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MSFC-HDBK-3074
BASELINE
EFFECTIVE DATE: December 11, 2002

National Aeronautics and
Space Administration

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Marshall Space Flight Center, Alabama 35812

ED42

MULTIPROGRAM/PROJECT COMMON-USE DOCUMENT

Selection Methodology for Orbital Replaceable Units

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DOCUMENT HISTORY LOG

Status (Baseline/ Revision/ Canceled)	Document Revision	Effective Date	Description
Baseline		December 11, 2002	Baseline Release

FOREWORD

1. This handbook is approved for use by all directorates of the Marshall Space Flight Center (MSFC).

2. This handbook is for guidance only. This handbook cannot be cited as a requirement; if it is, the contractor does not need to comply.

3. To provide more affordable flight systems, NASA is focusing on the total cost of ownership throughout the project’s life cycle, which depends upon effective supportability engineering planning and management. The information contained herein is applicable, in part or in whole, to all types of flight systems and supportability strategies.

4. This handbook offers guidance on a subset of the supportability engineering process by focusing on the identification of the orbital replaceable units (ORUs), their associated issues, and integrating this activity as part of an overall systems engineering process. This handbook does not present a "cookbook" approach to ORU selection; rather it does offer guidance, examples and issues to consider as the project’s ORU selection criteria are developed. The examples provided are just that - examples only. They are not meant to be a definitive solution; rather they provide insights to aid development of an innovative solution for the project's particular needs.

5. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to:

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6. Special appreciation is expressed to Mr. George “Jay” Lasher, Logistics Support Activity (LOGSA), Redstone Arsenal, U.S. Army, for his expert contributions to the draft of this document.

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1.0 SCOPE

This handbook provides guidance on selecting the appropriate ORU items to ensure that a flight system is supportable on-orbit. It addresses:

- The need for an ORU selection process.
- The ORU selection as an integral function of systems engineering and the supportability engineering processes.
- The key decision logic and selection criteria for the MSFC ORU Selection Methodology.
- Important design aspects that should be considered for ORU items.

2.0 APPLICABLE DOCUMENTS

2.1 Applicable documents. Unless otherwise specified, the latest versions of the following documents are applicable to this handbook.

NPD 7500.1	Program and Project Logistics Policy

2.2 Reference documents. The following documents are identified as references in this handbook.

D684-10041-1-1	ISS Program Integrated Logistics Support Plan, Volume 1, Logistics Analysis Plan, Book 1 (Boeing)
MIL-STD-1843	Reliability-Centered Maintenance for Aircraft, Engines and Equipment (USAF)
MSG-3	Maintenance Program Development Document (ATAA)
NASA-STD-3000	Man-Systems Integration Standards (NASA)
NSTS 1700.7	Safety Policy and Requirements for Payloads Using the Space Transportation System (NASA)
NSTS 5300.4	Shuttle Safety Policy and Requirements (NASA)
SSP 50005	ISS Flight Crew Integration Standard (NASA)
SSP 50021	ISS Safety Requirements Document (NASA)

3.0 ACRONYMS AND DEFINITIONS

3.1 Acronyms and abbreviations.

Ai	Inherent availability
ATAA	Air Transport Association of America
BIT	Built-in test
BITE	Built-in test equipment
CIL	Critical items list
CM	Corrective maintenance
COTS	Commercial off-the-shelf
DMSMS	Diminishing Manufacturing Sources and Materiel Shortages
ESD	Electrostatic discharge
EVA	Extravehicular activity
FD/FI	Fault detection/fault isolation
FDIR	Fault detection, isolation and recovery
FMEA	Failure modes and effects analysis
FSE	Flight support equipment
FTA	Fault tree analysis
GIDEP	Government-Industry Data Exchange Program
GSE	Ground support equipment
HDBK	Handbook
IMS	Inventory management system
IPB	Illustrated parts breakdown
ISS	International Space Station
IUA	Item under analysis
IVA	Intravehicular activity
LCC	Life cycle cost
LCN	Logistics control number
LLI	Limited life item
LRU	Line replaceable unit
LWD	Length-width-depth
Max-TTR	Maximum time to repair
MIL	Military (USA)
MMH	Maintenance man hours
MSFC	Marshall Space Flight Center (NASA)
MTBF	Mean time between failure
MTTR	Mean time to repair
NASA	National Aeronautics and Space Administration
NHA	Next higher assembly
NPD	NASA Policy Directive
NSTS	National Space Transportation System
O&M	Operations and maintenance
ORU	Orbital replaceable unit

OSD	Operational sequence diagram
PIP	Push-in-place
PM	Preventive maintenance
RBD	Reliability block diagram
RCM	Reliability-centered maintenance
Ref.	Reference
RMS	Reliability, maintainability and supportability
RLA	Repair level analysis
RLV	Reusable launch vehicle
RVA	Robotic vehicular activity
SD&D	Source data and documentation
SRD	Systems requirement document
SRU	Shop replaceable unit
SSP	Space Station Program (ISS)
STD	Standard
TD&D	Technical data and documentation
USAF	United States Air Force
WBS	Work breakdown structure

3.2 Definitions.

Accessibility: A human factors issue indicating if required maintenance can be performed without physical difficulty.

Assembly: A number of parts or subassemblies, or any combination thereof, joined together to perform a specific function and capable of disassembly (e.g., fan assembly, audio frequency amplifier). NOTE: The distinction between an assembly and subassembly is determined by the individual application. An assembly, in one instance, may be a subassembly in another where it forms a portion of an assembly.

Candidate item: Any piece part, module, component, subassembly, assembly, subsystem, system, or end item that must be repaired or replaced. Any of these may be considered an ORU candidate item.

Component: An assembly or any combination of parts, subassemblies, and assemblies mounted together normally capable of independent operation in a variety of situations.

Corrective maintenance: Unscheduled maintenance actions performed, as a result of failure, to restore a system to a specified level of performance.

End item: A final combination of end products, component parts/materials which is ready for its intended use.

Induced failures/damage: Induced malfunctions are those initiated in the system, equipment, or item under analysis (IUA) from external sources (i.e. other equipment, personnel, etc.)

Inherent availability: The probability that, when used under stated conditions in an ideal support environment without considerations for preventive actions, a system will operate satisfactorily at any time. The “ideal support environment” referred to, exist when the stipulated tools, parts, skilled manpower, manuals, support equipment and other support items required are available.

Limited life item: (a) An item which can be operated or repaired a limited number of times. (b) An item which can be subjected to a limited number of duty cycles. (c) An item whose usage is age-dependant (e.g., limited shelf life).

Line replaceable unit: An LRU is an essential support item, which is removed and replaced at the organizational (i.e., operational) maintenance level to restore the end item to an operationally ready condition.

Logistics: The process of planning, analyzing and implementing project resources (e.g., manpower, spares, facilities, transportation, etc.) necessary to support the system based upon its inherent reliability, availability, maintainability and supportability characteristics.

Maintainability: The capability of the system to be restored to a specified operating condition.

Orbital replaceable unit: An ORU is an essential support item, which is removed and replaced in orbit to restore the end item to an operationally ready condition (i.e., an ORU is an LRU whose organizational maintenance level is on-orbit).

Operational life: The number of years the item is expected to be in operation.

Part obsolescence: An item will no longer be manufactured and may not be available in the inventory.

Pre-planned product improvement: A process of planning for a product replacement when an improved version is available.

Preventive maintenance: Scheduled maintenance actions performed to retain a system at a specified level of performance or to preclude failure. Can include systematic inspection, detection, calibration, condition monitoring, or replacement of critical items.

Reliability: The probability that the system will perform satisfactorily for a given period of time under specified operating conditions.

Repair part: Materiel capable of separate supply and replacement that is required for the maintenance, overhaul, or repair of a system, equipment, or end item. This definition does not include support equipment, but does include repair parts for support equipment.

Spares: Articles identical to or interchangeable with repairable items, which are procured for support of a system, over and above the quantity, needed for initial assembly of the system.

Subassembly: Two or more parts that form a portion of an assembly or a component replaceable as a whole, but having a part or parts which are individually replaceable (e.g., window recoil mechanism, floating piston, telephone dial, mounting board with mounted parts).

Support equipment: Equipment that is required to make an item, system, or facility operational in its intended environment. This includes all equipment required to maintain and operate the item, system, or facility, including ground equipment.

Support items: Items subordinate to or associated with an end item (i.e., spares, repair parts, and support equipment).

Supportability: The degree to which a system's operational capabilities can be cost-effectively maintained for the planned operational scenarios. Supportability is dependent upon the inherent design characteristics of the system, its dynamic operational environment, and its dynamic support infrastructure.

Up/down mass: The amount of payload mass taken up into orbit or returned from orbit to the ground

Up/down volume: The amount of payload volume taken up into orbit or returned from orbit to the ground.

4.0 THE NEED FOR AN ORU SELECTION PROCESS

In the past, NASA has had few programs that needed routine maintenance accomplished in the "on-orbit" or space environment. The Skylab, Shuttle, Hubble Space Telescope, Spacelab, and International Space Station (ISS) programs have all illustrated the importance of a disciplined approach to designing for on-orbit maintenance. With the long-term, permanently manned presence of ISS, and the development of reusable launch vehicles (RLVs) that rely upon quick mission turn-around times, the need to design for field supportability is now being emphasized.

