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GUIDELINES FOR MASS PROPERTIES CONTROL ON INTERNATIONAL SPACE & MISSILE SYSTEMS

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Society of Allied Weight Engineers

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1.0 INTRODUCTION

It is the objective of this document to provide interested parties involved in the initiation of a new missile or space system on the international level, a reference book of "guidelines" for the establishment of an effective mass properties control program. This document has been compiled by a panel of mass properties engineers representing both government agencies and industry in the United States and in Europe. Drawing Collectively on the wealth of experience represented in the international Society of Allied Weight Engineers (S.A.W.E.), and specifically on the experience of the Space Shuttle/Space lab program, a list of elements to be considered is furnished along with related comments.

In order for this document to be effective tool, it is necessary for it to be both current and flexible. A proposed method for document maintenance and updating is included. Also, a list of selected references is included which may be of use to the reader.

2.0 BACKGROUND

In the aerospace industry, it has long been recognized that weight and system performance are intimately related. This has led to the specialized technical discipline of weight or mass properties engineering. Since 1941 these engineers have had common meeting ground in the Society of Allied Weight Engineers. Through mutual cooperation between members from industry and government, this Society has been very instrumental in the development and acceptance of various government specifications dealing with mass properties development, analyses, reporting and control.

With the advent of more international participation in the development of future aerospace systems, it became apparent that new problems would be added to the basic task of effective mass properties control. The Space Shuttle/Space Lab program is a prime example. As a result, the theme of the 37th Annual International Conference of the S.A.W.E., held in Munich, Germany in May 1978 was "Multinational Cooperation and Mass Properties Systems, Standards and Specifications". During the Space and Missile Government and Industry session, presentations and discussions took place dealing with this topic. Again in the same session held as part of the 1979 conference in New York City, further presentations and discussions took place.

The outcome of this dialogue was a consensus of opinion that the writing and implementation of another mass properties control specification was neither practical at that time nor desired. On the other hand, it evolved that what would be of use to planners of the next program involving international cooperation would be a set of mass properties program "guidelines". Such a reference would serve as a checklist of those things that must be considered in setting up any mass properties control effort, hopefully avoiding much wasted time and money both at the beginning of and during the development cycle. Such guidelines, it was concluded, should be broad in scope, clear in definition and flexible in application.

Having selected a direction in which to proceed, and a final product to develop and maintain the next step was to implement those actions necessary to accomplish the objective.

A first draft of the subject document was compiled and routed for critique in July 1979. This process was continued with a second and third draft, along with a thorough review and workshop discussion at the 1980 conference in St. Louis. Final comments were incorporated and the resulting product issued for use as a S.A.W.E. Recommended Practice following the Societies' 1981 conference.

3.0 CHECKLIST OF ELEMENTS

The following subsections are titled for identification of those various elements of an effective mass properties program deemed necessary for consideration at the onset of development of any new aerospace system. Each contains a brief elaborating discussion with recommendations, where applicable.

It is recognized that each program, though similar to its predecessors in many ways, is unique and as a result, requires unique disciplines for control. It is intended that planners review the following subsections, see what factors should be considered, become aware of experiences of others, and then tailor a program to suit their current needs. Appendix A provides a checklist form that may be used to facilitate this activity.

Fundamental to the subject of mass properties control is recognition that, in the end, the mass of any aerospace system is the result of the many design decisions made by the program management during the design and development phases. The Mass Properties Group should be the single source of all mass properties data developed and used; they should report the data, trends and recommendations in a manner usable by program management; and they should be the catalyst for keeping mass properties impacts a part of all design decisions. They do not, however, unilaterally dictate what the mass properties will be.

3.1 Participants

Definition of all the various participants is an obvious, but none the less important, first step in the subject process. All participating government agencies and companies from industry to be involved in a system development program need to be identified. For each, a judgment of their background and related experience is required. The checklist provides a minimum of data suggested for definition.

3.2 Roles and Responsibilities

Each participant will have a specific role and level of responsibility, which must be clearly delineated. Most likely, the controlling authority for mass properties related activities would rest with the government agency contracting for the system. If more than one government agency is involved, which one has the final say? Between the contracting agency and industry, are their respective responsibilities clearly defined? Within industry, do the various companies have a prime-subcontractor relationship or are they on an equal co-associate level? And finally, within any one company, is there a specific individual or group tasked to provide mass properties analyses, reporting and control?

It is recommended that these relationships be very clearly defined and accepted at the beginning of the program. Contract documents, where this can be done, are Statements of Work, Interface Control documents, and most I likely a separate Mass Properties Control Plan document approved by the contracting agency.

3.3 Resources

Having established the task and responsibility for mass properties control, the next most important element to be considered is proper allocation of the necessary budgetary resources to enable this function to be accomplished.

