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WEIGHT AND BALANCE CONTROL FOR GUIDED MISSILES

Prepared by
Government - Industry Workshop
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SAWE RECOMMENDED PRACTICE

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Recommended Practice

RP-9

Weight and Balance Control System for Guided Missiles

1. This SAWE recommended practice provides guidelines for monitoring, controlling, and reporting mass properties of missiles.
2. This SAWE recommended practice is based on Reference 2.1.1 (MIL-STD-3947B), and incorporates the updates that were proposed for Rev. 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 forwarded to the Executive Director at the above address.

Recommended Practice

RP-9

WEIGHT AND BALANCE CONTROL SYSTEM

FOR

GUIDED MISSILES

1. SCOPE

1.1 Purpose

This recommended practice requires the establishment of a weight and balance control system to provide for the management of mass characteristics programs and to facilitate the preparation and submission of data as specified herein. The term "Weight and Balance" as used herein is intended to include terms relating to mass and mass properties. This document is derived from Reference 2.1.1 to serve as a continuing, maintained, industry recommended practice. As such, it contains practices which are applicable primarily to United States Government guided missile development and acquisition programs.

1.2 Classification.

The vehicles for which the requirements apply (but are not limited to) are of the following categories:

1.2.1 Guided Missiles and Vehicles.

Surface to Air, Air to Surface, Surface to Surface (Ballistic Type), and Air to Air Guided Missiles and combinations thereof (such as Underwater to Air types). Expendable Unmanned Aerial Vehicles (UAVs) are also included.

1.2.2 Other

Configurations not covered in the above categories but for which the system requirements may be adaptable to include : smart bombs, projectiles, etc. This recommended practice covers mainly Endo-atmospheric missiles and vehicles but Exo-atmospheric is not excluded.

2. REFERENCED DOCUMENTS

The following specifications and recommended practices of the latest issue are herein referenced for this Recommended Practice.

2.1 MILITARY SPECIFICATION

This Recommended Practice is based on the following Military Specification: MIL-STD-3947B, "Weight and Balance Control System for Guided Missiles and Space Launch Vehicles"

2.2 RECOMMENDED PRACTICE

The following SAWE Recommended Practices form a part of this Recommended Practice.

2.2.1 SAWE Recommended Practice Number 6, "Standard Coordinate Systems for Reporting the Mass Properties of Flight Vehicles"

2.2.2 SAWE Recommended Practice Number 10, "Weight and Balance Data Reporting Forms for Guided Missiles and Space Launch Vehicles"

3. REQUIREMENTS

3.1 Procedure Certification. During pre-award negotiations or immediately following the contract award, representatives of the prime contractor and/or associate contractors shall consult with the procuring agency in modifying and certifying the procedure for the management of an overall mass characteristics program. Additionally the contractor's plan for meeting the design objectives will be reviewed and agreed to by the procuring agency.

3.2 The prime contractor or system contractor shall be responsible for insuring that all associate and subcontractors provide a high degree of weight and balance control for their respective systems and that there is an appropriate interchange of data to support the integration of sub-units into the complete system. The prime contractor shall also be responsible for correlation of the reference systems (reference datum), and systems of units, of all associate contractors to ensure that the balance calculations have been properly integrated for the complete vehicle.

3.3 Personnel and Equipment. For all contracts requiring compliance with RP-9 the contractor shall establish and maintain a weight and balance control system by:

3.3.1 Assigning technically competent Mass Properties personnel who shall have responsibility for fulfilling the requirements of this Recommended Practice.

