INTERNATIONAL

SOCIETY OF ALLIED WEIGHTS ENGINEERS, INC.

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MASS PROPERTIES CONTROL FOR SPACE VEHICLES

Revision Letter B

Prepared by
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Society of Allied Weight Engineers, Inc.

SAWE RECOMMENDED PRACTICE

PAGE AND REVISION LOG

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[1] - Revision A was completely reformatted and repaginated with changes.

Society of Allied Weight Engineers
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Recommended Practice

RP-11

Mass Properties Control for Space Vehicles

1. This recommended practice is provided by the SAWE to provide guidelines for monitoring, controlling, and reporting mass properties of spacecraft, launch vehicles, and exo-atmospheric missiles.

2. This recommended practice is based on Reference 1, and incorporates the updates that were proposed for Revision A of that document.

3. Beneficial comments (recommendations, additions, and deletions) and any pertinent data that may be of use in improving this document should be submitted to the above address.

CONTENTS

SECTION 1

1. SCOPE

1.1 PURPOSE

This recommended practice establishes uniform procedures for the control, determination, and documentation of mass properties of space vehicles and their subsystems and components. This document is derived from Reference 1 to serve as a continuing, maintained, industry recommended practice. As such, it contains some sections that are applicable primarily to United States Government space vehicle development and acquisition programs. Other sections are more general in nature, describing terminology, processes, and procedures that are generally accepted in the industry, and reflect sound mass properties engineering practices in the development and production of space vehicles. This recommended practice is, therefore, applicable for mass properties control of all space vehicle development and acquisition, government and private.

1.2 APPLICATION

This recommended practice is intended for use in acquisition and study contracts for selected space systems and space vehicles. It may be cited in contract statements of work to specify the mass properties control requirements for space vehicles as may be applicable to the acquisition.

This recommended practice may also be used as a reference document to specify mass properties control requirements for upper stage vehicles, injection stages, satellite payloads, reentry vehicles, launch vehicles, ballistic vehicles, or for other vehicles. For these applications the term "space vehicle" is to be interpreted as the applicable vehicle.

For air-breathing or non air-breathing rocket and missile systems which operate totally within the sensible atmosphere, SAWE Recommended Practices 9 and 10 are recommended for use in lieu of or in concert with this standard.

1.3 SHALL OR SHOULD, USE OF

The use of “shall” or “should” has no bearing on the voluntary nature of SAWE Recommended Practices. Inclusion of an SAWE Recommended Practice in a document, standard, or contract by a company or agency is a voluntary act. When an SAWE Recommended Practice is so cited, the SAWE Recommended Practice becomes a requirement within the limitations set forth by the document, standard, or contract. The following shall apply to the use of these words:

Shall - “Shall” was used whenever the criterion for conformance with the specific recommendation requires that there be no deviation. Its use was not avoided on the grounds that compliance with the SAWE Recommended Practice was considered voluntary.

Should - “Should” was used wherever noncompliance with the specific recommendation was permissible. “Should” was not substituted for “shall” on the grounds that compliance with the SAWE Recommended Practice was considered voluntary.

SECTION 2

2. REFERENCED DOCUMENTS

Utilize the latest version of these references unless otherwise specified.

1. MIL-STD-1811 (USAF) “Military Standard - Mass Properties Control for Space Vehicles”

2. MIL-M-38310B (USAF), Amendment 2 “Military Specification - Mass Properties Control Requirements for Missile and Space Vehicles”

3. SAWE Recommended Practice Number 6, “Standard Coordinate Systems for Reporting the Mass Properties of Flight Vehicles”

4. MIL-HDBK-1811 “Department of Defense Handbook, Mass Properties Control for Space Vehicles”

SECTION 3

3. DEFINITIONS

3.1 MASS PROPERTIES

The mass properties of an item include the item's weight (or mass), center of gravity (or center of mass), mass moments of inertia, and mass products of inertia.

3.2 BASIC MASS PROPERTIES

The basic mass properties of an item are the mass properties data based on an assessment of the most recent baseline design. This design assessment includes the estimated, calculated, or measured mass properties, and also includes an estimate for undefined design details. The weight growth allowance is not included.

3.3 WEIGHT GROWTH ALLOWANCE

The weight growth allowance is the predicted change to the basic mass properties of an item based on an assessment of the design and fabrication status of the item, and an estimate of the design changes that may still occur. These design changes are changes that may be implemented by the contractor to meet contracted design requirements. The weight growth allowance associated with these design changes generally compensates for the lack of design maturity.

