INTERNATIONAL STANDARD ISO 2533

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION • МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ • ORGANISATION INTERNATIONALE DE NORMALISATION

Standard Atmosphere

(identical with the ICAO and WMO Standard Atmospheres from – 2 to 32 km)

Atmosphère Type
(identique aux atmosphères standard de l'OACI et de l'OMM entre – 2 et 32 km)

Стандартная атмосфера
(от — 2 до 32 км идентична стандартным атмосферам ИКАО и ВМО)

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FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO Member Bodies). The work of developing International Standards is carried out through ISO Technical Committees. Every Member Body interested in a subject for which a Technical Committee has been set up 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.

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.

International Standard ISO 2533 was drawn up by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, and circulated to the Member Bodies in April 1972. [The tables of the ISO Interim Standard Atmosphere (see page iii) were circulated separately to the Member Bodies in August 1972 as Addendum 1 and have now been incorporated in the present document.]

It has been approved by the Member Bodies of the following countries :

Austria*
Belgium*
Brazil
Czechoslovakia*
Egypt, Arab Rep. of*
France*
Germany*
India*
Ireland*
Japan
Netherlands*
New Zealand*
Portugal
Romania*
South Africa, Rep. of*
Thailand*
Turkey*
United Kingdom*
U.S.A.*
U.S.S.R.*

* Also approved Addendum 1.

No Member Body has expressed disapproval of the document.

NOTE — The following International Organizations took part in the discussion of this International Standard at all stages of its development :

International Civil Aviation Organization (ICAO).

World Meteorological Organization (WMO).

The characteristics of the ISO Standard Atmosphere have been calculated as functions of geometric and geopotential altitudes for altitudes from − 2 000 to 50 000 m based on the standard atmospheres of ICAO 1964 and USA 1962, which for these altitudes were recognized as the most representative when comparing the current national and international standards and recommendations on the atmosphere [1-4], [6-7] with the results of recent research.

Data from this recent research have been used for calculation of the atmospheric characteristics for altitudes from 50 000 to 80 000 m, representing the ISO Interim Standard Atmosphere.

CONTENTS

Standard Atmosphere

(identical with the ICAO and WMO Standard Atmospheres from −2 to 32 km)

1 SCOPE AND FIELD OF APPLICATION

This International Standard specifies the characteristics of an ISO Standard Atmosphere and is intended for use in calculations and design of flying vehicles, to present the test results of flying vehicles and their components under identical conditions, and to allow unification in the field of development and calibration of instruments. Its use is also recommended in the processing of data from geophysical and meteorological observations.

2 BASIC PRINCIPLES AND CALCULATION FORMULAE

2.1 Primary constants and characteristics

The tables of the ISO Standard Atmosphere have been calculated assuming the air to be a perfect gas free from moisture and dust and based on conventional initial values of temperature, pressure and density of the air for mean sea level. The following constants and characteristics are used for calculations and their numerical values are given in table 1 :

g_n — standard acceleration of free fall. It conforms with latitude $\varphi = 45° 32' 33''$ using Lambert's equation of the acceleration of free fall as a function of latitude φ [5] :

$$g_\varphi = 9{,}806\ 16\ (1 - 0{,}002\ 637\ 3 \cos 2\varphi + 0{,}000\ 005\ 9 \cos^2 2\varphi)$$

M — air molar mass at sea level, as obtained from the perfect gas law (2) when introducing the adopted values p_n, ρ_n, T_n, R^* (see table 1);

N_A — Avogadro constant, based on the value of the nuclide ^{12}C, atomic mass = 12,000, as adopted in 1961 by the Conference of the International Union of Pure and Applied Chemistry as the basic atomic mass unity;

p_n — standard air pressure;

R^* — universal gas constant;

R — specific gas constant;

S and β_s — Sutherland's empirical coefficients in the equation for dynamic viscosity;

T_o — thermodynamic ice-point temperature, at mean sea level;

T_n — standard thermodynamic air temperature at mean sea level;

t_o — Celsius ice-point temperature at mean sea level;

t_n — standard Celsius air temperature at mean sea level;

$\kappa = \frac{c_p}{c_v}$ — adiabatic index, the ratio of the specific heat of air at constant pressure to its specific heat at constant volume;

ρ_n — standard air density;

σ — effective collision diameter of an air molecule; taken as constant with altitude.

