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Foreword

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The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

This International Standard provides guidelines for determining the Earth's upper atmosphere properties (above 120 km). A good knowledge of temperature, total density, concentrations of gas constituents, and pressure is important for many space missions exploiting the low-earth orbit (LEO) regime below approximately 2 500 km altitude. Aerodynamic forces on the spacecraft, due to the orbital motion of a satellite through a rarefied gas, which itself can have variable high velocity winds, are important for planning satellite lifetime, maintenance of orbits, collision avoidance maneuvering and debris monitoring, sizing the necessary propulsion system, design of attitude control system, and estimating the peak accelerations and torques imposed on sensitive payloads. Surface corrosion effects due to the impact of large fluxes of atomic oxygen are assessed to predict the degradation of a wide range of sensitive coatings of spacecraft and instruments. The reactions of atomic oxygen around a spacecraft can also lead to intense "vehicle glow".

The structure of Earth's upper atmosphere, accepted empirical models that can specify the details of the atmosphere, and the details of those models (Annex A) are included in this International Standard. Annex B provides a detailed description of the Neutral Electromagnetic Radiation and Indices.

Space environment (natural and artificial) — Earth upper atmosphere

1 Scope

This International Standard specifies the structure of Earth's atmosphere above 120 km, provides accepted empirical models that can specify the details of the atmosphere, and uses annexes to describe the details of those models. Its purpose is to create a standard method for specifying Earth atmosphere properties (densities, etc.) in the low Earth orbit regime for space systems and materials users.

2 Terms and definitions

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

2.1
homosphere
region of the atmosphere that is well mixed, i.e. the major species concentrations are independent of height and location

Note 1 to entry: This region extends from 0 to ~100 km, and includes the temperature-defined regions of the troposphere (surface up to ~8 - 15 km altitude), the stratosphere (~10 - 12 km up to 50 km altitude), the mesosphere (~50 km up to about 90 km altitude), and the lowest part of the thermosphere.

2.2
heterosphere
portion of the atmosphere, above ~125 km, where diffusive separation of species dominates and atmospheric composition depends on height

2.3
thermosphere
region of the atmosphere between the temperature minimum at the mesopause (~90 km) and the altitude where the vertical scale height is approximately equal to the mean free path (400 - 600 km) altitude, depending on solar and geomagnetic activity levels

2.4
exosphere
region of the atmosphere that extends from the top of the thermosphere outward

2.5
NRLMSISE-00
Naval Research Labatory Mass Spectrometer, Incoherent Scatter Radar Extended Model
model that describes the neutral temperature and species densities in Earth's atmosphere

Note 1 to entry: It is based on a very large underlying set of supporting data from satellites, rockets, and radars, with extensive temporal and spatial distribution. It has been extensively tested against experimental data by the international scientific community. The model has a flexible mathematical formulation.

Note 2 to entry: It is valid for use from ground level to the exosphere. Two indices are used in this model: $F_{10.7}$ (both the daily solar flux value of the previous day and the 81-day average centred on the input day) and A_p (geomagnetic daily value).

Note 3 to entry: See Reference[1]

2.6
JB2008
Jacchia-Bowman 2008 Model
model that describes the neutral temperature and the total density in Earth's thermosphere and exosphere

Note 1 to entry: Its new features lead to a better and more accurate model representation of the mean total density compared with previous models, including the NRLMSISE-00.

Note 2 to entry: It is valid for use from an altitude of 120 km to 2 500 km in the exosphere. Four solar indices and two geomagnetic activity indices are used in this model: $F_{10.7}$ (both tabular value one day earlier and the 81-day average centred on the input time); $S_{10.7}$ (both tabular value one day earlier and the 81-day average centred on the input time); $M_{10.7}$ (both tabular value five days earlier and the 81-day average centred on the input time); $Y_{10.7}$ (both tabular value five days earlier and the 81-day average centred on the input time); a_p (3 hour tabular value); and Dst (converted and input as a dTc temperature change tabular value on the input time).

Note 3 to entry: See Reference[2]

2.7
HWM07
Horizontal Wind Model
Comprehensive empirical global model of horizontal winds in the mesosphere and thermosphere (middle and upper atmosphere).

Note 1 to entry: Reference values for the a_p index needed as input for the wind model are given in Annex A.

Note 2 to entry: HWM07 does not include a dependence on solar EUV irradiance. Solar cycle effects on thermospheric winds are generally small during the daytime, but can exceed 20 m/s at night.

Note 3 to entry: HWM07 thermospheric winds at high geomagnetic latitudes during geomagnetically quiet periods should be treated cautiously.