3.4 PREDICTED MASS PROPERTIES

The predicted mass properties of an item are the basic mass properties plus the weight growth allowance.

3.5 MASS PROPERTIES UNCERTAINTY

The variations in mass properties about the nominal due to predicted or foreseeable dispersions in the mass properties of component or vendor items, uncertainties in the position or orientation of component parts, or other sources of variation from article to article. Typical sources are manufacturing tolerances, material thickness tolerances, moisture absorption, location of movable items, shim and ballast mass, application thickness of paint and adhesives, density variations in foams, woods, and other materials, etc.

3.6 MASS PROPERTIES LIMITS

Maximum or minimum limiting values of weight (or mass), center of gravity (or center of mass), mass moments of inertia, mass products of inertia, or any combination thereof, which are imposed on a vehicle due to contractual, performance, control, transport, or other requirements.

SECTION 4

4. GENERAL REQUIREMENTS

4.1 CONTROL PROGRAM

The mass properties control program for space vehicles should be in accordance with the guidelines of this recommended practice and shall be in accordance with any contractual requirements. The contractor should implement and maintain the mass properties control program with the objective of meeting the space vehicle mass properties requirements. Qualified personnel shall be assigned the responsibility and authority to assure the establishment and maintenance of mass properties objectives and the effective planning and execution of mass properties control functions. The program level of effort shall be adequate to determine, control, and document the mass properties of the space vehicle, subsystems, and components. The mass properties control program includes all subcontractor items, associate contractor items, Government Furnished Equipment (GFE) items, as well as contractor furnished items.

4.2 DETERMINATION

The space vehicle mass properties shall be determined as required for all analyses requiring mass properties data such as performance analyses, stability and control analyses, and structural dynamic and loads analyses.

SECTION 5

5. DETAIL REQUIREMENTS

5.1 CONTROL PROGRAM

5.1.1 Mass Properties Control Plan

This practice recommends that a mass properties control plan be developed and implemented. Whether contractually required or deemed necessary by internal management, it is recommended that a mass properties control plan shall be developed and implemented. The objectives of this plan should be to:

1. Identify which mass properties must be controlled due to contractual, performance, control, or other requirements, consistent with a defined coordinate system per Reference 3.

2. Define the mass properties limits applicable to the space vehicle in verifiable terms.

3. Formulate an organized mass properties control program that can be effectively implemented early in the contract period to monitor mass properties and meet the space vehicle mass properties requirements. This plan should identify how the mass properties of the vehicle will be monitored, compared to mass properties limits, controlled, and verified.

5.1.2 Subcontractor Mass Properties Control

The contractor shall be responsible for overseeing the mass properties control of each subcontractor and vendor. In each procurement document for items which may affect the space vehicle mass properties, a mass properties control section shall be included to impose the applicable requirements of the mass properties control plan on the subcontractor or vendor.

5.1.3 Associate Design Subcontractors and GFE Suppliers Interfaces

Associate Design Activities and Government Furnished Equipment (GFE) Suppliers shall be responsible for the interchange of all the mass properties data needed to support the integration of sub-unit mass properties into the complete unit mass properties. They shall respond promptly to requests from the interfacing and integrating contractors for information required by the contractors.

5.1.4 Management Participation

High level management shall participate in the development and maintenance of the mass properties control program. Control of mass properties is proportional to the level of direct participation and support of high level management. High-level management emphasis on mass properties control encourages designers to consider the trade-off of light weight design and performance margins.

It is the responsibility of high level management to appropriately balance the requirements of cost, producibility, mass properties, performance, customer needs, and

other considerations on any space vehicle development. Experience has proven that neglect of any of these aspects, or excessive emphasis of some in lieu of the others often results in failure to meet critical requirements, costly redesign, schedule delays, and contract cancellations. For this reason, it is imperative that high level management:

1. Understand the ramifications of mass properties on vehicle performance, control, and meeting of customer requirements.

2. Actively participate in the up-front determination and setting of mass properties limits.

3. Clearly define the relative priorities of meeting conflicting requirements.

4. Review the status of all critical requirements on a regular basis, directing corrective measures as required.

5. Provide tangible incentives for engineering and manufacturing to meet mass properties control requirements.

Successful mass properties control requires early development of a balanced set of target priorities, consistent application of those priorities, management support for adequate status monitoring, and interactive management participation.

