भारतीय मानक

Indian Standard

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ISO 22010 : 2022

अंतरिक्ष पद्धतियाँ — मास गुण नियंत्रण

Space Systems — Mass Properties Control

ICS 49.140

भारतीय मानक ब्यूरो
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Air and Space Vehicles Sectional Committee, TED 14

NATIONAL FOREWORD

This Indian Standard which is identical to ISO 22010 : 2022 'Space systems — Mass properties control' issued by International Organization for Standardization (ISO) was adopted by the Bureau of Indian Standards on the recommendation of the Air and Space Vehicles Sectional Committee and approval of the Transport Engineering Division Council.

The text of ISO standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions and terminologies are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker, while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

The Committee has reviewed the provisions of following International Standard referred in this adopted standard and has decided that it is acceptable for use in conjunction with this standard:

International Standard	*Title*
ISO 22108	Space systems — Non-flight items in flight hardware — Identification and control

Attention is drawn to the possibility that some of the elements of this standard may be the subject of patent rights. The Bureau of Indian Standards shall not be held responsible for identifying any or all such patent rights.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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Introduction

This document establishes the minimum requirements for providing adequate control of the mass properties of space systems to meet mission requirements. In addition, many recommended practices that add value to the mass properties monitoring tasks are presented. Throughout this document, the minimum essential criteria are identified by the use of the key word "shall." Recommended criteria are identified by the use of the key word "should," and while not mandatory, are considered to be of primary importance in providing timely and accurate mass properties support for contracts. It is advisable that deviations from the recommended criteria only occur after careful consideration and thorough evaluation have shown alternative methods to be satisfactory.

The requirements can be tailored for each specific space programme application.

Indian Standard

SPACE SYSTEMS — MASS PROPERTIES CONTROL

1 Scope

This document describes a process for managing, controlling and monitoring the mass properties of space systems. The relationship between this management plan and the performance parameters for mass properties to be met throughout the mission is described. Ground handling, dynamics analysis and test set-ups that rely on accurate mass properties inputs are identified. This document covers all programme phases from pre-proposal through to end of life.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 22108, *Space systems — Non-flight items in flight hardware — Identification and control*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
basic mass
best engineering estimate based on an assessment of the most recent baseline design, excluding *mass growth allowance* (3.8)

3.2
calculated properties
mass properties (3.9) determined from released drawings or controlled computer models

3.3
contractor limit
predicted mass (3.13) plus a *contractor margin* (3.4) to allow for uncertainties during the design cycle

3.4
contractor margin
system margin
difference between the *contractor limit* (3.3) and the *predicted mass* (3.13)

3.5
customer reserve
allowance defined by the customer according to the agreements of the contract

3.6
estimated properties
mass properties (3.9) determined from preliminary data, such as sketches or calculations from layout drawings

3.7
mass control parameters
factors used as an indicator of the *basic mass* (3.1), *predicted mass* (3.13) and margins/limits for a *space system* (3.14)

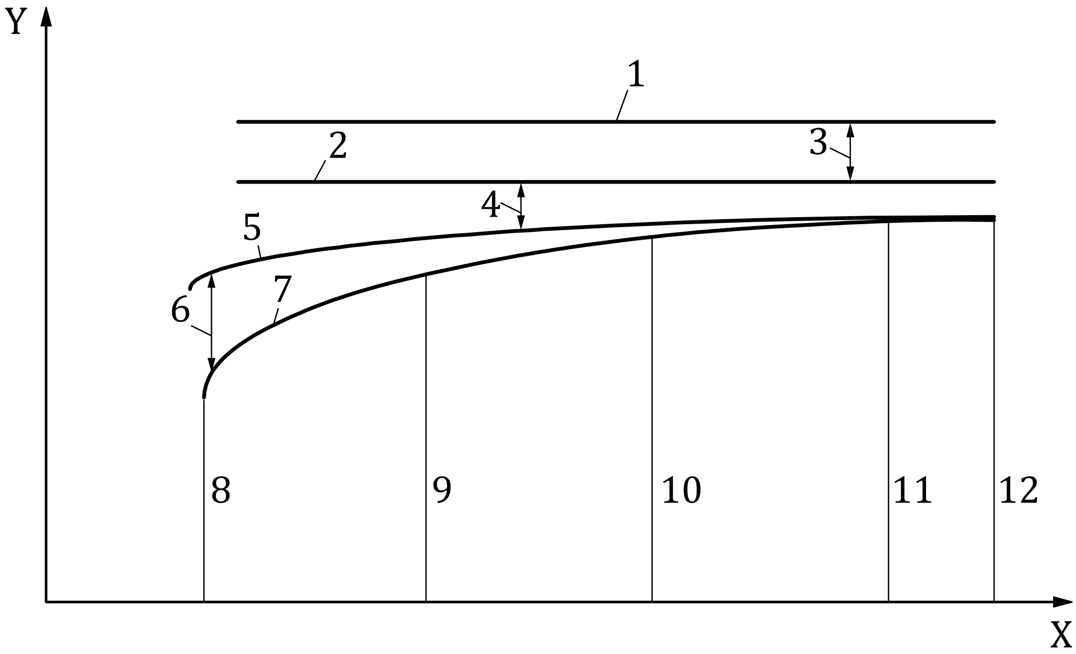
Note 1 to entry: See Figure 1.

