DEUTSCHE NORM Mai 2015

DIN EN 16603-10-04

DIN

ICS 49.140

Ersatz für
DIN EN 14092:2003-11

Raumfahrttechnik – Raumfahrtumweltbedingungen; Englische Fassung EN 16603-10-04:2015

Space engineering – Space environment; English version EN 16603-10-04:2015

Ingénierie spatiale – Environnement spatial; Version anglaise EN 16603-10-04:2015

Gesamtumfang 206 Seiten

DIN-Normenausschuss Luft- und Raumfahrt (NL)

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Nationales Vorwort

Dieses Dokument (EN 16603-10-04:2015) wurde vom Technischen Komitee CEN/CLC/TC 5 „Raumfahrt“ erarbeitet, dessen Sekretariat vom DIN (Deutschland) gehalten wird.

Das zuständige deutsche Normungsgremium ist der Arbeitsausschuss NA 131-10-01 AA „Interoperabilität von Informations-, Kommunikations- und Navigationssystemen“ im DIN-Normenausschuss Luft- und Raumfahrt (NL).

Dieses Dokument (EN 16603-10-04:2015) basiert auf ECSS-E-ST-10-04C.

Dieses Dokument enthält unter Berücksichtigung des DIN-Präsidialbeschlusses 1/2004 nur die englische Originalfassung von EN 16603-10-04:2015.

Dieses Dokument wurde speziell zur Behandlung von Raumfahrtsystemen erarbeitet und hat daher Vorrang vor jeglicher Europäischer Norm, da es denselben Anwendungsbereich hat, jedoch über einen größeren Geltungsbereich (z. B. Luft- und Raumfahrt) verfügt.

Änderungen

Gegenüber DIN EN 14092:2003-11 wurden folgende Änderungen vorgenommen:

a) Norm-Nummer geändert.

b) Begriffe und Definitionen wurden angepasst.

Frühere Ausgaben

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Nationaler Anhang NA
(informativ)

Begriffe und Abkürzungen

Die Benummerung der folgenden Begriffe und Abkürzungen sind identisch mit der Benummerung in der englischen Fassung.

3 Begriffe und Abkürzungen

3.1 Begriffe aus anderen Normen

Für die Anwendung dieser Norm gelten die Begriffe nach ECSS-S-ST-00-01, insbesondere die folgenden Begriffe:

Verunreinigung

Umgebung

Mission

Weltraummüll

3.2 Spezifische Begriffe für die vorliegende Norm

3.2.1
A_p-, K_p-Indizes
Indizes der geomagnetischen Aktivität zur Beschreibung von Schwankungen des geomagnetischen Felds

ANMERKUNG A_p-Werte reichen von 0 bis 400 und werden in Einheiten von nT (Nanotesla) angegeben. K_p ist im Wesentlichen der Logarithmus von A_p.

3.2.2
Energiedosis
Energie, die durch Strahlenbelastung infolge Ionisation und Anregung je Masseneinheit örtlich absorbiert wird

ANMERKUNG Ein Teil der Energieabsorption kann aufgrund einer Verrückung von Atomen zu einer Beschädigung der Gitterstruktur von Feststoffen führen, und das wird gewöhnlich als nicht-ionisierender Energieverlust (NIEL) bezeichnet.

3.2.3
Akkomodationskoeffizient
Maß für die Größe der Energieübertragung zwischen einem Molekül und einer Oberfläche

3.2.4
Albedo
Teil des Sonnenlichts, der von einem Planeten reflektiert wird

3.2.5
atmosphärische Albedo-Neutronen
Neutronen, die durch die Wechselwirkung von kosmischer Strahlung und Sonnenteilchen entstehen und anschließend die Erdatmosphäre verlassen

ANMERKUNG Atmosphärische Albedo-Neutronen können auch durch andere Planetenatmosphären und Oberflächen erzeugt werden.

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3.2.6
Bremsstrahlung
hochenergetische elektromagnetische Strahlung im Energiebereich von Röntgen- bis Gammastrahlung, die durch Abbremsen geladener Teilchen infolge Streuung an Atomkernen emittiert werden

ANMERKUNG Das Primärteilchen wird schließlich absorbiert, während die Bremsstrahlung hoch durchdringend ist. In der Raumfahrt ist die üblichste Quelle für Bremsstrahlung die Elektronenstreuung.

3.2.7
Verunreinigung
molekulare oder teilchenförmige Substanz, die die Wirksamkeit eines Bauteils beeinflussen oder verschlechtern kann, wenn sie sich in Sicht zu diesem Bauteil oder sich auf diesem befindet

3.2.8
Verunreinigungsumgebung
die durch ein Raumfahrzeug in seiner Nähe verursachte molekulare oder teilchenförmige Umgebung

3.2.9
Strom
Geschwindigkeit des Teilchentransports durch eine Grenzfläche

ANMERKUNG Im Gegensatz zur Flussdichte hängt der Strom von der Richtung des Durchgangs der Teilchen durch die Grenzfläche ab (sie ist ein Vektorintegral). Eine isotrope ungerichtete Flussdichte f, die auf eine Ebene einfällt, führt gewöhnlich zu einem Strom von 1/4 f in jeder Richtung durch die Ebene. Strom wird häufig bei der Untersuchung des Strahlungstransports verwendet.

3.2.10
direkte Flussdichte
freie Strömung oder Ausgasung von Molekülen, die direkt auf eine kritische Oberfläche auftrifft, d. h. ohne vorherige Zusammenstöße mit anderen Gasen oder einer anderen Oberfläche

3.2.11
Verteilungsfunktion $f(x,v)$
Funktion, die die Teilchendichte eines Plasmas im 6-D-Raum beschreibt, der aus den drei Raumvektoren und den drei Geschwindigkeitsvektoren gebildet wird, in $s^3 \cdot m^{-6}$

ANMERKUNG Für räumlich gleichmäßige und isotrope Verteilungen wird sie oft mit $f(v)$, einer Funktion der skalaren Geschwindigkeit, in $s \cdot m^{-4}$, oder mit $f(E)$, einer Energiefunktion, in $J^{-1} \cdot m^{-3}$, bezeichnet und kann wie folgt in die Flussdichte umgewandelt werden:

$$\text{Flussdichte} = \int v f(v) dv \qquad (3\text{-}1)$$

oder

$$\text{Flussdichte} = \int \frac{f(E)}{m} dE \qquad (3\text{-}2)$$

Dabei ist

v die skalare Geschwindigkeit;

E die Energie;

m die Teilchenmasse.

3.2.12
Dosis
an eine Stelle übertragene Strahlungsenergiemenge

ANMERKUNG Im weitesten Sinne kann hierzu die Teilchenflussdichte gehören, jedoch bezieht sie sich üblicherweise im Zusammenhang mit den Wirkungen der energiereichen Teilchenstrahlung des Weltraums auf die Energie, die je Masseneinheit infolge von Strahlenbelastung absorbiert wird.

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3.2.13
Äquivalentdosis
Strahlungsgröße, die gewöhnlich für die biologischen Strahlenwirkungen angewendet wird und zur Berücksichtigung der stärkeren Wirkungen bestimmter Strahlungsarten Normierungsfaktoren enthält

3.2.14
Staub
Teilchen von einem spezifischen Körper des Sonnensystems, das gewöhnlich in der Nähe der Oberfläche dieses Körpers auftritt (z. B. Mond-, Mars- oder Kometenstaub)

3.2.15
Infrarotstrahlung der Erde
von der Erde emittierte Wärmestrahlung

ANMERKUNG Auch ausgesandte Langwellenstrahlung genannt.

3.2.16
energiereiches Teilchen
Teilchen, das hinsichtlich der Wirkung von Strahlung auf Raumfahrtsysteme die Außenflächen des Raumfahrzeugs durchdringen kann

ANMERKUNG Bei Elektronen tritt dies üblicherweise oberhalb von 100 keV auf, bei Protonen und anderen Ionen oberhalb von 1 MeV. Neutronen, Gammastrahlen und Röntgenstrahlen werden in diesem Zusammenhang ebenfalls als energiereiche Teilchen betrachtet.

3.2.17
Äquivalentfluenz
Größe, mit der versucht wird, die Schädigung bei verschiedenen Energien und von verschiedenen Spezies darzustellen

ANMERKUNG 1 Beispiel: Für den Güteabfall von Sonnenzellen wird oft verwendet, dass ein 10-MeV-Proton 3 000 1-MeV-Elektronen „äquivalent“ ist. Dieses Konzept wird auch bei der Betrachtung von Effekten von nichtionisierenden Energieverlusten (NIEL) verwendet.

