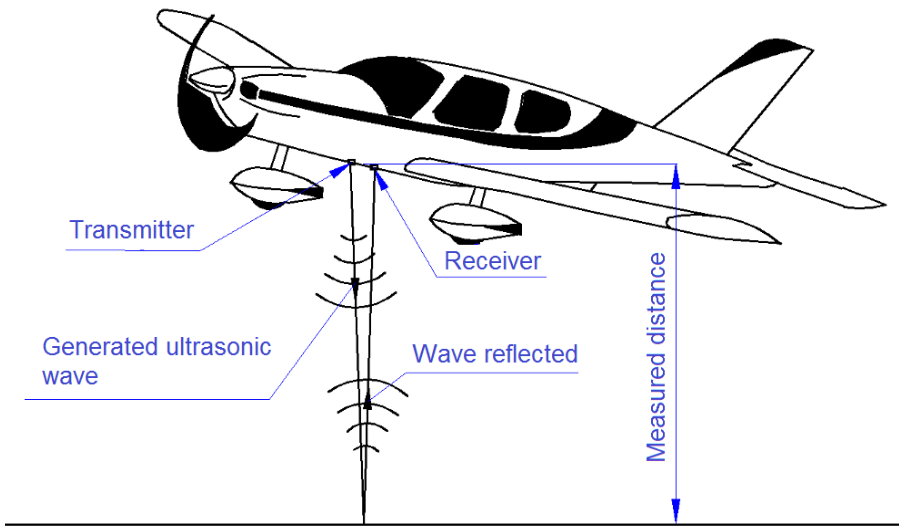

Fig. 1. Schematic view of the AVI system operating principle

An ultrasonic pulse is formed by the transmitter and sent periodically with repetition time T. The generated wave after reflection from the landing plane returns to the receiver head after T_r^i, (Fig. 2). The distance between the sensor and the reflection plane H_i is equal to the product of the half-wave propagation time and propagation velocity in the medium:

$$H_i = \frac{1}{2} c \, TR_i \quad (1)$$

where T_R^i is the ultrasonic wave propagation time; and c is the propagation velocity (for air 343 m / s at 20°C). The vertical component of the landing velocity can be determined using differential methods (Fig. 3).

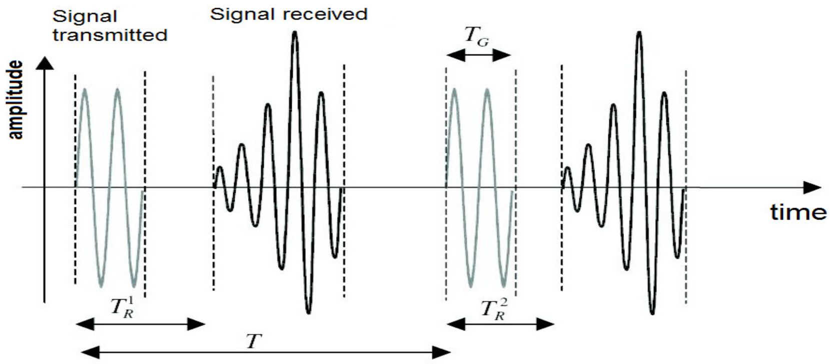

Fig. 2. Ultrasonic signal in the time domain

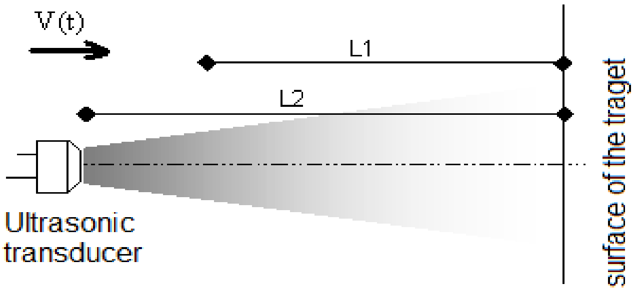

Fig. 3. Speed determination scheme

The measured velocity is described with the relationship:

$$V_i = \frac{L^i - L^{i-1}}{T} \tag{2}$$

or more accurately:

$$V_i = \frac{L^i - L^{i-1}}{\left(T + T_R^i - T_R^{i-1}\right)} \tag{3}$$

where V_i is the measured speed; L ^{i} and L^{i-1} are the consecutive distances; and T is the repetition time.