3.8
mass growth allowance
predicted change to the *basic mass* (3.1) of an item, based on an assessment of the design and fabrication status of the item and an estimate of the in-scope design changes that may still occur

Note 1 to entry: See Annex A.

Note 2 to entry: This mass growth allowance is not intended to be a tolerance.

Note 3 to entry: Figure 1 is an illustration of related terms commonly used in reporting *mass properties* (3.9) during the development of *space systems* (3.14) hardware.



Key

X	time
Y	mass
1	mission limit
2	contractor limit
3	customer reserve
4	contractor margin/system margin
5	predicted mass
6	mass growth allowance
7	basic mass
8	authorization to proceed
9	preliminary design review
10	critical design review
11	actual mass
12	system delivery

Figure 1 — Mass control parameters

3.9
mass properties
mass, centre of gravity, moments of inertia, and products of inertia

3.10
mass properties categories
criteria used to indicate the confidence in or maturity of the design

3.11
measured properties
mass properties (3.9) determined by measurement or by comparison of nearly identical components, for which measured mass properties are available

3.12
mission limit
maximum mass that can satisfy all of the mission performance requirements

3.13
predicted mass
sum of the *basic mass* (3.1) and the *mass growth allowance* (3.8), intended to estimate the final mass at system delivery

3.14
space system
system that contains at least a space, a ground or a launch segment

Note 1 to entry: This document addresses only flight systems: launch vehicles, satellites, space vehicles, or components thereof.

4 Abbreviated terms

ACS	attitude control system
ANSI	American National Standards Institute
ATP	authorization to proceed
GSE	ground support equipment
MPCB	mass properties control board
NTE	not to exceed
TPM	technical performance measurement

5 Mass properties control plan

5.1 General

A mass properties control plan shall be documented.

A mass properties control plan shall be based on the critical parameters that need to be controlled. In some cases, that may only be mass. In the extreme, a spin-stabilized space system may have a set of requirements that warrants control of all the mass properties, including final measurements of mass, centre of mass, and moments and products of inertia. The depth and detail of analysis, reporting and testing shall reflect the critical parameters.

5.2 Control process

5.2.1 Basis of the process

The mass properties control process shall be started in the pre-proposal or conceptual design phases, where an initial mass budget is established. A proposal team may be established so as to guide subsystem and component mass allocations and the launch vehicle selection process, if applicable. This team should be supported by other members who have experience in the allocation process.

NOTE Space system mass is a prime concern. Without early mass properties control, there is a significant risk of performance, schedule, and/or cost problems later in the programme.

The control process after authorization to proceed (ATP) may include one or more of the following elements:

a) understanding of the flow-down of requirements that affect mass properties analysis and test plans;

b) a mass reduction plan;

c) implementation of a mass properties control board (MPCB);

d) mass allocation and trend analysis;

e) mass properties monitoring;

f) subcontractor mass control.

Application of some of the more stringent elements listed above is contingent on available mass and stability margins, cost considerations and the planned verification (measurement versus analysis) schema. The various elements and their applicability are discussed in 5.2.2 to 5.2.7.

5.2.2 Requirements definition

There shall be a review of all requirements that affect mass properties including, but not limited to, the contractual, attitude control, mission and ground handling requirements. Different space system designs have different mass properties requirements.

EXAMPLE A space system that is spin-stabilized throughout its mission requires a finer balance than one that is three-axis-stabilized.