ANMERKUNG 2 Güteabfallkoeffizienten werden benutzt, um den Schaden einzuschätzen, der durch ein gegebenes Teilchen relativ zu einem Normteilchen und einer Normenergie verursacht wird.

3.2.18
Exosphäre
Teil der Erdatmosphäre, der sich an die Thermosphäre anschließt, bei der die mittlere freie Weglänge die Skalenhöhe überschreitet und innerhalb der sehr wenige Zusammenstöße zwischen Atomen und Molekülen auftreten

ANMERKUNG 1 Im unteren Bereich der Exosphäre ist üblicherweise atomarer Sauerstoff der hauptsächliche Bestandteil.

ANMERKUNG 2 Mit zunehmender Höhe steigt der Anteil an atomarem Sauerstoff; bei mehr als etwa 1 000 km wird Wasserstoff üblicherweise der hauptsächliche Bestandteil. Unter eher besonderen Bedingungen (d. h. während der Winter in Polargebieten) können He-Atome die hauptsächlichen Bestandteile oberhalb eines begrenzten Höhenbereichs werden.

ANMERKUNG 3 Ein geringer Anteil an H- und He-Atomen kann Fluchtgeschwindigkeiten innerhalb der Exosphäre erreichen.

3.2.19
externes Feld
Teil des gemessenen geomagnetischen Feldes, der durch außerhalb der festen Erde befindliche Quellen erzeugt wurde

ANMERKUNG Die externen Quellen sind hauptsächlich: elektrische Ströme in der Ionosphäre, der Magnetosphäre und Koppelströme zwischen diesen Bereichen.

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3.2.20
$F_{10,7}$-Flussdichte
solare Flussdichte bei einer Wellenlänge von 10,7 cm in Einheiten von 10^4 Jansky (1 Jansky entspricht 10^{-26} W·m^{-2}·Hz^{-1})

3.2.21
Fluenz
zeitliches Integral der Flussdichte

3.2.22
Flussdichte
Strahlungsmenge, die eine Fläche je Zeiteinheit durchsetzt, oft in „integraler Form“ als Teilchen je Flächeneinheit je Zeiteinheit (z. B. Elektronen cm^{-2}·s^{-1}) über einer bestimmten Schwellenenergie angegeben

ANMERKUNG Die gerichtete Flussdichte ist das Differential, bezogen auf den Raumwinkel (z. B. Teilchen cm^{-2}·Steradiant^{-1}·s^{-1}), während die „differentielle“ Flussdichte das Differential, bezogen auf die Energie (z. B. Teilchen cm^{-2}·MeV^{-1}·s^{-1}), ist. In manchen Fällen werden Flussdichten auch als Differential, bezogen auf das lineare Energieübertragungsvermögen, behandelt (siehe 3.2.32).

3.2.23
freie Molekularströmung
die mittlere freie Weglänge eines Moleküls ist größer als die Abmessungen des interessierenden Volumens (charakteristische Länge)

3.2.24
sonnenorientierte, geozentrische Koordinaten der Erdmagnetosphäre (GSM)
Elemente eines rechtshändigen kartesischen Koordinatensystems (X, Y, Z), dessen Ursprung der Erdmittelpunkt ist

ANMERKUNG X weist zur Sonne; Z verläuft senkrecht zu X und liegt in der Ebene, die die X- und die geomagnetische Dipolachse enthält; Y verläuft senkrecht zu X und Z und weist in etwa in Richtung der magnetischen Ortszeit (MLT) der Abenddämmerung.

3.2.25
Heterosphäre
Erdatmosphäre oberhalb 105 km, wo wegen des Diffusionsgleichgewichts artenweise neutrale Konzentrationsprofile auftreten

ANMERKUNG N_2-Dominanz tritt normalerweise unter etwa 200 km, O-Dominanz zwischen etwa 200 km und 600 km und He-Dominanz bei sehr großen Höhen auf. Diese Bedingungen hängen von den solaren und geomagnetischen Aktivitäten ab; in großen Höhen können die Situationen während großer geomagnetischer Störungen wesentlich voneinander abweichen.

3.2.26
Homosphäre
Erdatmosphäre unter 105 km, wo eine vollständige vertikale Durchmischung zu einer nahezu homogenen Zusammensetzung von etwa 78,1 % N_2, 20,9 % O_2, 0,9 % Ar und 0,1 % CO_2 und von Spurenbestandteilen führt

ANMERKUNG Die Homopause (oder Turbopause) kennzeichnet den oberen Abschluss der Homosphäre.

3.2.27
indirekte Flussdichte
Moleküle, die nach Zusammenstoß mit anderen Molekülen oder nach Zusammenstoß und Verweilen auf anderen Oberflächen auf eine kritische Oberfläche auftreffen

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3.2.28
internes Feld
Teil des gemessenen geomagnetischen Feldes, der durch innerhalb der festen Erde befindliche Quellen erzeugt wurde, vorrangig aufgrund des im äußeren Kern der Erde zeitlich variierend betriebenen Dynamos

3.2.29
interplanetares Magnetfeld
koronales Magnetfeld der Sonne, das durch den Solarwind nach außen getragen wird und das Solarsystem durchdringt

3.2.30
isotrop
Eigenschaft einer Verteilung von Teilchen, bei der die Flussdichte über alle Richtungen konstant ist

3.2.31
L oder L-Schale
Parameter des geomagnetischen Felds, der häufig zur Beschreibung von Positionen im erdnahen Weltraum verwendet wird

ANMERKUNG Die L oder L-Schale hat einen komplizierten Ursprung, der auf einer Invarianten der Bewegung geladener Teilchen im Erdmagnetfeld beruht (siehe Anhang E). Bei der Definition von Plasmaregimen innerhalb der Magnetosphäre ist sie jedoch sinnvoll, weil sie für ein Dipolmagnetfeld gleich der geozentrischen Höhe in Erdradien der örtlichen Magnetfeldlinie ist, wo sie den Äquator kreuzt.

3.2.32
lineares Energieübertragungsvermögen (LET)
Energie, die von einem abgebremsten energiereichen Teilchen beim Durchlaufen eines Wegs dem Material zugeführt wird

ANMERKUNG Der Begriff wird gewöhnlich zur Beschreibung der Ionisierungsspur infolge eines durchlaufenden Ions verwendet. Das LET ist materialabhängig und weiterhin eine Funktion der Teilchenenergie. Bei Ionen, die an Strahlenwirkungen bei der Raumfahrt beteiligt sind, erhöht es sich mit abnehmender Energie (es erhöht sich auch bei hohen Energien über die Mindestionisierungsenergie). Das LET ermöglicht es, unterschiedliche Ionen durch einfaches Darstellen der Ionenumgebung als Summe der Flussdichten aller Ionen als Funktionen ihrer LET gemeinsam zu betrachten. Dies vereinfacht die Berechnung der Störung durch ein Einzelereignis. Die Energieverlustrate eines Teilchens, die auch emittierte Sekundärstrahlungen umfasst, wird als Bremsvermögen bezeichnet.

3.2.33
magnetische Ortszeit (MLT)
Parameter, der analog zum Längengrad häufig zur Beschreibung von Positionen im erdnahen Weltraum verwendet wird

ANMERKUNG Der Druck des Sonnenwinds verformt das Erdmagnetfeld in eine kometenähnliche Form. Diese Struktur bleibt fest mit ihrem Vorderteil auf die Sonne und mit dem Schweif von ihr abgewandt gerichtet, wobei die Erde sich in ihr dreht. Somit ist der sich mit der Erde drehende Längengrad kein sinnvoller Weg zur Beschreibung der Position in der Magnetosphäre. Stattdessen wird die magnetische Ortszeit verwendet. Sie hat den Wert 0 (Mitternacht) in der von der Sonne abgewandten Richtung, 12 (Mittag) in der auf die Sonne weisenden Richtung und 6 (Morgendämmerung) und 18 (Abenddämmerung) in Richtung senkrecht zur Sonnen-/Antisonnen-Linie. Sie bedeutet im Grunde eine Ausdehnung der solaren Ortszeit auf der Erde vertikal aufwärts in den Weltraum, wobei die Neigung des Dipols berücksichtigt wird.

