INTERNATIONAL STANDARD

# ISO 1151-8

First edition
1992-06-15

# Flight dynamics — Concepts, quantities and symbols —

## Part 8:
## Concepts and quantities used in the study of the dynamic behaviour of the aircraft

*Mécanique du vol — Concepts, grandeurs et symboles —*

*Partie 8: Concepts et grandeurs utilisés pour l'étude du comportement dynamique de l'avion*



Reference number
ISO 1151-8 : 1992 (E)

## 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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 1151-8 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Sub-Committee SC 3, *Concepts, quantities and symbols for flight dynamics*.

ISO 1151 consists of the following parts, under the general title *Flight dynamics — Concepts, quantities and symbols*:

- *Part 1: Aircraft motion relative to the air*
- *Part 2: Motions of the aircraft and the atmosphere relative to the Earth*
- *Part 3: Derivatives of forces, moments and their coefficients*
- *Part 4: Parameters used in the study of aircraft stability and control*
- *Part 5: Quantities used in measurements*
- *Part 6: Aircraft geometry*
- *Part 7: Flight points and flight envelopes*
- *Part 8: Concepts and quantities used in the study of the dynamic behaviour of the aircraft*
- *Part 9: Models of atmospheric motions along the trajectory of the aircraft*





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Case postale 56 • CH-1211 Genève 20 • Switzerland
Printed in Switzerland

ISO 1151 is intended to introduce the main concepts, to include the more important terms used in theoretical and experimental studies and, as far as possible, to give corresponding symbols.

In all the parts comprising ISO 1151, the term "aircraft" denotes a vehicle intended for atmosphere or space flight. Usually, it has an essentially port and starboard symmetry with respect to a plane. That plane is determined by the geometric characteristics of the aircraft. In that plane, two orthogonal directions are defined: fore-and-aft and dorsal-ventral. The transverse direction, on the perpendicular to that plane, follows.

When there is a single plane of symmetry, it is the reference plane of the aircraft. When there is more than one plane of symmetry, or when there is none, it is necessary to choose a reference plane. In the former case, the reference plane is one of the planes of symmetry. In the latter case, the reference plane is arbitrary. In all cases, it is necessary to specify the choice made.

Angles of rotation, angular velocities and moments about any axis are positive clockwise when viewed in the positive direction of that axis.

All the axis systems used are three-dimensional, orthogonal and right-handed, which implies that a positive rotation through $\pi/2$ around the $x$-axis brings the $y$-axis into the position previously occupied by the $z$-axis.

The centre of gravity coincides with the centre of mass if the field of gravity is homogeneous. If this is not the case, the centre of gravity can be replaced by the centre of mass in the definitions of ISO 1151; in which case, this should be indicated.

**Numbering of sections and clauses**

With the aim of easing the indication of references from a section or a clause, a decimal numbering system has been adopted such that the first figure is the number of the part of ISO 1151 considered.

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# Flight dynamics — Concepts, quantities and symbols —

## Part 8:
## Concepts and quantities used in the study of the dynamic behaviour of the aircraft



### 8.0 Introduction

This part of ISO 1151 deals with the concepts and quantities characterizing some classes of aircraft motion and their fundamental dynamic characteristics.

The aircraft is assumed to be rigid, of constant mass and of constant inertia. It is not equipped with systems modifying its natural dynamic behaviour. However, most of the definitions can be applied to the case of a flexible aircraft, of variable mass and of variable inertia.

The general concepts defined in this part of the ISO 1151 are applicable to the atmospheric flight phase.