Note 4 to entry: See Reference[3]

2.8
Earth GRAM 2010
Earth Global Reference Atmosphere Models (latest version is GRAM 2010) produced on behalf of NASA, that describe the terrestrial atmosphere from ground level upward for operational purposes

Note 1 to entry: GRAM 2010 provides a global reference terrestrial atmosphere model based on a combination of empirically based models that represent different altitude ranges up to ~120 km. The upper atmosphere section above ~120 km has the option of three different atmosphere models, the Marshall Thermosphere (MET-07), the Naval Research Laboratory Mass Spectrometer, Incoherent Scatter Radar Extended (NRLMISE-00) and the Jacchia-Bowman (JB-2008) model. In addition the NRL1993 Harmonic Wind Model (HWM-93) is included for use in conjunction with the NRLMISE-00.

Note 2 to entry: These models are available via license from NASA to qualified users and provide usability and information quality similar to that of the NRLMSISE-00 Model. Earth GRAM 2007 includes options for NRLMSIS-00, HMW-93, and JB2006 models.

Note 3 to entry: See Reference[4].

2.9
DTM-2009
Drag Temperature Model 2009
model that describes the neutral temperature and major and some minor species densities in Earth's atmosphere between an altitude of 120 km to approximately 1 500 km

Note 1 to entry: DTM-2009 is based on a large database going back to the early '70s, essentially the same that was used for NRLMSISE-00 except for the radar data. In addition, high-resolution CHAMP and GRACE accelerometer-inferred densities are assimilated in DTM-2009.

Note 2 to entry: DTM-2009 is valid from an altitude of 120 km to approximately 1 500 km in the exosphere. Two indices are used in this model: $F_{10.7}$ solar flux (both daily solar flux of the previous day and the 81-day average centred on the input day) and Kp (3-hour value delayed by three hours, and the average of the last 24 hours).

Note 3 to entry: The DTM model codes (DTM-94, DTM-2000, DTM-2009) are available for download on the ATMOP project website[1].

Note 4 to entry: See Reference[5]

3 Symbols and abbreviated terms

a_p the 3-hour planetary geomagnetic index, in units nT

A_p the daily planetary geomagnetic index, in units nT

CIRA COSPAR International Reference Atmosphere

COSPAR Committee on Space Research

Dst the hourly disturbance storm time ring current index, in units nT

F_{10} the $F_{10.7}$ solar proxy, in units of solar flux, $\times 10^{-22}$ W m^{-2}

M_{10} the $M_{10.7}$ solar proxy, in units of solar flux, $\times 10^{-22}$ W m^{-2}

S_{10} the $S_{10.7}$ solar index, in units of solar flux, $\times 10^{-22}$ W m^{-2}

URSI International Union of Radio Science

Y_{10} the $Y_{10.7}$ solar index, in units of solar flux, $\times 10^{-22}$ W m^{-2}

4 General concept and assumptions

4.1 Earth atmosphere model use

The NRLMSISE-00 model [1] should be used for calculating both the neutral temperature and the detailed composition of the atmosphere.

The JB2008 model [2] should be used for calculating the total atmospheric density above an altitude of 120 km, for example as used in determining satellite drag in LEO.

The Earth-GRAM model 2010 [4] may be used for calculating the total atmospheric density above an altitude of 120 km, for example as used in determining satellite drag in LEO.

The DTM-2009 [5] may be used for calculating the total atmospheric density above an altitude of 120 km, for example as used in determining satellite drag in LEO.

For altitudes below 120 km, NRLMSISE-00 or Earth GRAM 2010 should be used for calculating the total air density.

NOTE This usage follows the advice of the CIRA Working Group, sponsored by COSPAR and URSI, and following the resolution of the Assembly of COSPAR in Montreal in July 2008.

4.1.1 Application guidelines

a) The NRLMSISE-00 model for species densities should not be mixed with the JB2008, Earth GRAM 2010 or DTM-2009 model for total density.

b) For worst-case high solar activity results and analysis periods not exceeding 1 week, high daily short-term values given in Annex A should be used as input for daily activity together with the high long-term values for the 81-day average activity.

1) http://www.atmop.eu/downloads.php

c) For analysis periods longer than 1 week the long-term solar activities given in Annex A should be used as input for both the daily and the 81-day averaged values.

d) For analysis periods longer than 1 week and conditions specified in Annex A, the daily and 81-day averaged solar activities given in Annex A should be used.

e) Short-term daily high solar activity values should not be used together with low or moderate long-term solar activity values.

NOTE 1 The JB2008, NRLMSISE-00, and Earth GRAM 2010 models can only predict large scale and slow variations in the order of 1 000 km (given by the highest harmonic component) and 3 hours. Spacecrafts can encounter density variations with smaller temporal and spatial scales partly since they are in motion (for example, +100% or -50% in 30 s), and partly because smaller-scale disturbances certainly occur during periods of disturbed geomagnetic activity.