The distributed pole effectiveness of the directional transmitting head diagram is shown in Fig. 4.

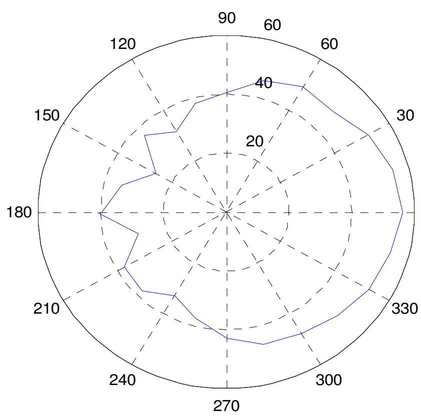

Fig. 4. Distributed pole effectiveness of the directional transmitting head

A modified AVI velocity identification and acceleration (AVI-a) system has been developed and implemented, which measures the height of the aircraft, the vertical velocity of the touchdown in the final phase of landing, and the vibration amplitude of selected aircraft components. Fig. 5 shows a block diagram and Fig. 6 shows a general view of the AVI-a system.

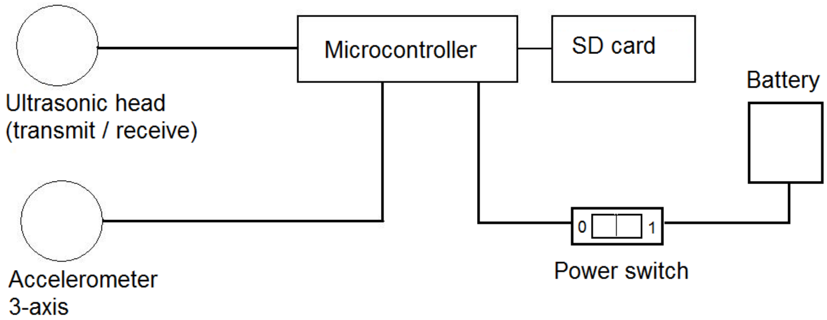

Fig. 5. Block diagram of the AVI-a system

Fig. 6. General view of the AVI-a system

The vibration acceleration measurement allows us to determine the loads to be delivered to the aircraft during the landing and gives a better estimate of the wear rate of the structure, which is important for determining the cause of any landing failures. The system can be used to evaluate the art of piloting (quantitative identification of pilot skills).

2. AVI-A SYSTEM TESTS WITH CZAJKA AIRCRAFT BALLAST

The purpose of this AVI research was to verify the assumptions about the system's suitability in aviation applications.

The methodology for the study consisted of the simultaneous measurement of distance and acceleration in the course of the falling of the ballast and the impact on the protective barrier, which was supposed to simulate the moment of plane touchdown. The measurement station diagram is shown in Fig. 7.

Handles were mounted on the ballast, with which it was suspended on the ropes. The hitch was at a height of 7 m, while their other end was mounted at a height of about 1 m.

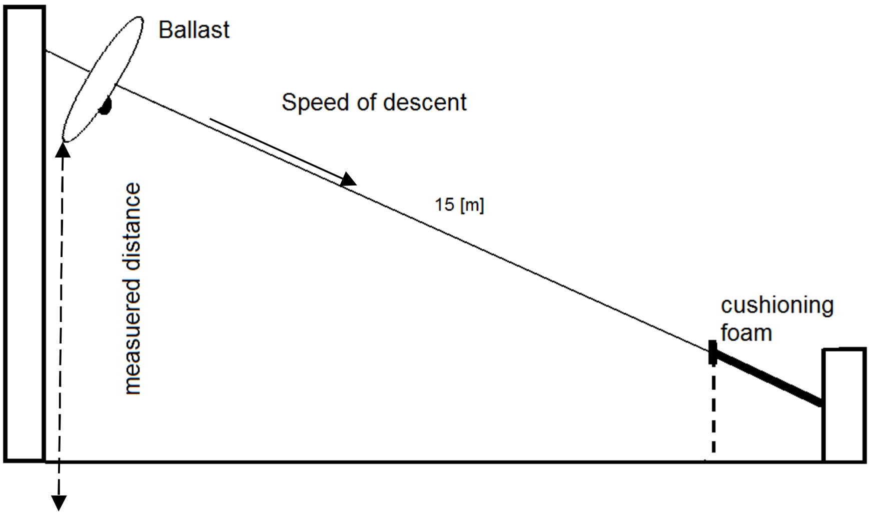

Fig. 7. The scheme of the AVI-a system for testing

An ultrasonic transceiver head and an accelerometer measuring acceleration in three mutually perpendicular directions, x, y, z, was placed on the ballast. The view of the ballast with sensors and the accelerometer is shown in Fig. 8.

