

---

---

**Space systems — Mass properties  
control**

*Systèmes spatiaux — Contrôle des propriétés de masse*

STANDARDSISO.COM : Click to view the full PDF of ISO 22010:2022



STANDARDSISO.COM : Click to view the full PDF of ISO 22010:2022



**COPYRIGHT PROTECTED DOCUMENT**

© ISO 2022

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office  
CP 401 • Ch. de Blandonnet 8  
CH-1214 Vernier, Geneva  
Phone: +41 22 749 01 11  
Email: [copyright@iso.org](mailto:copyright@iso.org)  
Website: [www.iso.org](http://www.iso.org)

Published in Switzerland

# Contents

	Page
Foreword.....	iv
Introduction.....	v
<b>1 Scope.....</b>	<b>1</b>
<b>2 Normative references.....</b>	<b>1</b>
<b>3 Terms and definitions.....</b>	<b>1</b>
<b>4 Abbreviated terms.....</b>	<b>3</b>
<b>5 Mass properties control plan.....</b>	<b>3</b>
5.1 General.....	3
5.2 Control process.....	3
5.2.1 Basis of the process.....	3
5.2.2 Requirements definition.....	4
5.2.3 Mass reduction plan.....	4
5.2.4 Mass properties control board (MPCB).....	4
5.2.5 Mass allocation and trend analysis.....	4
5.2.6 Mass properties monitoring.....	5
5.2.7 Subcontractor mass properties control.....	5
5.3 Documentation.....	5
5.3.1 General.....	5
5.3.2 Control plan.....	5
5.3.3 Report plan.....	5
5.3.4 Analysis plan.....	5
5.3.5 Verification plan.....	6
5.3.6 Status reports.....	6
5.3.7 Trend analysis reports.....	6
5.4 Analysis.....	7
5.4.1 General.....	7
5.4.2 Flight hardware analysis.....	7
5.4.3 Ground handling.....	8
5.4.4 Special analysis.....	8
5.4.5 Verification.....	9
<b>Annex A (informative) Mass growth guidelines.....</b>	<b>11</b>
<b>Bibliography.....</b>	<b>12</b>

## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

This second edition cancels and replaces the first edition (ISO 22010:2007), which has been technically revised.

The main changes are as follows:

- the reference to ANSI/AIAA S-120-2015 has been changed to ANSI/AIAA S-120-2015 (2019);
- the reference to "SAWE Recommended Practice Number A-3 (RP-A-3), Mass Properties Control for Space Systems" has been added.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## 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.

STANDARDSISO.COM : Click to view the full PDF of ISO 22010:2022

[STANDARDSISO.COM](https://standardsiso.com) : Click to view the full PDF of ISO 22010:2022