5.1.5 Mass Properties Limits

The contractor shall determine and document the mass properties limits. The mass properties limits shall include those established for system, subsystem, and component performance, as well as design requirements and the contractual mass properties limits.

5.1.6 Weight Growth

The contractor shall include in the weight data an allowance for the expected weight growth. The weight growth allowance should be depleted from the beginning to the end of the contract according to an approved plan. Weight growth allowances shall be identified in the contractor's mass properties records.

5.1.7 Basic Mass Properties

The contractor's space vehicle mass properties database shall be maintained by periodic updating using the most recent information from design data, drawings, mass properties measurements, GFE data, associate contractors, subcontractors, and vendors. These data should be updated frequently in the early developments phase; once per week is recommended. Less frequent updating is acceptable late in the development phase when mass properties changes are small; once per month is a recommended minimum. More frequent updating may be required during launch preparation.

For United States Government contracts, the contractor's selection of updating frequency is subject to the approval of the contracting officer. The updating frequency is not necessarily related to the frequency of submitting official mass properties reports.

5.1.8 Limit Monitoring

The contractor shall maintain a documented comparison of the predicted mass properties (See 3.4) and the limits discussed in 5.1.5. The comparison shall identify the current weight growth allowance. Mass properties uncertainties (See 5.2.6.2) should also be included and identified. Unless otherwise specified, limit mass properties should be compared to predicted mass properties with a specified level of uncertainties.

5.1.9 Corrective Action

For United States Government contracts, the contracting officer shall be notified immediately when the mass properties limits described in paragraph 5.1.5 are equaled or exceeded. The contractor shall advise the contracting officer of the resulting effects on system performance and recommend corrective action.

For Non-Government contracts or internal development, the program management and customer (if applicable) shall be notified immediately when the mass properties limits described in paragraph 5.1.5 are equaled or exceeded. The effects on system performance and recommended corrective action should be determined in conjunction with management and customer (if applicable).

5.1.10 Document Release

Personnel responsible for the contractor's mass properties control should approve documents controlling the design, manufacture, and procurement of system components, prior to release.

5.2 DETERMINATION

5.2.1 Changes

A documented accounting of all weight changes shall be maintained throughout the contract. For all weight changes the accounting shall include the magnitude of the change and the reasons for the changes. This accounting shall be updated when the mass properties are updated (See 5.1.7). Appendix D provides recommended weight change codes and a general description of the types of changes for each category. It is recommended that, as a minimum, the weight changes be gathered into these categories and accumulated throughout the Program.

5.2.2 Sequential Mass Properties

The space vehicle mass properties shall be determined and documented as a function of time or percent of steady state thrust from mission initiation through mission completion. Time increments should be selected based on requirements of other analyses or on significant mission events. All items that are expended, jettisoned, ablated, or moved during the mission shall be identified in the contractor's mass properties records.

5.2.3 Ground Operations Support

Adequate mass properties shall be developed and documented for the support of ground and launch operations. These data shall be in agreement with the actual vehicle configuration and with the planned loading and utilization of fluids and propellants.

The contractor's records of all changes to the space vehicle subsequent to final mass

properties measurements and the resulting mass properties shall be made available for review. For United States Government contracts, the resultant mass properties shall be made available for review by the contracting officer.

5.2.4 Postflight Analysis

Actual mass properties data should be determined by analysis of postflight data for significant mission events. Differences from the planned conditions should be itemized and explained.

5.2.5 Trade Studies

For United States Government contracts, the contractor shall maintain, available for the contracting officer's review, mass properties data developed for trade studies or other screening processes used in the design process.

5.2.6 Mass Properties Uncertainty Analysis

Knowledge is required of the accuracies of mass properties data used in space vehicle performance, stability, control, and structural analyses. This is true not only for the total space vehicle but also for elements of the space vehicle such as fluids, deployables, and independently moving parts. Mass properties approaching a limit may require an uncertainty analysis. In some cases, the accuracy of the combination of certain mass properties may be required.

5.2.6.1 Requirements for Uncertainty Analyses

Mass properties uncertainty analyses shall be conducted when mass properties dispersions are required for other analyses, or when the uncertainties may cause mass properties limits to be exceeded.