Fig. 8. View of the ballast during tests with the AVI-a system

There were two types of tests on the station. The first was a free throw of the ballast, while the second was a throw-in with a controlled braking force. Simultaneously with the height measurement, the vibration of the ballast was measured.

An example of the elevation change as a function of time for free discharge is given in Fig. 9, while Fig. 10 shows the acceleration waveforms for the three directions recorded during the discharge.

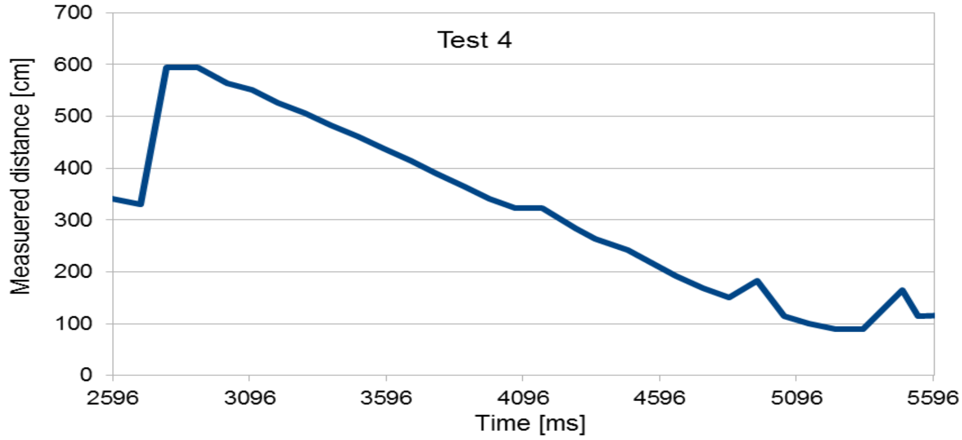

Fig. 9. The waveform of height change as a function of time for a freefall

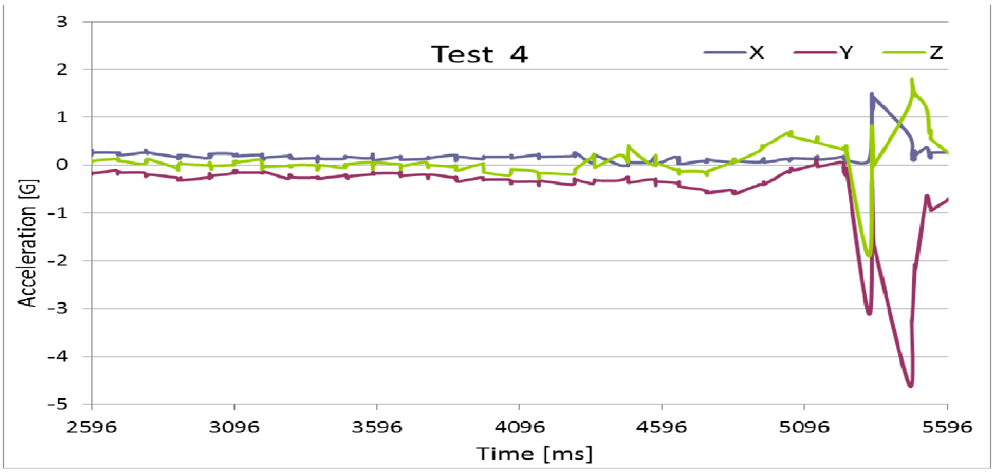

Fig. 10. Waveforms of the vibration acceleration of three directions as recorded during discharge

In addition, tests were carried out on a high-speed object (up to 140 km/h) to verify the operation of the ultrasound head. The tests confirmed the possibility of using the above head during high-speed measurements.

3. AVI SYSTEM TEST ON SKYLEADER 600 AIRCRAFT

The AVI system was also tested under operational conditions on the Skyleader 600 aircraft (Fig. 11).

Fig. 11. View of the Skyleader 600 aircraft

AVI system tests were carried out at airports with different runway surfaces: on a grass runway (Rybnik) and on a concrete runway (Kaniów).

