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Maintainability requirements for ESA space systems

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ABSTRACT

This specification defines the maintainability assurance requirements which are applicable to ESA space systems.

DOCUMENT CHANGE RECORD

Issue number and date	Sections affected	Remarks

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SECTION 1: SCOPE

This specification defines the maintainability assurance requirements which are applicable to ESA space systems.

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SECTION 2. GENERAL

Maintainability is an inherent characteristic of a system which is determined by its design.

It pertains to the ease, accuracy, safety, and economy in the performance of the maintenance actions that are necessary to restore or retain the system in specified conditions within established programme and mission constraints.

2.1 Applicability

The requirements defined in this document shall apply to all systems where maintenance is to be used to achieve or sustain system capabilities for mission success.

This document does not address maintainability requirements for the software parts of systems.

The requirements of this specification will be tailored by ESA in its Statement of Work to fit the needs and constraints of each programme to which these requirements are applied.

In case of conflict between the requirements of this document and those stated in the contract, the contractual statement shall be given priority.

2.2 ESA maintainability assurance policy

The ESA maintainability policy is defined in ESA PSS-01-0 'Product assurance and safety policy and basic requirements for ESA space systems'.

All systems where maintenance is used to achieve or sustain system capabilities for mission success shall be designed for maintainability.
System maintainability characteristics shall be traded off with other system attributes such as performances, reliability, availability, cost, weight, and size.

Design for maintainability shall address all elements of maintainability including:

(a) Simplification of maintenance tasks;

(b) Consideration of human-factor requirements;

(c) Minimisation of the need of preventive maintenance;

(d) Minimisation of the need for special tools and special test equipment;

e) Minimisation of design complexity and costs;

(f) Minimisation of requirement for special skills;

(g) Maximisation of accessibility;

(h) Maximisation of modularity;

(i) Maximisation of commonality/interchangeability;

(j) Standardisation of hardware;

(k) Optimisation of testability and fault isolation capability.

In any case when safety and maintainability requirements are in conflict, safety considerations shall have absolute priority.

2.3 Basic approach

1. System maintainability requirements will be defined by ESA and will appear in the appropriate sections of the system specifications.

2. The contractor shall make an apportionment of system maintainability requirements to lower levels.

3. The contractor shall evaluate the maintainability characteristics of the system and its elements through a programme of analyses, when applicable, reviews and demonstrations.

2.4 Quantitative maintainability requirements

Quantitative system maintainability requirements will be defined by ESA in one or more of the following ways:

(a) Mean corrective maintenance time (or mean time to repair) for mission critical items.

(b) Maximum active corrective maintenance time for safety critical items.

(c) Mean preventive maintenance time.

(d) Time between preventive-maintenance actions.

(e) Mean active maintenance time.

(f) Mean time between maintenance actions.

(g) Maintenance man-hour per operating hour.

(h) Proportion of faults or failure modes to be detected and/or isolated by automatic or built-in test equipment.

(i) Maximum contribution of false alarms to all fault or failure indications provided by automatic or built-in test equipment.

(j) Maximum crew time for maintenance activities.

2.5 Applicable documents

The specifications listed below are directly applicable to this specification to the extent defined herein.

ESA PSS-01-0 Product assurance and safety policy and basic requirements for ESA space systems

ESA PSS-01-001 ESA glossary of product assurance and safety terms.

ESA PSS-01-10 Product assurance management requirements for ESA space systems.

ESA PSS-01-12 ESA contractor product assurance assessment system.

ESA PSS-01-20 Quality assurance requirements for ESA space systems.

ESA PSS-01-30 Reliability assurance requirements for ESA space systems.

ESA PSS-01-303 Requirements for failure modes, effects and criticality analysis and associated activities on ESA space systems.

ESA PSS-01-40 System safety requirements for ESA space systems.

2.6 Definitions

The definitions listed in ESA PSS-01-001 shall apply.

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SECTION 3: MAINTAINABILITY PROGRAMME MANAGEMENT

3.1 General

The contractor shall organise maintainability assurance as an integral part of his product assurance discipline. The requirements of ESA PSS-01-10 shall apply.

3.2 Maintainability programme plan

The contractor shall develop, maintain, and implement a maintainability programme plan for each programme phase, which describes how compliance with the maintainability programme requirements will be assured.