5.2.3 Mass reduction plan

After establishing a credible mass summary during the proposal phase, a database shall be used with the tools necessary to develop a predicted mass for the space system at delivery. A contractor or system mass margin against the contractor limit shall be determined. If the mass margin is not sufficient, a rigorous mass reduction programme should be initiated. In this case, the programme office should fully support the effort.

Mass reduction is generally a costly undertaking, therefore it is advisable that programme offices allocate a sufficient budget to accomplish the goal. A historical database of previous weight reduction ideas is advisable.

5.2.4 Mass properties control board (MPCB)

In conjunction with a mass reduction plan, an MPCB may be convened to audit the mass properties database, critically review designs for optimum mass, and perform cost/mass trades as well as review margins. The MPCB should have a programme office and systems engineering representation. Some of the MPCB members should also have experience with this process. The MPCB should have the authority to direct design changes that reduce mass, within the considerations of cost, schedule and technical performance. MPCB members should attend all design reviews to ensure that mass optimisation is considered.

5.2.5 Mass allocation and trend analysis

One of the most effective ways of controlling mass is to set maximum, “not to exceed” (NTE), allocations at the subsystem or unit level. With reference to Figure 1, if the contractor margin at the beginning of the programme is small or negative, it may be necessary to challenge each subsystem so as to ensure that the contractor limit is exceeded. The same idealized chart can be used to represent each subsystem's mass NTE allocation. These technical performance measurement (TPM) charts should be used to monitor the progress of each subsystem. If the predicted mass exceeds the NTE allocation, mass reduction is necessary; in some cases, a re-allocation among subsystems may solve the problem. This trend analysis is particularly critical prior to preliminary design review, when designs are still evolving and mass reduction efforts are less costly.

5.2.6 Mass properties monitoring

For programmes with adequate margins in all mass properties parameters, a simple mass history chart and a table showing the predicted mass properties versus the requirements suffice. The chart and table should be included in periodic reports to the customer (see 5.3.6).

5.2.7 Subcontractor mass properties control

The prime contractor shall be involved in the development of NTE masses in the procurement specification that is issued to subcontractors. If additional controls, such as centre of mass or inertia, are required, those NTE values shall also be added to the specification and contract. The status of the critical values shall be reported by the subcontractor in periodic reports as specified by the contractor. If mass reduction is needed to bring the deliverable items within specification, the programme office may want to set up regular meetings with the subcontractor (including a mass review board) until the problem is mitigated, or until all avenues for meeting the specification have been exhausted. Incentives and penalties against specification values written into the contract may be of use.

5.3 Documentation

5.3.1 General

Mass properties documentation consists of plans and reports. Plans define the programme management methods for controlling, reporting and measuring mass properties. Reports provide visibility into the hardware configuration and design maturity through the development process.

5.3.2 Control plan

The overall control plan described in 5.1 and 5.2 shall be documented so as to provide an organized process that can be implemented early in the development phase and carried through to hardware delivery. The control plan should contain the applicable elements of the control process outlined in 5.2, as applicable, as well as a reporting plan and a verification plan.

5.3.3 Report plan

Report format and frequency of delivery may be specified in the contract. An initial report may be expected one month after ATP. Formal monthly reports should be provided through critical design review, with quarterly reports thereafter. For mass critical programmes, a weekly mass update may be required. A final test report provides the customer with the space system's measured mass properties, from which mission predictions are made.

5.3.4 Analysis plan

In some cases, full space systems analysis using computer-aided design (CAD) systems may not be possible, because of resource limitations. In other cases, parametric data from other programmes may prove to be accurate enough until programme-specific hardware measurements are taken. In those cases, an analysis plan should be documented, informing the customer of the uncertainties related to the mathematical model.

5.3.5 Verification plan

The verification plan shall define the methods to be used to verify the mass properties data. The plan shall address the process for determining part, unit, subassembly-and assembly-level verification. The verification plan should be formulated in the early stages of the programme.

EXAMPLE Mass properties measurement requirements can affect the hardware design. Consequently, procurement of long-lead measurement devices, such as adapters and handling equipment, can be necessary.

The plan shall define the method of verification, analysis or test for each mass properties parameter. If margins are small, an uncertainty analysis should be performed to verify whether analysis is sufficient. A more detailed plan, including which units, parts, subassemblies or modules are to be weighed, may be delivered to manufacturing planning for implementation. A note should be placed on each detail or assembly drawing defining which items should be weighed. On programmes with multiple identical space systems, it may be sufficient to weigh only the first serial number at the detail part or unit level. Such information shall be transmitted to manufacturing.

