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Acoustics – Description and measurement of physical properties of sonic booms

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FOREWORD

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Draft International Standards adopted by the Technical Committees are circulated to the Member Bodies for approval before their acceptance as International Standards by the ISO Council.

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Austria	Ireland	Romania
Belgium	Israel	South Africa, Rep. of
Canada	Japan	Sweden
Czechoslovakia	Korea, Dem. P. Rep. of	Switzerland
Denmark	Netherlands	Turkey
France	New Zealand	United Kingdom
Germany	Norway	U.S.A.
Hungary	Poland	U.S.S.R.

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Acoustics — Description and measurement of physical properties of sonic booms

1 SCOPE AND FIELD OF APPLICATION

This International Standard establishes the terminology for describing the physical properties of sonic booms caused by overflight of supersonic aircraft, and specifies the minimum performance requirements of equipment and the method to be used for their measurement. The conditions of measurement envisaged include those in which the direction and time of arrival of the pressure disturbance and even its approximate intensity are not necessarily known in advance. This International Standard provides the basis for the measurement and description of sonic boom pressure signatures suitable for evaluating their effects on people, structures, animals and unstable terrain features.

NOTE — The physical properties described by these procedures are properties of particular acoustic events (sonic booms) occurring at a specified location. They cannot be considered as properties of a particular aircraft, since the measured quantities depend also on prevailing conditions of flight, of atmosphere and of ground.

2 TERMINOLOGY

2.1 sonic boom : The acoustic event which is a manifestation of the shock wave system generated by an aircraft when it flies at a speed greater than the local sound velocity.

A typical example of a graphical display (pressure signature) of a ground-reflected sonic boom is illustrated in the Figure, which may assist the understanding of the terminology stated below.

Broadly the event comprises bow shocks and stern shocks, with a progressive pressure decrease between the occurrences of the two groups of shocks. Although the two groups of shocks may be heard separately, the whole event is conventionally described as a single sonic boom.

2.2 overpressure — symbol, p; unit, Pa (or lbf/ft^2)[1) : The difference between the pressure at a point at any instant and the ambient atmospheric pressure; positive when the pressure is greater than the ambient atmospheric pressure, negative when it is less.

NOTE — The symbol p for overpressure used in this document is in accordance with the symbol for (instantaneous) sound pressure given in ISO/R 31, Part VII, *Quantities and units of acoustics*. The symbol Δp has frequently been used in the past to describe the sonic boom overpressure.

2.3 peak overpressure — symbol p_{max}; unit, Pa (or lbf/ft^2) : The highest positive value of the overpressure.

2.4 pressure signature : The time history of the overpressure.

NOTE — The free field signature, when displayed graphically, often resembles the letter N and is then called an N-wave.

2.5 pressure rise — symbol, Δp; unit, Pa (or lbf/ft^2) : The increase in pressure between the onset and the termination of a given shock.

NOTE — In practice the time of onset of a shock is usually well defined, but the termination is often subject to some uncertainty of interpretation, and may have to be arbitrarily specified.

2.5.1 incident pressure rise — symbol, Δp_i; unit, Pa (or lbf/ft^2) : The pressure rise in the shock wave arriving direct at the measurement point without being affected by reflection from the ground or other objects.

2.5.2 reflected pressure rise — symbol, Δp_r; unit, Pa (or lbf/ft^2) : The pressure rise in the shock wave arriving at the measurement point after being reflected from the ground or other surfaces.

2.6 free-field conditions : Conditions existing when the ground and other reflecting objects are sufficiently remote that their effects on the shock wave system are negligible. Quantities measured under free-field conditions are denoted by symbols with the subscript f.

2.7 ground conditions : Conditions existing when reflecting objects not including those in the plane of the ground or the ground itself are sufficiently remote that their effects on the shock wave system are negligible. Quantities measured under ground conditions are denoted by symbols with the subscript g.

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1) 1 N/m^2 = 1 Pa (pascal)
1 bar = 10^{-5} Pa
1 lbf/ft^2 ≈ 48 N/m^2

2.8 ground reflection coefficient – symbol, r : A coefficient defined as the ratio of the reflected pressure rise to the incident pressure rise, both originating from the same ray.

2.9 ground reflection factor – symbol, K_r : A factor defined by the equation

$$K_r = 1 + r$$

NOTE – For a weak shock and a smooth rigid ground, K_r is approximately equal to 2.