Specific guidelines are difficult to provide in that each program is unique and each program's relative emphasis on technical and cost performance varies. Suffice to say that if the function is to be effectively accomplished, it must be funded. Experience has proven that those programs which have recognized the mass properties function from the <u>beginning</u> of the program have been most successful in keeping excess mass out of the system design.

Having selected a direction in which to proceed, and a final product to develop and maintain the next step was to implement those actions necessary to accomplish the objective.

3.4 Language(s) for Communication

A significant problem identified in previous international programs was that of verbal communication between participants. Due to large variations in the user's ethnic backgrounds and language proficiencies, many confusions and misunderstandings resulted. In a technical community this is very bad.

An answer to this item is not apparent, but it is of such significance that program attention should be devoted to recognizing it and dealing with it. Points to be remembered by the participants include:

- International counterparts may not be conversing in their native language. Communication must take this into consideration and stress simplicity
- In verbal communications, if you think you haven't gotten through, repeat using different words. Speak slowly and distinctly. Be aware of words that sound alike and could cause confusion
- Telephone conversations will be especially difficult when there is a low level of proficiently in the language being used
- In written communications, be alert for variations in the spelling of common words, e.g.,

program		programme
center		centre
meter	versus	metre
draftsman		draughtsman
aluminum		aluminium

3.5 Mass Properties Control Plan

For any program starting out, which will be of a size to involve international cooperation, it is strongly recommended that a formal plan for mass properties control be established, documented, and approved. This documentation should delineate the procedures and methods for all involved parties to develop, analyze, verify, report and control the related mass properties data. It is also important that these procedures be understood and accepted by all participants in the consortium.

Most of the elements subsequently listed should be addressed in the formal plan documentation. Considerable effort and management support will be required to accomplish these tasks and produce the required motivation of all involved parties. The control documents must be approved the governing agency (or customer) and be accepted by the total consortium.

Each participant must also understand them. Based on previous consortium experiences, knowledge of the proposed program is recommended. All participants (from manager to designers) should receive a thorough briefing of how mass properties control will be accomplished.

3.6 Mass Property Constraints

Is the design mass-limited? Does the center of gravity have to be held within a certain envelope? If so, when in the mission do these constraints apply? Answers to these and other similar questions must be provided at the earliest possible time so that design decisions and methods for mass properties control can be tailored accordingly.

3.7 Data Requirements Between Participants

An international program requires a substantial exchange of formal mass properties data. In order that all participants generate and/or receive the required data, it is recommended that while writing the Mass Properties Control Plan, a Mass Properties Data Requirements document also be developed and agreed to by all participants. Such a document could be updated as the program matures, and it would form the reference to resolve questions of what data is beyond the limits of the contract (out-of-scope) versus within the limits of the contract ("in-scope").

Common problems that can be avoided with proper planning include:

a) data consistency - Agency A, when compiling an integrated report to define current status, receives only specification or not-to-exceed values from Agency B.

b) data compliance-Agency A needs a complete mass properties description (3-axis center of gravity and moments of inertia), but receives only a definition of mass.

These, and similar occurrences, only lead to publication of inaccurate data and additional (and probably unplanned) workloads.

3.8 Data Exchange

Exchange of mass properties data, like exchange of any other data on a program of the scale envisioned, must be disciplined and go through appropriate channels. Such exchanges, however, can introduce delays that often result in integrated reports containing inconsistent inputs from a timing standpoint. It is strongly recommended that channels for report flow and report approvals be formulated in such a way as to maximize the timely exchange of mass properties data. Also, it has proven invaluable on past programs in matter of question items needing clarification, that the mass properties engineers have free access to communicate directly. It is recommended that no hindrance to this communication be introduced in the next program. These changes, even if by telephone, should be documented.

3.9 Units to be Used

Are English units (pounds, inches), metric units (kilograms, centimeters), or a hybrid (combination of both) system to be used? Here the specified usage should be tailored to that selected for the overall program. Relative costs are certainly a consideration not be overlooked.

A hybrid system is considered the least desirable approach since it involves the extra effort of preparing and presenting data in two separate systems. It would not speed the transition of the U.S. users to look only at the English values and not really use the metric. The use of only English common units would be difficult for countries using the metric system. The recommendation is, therefore, that all future international cooperative ventures have mass properties presented solely in the metric system.

Many U.S. companies have either gone, or are going metric. Some are finding that the costs of conversion are so low (about 1%) that the monitoring costs are more expensive than the conversion costs.

U.S. Companies that have not already converted their mass property computer programs to metric may find that some simple reprogramming and load sheet changes (change field descriptions and unit designations) will accomplish the changeover; e.g.:

Systems of Units	**English**	**Metric**
Column	Mass (lb.)	Mass (Kg)
Field Description	F6.2	F6.3
(FORTRAN)	XXXX.XX	XXX.XXX
Smallest Unit	1/100 of a lb.	gram

When double units are used, conversions should be specified per some accepted reference and so identified in all reports. Reference 5.1. is recommended.