5.3.6 Status reports

A report format shall be established that satisfies the needs of the customer, programme office and the other internal customers who rely on the timely communication of mass properties information.

Periodic status reports provide insight into the space system's mass properties throughout development. The report may consist of a full set of mass properties, or a subset thereof, depending on the contractual requirement for reporting. In some cases, where margins are large and control systems robust, reporting total predicted mass is sufficient. The level of detail to be reported may also vary depending on the degree of visibility required of a particular assembly or subsystem as stated in the contract.

EXAMPLE Typically, the details of the masses of the components within an electronic box are not required, so there can be a request to report only the predicted total mass of the unit. Conversely, at certain points in the programme, the customer can view the entire detail mass properties database for an independent review.

The report plan described in 5.3.3 shall specify the level of detail required.

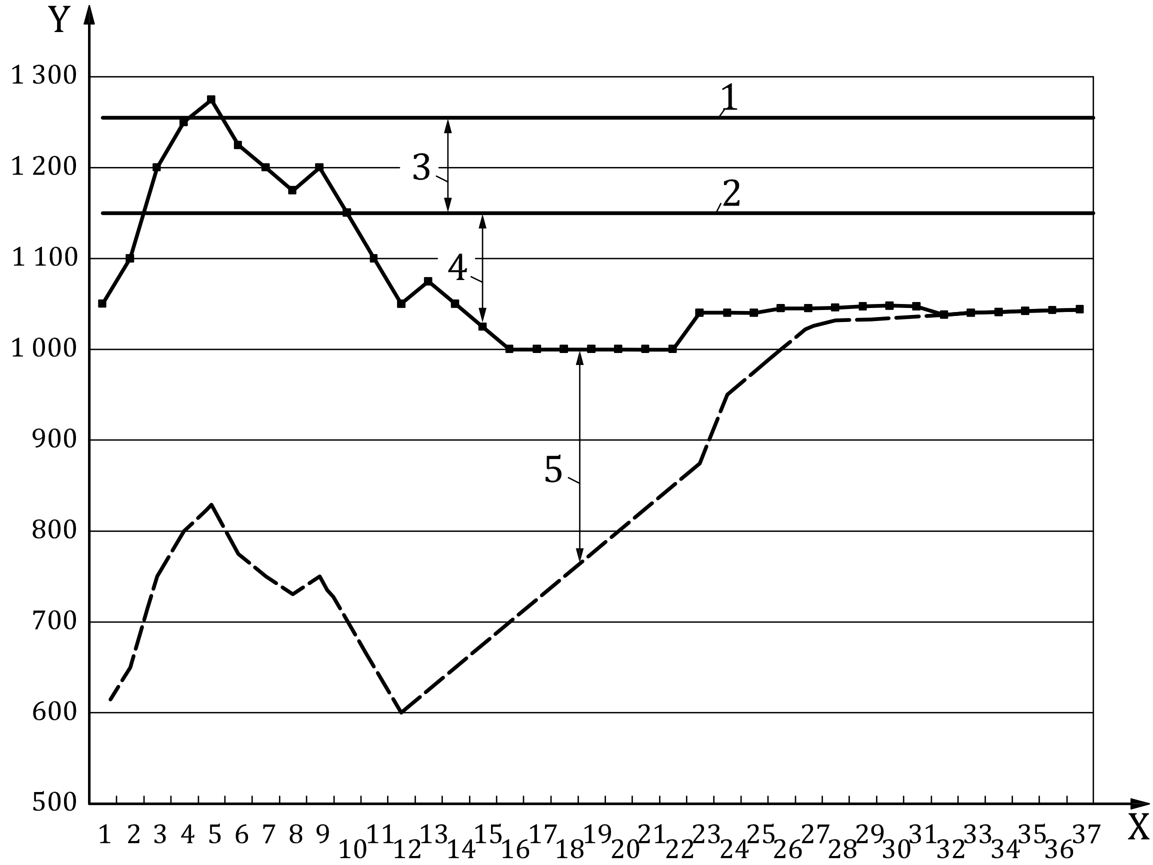
5.3.7 Trend analysis reports

Trend analysis reports may be submitted as part of the status report mentioned in 5.3.6 or may be submitted separately. The space system mass trend analysis is simply the summation of the subsystem TPM mentioned in 5.2.5, with the mission and contractor limits specified. Charts tracking centre of mass or moments of inertia may be developed, if those parameters are critical.