### 8.1 General concepts

| No. | Term | Definition |
|---|---|---|
| **8.1.1** | Flight variable | Quantity, the value of which as a function of time characterizes the aircraft motion. |
| **8.1.2** | Flight state | Set of values of the flight variables (8.1.1).<br><br>NOTE — This concept should not be confused with that of flight point (7.5.5). |
| **8.1.3** | Steady flight state | Flight state (8.1.2) in which the flight variables (8.1.1) considered remain constant with time. |
| **8.1.4** | Quasi-steady flight state | Flight state (8.1.2) in which the flight variables (8.1.1) considered vary so slowly with time that their variations can be disregarded in the study. |
| **8.1.5** | Unsteady flight state | Flight state (8.1.2) in which at least one of the flight variables (8.1.1) considered varies so rapidly with time that its variations cannot be disregarded in the study. |
| **8.1.6** | Reference flight state | Flight state (8.1.2) chosen as reference in a given study.<br><br>NOTES<br><br>1 In most cases, a steady flight state (8.1.3) or a quasi-steady flight state (8.1.4) is chosen as reference.<br><br>2 In a study covering a certain period of time, it is normal to choose the flight state (8.1.2) immediately prior to this period as a reference. |

| No. | Term | Definition |
|---|---|---|
| 8.1.7 | Control input | Action on an aircraft intended to alter or to maintain the flight state (8.1.2). |
| 8.1.8 | Disturbance | Involuntary action which results in a modification in the flight state (8.1.2).<br>NOTE — The nature of this action can be:<br>— human;<br>— atmospheric;<br>— mechanical;<br>— etc. |
| 8.1.9 | Input variable | Element of the set of quantities characterizing the control input (8.1.7) or disturbance (8.1.8). |
| 8.1.10 | Output variable | Element of the set of flight variables (8.1.1), the developments of which over time characterize the response of the aircraft to the control input (8.1.7) or disturbance (8.1.8) considered. |

## 8.2 Types of aircraft motion

| No. | Term | Definition |
|---|---|---|
| 8.2.1 | (Aircraft) flight-path; trajectory | Three-dimensional locus of origin of the flight-path axis system (2.1.1), usually the centre of mass, relative to the Earth. |
| 8.2.2 | Aircraft plane motion | Motion of the aircraft characterized by a flight-path (8.2.1) contained within a plane. |
| 8.2.3 | Straight flight | Aircraft plane motion (8.2.2) characterized by a straight flight-path (8.2.1). |
| 8.2.4 | Horizontal flight | Aircraft plane motion (8.2.2) characterized by a flight-path (8.2.1) contained within a horizontal plan. |
| 8.2.5 | Symmetrical flight | Flight state (8.1.2) of an aircraft with zero angle of sideslip (1.2.1.1).<br>NOTE — The geometry of the aircraft and the flow are not necessarily symmetrical. |
| 8.2.6 | Turn | Motion of the aircraft resulting in a change of flight-path azimuth angle (2.3.1). |
| 8.2.7 | Horizontal turn | A turn (8.2.6) in horizontal flight (8.2.4). |
| 8.2.8 | Steady turn | A horizontal turn (8.2.7) for which the airspeed (1.3.1) and the load factor (1.5.9) are held constant.<br>NOTE — If the wind speed, $V_W$, (2.2.3) is zero, the flight-path (8.2.1) is circular. |
| 8.2.9 | (Isolated) longitudinal motion | Motion characterized by variations in relation to a reference flight state (8.1.6) of<br>— angle of attack, $\alpha$, (1.2.1.2);<br>— inclination angle, $\Theta$, (1.2.2.2);<br>— airspeed, $V$, (1.3.1);<br>— flight-path inclination angle, $\gamma$, (2.3.2); and<br>— rate of pitch, $q$, (1.3.6),<br>while the variations of<br>— angle of sideslip, $\beta$, (1.2.1.1);<br>— rate of roll, $p$, (1.3.6); and<br>— rate of yaw, $r$, (1.3.6)<br>are zero or negligible. |
| 8.2.10 | (Isolated) lateral motion | Motion characterized by variations in relation to a reference flight state (8.1.6) of<br>— angle of sideslip, $\beta$, (1.2.1.1);<br>— bank angle, $\Phi$, (1.2.2.3);<br>— azimuth angle, $\Psi$, (1.2.2.1);<br>— rate of roll, $p$, (1.3.6); and<br>— rate of yaw, $r$, (1.3.6)<br>while the variations of<br>— angle of attack, $\alpha$, (1.2.1.2);<br>— airspeed, $V$, (1.3.1);<br>— flight-path inclination angle, $\gamma$, (2.3.2); and<br>— rate of pitch, $q$, (1.3.6)<br>are zero or negligible. |

## 8.3 Natural modes of aircraft motion

In the following clauses, the modes considered correspond to small motions superimposed on a steady (8.1.3) or quasi-steady (8.1.4) reference flight state. These are motions of the aircraft following a control input (8.1.7) or disturbance (8.1.8).