5.2.6.2 Contents

The uncertainty analysis should include a detailed analysis of each uncertainty source with a description of the derivation of the uncertainties. The uncertainties should include, but are not limited to, measurement uncertainties, manufacturing variations, environmental effects, and uncertainties derived or assumed for mass properties estimations or calculations.

For United States Government contracts, documentation of the uncertainty analysis shall be available for review by the contracting officer.

5.2.7 Verification

5.2.7.1 Requirements

The contractor shall verify each mass property and its conformance to the limits. Verification shall be accomplished by approved analytical methods, by test, or by a combination of both. The selection of the verification methods shall be justified by a documented and approved verification plan. The verification methods should be selected early enough in the program to provide time for the acquisition, modification, or preparation of measurement equipment (handling, fixturing and support equipment) and measurement sites. The verification plan shall also include the general procedures for the measurement tests. A guide for a verification plan is provided in Appendix A.

5.2.7.2 Procedures

Mass properties measurement tests shall be conducted in accordance with approved, documented procedures.

5.2.7.3 Notification of Measurement

The customer may require the witnessing of mass property measurements and tests. This requirement should be reflected in the procurement contract. Exceptions, e.g. weighing small hardware items, may be mutually agreed between contractor and customer. The contractor must give reasonable advance notification of a measurement or test to the customer. Minimum notice is considered to be one week prior to testing.

5.2.7.4 Test Conditions

The item should simulate the dry or wet flight condition as required by the intent of the test; and should be at least 95-percent complete by weight, excluding hazardous components or components not normally installed at the measurement site. A mass properties engineer shall verify and record the configuration of the item and record mass properties related data for all missing items, added non-flight items, and tare items.

As applicable, the mass properties engineer should assess and record all environmental conditions such as air movement, temperature, relative humidity, gas or fluid buoyancy effects, local gravity, local magnetic fields, RF interference, ground vibrations, A/C power stability, or other conditions which may affect measurements, and assess if accurate measurements can be achieved.

5.2.7.5 Data Records

The contractor should maintain mass properties verification data in a readily accessible form for verification of analytical data, and for resolution of investigative activities.

For United States Government contracts, mass properties verification data shall be documented and made available for review by the contracting officer.

5.2.8 Data Organization

The mass properties data should be organized and maintained by the contractor in accordance with the requirements stated in this recommended practice.

5.2.8.1 Functional Organization

To provide a uniform basis for mass properties comparisons, the space vehicle mass properties should be categorized on a functional basis. For example, the weights of all items that function primarily as the space vehicle structure should be accumulated for the total weight of the space vehicle structure. Appendix B provides a discussion of the need for a functional breakdown and guidelines for the functional categorization of the component weights. In order to achieve function weight breakdown consistency, the contractor should use the guidelines in Appendix B.

5.2.8.2 Sectional Organization

When the space vehicle is comprised of sections for which analytical isolation of the section mass properties is required, the mass properties data for the sections shall be developed separately. Examples of this include a propulsive vehicle having more than

one stage, or an independently movable section of a space vehicle. The functional organization should be maintained within the mass properties data of each section.

5.2.8.3 Government Furnished Equipment

For United States Government contracts, the contractor's mass properties records shall have a separate tabulation of all Government Furnished Equipment.

5.2.8.4 Correlation of Weights and Part Numbers

The contractor's mass properties records shall include the correlation of weights with their respective drawing numbers. This shall be done at a level of detail that permits the determination that the weights of all items on the space vehicle have been included correctly.

5.2.8.5 Basis of Mass Properties

The basis of space vehicle mass properties can be categorized by the methods used for their determination, for example: estimated, calculated, or measured. The measured category has historically been called "actual." The percent of the space vehicle weight that is based on each of these categories is an indication of the confidence that can be placed in reported mass properties data. Mass properties determined from preliminary data such as sketches or calculations from layout drawings are typically considered to be in the estimated category. Mass properties determined from released drawings are typically considered in the calculated category. Mass properties determined by measurement or by comparison of nearly identical components for which measured mass properties are available are in the measured category. When ambiguities occur, the most representative category should be used, keeping in mind that the purpose of this categorization is to provide an indication of the confidence of the reported mass properties. The basis (estimated, calculated, measured, etc.) of each component weight shall be included as part of the recorded component data. As many categories as is necessary to accurately define the status of the mass properties may be used. Totals of each of these categories shall be recorded to provide an indication of the mass properties confidence at the subsystem level and for the complete vehicle.