The plan shall address the applicable requirements of this document including:

(a) Description of the duties of each organisational element involved in the accomplishment of the maintainability tasks;

(b) Identification of each organisation that will have the lead and assist roles in the execution of each task, and the organisations that have review or approval authority over the document generated as part of the maintainability programme;

(c) Identification of the interfaces between maintainability organisation and other project organisations as management, design, reliability, safety, software and logistics;

(d) Identification of each maintainability task to be performed,together with narrative descriptions, sequence of tasks and schedules with estimated start and completion points, and supporting documentation that describes in detail the plan for execution and management of each task;

(e) Description of the integration of the maintainability programme with other product assurance programme elements, in particular with the quality, reliability, and safety assurance programmes defined in ESA PSS-01-20, ESA PSS-01-30, and ESA PSS-01-40, respectively;

(f) Description of the extent to which the maintainability function participates in informal and formal design reviews.

A more specific list of the maintainability activities and their relationship with the programme phases is given as guidance in Appendix A.

3.3 Design reviews

The contractor shall ensure that all data necessary for a complete system maintainability assessment are available for design reviews and presented to the reviewing authority in accordance with the project review schedule.

The level of detail of these data shall be consistent with the objective of the review.

The contractor's maintainability function shall participate in all design reviews.

The contractor shall prepare the documented record of analyses, predictions and reports performed in accordance with the contract. All maintainability data submitted shall clearly indicate the applicable design baseline.

All design changes shall be assessed for their impact on maintainability. All recommendations for design improvement shall be fully justified and documented. Formal evidence of the acceptance of the recommendation or rationale for its rejection by the contractor's management shall be provided and documented in the maintainability recommendation status log.

3.4 Maintainability data file

The contractor shall maintain a project maintainability data file as part of his overall product assurance documentation system. The file shall contain, in addition to that required by ESA PSS-01-10, the following as a minimum:

(a) Maintainability analyses, lists, reports and input data;

(b) Copies of analyses, lists and reports delivered for milestone reviews;

(c) Supporting analyses (maintainability models, computer simulations and other supporting data);

(d) Maintainability recommendation status log;

(e) Supporting documentation for any of the maintainability analyses.

The Agency shall be allowed access, on request, to the data contained in the maintainability data file.

3.5 Subcontractor control

General requirements for the control of subcontractors are defined in ESA PSS-01-10. In particular, the contractor shall be responsible for ensuring that elements obtained from subcontractors and suppliers meet the maintainability requirements specified for the overall system.

For this purpose the contractor shall provide appropriate requirements, guidance, and controls to subcontractors and suppliers.

The level of maintainability requirements imposed on subcontractors and suppliers shall be tailored and identified to be consistent with those imposed on the prime contractor.

3.6 Maintainability audits

The contractor shall perform maintainability audits of his own, and of his subcontractor's project activities to verify compliance with the project maintainability policies and requirements, and to identify maintainability problem areas. Maintainability audit may be part of a Product Assurance audit. The Agency shall be informed of the audit schedule.

Audits by the Agency of the contractor's maintainability programme are defined in ESA PSS-01-12.

3.7 Maintainability design incorporated in previously designed, manufactured or flown components

Where the contractor proposes to use previously designed, manufactured or flown elements in his system, he shall demonstrate that the proposed elements will comply with the maintainability assurance requirements of the design specification.

Where the contractor considers that such elements fulfil these requirements, he shall submit evidence of their compliance. Nonconformances to requirements shall be identified and the rationale for retention shall be provided with supporting documentation. This includes modifications that would render the equipment compliant.

3.8 Design for maintainability of property furnished by the Agency

Where the overall system includes items furnished by the Agency, the contractor shall define the maintainability data to be obtained from the Agency. Where the overall maintainability requirements of the system cannot be met with the use of such property, the contractor shall inform the Agency of the necessary appropriate action.

3.9 Maintainability programme documentation

The contractor shall provide the Agency with adequate documentation of the tasks performed throughout the programme.

A recommended list of maintainability documents is given in Appendix B.

3.10 Training

General training requirements are those specified in ESA PSS-01-10; in addition, training and indoctrination of maintenance personnel in new technologies and techniques shall be provided as required by the project.

SECTION 4: MAINTAINABILITY ENGINEERING

4.1 General

Maintainability engineering includes the establishment of design requirements and a number of engineering tasks that are an integral part of the systems engineering process. These tasks include:

(a) Assisting designers in arriving at a design definition which meets the maintainability requirements as specified in the design specification;

(b) Performing analyses and reviews of the design;

(c) Specifying ways to enhance the maintainability of the selected design.