The block diagram of the applied system is given in Fig. 12, and the system view with ultrasonic heads is shown in in Fig. 13.

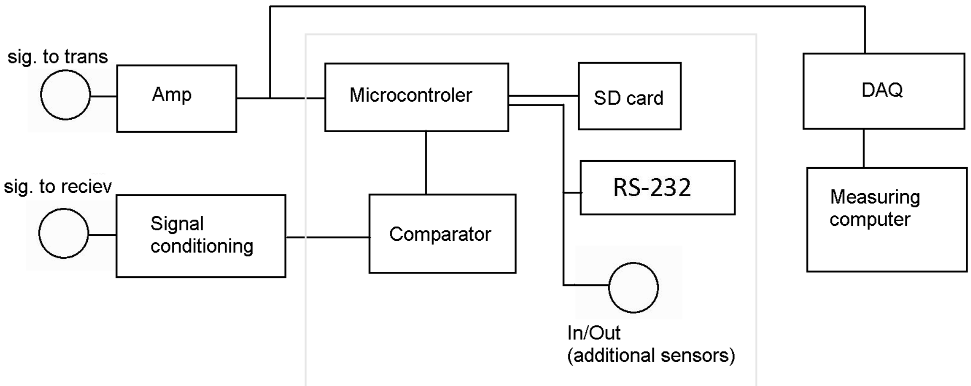

Fig. 12. Block diagram of the AVI system

Fig. 13. View of the AVI system with ultrasonic heads

A view of the AVI system mounted on the Skyleader 600 aircraft is shown in Fig. 14. The heads were placed under the wing at a height of about 66 cm.

Fig. 14. Location of transmitter and receiver head

4. TESTS RESULTS

During the measurement session, many landings were conducted under the same weather conditions with the same pilot. It can be observed that each landing had a different character.

Below are graphs showing the individual touchdown processes on the concrete runway (Figs. 15 and 16) and on the grass runway (Figs. 17 and 18).

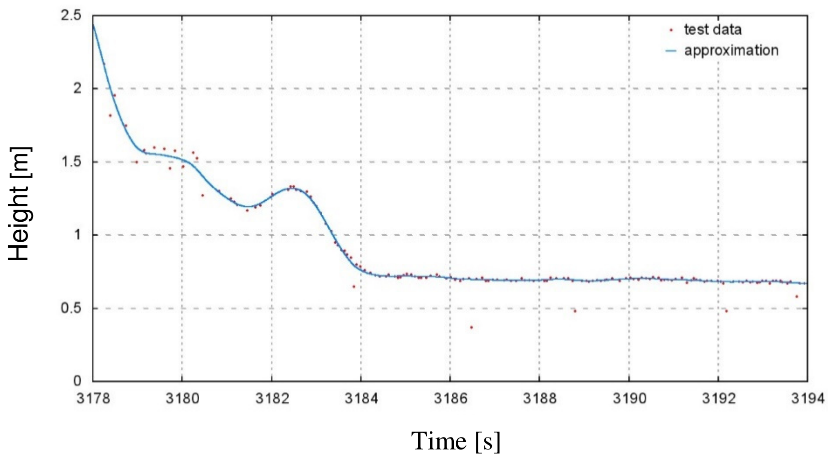

Fig. 15. Touchdown: concrete runway (Test 3)

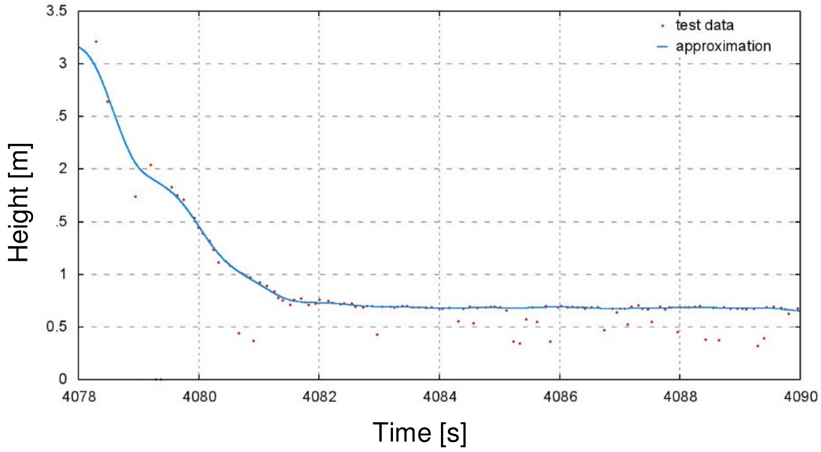

Fig. 16. Touchdown: concrete runway (Test 5)

