RESEARCH REPORT

METRICATION STUDY FOR
LARGE SPACE TELESCOPE

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

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Battelle
Columbus Laboratories

FINAL REPORT

on

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by

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ABSTRACT

The objective of this brief study was to analyze and evaluate the various approaches which could be taken in developing a metric-system design for the Large Space Telescope, considering potential penalties on development cost and time, commonality with other satellite programs, and contribution to national goals for conversion to the metric system of units. In conducting this study, the Battelle-Columbus staff collected information on the problems, potential approaches, and impacts of metrication from published reports on previous aerospace-industry metrication-impact studies and through numerous telephone interviews. The recommended approach to LST metrication formulated in this study calls for new components and subsystems to be designed in metric-module dimensions, but U.S. customary practice is allowed where U.S. metric standards and metric components are not available or would be unsuitable. Electrical/electronic-system design, which is presently largely metric, is considered exempt from further metrication. An important guideline is that metric design and fabrication should in no way compromise the effectiveness of the LST equipment. For the recommended approach, it was estimated that design costs would increase about 4 percent, but that this increase would be less for those organizations having metric-design experience or which have conducted education and training in the metric system for their staff. Fabrication-cost requirements were estimated to increase less than 5 percent, and perhaps negligibly.

Battelle-Columbus staff on this project were: Frederick A. Creswick, Project Director, Albert E. Weller, Technical Coordinator, Bruce W. Davis, Program Manager, and Thomas M. Trainer. Contracting Officers Representatives for Marshall Space Flight Center were R. Lee Graham, Principal, and Harry L. Atkins, Alternate. This study was initiated on October 10, 1972.

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INTRODUCTION

A national goal is the eventual conversion of our units of measurement to the metric system. Consistent with this goal, the Large Space Telescope (LST) Program--particularly since it will be operational during the 1980's, could be a forerunner for NASA in accomplishing metrication. The resulting engineering experience and public exposure would serve to expedite public acceptance of the metric system. In addition, the ability of LST to conveniently and effectively interface with an international complement of focal-plane instruments would be significantly enhanced, thereby achieving a truly international astronomical facility.

In considering the metrication of LST, at least three factors must be considered. These are:

- The impact on the LST cost and schedule
- The impact on commonality with other satellite programs, such as the HEAO
- The probable existance of a threshold level of metrication required for a significant contribution to the goal of eventual national metrication.

Consideration of these factors leads naturally to a concept of partial metrication which controls the undesirable impacts on costs, schedules and commonality, but which achieves a level of metrication sufficient to make a significant contribution to the national metrication goal. This study defines such a level of metrication and supplies a rationale to support the specific level recommended.

Because of the limited time and resources available for this study, it was necessary for the Battelle-Columbus Laboratories (BCL) staff to rely heavily on data and other information from:

(1) Previous industry aerospace-system metrication-impact studies which

(a) were involved with systems comprising similar (to LST) components and work elements

(b) led to results that are generally accepted as both credible and realistic

(c) involved the expenditure of significant resources to achieve a desired depth and thoroughness in the analysis. (It was not considered appropriate to expend resources to repeat the previous detailed analyses.)

(2) Numerous interviews with experts (See Appendix B for a list of individuals contacted) involved in establishing metric standards and/or in industrial response to the national metrication requirement. These experts provided:

(a) insight on problems associated with conversion

(b) definitions and qualitative measures of the impact of various approaches to metrication

(c) quantitative measure of the impact of metrication on various design and fabrication activities.

Since the foregoing efforts and sources have already expended substantial resources in establishing the present state of art (and knowledge) in accomplishing metrication for various activities and types of equipment, it was deemed most appropriate that this study be restricted to application of available data and other information to estimate the impact of metrication on LST-program design and fabrication activities. It was considered that test, evaluation, and operational activities would not be significantly impacted by metrication.

A recommended approach to metricating the LST was formulated in terms of the basic engineering functions associated with the design of an assumed satellite concept [See Appendix A for detailed information on the principal subsystems--Optical Telescope Assembly (OTA), Scientific Instruments (SI), and Support System Module (SSM)]. The basic levels of metrication considered were "no", "soft", and "hard" metrication which are defined in Appendix C for various functions which will be involved in the LST program. In addition to these basic levels, other levels (mixes of the basic levels) naturally evolved for various system elements and subactivity elements.

The impacts of the recommended approach were analyzed at the subsystem level, considering the component and design-activity content of these subsystems on a qualitative basis, and considering the impact of the recommended approach to metrication for each of the program activities having a significant impact on cost and time. Impacts were reported in terms of percent increase in time and cost for each of the system elements: the OTA, the SI, and the SSM. Impacts on design activity and fabrication were considered separately.

Problems associated with conversion to the metric system are discussed in some detail in this report. These discussions are presented to provide background information in support of the various decisions made after considering various levels of metrication in formulating the recomended approach to metrication.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that, although there are many potential problems associated with metricating the LST, there are, nevertheless, practical approaches by which a basic metric design for the LST can be achieved.

The recommended approach is described as follows:

1. General. In general, it is intended that new components and subsystems for the LST shall be designed in metric-module* dimensions. This guideline is subject to interpretations and exceptions.

2. Product Effectiveness. It is intended that metric design shall in no way compromise the effectiveness of the LST equipment. Where it can be shown that metric design practice will result in a lower effectiveness than would customary U.S. practice, the customary practice should be followed.

3. Analytical Design. Analytical design calculations for all components and for systems analysis shall be reported in SI (Systeme International d'Unites)[(1)**] metric units. Where it is apparent that SI units may complicate communications, customary units may also be reported. Where results are rounded off into even units, metric modules shall be used. Deliverable software shall be in SI metric units.

4. Mechanical-Design Standards. Where ISO (International Organization for Standardization) metric standards for mechanical design are available, applicable, and equivalent or superior to U.S. customary standards, they shall be used. The use of other metric design standards such as British Standards or DIN (Deutscher Industrie Norm) is not necessarily encouraged unless justification can be shown. In general, it is intended that those metric design standards will

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* Designers tend to work with even or convenient modules of their measurement system. For example, U.S. designers tend to select dimensions in whole numbers of inches or integer fractions of inches. For the case of the LST, for example, a 3-meter mirror (118.11 in.) is clearly a metric-module dimension, while a 120-inch mirror (3.048 m) is clearly an inch-module dimension.

** Numbers in parentheses refer to References, p. 51.

be used that will likely become U.S. standard practice. Otherwise, U.S. customary standards shall be used and shall be translated into metric units if necessary.

5. Electrical/Electronic System Design. U.S. customary practice shall be allowed for the design of electrical and electronic-system circuitry and electromechanical internals. An exception, previously stated, is that analytical calculations shall be reported in SI units (customary practice is already largely metric at present).

6. Optical-Component Design. The mechanical design of new non-standard optical components shall be in metric modules.

7. Materials Selection. Special-order material stock shall be specified in metric units. Otherwise, materials in U.S. customary sizes may be used if cost effective.

8. Parts Selection. Where metric-system piece-parts (nonelectrical) are available from customary sources and are acceptable and not inconsistent with ISO recommendations, they shall be used in preference to equivalent inch-module parts. In the case of threaded fasteners, ISO standards shall be preferred where commercial-quality fasteners are acceptable. Guidelines for the selection of aerospace-quality fasteners require further study at this time.

9. Mechanical Interfaces. Where there are mechanical interfaces with new or existing English-system components, the English-system dimensions shall be retained and a conversion of the dimensions into metric equivalents shall be made.

10. Working Drawings. Working drawings shall be in metric units (with the exception of electrical and electronic components). The option of dual dimensioning is allowed. If dual dimensioning is used, a standard procedure for conversion of dimensions shall be established and adhered to diligently.

11. Fabrication. It is recommended that NASA plan tentatively to allow fabricators the option of working in either metric units or their English equivalents, using dual dimensioned drawings in which the baseline units are metric, but to delay a final decision on this point. Optional units appears to be an appropriate recommendation if fabrication were to begin presently; however, by the time LST fabrication is in progress, it could possibly be counterproductive not to insist on fabrication in metric units.

The above approach will result in there being both metric-system and English-system components within the LST. However, the design of the optical system, the scientific instruments, and the supporting structure will be predominantly metric.

The principal contribution to national goals that can be achieved by the recommended approach is symbolic in nature, that is, it will give solid evidence to the U.S. aerospace industry that a conversion to the metric system of units has indeed begun. This will be particularly true if NASA serves notice to the aerospace industry that metric design will be a feature of all future space projects. Also, the fact that the LST has a basic metric design can be expected to enhance understanding of and interest in the LST program by the international scientific community. It will have accomplished a significant portion of the education and training of the affected engineering work force to work and think in the metric system of units. While this segment of the total U.S. work force is minute, total conversion will eventually come as the aggregate of such stepwise conversions of small groups.

A beginning of the task of converting engineering software such as standards, computer programs, and handbooks will have been made. However, this task is extensive and could require one or two decades for completion. Metrication of the LST may lend a sense of urgency to the adoption of U.S. metric standards in certain areas where none are currently accepted.

It is expected that the metric LST will not provide a significant incentive for conversion of manufacturing facilities for working in metric units, nor will there be significant impact on the availability of metric-system materials and hardware.

It is estimated that the recommended approach to metrication will result in the following increases in required design effort:

Design Category	Increase
Mechanical design	8 percent
Electrical/electronic design	2 percent
Optical design	0 percent.

Translating the above factors into the expected design-activity breakdown for the LST results in an estimated design cost-and-time increase as follows:

Element	Increase
Optical Telescope Assembly	5 percent
Scientific Instruments	3 percent
Support Systems Module	4 percent.

The above figures bracket the overall design-cost impact between 3 and 5 percent.

It should be pointed out that Phase B bids may reflect less than this percentage increase if (1) contractors have already engaged in education and training of their engineering work force for working in the metric system of units or (2) if contractors are willing to conduct appropriate education and training sessions at their own expense or partly at their own expense.

Subsequent fabrication costs are estimated to increase by less than 5 percent, and possibly negligibly.

It is believed that the recommended approach will have negligible effect on commonality with other NASA satellite programs.

LST MISSION AND CONFIGURATION

The LST has been described as a logical "next step" for optical stellar-space astonomy, and is expected to contribute substantially to every phase of astronomy. This orbiting telescope will have a large collecting area, broad spectral coverage, and high resolution. It will provide an unparalleled extension of our observational capability for investigations of stars interstellar matter, planets, comets, and extragalactic phenomena.

It is planned that the LST will operate in a circular orbit at an altitude of 600 to 750 km with an inclination of 0.5 radians (28.5 degrees). Launch of the first LST is planned for 1979. A high-performance LST is to follow in 1983. As necessary, in-orbit maintenance and servicing will be performed by rendezvous with the Space Shuttle.

The LST scientific payload is composed of 3 functional elements: an Optical Telescope Assembly (OTA), Scientific Instruments (SI), and a Support Systems Module (SSM). Figure 1 shows a cross section of the OTA and SI assembly, and Figure 2 shows a view of the SSM.