It was not until the ISS that a programmatic methodology for identifying ORU candidates was documented (ref. D684-10041-1-1). Although the ISS ORU selection methodology laid a good foundation, it does not address all of the criteria that influence the selection of maintenance items as ORUs. For example, no consideration is provided for hardware obsolescence, provisioning availability (e.g., discontinued parts), accessibility nor maintenance-induced damage.

Naturally, the ISS ORU selection methodology contains programmatic criteria that are specific to the ISS Program. Therefore, more general guidelines are needed that could be adapted to any system requiring on-orbit maintenance - be it an intravehicular activity (IVA), extravehicular activity (EVA), or robotic vehicular activity (RVA) environment.

Further, it is observed that many designers select the ORU candidates without first identifying all of the system's preventive maintenance (PM) items. Reliability-centered maintenance (RCM) analysis is a proven technique for identifying the appropriate PM items within a system (ref. MSG-3 and MIL-STD-1843). Therefore, it is desirable to include the RCM logic within the ORU selection logic to ensure that all of the ORU candidates are correctly identified.

This ORU selection methodology seeks to remedy the above shortcomings and to provide more detailed guidance for its adaptation and implementation. The methodology described herein will help the designers of future hardware to identify a system, subsystem, assembly, subassembly, or component as an ORU candidate. Once properly identified, they will be able to plan and design for the removal, replacement, and maintenance of these items.

5.0 EFFECTIVE ORU SELECTION IS INTEGRAL TO SUPPORTABILITY AND SYSTEMS ENGINEERING

To appreciate the importance of an effective ORU selection, it is necessary to recognize that an ORU is the basic “building block” for on-orbit supportability - all of the on-orbit maintenance resource requirements are driven by the system’s ORU selection. Recognizing that the on-orbit maintenance resources are often very limited (e.g., limited stowage, crew time, tools/equipment, and resupply/return manifesting opportunities), it is imperative to identify the ORU items early on so that the system design will minimize the demand upon these constrained resources.

Also, it is important to note that the ORU selection process is fundamentally a systems engineering process. The design and operational impacts that an ORU has on the rest of the system needs to be thoroughly assessed and iteratively evaluated as the system design matures. To establish the ORU selection criteria for a specific project, it is best to maintain a systems engineering perspective.

5.1 Systems engineering.

Systems engineering is an iterative, interdisciplinary approach to evolve and verify an integrated and balanced set of product and process solutions (i.e., a total system) that satisfy the customer’s needs over a specified life cycle. The interdisciplinary nature of systems engineering is reflected by the breadth of technical knowledge and variety of analytical skills necessary to satisfactorily evaluate a total system design, which includes the system hardware, software, operations and logistics concepts, supporting infrastructure and programmatic resources. Its iterative nature is reflected by its applicability to all phases of a project (i.e., initial planning, concept development, design development, deployment, operations, sustaining engineering and disposal), to all levels of design (i.e., end item, system, subsystem and component), to all levels of operations (i.e., mission, ground processing, maintenance and logistics), and to all levels of maintenance support (i.e., organizational, intermediate and depot). Plus, there is an inherent feedback of verification and validation at each level to ensure that the total system criteria are being achieved.

Figure 1 depicts the systems engineering process as a classical cycle of requirements development, decomposition/allocation, integration/synthesis, and control feedback in the form of verification/validation.

The systems engineering process follows a logical top-down progression of design refinement. It employs an iterative process in which operational requirements are translated into performance requirements for the functional elements of a system. Design alternatives for each of the system's functional elements are identified and analyzed. The results are then used to select the best combination of element designs to achieve the system objectives.

The functional decomposition of requirements continues to the lowest logical "generation breakdown" of a performance function. At this point the top-down design becomes a bottom-up build. Synthesis of the physical design begins when hardware items are selected to provide identified functions and are arranged in a physical relationship with one another. During this stage of the design's development, adherence to each successively higher level of requirement is verified. Estimates and projections are refined and verified through analysis, demonstrations and tests.

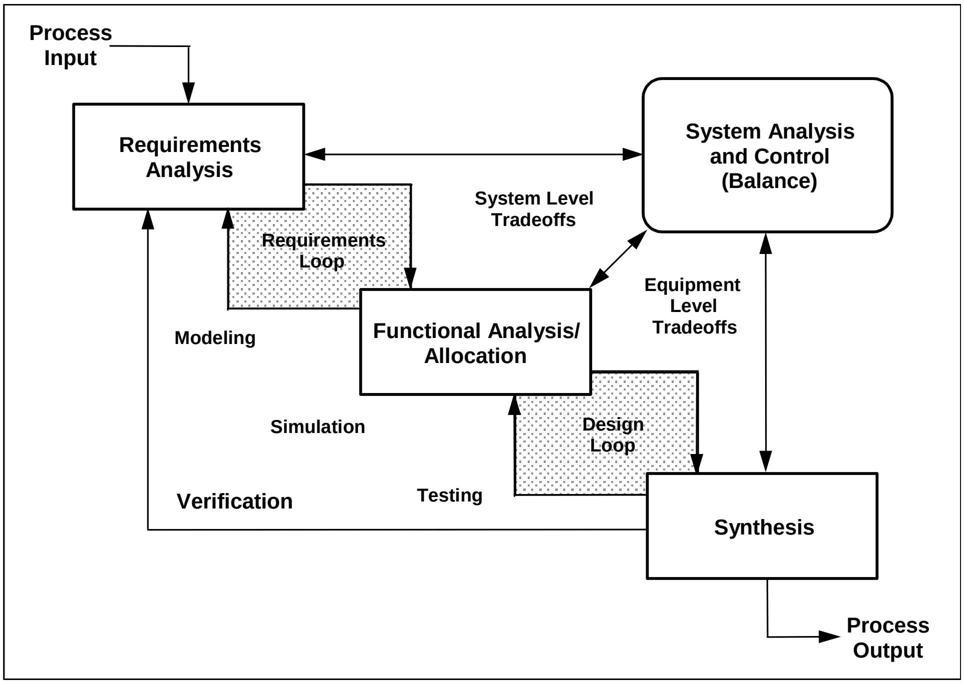


FIGURE 1. Systems Engineering Process Flow

System analysis and control activities in a program serve as a basis for evaluating alternatives, selecting the best solution, measuring progress, and documenting design decisions. These activities include:

- Trade-off studies among requirements, design alternatives, and other cost, schedule and performance related issues.
- Risk management that, throughout the design process, identifies and evaluates potential sources of technical risks (based on the technology being used, the design, manufacturing, test and support processes being used), and risk mitigation efforts.
- Configuration management to control the system products, processes and related documentation. The configuration management effort includes identifying, documenting, and verifying the functional and physical characteristics of an item; recording the configuration of an item; and controlling changes to an item and its documentation. It provides a complete audit trail of decisions and design modifications.
- Data management to capture and control the technical baseline (configuration documentation, technical data, and technical manuals), provide data correlation and traceability, and serve as a ready reference for the systems engineering effort.
- The establishment of performance metrics to provide measures of how well the technical development and design are evolving relative to what was planned and relative to meeting system requirements in terms of performance, risk mitigation, producibility, cost, and schedule.
- Identification of safety hazards and appropriate safety controls (and associated verification of those controls) to ensure hazard mitigation.
- Integration and analysis of aggregate performance data and system-level test data to determine if system requirements have been met. For example, component or subsystem acoustic data must be included in an overall systems acoustic analysis to determine if the overall acoustic environment requirements have been met.
- The establishment of interface controls to ensure all internal and external interface requirement changes are properly recorded and communicated to all affected configuration items.
- Structured program reviews to demonstrate and confirm completion of required accomplishments and their exit criteria as defined in program planning.

Likewise, the supportability engineering discipline of systems engineering employs this structured approach and these analyses and control activities to determine the best set of maintenance features and planned logistic resources for a system.

5.2 Supportability engineering.

Supportability engineering strives to ensure cost-effective support of the total system operations by integrating the reliability, availability, maintainability and logistics analyses into a cohesive evaluation of the total system's life-cycle support resources. As an integral component of systems engineering, supportability engineering should be practiced during all phases of the project's life cycle, especially during the conceptual phase. The greatest benefits to a project are achieved when supportability issues are identified and addressed at the beginning of a project instead of waiting until the system design is mature. Approximately 60% of a project's life cycle costs (LCC) are determined during the concept phase (ref. Benjamin S. Blanchard, "Logistics Engineering and Management", Prentice Hall, Fifth Edition, 1998, p. 82). This emphasis upon the early integration of supportability engineering is highlighted in NPD 7500.1, which requires that supportability engineering be applied “to all phases of the program or project life cycle” and that the logistics (supportability) manager be designated “at the beginning of the mission needs and conceptual studies phase”.

The early focus of supportability analysis should result in the establishment of support related parameters or specification requirements. These parameters should be expressed both quantitatively and qualitatively in operational terms, and specifically relate to the system readiness objectives and the support costs of the system. Achieving and sustaining affordable system supportability is a life cycle management activity and is the result of sound systems engineering. It is accomplished through analysis of those design characteristics that generate a need for, or are associated with, providing operational support to the total system. These design characteristics are developed by many different disciplines pursuing a wide range of systems engineering activities. Individually they may be viewed as either hardware, software, or support system design characteristics. Collectively they represent the “supportability” of a total system.