These motions can usually be represented, after linearization, by a system of linear differential equations with constant coefficients.

In this case, each mode can be characterized by

a) a sub-set of flight variables (8.1.1), the developments of which with time are predominant;

b) a damping coefficient (8.4.2) or time constant (8.4.3);

c) a frequency (8.4.7) or period (8.4.6), in the case of an oscillatory mode.

For many aircraft, there are three modes of longitudinal motion and three modes of lateral motion as defined in 8.3.1 to 8.3.3 and in 8.3.4 to 8.3.6, respectively.

NOTE — Where the aircraft is equipped with closed-loop control systems, these modes can be modified and other modes can appear.

| No. | Term | Definition |
|---|---|---|
| **8.3.1** | Short period oscillation | Oscillatory longitudinal motion (8.2.9) characterized by variations in the angle of attack, $\alpha$, (1.2.1.2) and the rate of pitch, $q$, (1.3.6) at nearly constant airspeed, $V$, (1.3.1), with a frequency, $f$, (8.4.7) higher than that of the phugoid mode (8.3.2).<br><br>NOTE — The damping coefficient, $\delta$, (8.4.2) is generally large. |
| **8.3.2** | Phugoid (oscillation) | Oscillatory longitudinal motion (8.2.9) characterized by variations in the horizontal and vertical components of the aircraft velocity, $\vec{V}$, (1.3.1) and the inclination angle, $\Theta$, (1.2.2.2) of the aircraft, at a nearly constant angle of attack, $\alpha$, (1.2.1.2).<br><br>NOTE — The frequency, $f$, (8.4.7) and the damping coefficent, $\delta$, (8.4.2) are generally low. |
| **8.3.3** | Aperiodic longitudinal mode | Aperiodic longitudinal motion (8.2.9) characterized by variations in the vertical component of the aircraft velocity, $\vec{V}$, (1.3.1).<br><br>NOTES<br>1 The damping coefficient, $\delta$, (8.4.2) is generally large.<br>2 The aperiodic longitudinal mode is due to the variation with altitude of the density of the air (5.1.3). |
| **8.3.4** | Roll mode | Aperiodic lateral motion (8.2.10) characterized by variations in the bank angle, $\Phi$, (1.2.2.3), at nearly zero angle of sideslip, $\beta$, (1.2.1.1) and rate of yaw, $r$, (1.3.6).<br><br>NOTE — The damping coefficient, $\delta$, (8.4.2) is generally large. |
| **8.3.5** | Dutch roll (oscillation) | Oscillatory lateral motion (8.2.10) characterized by variations in the angle of the sideslip, $\beta$, (1.2.1.1), the bank angle, $\Phi$, (1.2.2.3) and azimuth angle, $\Psi$, (1.2.2.1). |
| **8.3.6** | Spiral mode | Aperiodic lateral motion (8.2.10) characterized by slow variations in the bank angle, $\Phi$, (1.2.2.3) and the angle of sideslip, $\beta$, (1.2.1.1).<br><br>NOTE — The damping coefficient, $\delta$, (8.4.2), positive or negative, has generally a small absolute value. |

## 8.4 Characteristic parameters of individual modes of motion

The modes defined in 8.3 are either aperiodic modes or oscillatory modes.

An aperiodic mode can be represented by the equation

$$x(t) = A_0 \, e^{-\delta t}$$

An oscillatory mode can be represented by the equation

$$x(t) = A_0 \, e^{-\delta t} \sin(\omega t + \varphi)$$

where $A_0$, $\omega$, $\delta$ and $\varphi$ are real constants and $\omega$ is called the circular frequency and $\varphi$ the phase shift.