Optical Telescope Assembly (OTA)

The OTA is composed principally of the 3-meter main optical objective mirror, its associated secondary mirror (the two comprising a Ritchey-Chretien Cassegrain telescope arrangement), and a supporting structure. A graphite-epoxy truss structure supports the primary and secondary mirrors. This structure is enclosed by an aluminum light baffle, thermal insulation blankets, and an aluminum meteoroid shield on a ring-and-stringer structure. Hinged aperture doors enclose the open end of the telescope for protection against contamination during rendezvous. The OTA is further surrounded by an extendable light shield. Behind the primary mirror is a titanium-dome pressure bulkhead stiffened by an aluminum honeycomb structure. A central door in the bulkhead can be closed for shirtsleeve-environment maintenance of the SIP.

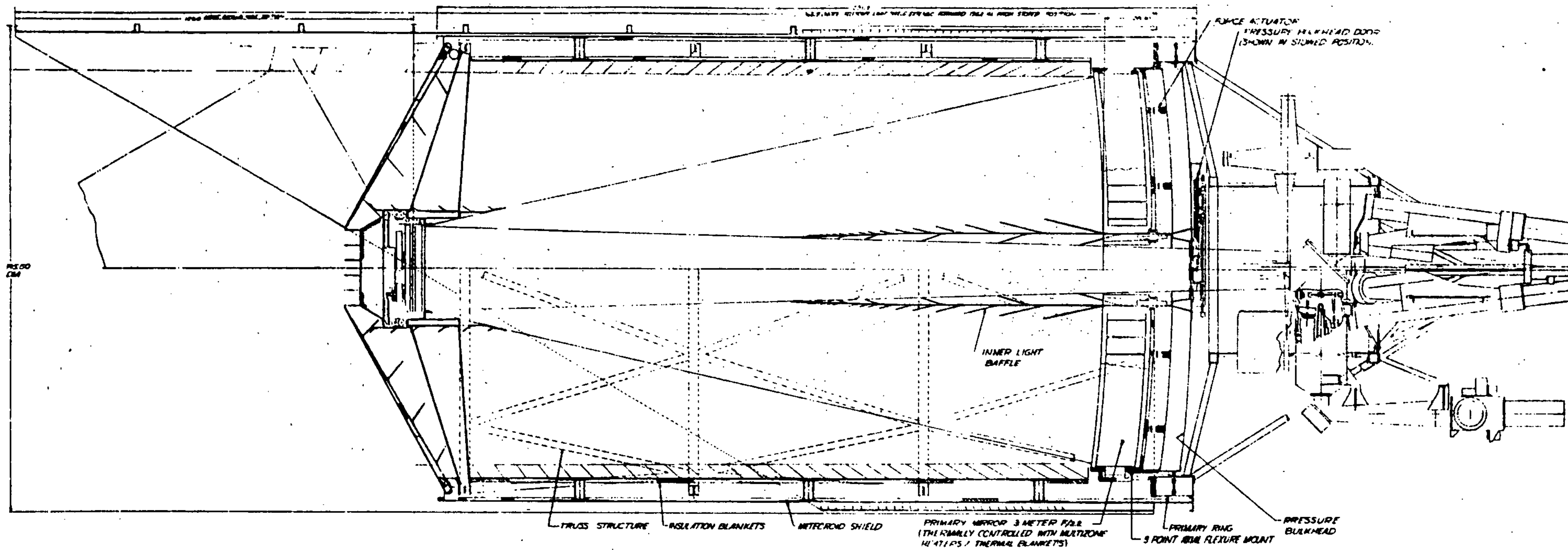

FIGURE 1. OTA/SI CONFIGURATION

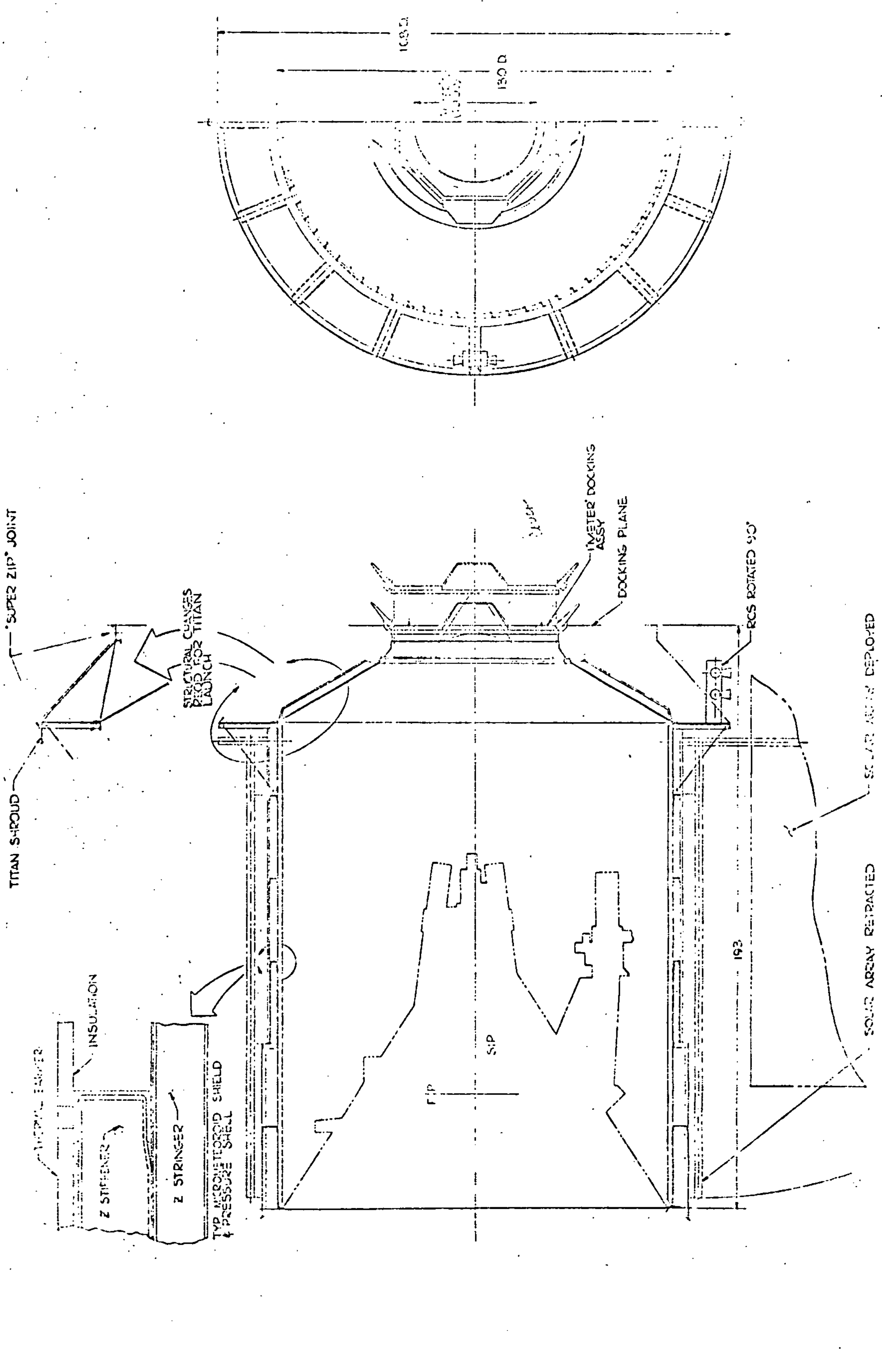

FIGURE 2. SSM CONFIGURATION

Scientific Instruments (SI)

The SI consist principally of eight image-tube cameras to be used as field cameras, spectrographs, or interferometers. A ninth camera is used to monitor orientation, and space is provided for a tenth instrument. The image-tube cameras are to be developed using present television-camera-tube state of art as a starting point. Cameras are arranged in two bays. Radial-bay cameras are selected by the use of a series of fold mirrors and off-axis alignment of the secondary mirror. Axial-bay instruments are selected by a selector mirror. Instruments are mounted in a truss structure fastened to the pressure bulkhead.

Support Systems Module (SSM)

The SSM contains systems for telescope orientation, electrical power, and communications and data management. Orientation is controlled by GN_2 thrustors, control-moment gyros, and magnetic torquers. Electrical power is provided by solar cells mounted in an extendable structure. The external structure of the SSM is principally an aluminum ring-and-stringer structure with an aluminum pressure wall inside and an aluminum meteoroid shield outside. Integral with the SSM structure is an adapter ring for support during launch and a universal 1-meter docking adapter for access during maintenance from the Space Shuttle. Most support systems in the SSM will be adaptations of systems designed for HEAO (High Energy Astronomical Observatory).

Alignment and actuating mechanisms within the LST are all electrically powered. There is no hydraulic system.

Thermal control is achieved by a combination of electric heaters, thermoelectric coolers, insulation blankets, heat pipes, selected thermal emittance coatings, and an active louver system. There is no coolant loop within the LST, and the sole heat sink is by radiation to space.

A breakdown of LST subsystems and components is presented in Appendix A.

CONTRIBUTION TO NATIONAL GOALS

The U.S. Metric Study[2] conducted by the National Bureau of Standards at the direction of the United States Congress resulted in the following principal conclusions:

- Increased use of the metric system is in the best interests of the United States
- The nation should change to the metric system through a coordinated national program
- The transition period should be ten years, at the end of which the nation would be predominantly metric.

The expected benefits of conversion to the metric system include improved competitiveness of U.S. products in world trade, improvement in communication and relations with other countries, benefits to national security, improved efficiency in scientific and engineering calculations, and eventual simplification of conventions for stock materials and machine components.

Public Exposure

Perhaps one of the most important contributions that metrication of the LST will make toward national goals is symbolic in nature; that is, as a precursor metricated project, the LST can lend credence to the presumption that the U.S. will indeed become a metric nation in the near future, and will thereby contribute to establishing momentum toward a rapid (and least costly) conversion. To this end, it is important that the degree of metrication selected for the LST program appear significant to the business, industrial, and scientific communities.

Specific Contributions

In moving toward conversion in the United States to the metric system, a number of types of activity must be conducted to which the LST can contribute. These include the following:

- education and training of the affected work force to work and think in the metric system of units
- conversion of software to the metric system
- conversion of affected manufacturing facilities to work in metric units

Education and Training. One of the costs of conversion to metric units will be loss of efficiency of the affected work force while personnel are learning to work in a new system. This loss of efficiency can be offset in part by formal metrication training courses, or the loss of efficiency can be considered to be the consequence of an on-the-job learning experience. As the United States converts to the metric system, virtually all engineers, scientists, designers, draftsmen, machinists, production workers, executives, and office staffs will need to go through an education and training experience, whether it be formalized or on-the-job. One contribution of metricating the LST can be to necessitate the education and training of a segment of the U.S. aerospace and scientific community. While this segment is very small, conversion will undoubtably be accomplished by the aggregate of a great number of such stepwise conversions of small segments of the work force. It is estimated that the education and training of the affected work-force segment for working in metric units can be largely completed within the time span of a single study of the scope of the LST program.

Software Conversion. In the process of national conversion to the metric system, substantial numbers of documents impacting scientific and engineering design and manufacturing operations will ultimately be converted to metric units. These include standards, specifications, computer programs, handbooks and reference material, maps, and records. This conversion will be an extensive task requiring many years for completion.

Accordingly, any software conversion accomplished in the course of the LST program could be considered only a beginning. More significantly, it is probable that a metricated LST program could contribute by emphasizing those areas where software conversion is most urgently needed. For example, the recommendation presented in this report concerning threaded fasteners could have been substantially different had universally acceptable standards for aerospace-quality threaded fasteners been established. Also, to this point, education and training efforts can be expected to be most productive where there are accepted metric standards to replace customary practice.