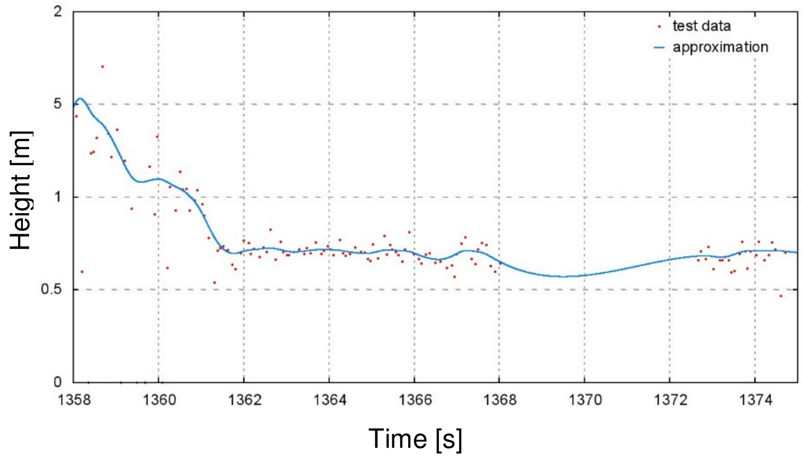

Fig. 17. Touchdown: grass runway (Test 8)

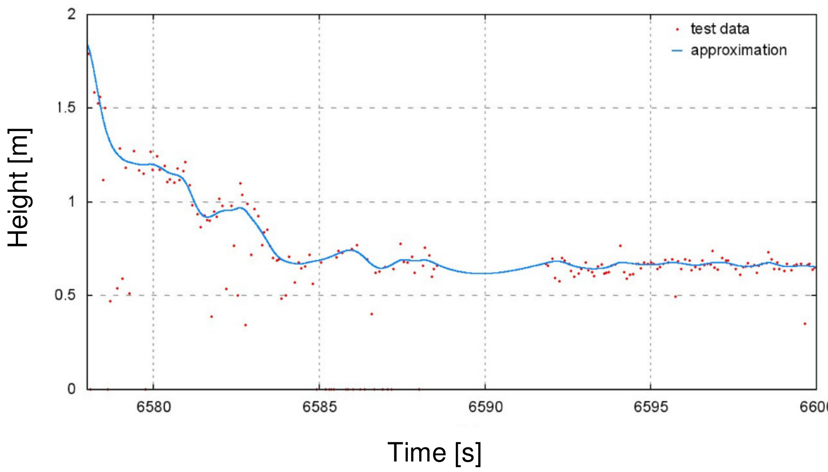

Fig. 18. Touchdown: grass runway (Test 12)

The above charts can be read for different types of landing, i.e., slowly (Fig. 15) or faster (Fig. 16). For the grassland runway, the measurement noise was greater than for the concrete runway.

5. CONCLUSION

The system can be used to assess pilotage during the landing phase in terms of quantifying the pilot's skills and assessing the impact of the landing on the construction of the aircraft, as well as determining the wear rate of the structure, which is important for establishing the cause of any landing failure. All data for height, the vertical velocity component and the vibration acceleration amplitude of the test element are recorded on a micro SD card, allowing for historical data recovery and subsequent analysis.

The system can be used to:

1. Determine the kinetic energy of the touchdown for optimal adjustment of the energy absorber (e.g., in an adaptive pneumatic landing gear).
2. Quantitatively evaluate the touchdown manoeuvre as a training aid for pilots.
3. Measure the position and speed in small planes and helicopters equipped with an adaptive chassis.
4. Track the course of landings during training flights.

Thanks to data archiving, the AVI system allows for better estimation of the wear rate of the structure, which is important for determining the causes of possible failures. It can be used in light and ultralight aircraft and, after adaptation, in unmanned aircraft. It can also be used to evaluate the art of piloting during landing.

In the case of unmanned aircraft, it is possible to use such signals in automatic control systems at the moment of touchdown.

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