TABLE 1 — **Main constants and characteristics adopted for the calculation of the ISO Standard Atmosphere**

Symbol	Value	Unit of measurement
g_n	9,806 65	$m \cdot s^{-2}$
M	28,964 420	$kg \cdot kmol^{-1}$
N_A	$602{,}257 \times 10^{24}$	$kmol^{-1}$
p_n	$101{,}325 \times 10^3$	Pa
	$1{,}013\ 250 \times 10^3$	mbar
	760	mmHg
R^*	8 314,32	$J \cdot K^{-1} \cdot kmol^{-1}$ or $kg \cdot m^2 \cdot s^{-2} \cdot K^{-1} \cdot kmol^{-1}$
R	287,052 87	$J \cdot K^{-1} \cdot kg^{-1}$ or $m^2 \cdot K^{-1} \cdot s^{-2}$
S	110,4	K
T_o	273,15	K
T_n	288,15	K
t_o	0,00	°C
t_n	15,00	°C
β_s	$1{,}458 \times 10^{-6}$	$kg \cdot m^{-1} \cdot s^{-1} \cdot K^{-1/2}$
κ	1,4	dimensionless
ρ_n	1,225	$kg \cdot m^{-3}$
σ	$0{,}365 \times 10^{-9}$	m

2.2 The equation of the static atmosphere and the perfect gas law

Being static with respect to the earth, the atmosphere is subject to gravity. The conditions of air static equilibrium are determined by the equation of the static atmosphere which relates air pressure p, density ρ, acceleration of free fall g and altitude h as follows :

$$-\mathrm{d}p = \rho g \mathrm{d}h \qquad \ldots (1)$$

The perfect gas law relates air pressure to density and temperature as follows :

$$p = \frac{\rho R^* T}{M} \qquad \ldots (2)$$

At the altitudes considered in this International Standard,

$\frac{R^*}{M}$ = constant = R, then

$$p = \rho R T \qquad \ldots (3)$$

2.3 Geopotential and geometric altitudes; acceleration of free fall

In considering pressure distribution in the atmosphere it is convenient to introduce the gravity potential or geopotential Φ, which characterizes the potential energy of an air particle at a given point.

Any point with x, y, z co-ordinates may be characterized by a single value of gravity potential Φ (x, y, z) in it. The surface defined by the equation

$$\Phi\ (x, y, z) = \text{constant}$$

is of the same potential in all points and is called an isopotential or geopotential surface. When moving along an external normal from any point on the surface Φ_1, to the infinitely close point where the value of the potential is $\Phi_2 = \Phi_1 + \mathrm{d}\Phi$, the work performed for shifting a unit mass from the first surface to the second one will be

$$\mathrm{d}\Phi = g(h)\mathrm{d}h \qquad \ldots (4)$$

hence

$$\Phi = \int_0^h g(h)\mathrm{d}h \qquad \ldots (5)$$

By dividing the geopotential Φ by the standard acceleration of free fall g_n, one obtains the value of a length dimension which, symbolized as H, will be :

$$H = \frac{\Phi}{g_n} = \frac{1}{g_n}\int_0^h g(h)\mathrm{d}h \qquad \ldots (6)$$

Expressed in metres, the value H is numerically equal to the geopotential altitude, which in meteorology is measured in so-called standard geopotential metres[1]; hence, this value will be called geopotential altitude. The mean sea level is taken as a reference for readings for both geopotential and geometrical altitudes.

From equation (6) it can be seen that, in order to relate geopotential and geometric altitudes, it is necessary first to find a relation between acceleration of free fall g and geometric altitude h.