3.2.34
Massenstrom
Masse (g) einer Molekülspezies, die eine festgelegte Ebene je Zeiteinheit und Flächeneinheit ($g \cdot cm^{-2} \cdot s^{-1}$) durchdringt

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3.2.35
Maxwell-Verteilung
Plasmaverteilungsfunktionen können als Funktion der skalaren Geschwindigkeit v durch die Maxwell-Verteilung beschrieben werden:

$$f(v) = 4\pi n\left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} v^2 \exp\left(-\frac{v^2 m}{2kT}\right) \quad (3\text{-}3)$$

Dabei ist

- n die Dichte;
- k die Boltzmann-Konstante;
- T die Temperatur.

ANMERKUNG Die vollständige Verteilung ist somit durch ein Zahlenpaar aus Dichte und Temperatur beschrieben. Diese Verteilung ist gilt im thermischen Gleichgewicht. Auch Verteilungen, die sich nicht im Gleichgewicht befinden, können häufig durch die Kombination von zwei Maxwell-Verteilungen sinnvoll beschrieben werden.

3.2.36
Meteoroide
Teilchen natürlichen Ursprungs im Weltraum

ANMERKUNG Nahezu alle Meteoroide haben ihren Ursprung in Asteroiden oder Kometen.

3.2.37
Meteoroidstrom
Meteoroide, die die Umlaufbahn ihrer Elternkörper beibehalten und zeitweise hohe Flussdichten bewirken können

3.2.38
Molekulare Säulendichte (MCD)
Integral der Anzahldichte (Anzahl einer besonderen Molekülspezies je Volumeneinheit) längs einer festgelegten Sichtlinie, die von einer (Target-, kritischen, Mess-, Referenz-)Oberfläche ausgeht

3.2.39
molekulare Verunreinigung
Verunreinigung ohne messbare Abmessungen

3.2.40
Nanotesla
genormte Einheit des Geomagnetismus

ANMERKUNG Eine ältere Einheit, die heutzutage nicht sehr oft angewendet wird, ist Gauss, das sind 10^5 nT.

3.2.41
ungerichtete Flussdichte
skalares Integral der Flussdichte über alle Richtungen

ANMERKUNG Dies besagt, dass eine Richtungsverteilung der Teilchen, die auch nicht-isotrop sein kann, nicht berücksichtigt wird. Die Flussdichte an einem Punkt ist die Anzahl der Teilchen, die eine Kugel mit Einheitsquerschnittsfläche (d. h. mit dem Radius $1/\sqrt{\pi}$) durchdringen. Eine ungerichtete Flussdichte darf nicht mit einer isotropen Flussdichte verwechselt werden.

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3.2.42
Ausgasrate
Masse einer Molekülspezies, die von einem Material je Zeiteinheit und je Flächeneinheit ausgeht ($g \cdot cm^{-2} \cdot s^{-1}$)

ANMERKUNG Die Ausgasrate kann auch in anderen Einheiten angegeben werden, wie z. B. in relativer Masseneinheit je Zeiteinheit: ($g \cdot s^{-1}$), ($\% \cdot s^{-1}$) oder ($\% \ s^{-1} \cdot cm^{-2}$).

3.2.43
Teilchenverunreinigung
feste oder flüssige Verunreinigungsteilchen

3.2.44
permanente molekulare Ablagerung (PMD)
molekularer Stoff, der infolge Reaktion mit dem Oberflächenmaterial, einer UV-Bestrahlung oder Reaktionen auslösenden Restatmosphäre (z. B. Polymerisation, Bildung von anorganischen Oxiden) ständig auf einer Oberfläche (nichtflüchtig unter den gegebenen Umständen) haftet

3.2.45
Plasma
teilweise oder vollständig ionisiertes Gas, dessen Teilchen eine gemeinsame Reaktion auf Magnet- und elektrische Felder aufweisen

ANMERKUNG Die gemeinsame Bewegung erfolgt aufgrund der elektrostatischen Coulomb-Kraft zwischen geladenen Teilchen. Diese bewirkt eine Neuanordnung der Teilchen, um elektrischen Feldern innerhalb einer Entfernung in der Größenordnung der Debye-Länge entgegenzuwirken. Bei räumlichen Abmessungen größer als die Debye-Länge ist ein Plasma elektrisch neutral.

3.2.46
Strahlung
Energieübertragung durch Teilchen (einschließlich Photonen)

3.2.47
Rückflussdichte
Moleküle, die zur Quelle oder einer Oberfläche, die nicht direkt sichtbar ist, zurückkehren

ANMERKUNG Ursachen können sein:

— Zusammenstöße mit anderen natürlichen atmosphärischen Restspezies (Umgebungsstreuung) oder mit anderen identischen oder nicht identischen Verunreinigungsspezies (Eigenstreuung) vor Erreichen der kritischen Oberfläche;

— Ionisation oder dissoziative Ionisation der Moleküle bei Bestrahlung (z. B. UV- oder Teilchenstrahlung) und anschließende Anziehung an eine geladene Oberfläche.

3.2.48
Störung durch ein Einzelereignis (SEU), Auswirkung durch ein Einzelereignis (SEE), permanenter Schaden durch ein Einzelereignis (SEL)
Effekte, die das Ergebnis einer örtlich eng begrenzten Energiedeposition durch einzelne Teilchen oder deren Reaktionsprodukte sind, wobei die Energiedeposition ausreicht, um sichtbare Effekte hervorzurufen

3.2.49
sporadische Flussdichte
zufällige Flussdichte ohne deutliches Muster

3.2.50
Solarkonstante
elektromagnetische Strahlung der Sonne, die je Zeiteinheit auf eine über der Atmosphäre bei einer astronomischen Einheit liegende, senkrecht zu den einfallenden Sonnenstrahlen gerichtete, Flächeneinheit einer Oberfläche fällt

ANMERKUNG 1 AU = mittlerer Abstand Erde-Sonne

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3.2.51
Sonneneruption
Emission optischer, UV- und Röntgenstrahlung infolge eines energiereichen Ereignisses auf der Sonne

ANMERKUNG Es gibt kontroverse Ansichten über den kausalen Zusammenhang von Sonneneruptionen und dem Eintreffen großer energiereicher Teilchenströme auf der Erde. Somit ist es günstiger, sich allein auf die Ereignisse durch energiereiche Sonnenteilchen (SEPE) zu beziehen.

3.2.52
Haftwert
Parameter, der die Wahrscheinlichkeit definiert, dass ein auf eine Oberfläche auftreffendes Molekül, verglichen mit den untersuchten Erscheinungen, lange auf ihr verweilt

ANMERKUNG Er ist eine Funktion von Parametern, wie z. B. der Paarung von Verunreinigung und Materialoberfläche, Temperatur, Photo-Polymerisation, Reaktionsfreudigkeit mit atomarem Sauerstoff.

3.2.53
Oberflächenakkommodation
Situation, die auftritt, wenn ein Molekül lange genug auf einer Oberfläche haftet, um mit dieser Oberfläche in thermisches Gleichgewicht zu kommen

3.2.54
Thermosphäre
Erdatmosphäre zwischen 120 km und 250 km bis etwa 400 km (abhängig vom Aktivitätswert), wo die Temperatur exponentiell bis zu einem Grenzwert $T\infty$ bei der Thermopause ansteigt (dabei ist $T\infty$ die Temperatur der Exosphäre)

3.2.55
verfolgbare Objekte
Objekte, die regelmäßig von Bodensensoren eines Weltraumüberwachungssystems verfolgt und katalogisiert werden (üblicherweise Objekte, die größer als etwa 10 cm in der LEO sind und die größer als etwa 1 m in der GEO sind)

3.2.56
VCM-Test
Thermovakuum-Screening-Test zur Bestimmung der Ausgaseigenschaften von Materialien

ANMERKUNG Der Test ist in ECSS-Q-ST-70-02 [RD.23] und in ASTM-E595 [RD.24] beschrieben. Der Test führte zu folgenden Ergebnissen:

— TML — Gesamtmasseverlust, gemessen nach dem als Differenz der Masse vor und nach einer Vakuumbelastung unter den im Ausgasversuch festgelegten Bedingungen, der gewöhnlich in % der Anfangsmasse des Materials angegeben wird.

— CVCM — gesammeltes flüchtiges kondensierbares Material, gemessen nicht am Einsatzort auf einer Kollektorplatte nach einer Vakuumbelastung unter den im Ausgasversuch festgelegten Bedingungen, das gewöhnlich in % der Anfangsmasse des Materials angegeben wird.