5.3 DOCUMENTATION SUMMARY

This section describes mass properties reports and documentation that are generally required as contract deliverables in the Contract Data Requirements List (CDRL) for United States Government contracts. They may also be contractually called out on a Subcontract Data Requirements List (SDRL) for contracts supporting a United States Government prime contractor. The CDRL, or SDRL, (incorporated into the contract) may require that these plans be delivered to, or approved by, the contracting officer, customer, or prime contractor.

Although the documents in this list pertain primarily to United States Government contract deliverables, documentation of similar content should also be considered, as applicable, for commercial or company internal space vehicle development programs. For such commercial ventures, the term “shall” may be replaced by “should” in the following subsections, as applicable for the customer, management, and engineering requirements of the program.

5.3.1 Mass Properties Control Plan

A Mass Properties Control Plan in accordance with Section 5.1.1 shall be developed and documented by the contractor. This report shall state the management program and procedures to be used for mass properties control and verification during the various procurement phases.

5.3.2 Verification Plan

A Verification Plan that describes and substantiates the methods to be used to verify the mass properties data (See 5.2.7.1) shall be developed and documented by the contractor.

5.3.3 Status Report

A Mass Properties Status Report that includes the elements described in the following subparagraphs shall be developed and documented by the contractor.

5.3.3.1 Mass Properties Summary

The following Mass Properties Summary description applies for each section of the space vehicle as discussed in 5.2.8.2. The predicted mass properties shall be tabulated by subsystem and combined for the total predicted mass properties. Items that are ablated, expended, or jettisoned shall be so noted. Each section's total predicted mass properties and the space vehicle total predicted mass properties shall be presented for the launch condition. For each weight item reported, the basis used shall be indicated (See 5.2.8.5). This may be done by percentages.

5.3.3.2 Mass Properties Limit Monitoring

As described in 5.1.8, a comparison of the predicted mass properties and the mass properties limits shall be documented.

5.3.3.3 Changes

As described in 5.2.1, all weight changes incorporated since the previous Status Report shall be documented. Each weight change in the accumulated weight changes should be assigned a weight change code as recommended in Appendix D, and should be documented.

5.3.3.4 Potential Changes

All pending or potential weight changes shall be documented.

5.3.3.5 Sequential Mass Properties

As described in 5.2.2, the sequential mass properties shall be documented.

5.3.3.6 Government Furnished Equipment (GFE)

As described in 5.2.8.3, a tabulation of GFE and the associated mass properties shall be documented.

5.3.3.7 Reference Axes

A diagram shall be prepared which relates the location and orientation of the reference axis system used for mass properties determination to the space vehicle. The exact location of the reference axis system origin with respect to the vehicle shall be noted on the diagram. If the space vehicle is comprised of more than one section, and each

section has a different reference axis system, each system shall be similarly described. Their mutual relative locations and orientations shall also be described.

5.3.3.7.1 Recommended Practice

Guidelines for reporting the mass properties of flight vehicles are provided by the Society of Allied Weight Engineers (S.A.W.E.) Recommended Practice 6 (see Reference 3).

5.3.3.8 Weight Growth

The current status of both the weight growth allowance and the weight growth depletion plan (See 5.1.6) shall be documented.

5.3.4 Detail Mass Properties Report

A Detail Mass Properties Report that includes the elements specified in 5.3.3 plus the elements described in the following subparagraphs shall be developed and documented by the contractor. The Contract Data Requirements List (CDRL), incorporated into the contract, may require this report to be delivered to or approved by the contracting officer.

5.3.4.1 Detail Weight Statement

The detail weight statement shall tabulate the basic weights by subsystem (See 5.2.8) to a level of detail as described in paragraph 30.2 of Appendix B.

5.3.4.2 Design Data

These data include the design parameters that have major impacts on subsystem weights. The information is useful for evaluating weights in the early design phase and also for improving weight estimating methods. Appendix C presents a list of design parameters to be used as a guide for reporting the data.

5.3.5 Miscellaneous Mass Properties Report

A Miscellaneous Mass Properties Report that includes the mass properties data associated with contract change proposals, fluid and propellant verification, or current operational data (See 5.2.3) shall be developed and documented.