The LST program can contribute to national goals by promoting the conversion of software to metric units, particularly in regard to the definition of acceptable metric design standards.

Manufacturing Facilities. As conversion to the metric system takes place it can be expected that there will be a concurrent conversion of manufacturing facilities: machine tools, gages, and measurement equipment and instrumentation. Machine tool conversion will take place both by modification and replacement. Ideally, replacement of inch-system tooling by metric tooling would occur only at the end of the normal lifetime of each piece of machinery.

In metricating the LST design, the option exists to select design features and working-drawing formats that will necessitate some level of conversion of manufacturing. As is the case with software conversion, the conversion of manufacturing facilities to be accomplished ultimately is extensive, and, at best, the impact of LST metrication on this conversion would only be a beginning. However, in the affected organization, it would serve as a starting point, assuming conversion was not already underway.

Areas of No Contribution

As national metrication gathers momentum, it can be expected that metric-module materials and hardware will become commercially available to meet the growing demand for replacements of inch-module items. Even though LST program funding will be well in excess of $100 million, it is judged that the LST demand for such items will be too small to impact the availability of metric-module materials and hardware, regardless of the degree of design metrication.

Product Effectiveness

Although the effect of metrication on the effectiveness of the LST program is not an area of contribution to national metrication goals, it is an area of vital concern. Guidelines to LST metrication should be established such that the selected approach to metrication will not compromise the effectiveness of the program. If this guideline can be followed, it can be assumed that metrication would in fact enhance the effectiveness of LST by virture of providing an astronomical telescope whose principal features and dimensions are described in an internationally accepted system of units.

METRICATION APPROACHES - DISCUSSIONS AND DETAILED RECOMMENDATIONS

The metrication discussions and recommendations in this report section are presented in terms of the sequential steps required in the development and operation of a one-of-a-kind assembly. The impacts of the recommended approaches on the development and operation of the LST are summarized in the next major report section. The categories discussed in this report section are:

- General
- Design
- Fabrication
- Test, Evaluation, and Operational Activities

General

Information broadly applicable to the use of the metric system in the LST development effort is presented in terms of: (1) descriptive terms, (2) guiding principles, and (3) units and standards.

Descriptive Terms

A discussion of metrication normally involves three concepts which require some definition: (1) basic design units (English or metric), (2) translation of units or soft conversion, and (3) hard conversion.

Basic Design Units. A design may be originally accomplished in either English units or metric units. Each system of units has basic or preferred numbers which form the basis for the designer's thinking. Thus, a basic metric design will not only be expressed in metric units but will be based on certain whole units such as millimeters. The terms "basic English design" and "basic metric design" are useful for expressing these concepts. The terms "metric-module" and "inch-module" are also used to describe these concepts.

Translation or Soft Conversion. It is possible to use a component designed and manufactured to one system of units in an assembly designed and manufactured to another system of units. For convenience, the units of the "foreign" design are "translated" to the units used for the assembly. Since this requires only a change in descriptive terms, the translation of units is commonly called a "soft conversion".

Hard Conversion. When the general configuration of the foreign part (see above) is retained, but the dimensions are changed to the even-module units of another system, this is commonly referred to as a "hard conversion". Such a conversion requires not only a change in manufacturing (to achieve the slightly different dimensions), but also some engineering judgement to evaluate the effect of the dimensional changes.

Guiding Principles

Guiding principles for the recommended basic approach for the use of the metric system in the LST development program can be summarized as stated below.

> In general, it is desired that new components and subsystems shall be designed in metric-module dimensions. It is further desired that available metric standards be applied to all components of the LST which are to undergo development where such standards are available, applicable, and equivalent or superior to standards in U.S. customary units. This application of available metric standards is not to be merely a translation of English unit values to metric unit values, but rather the intent is to achieve a basic metric-module design for the developed components.
>
> In achieving this basic metric design, available* parts, modules, and materials are to be used to the maximum extent feasible. Where such hardware is used, it is to be specified in terms of existing descriptions, specifications, or standards.

* "Available" is used here in the sense of already developed, already qualified, etc., rather than in the restricted sense of ready for delivery.

From the above, a differentiation is seen between components which are to be developed and components which are available. For the former, it is desirable that available metric standards be applied. For the latter, the principal criterion is that there be existing descriptions, specifications, or standards, whether they be in English units or in metric units. Where the hardware is available in both systems of units, and the metric version is satisfactory from quality and schedule standpoints, the metric version would normally be preferred.

Where there is available hardware which requires changes for use in LST, it is to be considered peculiar hardware and the required changes to this hardware are normally to be accomplished in the metric system. Restating this approach, whenever new drawings are created, these new drawings should use the metric system. Occasionally, exceptions to this approach may be justified.

Where there are necessary interfaces with new or existing English-system hardware, the English-system dimensions shall be retained and a "soft" conversion of the dimensions into metric equivalents will be made.

It is intended that metric design shall in no way compromise the effectiveness of the LST equipment. Where it can be shown that metric design practice will be less effective than U.S. customary practice, the customary practice should be followed.

The general approach described above will result in there being both English-system and metric-system components within the LST. However, the LST structure, optical components, and scientific instruments will be largely of metric-module design. The metric design conventions and metric hardware are used where they are available and where their use would contribute to the significance of LST metrication. However, where metric standards and components are not available or acceptable, the LST designers are not penalized. Thus, it is believed that this basic approach is both practical and significant in contributing to national goals.

The significance of producing a design whose dimensions are principally metric-module is subtle and perhaps requires amplification at this point. Obviously, a given dimension, once defined, is the same expressed in any system of units.

The significance of a metric-module dimension is that it will be achieved naturally only by working and thinking in metric units. Since training of a work-force segment is one of the expected contributions of LST metrication, requiring a basic metric-module is considered necessary (if not sufficient) to accomplish this training function.

Units and Standards

In view of the many years of work with English and metric units and standards it would appear that the required definitions would be readily available. There is still considerable confusion and misunderstanding, however, and the major aspects are discussed briefly.

Units. There is comparatively little confusion in the U.S. about the units of the English system since these are widely used. The use of the term "customary" to describe this system of units is still not generally understood, however.

The term "metric system" is a common cause of misunderstanding because there is no single, common system of metric units. Dimensional specifications in different metric countries are frequently incompatible. The growing acceptance of the SI system of units (adopted for use by NASA in 1971) promises a clarification of this problem in the next few years. However, even the SI system is still being reviewed. For instance, a convenient expression for pressure is being sought for use in engineering.

The translation of the units of one system into the units of another system still represents a significant problem because judgment is required in rounding off basic dimensions and in selecting equivalent tolerances. However, guidance for such translations is given in SAE J-916[3] "Metric Equivalents of U.S. Conventional Units of Measure". This recommended practice, published in June 1965, is consistent with conversion practices of ISO R370[4] and ASTM Designation E380-70[5], and its use is recommended for the LST.

Standards. At first glance it would appear that the use of "available metric standards" as specified previously in the Guiding Principles Section would present few problems. Actually, metric standards are available from a number of countries, from international societies, and from United States societies, institutes, and companies. To fulfill NASA's purpose for the LST, the basic problem is the selection of those metric standards which: (1) will be generally used by U.S. industry in the future, and/or (2) will illustrate the use of metric units in an engineering program.

There is little question that the recommendations developed by the International Organization for Standardization (ISO) will be the major international standards for the U.S. in the future. ISO standards are already important to several segments of U.S. industry. Thus, where an ISO recommendation in the metric system is applicable to the LST, serious consideration should be given to its use. The work at ISO is moving slowly, however, and most aspects of engineering are still not covered. ISO recommendations cover less than 1% of the standards used by U.S. industry. Therefore, consideration can be given to the use of metric standards from other sources. Since there are so many of these, and since they often represent conflicting or competing engineering viewpoints, it is recommended that a non-ISO metric standard be used for the LST only if: (1) its adoption by the ISO or by U.S. industry appears highly likely, or (2) its use would demonstrate some important aspect of metrication.

In addition to the above guidelines, the designer should be cautioned about the difference between a procurement "standard" as commonly used for U.S. Government part procurement and a part "standard" as developed by most foreign countries. The former is essentially a controlling document. It is often complete in itself, controlling the configuration, quality, performance, and interchangeability of the part it defines. European parts standards usually control only a limited number of features of the parts, leaving other important aspects, such as quality, to each manufacturer. Thus, a careful examination of any foreign metric standard must be made to determine that its use will help meet the objectives of the LST program and that the costs of compliance with the standard are acceptable.

Design

The use of metric units in design for the LST is discussed in terms of:

- Mechanical-design analysis
- Electrical/electronic-design analysis
- Optical-design analysis
- Systems-design analysis
- Materials selection
- Components selection
- Drafting

Most engineers are familiar with the metric system because these are the units of measure universally used in the study of chemistry and physics. Some engineering disciplines, particularly electrical and electronic, presently use some metric units because the basic units of measure are the same in both systems. Other engineering disciplines, such as optics, traditionally use metric units extensively although manufacturing is customarily done in English units. The principal design problems associated with metric units occur in areas that are mechanically oriented, such as mechanics and stress analysis.

The major factors associated with the development of a metric design are discussed below for each of the major pertinent disciplines (mechanical, electrical/electronic, optical, and systems design analyses) and for three associated design functions (material selection, component selection, and drafting). Recommended metrication approaches are described for each of the seven design activities, and the cost impact of these recommendations is estimated.

Mechanical-Design Analysis

For purposes of this discussion, mechanical-design analysis is assumed to include analytical calculations, conceptual design, and establishing principal dimensions.

Major Factors. Four major problem areas are envisioned in the metric design of mechanical components and assemblies by engineers accustomed to using English units: (1) the selection of appropriate metric standards, (2) the translation of English engineering standards, (3) the use of established calculation procedures, and (4) the loss of engineering efficiency. Each of these is discussed briefly.

As mentioned previously, metric standards are available from a wide variety of sources. Many of these are either conflicting or competitive. In addition, most metric standards do not completely define the item and extensive design and production information often must be formulated to supplement a metric standard. Finally, many design areas and parameters have no available metric standards. Thus, the transitional state of metric standards presents the designer with a major problem in the development of a basic metric design.

U.S. industry in general and U.S. Government procurement in particular is based on a wide variety of engineering standards. All U.S. industry is estimated to use about 60,000 standards. Typical of these are: Government standards (for procurement and engineering), technical society standards (for materials and components), industrial standards (for materials and products), and company standards (which are extensive in aerospace companies). Information in these standards for the mechanical engineer is usually given in English units. Thus, judgments must be made concerning: (1) the standards that are applicable to the LST, (2) the values in the applicable standards that must be translated, and (3) the documentation of the necessary translations so that appropriate engineering personnel will have the proper values at the proper time. For the Metric Maverick[6], as an example, Hughes found that 35 of 98 first-tier documents, and 167 of 1108 second-tier documents required some degree of translation for design in metric units. This did not include standard design manuals such as MIL-HDBK-5.

It is generally acknowledged that engineers must gain design experience with metric units for the U.S. to make an effective transition to the metric system. This does not seem to be a major problem for hand calculations. However, many engineering calculations are made by or in conjunction with computer programs. Since most of these programs have factors based on English units, a significant problem is faced in the translation of these programs into metric units. Such conversions will have to be made eventually, but the cost for the LST program could be high if substantial conversion were required. This is particularly true for computer programs based on empirically developed data.