2.10 total duration (of a sonic boom signature) – symbol, Δt_t; unit, ms : The time interval between the beginning and the end of the pressure signature.

For an N-wave type signature, it is the time interval between the onset of the bow shock and the termination of the stern shock.

NOTE – Although it is often difficult to define precisely the termination of the sonic bang signature, it is of practical value to use an approximate total duration.

2.11 intershock interval – symbol, ΔT_n (n = 1,2,3 ...); unit, ms : The time interval between the onset of one shock and the onset of a following shock.

2.12 phase duration – symbol, Δt_n (n = 1,2,3 ...); unit, ms : The time interval between successive zero values of the overpressure.

NOTE – The phase durations shall be numbered chronologically.

2.13 rise time (of a shock) – symbol, $\Delta\tau$; unit, ms : The time interval between the onset of a shock and its specified termination.

2.13.1 incident rise time – symbol, $\Delta\tau_i$; unit, ms : The time interval between the onset of a shock and its termination before the shock wave has been affected by reflection from the ground or other objects.

2.13.2 reflected rise time – symbol, $\Delta\tau_r$; unit, ms : The time interval between the onset of a shock after being reflected from the ground or other surfaces and its specified termination.

2.14 time-to-peak – symbol, Δt_m; unit, ms : The time interval between the onset of the first bow shock and the occurrence of the peak overpressure.

2.15 impulse – symbol, I; unit, mPa·s : The running integral of the overpressure with respect to time.

2.16 maximum impulse – symbol, I_{max} ; unit, mPa·s : The maximum value of the impulse.

2.17 phase impulse – symbol, I_n (n = 1,2,3 ...); unit, mPa·s : The value of the impulse during a phase.

2.18 signature interval – symbol, Δt; unit, ms : The time interval between the onset of the first shock and the onset of the last shock in the sum of all the intershock intervals.

3 MEASURING SYSTEM

A sonic boom pressure signature shall be sensed by a pressure microphone. The signal from the microphone shall be amplified and recorded by a suitable recorder. The equipment shall conform to the following requirements.

3.1 General performance requirements

The measuring chain shall have an overall free-field frequency response over the range of at least from 0,1 Hz to 5 000 Hz, which shall be flat within ± 2 dB.

The frequency response required of the measuring system depends to some extent on the purpose of the measurement and the duration of the free-field signature. Extension of the frequency range to 0,02 Hz and/or to 10 000 Hz is advisable depending on the signature duration and the need for information about the acoustic energy over this total bandwidth. If such broader bandwidth can be achieved only with wider deviations from a flat response, the frequency spectrum of the signature should be corrected accordingly.

NOTE – Depending on the purpose of the measurement, the measurement chain may cover the whole frequency range or may be divided into two channels, one covering the whole frequency range and the other covering a limited frequency range, for example 100 to 5 000 Hz. This use of two channels gives the possibility of improved signal to noise ratio in the audio frequency range.

3.2 Microphone

The sensitivity of the microphone system above the frequency range of interest should have a smooth roll-off in order to restrict overshoot distortion in the recording of sonic booms with short rise time.

NOTES

1 The dimension of the sensitive surface of the microphone determines the degree of fineness with which the overpressure at a location can be measured. For most applications a dimension not exceeding 20 mm is recommended.

The total harmonic distortion of the microphone and its associated amplifier should not exceed 4 % at the maximum overpressure to be measured.

2 Fully sealed capsules should be used with extreme caution to avoid pressure unbalance either in calibration or in measurements.

The variations of the sensitivity of the microphone due to environmental conditions shall be corrected in such a way that the resulting sensitivity is within ± 0,3 dB of the calibration value. The microphone shall be calibrated in terms of free-field sensitivity; however, when the microphone is mounted in the ground condition (see 6.1) the pressure sensitivity shall be used for frequencies at which the difference between the free-field sensitivity and the pressure-sensitivity is not negligible.

3 The calibration at very low frequencies, i.e. below about 25 Hz, can be performed with a pistonphone operating into a volume in which the microphone is placed. In the case of a condenser

microphone it is essential that the calibration circumstances are in accordance with the circumstances that prevail during the measurements; this specifically applies to the sound path between calibrating source and air volume behind the diaphragm. The sound pressure generated is calculated from the known excursion of the piston and from the volume, allowing for corrections for the transition from the adiabatic to the isothermal condition.