NOTE 2 Reference values for the key indices needed as inputs for the atmosphere models are given in Annex A.

NOTE 3 The $F_{10.7}$ 81-day average solar activity can also be estimated by averaging three successive monthly predicted values.

NOTE 4 Information on density model uncertainties can be found in Annex A and in References[1] and.[2]

NOTE 5 For high solar activities, the atmosphere models only give realistic results if high short-term values are combined with high 81-day averaged values.

NOTE 6 High Dst values can be used corresponding to low, moderate or high solar activities.

4.2 Earth wind model use

The HWM07 wind model [3] should be used.

High daily short-term solar activity values should be used as worst-case for the daily activity but the 81-day average activity should not exceed the high long-term value.

NOTE 1 Reference values for the key indices needed as inputs for the wind model are given in Annex A.

NOTE 2 The $F_{10.7}$ 81-day average solar activity can also be estimated by averaging three successive monthly predicted values as given in Annex A.

NOTE 3 The use of the HWM07 model at high geomagnetic latitudes and for disturbed geomagnetic periods necessitates caution in the interpretation of model results.

4.3 Robustness of standard

The Earth's upper atmosphere models described in this International Standard are intended to be adapted and improved over time as the international scientific community obtains and assesses high quality data on the upper atmosphere. Therefore, the users of the models described should ensure they are utilizing the latest version of the respective models.

Annex A
(informative)

Neutral atmospheres

A.1 Structure of the Earth's atmosphere

The Earth's atmosphere can be classified into different regions based on temperature, composition, or collision rates among atoms and molecules. For the purposes of the document, the atmosphere is broadly divided into three regimes based on all three properties, as shown in Figure A.1:

i) The homosphere is the portion of the atmosphere that is well mixed, i.e. the major species concentrations are independent of height and location. This region extends from 0 to ~100 km, and includes the temperature-defined regions of the troposphere (surface up to ~8 - 15 km altitude), the stratosphere (~10 - 12 km up to 50 km altitude), the mesosphere (~50 km up to about 90 km altitude), and part of the thermosphere.

ii) The thermosphere is the region between the temperature minimum at the mesopause (~90 km) and the altitude where the vertical scale height is approximately equal to the mean free path (400 - 600 km altitude, depending on solar and geomagnetic activity levels).

iii) The exosphere extends from the top of the thermosphere into space.

In practice, the boundaries between these regions, whether determined in altitude or in a pressure co-ordinate system, vary with solar, seasonal, latitudinal, and other conditions.

Due to winds and turbulent mixing the homosphere has a nearly uniform composition of about 78,1% N_2, 20,9% O_2, and 0,9% Ar. The temperature profile of the thermosphere increases rapidly above a minimum of ~180 K at the mesopause, then gradually relaxes above ~200 km to an asymptotic value known as the exospheric temperature.

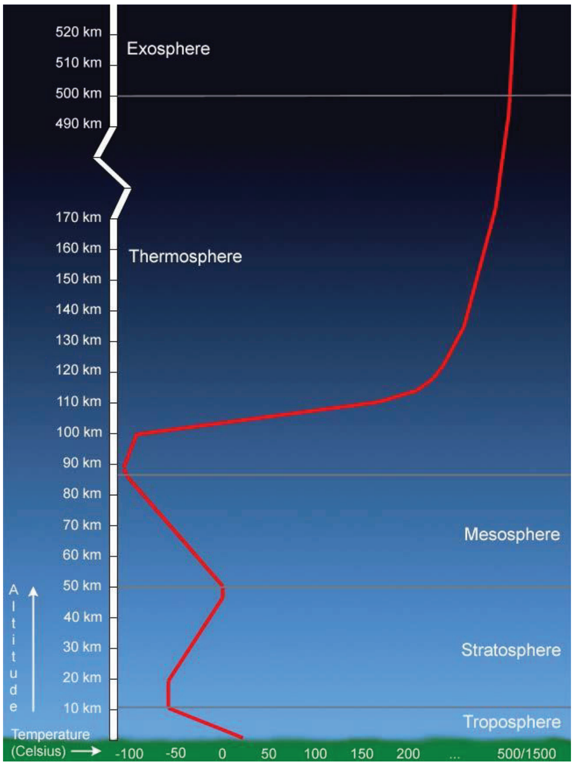

Figure A.1 — Representative temperature profile of the Earth's atmosphere

A.2 Development of models of the Earth's atmosphere

A "Standard Atmosphere" is defined as a vertical distribution of atmospheric temperature, pressure, and density, which by international agreement is taken to be representative of the Earth's atmosphere. The first "Standard Atmospheres" established by international agreement were developed in the 1920s primarily for purposes of pressure altimeter calibrations, aircraft performance calculations, aircraft and rocket design, ballistic tables, etc. Later, some countries, notably the United States, also developed and published "Standard Atmospheres". The term "Reference Atmosphere" is used to identify vertical descriptions of the atmosphere for specific geographical locations or globally. These were developed by organizations for specific applications, especially as the aerospace industry began to mature after World War II. The term "Standard Atmosphere" has in recent years also been used by national and international organizations to describe vertical descriptions of atmospheric trace constituents, the ionosphere, atomic oxygen, aerosols, ozone, winds, water vapour, planetary atmospheres, etc.