3.3.2 Providing necessary equipment and measuring devices essential to mass property determination.

3.4 Weight and Balance Control Data.

3.4.1 Submission of Data. The submission and type of data shall be in accordance with Table I and II for the applicable type of contractual program including feasibility study, proposal, experimental, prototype, production, and operational phases. All data shall be submitted for acceptance by the procuring agency except Status Reports which are submitted for information. Required data shall be in the possession of the procuring agency on or before the date specified. The schedule or interval of the submission for Actual Weight Reports shall be determined by the procuring agency based on the quantity of vehicles under contract and the rate of delivery. Generally, a report is required every four months on production contracts. The number of copies and distribution shall be as specified by the procuring activity. Weight Reports are titled as follows:

(a) Estimated, (b) Calculated, (c) Status, (d) Actual, (Detail and Intermediate).

Operational Weight Data are titled (a) Pre-Flight Weight Report, (including Loading Data and Check-Off List), (b) Post-Flight Weight Report, (c) Propellant Loading Weight Report, (d) Field Weight Coordination System and (e) Critical Performance Weight Error Analysis.

3.4.1.1 Specification Weight Derivation. During the negotiation stage of preparing a contract detail specification, the contractor shall furnish a running derivation of the vehicle weight for each draft of the specification until the weight status of the final draft is represented. The running derivation shall be based on the design proposal (on prototype or actual data when available) and shall be furnished on the Status Report weight changes involved. A list of weights of Government Furnished Equipment upon which the weights are based shall be attached.

3.4.2 Detail Requirements.

3.4.2.1 Title Page, Index of Contents and Forward. Include date of preparation, model, contract number, report number, contractor's name, preparer's name, approval signatures and titles, and applicable serial numbers (contractor's and government).

3.4.2.2 Summary. Table-Summarize the weight center of gravity, balance calculations, and inertias for weight empty, gross weight at lift off or launch and other important discrete points of the flight profile.

3.4.2.3 Summary Weight Statement (RP-10 Part I) Fill in as required. (See RP10, paragraph 5.1.1 through 5.1.1.3).

3.4.2.4 Detail Weight Statement (RP-10 Part II) Fill in as required including Appendix I. (See RP10, paragraph 5.1.2 through 5.1.1.14).

3.4.2.5 Weighing Data Sheet. Provide a table showing the scale readings, tare, net weight, arm and moment for longitudinal, vertical and lateral center of gravity. Provide a list of the items to be added or subtracted from the "as weighed" condition as entered in the actual weight empty determination. A diagram shall be provided showing

the pertinent dimension of the scale reactions with respect to the reference datums. Provisions shall be made for the signature of a Government witness. A photograph may be included with appropriate explanation of the procedure used. When approved by the procuring agency, the actual weight and center of gravity may be determined for each section of the vehicle in lieu of obtaining the actual weight and center of gravity of the complete assembly. Weighings shall provide for the determination of the weight empty. It is preferable to make all weighings with the vehicle completely assembled and in the dry condition (in liquid systems - before the fuel and oxidizer systems have been filled). All mission load items, insofar as practicable, shall be removed for weight empty weighings. Weights shall be determined by taking the average of readings from three independent operations with a complete upset and unloading of the weighing equipment. The lateral or vertical (Y or Z axis) center of gravity may be determined by calculations when size or configuration makes determination by physical means impracticable.

3.4.2.6 Derivation of Contractor Responsibility Under or Overweight. This derivation shall be determined from the following tabulation:

- (a) The weight Guarantee.
- (b) The weight increases or decreases due to the total weights of authorized changes, pending changes and the net under or overweight of the Government Furnished Equipment.
- (c) The guarantee as modified by (2) above.
- (d) Comparison of the actual weight with the revised guaranteed weight derived in (3) above to obtain the contractor responsibility under or overweight.

The under or overweight for a contract shall be taken as the average of the under or overweight values of weight empty as shown by the Actual Weight and Balance Reports submitted in accordance with contractual requirements.