It is known that gravity is a vectorial summation of the gravitational attraction and the centrifugal force induced by the earth's rotation; it is therefore a complex function of a latitude and a radial distance from the earth's centre and the expression for acceleration of free fall is generally awkward and unpractical for use. However, the acceleration g may be obtained with sufficient accuracy for the purpose of this standard atmosphere by formally neglecting centrifugal acceleration and using only Newton's gravitation law. In this case :

$$g = g_n\left(\frac{r}{r+h}\right)^2 \qquad \ldots (7)$$

where r = 6 356 766 m is the nominal earth's radius [5], for which acceleration of free fall and the vertical gradient of acceleration at mean sea level are very close to true values at the latitude 45° 32′ 33″.

The values of g as calculated using the simplified equation (7) with g_n = 9,806 65 $\mathrm{m{\cdot}s^{-2}}$ for the altitude of 60 000 m does not differ by more than 0,001 % from the values calculated using the more accurate equation of [6].

Integration of equation (6), substituting for g with its function from (7), gives the following relationship between geopotential and geometric altitudes :

$$H = \frac{rh}{r+h} \qquad \ldots (8)$$

$$h = \frac{rH}{r-H} \qquad \ldots (9)$$

2.4 Atmospheric composition and air molar mass

The earth's atmosphere is a mixture of gas, water vapour and a certain quantity of aerosol. Under certain conditions the quantity of water vapour, carbon dioxide, ozone and some

1) The standard geopotential metre (m′) which is equal to 9,806 65 $\mathrm{m^2{\cdot}s^{-2}}$ has been adopted by the World Meteorological Organization (see Technical Regulations, WMO, No. 49, vol. I, ed. 1971-Appendix C) and from the 1st July 1972 replaces the geopotential metre formerly in use. Its value was 1 gpm = 9,8 $\mathrm{m^2{\cdot}s^{-2}}$.

other ingredients the contents of which in the atmosphere is not significant, may vary. The water vapour content undergoes the greatest variations; its concentration at the earth's surface may reach 4 % under high temperature conditions and abruptly diminishes when altitude increases and temperature decreases. Dry clean air composition up to altitudes of 90 to 95 km remains practically constant and corresponds to that given in table 2 [6].

The air molar mass is determined from the perfect gas law (2) using the adopted standard values of pressure p_n, density ρ_n and temperature T_n for mean sea level, as well as the universal gas constant R^*.

TABLE 2 — **Dry clean air composition near sea level**

Gas	Content of volume %	Molar mass M, $kg \cdot kmol^{-1}$
Nitrogen (N_2)	78,084	28,013 4
Oxygen (O_2)	20,947 6	31,998 8
Argon (Ar)	0,934	39,948
Carbon dioxide (CO_2)	0,031 4 *	44,009 95
Neon (Ne)	$1,818 \times 10^{-3}$	20,183
Helium (He)	$524,0 \times 10^{-6}$	4,002 6
Krypton (Kr)	$114,0 \times 10^{-6}$	83,80
Xenon (Xe)	$8,7 \times 10^{-6}$	131,30
Hydrogen (H_2)	$50,0 \times 10^{-6}$	2,015 94
Nitrogen monoxide (N_2O)	$50,0 \times 10^{-6}$*	44,012 8
Methane (CH_4)	$0,2 \times 10^{-3}$	16,043 03
Ozone (O_3) in summer	up to $7,0 \times 10^{-6}$*	47,998 2
in winter	up to $2,0 \times 10^{-6}$*	47,998 2
Sulphur dioxide (SO_2)	up to $0,1 \times 10^{-3}$*	64,062 8
Nitrogen dioxide (NO_2)	up to $2,0 \times 10^{-6}$*	46,005 5
Iodine (I_2)	up to $1,0 \times 10^{-6}$*	253,808 8
Air	100	28,964 420**

* The content of the gas may undergo significant variations from time to time or from place to place.

** This value is obtained from the perfect gas law (2).

2.5 Physical characteristics of the atmosphere at mean sea level

For the calculation of the ISO Standard Atmosphere the mean sea level is defined as zero altitude for which the initial characteristics g_n, p_n, ρ_n and T_n given in table 1 apply. The remaining characteristics have been calculated using the initial ones as a basis and are presented in table 3 :

a_n — speed of sound;

H_{pn} — pressure scale height;

l_n — mean free path of air particles;

n_n — air number density;

$\bar{v}_n$ — mean air-particle speed;

γ_n — specific weight;

ν_n — kinematic viscosity;

λ_n — thermal conductivity;

μ_n — dynamic viscosity;

ω_n — air-particle collision frequency.