The fourth major problem area for mechanical engineers is an unfamiliarity with all the applicable SI units and the loss of intuitive judgment gained during many years of using English units. In using metric units, the mechanical engineer will be spending extra time in the design process deriving, validating, and applying the new translations and equations. He will also spend extra time checking his results, committing and correcting mistakes, and carrying along extra figures in the conversion calculations to protect the accuracy and consistency of his calculations. The inefficiency of these extra steps in the design process will be lessened but not eliminated by training. Even with the guidelines of SAE J-916, the engineer must make decisions on where to round off calculations and when to carry dual dimensions or dual calculations. These inefficiencies diminish as an engineers work continues, but the impact could be significant for up to 6 months.

Recommended Approaches. The following approaches are recommended in regard to the major problems facing the mechanical designer for the LST.

- Selection of Metric Standards. It is recommended that a small group (two or three may be sufficient) of mechanical engineers be assigned the task of deciding which available metric standards should be used for the LST. As mentioned previously, these standards should be limited, for the most part, to ISO recommendations. When foreign or domestic metric parts are considered, the controlling standards should be examined carefully for completeness and for lack of conflict with ISO recommendations.

- Translation of English Standards. It is recommended that a small group (one or two may be sufficient) of people be trained to serve as translators for the values in English standards into metric units on an as-needed basis. As the applicable values become identified, an expanded list of equivalents can be prepared periodically.

- Calculation Procedures. It is recommended that all hand calculations be made in SI units, and that any new computerized relationships be expressed in metric units. Where it is apparent that SI units may complicate communications, customary units may also be reported. Where results are rounded off into even units, metric modules shall be used. For existing computer programs that cannot be easily used in metric units, it is recommended that the input data be in basic metric units translated into English equivalents and that the output (in English units) be translated into metric units.

- Engineer Experience. It is recommended that each mechanical designer be given a brief (up to 1 week) introduction to the metric system and to the translation between English and SI units. This introduction should include the concept of designing in basic metric units. Periodic follow-ups should be made to alleviate unexpected problems.

While the requirement that analytical calculations be made in metric units will have a significant cost impact, the cost impacts will be accompanied by proportionate benefits. Much of the cost impact will be the result of engineer education and training, which is a desired benefit of LST metrication. Some software conversion will also be accomplished--the costs and benefits being equivalent.

It is believed that allowing mechanical-design calculations to be expressed in English units would seriously detract from the significance of LST metrication.

Electrical/Electronic Design Analysis

Major Factors. Electrical/electronic design can be divided into two major areas: (1) circuit analysis and design and (2) electromechanical design and drafting. Circuit design includes design, analysis, and breadboarding of a circuit to ensure that it meets functional requirements. Electromechanical design and drafting are the translation of the circuit design into formal documentation from which hardware can be produced. For this discussion, the former is considered to be the definition of electrical/electronic design analysis, and the latter is considered to be mechanical engineering design.

The impact of the use of SI metric units on circuit design is minor since the common electrical units of volts, ohms, amperes, watts, etc., already are largely metric. One exception is temperature, although requiring the use of the Kelvin scale should impose no particular burden on electrical/electronic design.

The impact of metric units on electrical/electronic product design could be fairly significant because of problems similar to those faced by the mechanical designer, i.e.: (1) selection of applicable metric standards, (2) translation of English standards, (3) inefficiency due to the use of unfamiliar units, and (4) difficulty in procuring metric hardware and pieceparts, if required.

Recommended Approaches.

- It is recommended that analytical calculations be carried out and reported in SI metric units
- In all other respects, U.S. customary practice is recommended for electrical/electronic system design, including electromechanical design, with the following exception
- It is recommended that metric-module design be used for mounting details of new electrical/electronic equipment to be developed.

It is judged that a more strict degree of metrication with regard to piece-parts and electromechanical design in particular would impose a substantial cost impact on the LST program. Further, it can be judged that since electrical/electronic circuit design analysis is significantly metric already, the requirement for stricter metrication would not accomplish any important education and training function for circuit designers. Additionally, electromechanical design does not have much visibility, being largely mechanically enclosed, potted, or imbedded in a circuit board. No intent to deceive is made in judging that it is more important to metrify those areas of the LST having the greatest visibility.

Optical-Design Analysis

Major Factors. Use of the metric system in the optical design of the LST should have little impact because optical design of the light path and component shape has historically been performed using metric units. As an example, the following advantages were found for the Metric Maverick[6] during consideration of the metric design.

- The optical laboratory equipment at Hughes uses the metric system. For most programs, much engineering time is needed to convert the measured results to English units. For instance, calculations are necessary in converting bench measurements to drawings for frame assemblies
- For any product using English units, each lens assembly must be dimensioned in the English system at some interface point. Engineering time is expended in making and checking the drawings to insure that the proper conversions have been made
- Metric specifications are more likely to be interpreted correctly by lens manufacturers and suppliers because it is current practice for lens manufacturers to work entirely in the metric system

However, in the case of optical components such as the primary and secondary mirrors, it is clear that U.S. customary practice is to dimension and rough machine in English units. Final polishing, on the other hand, is evaluated in terms of wavelengths--customarily a metric (but not necessarily SI metric) unit.

For purposes of this discussion, optical-design analysis will be considered that portion of the work excluding mechanical analysis, structural design, and drafting. The latter functions will be considered a mechanical-design activity.

Recommended Approaches. Because optical-design analysis is customarily metric, only the second of the following recommendations can be considered significantly different from customary practice:

- Optical-design analysis shall be conducted and reported in SI metric units
- Recommendations for mechanical design reported elsewhere in this report shall apply to the mechanical design of optical components.

The use of SI units in calculations may involve the use of nanometers instead of Angstrom units; however, no other significant impacts are expected. With regard to mechanical design of optical components, justification for the recommendation has been discussed elsewhere in this report.

Systems Design Analysis

Major Factors. The LST systems design analysis effort can be considered in three related areas of work: (1) integration of the three major subassemblies into the LST system, (2) integration of the major elements within each subassembly, and (3) LST system analysis. Brief discussions are given of major aspects of these work areas that relate to use of metric units.

The integration of the three major subassemblies into the LST involves the technical management and control of the interfaces between the subassemblies to assure proper fit and operation. Because both English and metric units are expected in each subassembly, the systems designers must be especially skilled in the use of both systems of units to insure proper translations between units and to check the selection of tolerances between parts using different units. The integration activities will probably be formalized in some kind of documentation (such as design reviews) that can be made available to the three facilities expected to produce the three subassemblies and to the controlling NASA technical office. The work of integration and of document preparation will be significantly increased because of the need to work with both English and metric units.

The integration of the major elements within each subassembly will be similar to the work of overall integration except that less documentation impact is expected. Since each subassembly will be tested against certain performance requirements within the manufacturing facility, much documentation can be replaced by manufacturing and test procedures. However, each subassembly will probably need systems designers specially versed in both systems to assist in the control of design and manufacturing quality.

The LST systems-analysis effort will be required during the evaluation of the assembled LST. It is basically a feed-back process whereby all the various test results are compiled and analyzed to insure the performance and reliability of the overall system. In this type of work, computer simulation studies will be made to determine the response of the LST to normal and abnormal operating conditions. The need to work with both English and metric units will reduce the efficiency of this activity.

Recommended Approach. It is recommended that systems-analysis calculations be conducted and reported in SI metric units.

It is believed that this approach is necessary to be consistent with the recommendation that other design-analysis calculations be carried out in SI metric units.

To minimize the problems of system design of the LST occasioned by the use of metric units, it is recommended that the system designers of all aspects be gathered together for a special course (up to approximately two weeks) during which the problems of unit translation could be explained and special skills could be gained. Common approaches to documentation could also be explained during the training period.

Materials Selection

Major Factors. In 1967, the Hughes Aircraft Company[6] decided that standard stock sizes in English units should be utilized for the Metric Maverick. Consideration of material selection for the LST has led to a different recommendation. The major factors considered were: (1) dimensional standards, (2) special aluminum orders, and (3) special steel orders. These factors are reviewed briefly as background for the recommendation.

Although ISO recommendations are becoming a significant factor in the thinking of U.S. metal suppliers, most of the recommendations to date have dealt with chemical analysis and quality control. The lead for dimensional recommendations is being taken by ISO steel committees, but this work is proceeding slowly. During the design of the LST, many shapes that are standard in English units will probably not be described in ISO recommendations, and few, if any, metric sizes may be available from stock. On the other hand, the specification of nonstandard dimensions for materials is a common aerospace procedure because of the need to achieve minimum weight. Therefore, the delineation of metric stock dimensions for the LST based on performance requirements would exemplify much future metric design in the aerospace industry even when standard metric stock becomes available.

The special ordering of aluminum is so standard that suppliers have set up procedures to furnish quick estimates and fairly quick delivery. An order in metric dimensions would be handled as any special order, although it may be necessary for the designer to translate metric units into English units. Special orders for aluminum are common for extrusions or rolled stock. For extrusions, the cost penalty is primarily related to the costs for special extruding dies. These can range from $150 up to several hundred dollars. Special aluminum orders are usually filled within 8 weeks.

According to the Republic Steel Company[7], aircraft-quality steels are so specialized that there is little attempt to fill orders from stock. Certain stock sizes are usually kept on hand as a source of material for forming to dimensions required by orders. Thus, no time or cost penalty would be incurred by the use of nonstandard dimensions. Republic Steel would not require English units. An order in metric units would be translated by Republic into English dimensions with tolerances equal to those achieved by the forming equipment. These translated dimensions would be placed on the confirming order for review by the LST designers. However, since competitive bidding may be required for materials, it may be necessary for the designer to translate the metric units into English units.

Recommended Approaches. It is recommended that special orders of aluminum and steel stock for components developed for the LST be dimensioned in basic metric units. This will impose no significant time or cost penalty on the program and it will help designers achieve a basic metric design. In some cases it may be possible to select dimensions according to ISO recommendations. It is recommended that U.S. customary materials properties be specified. Some suppliers have begun the translation of material properties from English units to SI units.

Parts Selection

Major Factors. As summarized previously in the Guiding Principles Section of this report, available parts are to be utilized on the LST to a large extent. Because little metrication has been accomplished yet in the U.S., most of these parts are expected to be described in English units. For an assembly made up of such parts, this will result in a uniformity of units for the assembly. For an assembly that consists largely of newly designed parts, it will be desirable to determine whether purchased parts are available with metric dimensions to assist in achieving a basic metric design. Some parts, such as bearings, have commonly been available with metric dimensions. Other parts, such as O-rings, are becoming available in metric dimensions. Still other parts are available from foreign sources with metric dimensions. For all such metric parts, it will be necessary to determine that the metric dimensions do not conflict with ISO recommendations and that the associated documentation of such parts assures adequate quality and performance.

The problems with threaded fasteners are unique and require special consideration. Much of the early work at ISO was involved with screw threads, and a number of recommendations have been prepared by the ISO on threaded fasteners. In addition, representatives of U.S. industry have been meeting for several years on the problems of metric threaded fasteners and some U.S. companies plan to produce metric fasteners in the near future.

However, little, if any, of this progress with commercial metric threaded fasteners is directly applicable to aerospace threaded fasteners. This primarily stems from three differences:

- Commercial threaded fasteners tend to use coarse threads to reduce fastener manufacturing costs and to facilitate assembly with power tools. Aerospace fasteners usually use fine threads for an improved strength/weight ratio.
- Commercial requirements tend to reduce the number of sizes to reduce tooling and inventory costs. Aerospace requirements tend to increase the number of sizes to permit low-weight joint designs.
- Commercial fasteners use materials which balance strength against fastener fabrication costs. Aerospace fasteners usually use much higher strength materials than commercial fasteners for low joint weight.

