DRAFT INTERNATIONAL STANDARD ISO/DIS 22010

ISO/TC **20**/SC **14** Secretariat: **ANSI**

Voting begins on: **2005-06-13** Voting terminates on: **2005-11-13**

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION • МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ • ORGANISATION INTERNATIONALE DE NORMALISATION

Space systems — Mass properties control

Systèmes spatiaux — Contrôle des propriétés de masse

ICS 49.140

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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.

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

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. Deviations from the recommended criteria should only occur after careful consideration and thorough evaluation have shown alternative methods to be satisfactory.

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

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 and stability to be met throughout the mission are described. Ground handling, dynamics analysis and test set ups that rely on accurate mass properties inputs are identified. This standard covers all programme phases from pre-proposal through end of life.

2 Normative references

The following normative documents contain provisions which, through referenced in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO DIS 15864 Space systems – General test standard for spacecraft, subsystems, and units

ISO CD 22108 Space systems – Non-flight items in flight hardware – Identification and control

3 Terms and definitions

For the purposes of this International Standard, 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

3.8
Mass growth allowance
predicted change to the basic mass based on an assessment of the design maturity, allowing for design changes and evolutions during development that may occur, excluding configuration changes due to major contract or requirements changes

NOTE 1 This allowance is not meant 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.

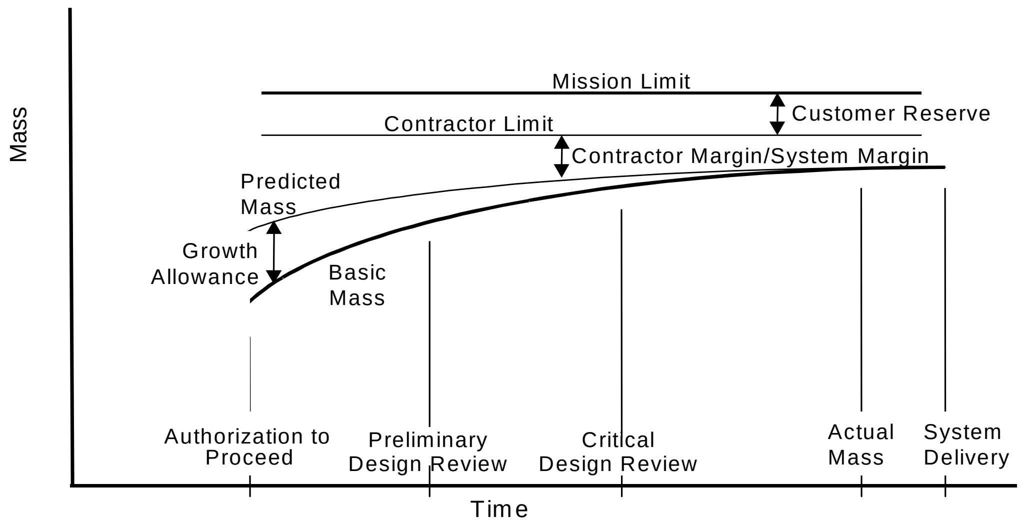

Figure 1 — Mass control parameters

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 still 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 obit 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 should be documented.

A mass properties control plan should 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 warrant 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 be reflective of 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 in order 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 previous experience in the allocation process.

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

The control process after authorization to proceed 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 successful 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 vs. analysis) schema. The various elements and their applicability are discussed below.

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 3-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 projected mass for the space system at delivery. A contractor or system mass margin against the contractor limit should 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 generally is a costly undertaking, and programme offices should allocate sufficient budget to accomplish the goal. An historical database of previous weight reduction ideas is recommended.

5.2.4 Mass Properties Control Board

In conjunction with a mass reduction plan, a Mass Properties Control Board 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 Board should have programme office and systems engineering representation. Some of the MPCB members should also have previous 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 to control mass is to set not-to-exceed (NTE) allocations at the subsystem or unit level. Referring 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 manager in order to ensure that the contractor limit will not be exceeded. The same idealized chart can be used to represent each subsystem's mass target, or NTE allocation. These technical performance measurement 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 (refer to subclause 5.3.6 on status reports).

5.2.7 Subcontractor mass properties control

The prime contractor should 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 subclauses 5.1 and 5.2 shall be documented in order 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 elements of the control process in subclause 5.1, 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 measured space system's mass properties from which mission predictions are made.

5.3.4 Analysis Plan

In some cases, full space systems analysis using CAD systems may not be possible, due to 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. Thus, procurement of long lead measurement devices, such as adapters and handling equipment, may 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 that 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 to 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.

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

The report plan in subclause 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 subclause 5.3.6, or may be submitted separately. The space system mass trend analysis is simply the summation of the subsystem TPM mentioned in subclause 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 continuous 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 in Annex A may be used.