3.2.57
World Magnetic Model
dient vorwiegend militärischen Zwecken; alle fünf Jahre erfolgt die Überarbeitung durch ein amerikanisch-britisches geomagnetisches Konsortium

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3.3 Abkürzungen

Für die Anwendung dieser Norm gelten die Abkürzungen nach ECSS-S-ST-00-01 und die folgenden:

Abkürzung	Bedeutung
ASTM	American Society for Testing and Materials
AE	Polarer Elektrojet (en: auroral electrojet)
AO	Atomarer Sauerstoff (en: atomic oxygen)
BIRA	Belgisch Instituut voor Ruimte-Aeronomie
CIRA	COSPAR Internationale Bezugsatmosphäre (en: COSPAR International Reference Atmosphere)
COSPAR	Committee on Space Research
CVCM	Gesammeltes flüchtiges kondensierbares Material (en: collected volatile condensable material)
DISCOS	Datenbank und Informationssystem der ESA zur Charakterisierung von Objekten im Weltraum (en: ESA's database and information system characterizing objects in space)
DTM	Dichte- und Temperaturmodell (en: density and temperature model)
emf	Elektromotorische Kraft (en: Eelectro-motive force)
ESP Model	Modell der Sonnenprotonenemission (en: Emission of Solar Protons Model)
GCR	Galaktische kosmische Strahlung (en: galactic cosmic ray)
GEO	Geostationäre Erdumlaufbahn (en: geostationary Earth orbit)
GNSS	Globales Navigationssatellitensystem (en: global navigation satellite system)
GRAM	Globales Bezugsatmosphärenmodell (en: global reference atmosphere model)
GSM	Sonnenorientierte, geozentrische Koordinaten der Erdmagnetosphäre (en: geocentric solar magnetospheric co-ordinates)
HEO	Umlaufbahn mit großer Exzentrizität (en: highly eccentric orbit)
HWM	Horizontales Windmodel (en: horizontal wind model)
IAGA	International Association for Geomagnetism and Aeronomy
IASB	Institute d'Aeronomie Spatiale de Belgique
ECM	Experiment zur Überwachung der Kontamination während des Fluges (en: in-flight experiment for contamination monitoring)
IERS	Internationaler Dienst für Erdrotation und Referenzsysteme (en: international earth rotation service)
IGRF	Internationales Geomagnetisches Referenzfeld (en: international geomagnetic reference field)
IMF	Interplanetares Magnetfeld (en: interplanetary magnetic field)
JB-2006	Halbempirisches Modell von Jacchia-Bowman (2006) (en: Jacchia-Bowman semi-empirical model (2006))
LDEF	Langzeit-Bestrahlungseinrichtung (en: long duration exposure facility)
LEO	Erdnahe Umlaufbahn (en: low earth orbit)
LET	Lineares Energieübertragungsvermögen (en: linear energy transfer)
MAH	Modell der Hochatmosphäre (en: model of the high atmosphere)

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Abkürzung	Bedeutung
MASTER	Referenzmodell der Erdumgebung für Meteoroide und Weltraummüll (en: meteoroid and space debris terrestrial environment reference model)
MCD	Molekulare Säulendichte (en: molecular column density)
MEO	Mittlere Erdumlaufbahn (Höhe) (en: medium (altitude) Earth orbit)
MET	Technisches Thermosphärenmodell nach Marshall (en: Marshall engineering thermosphere model)
MLT	Magnetische Ortszeit (en: magnetic local time)
MSIS	Massenspektrometer und inkohärente Rückstrahlung (en: mass spectrometer and incoherent scatter)
NIEL	Nicht-ionisierender Energieverlust (en: non-ionizing energy loss)
nT	Nanotesla (en: nano-Tesla)
PMD	Permanente molekulare Ablagerung (en: permanent molecular deposition)
R	Fleckenrelativzahl (en: sunspot number)
R_C	Orts- und richtungsabhängiger Mindestimpuls für die geomagnetische Abschirmung (en: rigidity cut-off for geomagnetic shielding)
R_E	Erdradius (en: Earth radius)
RHU	Thermoelektrischer Radioisotopgenerator (en: radiosisotope heater unit)
R_J	Radius von Riesenplaneten (en: jovian radius)
r.m.s.	Effektivwert (en: root-mean-square)
RTG	Thermoelektrischer Radioisotopgenerator (en: radioisotope thermo-electric generator)
SEU	Störung durch ein Einzelereignis (en: single-event upset)
SEE	Auswirkung durch ein Einzelereignis (en: single-event effect)
SEL	Energiekonzentration durch ein Einzelereignis (en: single-event latch-up)
SEPs	Energiereiche Sonnenteilchen (en: solar energetic particles)
SEPE	Ereignisse durch energiereiche Sonnenteilchen (en: solar energetic particle events)
sfu	Solar flux unit (en: solar flux unit)
SPE	Ereignisse durch Sonnenteilchen (en: solar particle events)
SRP	Sonnenstrahlungsdruck (en: solar radiation pressure)
SPIDR	Space Physics Interactive Data Resource
SW	Sonnenwind (en: solar wind)
TML	Gesamtmasseverlust (en: total mass loss)
TD	Gesamtdichtemodell (en: total density model)
URSI	Union Radio Science Internationale
USSA	US-Normalatmosphäre (en: US standard atmosphere)
VBQC	Vacuum Balance Quartz Contamination
VCM	Flüchtiges kondensierbares Material (en: volatile condensable material)
VUV	Vakuum-Ultraviolett (en: vacuum ultra violet)
WMM	World magnetic model

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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 16603-10-04

January 2015

ICS 49.140

Supersedes EN 14092:2002

English version

Space engineering — Space environment

Ingénierie spatiale — Environnement spatial

Raumfahrttechnik — Raumfahrtumweltbedingungen

This European Standard was approved by CEN on 28 December 2013.

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Foreword

This document (EN 16603-10-04:2015) has been prepared by Technical Committee CEN/CLC/TC 5 "Space", the secretariat of which is held by DIN.

This standard (EN 16603-10-04:2015) originates from ECSS-E-ST-10-04C.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2015, and conflicting national standards shall be withdrawn at the latest by July 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document supersedes EN 14092:2002.

This document has been developed to cover specifically space systems and has therefore precedence over any EN covering the same scope but with a wider domain of applicability (e.g. : aerospace).

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

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Introduction

This standard forms part of the System Engineering branch (ECSS-E-10) of the Engineering area of the ECSS system. As such it is intended to assist in the consistent application of space environment engineering to space products through specification of required or recommended methods, data and models to the problem of ensuring best performance, problem avoidance or survivability of a product in the space environment.

The space environment can cause severe problems for space systems. Proper assessment of the potential effects is part of the system engineering process as defined in ECSS-E-ST-10. This is performed in the early phases of a mission when consideration is given to e.g. orbit selection, mass budget, thermal protection, and component selection policy. As the design of a space system is developed, further engineering iteration is normally necessary with more detailed analysis.

In this Standard, each component of the space environment is treated separately, although synergies and cross-linking of models are specified. Informative annexes are provided as explanatory background information associated with each clause.

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1 Scope

This standard applies to all product types which exist or operate in space and defines the natural environment for all space regimes. It also defines general models and rules for determining the local induced environment.

Project-specific or project-class-specific acceptance criteria, analysis methods or procedures are not defined.

The natural space environment of a given item is that set of environmental conditions defined by the external physical world for the given mission (e.g. atmosphere, meteoroids and energetic particle radiation). The induced space environment is that set of environmental conditions created or modified by the presence or operation of the item and its mission (e.g. contamination, secondary radiations and spacecraft charging). The space environment also contains elements which are induced by the execution of other space activities (e.g. debris and contamination).

This standard may be tailored for the specific characteristic and constrains of a space project in conformance with ECSS-S-ST-00.

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Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revision of any of these publications do not apply, However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

EN reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS system – Glossary of terms

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3 Terms, definitions and abbreviated terms

3.1 Terms defined in other standards

For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply, in particular for the following terms:

contamination

environment

mission

space debris

3.2 Terms specific to the present standard

3.2.1 Ap, Kp indices

geomagnetic activity indices to describe fluctuations of the geomagnetic field

NOTE Values of *Ap* range from 0 to 400 and they are expressed in units of nT (nanotesla). *Kp* is essentially the logarithm of *Ap*.

3.2.2 absorbed dose

energy absorbed locally per unit mass as a result of radiation exposure which is transferred through ionization and excitation

NOTE A portion of the energy absorption can result in damage to the lattice structure of solids through displacement of atoms, and this is now commonly referred to as Non-Ionizing Energy Loss (NIEL).