3.3 Recorder

The dynamic range of the recorder shall be at least 45 dB, under the condition that the total harmonic distortion measured at 1 000 Hz is less than 1 %.

NOTES

1 Since accurate prediction of the overpressures is difficult, the optimum system gain setting cannot be predetermined. For this reason it is recommended to record more than one channel simultaneously with different gain settings at 5 or 10 dB intervals. This method will ensure recordings of the sonic boom with adequate signal to noise ratio by utilizing the full dynamic range of at least one channel of the recording system. An overload indicator, which may be in the form of a peak reading meter or an automatic recorded overload indication, is desirable.

2 The specified minimum dynamic range of the recorder may be insufficient to permit full range frequency analysis of a sonic boom. For these measurements, it may be desirable to include pre-emphasis in one channel of the recording system to improve signal to noise ratio at the higher frequencies, the inverse de-emphasis being applied to the playback system during frequency analysis; such equalization should not be used for the recording and reproduction of the pressure signature, except where necessary to meet the frequency response requirement of the measuring chain in 3.1.

3.4 Equipment for unattended recording

For recording sonic booms over a long period, specially designed data recorders should be used since conventional recording systems are limited in operation for this purpose.

The recorder should include the capability for unattended operation and instantaneous response to transients. Where operation is provided for predetermined times during the day and an immediate response to sonic booms, appropriate control circuitry shall be used.

The equipment should be self-contained with associated signal-conditioning networks. Appropriate calibration signals for each channel shall be provided and recorded following each recording.

NOTE – The equipment should comply as closely as possible with the specifications in 3.1, 3.2 and 3.3. Deviations shall be reported.

4 PRINCIPLES OF ANALYSIS

For initial evaluation of the sonic boom pressure signature, the signal may be displayed on an oscilloscope. For detailed analysis, other display devices, for example digital read-out or a precision galvanometer, may be necessary, depending on the accuracy required.

The result of a frequency analysis of the signal shall be given in the form of either a spectral density function or a frequency band spectrum.

5 ENVIRONMENTAL CONDITIONS

5.1 Datum conditions

Two fundamental datum conditions can be delineated, namely ground and free-field conditions.

5.1.1 *Datum ground conditions*

Conditions of an open space that is essentially free from local undulations, and obstructions that in total subtend a solid angle of more than 0,004 steradian.

There shall be a hard surface surrounding the measurement point, in the form of a securely fixed rigid plane baffle in intimate contact with the ground. The baffle should be preferably not less than 1,5 m in diameter.

5.1.2 *Datum free-field conditions*

Conditions obtained when the obstructions in the upper half-space subtend a solid angle of less than 0,004 steradian and when the microphone can be mounted at a sufficient height.

NOTES

1 The determination of the whole pressure signature from an aircraft in level flight in free-field conditions may necessitate a height of more than 100 m. For this reason the datum ground conditions will usually be preferred. However, to resolve rise times an elevation of 5 m may be sufficient.

2 Overpressures measured in free-field conditions are approximately half those measured in datum ground conditions.

5.2 Deviations from datum conditions

On board ships or in mountainous or built-up areas, where the purpose is to approximate to results that would be obtained in datum conditions, the requirements stated in 5.1 should be followed as far as possible. Any deviations or special conditions, for example sea state, should be reported.

5.3 Specific environmental conditions

Measurements for the purpose of relating human or structural response to the specific environments created, or in terrain not covered by 5.1.1 or 5.2, shall be made with the microphone placed at appropriate positions for the receiver. For a seated human receiver, for example, the measurements shall be made at approximate ear level (1,2 m above ground) and in representative acoustic environments, i.e. including reflecting and absorbing surfaces, obstacles, etc.

6 INSTALLATION OF MICROPHONE

6.1 Measurement in ground condition

The microphone shall be mounted with its axis perpendicular to the ground with its sensitive surface facing upwards and flush with a hard surface at ground level.

NOTE – There are conditions, such as with hard concrete surfaces, when flush mounting is impracticable. In such conditions the microphone should be mounted with its axis either perpendicular or parallel to the ground and with its sensitive surface as close to the ground as possible, avoiding a face-down condition.

The microphone body and associated equipment shall be either below ground level or sufficiently remote that their presence does not influence the measurements.