APPENDIX A - MASS PROPERTIES VERIFICATION PLAN

This Appendix is a mandatory part of the recommended practice.

10. SCOPE.

This Appendix is a guide for preparing a Mass Properties Verification Plan. The purpose of the Verification Plan is to provide a document which engineering, management, and the customer can use to review planned methods for verifying the space vehicle mass properties. This review should assess the acceptability of the planned methods and accuracies, availability of company and vendor resources to support the verification, the availability of acceptable mass properties measurement equipment, (handling, fixturing and support equipment) and any safety concerns.

For United States Government contracts, the purpose of the Verification Plan is to provide a document that the contracting officer can use to review the contractor's planned methods for verifying the space vehicle mass properties. This review includes assessing the acceptability of the planned methods and the availability of acceptable mass properties measurement equipment, (handling, fixturing and support equipment) and measurement sites.

20. REFERENCED DOCUMENTS

SAWE Recommended Practice Number 6, “Standard Coordinate Systems for Reporting the Mass Properties of Flight Vehicles”.

30. REQUIREMENTS.

30.1 Selected Methods Description

The Verification Plan shall include a general description of the method selected to verify each mass property that is to be used in performance analyses, stability and control analyses, or other analyses which require mass properties data as an input. The element of the space vehicle for which the mass properties data have been developed shall be described. For example, if the mass moments of inertia about the hinge line of a deployable element have been specified or established by design limits, the Verification Plan shall describe the element being deployed and state if the mass moment of inertia is to be verified by test or analysis. If a combination of methods is planned, state the portions to be verified by each method.

30.2 Substantiation of Method Selection

Analyses shall be made to substantiate the methods selected to verify the mass properties. Technically logical explanations of the methods selected, particularly for analytical verifications, shall be included in the contractor's substantiation of the methods selected.

30.3 Test Plans. General test plans shall be prepared. The plans shall include a description of the item or items to be tested and the mass properties limits. A general description of the testing equipment, along with its accuracy and calibration schedule, shall be included. A test schedule showing the planned test site, planned schedule, and articles to be tested shall be included.

APPENDIX B - FUNCTIONAL BREAKDOWN OF WEIGHT

This Appendix is a mandatory part of the recommended practice.

10. SCOPE

Space vehicles are comprised of subsystems that perform specific functions. Examples of two subsystems are structural support for equipment and electrical power. Useful subsystem information is generated when component weights are accumulated on a functional basis. The uses of functional subsystem weights include the tracking of functional weight during design, for weights proposed for new vehicles, and the improvement of the database used for the refinement of weight-estimating methods. It is necessary to strive for consistency regarding which components comprise each subsystem if the objectives of subsystem weight estimation and evaluation are to be achieved. Consideration should also be given to the configuration for which actual weight data will be obtained. The following sections provide guidelines for achieving this consistency.

20. REFERENCED DOCUMENTS

JSC-23303 "Design Mass Properties, Guidelines and Formats for Aerospace Vehicles", dated March 1989, (NASA Johnson Space Center)

30. REQUIREMENTS.

30.1 Establishment of a Subsystem List

In accordance with Section B10, wherein the functional basis is discussed, a list shall be established which names each of the subsystems comprising the space vehicle. Since the term "space vehicle" is representative of a large variety of vehicles with a wide range of complexities, specifying a comprehensive subsystem list in this Appendix is not considered advisable. However, two subsystem lists are given in Tables B-I and B-II that are intended to serve as guides. Additional guidelines can be found in JSC 23303. The contractor shall develop a subsystem list suitable for the space vehicle being developed. This contractor's list shall contain subsystems in at least as much detail as represented in Tables B-I and B-II.

30.2 Subsystem Breakdown

30.2.1 Second Level of Detail

Each subsystem total weight shall be broken down to a second level of detail. This second level of detail shall be constructed to provide useful information for weight estimation and evaluation. For example, useful information is provided when a satellite electrical power subsystem is broken down into components of solar array, batteries, and power conditioning. Representative subsystem breakdowns to a second level of detail are shown in Tables B-I and B-II. The contractor shall establish the applicable second level weight breakdown and it shall be at least to the level of detail represented in Tables B-I and B-II.