Supportability engineering is also an iterative process with the supportability resources being continually reassessed as the design and operations concepts mature. In the classical systems engineering flow, supportability requirements are continually re-evaluated, allocated, synthesized and verified through analysis and demonstrations.

A system's supportability is a function of the system design. In general, supportability features cannot be added to a completed design, rather they can only be "designed in" as the system is being developed. Deferring, which in essence is ignoring, the supportability issues could easily result in a system that is too costly or impractical to maintain.

The major design aspects of supportability engineering are maintenance and logistics, which include the following activities:

- Identifying the maintenance items based upon their reliability and failure characteristics;
- Selecting the appropriate level of repair and repair sites;
- Designing for fault detection, fault isolation, accessibility and maintenance;
- Determining and planning the support resources (e.g., maintenance task analysis, spares provisioning, storage, transportation, etc.).

Again, all of these efforts are predicated upon correctly identifying the maintenance items and selecting the appropriate ORUs.

5.3 ORU selection.

ORUs are maintenance items that need to be removed, replaced, and possibly repaired while the system is in the space environment (generally, low Earth orbit). In logistics lingo, an ORU is the same as a line replaceable unit (LRU) whose organizational level is on-orbit. This broad context is not meant to construe that every removable piece part should be classified as an ORU; however, depending upon the maintenance scenario, some piece parts could be classified as ORUs. For example, mounting bolts and panel screws are not normally classified as ORUs, although they may be routinely removed and have spares available in case of damage or misplacement. However, it is conceivable that a memory chip or some other replaceable piece part on a circuit board could be identified and managed as an ORU.

Selection of the correct ORU items is very important to NASA. Many unique design and supportability parameters have to be taken into consideration when an item has to be repaired or maintained in space, such as restraints, captive fasteners, sharp edges, accessibility, storage, disposal, etc. The ORU selection process is a step-by-step methodology that helps the designer or systems engineer to identify the possible ORU candidates by taking these issues into account. Considering the unique operational environment of space, it is imperative that the correct ORU items be identified early in the design process so that their unique attributes can be accommodated for and that their resource requirements can be planned for.

As described, the ORU selection process is an integral part of the systems, design and supportability engineering processes. The ORU selection will in turn affect the supportability of the system and its overall life cycle cost.

6.0 ORU SELECTION METHODOLOGY

6.1 Initial data.

Before the ORU selection process can begin, a lot of information must be gathered about the system and the items that comprise the system. The first step is to capture and document the project requirements that are either stated, implied or derived. This helps build the system architecture and allocates the system requirements throughout the architecture. It will help in documenting the reliability predictions for end items, systems, subsystems, assemblies, subassemblies, and components. It will also help to identify the maintenance items for consideration as ORU candidates. After all of this information is gathered, and the reliability, maintainability and supportability (RMS) parameters allocated, then the ORU selection process can begin.

6.1.1 Collect the system RMS requirements.

The top-level system RMS requirements are usually explicitly stated or implied in the project’s triune planning documentation:

- Project Plan (mission need statement);
- Operations Plan (concept of operations);
- Supportability Plan (logistics and maintenance concepts).

But it is imperative that the RMS requirements be explicitly defined in the System Requirements Document (SRD) to ensure that they are reflected in the system design and verified. If the RMS requirements are not defined in the project's planning documentation, they will need to be derived and incorporated in the SRD. Quantifiable RMS requirements that are often derived, include:

- Inherent availability [Ai = MTBF/(MTBF+MTTR)]
- Mean time between failures (MTBF)
- Mean time to repair (MTTR)
- Maximum time to repair (Max-TTR) and its associated percentile (e.g., 90% of all repairs shall have a Max-TTR of one hour on-orbit crew-time)
- Frequency of preventive maintenance (PM) and corrective maintenance (CM)
- Available PM/CM maintenance man-hours (MMH).
- Common hardware, tools, ground support equipment (GSE) or flight support equipment (FSE) requirements
- Mission duration (e.g., duty cycle, maximum operating time, maximum non-operating time, shelf life)
- Crew size
- Crew skills
- Built-in test/built-in test equipment (BIT/BITE)
- Re-supply and maintenance opportunities
- Resource requirements (e.g., power, stowage, up/down mass and volume, etc.)
- Environmental requirements
- Criticality of failure (from FMEA/CIL)
- Safety hazards (from programmatic guidelines, e.g., NSTS 1700.7)
- Accessibility (from human factors analysis)
- Limitations upon removing interfacing/adjacent hardware (from programmatic guidelines; e.g., may be limited to removing only one ORU in order to access another ORU)

A suggested worksheet for collecting the input data is provided in Appendix B.

6.1.2 Identify the system architecture.

After gathering the top-level requirements, they must then be allocated down throughout the system architecture. Early on in the development of the item, there may not be many indenture levels to the hardware “generation breakdown”. As the system is further defined, it will be possible to evaluate the system layer-by-layer (i.e. end items, systems, subsystems, assemblies, subassemblies, and components) till the lowest repairable level is obtained. System architectures are defined either physically or functionally; listed below are some considerations for defining the system architecture:

- Physical architecture:
  - Develop a top-down generation breakdown (Level 0, 1, 2, etc.) identifying the hardware subassemblies, major components, etc.
  - Identify the part nomenclature, part numbers (if available), quantities, and their next higher assembly (NHA) levels.
- Functional architecture:
  - Develop a functional block diagram (which should closely follow the WBS).
  - Identify the “sub-functions” to identify the multi-functional hardware candidates.

6.1.3 Allocate the RMS requirements to the system architecture.

Once the system architecture has been developed, then allocate the RMS requirements down to the lowest level possible. Some approaches and issues to consider:

- Use whatever method(s) provide the most applicable information (e.g., comparative analysis, market analysis, maintenance databases, lessons learned, handbook data, etc.)
- Design to the worst-case environmental and support conditions
- Identify and allocate the RMS parameters (e.g., MTBF, MTTR, etc.)
- Develop the reliability block diagrams (RBDs) to match the system’s generation breakdown
- Periodically validate the allocations to the top-level system requirements as the system design matures
- Perform sensitivity analysis on the RMS allocations to identify potential design drivers.
- Identify candidates for redundancy, higher reliability, etc.

6.1.4 Identify the maintenance items.

After the system architecture has been defined and the RMS requirements have been allocated throughout the system, identify those items that are capable of being maintained or repaired. Listed below are some issues to consider:

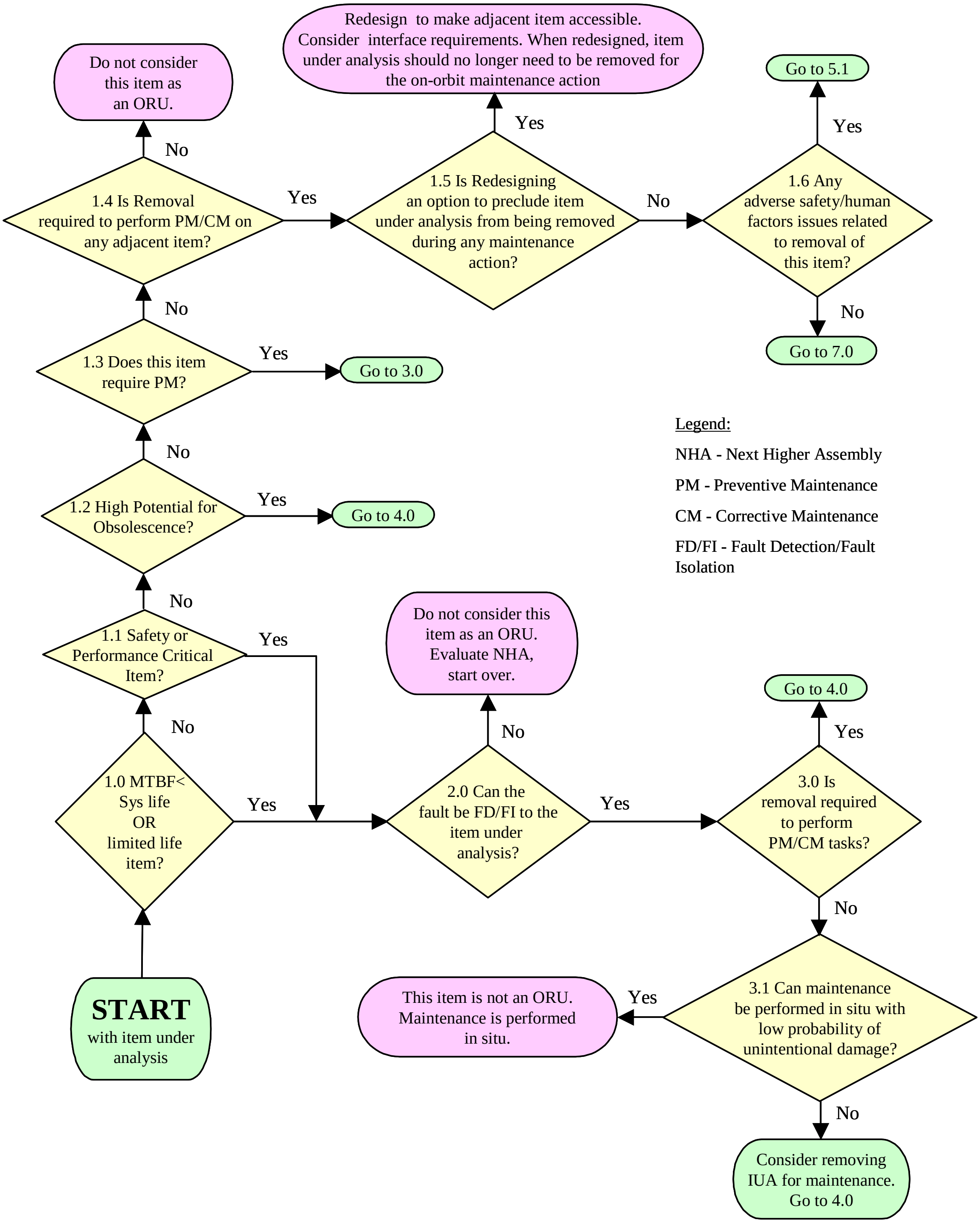
- Initially, identify everything that can be maintained/repaired to the lowest level possible, generally ignoring attachment hardware, piece parts, and support structure that are typically non-repairable.
- Major selection criteria include reliability, safety, maintenance resource requirements and physical capabilities. Inputs for these criteria are obtained from vendor data sheets, FMEA, safety hazards analysis, maintenance task analysis, and reliability analysis.
- Use a reliability-centered maintenance (RCM) approach to determine whether to allow the component to fail or to implement PM to prevent its failure. A number of RCM approaches are documented in literature, but a unique approach will need to be developed that includes the specific programmatic criteria. Two of the more common RCM approaches are the MSG-3 (ATA) and the MIL-STD-1843 (USAF)
- List the preventive maintenance (PM) and corrective maintenance (CM) items and the rationale for their selection.