Figure 2 illustrates the effects of large uncertainties and lack of mass control in the early stages of a programme. By month 5, in this example, mass reduction techniques are implemented, and the mass begins to decrease. By month 13, the design maturity is advanced enough to evidence a steady decrease in the mass growth allowance. By month 24, measured masses are available, and the basic and predicted masses converge.

The mass growth allowance applied to the basic mass shall be directly related to the maturity of the design. The maturity of each component, unit or assembly shall be categorized and assigned a percentage of mass growth. As the design evolves, the mass growth should decrease. This should be a continual process that is captured in each status report. Applying the mass growth allowance at the part level generally provides the most accurate representation of programme mass status.

Each contractor shall develop its own set of mass growth percentages based on its historical data. In the absence of historical data, Table A.1 may be used.



Key

X time, in months

Y mass, in kg

1 mission limit

2 contractor limit

3 customer reserve

4 contractor margin/system margin

5 mass growth allowance

basic mass (dashed line)

predicted mass (solid line with square markers)

Figure 2 — Programme mass tracking

5.4 Analysis

5.4.1 General

Mass properties analysis follows the methodology defined in the mass properties control plan and provides direct input to the various reports. The analyses should be divided into three main categories:

— flight hardware,

— ground handling, and

— special analysis.

5.4.2 Flight hardware analysis

All new subsystems, units and components may be subject to detailed analysis. These may include, but are not limited to, the following subsystems:

— antennas,

— wave guide and/or coaxial cables,

— electrical/electronic components,

— structure,

— thermal,

— propulsion,

— batteries, solar arrays and/or other power sources,

— wire harnesses,

— mechanisms, and

— instrumentation.

An analytical database shall be maintained that accurately represents the space system's mass properties throughout the mission, including launch, transfer orbit, on-station and return (if applicable). Software should have the capability of performing changes in configuration, such as deployments and fuel depletion.

5.4.3 Ground handling

Analysis of the combined ground support equipment (GSE) and flight hardware may be required during integration and test operations. Mass and centre of mass of various subassemblies or modules of flight hardware shall be analysed for the design of GSE, location of pickup points, rollover characteristics and stability during handling. The mass properties database should have enough detail and the software should be versatile enough to predict the mass properties of these unique configurations accurately. Non-flight items forming part of the configuration should be weighed and incorporated into the data reduction process.

5.4.4 Special analysis

5.4.4.1 General

Several special analyses may be requested. These requests are generally made by internal customers, such as structural analysis, flight mechanics, mission control, manufacturing, ground support operations, special test equipment, packaging, transportation, dynamics, attitude control or payload layout design organizations.

5.4.4.2 Layout analysis

Mass properties considerations, such as optimization of equipment from a balance standpoint, should be considered during the layout process.

5.4.4.3 Mass distribution analysis

The stress and dynamics analysis organizations may request a mass distribution for use in developing loads and for accurately predicting load concentrations that may require local strengthening. A sort capability in the mass properties software would greatly facilitate this analysis.

5.4.4.4 Balance mass analysis

On space systems requiring static or dynamic balancing, mass properties should be considered along with structural designs to provide the optimum locations and configuration of proposed balance masses if they are required. Special requirements, such as thermal finish or other considerations, shall be addressed in the design of the balance masses. The support schemes for the balance masses should have stress and dynamics analysis as well.

5.4.4.5 Mission/attitude control system (ACS) analysis

There are mass properties interfaces with the mission and ACS organizations in the iterative process of defining propellant budgets and deployment schemes. A separate file in a special format may be requested by the ACS organization to perform its analyses. In the data interchange with the ACS organization, the mass properties data shall indicate whether a positive or negative integral is used in the determination of the products of inertia.

5.4.4.6 Uncertainty analysis

The approximate uncertainty of the space system's mass properties at key points in the programme shall be known. Uncertainties can come from several sources, both analytical and measured.

The uncertainty may be based on historical or comparative data or may be rigorously derived. The mass growth allowance normally encompasses design uncertainties associated with design maturities for estimated, layout and pre-release drawing mass properties categories. In special cases where the mass growth allowance figures are believed inaccurate, a rigorous uncertainty analysis based on raw uncertainty data should be performed.

5.4.5 Verification

5.4.5.1 General

Mass properties verification is the confirmation that the required mass properties are known within the established limits. 5.4.5.2 to 5.4.5.4 provide criteria for determining which mass properties require verification and how best to meet these requirements.

