
**Space systems — Mass properties
control**

Systèmes spatiaux — Contrôle des propriétés de masse

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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.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 22010 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

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Introduction

This International Standard 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 International Standard, 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.

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Space systems — Mass properties control

1 Scope

This International Standard 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 International Standard covers all programme phases from pre-proposal through to end of life.

2 Normative references

The following referenced documents are indispensable for the application 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.

3.1

basic mass properties

best engineering estimate based on an assessment of the most recent baseline design, excluding mass growth allowance

3.2

calculated properties

mass properties determined from released drawings or controlled computer models

3.3

contractor limit

predicted mass plus a contractor margin to allow for uncertainties during the design cycle

3.4

contractor margin/system margin

difference between the contractor limit and the predicted mass

3.5

customer reserve

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

3.6

estimated properties

mass properties 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, predicted mass and margins/limits for a space system

See Figure 1.

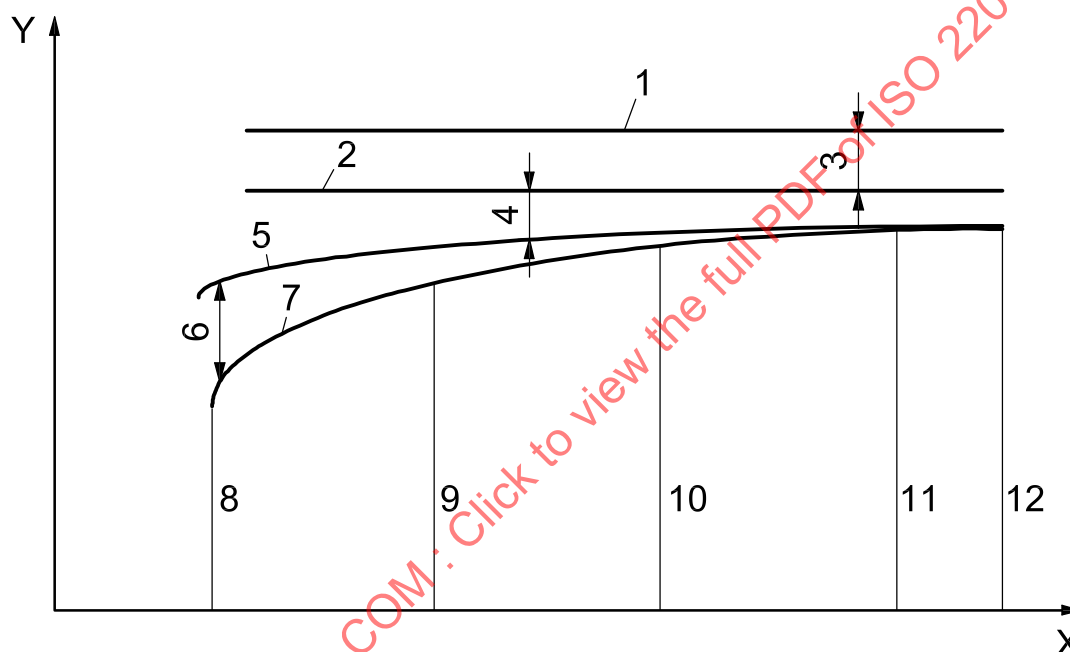
3.8

mass growth allowance

predicted change to the basic mass 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 This mass growth allowance is not intended to be a tolerance.

NOTE 2 Figure 1 is an illustration of related terms commonly used in reporting mass properties during the development of space systems hardware.



Key

- X time
- Y mass
- 1 mission limit
- 2 contractor limit
- 3 customer reserve
- 4 contractor margin/system margin
- 5 predicted mass
- 6 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 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 and the mass growth allowance, intended to estimate the final mass at system delivery

3.14

space systems

launch vehicles, satellites, space vehicles, or components thereof

4 Symbols and abbreviated terms

ACS attitude control system, alternative definition below

AOCS attitude and orbit control system

AIAA American Institute of Aeronautics and Astronautics

ANSI American National Standards Institute

ATP authorization to proceed

CAD computer aided design

CDR critical design review

CFE customer furnished equipment

GSE ground support equipment

IPT integrated product team

MPCB mass properties control board

NTE not to exceed

PDR preliminary design review

SAWE Society of Allied Weight Engineers

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 the following subclauses.

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 systems 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.