6.1.5 Identify the ORU selection criteria.

Before selecting the ORU items from the list of CM and PM items, the project's ORU selection criteria need to be documented and understood. Also, these criteria need to be reflected in an ORU selection logic tree that is tailored for the system being analyzed. Inputs for these programmatic criteria are usually derived from the system requirements documents, operations and maintenance concepts/plans, logistics plans, and the mission resource allocations. Major factors include the logistics and maintenance resources, safety criteria, reliability criteria, planned maintenance opportunities, FD/FI philosophy, human factors criteria, accessibility criteria, and the programmatic resources (e.g., schedule and budget).

6.2 Initiate the ORU selection process/flowchart.

The ORU selection logic flow is shown in Figure 2. Although each step on the flowchart is fairly self-descriptive, additional information is provided in Appendix A that describes the logic, input sources and output objectives. Also, some generic tables are provided in Appendix B for recording the input (source) data and for documenting the rationale for either selecting or not selecting a maintenance item as an ORU. It is very important to maintain this information in case the source data is updated, the programmatic criteria



Legend:

NHA - Next Higher Assembly

PM - Preventive Maintenance

CM - Corrective Maintenance

FD/FI - Fault Detection/Fault Isolation

FIGURE 2. ORU Selection Methodology (Page 1 of 2)

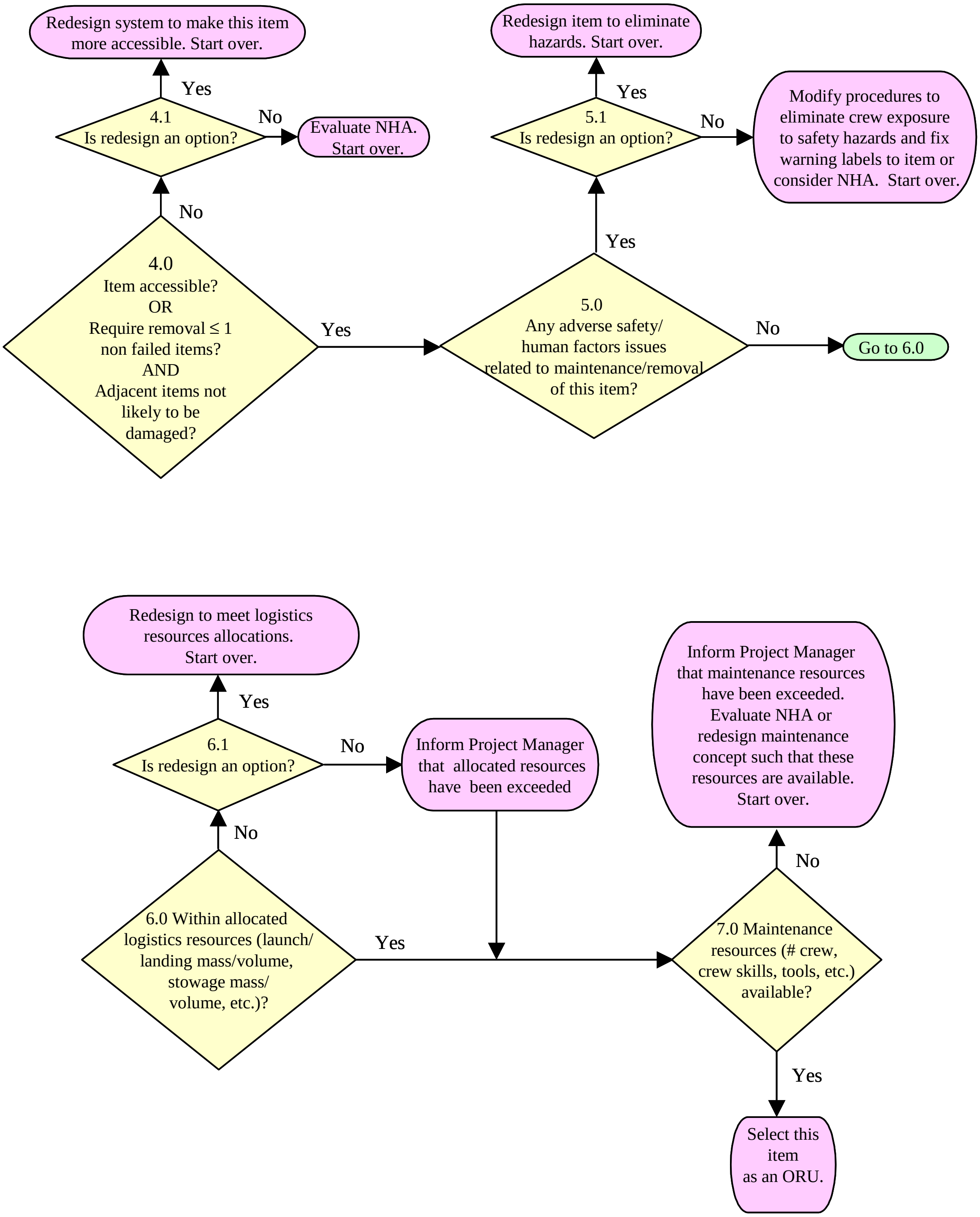


FIGURE 2. <u>ORU Selection Methodology</u> (Page 2 of 2)

changes, or the system changes such that the ORU selection rationale needs to be revisited.

The ORU selection logic flowchart presented in this handbook is intended as a guide for selecting the ORU candidates. This logic flow uses a “bottom-up” approach for evaluating the ORU candidates; in other words, this ORU selection process is biased towards selecting maintenance items from the lowest architectural levels. The intent is to ensure that all of the potential ORU candidates are identified and evaluated; to minimize the impact upon the on-orbit stowage resources; and to provide greater flexibility for manifesting opportunities (i.e., smaller items are generally easier to manifest than larger items). To a degree, “smaller is better” when selecting ORU items; however, often the “next higher assembly” (NHA) will need to be identified as the appropriate ORU level due to undesirable constraints inherent with the smaller ORU (e.g., inaccessibility, special tools, special skills, excessive crew time, etc.).

Again, it should be emphasized that this handbook provides guidelines, which may not be applicable for all flight systems. Also note that this ORU selection methodology may be easily tailored to reflect a “top-down” approach for selecting ORUs, which may be preferable for systems in their early conceptual design phase. For a “top-down” approach, other source data may be more applicable than those mentioned herein; for example, a FTA would probably be a more useful reliability analysis source instead of a FMEA for a “top-down” approach.

The ORU selection process should be accomplished as early as possible so that the designers can design the item to be removed/replaced on-orbit. Section 7 describes a variety of the design and programmatic considerations that are applicable to an ORU item.

6.3 Reiterate the ORU selection process as the system definition matures.

This process should also be repeated as the design of the system matures or changes. An item identified early on as an ORU candidate may fall out in the later iterations of this process, while others may be added on as program requirements change. This whole process is a fluid one, which means there should be multiple iterations of the ORU selection process.

7.0 ORU DESIGN CONSIDERATIONS

When an item has been identified as an ORU, it must then be designed as an ORU. In other words, hardware requiring on-orbit removal/replaceable has additional design considerations that are different from ground-based maintenance items and even other flight hardware. Two major themes of ORU design are to “design for safety” and to “minimize the on-orbit resources” (i.e., crew time, special tools, stowage, etc.). Following is an overview of the major ORU design considerations.