5.4.5.2 Determining mass properties verification requirements

Based on individual programme requirements, particular flight events generally require specific knowledge of flight mass properties and the allowable tolerances on these values. The mass properties shall be defined early in the design process and controlled within defined tolerances. A wide tolerance of mass properties may be acceptable, but an exact knowledge of the space system or parts thereof shall be available. The critical mass properties for selected assemblies or for the total space system shall be defined.

5.4.5.3 Determining mass properties limits

The allowable limits of the mass properties parameters generally define two distinct criteria to be established in the verification programme:

a) establishing acceptance criteria for the hardware assembly in terms of maximum and minimum mass, centre-of-mass location, and moments and products of inertia that are consistent with the verification requirements, and

b) establishing the accuracy required in conducting the measurements in the verification process that is consistent with the verification requirements.

The mass properties limits shall be defined in the verification plan and addressed in the specific procedures used to determine these parameters.

5.4.5.4 Mass properties verification process

5.4.5.4.1 General

Verification may be accomplished by direct or indirect measurement, by analysis, or by a combination of both methods. Methods of verification shall be selected that are consistent with the required levels of accuracy at each phase of the assembly. Verification shall be performed in accordance with the verification plan.

5.4.5.4.2 Verification requirements

A verification matrix shall be prepared that identifies which system-level mass properties shall be verified by test, which by analysis and which by a combination of the two methods. With customer and programme office approval, this plan should be flowed down to lower levels of assembly to determine which units, parts or subassemblies should be measured. The verification methods should be selected early enough in the programme to provide time for acquisition, modification or preparation of measurement equipment and sites. Verification should be performed at a low enough piece part level to adjust the estimated properties or calculated properties not being verified by test.

5.4.5.4.3 Verification procedures

Mass properties measurement tests shall be conducted in accordance with programme procedures that are approved and documented. The procedures shall contain stated goals of the test that are determined by requirements.

EXAMPLE ISO 15864 includes a dynamic balance test.

5.4.5.4.4 Test conditions

The test article shall simulate the flight condition as far as is practical, excluding hazardous components or components not normally installed at the measurement site. Deviations from the flight condition should be commensurate with test objectives, such that the test results are meaningful and measurement uncertainties are within expected ranges. The test article should have minimal non-flight hardware installed. The configuration shall be verified, and mass properties-related data for all missing flight items, installed non-flight items, other items that may be different from the flight model and tare items shall be recorded. A log of non-flight items shall be established in accordance with the requirements in ISO 22108.

5.4.5.4.5 Data records

Mass properties verification data shall be documented and made available for review on the current programme, as well as archived for reference on future programmes.

Annex A
(informative)

Mass growth guidelines

Table A.1 represents a compilation of historical data from several sources. In some cases, the percentage ranges are quite large. However, for a contractor with limited experience, or a relatively small database of programmes, the average percentage in each category should be a good indicator for the mass growth of the overall space system.

NOTE Data are derived from current technology applications and can be invalid for newer technology applications. For effects of newer technologies, modifications to the data in Table A.1 can be necessary.

Table A.1 — Mass growth allowance as a function of design maturity

Code	Design maturity (basis for mass determination)	Percentage mass growth allowance									
		Electrical/electronic components kg			Structure	Thermal control	Propulsion	Batteries	Wire harnesses	Mechanisms	Instrumentation
		0-5	5-15	>15							
E	Estimated (preliminary sketches)	20-35	15-25	10-20	18-25	15-30	15-25	20-25	25-100	18-25	25-75
L	Layout (or major modification of existing hardware)	15-30	10-20	5-15	10-20	10-20	10-20	10-20	15-45	10-20	20-30
P	Pre-release drawings (or minor modification of existing hardware)	8-20	3-15	3-12	4-15	8-15	5-15	5-15	10-25	5-15	10-25
C	Released drawings (calculated value)	5-10	2-10	2-10	2-6	2-7	2-7	3-7	3-10	3-4	3-5
X	Existing hardware (actual mass from another programme)	1-5	1-3	1-3	1-3	1-3	1-3	1-3	1-5	1-3	1-3
A	Actual mass (measured properties of flight hardware)	0	0	0	0	0	0	0	0	0	0
CFE	Customer furnished equipment (without modification).	0	0	0	0	0	0	0	0	0	0

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Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the website-www.bis.gov.in or www.standardsbis.in.

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