4.2 Maintainability requirements

Maintainability requirements that will be applied to the system, subsystem(s) or equipment being developed shall be established on the basis of the system maintenance concept.

The system maintenance concept will be developed by the cognizant ESA organisation or a contractor designated by ESA in accordance with the contract with the support of the maintainability function.

4.3 Maintainability inputs to maintenance plan

The maintainability engineering shall provide inputs to develop and review a maintenance plan prepared by the contractor to support the maintenance concept adopted.

These inputs shall include estimates of preventive and corrective maintenance requirements (including task times and frequencies) and the proportion of failures that will be localised by automatic, semiautomatic and manual means.

4.4 Maintainability design criteria

The contractor shall develop and implement design criteria to facilitate maintenance actions in predicted environments. In establishing maintainability design criteria the contractor shall use data obtained from previous maintenance activities. Design criteria shall include the elements of maintainability listed in Paragraph 1.4.

Examples of maintainability design criteria are given in Appendix C.

4.5 Analysis support

In order to arrive at a design that complies with the maintainability requirements, the maintainability function shall participate in the trade-off studies and support the following analyses as a minimum:

(a) Analyses to determine the optimum Orbital Replaceable Unit (ORU)/Line Replaceable Unit (LRU) configurations. These shall consider performance, mission and safety criticality, reliability, economy, fault diagnostics capability, and unit replacement times;

(b) Design analyses (structural, thermal, EMC, etc.) to ensure that the design complies with the maintainability requirements and design criteria;

(c) Analyses to identify safety hazards induceds a result of maintenance activities and to determine safety procedures, precautions, and protective devices to safeguard personnel during maintenance actions;

(d) An analysis of diagnostic alternatives to detect effectively and isolate failure to the ORU/LRU level and accurately verify system restoration;

(e) Analyses to support minimisation of preventive maintenance requirements through the application of cost-effective methods of monitoring equipment condition;

(f) An analysis to determine the quantity and types of spare ORUs/LRUs necessary to sustain satisfactory operational availability;

(g) An analysis to verify that the form and fit of each ORU/LRU will not be compromised by worst-case dimensional-tolerance build-up;

(h) An analysis to determine the maximum number of maintenance actions that each ORU/LRU can be subjected to without degradation in performance, and/or reliability;

4.6 Tool requirements

The system design shall minimise the need for maintenance tools. When tools are required, the contractor shall design to permit the use of tools and equipment previously qualified for the specific environment to the greatest degree practical. Use of tools shall be standardised to minimise the number of tools required.

4.7 ORU/LRU placement

Priority shall be given to placement of ORUs/LRUs for optimum accessibility. In general, ORUs/LRUs that have been designated for periodic replacement shall be located where removal and replacement can be most readily accomplished.

A failure mode, effects and criticality analysis (FMECA) and a hazard analysis (HA) shall be used to aid in prioritising the location of the ORUs/LRUs.

4.8 Problem reporting and corrective action

The contractor shall have a controlled system for identification, reporting, analysis, corrections, and recurrence prevention of maintainability problems and nonconformances.

Nonconformance reporting shall be performed in accordance with ESA PSS-01-20. The contractor shall assure that the system contains provisions for reporting maintainability problems and nonconformances encountered during all phases of testing. Problem and failure investigation, and handling shall also be reported.

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SECTION 5: MAINTAINABILITY ANALYSES

5.1 General

This chapter addresses the maintainability requirements specified by the maintenance concept (see Paragraph 3.2) and the quantitative maintainability requirements (see Paragraph 1.6).

The relationship between the activities that follow and the phases of the programme is given as guidance in Appendix A.

Recommended time for submittal of the documentation relevant to the activities is given in Appendix B.

5.2 Maintainability models

Maintainability models shall be developed and used to assist:

(a) The allocation and prediction process;

(b) The ORU/LRU definition process in achieving a performance, economy, reliability, and maintainability balance in the design of the system.

Maintainability models may be developed manually or through computer techniques.

Maintainability models shall be based on the systems engineering models, and shall be developed for alternative system concepts (or configurations) and design changes that are a normal part of the systems engineering process. These models shall be documented and used continually throughout the design process. These maintainability models shall be used to augment systems engineering trade-off studies.