3.2.3 accommodation coefficient

measure for the amount of energy transfer between a molecule and a surface

3.2.4 albedo

fraction of sunlight which is reflected off a planet

3.2.5 atmospheric albedo neutrons

neutrons escaping from the earth's atmosphere following generation by the interaction of cosmic rays and solar particles

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NOTE Atmospheric albedo neutrons can also be produced by other planetary atmospheres and surfaces.

3.2.6 bremsstrahlung

high-energy electromagnetic radiation in the X-γ energy range emitted by charged particles slowing down by scattering of atomic nuclei

NOTE The primary particle is ultimately absorbed while the bremsstrahlung can be highly penetrating. In space, the most common source of bremsstrahlung is electron scattering.

3.2.7 contaminant

molecular and particulate matter that can affect or degrade the performance of any component when being in line of sight with that component or when residing onto that component

3.2.8 contaminant environment

molecular and particulate environment in the vicinity of and created by the presence of a spacecraft

3.2.9 current

the rate of transport of particles through a boundary

NOTE In contrast to flux, current is dependent on the direction in which the particle crosses the boundary (it is a vector integral). An isotropic omnidirectional flux, *f*, incident on a plane gives rise to a current of ¼ *f* normally in each direction across the plane. Current is often used in the discussion of radiation transport.

3.2.10 direct flux

free stream or outgassing molecules that directly impinge onto a critical surface, i.e. without prior collisions with other gas species or any other surface

3.2.11 distribution function *f(x,v)*

function describing the particle density of a plasma in 6-D space made up of the three spatial vectors and the three velocity vectors, with units $s^3\ m^{-6}$

NOTE For distributions that are spatially uniform and isotropic, it is often quoted as *f(v)*, a function of scalar velocity, with units $s\ m^{-4}$, or *f(E)* a function of energy, with units $J^{-1}m^{-3}$. This can be converted to flux as follows:

$$Flux = \int Vf(v)dv \tag{3-1}$$

or

$$Flux = \int \frac{f(E)}{m}dE \tag{3-2}$$

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where

v is the scalar velocity;

E is the energy;

m is the particle mass.

3.2.12 dose

quantity of radiation delivered at a position

NOTE In its broadest sense this can include the flux of particles, but in the context of space energetic particle radiation effects, it usually refers to the energy absorbed locally per unit mass as a result of radiation exposure.

3.2.13 dose equivalent

radiation quantity normally applied to biological effects and includes scaling factors to account for the more severe effects of certain kinds of radiation

3.2.14 dust

particulates which have a direct relation to a specific solar system body and which are usually found close to the surface of this body (e.g. Lunar, Martian or Cometary dust)

3.2.15 Earth infrared

thermal radiation emitted by the Earth

NOTE It is also called outgoing long wave radiation.

3.2.16 energetic particle

particles which, in the context of space systems radiation effects, can penetrate outer surfaces of spacecraft

NOTE For electrons, this is typically above 100 keV, while for protons and other ions this is above 1 MeV. Neutrons, gamma rays and X-rays are also considered energetic particles in this context.

3.2.17 equivalent fluence

quantity which attempts to represent the damage at different energies and from different species

NOTE 1 For example: For solar cell degradation it is often taken that one 10 MeV protons is "equivalent" to 3 000 electrons of 1 MeV. This concept also occurs in consideration of Non-ionizing Energy Loss effects (NIEL).

NOTE 2 Damage coefficients are used to scale the effect caused by particles to the damage caused by a standard particle and energy.

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3.2.18 exosphere

part of the Earth's atmosphere above the thermosphere for which the mean free path exceeds the scale height, and within which there are very few collisions between atoms and molecules

NOTE 1 Near the base of the exosphere atomic oxygen is normally the dominant constituent.

NOTE 2 With increasing altitude, the proportion of atomic hydrogen increases, and hydrogen normally becomes the dominant constituent above about 1 000 km. Under rather special conditions (i.e. winter polar region) He atoms can become the major constituent over a limited altitude range.

NOTE 3 A small fraction of *H* and *He* atoms can attain escape velocities within the exosphere.

3.2.19 external field

part of the measured geomagnetic field produced by sources external to the solid Earth

NOTE the external sources are mainly: electrical currents in the ionosphere, the magnetosphere and coupling currents between these regions.

3.2.20 $F_{10.7}$ flux

solar flux at a wavelength of 10.7 cm in units of 10^4 Jansky (one Jansky equals 10^{-26} $Wm^{-2}Hz^{-1}$)

3.2.21 fluence

time-integration of the flux

3.2.22 flux

amount of radiation crossing a surface per unit of time, often expressed in "integral form" as particles per unit area per unit time (e.g. electrons $cm^{-2}s^{-1}$) above a certain threshold energy

NOTE The directional flux is the differential with respect to solid angle (e.g. particles cm^{-2} $steradian^{-1}s^{-1}$) while the "differential" flux is differential with respect to energy (e.g. particles cm^{-2} $MeV^{-1}s^{-1}$). In some cases fluxes are also treated as a differential with respect to Linear Energy Transfer (see 3.2.32).

3.2.23 free molecular flow regime

condition where the mean free path of a molecule is greater than the dimensions of the volume of interest (characteristic length)

3.2.24 geocentric solar magnetospheric coordinates (GSM)

elements of a right-handed Cartesian coordinate system (X,Y,Z) with the origin at the centre of the Earth

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NOTE *X* points towards the Sun; *Z* is perpendicular to *X*, lying in the plane containing the *X* and geomagnetic dipole axes; *Y* points perpendicular to *X* and *Z* and points approximately towards dusk magnetic local time (MLT).

3.2.25 heterosphere

Earth's atmosphere above 105 km altitude where the neutral concentration profiles are established due to diffusive equilibrium between the species

NOTE N_2 is normally dominant below approximately 200 km, *O* is normally dominant from approx 200 km to approx. 600 km, *He* is dominant above 600 km altitude, and H dominant at very high altitudes. These conditions depend on solar and geomagnetic activity, and the situation may be quite variable at high altitudes during major geomagnetic disturbances.

3.2.26 homosphere

Earth's atmosphere below 105 km altitude where complete vertical mixing yields a near-homogeneous composition of about 78,1% N_2, 20,9% O_2, 0,9% Ar, and 0,1% CO_2 and trace constituents

NOTE The homopause (or turbopause) marks the ceiling of the homosphere.

3.2.27 indirect flux

molecules impinging on a critical surface, after collision with, or collision and sojourn on other surfaces

3.2.28 internal field

part of the measured geomagnetic field produced by sources internal to the solid Earth, primarily due to the time-varying dynamo operating in the outer core of the Earth

3.2.29 interplanetary magnetic field

solar coronal magnetic field carried outward by the solar wind, pervading the solar system

3.2.30 isotropic

property of a distribution of particles where the flux is constant over all directions

3.2.31 *L* or *L* shell

parameter of the geomagnetic field, often used to describe positions in near-Earth space

NOTE *L* or *L* shell has a complicated derivation based on an invariant of the motion of charged particles in the terrestrial magnetic field (see Annex E).

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However, it is useful in defining plasma regimes within the magnetosphere because, for a dipole magnetic field, it is equal to the geocentric altitude in Earth-radii of the local magnetic field line where it crosses the equator.

3.2.32 linear energy transfer (LET)

rate of energy deposit from a slowing energetic particle with distance travelled in matter, the energy being imparted to the material

NOTE Normally used to describe the ionization track caused by passage of an ion. LET is material-dependent and is also a function of particle energy. For ions involved in space radiation effects, it increases with decreasing energy (it also increases at high energies, beyond the minimum ionizing energy). LET allows different ions to be considered together by simply representing the ion environment as the summation of the fluxes of all ions as functions of their LETs. This simplifies single-event upset calculation. The rate of energy loss of a particle, which also includes emitted secondary radiations, is the stopping power.

3.2.33 magnetic local time (MLT)

parameter analogous to longitude, often used to describe positions in near-Earth space

NOTE Pressure from the solar wind distorts the Earth magnetic field into a comet-like shape. This structure remains fixed with its nose towards the Sun and the tail away from it as the Earth spins within it. Hence longitude, which rotates with the Earth, is not a useful way of describing position in the magnetosphere. Instead, magnetic local time is used. This has value 0 (midnight) in the anti-sunward direction, 12 (noon) in the sunward direction and 6 (dawn) and 18 (dusk) perpendicular to the sunward/anti-sunward line. This is basically an extension of the local solar time on Earth, projected vertically upwards into space although allowance is made for the tilt of the dipole.