Representatives of U.S. aerospace interests have been meeting with the ISO committees on commercial fasteners and it is mutually hoped that compatible threaded-fastener standards can eventually be developed for both segments of the industry. However, there are many serious problems to be resolved in the development of satisfactory aerospace metric threaded fasteners. In addition, since many European aerospace companies use English-system threaded fasteners, there is less pressure internationally to develop aerospace metric fasteners. It has been estimated that it will probably take at least five years to develop an internationally recognized series of aerospace metric threaded fasteners. Typical of the basic problems awaiting agreement are:

- <u>Tolerances</u> - The U.S. and European philosophies on shank tolerances are significantly different and the difference appears difficult to resolve

- Thread Type - Thread type has not been selected because many want an asymmetric thread for improved performance
- Pitch-Diameter - The pitch-diameter relationship has been a strong point of contention

Recommended Approaches. The following approaches are recommended in regard to purchased parts for the LST:

- English-System Parts. It is recommended that English-system parts be procured when the majority of parts in the immediate assembly are defined in English units
- Metric-System Parts. It is recommended that serious consideration be given to metric system parts when the majority of parts in the immediate assembly are defined in metric units. Care should be taken to assure that the metric parts have adequate documentation and control and that the metric units do not conflict with ISO recommendations
- Threaded Fasteners. It is recommended that metric threaded fasteners of aerospace quality should not be required in the LST because of the expected absence of ISO standardization. It is recommended that metric threaded fasteners of commercial quality be used when: (1) their performance is acceptable, (2) their use will help achieve a basic metric design, and (3) their dimensions do not conflict with ISO recommendations. Guidelines for threaded fasteners should be studied further.

Drafting

Major Factors. The major drafting factors related to the use of metric units are discussed in terms of: (1) dimensions, (2) drafting standards, (3) drafting equipment, and (4) training.

The ISO has issued two major drafting recommendations: R128 - Engineering Drawing, Principles of Presentation, and R129 - Engineering Drawing, Dimensioning. For the Metric Maverick, Hughes[6] found that these recommendations were generally acceptable. The recommendations allow the use of either the European "first angle" or the American "third angle" drawing projection technique. After considerable investigation, Hughes judged the third angle technique to be much preferred because it was more familiar to the manufacturing personnel as well as to the design personnel. The SAE Metric Advisory Committee has formulated SAE Standard J390 Dual Dimensioning. This standard was the first standardized dual dimensioning procedure to be published in the U.S.

It is assumed that paper for drafting and for reproduction will be available in English units. The procurement of paper in metric units would undoubtedly be possible, but its use does not appear to be justified. Metric paper would not seem to assist personnel in "thinking metric". Drafting scales, on the other hand, are highly important in metric design for engineers as well as designers and draftsmen. Metric drafting templates are also important layout and detailing tools. One or two planimeters in metric units may be needed. A reasonable attempt should be made to obtain drafting machines calibrated in radians instead of degrees since this is a basic SI unit. However, if such machines are not available, translations can be made.

In addition to becoming familiar with the requirements of ISO R128 and R129, the primary problem for the draftsman is the development of familiarity with SI units. For example, the use of radians instead of degrees will require significant mental readjustment. Callouts that are second nature in English units must be made in basic metric units. Often the preferred numbers will not be readily available. For instance, what metric dimensions should be used for a 3/16-inch casting radius or a 1/4-inch weld fillet? Answers to such routine drafting problems can be found, but inefficiency will be encountered in the early months.

Recommended Approaches. The following recommendations are made in regard to drafting in metric units.

- Dimensions. It is recommended that drawings be prepared with dimensions in metric units. Metric-module dimensions are preferred where their use is feasible, and, in fact, it should be considered necessary that dimensions for new components be predominantly in metric modules. It is recommended that dual dimensioning be allowed. Where dual dimensions are to be used, careful study should be given in establishing a procedure for conversion to English units so that desired tolerances are preserved to the greatest reasonable extent. Once established, this procedure should be followed diligently.
- Drafting Standards. The recommendations of ISO R128 and R129 should be followed in the preparation of metric drawings. The third angle drawing projection technique should be used. Consideration should be given to the use of SAE Standard J390 for dual dimensioning.
- Drafting Equipment. Standard customary machines should be equipped with metric scales and with angular notations in radians, if possible. Metric templates should be used, if possible.
- Training. All drafting personnel should be given a short course (up to 3 days) in the use of metric units, and a few persons should be given special training to assist with special problems that arise in regard to drawing standards and translation between units.

As discussed previously, the consistent use of metric-module dimensions will be an important feature of LST working drawings. Using metric units for dimensions is considered a basic requirement for achieveing a metric-module design.

The allowance of dual dimensioning is considered consistent with the judgement that the fabricators will not necessarily be motivated to convert their equipment to the metric system for a one-of-a-kind manufacturing process.

Fabrication

The problems of metrication in the fabrication of the LST are discussed in terms of four areas: (1) machinery conversion, (2) small tool procurement, (3) personnel impact, and (4) subcontracting.

Machinery Conversion

Machine tools can be converted to metric operation by the addition of metric readout devices or, for numerically controlled machines, by changes in their program instructions. Several types of readout conversion devices are available for standard machines. Purely mechanical converters are among the least expensive, most easily installed, and sufficiently accurate for the many operations not requiring critical dimensional accuracies. Optical and electronic readout conversion devices can provide extreme accuracies with an attendant increase in cost, and digital devices, with a large increase in cost, provide both extreme accuracy and ease of use.

Simple mechanical converters consist of dial pointers, numerical indicators driven by gear trains attached to the ends of lead screws on lathes, grinders, and milling machines. The units cost approximately $300 and can be installed and removed in 30 minutes. They are sufficiently accurate for machines working to tolerances of 0.025 mm (0.001 inch) or larger; the unit accuracy depends on lead screw accuracy. More complex converters measure tool or head motion independently of the lead screws and indicate measurement by vernier position on a graduated scale. Most conventional machine tools will accept such an installation easily. These converters are an order of magnitude more accurate than the converters mentioned above because they are not vulnerable to lead screw inaccuracy. They are zero adjustable to allow rapid setup and eliminate the need for paper calculations. The units cost approximately $400.

An option requiring somewhat greater capital expenditure is the replacement of existing lead and crossfeed screws with metric screws.

Optical readout units use high precision engraved scales with dimensional resolution achieved through optical magnification. These provide precision capability and are commonly used on jig borers, precision lathes, and mills. The units cost approximately $600.

There are several digital readout (DRO) units on the market using electronic, photo-scanning measurement methods, and transducers attached to the lead screws to provide digital readouts of position. Some manufacturers are producing these systems in proven designs that can be purchased with metric unit displays and can be attached to almost any precision machine. Their prices range from $3000 to $12,000 per installation depending on how many axes are to be read out.

Small Tool Procurement

A number of small tools, machine accessories, perishable tools, and measuring devices for metric dimensions will be needed to sustain the fabrication and assembly of the LST. Typical of these are the following:

- Precision Measuring Tools: This category includes micrometers, calipers, height gauges, rules, squares, indicators, gauge blocks, Deltronic plug gauges, bore gauges and check rings, and Pla-checks.
- Machine Shop Assessories: This group includes collets for lathes and mills.
- Hand Tools: Hand tools include combination open end and box wrenches, socket wrench sets and torque wrenches calibrated in metric units of measure.
- Tool Kits for Operating Personnel: Machinists, sheet metal workers, electronic assemblers, and technicians will require a tool kit containing a selected grouping of tools for each of the various familiar efforts.
- Perishable Tools--Cutting Tools; This group includes all cutting tools, such as drills, reamers, end mills, hobs, etc.

Personnel Impact

The personnel impact can be divided into two areas: (1) training requirements and (2) loss of efficiency resulting from the use of English and metric systems.

The training requirements for fabrication personnel are of four general types: (1) develop an understanding of the ground rules of fabrication using two measuring systems, (2) become familiar with metric versus the English system, (3) perform metric-to-English conversion, and vice-versa, and (4) become knowledgable of the tools and documentation required in the performance of metric tasks. In the fabrication area, the depth to which these requirements must be covered is a function of the position classification; i.e., the requirements are significantly greater for a production engineer than for a lathe operator.

Personnel efficiency considerations include the factors of learning traits, regression tendencies, scrap rates, and personnel attrition. All areas of fabrication - machine shops, sheet metal shops, processing shops, mechanical assembly, support, and quality control - will be affected by the use of dual units. For the Metric Maverick, Hughes estimated that the increase in costs due to inefficiency and training would be 50 percent in the first 4 months, 30 percent in the next 2 months, and about 10 percent for the reaminder of the fabrication effort.

Subcontracting

No particular problems are envisioned in the subcontracting of LST components to be furnished in English units. The subcontracting of parts to be furnished in metric units, however, could present problems. Even with a potential production contract, Hughes[6] obtained a variety of responses from prospective subcontractors concerning the fabrication of parts to metric units for the Metric Maverick. In general, there was considerable reluctance to accomplish machinery conversion for one production run when the companies believed that satisfactory parts could be produced by using dimensions translated to English units.

This reluctance would appear to be much greater for the LST since no production run would be expected. Thus, it appears unlikely that significant metrication impact can be made on subcontractors for the LST unless a firm is so interested that a degree of company investment in metrication would be acceptable as a part of the subcontract.

Recommendation

It is recommended that NASA plan tentatively to give fabricators the option of working in metric or English units. If fabrication is done in English units, dual dimensioned working drawings should be prepared by the engineering group responsible for design so that proper control over tolerance conversion is maintained.

It is judged that, at present, many potential component fabricators are not prepared to begin working in metric units, and, therefore, NASA would be unjustifiably restricted in their choice of contractors and component vendors if fabrication in metric units only was a requirement.

It is also recommended that the chances for manufacturing error associated with the use of dual dimensioning be given further study by NASA and/or the LST prime fabricator. Such a study could lead, for example, to a recommendation that final inspection be conducted in metric units with metric equipment.

It should be emphasized that, while the above recommendations appear appropriate for the year 1973, the circumstances for such a decision may have changed by the time the final contracts for LST are to be let. For example, if many aerospace companies have conducted in-house conversion programs by then or have gained metric-system experience on other programs, it would probably be counterproductive for NASA to allow English-unit fabrication.

Therefore, it is further recommended that NASA remain open on specifications for fabrication at this time. The appropriate decision can be made only when the circumstances are known.

Test, Evaluation, and Operational Activities

It is expected that the recommended approach to metric design for the LST will have negligible impact on test, evaluation, and operational activities.

Metric design will have no impact on the function and output of the scientific instruments, i.e., the field cameras, spectrographs, and the interferometer, nor will it affect the function of the associated alignment sensors and mechanisms. It is assumed that light-path requirements, variations, and errors are customarily described in metric units. The function of neither the static nor the moveable structural components will be impacted by their metric design, except that it will probably be desirable to measure deflections or motions in metric units. Description of deflection in metric units will possibly simplify the handling of optical-system alignment and errors.

For components connected with sensing-and-control systems, electrical-power systems, communications, data management, and associated electronics, either existing equipment is used or U.S. customary practice is allowed. Accordingly, no impact is expected for these systems.