30.2.2 Subsequent Levels of Detail

A breakdown of the second level of detail to a third level may be useful. Examples of this are shown in Tables B-I and B-II. As in the case of the second level of detail, the third level may be needed for weight evaluation and estimation. The Contract Data Requirements List (CDRL), incorporated into the contract, may require the contractor's subsystem list, the second-level-of-detail list, and any subsequent level-of-detail lists,

be prepared for review and approval by the contracting officer.

30.3 Functional Coding

The contractor shall develop a functional code that is consistent with the subsystem list and level of detail lists described in Sections 30.1 and 30.2 of this Appendix B. The code format is not specified. As weights are determined they shall be coded and accumulated by the codes.

30.3.1 Ambiguities

In the process of coding items to a function, ambiguities are likely to occur. For example, a solid propellant motor case may have two functions; propulsion and basic structure. A cylindrical portion of a motor case may be partially designed by the loads produced by the payload the launch vehicle carries and partially designed by the case internal pressure. The domes are designed by the internal pressure` and the motor case skirts are designed by axial and bending loads. Another example would be the structure used to support the solar cells on a deployable solar array panel. Arguments can be made for either a structure or electrical power functional code. The numerous small equipment support provisions can be coded to either structure or the function of the equipment supported. Similar ambiguities arise in the case of wiring, plumbing, or thermal doublers.

30.3.2 Resolution of Ambiguities

For those items that have more than one function, the contractor should code them to the primary function. If the choice is not obvious, the contractor may make an arbitrary decision.

For United States Government contracts, when arbitrary decisions are made for items constituting at least 10 percent of the subsystem weight, the contractor shall maintain descriptive titles in the mass properties records of the space vehicle. This permits the transfer of these items from one function to another at the discretion of the contracting officer.

TABLE B-I

SAMPLE FUNCTIONAL BREAKDOWN (SATELLITE)

1. Payload

2. Structure
   - 2.1 Basic Structure
     - 2.1.1 Main Truss
     - 2.1.2 Equipment, Bulkheads, and Platforms
     - 2.1.3 Kick Motor Support Cone
   - 2.2 Secondary Structure
     - 2.2.1 RCS Tank Supports
     - 2.2.2 Momentum Wheel Supports
     - 2.2.3 Solar Array Retention Fittings
   - 2.3 Adapter, Separation
   - 2.4 Mechanical Integration (hardware, clips, misc.)

3. Thermal Control
   - 3.1 Louvers
   - 3.2 Heat Pipes
   - 3.3 Insulation
   - 3.4 Surface Mirrors, Paint

4. Electrical Power
   - 4.1 Solar Array
     - 4.1.1 Power Source
     - 4.1.2 Substrate
     - 4.1.3 Drives
   - 4.2 Converters
   - 4.3 Power Switches
   - 4.4 Electrical Integration (harness, connectors, hardware, misc.)

5. Guidance, Navigation

6. Data Management

7. Telemetry, Tracking, Command

8. Orientation Control

9. Reaction Control

10. Propulsion

11. Weight Growth Allowance

12. Fluid

TABLE B-II

SAMPLE FUNCTIONAL BREAKDOWN (Liquid Propulsion Stage)

1. Structure
    - 1.1 Fuel Tank
        - 1.1.1 Domes
        - 1.1.2 Cylinder
        - 1.1.3 Skirts
        - 1.1.4 Anti-slosh Devices
    - 1.2 Oxidizer Tank
    - 1.3 Intertank Structure
    - 1.4 Thrust Structure
    - 1.5 Launch Supports

2. Thermal Control

3. Main Propulsion
    - 3.1 Rocket Engine
        - 3.1.1 Thrust Chambers
        - 3.1.2 Pumps
        - 3.1.3 Engine Systems
    - 3.2 Fuel Feed
    - 3.3 Oxidizer Feed
    - 3.4 Pressurization
    - 3.5 Fill, Drain, Vent

4. Orientation Control (Thrust Vector Control)

5. Secondary Power
    - 5.1 Electrical
    - 5.2 Hydraulic

6. Instrumentation

7. Range Safety and Abort

8. Weight Growth Allowance

9. Fluids
    - 9.1 Impulse Propellant
    - 9.2 Residual Propellant
    - 9.3 Reserve Propellant
    - 9.4 Bias Propellant
    - 9.5 Outage Propellant
    - 9.6 Pressurization Gas

APPENDIX C - DESIGN DATA

This Appendix is a mandatory part of the recommended practice.
The contents are intended for guidance and information only.