5.3 Maintainability allocation

1. Quantitative maintainability requirements (see Paragraph 1.6) shall be allocated to the ORU/LRU level unless otherwise required to comply with the maintenance concept. These maintainability allocations shall be documented and used as the baseline against which design alternatives are evaluated.

2. Contractors shall specify quantitative maintainability requirements on subcontracted hardware.

5.4 Maintainability prediction

1. The contractor shall prepare and document maintainability predictions and employ them as a design tool to assess and compare design alternatives. Maintainability models (see Paragraph 4.2) shall be used as the basis for the maintainability predictions and as a means of assessing compatibility with the maintenance human resources requirements.

2. Maintainability estimates for ORU/LRU configurations identified as safety critical shall be so designated. These data shall be referred to the Safety Programme for appropriate analysis and risk assessment.

3. Maintainability estimates for ORU/LRU configurations identified as mission critical shall be so designated. These data shall be used as inputs to an assessment of overall programme risk.

5.5 Maintainability data classifications

The accuracy of the maintainability predictions depends upon the accuracy and validity of the data used. These data shall be classified into the following categories:

CATEGORY DEFINITION

A. Data that have been directly obtained from previous on-orbit repair or maintenance missions on hardware of similar function and configuration, or actually demonstrated on ground segment equipment.

B. Data that have been directly obtained from repair or maintenance tasks on hardware or similar function and configuration in a simulated Extravehicular Activity (EVA)/Intravehicular Activity (IVA) or ground environment. Data obtained in previous maintainability validation/verification tests constitute an example of Category B data.

C. Data obtained from task repair times for elemental activities to build up to the ORU/LRU (i.e. Predetermined Time Standards), or other data that cannot be classified as Category A or Category B.

Category A and B data shall be used in preference to Category C where available. The maintainability predictions shall identify the data category that was used.

5.6 Failure mode, effects and criticality analysis (FMECA) - maintainability information

The contractor shall develop maintainability information in conjunction with the FMECA task effort described in ESA PSS-01-303.

The maintainability information shall be used to allow:

(a) Identification of maintenance actions to prevent/correct failures;

(b) Test planning;

(c) Definition of inspection and checkout requirements;

(d) Identification of maintainability design deficiencies requiring redesign.

5.7 Preventive maintenance analysis

The contractor shall conduct an analysis to determine an optimum preventive maintenance schedule that will minimise the amount of support resources needed to sustain the required mission capability and will also minimise down time. Each preventive maintenance action shall be based on the results of the application of a systematic decision logic to be approved by the Agency.

5.8 Emergency maintenance analysis

The contractor shall perform the necessary analyses of the time-to-restore for any emergency restoration or repair procedures designed for sustaining mission capability in the absence of the necessary spare parts.

These analyses shall consider emergency actions to reconfigure components or other work around in an emergency state.

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SECTION 6: MAINTAINABILITY ASSESSMENT, DEMONSTRATION AND DATA COLLECTION

6.1 General

Maintainability assessment, demonstration and data collection includes test and analytical procedures to verify that space systems, subsystems, or related ground segment equipment possess the specified maintainability characteristics.

6.2 Maintainability Assessment

1. The contractor shall periodically assess the maintainability characteristics of the design.

2. Maintainability assessment shall be conducted by the maintainability assurance function with support from other programme functions including systems engineering, reliability, safety and logistics.

3. Informal maintainability assessments should be conducted throughout the design process. Formal maintainability assessments shall be conducted in preparation for all major design reviews. Findings of the formal maintainability assessments shall be presented at all major design reviews.

6.3 Maintainability demonstration

1. The contractor shall conduct maintainability demonstration tests as part of design verification to verify that preventive and corrective maintenance activities can be successfully executed within the scope of the maintenance concept.

   Maintainability demonstration shall be conducted in an environment which simulates, as closely as practicable, the operational environment planned for the system.

2. The contractor shall develop a maintainability demonstration plan as a separate document or as a part of system test procedures. This plan shall be reviewed and approved by the Agency. Updates to the plan shall be performed if the demonstration results do not accomplish the expected results.

3. The contractor shall prepare a report that documents the results of the maintainability demonstration. This report may be part of an overall system test report.

The report shall be used in assessing mission risk associated with the inherent ability to complete both preventive and corrective maintenance actions.