An area of possible impact is the stocking of spare parts for the LST. Components such as rivets and threaded fasteners which are normally standard items could possibly be peculiar to the LST, in which case special stocks would be required. It is believed this will result in a minor impact, particularly since few metric-standard components of these types will be available for use.

Similarly, and for the same reasons, it is expected that commonality with other NASA scientific-experiment payloads will not be impacted to any significant degree.

ESTIMATED COST IMPACT

The cost increase caused by the procedures recommended for metrication in design of the LST has been estimated for each design function. These estimates have then been integrated to derive an estimate for the overall design effort (including the effects of overall system integration effort) at the levels of the three major system elements--that is, the OTA, SI, and SSM. As noted previously, it was deemed satisfactory, desirable, and necessary to make maximum use of the results of previous systems studies and other efforts by individuals, companies, governmental agencies, etc. in view of the limited time and resources available for this study. Thus, the results of the substantial previous efforts by Hughes Aircraft Corporation for the Metric Maverick[6] and by North American Rockwell for the Space Station Phase C[8] have been used as the principal bases in deriving the results presented here. These previous results were tempered considering the efforts and experience of others and the BCL staff's own experience and engineering judgment. In applying all of these to analysis of the impact of metrication on LST design, the individual components for each of the major system elements were analyzed in terms of functional effort required in view of the nature of component (that is, mechanical, electrical/electronic, and optical elements) and whether the component to be used was "new" or "existing" (see Appendix A).

Estimate by Design Function

Figure 3 shows the estimates of LST design-cost increases (percentage) in terms of the seven design functions defined previously. Since the Maverick data was a principal base in the analyses performed here, it is useful to compare the BCL LST estimates with the Maverick estimates and comment briefly on the similarities and differences in approach and results for each function. The Space Station estimates cannot be compared in a similar manner because a less detailed breakdown of engineering effort was used.

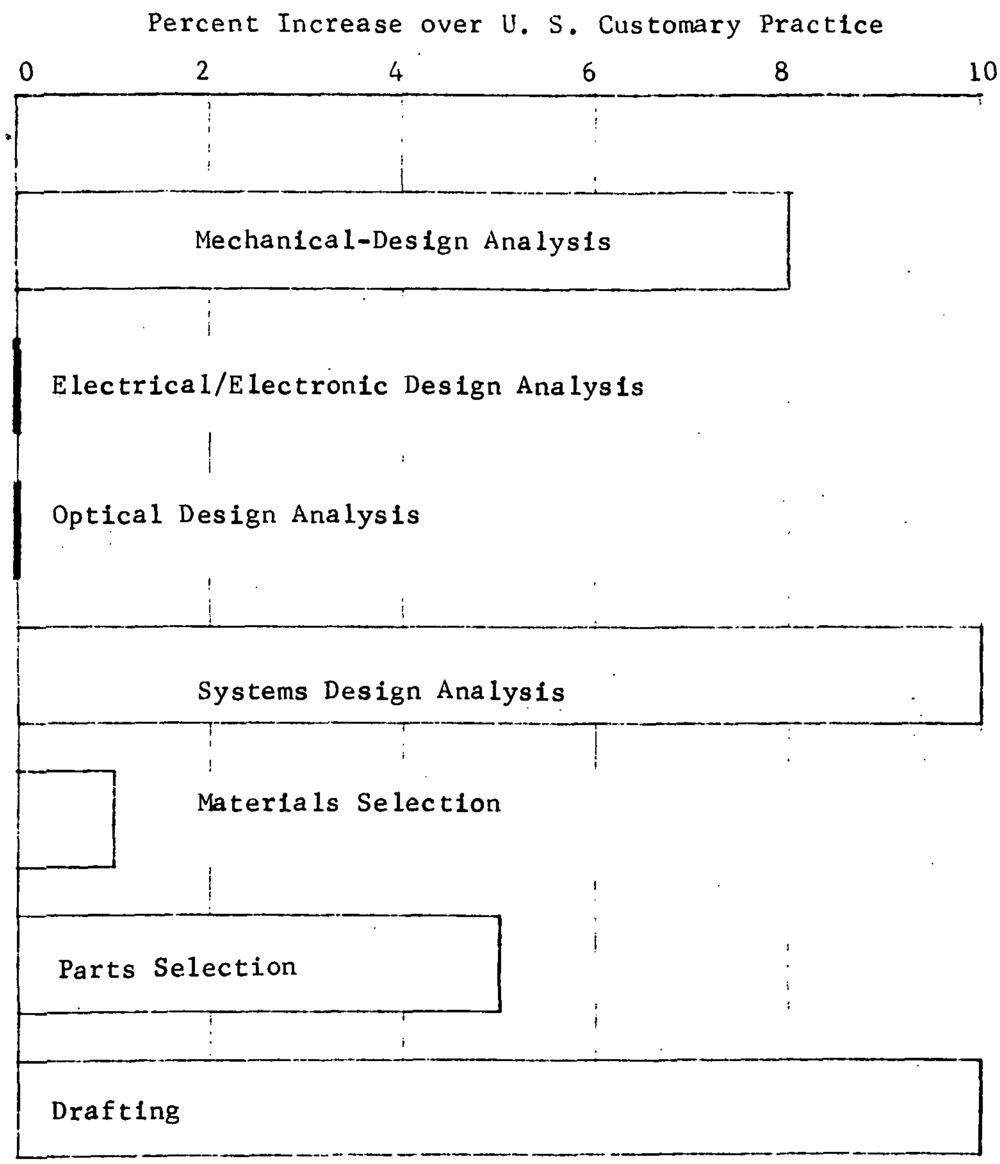

FIGURE 3. ESTIMATE OF COST INCREASE BY DESIGN FUNCTION

(1) Mechanical Design

- Maverick: +8 percent
- LST: +8 percent
- Comment: Recommended approaches are similar.

(2) Electrical/Electronic Design

- Maverick: +4 percent
- LST: Negligible impact
- Comment: Recommended approach for the LST differs little from customary U.S. practices. Therefore, there appears to be no reason to expect a significant impact.

(3) Optical Design

- Maverick: -1 percent
- LST: Negligible impact
- Comment: The Maverick estimate (negative) was considered optimistic. It is believed that the impact of savings (benefits) from reduced need for unit translation would be negligible relative to the total optical design effort. If it is not, this will be a bonus.

(4) System Design (and/or interaction)

- Maverick: +13 percent
- LST: +10 percent
- Comment: Some problems envisioned in integrating the Maverick with the aircraft are not considered significant for the LST which needs to be integrated with the shuttle only for brief periods during which it would be relatively independent of shuttle systems. Other problems are analogous.

(5) Materials Selection

- Maverick: Negigible
- LST: +1 percent
- Comment: Maverick proposed to use existing standard dimension materials, while some metric specifications is anticipated for the LST. It is believed that dialog with suppliers and procurement problems cannot be neglected for the LST.

(6) Parts Selection

- Maverick: Not estimated
- LST: +5 percent
- Comment: Approaches are similar; however, although except for structural and optical items many parts for the LST will be purchased to English specifications, it is considered that those parts purchased to metric standards will lead to significant expenditures of time and costs.

(7) Drafting

- Maverick: +12 percent
- LST: +10 percent
- Comment: Although the basic approach and problems are similar for the two systems, there should be less interface problems for LST.

Impact on Overall LST Design Effort

Using the estimates presented in the previous paragraphs for cost impact on the various design functions, it is necessary to approximate the relative amount of each type of function that will be expended in the design of the LST to obtain an estimate for overall impact on design effort. This has been done in a two-step procedure described below.

A rationale was used in which the design-effort content of each LST subsystem class was broken down into three categories: (1) mechanical, (2) electrical/electronic, and (3) optical. These breakdowns were based on a combination of engineering experience and a detailed study of the design of the subsystems as presently defined and described in tabular form in Appendix A.

To accompany these values, estimates of the increase in time and cost for the three design categories (mechanical, electrical/electronic, and optical) were derived from the cost-impact values presented in the preceeding section of the report. It will be recognized that the design of mechanical components includes not only what has been characterized previously as a "mechanical-design analysis" function, but also comprises the system analysis, materials selection, component selection, and drafting functions. Table 1 shows an assumed content for each of these functions in the overall mechanical design process. Using these content factors and the cost-impact values for each engineering function presented in the preceeding section of this report, a cost-increase estimate of 8 percent is derived for the overall mechanical design process.

TABLE 1. IMPACT OF RECOMMENDED METRICATION APPROACH ON MECHANICAL-DESIGN EFFORT

Activity	Assumed Fraction of Total Effort	Assumed Δ Effort for Type of Activity	Δ Effort
Mechanical Design Analysis	0.6	0.08	0.048
Systems Analysis	0.1	0.10	0.010
Materials Selection	0.05	0.01	0.001
Component Selection	0.05	0.05	0.002
Drafting	0.2	0.10	0.020
		Total	0.081

A cost increase of zero for electrical/electronic design analysis has been presented in the preceding section. However, it is judged that the overall electrical/electronic design process will be comprised of about 20 percent systems analysis. Systems analysis, in turn, has been estimated to increase by 10 percent. Accordingly, a 2 percent increase in cost for electrical/electronic design has been assumed.

It has been further judged that the optical-system design-analysis process will not be affected by metrication, and the cost impact for this function will be zero. It may be argued that optical design has a significant level of systems-analysis content; however, it is assumed that the systems-analysis content of optical-system design is traditionally in metric units and therefore the zero-impact assumption is believed to be valid.

In summary, the following estimates for cost increase of the three design categories are derived:

Design Category	Estimated Cost Increase
Mechanical	8 percent
Electrical/Electronic	2 percent
Optical	0

Using the above factors in the computations shown in Tables 2, 3, and 4 produces the desired cost-increase estimates. In these tables, the design-category content factors for each subsystem class (i.e., the relative amount of design effort in each of the mechanical, electrical/electronics, or optical categories) is multiplied by the cost-increase factors previously estimated for each category (8 percent, 2 percent, and zero, respectively). The sum of these products gives a Δ design effort for each subsystem class. Since not all subsystem classes represent an equal amount of design effort, a weight factor has been estimated for each class, expressed in terms of fraction of total effort. Multiplying each value for Δ design effort by the weight factor and summing the products produces the desired overall design-cost estimate for each subsystem. Rounding off the results gives the following derived estimates for increase in LST overall design costs, by element, consistent with the recommended approach:

TABLE 2. IMPACT OF METRICATION ON OTA DESIGN EFFORT

Subsystem Class	Design Content			Δ Design Effort for Class[1]	Subsystem Class Weight Factor, Fraction of Total Effort	Δ Design Effort for Element
	Mech.	Elect.	Optical			
1. Optical components	0.3	0	0.7	0.024	0.3	0.0072
2. Mechanical/ structural components	1.0	0	0	0.080	0.2	0.0160
3. Mechanisms	0.8	0.2	0	0.068	0.2	0.0136
4. Alignment sensors	0.3	0.4	0.3	0.032	0.2	0.0064
5. Heaters	0.6	0.4	0	0.056	negl	--
6. Electronics boxes	0.1	0.9	0	0.026	0.1	0.0026
					Δ Design Effort for Element	0.0458

(1) $\begin{bmatrix} \text{Mech.} \\ \text{Elect.} \\ \text{Optical} \end{bmatrix} \times \begin{bmatrix} 0.08 \\ 0.02 \\ 0 \end{bmatrix}$