7.1 Safety.

The main safety requirements for designing NASA spaceflight hardware are NSTS1700.7 (Space Shuttle) and SSP50021 (ISS). However, ORUs may present unique safety hazards that should be eliminated through their design, if possible. These safety hazards may be introduced through exposure to:

- The environment (e.g., EVA, IVA);
- Handling and stowage (e.g., sharp edges, excessive “touch” temperatures, pinch and entrapment features, excessive handling loads);
- Hazardous materials (note that materials that may be safe in ambient environments on Earth may not be safe in the space environment (IVA or EVA) – e.g., offgassing concerns are more pronounced in space); or
- Hazardous energy levels (e.g., electrical shock potential, gyroscopic forces).

Most of these hazards are controlled through careful design of the ORU containment and interfaces (both physical and functional). Wherever there is an inherent safety hazard, warning labels must be applied to the appropriate area of the ORU. If hazardous conditions do exist, then a safety indicator should be provided, and a door or protective cover installed which controls access to the hazardous area with an interlock that would de-energize the hazardous condition. Safety hazards that are controlled by procedures should be appropriately identified in those procedures with hazardous caution and warning labels.

7.2 Reliability.

Since the reliability-centered maintenance (RCM) approach is a preferred methodology for identifying PM items, then sometimes the best way to minimize the number of PM items (and thus the number of ORUs) is to increase an item’s reliability. Reliability can be increased by a variety of methods, such as:

- Substituting for another item that is inherently more reliable (e.g., robustness);
- Protecting the item from adverse environments (e.g., thermal isolation/cooling);
- Designing in redundancy.

Note that adding redundancy often adds complexity and weight to a system, which are usually not desirable results. However, there are also design approaches for reducing the impact of redundancy. For example, to maintain the existing system interfaces, redundancy can be added within an individual item.

7.3 Human factors.

An item that was easy to access and maintain on earth may be more difficult to work with in space; therefore, most of the ORU design considerations involve the “manmachine" interfaces. Two of the key technical standards that address human factors for space-based applications are NASA-STD-3000 (generic) and SSP-50005 (for ISS projects). Some important human factor issues for ORUs involve accessibility, interfaces and restraints.

7.3.1 Accessibility.

Accessibility affects both the maintenance repair time and ease of maintenance; therefore, ORUs should be easily accessible for removal and installation. Following are a few of the major accessibility guidelines.

- Many projects require that ORUs be "directly accessible", which means that no other hardware needs to be removed to gain access to an ORU – excluding panel doors and protective covers. Although obviously desirable, this "direct accessibility" provision is often too constraining for complex systems with limited volume allocations. Therefore, a more realistic criteria is to remove no more than one other hardware item for accessing an ORU.
- "Blind accesses" (i.e., when an ORU and its interfaces are not visible during removal/replacement) should be minimized to preclude damage to the ORU or adjacent hardware, and to prevent injury to the crew.
- Similarly, "blind mates" (i.e., electrical or mechanical interfaces that are not visible) should be prohibited since they cannot be inspected (i.e., cannot determine if the interface was mated correctly). Also, interfaces with blind mates and/or blind accesses should not require safety wiring to remain connected (i.e., unable to inspect and/or difficult to access).
- Accessibility also involves providing adequate clearances around adjacent hardware for removing/replacing/inspecting an ORU. These clearances and reach dimensions vary for gloved or ungloved hands (i.e., EVA or IVA), and hand-tool operations. If adequate clearances cannot be provided, then a special tool may need to be designed for the ORU removal/replacement.

7.3.2 Interfaces.

To minimize the maintenance time, it is best to design the ORU so that it can be removed easily and quickly. The design key for this is to consider how the ORU interfaces with the surrounding systems, and to minimize the number of those interfaces. Following are some general guidelines for interface characteristics.

- All ORU interfaces should be easily removable. For example, quarter-turn, captive fasteners and PIP-pins are preferred over individual, threaded bolts. Similarly, quick disconnects are preferred for fluid interfaces instead of threaded fittings.

- All ORU interfaces should be intuitive to operate in order to reduce the amount of training and maintenance time required.
- Connectors should also be unique to prevent improper installation. For example, electrical cables are often color-coded and keyed to prevent them from being mated in the wrong location.
- Limit stops, guides and self-aligning features are also desirable for ORU designs to ensure proper installation and to minimize the maintenance times.

7.3.3 Restraints.

Whatever item is removed needs to be restrained to keep it from floating away and being lost or causing a hazard. If the restraining mechanism cannot be permanently attached to the removed hardware (e.g., Velcro™, lanyards), then temporary restraints should be provided (e.g, bungee cords, stowage bags). As with most things, it's the smaller items that tend to get lost or lodged into inaccessible areas; therefore, small removable items such as lens covers, caps, and bolts should be carefully contained or restrained. Similarly, any tools or special equipment will also need to be captively restrained. It is also important to provide temporary restraints for disconnected harnesses, cables and hoses so that they do not inadvertently damage adjacent hardware. Not only does hardware require restraint, but the crew will also need restraint mechanisms (e.g., foot restraints, handholds) to maintain an effective working posture without over exerting themselves.

7.3.4 Handling.

Anything that is removed will also need to be handled. A number of safety issues, such as touch temperatures, sharp edges, frangible materials and hazardous materials, are important design considerations for handling. Therefore, appropriate handles, tethers, protective covers and/or handling provisions may need to be designed as part of the ORU or for use with it. Packaging for returning an ORU from orbit should also be considered, recognizing that these “flight handling containers” will have different requirements and therefore may be different than “ground handling containers”.

7.3.5 Labeling.

To minimize the maintenance times and induced failures/damage, effective labeling is mandatory. Following are some label types that normally apply to ORUs.

- Inventory management system (IMS) labels, which are often in the form of barcode labels, include the operations nomenclature for the ORU and an IMS reference number. This information is mostly used to identify which system the ORU belongs to and where it is to be stowed. But the supporting IMS database also contains a variety of information relative to the ORU (e.g., owner's contact information, vendor, part number, serial number, repair disposition, quantity on-orbit, quantity in stores, etc.). ORUs that are too small to accommodate a permanent label are often bagged or tagged for identification.

- All interfaces, ports, doors, test points, control switches/knobs should be properly labeled to guard against incorrect installation and operation. These labels should be uniquely identified, while conforming to the labeling standards for the overall end item. For international ventures, these labels may need to be multilingual.
- Caution and warning labels identify safety hazards or provide operational instructions.
- Orientation labels, alignment labels, or other installation instructions may also be needed to preclude the incorrect installation of an ORU.

7.4 Other design considerations.

7.4.1 Special tools or equipment.

It is highly desired to use standard tool kits for all ORU-related activities, but sometimes an ORU requires special tools or equipment for its on-orbit removal/installation, restraining, repair, handling or stowage. For example, many avionics items are electrostatic discharge (ESD) sensitive and require the use of wrist straps during handling, whether on orbit or on the ground. Similar issues should also be considered for its return to Earth and its ground-based handling and stowage. For example, a special transportation container may be needed for an ORU to protect it from the landing environment, ground transportation and handling. Also, a failed ORU may have lost an inherent level of safety protection and thus require special equipment that will restore a level of containment and/or safety monitoring. Therefore, all scenarios for handling and using an ORU should be evaluated to determine its need for special tools and equipment. But the best approach is to minimize the dependence upon special tools by designing the ORU to use the standard tool kits.

7.4.2 Commonality.

Not only should hardware commonality be emphasized for the system being designed in order to minimize its amount of unique ORUs, but a "total vehicle" viewpoint should also be considered when designing ORUs. In other words, most on-orbit systems will have some ORUs, so it would be ideal if the various systems featured ORUs that are interchangeable with those from other systems. For example, many systems use air/vacuum and water filters – to minimize the amount of ORUs needed to maintain the entire vehicle, it would be best to have those systems using the same filter designs. Of course, this will take considerable guidance and coordination from the program management, and cooperation from the various design organizations, but it's a design feature that would greatly simplify the on-orbit maintenance and contingency operations.

7.4.3 Design packaging.

Sometimes it may be desirable to minimize the number of ORUs at the expense of having slightly larger ORUs. For example, it may be better to package items with the same operational life into a single, larger ORU design, even though they may be dissimilar items. Thus only one ORU would need to be replaced periodically instead of a number of smaller ORU items, thereby simplifying the ORU interfaces and reducing the required maintenance time.

7.4.4 Fault detection, isolation and recovery (FDIR).

To minimize the system "trouble-shooting" time, and to ensure that the correct ORU is being removed, some form of FDIR methodology is needed for assessing a system failure. For complex systems with critical functions, an automatic FDIR may be required that features built-in test (BIT) or built-in test equipment (BITE) with interfaces to a health monitoring system. Simpler, non-critical systems may only need a manual FDIR capability. Either approach will require additional monitoring sensors that need to be integrated with the ORU design.

Of course, it's desirable not to have any failures at all. Therefore, robustness (i.e., additional capability beyond what is required or foreseen) is usually an appreciated design feature, but only when it is practical. Often, flight systems do not have the luxury of that option, due to the number of design trade-offs that must be made. However, whenever it is appropriate, a robust design should be developed.

7.4.5 Maintenance verification.

During the ORU design development, consideration should be given to how the ORU's operation and interfaces will be verified after it has been removed and replaced. Again, to minimize the maintenance time, it may be desirable to incorporate sensors, BIT/BITE or other design features that would simplify this task. For example, the ORU's wiring and interfacing cables might include an "integrity circuit" that would indicate whether the cables are correctly mated.