TABLE 3 — **Physical characteristics of the atmosphere at mean sea level**

Symbol	Value	Unit of measurement
a_n	340,294	$m \cdot s^{-1}$
H_{pn}	8 434,5	m
l_n	$66,328 \times 10^{-9}$	m
n_n	$25,471 \times 10^{24}$	m^{-3}
$\bar{v}_n$	458,94	$m \cdot s^{-1}$
γ_n	12,013	$N \cdot m^{-3}$
ν_n	$14,607 \times 10^{-6}$	$m^2 \cdot s^{-1}$
λ_n	$25,343 \times 10^{-3}$	$W \cdot m^{-1} \cdot K^{-1}$
μ_n	$17,894 \times 10^{-6}$	$Pa \cdot s$
ω_n	$6,919\,3 \times 10^{9}$	s^{-1}

2.6 Temperature and vertical temperature gradient

Thermodynamic temperature for the melting point of ice under a pressure of 101 325,0 Pa is taken as T_o =273,15 K. Thermodynamic temperature T (in kelvins, K) is :

$$T = T_o + t \qquad \ldots (10)$$

where t is the Celsius temperature.

According to the temperature variations with altitude, the atmosphere is divided into several layers.

The transitional zones between these layers are called tropopause, stratopause and mesopause respectively.

For calculating a standard atmosphere, the temperature of each layer is taken as a linear function of geopotential altitude, so that

$$T = T_b + \beta(H - H_b) \qquad \ldots (11)$$

where T_b and H_b are respectively the temperature and the geopotential altitude of the lower limit of the layer concerned and β is the vertical temperature gradient, $\frac{dT}{dH}$.

The values of temperature and its vertical gradients adopted for the ISO Standard Atmosphere are given in table 4.

TABLE 4 – **Temperatures and vertical temperature gradients**

Geopotential altitude H, km	Temperature T, K	Temperature gradient β, K·km^{-1}
– 2,00	301,15	– 6,50
0,00	288,15	– 6,50
11,00	216,65	0,00
20,00	216,65	+ 1,00
32,00	228,65	+ 2,80
47,00	270,65	0,00
51,00	270,65	– 2,80
71,00	214,65	– 2,00
80,00	196,65	

2.7 Pressure

Assuming a linear variation of the temperature with geopotential altitude, the simultaneous solution of the equation of static atmosphere (1) and the perfect gas law (2) yields the following expression for pressure :

$$\ln p = \ln p_b - \frac{g_n}{\beta R} \ln \frac{T_b + \beta(H - H_b)}{T_b}$$

$$\text{or } p = p_b \left[1 + \frac{\beta}{T_b}(H - H_b)\right]^{-g_n/\beta R} \quad \text{for } \beta \neq 0 \qquad \ldots (12)$$

and

$$\ln p = \ln p_b - \frac{g_n}{RT}(H - H_b)$$

$$\text{or } p = p_b \exp\left[-\frac{g_n}{RT}(H - H_b)\right] \quad \text{for } \beta = 0 \qquad \ldots (13)$$

Here subscript "b" refers the values of the pertinent characteristics to the lower limit of the layer concerned.

2.8 Density and specific weight

The density ρ is calculated from the pressure and the temperature using the perfect gas law :

$$\rho = \frac{p}{RT} \qquad \ldots (14)$$

The specific weight γ is the weight per unit volume of air, that is :

$$\gamma = \rho g \qquad \ldots (15)$$

2.9 Pressure scale height

Pressure scale height H_p is determined by the equation

$$H_p = \frac{R^*}{M} \cdot \frac{T}{g} = \frac{RT}{g} \qquad \ldots (16)$$

2.10 Air number density

The air number density n, i.e. the number of neutral air particles per unit volume, is given by the equation

$$n = \frac{N_A p}{R^* T} \qquad \ldots (17)$$

2.11 Mean air-particle speed

The mean air-particle speed $\bar{v}$ is defined as the arithmetic average of air-particle speeds obtained from Maxwell's distribution of molecular speeds in the monatomic perfect gas under thermodynamical equilibrium conditions disregarding any exterior force, hence

$$\bar{v} = \left(\frac{8}{\pi} RT\right)^{1/2} = 1{,}595\ 769 \sqrt{RT} \qquad \ldots (18)$$