3.2.34 mass flow rate

mass (g) of molecular species crossing a specified plane per unit time and unit area (g $cm^{-2}s^{-1}$)

3.2.35 Maxwellian distribution

plasma distribution functions described in terms of scalar velocity, v, by the Maxwellian distribution below:

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$$f(v) = 4\pi n \left(\frac{m}{2\pi kT} \right)^{\frac{3}{2}} v^2 \exp\left(-\frac{v^2 m}{2kT} \right) \quad (3\text{-}3)$$

where

n is the density;

k is the Boltzmann constant;

T is the temperature.

NOTE The complete distribution is therefore described by a pair of numbers for density and temperature. This distribution is valid in thermal equilibrium. Even non-equilibrium distributions can often be usefully described by a combination of two Maxwellians.

3.2.36 meteoroids

particles in space which are of natural origin

NOTE nearly all meteoroids originate from asteroids or comets.

3.2.37 meteoroid stream

meteoroids that retain the orbit of their parent body and that can create periods of high flux

3.2.38 molecular column density (MCD)

integral of the number density (number of molecules of a particular species per unit volume) along a specified line of sight originating from a (target, critical, measuring, reference) surface

3.2.39 molecular contaminant

contaminant without observable dimensions

3.2.40 nano-Tesla

standard unit of Geomagnetism

NOTE An older unit, not widely used now, is the Gauss, which is 10^5 nT.

3.2.41 omnidirectional flux

scalar integral of the flux over all directions

NOTE This implies that no consideration is taken of the directional distribution of the particles which can be non-isotropic. The flux at a point is the number of particles crossing a sphere of unit cross-sectional surface area (i.e. of radius $1/\sqrt{\pi}$). An omnidirectional flux is not to be confused with an isotropic flux.

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3.2.42 outgassing rate

mass of molecular species evolving from material per unit time and unit surface area (g $cm^{-2}s^{-1}$)

NOTE Outgassing rates can also be given in other units, such as in relative mass unit per time unit: (g s^{-1}), (% s^{-1}) or (% $s^{-1}cm^{-2}$).

3.2.43 particulate contaminant

solid or liquid contaminant particles

3.2.44 permanent molecular deposition (PMD)

molecular matter that permanently sticks onto a surface (non-volatile under the given circumstances) as a result of reaction with surface material, UV-irradiation or residual atmosphere induced reactions (e.g. polymerization, formation of inorganic oxides)

3.2.45 plasma

partly or wholly ionized gas whose particles exhibit collective response to magnetic and electric fields

NOTE The collective motion is brought about by the electrostatic Coulomb force between charged particles. This causes the particles to rearrange themselves to counteract electric fields within a distance of the order of the Debye length. On spatial scales larger than the Debye length plasmas are electrically neutral.

3.2.46 radiation

transfer of energy by means of a particle (including photons)

3.2.47 return flux

molecules returning to the source or a surface which is not in direct view of the incoming flux

NOTE The cause can be:

- collisions with other residual natural atmospheric species (ambient scatter) or with other identical or different contaminant species (self scatter) before reaching the critical surface;
- ionization or dissociative ionization of the molecules under radiation (e.g. UV or particles) and subsequent attraction to a charged surface

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3.2.48 single-event upset (SEU), single-event effect (SEE), single-event latch-up (SEL)

effects resulting from the highly localized deposition of energy by single particles or their reaction products and where the energy deposition is sufficient to cause observable effects

3.2.49 sporadic flux

random flux with no apparent pattern

3.2.50 solar constant

electromagnetic radiation from the Sun that falls on a unit area of surface normal to the line from the Sun, per unit time, outside the atmosphere, at one astronomical unit

NOTE 1 AU = average Earth-Sun distance

3.2.51 solar flare

emission of optical, UV and X-radiation from an energetic event on the Sun

NOTE There is some controversy about the causal relationship between solar flares and the arrival of large fluxes of energetic particles at Earth. Therefore, it is more consistent to refer to the latter as Solar Energetic Particle Events (SEPEs).

3.2.52 sticking coefficient

parameter defining the probability that a molecule, colliding with a surface, stays onto that surface for a time long compared to the phenomena under investigation

NOTE It is a function of parameters such as contamination/surface material pairing, temperature, photo-polymerization, and reactive interaction with atomic oxygen.

3.2.53 surface accommodation

situation which occurs when a molecule becomes attached to a surface long enough to come into a thermal equilibrium with that surface

3.2.54 thermosphere

Earth's atmosphere between 120 km and 250 km to approximately 400 km (depending on the activity level), where temperature has an exponential increase up to a limiting value T_∞ at the thermopause (where T_∞ is the exospheric temperature)

3.2.55 trackable objects

objects regularly observed and catalogued by ground-based sensors of a space surveillance network (typically objects larger than about 10 cm in LEO and larger than about 1 m in GEO)

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3.2.56 VCM-test

screening thermal vacuum test to determine the outgassing properties of materials

NOTE The test is described in ECSS-Q-ST-70-02 [RD.23] and ASTM-E595 [RD.24]. The test results are:

- TML - Total Mass Loss, measured ex-situ as a difference of mass before and after exposure to a vacuum under the conditions specified in the outgassing test, normally expressed in % of initial mass of material.
- CVCM - Collected Volatile Condensable Material, measured ex-situ on a collector plate after exposure (to a vacuum) under the conditions specified in the outgassing test, normally expressed in % of initial mass of material.

3.2.57 world magnetic model

revised every five years by a US-UK geomagnetic consortium, primarily for military use

3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

Abbreviation	Meaning
ASTM	American Society for Testing and Materials
AE	auroral electrojet
AO	atomic oxygen
BIRA	Belgisch Instituut voor Ruimte-Aeronomie
CIRA	COSPAR International Reference Atmosphere
COSPAR	Committee on Space Research
CVCM	collected volatile condensable material
DISCOS	ESA's database and information system characterizing objects in space
DTM	density and temperature model
emf	electro-motive force
ESP Model	Emission of Solar Protons Model
GCR	galactic cosmic ray
GEO	geostationary Earth orbit
GNSS	global navigation satellite system
GRAM	global reference atmosphere model

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GSM	geocentric solar magnetospheric co-ordinates
HEO	highly eccentric orbit
HWM	horizontal wind model
IAGA	International Association for Geomagnetism and Aeronomy
IASB	Institute d'Aeronomie Spatiale de Belgique
ECM	in-flight experiment for contamination monitoring
IERS	international earth rotation service
IGRF	international geomagnetic reference field
IMF	interplanetary magnetic field
JB-2006	Jacchia-Bowman semi-empirical model (2006)
LDEF	long duration exposure facility
LEO	low Earth orbit
LET	linear energy transfer
MAH	model of the high atmosphere
MASTER	meteoroid and space debris terrestrial environment reference model
MCD	molecular column density
MEO	medium (altitude) Earth orbit
MET	Marshall engineering thermosphere model
MLT	magnetic local time
MSIS	mass spectrometer and incoherent scatter
NIEL	non-ionizing energy loss
nT	nano-Tesla
PMD	permanent molecular deposition
R	sunspot number
R_C	rigidity Cut-off for geomagnetic shielding
R_E	Earth radius
RHU	radiosisotope heater unit
R_J	jovian radius
r.m.s.	root-mean-square
RTG	radioisotope thermo-electric generator
SEU	single-event upset
SEE	single-event effect
SEL	single-event latch-up
SEPs	solar energetic particles
SEPE	solar energetic particle events
sfu	solar flux unit
SPE	solar particle events
SRP	solar radiation pressure

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SPIDR	Space Physics Interactive Data Resource
SW	solar wind
TML	total mass loss
TD	total density model
URSI	Union Radio Science Internationale
USSA	US standard atmosphere
VBQC	vacuum balance quartz contamination
VCM	volatile condensable material
VUV	vacuum ultra violet
WMM	world magnetic model

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4
Gravity

4.1 Introduction and description

4.1.1 Introduction

Any two bodies attract each other with a force that is proportional to the product of their masses, and inversely proportional to the square of the distance between them (Newton's law):

$$F = G\frac{m_1\, m_2}{r^2} \tag{4-1}$$

where

F is the gravitational force

G $= (6{,}6726 \pm 0{,}0009)\times 10^{-11}\mathrm{m^3kg^{-1}s^{-2}}$ is the universal gravitational constant

m_1, m_2 are the two point masses

r is the distance between the masses

The simplest case of gravitational attraction occurs between bodies that can be considered as point masses. These are bodies at a relative distance r that is sufficiently large in comparison to the sizes of the bodies to ignore the *shape* of the bodies. For two spherical bodies with a homogeneous mass distribution Newton's law is correct also at all locations above their surface ("2-body problem").