TABLE 3. IMPACT OF METRICATION ON SI DESIGN EFFORT

Subsystem Class	Design Content			Δ Design Effort for Class (1)	Subsystem Class Weight Factor, Fraction of Total Effort	Δ Design Effort for Element
	Mech.	Elect.	Optical			
1. Image-tube electro-optical systems	0.1	0.6	0.3	0.020	0.4	0.0080
2. Optical-mechanical systems	0.3	0.2	0.5	0.028	0.2	0.0056
3. Electronics boxes	0.1	0.9	0	0.026	0.2	0.0052
4. Electrical cabling and connectors	0	1.0	0	0.020	negl	--
5. Static structural components	1.0	0	0	0.080	0.1	0.0080
6. Thermoelectric thermal control devices	0.3	0.7	0	0.038	0.1	0.0038
					Δ Design Effort for Element	0.0306

(1) $\begin{bmatrix} \text{Mech.} \\ \text{Elect.} \\ \text{Optical} \end{bmatrix} \times \begin{bmatrix} 0.08 \\ 0.02 \\ 0 \end{bmatrix}$

TABLE 4. IMPACT OF METRICATION ON SSM DESIGN EFFORT

Subsystem Class	Design Content			Δ Design Effort for Class (1)	Subsystem Weight Factor, Fraction of Total Effort	Δ Design Effort for Element
	Mech.	Elect.	Optical			
1a. Sensing and Control (New)	0.3	0.7	0	0.038	0.05	0.0019
1b. Sensing and Control (Existing)	-	-	-	0	0.15	--
2a. Electrical (New)	0.6	0.4	0	0.056	0.1	0.0056
2b. Electrical (Existing)	-	-	-	0	0.1	--
3a. Communications & Data Management (New)	0.5	0.5	0	0.050	negl	--
3b. Communications & Data Management (Existing)	-	-	-	0	0.2	--
4. Thermal Control (New)	0.8	0.2	0	0.068	0.05	0.0034
5. Contamination Control (New)	1.0	0	0	0.080	0.05	0.0040
6. Structure (New)	1.0	0	0	0.080	0.3	0.0240
					Total	0.0389

Element	Cost Increase
Optical Telescope Assembly	5 percent
Scientific Instruments	3 percent
Support Systems Module	4 percent

On the basis of these estimates, it is reasonable to expect the overall design cost increase to lie within a range of 3 to 5 percent, probably about 4 percent, if the recommended approach to metrication is followed.

Since increased costs are principally the result of increased engineering-effort requirements, the estimated time and cost increases are assumed to be equivalent.

It should be pointed out that these costs would be incurred only if the contractor has no previous metric-design experience. Those organizations having previous experience or having previously conducted metric training courses for their staff would be expected to incur lesser costs. Further, since there will be a competitive bidding situation for Phase B contracts, potential contractors may elect to conduct all or part of the necessary training at their own expense.

The overall LST design cost increased estimate of 4 percent is modest compared to the Hughes estimate of 13 percent for the Metric Maverick[6] and the North American Rockwell estimate of an 11-percent increase in engineering effort (not total design effort) for Phase C of the Space Station[8]. This can be attributed to the following:

(1) A somewhat less strict degree of metrication is recommended for LST, particularly in regard to electrical/electronic system design

(2) LST has a large optical-system design content which is not significantly impacted by metrication

(3) A substantial portion of the SSM will consist of adapted existing components which are not impacted by LST metrication.

Impact on Fabrication Costs

The impact of the use of dual-dimensioned drawings on the cost of fabrication was discussed with several knowledgeable sources within aerospace and other manufacturing industries, with optical-component manufacturers, and with Battelle-Columbus personnel. Without exception, there was the opinion that the cost impact would vary with the experience and attitude of the organization, but that it could be "almost negligible". Those organizations having conducted a conversion program would prefer to work in metric units; those who have not converted would prefer to work in English units.

One organization having recently converted an experimental shop to metric reported that no change in burden rate for that shop was encountered. An organization that has converted internally uses metric drawings with a conversion table on the drawing for outside procurement, and reports that they make it clear to their vendors that they do not expect any cost increase to result from the use of metric drawings. One organization contacted believed that the use of metric inspection equipment was needed even if machining was done in English units, and that the principal penalty would be the cost (minor) of this equipment.

Sources were generally reluctant to place an upper bound on the probable cost impact of the use of dual-dimension drawings; however, an increase of 5 percent appears to be consistent with the qualitative discussions relative to this point.

It would appear appropriate for NASA to assume a position that the fabrication cost increase due to metric design should be "almost negligible", and to make this position clear to potential contractors.

REFERENCES

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(3) SAE Handbook, Society of Automotive Engineers, Inc., 2 Pennsylvania Plaza, New York, New York, 10001.

(4) ISO Standards are available from American National Standards Institute, Inc., 1430 Broadway, New York, New York, 10018.

(5) Annual Book of ASTM Standards, American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19130.

(6) Metric Maverick System, Study Report, Volume 2, HAC Reference No. B 5158, Hughes Aircraft Company (1968) (AD 870 902).

(7) Personal communication with representative of Republic Steel Corporation, Cleveland District Sales Office.

(8) "International System of Units Conversion Assessment", Space Station Program Phase B Definition, NASA CR116458, Space Division, North American Rockwell (January, 1971) (X71-10242).

APPENDIX A

DESCRIPTION OF LST COMPONENT/SUBSYSTEMS

APPENDIX A

DESCRIPTION OF LST COMPONENT/SUBSYSTEMS

Tables A-1, A-2, and A-3 present a mechanical description of the OTA, SI, and SSM elements as they were believed to exist at the conclusion of the Phase A study. It should be emphasized that this configuration is tentative and can be expected to change in an evolutionary manner in subsequent study phases. Weight estimates are presented only for the purpose of describing component sizes, and no other use of these values is intended.

TABLE A-1. DESCRIPTION OF OPTICAL TELESCOPE ASSEMBLY COMPONENT/SUBSYSTEMS

Component/ Subsystem Class	Descriptors	No. Required	Estimated Weight, kg, each	Class Mechanical Description
1. Optical Components	1.1 Primary Mirror	1	2106	1. Glass-ceramic or doped silica monolithic mirrors. Primary mirror is hexagonal-honeycomb-cell cored. Secondary mirror is solid. Material alternatives are "Cer-Vit" and "ULE".
	1.2 Secondary Mirror	1	42	
2. Mechanical/ Structural Components	2.1 Primary Reference	1	440	2. Reference ring and pressure bulkhead assembly is titanium spherical dome with aluminum honeycomb core. Main truss and secondary mirror spider are graphite/epoxy structures. Aperture doors are aluminum honeycomb. Meteoroid shield, extendable sunshield, and light baffles are aluminum sheet skin over aluminum ring-and-stringer structure. Rings and stringers are angle, channel, hat, T, and Z sections fabricated from sheet metal; riveted construction assumed. Insulation blankets wrapped on outside of main light baffle; assumed to be metal-foil-jacketed fibrous material.
	2.2 Secondary Mirror and Spider Assembly	1	11	
	2.3 Main Truss	1	402	
	2.4 Aperture Doors	8	99 total	
	2.5 Meteoroid Shield	1	672	
	2.6 Extendable Sun Shield	1	343	
	2.7 Light Baffles, Main, Secondary and Inner	3	292 total	
	2.8 Insulation Blankets	?	?	

TABLE A-1. DESCRIPTION OF OPTICAL TELESCOPE ASSEMBLY COMPONENT/SUBSYSTEMS (Continued)

Component/ Subsystem Class	Descriptors	No. Required	Estimated Weight, kg, each	Class Mechanical Description
3. Mechanisms	3.1 Aperture Door Mechanism	8	?	3. Mechanical/structural parts linked by hinges, cam and roller, or track and roller. Actuator types include motor-driven jack-screw, linear harmonic drive motor, and piezo-electric force transducers.
	3.2 Pressure Bulkhead Door Mechanism	1	48	
	3.3 Sun Shield Extender Mechanism	6	?	
	3.4 Primary Mirror Force Actuators	25	?	
	3.5 Secondary Mirror Alignment Mechanism	1	23	
4. Alignment Sensors	4.1 Decenter Sensor	1	16	4. Electro-optical devices. Optical components statically mounted in tubular housings in most cases. Active mechanisms in focus and fine guidance sensor.
	4.2 Tilt Sensor	1	9	
	4.3 Figure Sensor	1	17	
	4.4 Focus Sensor	1	13	
	4.5 Fine-Guidance Sensor	1	116	
5. Heaters	No breakdown	?	45	5. Electrical resistance heaters bonded to rear surface of primary and secondary mirrors and to primary reference ring.
6. Electronics Boxes	No breakdown	?	135	6. Assumed to be circuit-board construction mounted in lightweight metal boxes.

TABLE A-2. DESCRIPTION OF SCIENTIFIC INSTRUMENTS COMPONENT/SUBSYSTEMS

Component/ Subsystem Class		Descriptors	No. Req'd.	Estimated Weight, kg, each	Class Mechanical Description
1. Image-tube electro-optical system	1.1	F/12 Field Camera & Filter Wheel	1	75	1. Special-purpose electro-optical devices. All employ an electronic image-tube sensor to be developed using present television-camera-tube technology as a starting point. Associated optics (mirrors, gratings, etc.) are special-purpose--most static mounted and some mounted in mechanical switching devices actuated by an electric motor. Associated electronics to be developed to control exposure time, scanning, and related functions. Presumed that electronics will be both internal and in external boxes. Equipment housings consist largely of tubular sections with machined end caps and some complex tube-like shapes presumed to be castings. Housing materials assumed to be typically aluminum. Mounting to support structures by slide plus locking fastener. Housings on the order of 1 to 2 m length.
	1.2.	F/96 Field Camera	3*	245 total	
	1.3	High Resolution Spectrograph, HRS I, Echelle Grating, 110-180 nm	1	55	
	1.4	High Resolution Spectrograph, HRS II, Echelle Grating, 180-350 nm	1	55	
	1.5	Low Dispersion Spectrograph, FOS I, Faint Object Spectrograph, Czerny-Turner, A&B Gratings, A 110-160 nm, B 160-220 nm	1	50	
	1.6	Low Dispersion Spectrograph, FOS II, Faint Object Spectrograph, Wadsworth, Dichroic Mirror Beam Splitter, A 220-350 nm, B 350-660 nm	1	50	

TABLE A-2. DESCRIPTION OF SCIENTIFIC INSTRUMENTS COMPONENT/SUBSYSTEMS (Continued)

Component/ Subsystem Class	Descriptors	No. Req'd	Estimated Weight, kg, each	Class Mechanical Description
	1.7 Low Dispersion Spectrograph, FOS III, Faint Object Spectrograph, Czerny-Turner, Slit Mechanism, 660 nm - 1 μm	1	50	
	1.8 Mid-IR Interferometer, Fourier Interferometer, 1-5 μm	1	25	
	1.9 Slit Jaw Camera	1	55	
2. Optical-mechanical systems	2.1 Focal Plane Folding Mirror Assy.(Static)	1		2. Special-purpose optical components mounted in appropriate metallic housings presumed similar in construction to image-tube instrument housings. Two of the four systems employ active motor-driven mechanisms for switching optical components. Mounting details not defined.
	2.2 Axial Spectrograph Slit Selector Mechanism (Active)	1	5	
	2.3 Axial Spectrograph Collimating Mirror Selector Assy. (Active)	1	9	
	2.4 F/96 Magnifier* (Static)			
3. Electronics boxes	No breakdown	-	20	3. Construction not defined. Presumed to be circuit board construction mounted in aluminum or magnesium alloy box.