NOTE 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 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 will not be 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 will 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, might be required.

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 might be a request to report only the predicted total mass of the unit. Conversely, at certain points in the programme, the customer might want to 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 technical performance measurement (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.

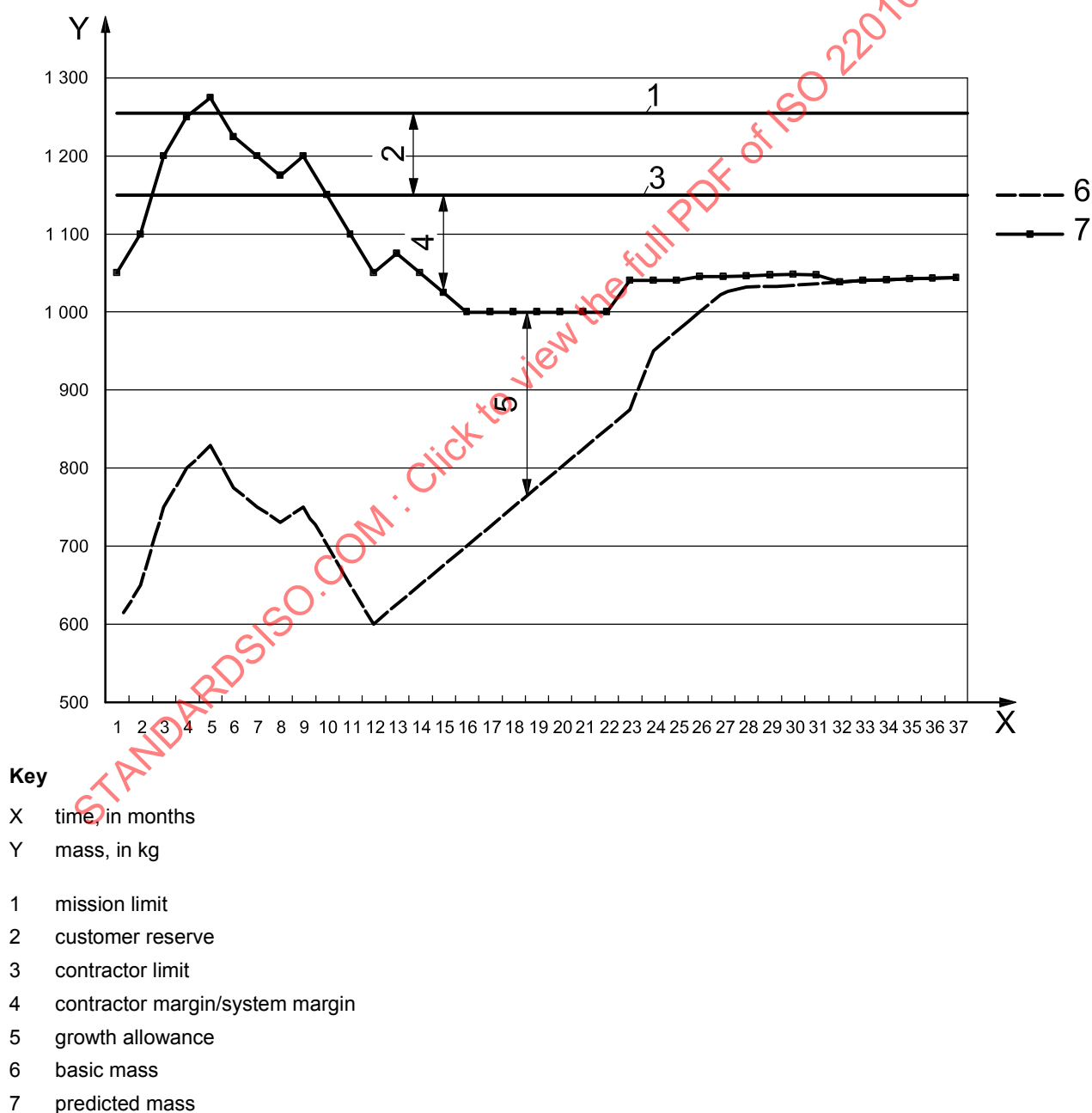


Figure 2 — Programme mass tracking

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 analyses

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 will normally encompass design uncertainties associated with design maturities for estimated, layout and pre-release drawing maturity 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. The following subclauses 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 calculated values of the mass 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.