Also third body perturbations and tidal effects are important for an accurate analysis of the gravitational interaction.

4.1.2 Gravity model formulation

Without compromising the general validity of underlying theories, all subsequent gravity model discussions are focused on the Earth. The gravity acceleration acting on a point mass, which is external to the central body, is the gradient of the potential function U of that body. The corresponding geopotential surface satisfies the so called Laplace equation:

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$$\nabla^2 U = 0 \tag{4-2}$$

The corresponding perturbing acceleration can be determined from equation (4-3) by means of computationally efficient recursion algorithms (e.g. as in [RD.1]).

$$\ddot{\vec{r}} = \nabla U \tag{4-3}$$

where

$\ddot{\vec{r}}$ is the 2nd time derivative of the position vector.

The solution U of the partial differential equation (4-2) is typically written in the form of a series expansion, in terms of so-called surface spherical harmonic functions, for a location defined in spherical coordinates r, λ, φ.

$$U = \frac{GM}{r}\left\{1 + \sum_{l=2}^{N}\left(\frac{a_e}{r}\right)^l \sum_{m=0}^{l}\left[C_{lm}\cos(m\lambda) + S_{lm}\sin(m\lambda)\right]P_{lm}(\sin\varphi)\right\} \tag{4-4}$$

where

$GM = \mu$ is the gravity constant of the Earth (M being its mass);

$\mu = 3{,}98604415\times10^{14}$ m^{3}s^{-2} for the EIGEN-GL04C model

a_e is the mean equatorial radius of the Earth;

$a_e = 6\,378\,136{,}460$ m for the EIGEN-GL04C model

r is the radial distance from centre of the Earth to satellite

N is the maximum degree of the expansion

l is the degree of a certain harmonic function

m is the order of a certain harmonic function

C_{lm}, S_{lm} are coefficients that determine amplitude and phase of a certain harmonic function

λ is the geodetic longitude of the sub-satellite point

φ is the geodetic latitude of the sub-satellite point

P_{lm} are associated Legendre functions of the first kind, of degree l and order m; recurrance relations for these functions are available in the literature (e.g. [RD.1]).

A gravity model consists of adopted values for GM, a_e, and a set of model coefficients C_{lm}, S_{lm}. Practical implementations of gravity models, e.g. for numerical integration of a satellite orbit, are typically interested in the gravity acceleration resulting from the potential function U in (4-4). Corresponding partial derivatives of (4-4) in Cartesian coordinates of an Earth-fixed system x, y, z can be computed recursively (see [RD.1]).

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The model coefficients C_{lm}, S_{lm} are typically provided in their normalized versions, according to (4-5) in order to limit their numerical range for higher degrees and orders.

$$\begin{Bmatrix} \overline{C}_{lm} \\ \overline{S}_{lm} \end{Bmatrix} = \sqrt{\frac{(l+m)!}{k\,(2l+1)\,(l-m)!}} \begin{Bmatrix} C_{lm} \\ S_{lm} \end{Bmatrix} \qquad k = \begin{cases} 1 & \text{for } m = 0 \\ 2 & \text{for } m \neq 0 \end{cases} \tag{4-5}$$

The Legendre functions $P_{lm}(\sin \varphi)$ in this case are normalized by the inverse of the square root in equation (4-5).

4.1.3 Third body gravitation

When acting as a third-body perturbation, the gravitational attraction by the Sun and its planets can be modelled by means of point mass attractions. This requires knowledge on the masses and positions of the bodies, as well as some guidelines on which effects are important. In general, for orbit computations of Earth-orbiting satellites it is sufficient to include the planetary gravity due to Venus, Mars, Jupiter and Saturn; the other planets are either too small, or too far away to have any significant impact on a satellite orbit around the Earth.

4.1.4 Tidal effects

The gravity potential of a central body only represents the static part of the gravitational acceleration acting on a satellite. There are, however, additional gravity-related effects due to tides that can be important for precise applications. Several tidal effects can be distinguished (see [RD.1]):

- Solid Earth tides associated with the deformations of the Earth's body under the gravitational effects of Sun and Moon and leading to complicated variations in the geopotential coefficients.
- Ocean tides, associated with the displacements of the ocean water masses under the effect of solar and lunar tides. The water displacements in turn modify the geopotential in complicated variational patterns.
- The permanent tide, which is a non-zero constant component of the above tides which nonetheless is not considered part of the static geopotential.
- Pole tides, which are due to the centrifugal effects of polar motion, which in turn is the movement of the Earth's body axis relative to the instantaneous axis of rotation.

4.2 Requirements for model selection and application

4.2.1 General requirements for gravity models

a. Gravity effects shall be included in all orbit determination and orbit prediction processes, and in attitude determination and prediction processes for Earth and planetary orbiters.

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b. The inclusion of different gravity sources, their associated model details, and corresponding model truncation errors shall be compliant with the requirements on orbit and/or attitude determination accuracy, and they shall be at least of the same perturbation order as considered perturbing accelerations due to non-gravitational effects.

c. The retained accuracy level of a gravity model shall be compliant with the accuracy of the position and orientation of the central body.

NOTE Harmonic coefficients can lead to resonance effects, if they have a degree or order close to some integer multiple of the ground track repeat cycle. For orbits that are known to be repetitive, it is then recommendable to include discrete resonant harmonics of degrees that normally fall outside the truncated expansion series.

4.2.2 Selection and application of gravity models

a. For Earth orbits the gravity model EIGEN-GLO4C given in [RN.1] shall be used.

NOTE The EIGEN-GLO4C model has a spatial resolution in latitude and longitude of 1° × 1° (corresponding to degree × order = 360 × 360).

b. Data on gravitational effects from tides and on Earth orientation parameters shall be obtained from the International Earth Rotation Service IERS given in [RN.2].

c. For third body gravitational perturbations the Development Ephemerides data on planets (DE-405) and the Lunar Ephemerides data (LE-405), both given in [RN.3], shall be used.

d. For planetary mass values the 2003 standards of the International Earth Rotation Services IERS, as described in IERS Technical Note 32 [RN.2], shall be used.

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5
Geomagnetic fields

5.1 Introduction and description

5.1.1 The geomagnetic field and its sources

Within the magnetopause, the boundary between the influence of the solar wind and embedded IMF of solar origin, the near-Earth environment is strongly influenced by the geomagnetic field. The geomagnetic field is due to a variety of sources, those within the Earth, those within the ionosphere, and those within the magnetosphere.

The Earth's magnetic field is responsible for organizing the flow of ionized plasmas within most regions of the near-Earth environment. Hence, it determines the boundaries of distinct plasma regimes. The magnetic field is also used widely for attitude measurement and for important spacecraft sub-systems such as magneto-torquers.

5.1.2 The internal field

Under quiet solar and geomagnetic activity conditions, the magnetic field measured at the Earth's surface is primarily (>90%) due to a magneto-hydrodynamic dynamo, operating in the liquid outer core of the Earth. The secular (or time) variation of this field operates on a scale of months to centuries, or more, with position dependent amplitude of anywhere between zero and up to a few hundred nT $year^{-1}$. The core field morphology is closely dipolar, at least far from the Earth, and is inclined to the Earth's rotation axis by around 11 degrees at the present time (see Figure E-1).

Superimposed on this core field is the static magnetic field of geological sources in the lithosphere and upper mantle. Typically the field from these crustal rocks decays rapidly away from the source. For example, in low Earth orbit, the crustal signature is probably no more than about 20 nT, decaying rapidly with altitude.

Traditionally the combination of the core and crustal field is referred to as the 'main field'. The mean "main field" as measured at the Earth's surface is depicted in Figure E-1.

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5.1.3 External field: ionospheric components

Currents flowing in the ionosphere induce an external magnetic field component. Sources of these currents include wind-driven motion of ionospheric plasma that produces a daily variation field known as *Sq* ('solar quiet'). This takes the form of two vortices, fixed north and south of the Sun-Earth line, on the dayside of the Earth, as the Earth rotates beneath. Along the geomagnetic equator an equatorial electrojet is formed, due to a high conductivity channel related to the near-horizontal field morphology. Below (or above) this electrojet the field amplitude can be enhanced by several hundred nT, within about five degrees i.e. a few hundred km of the magnetic equator.