NOTE — The definitions of 8.4.6 to 8.4.8 apply only to oscillatory modes.

| No. | Term | Definition | Symbol |
|---|---|---|---|
| **8.4.1** | Amplitude | Time function, defined by the relation<br>$A = \lvert A_0 \rvert \cdot e^{-\delta t}$ | $A$ |
| **8.4.2** | Damping coefficient | Quantity defining the decreasing or increasing of the amplitude (8.4.1) with time. This is calculated from the amplitude (8.4.1) by the relation<br>$\delta = -\frac{1}{A} \times \frac{dA}{dt}$ | $\delta$ |
| **8.4.3** | Time constant | Quantity defined by the relation<br>$\tau = \frac{1}{\delta}$<br>where $\delta$ is the damping coefficient (8.4.2).<br>NOTES<br>1 Where $\delta$ is positive, $\tau$ is the time interval during which the amplitude, $A$, (8.4.1) is divided by e, the base of natural logarithms ($1/e \approx 0{,}367\,9$).<br>2 Where $\delta$ is negative, $-\tau$ is the time interval during which the amplitude, $A$, (8.4.1) is multiplied by e.<br>3 Where the amplitude, $A$, (8.4.1) is constant, $\tau$ is not defined. | $\tau$ |
| **8.4.4** | Time to half amplitude | Where the amplitude, $A$, (8.4.1) is a decreasing function of time ($\delta > 0$), $\tau_{1/2}$ is the time interval during which the amplitude is reduced by half.<br>NOTE — $\tau_{1/2}$ is a constant linked to the damping coefficient, $\delta$, (8.4.2) by the relation<br>$\tau_{1/2} = -\frac{\ln(1/2)}{\delta} \approx \frac{0{,}693\,1}{\delta}$ | $\tau_{1/2}$ |
| **8.4.5** | Time to double amplitude | Where the amplitude, $A$, (8.4.1) is an increasing function of time ($\delta < 0$), $\tau_2$ is the time interval during which the amplitude has doubled.<br>NOTE — $\tau_2$ is a constant linked to the damping coefficient, $\delta$, (8.4.2) by the relation<br>$\tau_2 = -\frac{\ln(2)}{\delta} \approx -\frac{0{,}693\,1}{\delta}$ | $\tau_2$ |
| **8.4.6** | (Oscillation) period | Period of the sinusoidal factor of the oscillatory function.<br>$T = \frac{2\pi}{\omega}$<br>NOTES<br>1 The period of the oscillatory function is the time interval separating two successive passages through zero in the same direction.<br>2 The term "pseudo-period" can be used to point out that an oscillatory function is not strictly periodic. | $T$ |

| No. | Term | Definition | Symbol |
|---|---|---|---|
| **8.4.7** | (Oscillation) frequency | Frequency of the sinusoidal factor of the oscillatory function.<br>$f = \dfrac{1}{T}$<br>where $T$ is the oscillation period (8.4.6). | $f$ |
| **8.4.8** | Logarithmic decrement | Product of the damping coefficient, $\delta$, (8.4.2) and the period, $T$, (8.4.6).<br>$\Lambda = \delta T$<br>NOTE — The logarithmic decrement is the natural logarithm of the ratio of the amplitude, $A$, (8.4.1) at time $t$ to the amplitude at time $(t + T)$:<br>$\Lambda = \ln \dfrac{A(t)}{A(t + T)}$ | $\Lambda$ |



## 8.5 Standard input signals

In studies of the dynamic behaviour of aircraft, various standard input signals are used. The standard signal and its characteristics are chosen according to the mode (8.3) to be studied. Other signals can be defined on the basis of the signals listed below.

In the following clauses, the symbol "a" represents a constant value. A subscript $i$ characterizes the input quantity considered. The symbol $t_o$ represents the initial instant of the signals. All the signals are equal to 0 for $t < t_o$. If $t_o = 0$, it can be omitted from the symbol.