3.4.2.7 Balance Calculation. Show longitudinal, vertical and lateral balance calculations for weight empty, mission loads and all phases of gross conditions of the flight profile. The balance calculations shall be tabulated when practical in the same sequence and order shown on the Weight RP-10 Part II. Intermediate Reports need not include the detail balance calculations for RP-10 Part II. The longitudinal moment axis (X) shall be so located that all moments will have the same sign; and it shall be dimensioned from a convenient fixed point on the vehicle. Balance calculations for the vertical or lateral (Y or Z axis) center of gravity (or for vehicles which are symmetrical about one or more axis) may include only those items which are non-symmetrical about the axis of symmetry. Refer to 2.2.1, SAWE RP-6.

3.4.2.8 Authorized Changes. All Authorized Changes to weight empty or mission load applicable to a report shall indicate the weight group to which the weights are allocated. Incorporated pending changes shall also be listed separately. Changes shall be identified by contract change designations and by subject.

Engineering Change Procedure (ECP), Engineering Change Order (ECO), numbers, etc., or correspondence references may be used for pending changes. The definition of authorized changes may differ with the procuring agency, however, in general a change to guarantees will not be allowed unless it is over and above the requirements or the contract specification.

3.4.2.9 Government Furnished Equipment. Provide a tabulation of the specified weight of all Government Furnished Equipment for the Estimated and Calculated Reports. For Actual Weight Reports, tabulate the actual weights of this equipment and determine the net under or overweight.

3.4.2.10 Drawings, Solid Models, and Interface Control Documentation. Provide views in elevation and plan locating and identifying the following (Inboard Profile and General Arrangement Drawings may be used if the following are included):

(a) Principal structural stations of the body, wings and stabilizing surfaces, including location of the sectionalization joints provided for shipping and handling purposes.

(b) Sections of the missile as sectionalized for shipping and handling, identified by capital letters and descriptive names.

(c) Reference datum for the longitudinal, vertical, and lateral moment arms.

(d) Locations of jig, leveling, handling and weighing points giving 3-axis coordinate reference to location.

(e) Longitudinal, vertical, and lateral scales dimensioned from each reference datum.

(f) Thrust line (or cone) for each propulsion unit and reaction type control, including maximum angle of variation in the thrust.

(g) Major items of equipment, fuels and/or propellants.

(h) Significant lengths, heights, widths, and diameters.

(i) Major equipment, main engines and supports, control devices, propellant systems, armament and auxiliary power units.

(j) Types of construction and materials used in each major structural section and tanks.

3.4.2.11 Appendices to Actual Weight and Balance Reports. These appendices shall reflect all modifications subsequent to the actual weighing and prior to delivery. The data shall include a detailed tabulation of modifications made in the above specified period including their effect on the actual and guaranteed weight and balance and the contractor responsibility under or overweight.

3.4.2.12 Sectionalized Weight Data. When the Vehicle is sectionalized for shipping and handling, the following data shall be furnished:

A tabulation by sections of structure and all items of equipment therein including weights, arms and moments (longitudinal, vertical and lateral). Equipment not included in the above shall be listed under a "miscellaneous" items to arrive at the total weight and moment of each section as prepared for shipping or handling.

3.4.2.13 Status Reports (RP-10 Part III) Fill in as required (See RP10, paragraph 5.1.3).

3.4.2.14 Substantiating Data. These data shall include analytical, statistical and empirical methods as used by the contractor to justify his design and weight derivations. It is to be furnished primarily for study and proposal phases. For airborne systems, weights shall be given for all elements of the system. When proposed for specific aircraft (or other launch vehicles) installation, the effect of the weights of the fixed and expendable elements on the normal extreme balance conditions of the vehicle shall be derived.

3.4.2.15 Tolerance and Dispersion Data.

When required by the procuring agency:

(a) Submit system tolerance requirements based on an assessment of the requirements of each sub-system (Weight, C.G., MOI, POI, Principal Axis Angles, Perpendicularity, dynamic consideration, etc.).

(b) Submit a summarized statistical analysis showing the degree of accuracy of the weight, c.g. location, mass moment and products of inertia and the computation method employed.