7.4.6 Repair level analysis (RLA).

The RLA is a method for determining whether an ORU should be discarded or repaired, and, if repaired, what its repairable items should be. Typically, a repairable ORU would be returned to Earth (i.e., depot maintenance level) for repairs, in which case its repairable items would be referred to as shop replaceable units (SRUs). If an ORU is repaired on-orbit, then its repairable items would themselves be ORUs, and need to be designed as such. For either scenario, a thorough maintenance task analysis is required to determine the maintenance procedures and the resources needed for those tasks.

7.4.7 Technical data and documentation (TD&D).

Collecting and maintaining the appropriate TD&D is the most overlooked activity of the design development phase, but one that has significant influence upon the supportability of an item. Emphasis should be placed upon obtaining sufficient vendor data, especially for specialty items with limited production runs - the procurement contracts for those items should basically specify as much TD&D as is available from the vendor. The vendor’s TD&D will be invaluable if it becomes necessary to search for alternate parts or alternate sources. Also, the design TD&D is the source data for the life cycle operations and maintenance activities – all of the fabrication, integration, training, operations and repair procedures are based upon these inputs. The key is to not only collect the design TD&D, but to maintain it in an accessible and useable manner – often a database of source data is developed to ensure that the appropriate information is being used. Following are some of the more important design TD&D items.

- Illustrated parts breakdown (IPB) that provides an exploded view and indentured parts list for all delivered hardware.
- Engineering design information (e.g., schematics, specifications, interfaces, drawing trees, etc.) down to the component level, with drawings and parts lists down to the piece-part level.
- System engineering analyses (e.g., safety hazards analysis, failure analysis, reliability and maintainability analysis, etc.).
- Imagery (i.e., photographic and video data) of the ORUs, support equipment and integrated assembly that is developed during assembly, check-out and close-out. The intent is to have imagery data to support every maintenance activity that clearly depicts the hardware configurations, labels and interfaces. Digital imagery is desired since it can be easily stored and transmitted electronically.
- Commercial off-the-shelf (COTS) data (e.g., design specifications, performance, reliability and maintainability data) and operations and maintenance (O&M) manuals.
- System O&M manuals, including the trouble-shooting logic flows.

- Operational sequence diagrams (OSDs) that provide the operational timeline, operational resources and their functional allocation. OSDs are developed for nominal, malfunction and maintenance operations.
- Test data.
- Procurement data (e.g., bill of materials, quality certification records).
- Provisioning data (e.g., vendor sources, costs, production forecasts) for spares and maintenance support.
- A source data and documentation (SD&D) index, which provides a cross-reference between the procedures and their various information sources.
- The source data contact information that indicates the person(s) or organization(s) responsible for collecting and maintaining the data, where the data is maintained, data format and data delivery schedules, if applicable.

8.0 SUMMARY

There are many things to consider when selecting and designing an item to be an ORU; this handbook is not intended to be a comprehensive discourse on all of those issues. Rather the major issues are provided for awareness and to help stimulate the system engineers' and designers' thought processes.

Each project is different, just as each system design is different; therefore please note that this handbook is not a cookbook process. The ORU selection methodology should be tailored to the project's unique criteria and for the system being analyzed. Also, the ORU selections should be periodically reanalyzed as the system matures, so please ensure that the system's ORU selection rationale is adequately maintained.

Appendix A: ORU Selection Flowchart Logic

The following flowchart logic uses a "bottom-up" approach for selecting ORU candidates; therefore, the "item under analysis" (IUA) would typically be a component of a system (e.g., valve, connector, circuit board, etc.). However, engineering experience should be relied upon for determining the appropriate system level for beginning this analysis. For example, often the appropriate ORU level is a subassembly (e.g., pump, "black box", etc.).

Step 1.0, "MTBF < System Life or Limited Life Item?":
Begin by assessing the basic reliability and expected life of the hardware.

- Input: Obtained from predictive/probabilistic reliability analysis and/or vendor data.
- Logic: (a) Is the IUA's mean-time-between-failure (MTBF) less than the system's design operating life? Obviously this is a very crude comparison, since the reliability of a component must be greater than that specified for the entire system to ensure the overall system's reliability. However, the MTBF databases for components are readily available, which makes this an easy and useful initial "sanity check".
  (b) Is the IUA a "limited life" item? In other words, are there any cyclical or time dependant constraints upon the IUA that would prohibit it from achieving the design operating life? For example: Are there any limits upon the number of duty cycles (e.g., on/off, mate/demate, hot/cold)? Are there any limits upon the number of repetitive alignments or other maintenance actions? Are there any time dependant constraints, such as shelf life or exposure time limits?
- Output: Yes - If the answer to any of the above questions is "Yes ", then the IUA is probably a maintenance item and might need to be an ORU; proceed to Step 2.0.
  No - If the answer to all of the above questions is "No", then proceed to Step 1.1.

Step 1.1, "Safety or Performance Critical Item?":
Although an item's inherent reliability may exceed the system's reliability or operational life requirements, the effect of that item's potential failure upon the system safety and performance must be evaluated.

- Input: Failure effects and their criticality are obtained from failure modes and effects analysis (FMEA), or fault tree analysis (FTA). The performance requirements are obtained from the SRD and lower-tiered requirements specifications.
- Logic: (a) Is the IUA a safety critical item? The criticality levels are determined

by the program's risk tolerance criteria; for example, NSTS 5300.4, "Shuttle Safety Policy and Requirements" defines the criticality levels for the Space Shuttle Program.
(b) Is the IUA a performance critical item? This determination involves comparing the failure effects to the system requirements and the project's priorities.

- Output: Yes - If the answer to any of the above questions is "Yes ", then the IUA is probably a maintenance item and might need to be an ORU; proceed to Step 2.0.
  No - If the answer to all of the above questions is "No", then proceed to Step 1.2.

Step 1.2, "High Potential for Obsolescence?":
Although an item may not be expected to fail, it may still need to be replaced due to its technical obsolescence or limited availability. Obsolescence is an issue primarily for long-duration projects for which spares availability may be a concern, or for "cutting edge" projects for which the latest "state of the art" technology is required.

- Input: The Government-Industry Data Exchange Program (GIDEP) Diminishing Manufacturing Sources and Materiel Shortages (DMSMS) alert database is an excellent source for identifying obsolete part candidates. Also, obsolescence issues are identified through provisioning assessments (e.g., sole source limitations, production plans, spares availability throughout the system life) and upgrades planning (i.e., pre-planned product improvement or modernization through spares). Technical obsolescence criteria are provided through the science requirements, trade studies and evaluations of the science instrumentation.
- Logic: (a) Does the IUA have a high potential for becoming obsolete during the system’s operational life due to limited spares availability? This is often a serious issue for space hardware due to the small market size of specialty hardware with few vendors. Stockpiling spares, purchasing the manufacturing rights, securing alternate sources, or designing for alternate replacement parts can minimize this risk. Sometimes, the specialty item is only available from a small, sole-source manufacturer that retains the proprietary design and manufacturing rights, so these risks cannot be satisfactorily alleviated; therefore, the item should be considered as replaceable items.
  (b) Does the IUA have a high potential for becoming technically obsolete during the system’s operational life? Historically, the technology for electronics has rapidly improved their capabilities, thus effectively reduced their technical life and product support life – some examples are computers, video cameras and electronic sensors. Many science experiments demand the most accurate measurements and greater data processing capabilities, which require that such equipment be easily upgraded.

- Output: Yes - If the answer to any of the above questions is "Yes ", then the IUA is probably needs to be designed to be replaceable; go to Step 4.0.
  No - If the answer to all of the above questions is "No", then proceed to Step 1.3.

Step 1.3, "Does this item require preventive maintenance (PM)?":
Although an item may not need to be removed/replaced due to corrective maintenance (CM) (i.e., the IUA has sufficient reliability; it is not a safety or performance critical item; obsolescence is not an issue; etc.), it may need to be accessed for PM.

- Input: The vendor data sheets and/or the system's maintenance assessments will indicate whether PM is required for the IUA.
- Logic: Does the IUA have any PM requirements (e.g., servicing, adjustment, calibration, replacement, upgrading, etc.)?
- Output: Yes - If the IUA does require PM, then go to Step 3.0.
  No - If the IUA does not require PM, then proceed to Step 1.4.

Step 1.4, "Is removal required to perform PM/CM on an adjacent item?":
Although not desired, often a non-maintenance item needs to be removed to enable access to a maintenance item. Designers try to minimize this risk by providing access panels, or mounting the maintenance items on hinged platforms or sliding trays. Often the design packaging constraints do not enable sufficient accessibility to avoid removing non-maintenance items – in those instances, the non-maintenance item might need to be considered as an ORU.

- Input: The system's maintenance assessments, coupled with the design drawings and human factors requirements, will indicate whether a maintenance item is adequately accessible.
- Logic: Does the IUA need to be removed to enable access to an adjacent maintenance item?
- Output: Yes - If the IUA does need to be removed for accessibility, then go to Step 1.5.
  No - If the answer is "No", then this item is not an ORU candidate.