For signals which are composed of different functions over different time intervals, the duration $\Delta t$ of the basic time interval is a parameter. $\Delta t$ can be omitted from the symbol if the basic interval is clearly defined and is the same for all signals considered.

| No. | Term | Definition | Recommended symbol |
|---|---|---|---|
| **8.5.1** | Step | Input signal defined by<br>$\Gamma_i(t_o) \begin{cases} = 0 & \text{if } t < t_o \\ = a & \text{if } t \geqslant t_o \end{cases}$<br>(See figure 1.) | $\Gamma_i(t_o)$ |
| **8.5.2** | Dirac impulse | Input signal defined by<br>$\delta_i(t_o) \begin{cases} = 0 & \text{if } t \neq t_o \\ = \infty & \text{if } t = t_o \end{cases}$<br>with $\int_{-\infty}^{+\infty} \delta_i(t_o)\, dt = 1$ | $\delta_i(t_o)$ |
| **8.5.3** | Limited ramp | Input signal defined by<br>$\varrho_i(t_o,\Delta t) \begin{cases} = 0 & \text{if } t < t_o \\ = \dfrac{a(t - t_o)}{\Delta t} & \text{if } t_o \leqslant t \leqslant t_o + \Delta t \\ = a & \text{if } t > t_o + \Delta t \end{cases}$<br>(See figure 2.) | $\varrho_i(t_o,\Delta t)$ |

| No. | Term | Definition | Recommended symbol |
|---|---|---|---|
| **8.5.4** | Sinusoidal input signal | Input signal defined by $\Sigma_i(t_o) \begin{cases} = 0 & \text{if } t < t_o \\ = a \sin \omega t & \text{if } t \geqslant t_o \end{cases}$ | $\Sigma_i(t_o)$ |
| **8.5.5** | Rectangular input signal | Input signal defined by $\Pi_i(t_o, \Delta t) \begin{cases} = 0 & \text{if } t < t_o \\ = a & \text{if } t_o \leqslant t \leqslant t_o + \Delta t \\ = 0 & \text{if } t > t_o + \Delta t \end{cases}$ (See figure 3.) | $\Pi_i(t_o, \Delta t)$ |
| **8.5.6** | Rectangular doublet | Input signal defined by $\Delta_i(t_o, \Delta t) \begin{cases} = 0 & \text{if } t < t_o \\ = a & \text{if } t_o \leqslant t < t_o + \Delta t \\ = -a & \text{if } t_o + \Delta t \leqslant t < t_o + 2\Delta t \\ = 0 & \text{if } t \geqslant t_o + 2\Delta t \end{cases}$ (See figure 4.) | $\Delta_i(t_o, \Delta t)$ |
| **8.5.7** | Triangular input signal | Input signal defined by $\Lambda_i(t_o, \Delta t) \begin{cases} = 0 & \text{if } t < t_o \\ = \dfrac{2a(t-t_o)}{\Delta t} & \text{if } t_o \leqslant t < t_o + \dfrac{\Delta t}{2} \\ = 2a\left(1 - \dfrac{t-t_o}{\Delta t}\right) & \text{if } t_o + \dfrac{\Delta t}{2} \leqslant t < t_o + \Delta t \\ = 0 & \text{if } t \geqslant t_o + \Delta t \end{cases}$ (See figure 5.) | $\Lambda_i(t_o, \Delta t)$ |

## 8.6 Response of the aircraft to a step

The concepts defined in 8.6.1 to 8.6.7 are used to estimate the dynamic characteristics of the aircraft, in longitudinal motion (8.2.9) and in lateral motion (8.2.10). In the following definitions, the initial instant is that of the step input.