(c) A statistical error analysis of the physical measuring methods or procedure employed in ascertaining the actual mass characteristics shall be prepared (and referenced in the Actual Weight Reports) prior to implementation with substantiation as to cost, method of calibration, etc.

(d) Submit statistical compilation of actual measured values for R&D and Operational (Weight root sum squared, etc.).

3.4.2.16 Moments of Inertia Data.

- (a) A table summarizing the estimated and calculated mass moments and product of inertia about the roll, pitch, and yaw center of gravity axis shall be provided for all gross weight and critical flight conditions. The format shall be patterned after the RP-10 weight breakdown (as practicable) and shall be included in the Estimated & Calculated Weight Reports.
- (b) Sequenced mass properties shall be shown by curves showing burn time vs weight and mass moments and products of inertia about the roll, pitch, and yaw axis passing through the instantaneous c.g. shall be included with the Estimated, Calculated, Actual, and Status Reports.
- (c) Physical measurement of the missile mass moments and products of inertia shall be made and summarized in the Actual Weight Report when required by the procuring agency. Measured values should reflect launch conditions insofar as is practical.

3.4.2.17 C.G. Limits for Stability and Control. Contractor shall determine and publish the C.G. limits for providing satisfactory stability and control during the flight profile of the vehicle.

3.4.2.18 Weight Summary for Performance Analysis. Appendix II to RP-10 - To be submitted when required by the procuring agency (See RP10, paragraph 6).

3.4.3 Operational Weight Data

3.4.3.1 Pre-Flight Weight Report. In order to provide weight and balance information to the test activity concerning the specification and as delivered condition of the missile, the Pre-Flight Weight Report shall include the items indicated in Table II. Items required in the Pre-Flight Weight Report by Table II and not previously covered in the specification are as follows:

- (a) Check List of removable equipment items, weights, arms, and moments included in the empty weight.
- (b) Longitudinal, vertical and lateral gross weight balance calculations covering each mission load condition, and discrete points of the flight profile.
- (c) Curves showing weight, center of gravity and percent of fuel or propellants consumed versus flight time.
- (d) Tabulation of weights, arms and moment data on the following for the "as delivered" condition of the missile. These data shall be detailed sufficiently to enable test activity personnel to identify all components of the items.
 - (1) Test and other equipment installed, but not part of the specified configuration.

- (2) Missing items of the specified configuration.
- (3) Ballast installed, and information indicating its function.

3.4.3.2 For the more complex systems, additional requirements will be specified by the procuring agency for performance oriented mass characteristics data such as Post-Flight Weight Reports, Error Analysis data dealing with Critical Performance Weight, detailed Propellant Loading Weight Report and Field Weight Coordination Plans. The general purpose and content of these reports is stated briefly herein whereas detail format and contents will be determined during the procedure certification required under paragraph 3.1.

(a) Critical Performance Weight Error Analysis. The purpose is to develop by analysis the Critical Performance Weight Uncertainties which will be used in association with nominal trajectory dispersion studies and permit determination of those sources of error which are large enough to warrant test verification of weight nominal and uncertainties or to warrant the use of operational "red-lines". It shall generally describe the derivation of each measured, calculated or assigned sigma variation, state each uncertainty derived together with its assumed nominal and describe the selection of error sources.

(b) Post-Flight Weight Reports. The purpose of this report is to verify the Critical Performance Weight inputs used in pre-flight planning, to determine modifications needed in Critical Performance Weights for succeeding flights and to provide the capability for post-flight trajectory reconstruction. It shall generally document the weight conditions of the launch and flight test including an evaluation of the Critical Flight Performance Weights and uncertainties experienced.

(c) Propellant Loading Weight Report. The purpose is to present, for all propellant and fluid systems, complete data needed to determine parameters and procedures for pre-flight and post-flight evaluation of loaded, beginning, and unexpended weights. It shall contain volumes (minimum, usable, trapped, unusable, etc.), describe loading procedures and list gas constants (R) and propellant and liquid densities versus temperature and pressure.