Currently some of the most commonly used Standard and Reference Atmospheres [6] include: the ISO Standard Atmosphere 1975, 1982; the U. S. Standard Atmosphere Supplements, 1962, 1966, 1976; the COSPAR International Reference Atmosphere (CIRA), 1986 (previously issued as CIRA 1961, CIRA 1965 and CIRA 1972); the NASA/MSFC Global Reference Atmosphere Model, Earth GRAM 2010 (previously issued as GRAM-86, GRAM-88, GRAM-90, GRAM-95, GRAM-99 and GRAM-07); the NRLMSISE-00 Thermospheric Model, 2000 (previously issued as MSIS-77, -83, -86 and MSISE-90); and most recently the JB2006 and JB2008 density models.

A.3 NRLMSISE-00 and JB2008 — Additional information

A.3.1 The Mass Spectrometer and Incoherent Scatter (MSIS) series of models developed between 1977 and 1990 are used extensively by the scientific community for their superior description of neutral composition. The models utilized atmospheric composition and temperature data from instrumented satellites and ground-based radars. The initial MSIS 1977 model utilized a Bates-Walker temperature profile (which is analytically integrable to obtain density), and allowed the density at 120 km to vary with local time and other geophysical parameters to fit the measurements. The temperature and density parameters describing the vertical profile were expanded in terms of spherical harmonics to represent geographic variations. Subsequent versions of the model include the longitude variations, a refined geomagnetic storm effect, improved high latitude, high solar flux data, and an extension of the lower boundary down to sea level.

The NRLMSISE-00 model represents atmospheric composition, temperature, and total mass density from the ground to the exosphere. Its formulation imposes a physical constraint of hydrostatic equilibrium to produce self-consistent estimates of temperature and density. NRLMSISE-00 includes the following enhancements compared to MSISE-90:

i) drag data based on orbit determination,

ii) more recent accelerometer data sets,

iii) new temperature data derived from Millstone Hill and Arecibo incoherent scatter radar observations,

iv) observations of O_2 by the Solar Maximum Mission (SMM), based on solar ultraviolet occultation,

v) a new species, “anomalous oxygen,” primarily for drag estimation, allows for appreciable O+ and hot atomic oxygen contributions to the total mass density at high altitudes.

A.3.2 The Jacchia-Bowman density (JB2008) model is based on the Jacchia model heritage. It includes two key novel features. Firstly, there is a new formulation concerning the semi-annual density variation observed in the thermosphere, but not previously included in any of the semi-empirical atmospheric models. Secondly, there is a new formulation of solar indices, relating more realistically the dependence of heat and energy inputs from the solar radiation to specific altitude regions and heating processes within the upper atmosphere. The Dst index (equatorial magnetic perturbation) is used in JB2008 as the index representing the geomagnetic activity response. JB2008 inserts the improved J70 temperature formulations into the CIRA 1972 model to permit integrating the diffusion equation at every point rather than relying on look-up tables (the integration must be done numerically, in contrast to the analytically integrable Bates-Walker temperature formulation used in MSIS). In order to optimally represent the orbit-derived mass density data on which JB2008 is based, the model formulation sacrifices the physical constraint of hydrostatic equilibrium since it does not include all physical processes that may actually be present in thermosphere affecting temperatures and densities.

A.4 The series of GRAM atmospheric models

The National Aeronautics and Space Administration’s NASA/MSFC Global Reference Atmospheric Model version 2007 (Earth GRAM 2010) is a product of the Natural Environments Branch, NASA Marshal Space Flight Center. These models are available via license to qualified users and provide usability and information quality similar to that of the NRLMSISE-00 Model. Like the previous versions of GRAM, the model provides estimates of means and standard deviations for atmospheric parameters such as density, temperature, and winds, for any month, at any altitude and location within the Earth’s atmosphere. GRAM can also provide profiles of statistically-realistic variations (i.e., with Dryden energy spectral density) for any of these parameters along computed or specified trajectory. This perturbation feature makes GRAM especially useful for Monte-Carlo dispersion analyses of guidance and control systems, thermal protection systems, and similar applications. GRAM has found many uses, both inside and outside