Step 1.5, "Is redesigning an option to preclude the IUA from being removed during any maintenance action?":
The question emphasizes the importance of determining the ORU items early in the design process - and repetitively as the design matures - due to the design considerations for ORUs. If the ORUs are not identified until the system design is fairly mature, then the opportunity to design for their accessibility may not be available. The designer's goal is always to minimize the number of items requiring removal during maintenance actions.

- Input: The design's packaging constraints coupled with the project's resources (i.e., budget, schedule, and technical support), will indicate whether redesigning for accessibility is a practical option.

- Logic: Is it practical to redesign the system to preclude the IUA from being removed during a maintenance action on another item?
- Output: Yes - If redesigning is still a programmatic and design option, then the IUA is not an ORU candidate. However, when redesigning to provide accessibility to the adjacent maintenance item, ensure that the interface and performance requirements are maintained. Sometimes the arrangement of hardware items is a compromise between accessibility and other system requirements (e.g., electromagnetic interference considerations).
  No - If redesigning is not an option, then proceed to Step 1.6.

Step 1.6, "Any adverse safety or human factors issues related to removal of this item?": Although an item may be physically accessible, the maintenance tasks for this item need to be assessed for hazards to the crew.

- Input: A complete maintenance task analysis, coupled with the system's safety hazard analysis and human factors analysis, should identify all possible maintenance hazards to the crew. Of course, the design drawings, layouts, development hardware and maintenance demonstrations are also used in these assessments.
- Logic: Consider all possible crew hazards related to removal/replacement of the IUA. For example, are the touch temperatures within limits, or will protective clothing be required? Are there any sharp edges that are accessible? Is the IUA and its connecting hardware visible during the removal task, or does it require blind access? Does removing the IUA place awkward or excessive loads on the crew? Does removing the IUA expose the crew to hazardous materials or hazardous environments?
- Output: Yes - A positive ("Yes ") response to these questions will require either a redesign; a change in procedures to minimize the crew hazard; special equipment to protect the crew; or considering the next-higher assembly (NHA) as an ORU in lieu of the IUA (go to Step 5.1). Whenever a crew hazard cannot be eliminated by redesign, then warning and caution labels should be placed on the hardware and in the procedures to notify the crew of the inherent hazards.
  No - If removing the IUA does not pose any crew hazards, then proceed to Step 7.0.

Step 2.0, "Can the fault be fault detected (FD) or fault isolated (FI) to the item under analysis?":

If the IUA has a low reliability, if it is a limited-life item (LLI), or if it has adverse failure consequences (i.e., if it is a safety critical or performance critical item), then it needs to be determined if the IUA failure can be detected by the operator(s). An effective FD/FI assessment will preclude unnecessary maintenance actions on "non-failed" items.

- Input: The failure parameters can be obtained from the vendor's data, design documentation, FMEA, FTA, and test plans/procedures.

- Logic: Assess the ability to detect and isolate a failure to this item by considering the FD/FI issues, such as: Are the IUA's failure parameters available for automatic or manual FD/FI? Is built-in test (BIT), built-in test equipment (BITE), or other special test equipment available for FD/FI to the IUA? Are test points on the IUA available or accessible?
- Output: Yes - If the failure can be FD/FI to the IUA, then proceed to Step 3.0.
  No - If FD/FI cannot be traced to the IUA, then the IUA should not be considered as an ORU. Instead, the NHA should be evaluated as an ORU candidate.

Step 3.0, "Is removal required to perform PM/CM tasks?":
The basic criteria for an ORU is addressed by the simple question, "Does it need to be removed?"

- Input: The answer to this question can be obtained from a number of sources: the design documentation, maintenance assessments, safety hazards analysis, human factors analysis, and the verification procedures.
- Logic: Assess the ability to perform "in-situ" (i.e., in place) maintenance on the IUA: Are the test ports and maintenance sections accessible? If necessary, are the maintenance tools and equipment available? Can the maintenance task be verified in-situ? Are there any adverse safety or human factors issues (reference criteria in Step 1.6) related to in-situ maintenance? If the IUA cannot be maintained in-situ, then it will need to be removed for the maintenance activities.
- Output: Yes - If the IUA must be removed for maintenance, then go to Step 4.0
  No - If the IUA can be maintained in-situ, then proceed to Step 3.1.

Step 3.1, "Can maintenance be performed in-situ with a low probability of unintentional damage?":
The impact and effect of unintentional (i.e., collateral) damage needs to be evaluated for in-situ tasks.

- Input: The design documentation, FMEA, FTA, and maintenance concepts provide insights on the opportunities and effects of unintentional damage.
- Logic: Assess the potential adverse effects of maintenance activities upon this item and adjacent hardware: Is there a potential for propagating failures, or other interface restrictions?
- Output: Yes - If the maintenance tasks can be effectively performed in-situ, then the IUA is not an ORU.
  No - If in-situ maintenance may result in collateral damage, then consider removing the IUA for maintenance and proceed to Step 4.0.

Step 4.0, "Item accessible OR require removal of no more than one non-failed item AND adjacent items not likely to be damaged?":
Once it's been determined that the IUA needs to be removed for maintenance, then the practicality of removing that item needs to be assessed. Accessibility and collateral damage are key considerations.

- Input: The design documentation, FMEA, FTA, maintenance assessments, human factors analysis, and safety hazards analysis are sources of information for this evaluation.
- Logic: (a) Is the IUA accessible? If not, then do more than one non-failed item need to be removed for access? (Note that this is a programmatic criterion - some projects require all ORUs to be directly accessible, while others allow more than one other item to be removed for accessibility). Are there any panels or cables that need to be removed? Does this IUA have any blind accesses? Also, since the accessibility criteria vary among environments, will this maintenance be performed as an intravehicular activity (IVA) or extravehicular activity (EVA)?
  (b) Is there a low probability of unintentional, collateral damage? Are there any interface restrictions? Is there a potential for propagating failures?
- Output: Yes - If the IUA is accessible with low probability of collateral damage, then proceed to Step 5.0.
  No - If the IUA is not accessible, or the adjacent items are likely to be damaged, then continue to Step 4.1.

Step 4.1, "Is redesign an option?":
At this point, its been determined that the IUA needs to be removed for maintenance; however, it is either not accessible, or it is likely that the adjacent items will be damaged while removing the IUA. Therefore, the final options are to redesign the system to make the IUA more accessible, or to not consider this IUA as an ORU.

- Input: The design's packaging constraints, coupled with the project's resources (i.e., budget, schedule, and technical support), will indicate whether redesigning for accessibility is a practical option.
- Logic: Is it practical to redesign the system to enable the IUA to be more accessible without damaging the adjacent hardware?
- Output: Yes - If redesigning is still a programmatic and design option, then redesign the IUA to make it more accessible and repeat the ORU selection evaluation (go to Step 1.0). However, during redesign, ensure that the interface and performance requirements are maintained. Sometimes the arrangement of hardware items is a compromise between accessibility and other system requirements (e.g., electromagnetic interference considerations).
  No - If redesigning is not an option, then this IUA is not an ORU candidate. Instead begin evaluating the NHA as an ORU candidate – go to Step 1.0.

<u>Step 5.0, "Any adverse safety/human factors issues related to the maintenance/removal of this item?"</u>:
Although an item may be physically accessible, the maintenance tasks for this item need to be assessed for hazards to the crew.

- <u>Input</u>: A complete maintenance task analysis, coupled with the system's safety hazard analysis and human factors analysis, should identify all possible maintenance hazards to the crew. Of course, the design drawings, layouts, development hardware and maintenance demonstrations are also used in these assessments.
- <u>Logic</u>: Consider all possible crew hazards related to removal/replacement of the IUA. For example, are the touch temperatures within limits, or will protective clothing be required? Are there any sharp edges that are accessible? Are the IUA and its connecting hardware visible during the removal task, or does it require blind access? Does removing the IUA place awkward or excessive loads on the crew? Does removing the IUA expose the crew to hazardous materials or hazardous environments?
- <u>Output</u>: Yes - A positive ("Yes ") response to these questions will require other careful considerations - go to Step 5.1.
  No - If removing the IUA does not pose any crew hazards, then proceed to Step 6.0.

<u>Step 5.1, "Is redesign an option?"</u>:
If maintenance or removal of the IUA poses hazards to the crew, then a redesign should be considered for eliminating those hazards.

- <u>Input</u>: The design documentation, design packaging constraints, the safety hazards analysis, and the human factors analysis provide the factual information for evaluating a redesign. However, this information needs to be coupled with the project's resource information (i.e., budget, schedule, and technical support) to determine whether redesigning to eliminate crew hazards is a practical option.
- <u>Logic</u>: Is it practical to redesign the system to eliminate the crew hazards associated with maintaining or removing the IUA?
- <u>Output</u>: Yes - If redesigning is still a programmatic and design option, then redesign to eliminate the crew hazards and repeat the ORU selection evaluation (go to Step 1.0). However, during redesign, ensure that the interface and performance requirements are maintained. Sometimes the arrangement of hardware items is a compromise between accessibility and other system requirements (e.g., electromagnetic interference considerations).
  No - If redesigning is not an option, then:
  (a) Investigate modifying the removal and maintenance procedures to eliminate the crew hazards, and select the IUA as an ORU.

(b) If the procedures cannot be modified to eliminate the hazards, then this IUA is not an ORU. Instead the NHA should be evaluated as an ORU candidate (go to Step 1.0).