At auroral latitudes (approximately 55-65 magnetic degrees), the auroral electrojet is formed at the open/closed field line boundary. This electrojet is fed by field-aligned currents that connect the ionosphere to the magnetospheric flanks and to the night-side tail and partial ring current sheet. The magnitude of the resulting induced fields is very dynamic and can be many hundreds of nT as observed at ground level or in low Earth orbit during periods of disturbed geomagnetic activity.

In the lower magnetosphere there are inter-hemispheric (field-aligned) currents of several nT at around 400 km altitude. Plasma 'bubbles' can also cause localised magnetic variations of a few nT to be measured by low-Earth orbit satellite altitudes. At high and polar latitudes the Earth's field is also open to the solar wind and cusp currents, also known as Region 0 currents flow.

5.1.4 External magnetic field: magnetospheric components

In the magnetosphere, there are several major current systems controlled by the interaction of the Earth's field with the solar wind. The strength of the total magnetospheric field is closely tied to solar and solar wind variations and to plasma outflow from the ionosphere. The major magnetospheric magnetic fields are a result of: magnetopause currents; cross-tail currents, and the symmetric and partial ring currents.

Magnetopause currents flow to shield the internal field from the IMF. And connect to a cross-tail current sheet that separates lobes of opposite magnetic polarity, extending hundreds of Earth radii down-wind from the Earth. An azimuthal drift of plasma (westward for ions, eastwards for electrons) around the Earth produces the symmetric ring current. The partial, or asymmetric, ring current is found on the dusk-side of the Earth and is closed via ionospheric currents. 0 provides the general morphology of model magnetospheric field lines, according to the Tsyganenko 1989 model [RD.111] showing the seasonal variation, dependent on rotation axis tilt. This figure shows a cut in the noon-midnight plane.

5.1.5 Models of the internal and external geomagnetic fields

The magnetic field is commonly modelled by expressing the field as a series of spherical harmonic terms. At the present time (2000-2010) there is much

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scientific activity in the field modelling community and in source field reconstruction. This is due to several successful satellite magnetometer surveys, such as those of Ørsted and Champ.

5.1.5.1 Models of the internal field

Scientific models of the internal field now extend to around spherical harmonic degree 100, equivalent to a minimum wavelength of 400 km at the Earth's surface. However the effective amplitudes of these high degree terms decrease rapidly with increasing altitude above the Earth's surface. The core field, which dominates for degrees less than about 14 at the Earth's surface, can be readily simplified to that of a simple inclined and offset dipole or a low-degree model for spacecraft operation above a few hundred km altitude.

Although they are by no means the only recognised high quality models, the IGRF models are products of the international community of geomagnetic scientists, updated on a five-year basis, assuming a linear secular variation between updates.

The descriptive annex to this Chapter (Annex E) describes in more detail the current revision of the IGRF, and further information on other internal field models.

5.1.5.2 Models of the external field

There are a number of dynamic models of the external field. These are typically either empirical (in the sense of a simplified mathematical model fit to measured data), analytic (based on physical models of the various external current systems), or magneto-hydrodynamic (or 'general circulation models'). Of the latter type, the science is rapidly evolving and whilst, in principle, they should fully capture the details of magnetospheric processes, such models are judged not yet mature enough to serve as a reliable standard.

Of those models that are currently maintained and updated in the light of new data and new field parameterisations, the model of Tsyganenko (revised repeatedly between 1987 and 2006 [RN.31] [RD.98] [RD.99] [RD.111] [RD.112]) is well used and is empirical in nature. The model of Alexeev *et al* (2001) [RN.30] is described as an analytic model. This model is at the core of a proposed International Standards Organisation (ISO) standard external field model [RD.113].

The availability of suitable inputs to external models is a factor that affects whether they can be useful in common applications. *Alexeev et al (2001)* [RN.30] has inputs of date, time, solar wind density and velocity, and *Tsyganenko 1996* [RN.31]has inputs of solar wind pressure, Dst and IMF By and Bz components. *Tsyganenko 2002 to 2005* [RD.98] [RD.99] models require a more complex set of inputs.

Further discussion of these models and of their applications are dealt with in Annex E.

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5.2 Requirements for model selection and application

5.2.1 The internal field

a. IGRF 10 [RN.29] shall be used as the Internal Geomagnetic Field Model.

NOTE As a stand-alone model, the inputs required of the IGRF-10 are either position in geodetic coordinates, according to the reference 'World Geodetic Service 84' standard ellipsoid, or position in a geocentric system, with respect to the centre of the Earth and for which the reference Earth radius is 6 371,2 km. The coordinates are therefore geodetic or geocentric latitude in decimal degrees, longitude (same in both coordinate systems), altitude in km above the reference ellipsoid, or distance in km from the centre of the Earth. Time is input in decimal years, e.g. 2 007,5. It is recommended that geocentric data are used, to avoid errors or confusion in respect of the reference ellipsoid.

b. If a different model is an inherent part of a specific space environment model, then that specific geomagnetic field model shall be used.

NOTE An example is the AE8 and AP8 radiation flux / belt models (see Clause 9)

5.2.1.2 Application

a. For times in the past and in the future, IGRF-10 shall be used, in association with its secular variations.

NOTE 1 IGRF-10 and future versions contain revisions of models of earlier epochs.

NOTE 2 Beyond 5 years from the assumed epoch, the precision of the model is considerably reduced. IGRF-11 is expected to be issued for the epoch 2010, and can be used post 2010.

5.2.2 The external field

a. For modelling the average characteristics of the terrestrial magnetic field and its variation according to geomagnetic and solar activity, one of the following two external magnetic field models shall be used:

— Alexeev et al 2001, [RN.30]

— Tsyganenko 1996 [RN.31]

NOTE 1 These models are suitable for assessment of the mean and range of magnetic field strength; for estimation of B and L coordinates (but not for input to radiation belt models created with different field models); and in calculation of

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geomagnetic shielding of cosmic rays and solar particles.

NOTE 2 Recently, external field models have been created (e.g. Tsyganenko 2001 [RD.98], 2004 [RD.99]) that are used in research environments for dynamic modelling of field variations, e.g. substorm development. These have the capacity to represent more accurately the instantaneous magnetic field, but are not given here as standards because the definition of inputs to the models is not reasonably achievable in an engineering environment.

5.3 Tailoring guidelines

a. While the IGRF 10 model should normally be used for internal fields, a low-fidelity dipole model (using aligned, eccentric or tilted dipoles as appropriate) may suffice for some engineering applications.

b. For the external field, the recent Tsyganenko 2001 [RD.98] and 2004 [RD.99] models may be used instead of the reference models defined in clause 5.2.2.

NOTE Most engineering applications do not need the external-source model augmentation of these later Tsyganenko models. These are only useful for certain scientific magnetospheric missions, for instance if data on high latitude or high altitude variability of the fields with respect to local time and solar-geomagnetic activity was important.

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6 Natural electromagnetic radiation and indices

6.1 Introduction and description

6.1.1 Introduction

A spacecraft in LEO receives electromagnetic radiation from three primary external sources. The largest source is the direct solar flux. The mean value of this solar flux at the mean Sun-Earth distance is called the "solar constant". It is not really a constant but varies by about 3,4 % during each year because of the slightly elliptical orbit of the Earth about the Sun. The two others radiation sources are the fraction of the incident sunlight reflected off the planet, termed albedo, and the Earth infrared radiation.

Solar and geomagnetic activities are often described by indices. The UV radiation of the Sun, which strongly affects the Earth atmosphere, cannot be directly measured from the ground. But it was found to be strongly correlated with e.g. the sunspot number and the cm wavelength Sun radiation. For example, the widely used 10,7 cm radio flux index (*F10.7*) gives an indication of the solar UV radiation output which is highly variable over a solar cycle.

Geomagnetic indices typically describe the variation of the geomagnetic field over a certain time period. They provide a measure of the disturbance of the magnetosphere which has direct consequences for the charged particle space environment, or the external component of the geomagnetic field.

Solar and geomagnetic indices are used as input for upper atmosphere and other models of the near Earth space environment. They are provided for short durations or as long time averages. Predictions for future index values are usually provided at different confidence levels and they are available for complete solar cycles. The given data are mainly average values. For detailed thermal analyses or certain special applications, more detailed data and models are required. These are outside the scope of this Standard.

6.1.2 Electromagnetic radiation and indices

6.1.2.1 Solar constant

The solar constant is defined as the radiation that falls on a unit area of surface normal to the line from the Sun, per unit time, outside the atmosphere, at one

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