3.10 Numbers

3.10.1 Punctuation

The custom in continental Europe to use commas and decimal points to punctuate numbers is opposite that used in the United States. For example, one thousand kilograms would be written 1.000,00 kg in continental Europe, whereas it would be written as 1,000.00 kg in the U.S.

The British use a point for the decimal marker (the same as the U.S.), except that the point is at half-mast. For example, 1.5 lb. in the U.S. would be presented as 1-5 lb. by the British. Although the comma is normally used for the decimal marker in Germany, on postage the decimal marker is a point. A 1 and 20/100 Deutsche Mark stamp would have its value shown as 1.20 DM. Other examples are as follows:

U.S.	**Continental Europe**	**United Kingdom**
1.5	1,5	1-5
0.5	0,5	0-5
$1,500	$1.500-	£ 1,500
$0.63 or 63¢	$0,63	63P
$2.00	$2,00 -	£2

These differences in custom lead to confusion and should be recognized.

3.10.2 Characters

Care must be taken with written numbers to differentiate between such figures as the United States 7 (seven) and the European 1 (one), or the United States 4 (four) and the European 7 (seven).

3.10.3 Dates

Dates can be written three ways. For October 5, 1979: (1) International Standards Organization (used by ESA) as 79/10/5; (2) British/European as 5/10/79; or (3) United States as 10/5/79. Consistency throughout any given program should be a goal.

3.11 Formats For Data

The consistent use of mass properties data by all properties engineers working on a system under development is a requirement. Even more important is the clear understanding and interpretation of the mass properties summary and trend data presented to program management for their decision making process. Well thought out data formats tailored to the peculiar requirements of the particular program will contribute greatly to meeting these requirements.
Considerations include:

- Is the level of detail tailored to the user's need?
- Is the arrangement and grouping of data simple, clear and precise?
- Is some measure of data quality or maturity provided?
- Is the status versus requirement, if applicable, depicted?
- Are the data dated?

For reference, the reader is referred to the several military specifications developed and used in the United States aerospace industry. These have evolved through many years of experience and are now widely recognized and used. Typical are:

- MIL-STD-1811 (USAF), "Mass Properties Control for Space Vehicles". (Ref. 5.2)
- MIL-STD-176, "Weight and Balance Data Reporting Forms for Guided Missiles and Space Launch Vehicles". (Ref. 5.3)

3.12 Functional Code

This element of a mass properties control program has to do with the establishment of a uniform way of grouping mass properties data for consistency and clear understanding among users. Over the years, mass properties have tended to be grouped on a functional basis and this has been specifically defined in the military specifications for adherence by all involved. More recently, with the increasing emphasis on sophisticated cost control systems, the possibility of grouping mass properties on the same basis as the cost groupings has been raised. Here the common denominator is the program "work breakdown structure" or dictionary to which individual design responsibilities are assigned and control led.

The recommendation on coding is to establish the basic use to which the mass properties data is to be put, reach agreement by all parties and finally to have these instructions documented for uniform use during the life of the program.

3.13 Coordinate Reference System

In any aerospace system comprised of many sub-elements, it is a desirable objective to have just one coordinate reference system. In practice, though, situations arise where compromises must be made. With communication and planning between participants, such compromises can be minimized and potential sources of calculation errors minimized. When more than one system is called for, commonality of axes designation, signs and origins should be agreed upon.

3.14 Treatment of an Allowance for Mass Growth

The subject of mass growth is, in simple terms, the phenomenon most systems demonstrate X during their development cycle of growing in mass from early prediction to final delivery. The contributors to this process are many and the approaches taken on past programs to control it have also been many. For the purpose of these guidelines the important items to be considered are:

- **Definition** - does a clear definition of the term exist and do all affected parties agree to it? (A suggested definition is included in Section 4.0).

- **Allowance** - is there to be included in the hardware mass estimates a specific allowance for growth? If so, the basis for this allowance must be documented along with agreement as to the coding level at which it is to be distributed.
- **Depletion** - if included, does there exist an agreed to schedule for the systematic depletion of the growth allowance with calendar time or program maturity?
- **Visibility** - if included, do the formats for the various data presented to management provide visibility of the mass growth status and trends?

3.15 Computer Program Interfaces

Extensive use of electronic computers is now being made throughout the industry to process and calculate mass properties data. As the requirements for data among the various participants of any new consortium are formulated (Section 3.7), recognition should be given to the computer facilities which are either available or not available to the participants. Considerable program costs may be avoided by exploiting areas of commonality between computer programs with regard to data formatting and data content.