(d) Field Weight Coordination Plan. The purpose is to enable the Contractor to establish a system to assure that the weight, balance and inertia characteristics of the vehicle are maintained in a current status and reported in a timely manner during research and development and operational phases. It shall provide for continuous Critical Performance Weight inputs for trajectory simulations and targeting parameters during the development and operational phases and be designed such that it may be executed by either the military user or some other agency of the government.

3.5 Deviations. The requirements of this specification shall not be deviated from unless written approval is obtained from the procuring agency. Specific deviations should be determined during the Procedure Certification (Paragraph 3.1) and Tables I and II modified accordingly.

3.6 Proposed Changes. The data listed below shall be furnished as an enclosure with engineering change proposals, and resubmitted or summarized in all proposed contract changes of amendments, which affect the weight or balance of the missile. Balance calculations shall be based on the latest Weight and Balance Status Report of the most recent Actual Weight and Balance Report.

- (a) The change in guaranteed weight empty mass properties.
- (b) The change in mission load and moment for the principal loading conditions in the contract detail specification.
- (c) Weight breakdowns prepared in reasonable detail substantiating the changes in weight empty and mission load. The weight report on which the weight breakdown is based shall be referenced. Weights of Government Furnished Equipment (GFE) items deleted shall be the specified (nominal) weights on which the current guaranteed weight empty is based. The weights of GFE items added, upon which the revised guaranteed weight empty will be based shall be listed specifically. In any case where the change in guaranteed weight empty will differ materially from the change in predicted weight empty, due to difference between specified and predicted weight of GFE for other reasons, appropriate comment shall be included, calling attention to and indicating the magnitude of the changes in weight and center of gravity.
- (d) When a proposed change involves a large center of gravity shift, information to justify that center of gravity limits will not be exceeded shall be submitted.
- (e) When a proposed change involves a major modification of one missile or group of missiles, the data required above shall be submitted in the form of a brief weight report deriving the calculated and guaranteed weight and balance of the modified missile, mission load, and the extreme balance conditions of the missile gross weights.

3.7 Extension of contract for additional quantity. If an additional quantity of the same type of missile without major changes is procured on an extension to a production contract, the schedule of intermediate reports shall automatically be extended to include the additional quantity. The Actual Weight and Balance Report for the last missile of the original quantity shall be furnished for each of the missiles of the extended quantity.

3.8 Major modification of missiles. If a contract is amended to provide for a major modification of one missile or group of missiles, an "Intermediate Report" shall also be submitted for the first modified missile, and shall include weight statement details and balance calculations as necessary to show differences over the detailed data furnished for the basic missile.

4. QUALITY ASSURANCE PROVISIONS

4.1 General. The Government shall certify the correctness of vehicle actual mass properties determination. This agency shall also ensure that the measuring and testing equipment requirements are adequately fulfilled. The cognizant representative of the procuring activity shall also comment in appropriate detail on all weight estimates and discussions submitted in correspondence concerning proposed contract changes or amendments.

4.2 Final Approval. Final approval shall be obtained from the procuring activity.

5. PREPARATION FOR DELIVERY.

5.1 Packaging and packing. Weight and balance control data shall be packaged in such a manner that it will not be damaged in transit by common carrier.

5.2 Marking of shipments. All weight and balance control data shall be marked and transmitted in accordance with the security regulations of the procuring activity.

6. NOTES

6.1 Intended Use. The data required by this specification are intended for use in formulating, and improving guided missile weight estimating methods, in evaluating the weights of new guided missile proposals, and for controlling the weight and balance during design, construction, and service operations.