| No. | Term | Definition |
|---|---|---|
| **8.6.1** | Step response | Function of time representing the difference between the output variable (8.1.10) considered, caused by a step (8.5.1) on an input variable (8.1.9), and its value in the initial steady state. |
| **8.6.2** | Steady-state response | Difference between the value of the output variable (8.1.10) in the final steady-state condition, where this exists, and its value in the initial steady state (see figure 6). |
| **8.6.3** | Transient response | Function of the time representing the difference between the step response (8.6.1) and the steady-state response (8.6.2). |
| **8.6.4** | Response time (at $x$ %) | Time taken for the step response (8.6.1) to reach, for the first time, a given percentage of the steady-state response (8.6.2) (see figure 6). |
| **8.6.5** | Overshoot | Extreme value of the transient response (8.6.3) having the same sign has the steady-state response (8.6.2) (see figure 6). |
| **8.6.6** | Relative overshoot | Quotient of the overshoot (8.6.5) by the value of the steady-state response (8.6.2). |
| **8.6.7** | Settling time | Time after which the absolute value of the transient response (8.6.3) no longer exceeds a given percentage of the steady-state response (8.6.2) (see figure 6). NOTE — The percentage often used is 5 %. |

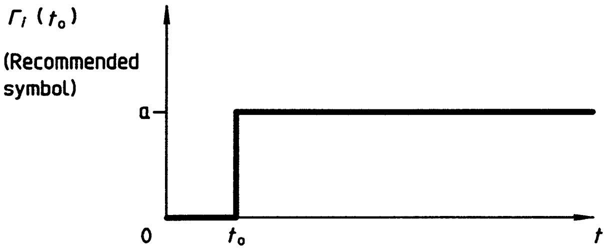


Figure 1 — Step

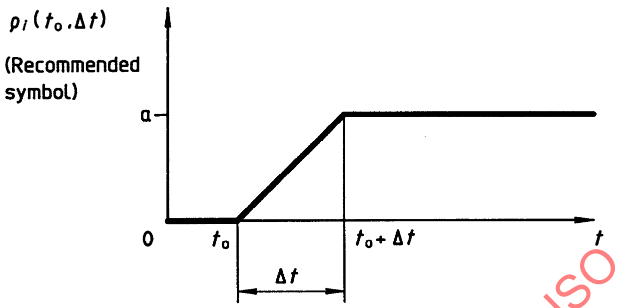


Figure 2 — Limited ramp

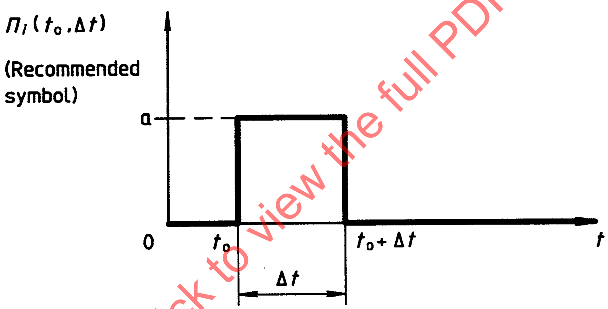


Figure 3 — Rectangular input signal

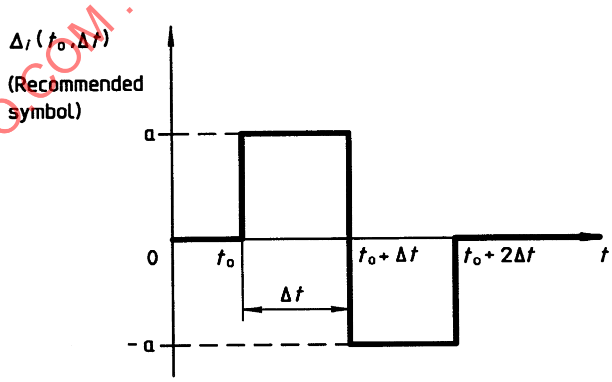


Figure 4 — Rectangular doublet

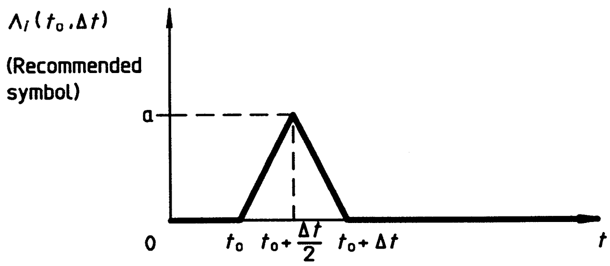


Figure 5 — Triangular input signal

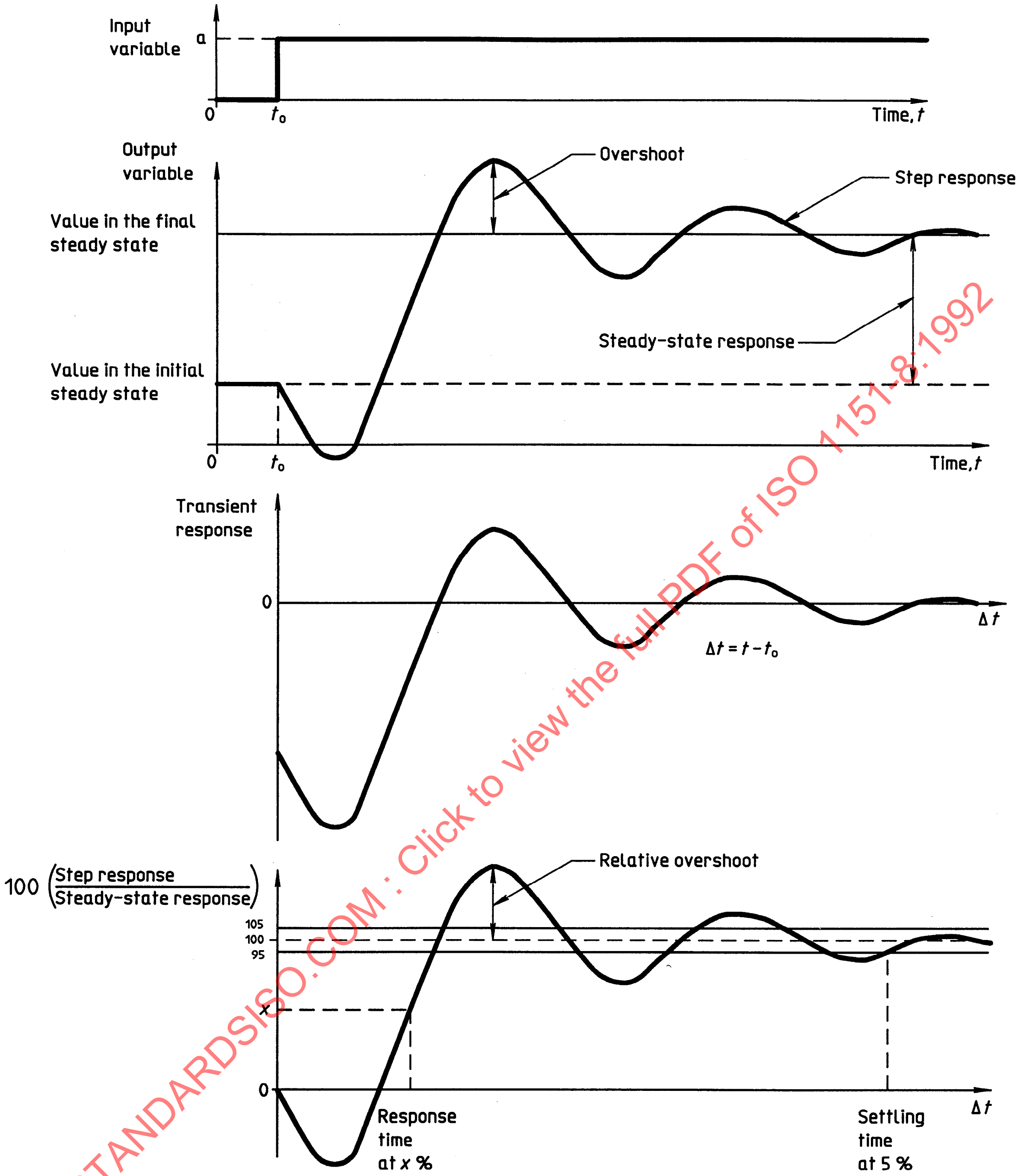


Figure 6 — Step response