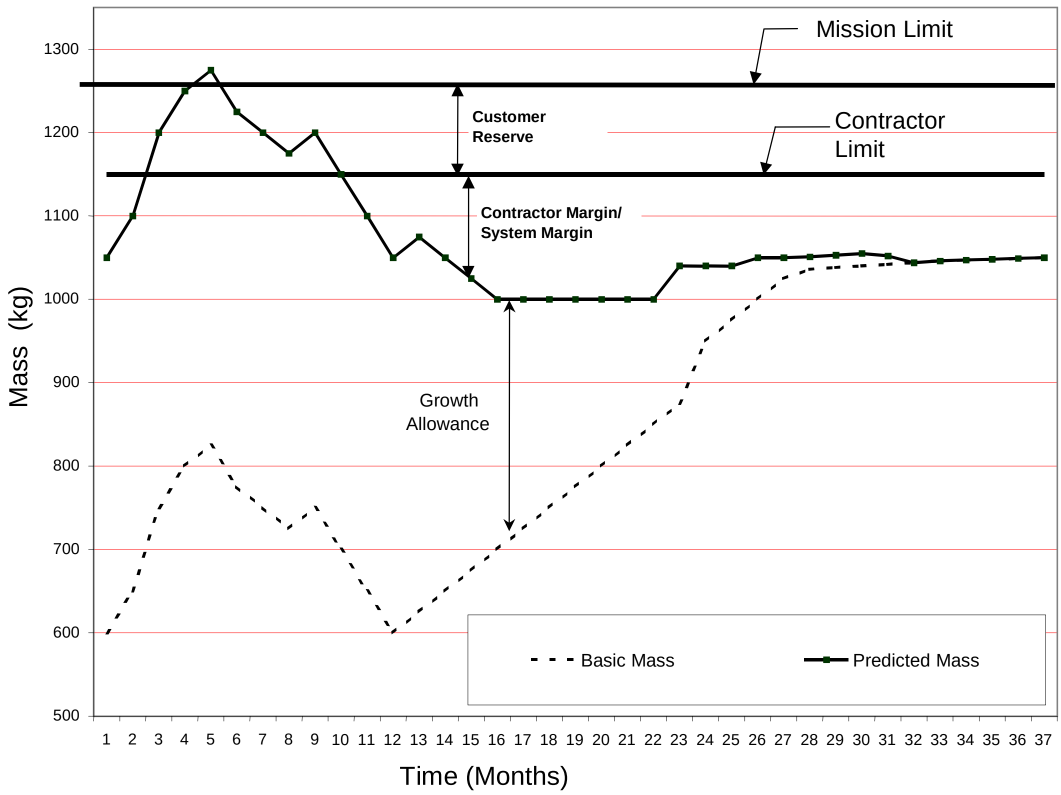

Figure 2 — Programme mass tracking

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,

— 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.

— antenna,

— wave guide and/or coax cables,

— electrical/electronic components,

- structure,
- thermal,
- propulsion,
- batteries, solar arrays and/or other power sources,
- wire harnesses,
- mechanisms,
- instrumentation.

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

5.4.3 Ground handling

Analysis of the combined ground support equipment 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 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

There are several special analyses that 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.

5.4.4.2 Layout analysis

Mass properties considerations, such as optimisation of equipment from a balance standpoint, should be taken into account 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 considerations should be taken into account along with structural design to provide the optimum locations and configuration of the proposed balance weights. Special requirements, such as thermal finish, shall be addressed in the design of the weights. Stress and dynamics engineers should analyse the support schemes for the weights.

5.4.4.5 Mission/attitude control system 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 ACS to perform their analyses. In the data interchange with ACS, the mass properties shall indicate whether a positive or negative integral is used in the determination of the products of inertia.

5.4.4.6 Uncertainty analysis

There shall be knowledge of the approximate uncertainty in the space system's mass properties at key points in the programme.

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 too inaccurate, a rigorous uncertainty analysis based on raw uncertainty data can 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, specific 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 systems 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) establish 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) establish 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. Based on the accuracy required, 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 be flight representative and should be no less than 90% of the total flight mass, excluding propellant and explosive devices, and with minimal non-flight hardware installed. The configuration shall be verified and mass properties related data for all missing items, non-flight items installed, other items that may be different from the flight model and tare items recorded. A log of non-flight items shall be established according to 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

A.1 General

The following table represents a compilation of historical data from several sources. In some cases, the percent ranges are quite large. However, for a contractor with limited experience, or a relatively small database of programmes, the average percent in each category should be a good indicator for the mass growth of the overall space system. Note that the table below is derived from current existing technology applications and may not apply to newer technology applications. For impacts of newer technologies, modifications of Table A.1 may be required.

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

Code	**Design maturity** (basis for mass determination)	**Percent mass growth allowance**									
		Electrical/Electronic Components			Structure	Thermal Control	Propulsion	Batteries	Wire Harnesses	Mechanisms	Instrumentation
		0-5 kg	5-15 kg	>15 kg							
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 flight hardware)	0	0	0	0	0	0	0	0	0	0
CFE	**Customer furnished equipment**	0	0	0	0	0	0	0	0	0	0

Bibliography

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Society of Allied Weight Engineers, *SAWE Recommended Practice Number 11* (RP-No. 11)*, Mass Properties Control for Space Vehicles*