6.2 Ordering Data.

6.2.1 Procurement Document should specify Title, Number and Date of this specification.

6.3 A change page shall be used to identify changes, with respect to the previous issue.

Table I. Weight and balance data requirements for study and proposal phase

(Items may be added, modified, or deleted as negotiated between the contractor and procuring agency)

Item	Para. #	Estimated Report	Status Report
When submitted		Studies – At completion of contract	For studies – Bi-monthly beginning immediately after contract award and during the course of the contract
Title Page and Index	3.4.2.1	X	X
Summary Table	3.4.2.2	X	
Part I RP-10	3.4.2.3	X	
Part II RP-10	3.4.2.4	X	
Balance Calculations	3.4.2.7	X	
Moment & Product of Inertia	3.4.2.16 (a)	X	
Curves (Burn Time – Mass Characteristics)	3.4.2.16 (b)	X	X
Drawings & Views	3.4.2.10	X	
List of GFE	3.4.2.9	X	
Substantiating Data	3.4.2.14	X	
Appendix II to RP-10 Weight Summary for performance analysis	3.4.2.18	X	
C.G. Limits for stability/control	3.4.2.17	X	X
Part IIIA/B RP-10	3.4.2.13		X

Table II. Weight and balance data requirements for development, procurement, and operational phases

(Items may be added, modified, or deleted as negotiated between the contractor and procuring agency)

Item	Paragraph number	Estimated report	Status report	Calculated report	Actual reports		Pre-flight report
					(Detail)	(Intermediate)	
When submitted...		As soon as practical after contract award and be in agreement contract detail or model specification	Bi-monthly beginning immediately after contract award and until first actual data are submitted	When weight is approximately 50% calculated but no later than midway between design phase represented by Estimated and Actual Weight Reports	Within 30 days after actual weighing		Within 10 days after Actual Mass Property Determination. One copy to be delivered with the missile
Title Page and Index	3.4.2.1	X	X	X	X	X	X
Summary Table	3.4.2.2	X	X	X	X	X	X
SAWE RP 10, Part I	3.4.2.3	X		X	X	X	
SAWE RP 10, Part II	3.4.2.4	X		X	X		
Actual Weighing	3.4.2.6				X	X	X
Determination of contractor over/under weight	3.4.2.6			X	X	X	
Balance Calculations	3.4.2.7	X		X	X	X	X 3.4.3.1 (b)
Authorized changes	3.4.2.8			X	X	X	
List of GFE Wts. & Comparison with Actuals	3.4.2.9	X		X	X	X	
Drawings & Views	3.4.2.10	X		X	X	X	
Appendices to Wt. Reports	3.4.2.11	X		X	X	X	X
Curves (Burn Time Mass Characteristics)	3.4.2.16 (b)	X	X	X	X	X	X

Table II, continued

Item	Paragraph number	Estimated report	Status report	Calculated report	Actual reports (Detail)	Actual reports (Intermediate)	Pre-flight report
Sectional Data	3.4.2.12	X		X	X	X	
SAWE RP 10, Part III A/B	3.4.2.13		X				
Substantiating Data	3.4.2.14	X					
Spec Derivation *	3.4.1.1						
Tolerance & Dispersion	3.4.2.15		X	X	X	X	
Moment & Product of Inertia	3.4.2.16 (a)	X		X			
Measurement of Mass Moments & Products of Inertia	3.4.2.16 (c)				X	X	
C.G. limits for Stability Control	3.4.2.17	X		X	X	X	
Weight Summary for Performance Analysis (Appendix II RP-10)	3.4.2.18	X	X	X	X	X	X
Inventory Check List	3.4.1 (a&d) **						X
Weight Error Analysis Report	3.4.3.2 (a) **						
Post-Flight Weight Report	3.4.3.2 (c)**						
Propellant Loading Wt Report	3.4.3.2 (c) **						
Field Weight Coordination Plan	3.4.3.2 (d) **						

* Submit during contract specification negotiation.

** See paragraph 3.1 and 3.4.3.2 as guides in the preparation and submission of these reports.