Whether or not any mass properties data are to be transmitted other than by mass property status reports should be defined. Options would include punched card, magnetic tape and remote access to computer data files. Whatever the method, it should be agreed to and formats coordinated between the participants.

4.0 DEFINITION OF TERMS

Included in this section are suggested definitions to many mass properties terms that are likely to be sources of confusion, and should therefore be considered in any new international space or missile program.

Actual Mass - The highest maturity of mass data. Based upon actual mass measurement of flight configuration hardware.

Calculated Mass - A mass value based upon the calculation from released engineering drawings for flight configuration hardware.

Control Mass - Mission requirements generally result in the customer establishing an upper limit to the mass of each segment of a composite vehicle. This limit, designated as the control mass, the maximum mass of given segment can have and still meet the mission performance requirements. (Figure 4.0-1)

Contractor - The company with whom the procuring governmental agency is contracting for goods and/or services.

Contractor Margin - The difference between the specification mass and the projected mass.

Current Mass (Nominal) - The mass status of the hardware maintained throughout the hardware development period in periodic mass reports. The nominal current mass is the sum of the identified mass and the contingency mass.

Current Mass (Maximum) - The sum of the nominal current mass and the root sum square (RSS) of the manufacturing and verification dispersions.

Customer Margin - The difference between the control mass established by the customer and the specification mass.

Datum Plane - A plane of reference from which to measure center of gravity locations.

Dry Mass - The mass of a system or component without fluids.

Estimated Mass - An estimated mass is the lowest maturity of mass data. It may be based on a pure guess, and approximation based upon similar hardware or a calculation based upon a design description and/or a preliminary drawing or layout.

Identified Mass - The nominal mass based on all available design definition identified to date.

Manufacturing Dispersion - The predicted or calculated random dispersions in mass and/or dimension characteristics resulting from variations in such things as material tolerances, manufacturing processes, etc.

Mass Class - To establish the "class" or maturity of the mass data for a given status report, masses will be classified as estimated, calculated or actual. The percentage of mass in each category is then a measure of maturity of the mass records at a given time.

Mass Contingency - The mass included for deficiencies is identified mass resulting from lack of detail in current design data. (The amount of contingency is generally determined as a percent of the basic installation or subsystem mass where the percent is determined empirically from similar systems developed on previous programs.)

Mass Growth Allowance - The allowance made for changes in mass to be expected because of program development, cost and/or schedule problems. Such causes of mass growth are usually considered "in scope" unless the contracting agency directs a change such as increased system performance that causes mass to grow. These causes of mass growth are "out of scope" and may be, but are not usually provided for.

Maximum Mass - The maximum expected mass of a group of like items. Includes the nominal mass plus the RSS of the manufacturing and verification dispersions.

Pending Changes - A category of approved changes established subsequent to the basic report closeout date.

Potential Change - A category of changes that are either still being evaluated for incorporation or which could evolve into a mass properties impact. Included are design trade studies, design improvement studies and make-work changes.

Projected Mass (Nominal) - The nominal mass currently projected for the item at delivery. Includes current mass plus available remaining mass growth allowance.

Specification Mass - The upper limit mass quoted in specifications as not to be exceeded by the contractor. (Where there is a change to the hardware requirements that affects mass, this will constitute a basis for negotiation of an adjustment to the specification mass).

Supplier - Any company supporting and/or furnishing system elements to the contractor. This term is synonymous with vendor or co-contractor.

Target Mass - The mass considered to be realistic and achievable based on all currently known or foreseeable elements comprising the element.

Verification Dispersion - The root sum square of the random error associated with the measurement equipment and techniques used to verify the hardware mass properties.

5.0 SELECTED REFERENCES

Listed in Table 5.0-1 are several references to documents related to the subject of mass properties control. The reader is encouraged to obtain copies of any or all of these for specific reference to details that may not be adequately covered in this "guideline". Readers are also encouraged to add to this list, via the procedure outlined in the next section, any references that may be useful to others.

6.0 PROCEDURE FOR REVISIONS

In order for this document to remain a current and useful tool, the following procedure for document maintenance is set forth.

a. The keeper of the document original shall be the incumbent chairman of the Space and Missile Government/Industry Panel of the Society of Allied Weight Engineers. (At this writing, this person is Wayne L. Peterson, NASA Johnson Space Center, Mail Code EA6, 2101 NASA Rd. 1, Houston, Texas 77058 USA)

b. He may be contacted through the S.A.W.E. Executive Secretary, whose address in turn is shown with the Title Page logo.

c. The keeper of the document shall:

- Collect all additions, changes, etc. as recommended to him for incorporation.
- Depending on backlog, incorporate changes and issue revised copies.
- For those changes of a controversial nature, add an agenda item for review at the next S.A.W.E. International Conference or any other action necessary for resolution.
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