Step 6.0, "Within allocated logistics resources (launch/landing mass/volume, stowage mass/volume, etc.)?":

Although it may be technically feasible to remove/replace the IUA, its logistics requirements need to be compared to the project's logistics resource allocations. Nothing is gained if a maintenance item cannot be delivered to the organizational site.

- Input: The design documentation, maintenance task assessments, and the project's allocated manifesting and logistics resources provide the information necessary for this determination.
- Logic: Assess the manifesting (i.e., resupply and return opportunities) and logistics resources (e.g., transportation and stowage) required:
  - (a) What are the IUA's launch and landing stowage mass, volumes (including packaging materials) and locations? Do they exceed the project's launch/landing stowage allocations?
  - (b) What are the IUA's on-orbit stowage mass, volumes (including packaging materials) and locations? Do they exceed the project's on-orbit stowage allocations?
  - (c) Does the IUA require any unique environment, logistics resources (e.g., continuous power), or handling requirements? Are these resources available to the project?
  - (d) Does the launch manifest provide adequate resupply and return opportunities?
- Output: Yes - If the project has adequate logistics resources to support the IUA, then proceed to Step 7.0.
  No – Exceeding the project's allocations require either redesigning to achieve the budgeted allocations, or obtaining additional resources – go to Step 6.1.

Step 6.1, "Is redesign an option?":

If the logistics resources are not available, then a redesign might be desired to meet those limited resource allocations.

- Input: The design documentation, design packaging constraints, the safety hazards analysis, and the human factors analysis provide the factual information for evaluating a redesign. However, this information needs to be coupled with the project's resource information (i.e., budget, schedule, and technical support) to determine whether redesigning to achieve the logistics resource allocations is a practical option.
- Logic: Is it practical to redesign the system to achieve the project's logistics resource allocations for the IUA?
- Output: Yes - If redesigning is still a programmatic and design option, then

redesign to meet the logistics resources allocations and repeat the ORU selection evaluation (go to Step 1.0). However, during redesign, ensure that the interface and performance requirements are maintained. Sometimes the arrangement of hardware items is a compromise between accessibility and other system requirements (e.g., electromagnetic interference considerations).
No - If redesigning is not an option, then inform the project management that the allocated logistics resources have been exceeded, and proceed to Step 7.0. The project manager may be successful in having the project's logistics resource allocations increased for specific flight manifests.

<u>Step 7.0, "Maintenance resources (# crew, crew skills, tools, etc.) available?"</u>: Although the logistics resources (e.g., transportation and storage) are available, the maintenance resources also need to be available.

- <u>Input</u>: The design documentation, maintenance task assessments, and the project's allocation of on-orbit maintenance resources are sources of information for this evaluation.
- <u>Logic</u>: Are the on-orbit maintenance resources available for the IUA? Are the crew skills, number of crewpersons, and crew time available? Are the maintenance tools and equipment available? Are the consumable items available?
- <u>Output</u>: Yes - If the maintenance resources are available, then select the IUA as an ORU.
  No - If the maintenance resources are not available, then:
  (a) Inform the project management so that they can negotiate for additional resources.
  (b) If additional maintenance resources cannot be obtained, then redefine the maintenance concept to fit within the available resources.
  (c) If the maintenance concept cannot be satisfactorily modified to fit the available resources, then do not consider the IUA as an ORU – instead evaluate the NHA as an ORU candidate (go to Step 1.0).

Appendix B: ORU Selection Flowchart Worksheets

The following worksheets are provided as an aid to collect data on the IUA and to capture the rationale developed through use of the ORU selection worksheet. These are not intended to be comprehensive worksheets; rather they're a starting point for collecting the data relative to the IUA and its parent system. Similarly, the logic flow depicted by these worksheets should be tailored to the system's specific programmatic criteria.

Worksheet 1: Input Data

Item Name:	Item Characteristics:	
	Inherent Availability (Ai):	
Part Number:	MTBF:	
	MTTR:	
LCN:	Max TTR:	
	MMH:	
RBD Reference Number:	PM Frequencies:	
	CM Frequencies:	
NHA:	Mission Duration:	
	Duty Cycle:	
Vendor:	Operational Life:	
	Shelf Life:	
	Crew Size:	
	Other Resource Constraints:	
	BIT/BITE Capability:	
	Tool/GSE/FSE Requirements:	
	Maintenance Constraints:	
	Environmental Constraints:	
	Safety Hazards:	
	Failure Criticality:	
	Other Design Limitations:	
	Maintenance Concept:	
	Dimensions (LWD):	
	Volume:	
	Mass:	
	Limited Life Issues:	
	Obsolescence Issues:	

Worksheet 2: ORU Selection Logic Flow

Item Name:		
Item Number:		
LCN:		
	Rationale	Data Source
1.0 MTBF < Sys life or limited life item?		
• System Life		
• MTBF		
• Shelf Life		
• Other Life Limitations		
1.1 Safety/performance critical item?		
• Safety criticality		
• Performance criticality		
1.2 High potential for obsolescence?		
• Spares availability		
• Technical obsolescence		
1.3 Does this item require PM?		
• PM requirements		
1.4 Is removal required to perform PM/ CM on any adjacent item?		
• Accessibility of other items		
1.5 Redesign to preclude IUA removal during any maintenance action?		
• Packaging constraints		
• Programmatic constraints		
1.6 Any Safety/human factors issues?		
• Safety hazards		
• Human factor issues		

Worksheet 2: ORU Selection Logic Flow (Continued)

Item Name:		
Item Number:		
LCN:		
	Rationale	Data Source
2.0 Can the fault be FD/FI to the IUA?		
• BIT/BITE		
• Test points availability		
3.0 Is removal required to perform PM/ CM tasks?		
• Maintenance/test ports accessibility		
• Tools/equipment availability		
• Verifiable in-situ		
• Adverse safety/human factors		
3.1 In-situ maintenance without collateral damage?		
• Failure propagation potential		
• Interface restrictions		
4.0 Item accessible?		
• Direct access?		
• Other items removed?		
• Collateral damage?		
4.1 Is redesign an option?		
• Technically?		
• Schedule?		
• Budget?		
5.0 Any Safety/Human factors issues related to maintenance?		
• Safety hazards		
• Human factors issues		

Worksheet 2: ORU Selection Logic Flow (Continued)

Item Name:		
Item Number:		
LCN:		
	Rationale	Data Source
5.1 Is redesign an option?		
• Technically?		
• Schedule?		
• Budget?		
6.0 Within allocated logistics resources?		
• Mass (Allocation)		
• Volume (Allocation)		
• Unique environment?		
• Logistics resources available?		
• Manifesting available?		
6.1 Is redesign an option?		
• Technically?		
• Schedule?		
• Budget?		
7.0 Maintenance resources available?		
• Crew resources		
• Special skills		
• Tools & Test Equipment		
• Consumables		
IUA selected as ORU?		

MSFC DOCUMENTATION REPOSITORY • DOCUMENT INPUT RECORD

I. GENERAL INFORMATION

1. APPROVED PROJECT: CDDF #99-42	2. DOCUMENT/ DRAWING NUMBER: MSFC-HDBK-3074	3. CONTROL NUMBER:	4. RELEASE DATE: 12/11/2002	5. SUBMITTAL DATE: 12/11/2002

6. DOCUMENT/DRAWING TITLE: Selection Methodology for Orbital Replaceable Units	7. REPORT TYPE: Mulit-program/project handbook

8. CONTRACT NUMBER / PERFORMING ACTIVITY: ED42	9. DRD NUMBER:	10. DPD / DRL / IDRD NUMBER:
11. DISPOSITION AUTHORITY (Check One): ☒ Official Record - NRRS 8/12/A ☐ Reference Copy - NRRS 8/5/A/3 (destroy when no longer needed)	12. SUBMITTAL AUTHORITY: ED42/Jim Sledd	13. RELEASING AUTHORITY:

14. SPECIAL INSTRUCTIONS:
Initial baseline of MSFC-HDBK-3074

15 CONTRACTOR/SUBMITTING ORGANIZATION, ADDRESS AND PHONE NUMBER: Jim Sledd MSFC/ED42 256-544-4058	16. ORIGINATING NASA CENTER: MSFC 17. OFFICE OF PRIMARY RESPONSIBILITY: ED42
18. PROGRAMMATIC CODE (5 DIGITS): 274-62-00	19. NUMBER OF PAGES: 42

II. ENGINEERING DRAWINGS

20. REVISION:	21. ENGINEERING ORDER:	22. PARTS LIST:	23. CCBD:

III. REPORTS, SPECIFICATIONS, ETC.

24. REVISION Baseline	25. CHANGE:	26. VOLUME:	27. BOOK:	28. PART:	29. SECTION:

30. ISSUE:	31. ANNEX:	32. SCN:	33. DCN:	34. AMENDMENT:
35. APPENDIX:	36. ADDENDUM:	37. CCBD:	38 CODE ID:	39. IRN:

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40. ORG. CODE: ED42	41. PHONE NUMBER: (000) 544-4058	42. NAME: Jim Sledd	43. SIGNATURE/DATE:

VI. TO BE COMPLETED BY MSFC DOCUMENTATION REPOSITORY

44 RECEIVED BY: Tammy Wiese	45. DATE RECEIVED: 12-18-02	46. WORK ORDER: 03-0084-3