2.12 Mean free path of air particles

An air particle between two successive collisions moves uniformly along a straight line, passing a certain average distance l called a mean free path of air particles. Taking into account the distribution of relative speeds of colliding particles, the mean free path of air particles is defined by the expression

$$l = \frac{R^*}{\sqrt{2}\pi N_A \sigma^2} \cdot \frac{T}{p} = \frac{1}{\sqrt{2}\pi \sigma^2 n} \qquad \ldots (19)$$

2.13 Air-particle collision frequency

The air-particle collision frequency ω is the mean air-particle speed divided by the mean free path of air particles at the same altitude, i.e. $\omega = \frac{\bar{v}}{l}$; hence, taking into account equations (18) and (19)

$$\omega = 4\sigma^2 N_A \left(\frac{\pi}{R^* M}\right)^{1/2} \cdot \frac{p}{T^{1/2}} = 0{,}944\ 541 \times 10^{-18} n \sqrt{RT} \qquad \ldots (20)$$

2.14 Speed of sound

The speed of sound a is given by the expression

$$a = (\kappa RT)^{1/2} = 20{,}046\ 796 \sqrt{T} \qquad \ldots (21)$$

where $\kappa = \frac{c_p}{c_v} = 1{,}4$.

This expression (21) presents the speed of propagation of an infinitesimal perturbation in a gas. That is why this formula may not be used for calculation, for example, of the speed of propagation of shock waves induced by blast, detonation, body motion in the air at supersonic speed, etc.

The concept of speed of sound loses its meaning with very intensive attenuation of sound pulses which occurs above the altitude limits considered for the ISO Standard Atmosphere.

2.15 Dynamic viscosity

The dynamic viscosity μ is defined as the value of internal friction between two neighbouring layers of air moving at different speeds. The tables are established using the following equation based on the kinetic theory with, however, constants derived from experiments :

$$\mu = \frac{\beta_s T^{3/2}}{T + S} \qquad \ldots (22)$$

In this equation β_s and S are Sutherland's empirical coefficients (see table 1).

Equation (22) is invalid for very high or very low temperatures and under conditions occurring at altitudes above 90 km.

2.16 Kinematic viscosity

The kinematic viscosity ν is defined as the ratio of the air dynamic viscosity to the air density, i.e. :

$$\nu = \frac{\mu}{\rho} \qquad \ldots (23)$$

The limits for the use of this equation are similar to those of the dynamic viscosity.

2.17 Thermal conductivity

The thermal conductivity λ is calculated from the following empirical formula :

$$\lambda = \frac{2{,}648\,151 \times 10^{-3} \cdot T^{3/2}}{T + [245{,}4 \times 10^{-(12/T)}]} \qquad \ldots (24)$$

where λ is expressed $W \cdot m^{-1} \cdot K^{-1}$ and T in kelvins.

3 TABLES OF THE ISO STANDARD ATMOSPHERE

The following tables were calculated using the constants, coefficients and equations given in clause 2.

Calculations were made on a Minsk-22 digital computer and the calculation of separate control points was made on other machines. The tables were established directly by digital printing devices on the computers and have been reproduced by duplicating machines in order to reduce the possibility of errors to a minimum.

Data in the tables are given in SI units except in table 5 in which temperatures are given in Celsius degrees and pressures are given in millibars and millimetres of mercury.

NOTE — A one- or two-digit number (preceded by a plus or a minus sign) following the initial entry of each block indicates the power of ten by which that entry and each succeeding entry of that block should be multiplied. A change of power occurring within a block is indicated by a similar notation.