A shield may be necessary in order to reduce the effects of wind on the microphone, or to protect it from rain and dirt. Such a shield shall be designed so that the response of the microphone is not significantly affected.

The microphone shall be adequately shock-mounted to reduce vibrations transmitted through the mountings.

6.2 Freedom from extraneous signals

Freedom from extraneous signals shall be obtained.

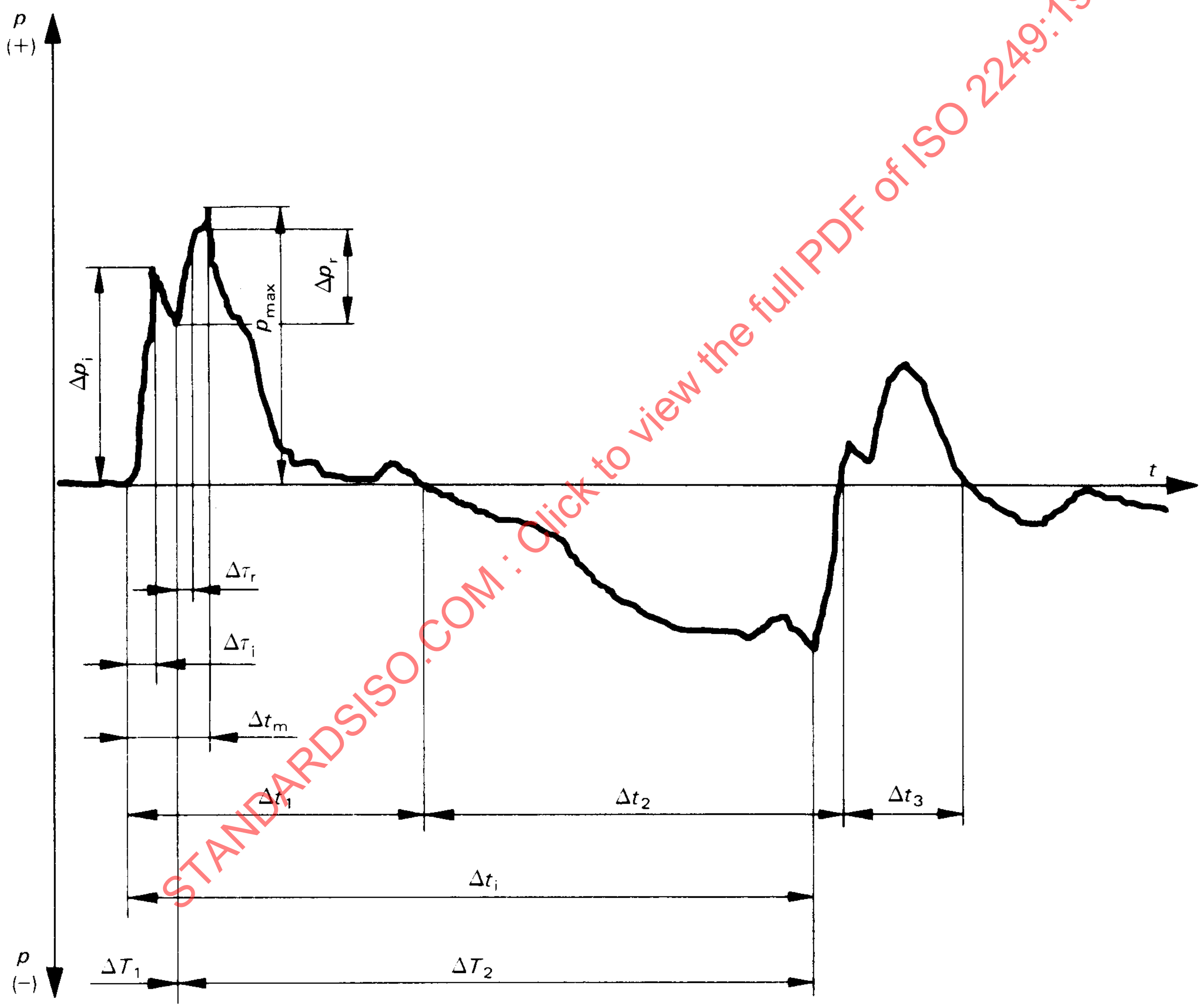

FIGURE – **Example of graphical display of a ground reflected sonic boom**