TABLE A-2. DESCRIPTION OF SCIENTIFIC INSTRUMENTS COMPONENT/SUBSYSTEMS (Continued)

Component/ Subsystem Class	Descriptors	No. Req'd	Estimated Weight, kg, each	Class Mechanical Description
4. Electrical Cabling and Connectors	No breakdown	-	3	4. No details. Assumed to be conventional wiring harnesses and connectors.
5. Static Structural Components	5.1 Focal Plane Structure	1	?	5. Tubular truss structures. Current baseline material is graphite/epoxy. Truss joints may be cemented or pinned with mechanical fasteners. Mechanical interfaces with main structure or adjacent structures not defined; presumed joined with mechanical fasteners.
	5.2 SIP Support Structure	1	110	
6. Thermoelectric Thermal Control Devices	No breakdown	10	?	6. Used for cooling image-tube cathodes. Not defined. Presumed to be bismuth-telluride thermoelectric cooling couples used in conjunction with Al or Cu heat collector and Al heat-pipe heat sinks.

* The 3 F/96 field cameras and the F/96 magnifier are housed as a single assembly.

TABLE A-3. DESCRIPTION OF SUPPORT SYSTEM MODULE COMPONENT/SUBSYSTEMS

Component/ Subsystem Class		Descriptors	No. Req'd	Estimated Weight, kg, each	Class Mechanical Description
1. Sensing and Control System					
		1. New Components			
	1.1	3-Axis Magnetometer	2	2.9	1. (New) Static electrical/electromagnetic/electronic devices
	1.2	Magnetic Torquers & Electronics	6	25	
		1. Existing, Modified Existing, or Off-the-Shelf Components			
	1.3	Coarse Sun Sensor (CSS)	5	0.07	HEAO
	1.4	Fixed Star Tracker (FST)	2	5.4	HEAO
	1.5	FST Shades	2	1.6	HEAO
	1.6	Control Moment Gyro (CMG) & Drive Electronics Assembly	4	81	HEAO
	1.7	Digital Processor Assembly (DPA)	1	8.5	HEAO
	1.8	Transfer Assy.	2	4.7	Modified HEAO
	1.9	Reaction Control System (RCS) Modules	4	2.0	RCS system assumed to be 90 percent existing hardware

TABLE A-3. DESCRIPTION OF SUPPORT SYSTEM MODULE COMPONENT/SUBSYSTEMS (Continued)

Component/ Subsystem Class		Descriptors	No. Req'd	Estimated Weight, kg, each		Class Mechanical Description
		1. Existing, Modified Existing, or Off-the-Shelf Components				
	1.10	RCS Electronics	2	7.3		RCS system assumed to be 90 percent existing hardware
	1.11	RCS Tank	1	32.3		ditto
	1.12	Lines, Valves, etc.	-	44		"
	1.13	GN_2	-	20		"
2. Electrical System		2. New Components				
	2.1	Solar Panels	12	15	2.	(New) Solar cells mounted in a foldable and steerable metalic structure (not defined).
	2.2	Solar-Panel Deployment and Orientation Mechanism				
		2. Existing, Modified Existing, or Off-the-Shelf Components				
	2.3	Batteries	6	21		New off-the-shelf
	2.4	Chargers	6	7		Similar to HEAO
	2.5	Regulators	6	3.5		Similar to HEAO
	2.6	Solar Power Distributors	2	5.4		New, standard cabling and connectors
	2.7	Electrical Control Assembly	2	7.3		Modified HEAO

TABLE A-3. DESCRIPTION OF SUPPORT SYSTEM MODULE COMPONENT/SUBSYSTEMS (Continued)

Components/ Subsystem Class	Descriptors	No. Req'd	Estimated Weight, kg, each	Class Mechanical Description
	2. Existing, Modified Existing, or Off-the-Shelf Components			
	2.8 Electrical Distribution Units (EDU)	8	1.1	Modified HEAO
	2.9 Support Lighting, Cabling, and Accessories	-	?	Off-the-shelf components
3. Communications and Data Management System	**3. New Components**			
	3.1 Antenna	2	0.9	3. (New) Fixed conical spiral antenna mounted on solar panels
	3. Existing, Modified Existing, or Off-the-Shelf Components			
	3.2 Transponders	2	25.4 total	Existing
	3.3 Command Processor and Memory	7	6.2	New, standard
	3.4 Remote Decoders	16	0.4	Existing
	3.5 Comm. & Data Hdl. Switch	2	0.5	Ditto
	3.6 Format Generators	2	1.8	"
	3.7 Data Control Unit	2	1.8	"

TABLE A-3. DESCRIPTION OF SUPPORT SYSTEM MODULE COMPONENT/SUBSYSTEMS (Continued)

Component/ Subsystem Class	Descriptors	No. Req'd	Estimated Weight, kg, each	Class Mechanical Description
	3. Existing, Modified Existing, or Off-the-Shelf Components			
	3.8 Tape Recorders	3	5.4	Existing
	3.9 Tape Control	2	1.4	Ditto
	3.10 Baseband Unit	1	0.9	"
	3.11 Digital Acquisition Unit	28	0.9	"
	3.12 Clock	1	0.5	"
4. Thermal Control System (All New)	4.1 Insulation	-	9	4. (New) Thermal insulation assumed metal-foil-jacketed fibrous. Strip heaters assumed electrical resistance type. Louvers assumed sheet metal with electromechanical positioning device.
	4.2 Louvers	?	16	
	4.3 Strip Heaters	?	12	
5. Contamination Control System	5.1 Ducting	-	13	5. (New) Filters and associated ducting. Principally off-the-shelf components.
	5.2 Fittings	Misc.	1.8	
	5.3 Quick Disconnect Joint	1	0.9	
	5.4 High Efficiency Particulate Air Filters	8	12 total	

TABLE A-3. DESCRIPTION OF SUPPORT SYSTEM MODULE COMPONENT/SUBSYSTEMS (Continued)

Component/ Subsystem Class	Descriptors	No. Req'd	Estimated Weight, kg, each	Class Mechanical Description
6. Structure (all new)	6.1 External Structure	1	630	6. (New) Side wall of external structure consists basically of outer meteoroid bumper shell and inner pressure shell over ring-and-stringer construction. Principally sheet aluminum. End wall is double-wall conical shell, aluminum. Shroud adapter is sheet aluminum structure. Docking port is 1-meter universal docking assembly.
	6.2 Mounting Brackets	?	65	
	6.3 Shroud Adapter	1	250	
	6.4 Docking Port Mechanism	1	200	

APPENDIX B

LIST OF PERSONS INTERVIEWED

APPENDIX B

LIST OF PERSONS INTERVIEWED

Individual	Organization
James Barr	Aluminum Association New York, New York
Peter Broochman	Aluminum Company of America Pittsburgh, Pennsylvania
Len Rettinger	Aluminum Company of America District Sales Office Cincinnati, Ohio
George Bowen Alex A. Pena	American National Standards Institute New York, New York
John Wilcox	Beloit Tool Company South Beloit, Illinois
Jose Elfalan	Boeing Company Seattle, Washington
Louis R. Strang	Caterpillar Tractor Company East Peoria, Illinois
Don Decker	Corning Glass Works Corning, New York
E. R. Friesth	Deere & Company Moline, Illinois
Lloyd Justice	General Electric Company Evendale, Ohio
Roy P. Trowbridge Ed Janus	General Motors Corporation Warren, Michigan
Richard R. Belford	Industrial Fastener Institute Cleveland, Ohio
Ken Lee Jack Rose	Itek Corporation Lexington, Massachusetts
John F. Roberts	North American Rockwell Corporation Columbus, Ohio
Gary Goodman Tom Brock Dave Caldwell	Owens-Illinois, Inc. Toledo, Ohio

Individual	Organization
John F. Simpson	Republic Steel Corporation District Sales Office Cleveland, Ohio
Roy Smith	Reynolds Metals Company Richmond, Virginia
Tom Baumgartner	Standard Pressed Steel Company Precision Fastener Division Jenkintown, Pennsylvania

APPENDIX C

RANGE OF METRICATION OPTIONS

APPENDIX C

RANGE OF METRICATION OPTIONS

The optional levels of metrication constitute a relatively continuous spectrum when viewed in terms of overall system design and fabrication; however, no meaningful functional relationship could be found to represent this spectrum. A much more useful approach appears to be a finite set (three) of specific levels which seems to be generally understood and accepted by most individuals involved in establishing metric standards and performing related analyses--namely, "no", "soft", and "hard". In the tabulation presented below, "hard" and "soft" levels of metrication are characterized for various engineering functions. The strictest possible degree of metrication would be that described as "hard" metrication for all of the functions listed. Intermediate or less strict degrees of metrication can be described by combinations of hard, soft, or no metrication for the various functions--although not all combinations would be meaningful.

Function	Hard Metrication	Soft Metrication
1. Scientific and engineering calculations	All in SI metric units. Convert all software to SI metric units. Deliverable software in SI metric units.	Use U.S. customary practice; convert results to SI metric units. Deliverable software in optional units.
2. Design standards	Use only those accepted standards expressed in metric-module units.	Convert applicable standards to equivalent metric units.
3. Materials	Use only those materials supplied in accepted metric-module sizes.	Allow inch-module materials; convert dimensions to equivalent metric units.
4. Purchased components and hardware (including electrical and electronic parts)	Use only those designed in metric-module dimensions	Allow inch-module hardware; convert dimensions in drawings.
5. Design of mandatory interfaces with existing inch-module components	Rework mounting to metric-module dimensions.	Use existing inch-module interface dimensions, convert in drawings.
6. Drawings	Metric units only; metric-module dimensions only	Dual dimension; conversion of inch-module dimensions.

Function	Hard Metrication	Soft Metrication
7. Fabrication	Fabricate in metric dimensions only. Convert tools and gages as necessary	Convert metric dimensions into inch equivalents. Fabricate in inch dimensions.

From the above characterizations of hard metrication, it should be apparent that the strictest degree of metrication is impractical, if not impossible, in the U.S. at present unless foreign design conventions, materials, and hardware are adopted. U. S. standards, stock materials, and stock hardware would be largely unuseable with the strictest degree of metrication.

Since the process of metricating the United States is regarded as an opportunity to improve U.S. standards, design conventions, and standard hardware component sizes and designs, it is not judged to be productive to specify a strict hard level of metrication for the LST. Rather, it is judged more productive to use U.S. metric standards where already accepted or metric standards assumed to be precursors for final standards to be accepted later, and to use customary practice where U.S. metric practice is not available. Converting U.S. software applicable to design to the metric system of units is a task that will probably require one or two decades for substantial completion; abandoning this body of software is not a desirable solution to the conversion problem.

With regard to conversion of manufacturing equipment, the logical time for conversion is that time when the distributed expense of equipment conversion is lower than the day-to-day additional costs of converting metric dimensions into their English equivalent. Since the LST is essentially a one-of-a-kind design, it is doubtful that any shop will find it advantageous to convert equipment for LST component fabrication alone.

Accordingly, it should be clear that an extreme hard metrication of the LST would not be desirable at present.