# 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](#).

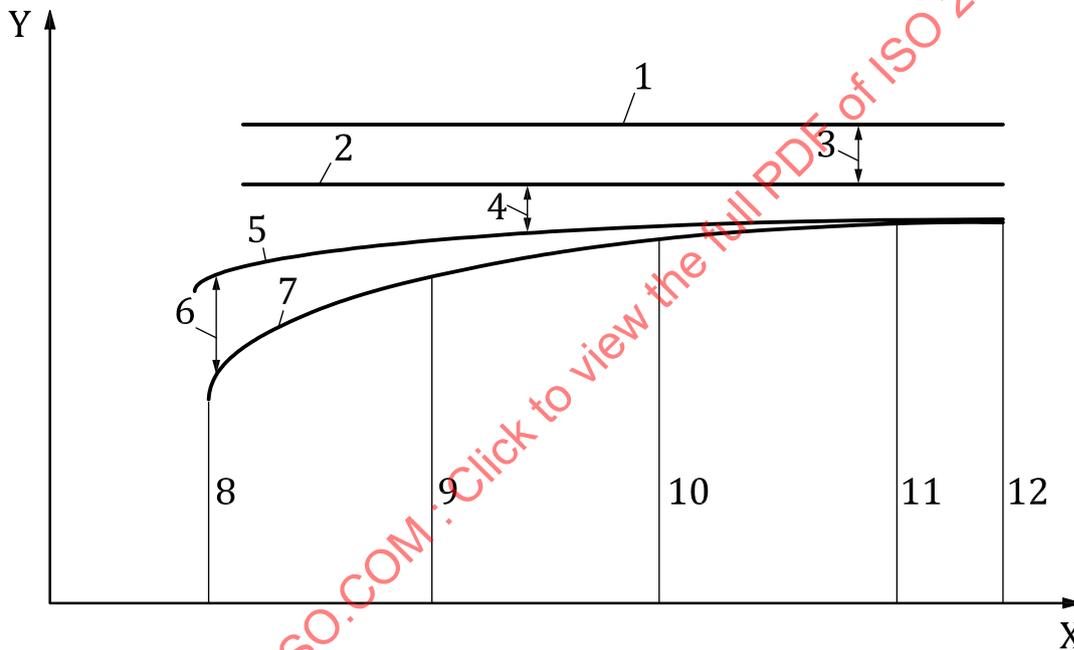
**3.8 mass growth allowance**

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

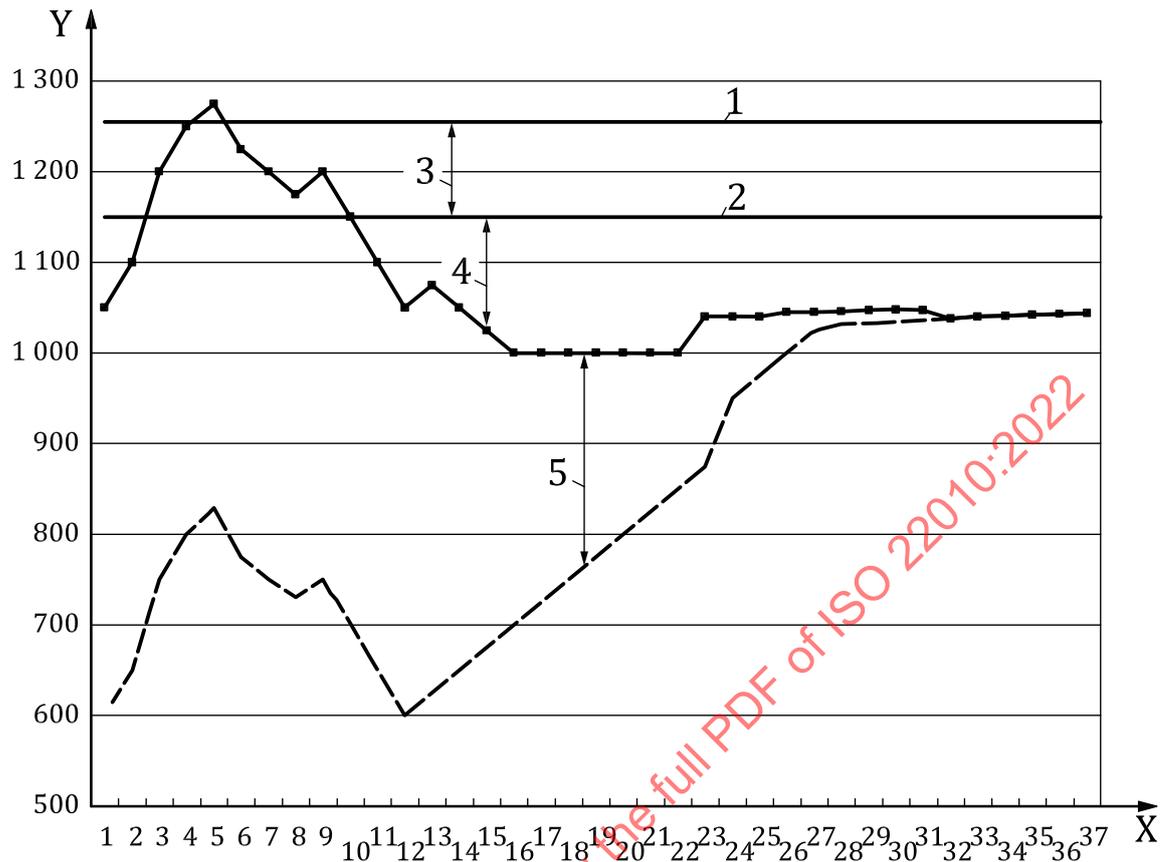
### 5.3.7 Trend analysis reports

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	4	contractor margin/system margin
Y	mass, in kg	5	mass growth allowance
1	mission limit	---	basic mass
2	contractor limit	—■—	predicted mass
3	customer reserve		

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.