10. SCOPE

This appendix is a guide for reporting design parameters that have major influences on space vehicle subsystem weights.

20. REFERENCED DOCUMENTS

(Not Applicable).

30. MAJOR REPORTING PARAMETERS

The following categories of data are useful for evaluating subsystem weights during the early design phase and for the improvement of weight estimating techniques.

30.1 Unmanned Satellite

a. Vehicle sketch giving major dimensions and the reference coordinate system
b. Design Life
c. Electrical power subsystem description (solar array, battery)
   - Solar array area, cell thickness, cover glass thickness, substrate type, and materials
   - Battery type, depth of discharge, capacity
   - Bus voltage, number of buses, number of battery cells
d. Attitude Control
   - Type (momentum, magnetic, mass expulsion, etc.)
   - Pointing accuracy, slew angles, and rates
e. Propulsion Subsystem - for maneuvering or orbit changes
   - Propellant Type
   - Pressurization Method
   - Number of tanks and tank size
   - Number of thrusters and thrust rating
   - Total Velocity Increment
f. Thermal Control
   - Type (Paint, insulation, louvers, heat pipes, refrigerators)
   - Radiator Area
g. Structure
   - Material Type(s)
   - Construction Type(s) (Monocoque, Skin/Stringer, etc.)
h. Payload

30.2 Liquid Propellant Stage

a. Vehicle sketch giving major dimensions, tank geometry, etc. and reference coordinate system
b. Structural materials and types
c. Tank design pressures and volumes
d. Safety factor
e. Structural design conditions, loads
f. Engine data
   - Thrust, Specific Impulse (Sea Level and Vacuum)
   - Expansion Ratio
   - Chamber Pressure
   - Throttling Ratio
   - Number of Engines
   - Number of Starts
   - Throat Area
g. Propellant type, mixture ratio by volume or weight, densities
h. Payload

30.3 Solid Propellant Stage

a. Vehicle sketch giving major dimensions and the reference coordinate system
b. Chamber pressure - average and maximum expected
c. Safety factor
d. Case structural material, number of segment joints
e. Burn time
f. Nozzle materials, throat area, expansion ratio(s)
g. Thrust vector control type
h. Propellant density, loading fraction
i. Specific impulse - sea level, vacuum
j. Payload

30.4 Reentry Vehicle

a. Vehicle sketch giving major dimensions and the reference coordinate system
b. Lift-to-drag ratio
c. Thermal protection system type
d. Wetted area (total)
e. Pressurized volume
f. Mission duration
g. Structural materials and types
h. Wing span, root chord length and thickness, plan area (define)
i. Safety factor
j. Ultimate load factor and associated weight
k. Stabilizing and control surface areas
l. Landing system type (parachute, retro-rockets, etc.)
m. Propellant type, mixture ratio, densities
n. Reaction control system type, propellant type
o. Auxiliary propulsion system type, propellant type
p. Crew size
q. Payload

APPENDIX D - Weight Change Codes and General Description

This Appendix is a mandatory part of the recommended practice.
The contents are intended for guidance and information only.

Code	Description
1	**Better definition of the design** (Design maturation) As the design progresses beyond the proposal stage the design criteria and requirements become better defined and assumptions made during the proposal cannot be justified. These changes are generally early in the program, but prior to drawing release.
2	**Out of scope changes** These are new scope changes caused by the customer adding or changing the requirements for the contracted vehicle beyond that of its original proposal.
3	**Redesign** When the original component or subsystem design criteria need to be changed due to: repackaging, failure of a component during testing, impact of other subsystem changes, etc.
4	**Maturing component design** Improvements in weight analysis due to updates in drawings after original release. (Item #1 generally relates to weight analysis prior to drawing release.)
5	**Error in previous estimate** The reason for change is an error in the weight calculations for an original or later estimate.
6	**Uncontrolled vendor changes** If none of the other change codes apply then this category is a catch all for vendor weight changes, over which you have had very little control.
7	**Weight reduction activity** Changes due to formal weight reduction activity.
8	**Measured vs. calculated** The differences caused by actual measured weights of components as opposed to the latest calculated value.
9	**Cost reduction, added weight** Where weight increases were incurred to save money, i.e., substitution for expensive exotic materials, machinery costs reduced by eliminating elaborate machined parts and cutouts, etc.