6.4 Maintainability inputs to project reviews

The contractor shall ensure that all pertinent maintainability data necessary to support each project milestone or review are provided in complete form and in a timely manner as determined by the Agency procuring activity. This shall include all pertinent data on subcontractor- and supplier-furnished articles that are a part of the specific hardware assembly to which the readiness review pertains.

6.5 Maintainability data collection

1. General requirements

The contractor shall implement and document a data collection and analysis programme to obtain the best possible data for this purpose. These data shall be based upon actual test or flight experience to the maximum degree possible.

2. Specific requirements

Data shall be developed and maintained in support of the maintainability program in the following areas:

(a) Design engineering guidelines that will accomplish design for maintenance in spaceflight or ground-based applications;

(b) Quantitative maintainability data.

Design engineering guideline data shall, as a minimum, include design and packaging constraints applicable to both preventive and corrective maintenance activities in both EVA/IVA and ground maintenance actions. Data developed under these requirements shall be based upon in-flight experience or test data (provided that the conditions under which test data were obtained are similar to the appropriate EVA/IVA and ground environment).

6.6 Maintainability acceptance

As a condition of acceptance, the contractor shall have verified through the appropriate demonstrations or analyses that the maintainability requirements have been met. All verifications of maintainability requirements shall be completed and available as an input to the flight readiness review process.

APPENDIX A

RELATIONSHIP BETWEEN MAINTAINABILITY ACTIVITIES AND PROGRAMME PHASES

PAR./DOC. NO.	REQUIREMENTS/ACTIVITIES	PROGRAMME PHASES			
		A	B	C	D
3.2	Maintainability programme plan	A	B	C	D
PSS-01-10	Maintainability programme control		B	C	D
PSS-01-10	Maintainability progress reporting	A	B	C	D
3.5	Subcontractor and supplier control		B	C	D
3.8	Maintainability of Agency-furnished property		B	C	
3.10	Maintainability training		B	C	D
4.2	Maintainability requirements	A	B	C	
4.3	Maintainability inputs to maintenance plan		B	C	D
4.4	Maintainability design criteria		B	C	
4.5	Analysis support		B	C	D
4.6	Tool requirements		B	C	D
4.7	ORU/LRU placement	A	B	C	
4.8	Problem reporting and corrective action		B	C	D
5.2	Maintainability models	A	B	C	
5.3	Maintainability allocations	A	B	C	
5.4	Maintainability predictions	A	B	C	

PAR./DOC. NO.	REQUIREMENTS/ACTIVITIES	PROGRAMME A	B	C	D
5.6	FMECA - Maintainability information		B	C	
5.7	Preventive maintenance analysis		B	C	D
5.8	Emergency maintenance analysis		B	C	D
6.2	Maintainability assessment	A	B	C	D
6.3	Maintainability demonstration		B	C	D
6.4	Maintainability inputs to project reviews		B	C	D
6.5	Maintainability data collection		B	C	D
6.6	Maintainability acceptance			C	D

APPENDIX B

RECOMMENDED LIST OF CONTRACTOR-GENERATED MAINTAINABILITY DOCUMENTS

The following list identifies the contractor-generated documentation required by this specification.

Each item (i.e. plan, report etc.) is related to the maintainability activity Paragraph, recommended time for submittal, and the appropriate Agency action.

The Agency using this document in support of a procurement will determine what documentation is required for the programme.

In tailoring requirements, the Agency may permit the contents of some of these documents to be combined into a single report, while others may not be required.

The Agency reserves the right to add, modify, or eliminate documentation requirements listed on page 24.

APPENDIX B:

RECOMMENDED LIST OF CONTRACTOR-GENERATED MAINTAINABILITY DOCUMENTS

ITEM	PAR. REF.	DUE DATE	AGENCY
Maintainability programme plan (include one copy of each procedure referenced in the plan)	3.2	a. With proposal b. Negotiated changes before contract execution c. Update to include negotiated changes 30 days after contract award	I A A
Maintainability models, allocations and predictions	5.2 5.3 5.4	Before PDR then updated for CDR	R
Maintainability demonstration Plan	6.3	a. Initial submittal 30 days prior to PDR b. Updates as revised, final plan 30 days before each test	A A
Maintainability demonstration reports	6.3	30 days after each test	R

Key to table

PDR = Preliminary Design Review
CDR = Critical Design Review

A = Approval
R = Review
I = Information

APPENDIX C:

EXAMPLES OF MAINTAINABILITY DESIGN CRITERIA

1. Each ORU/LRU shall include both coarse and fine installation alignment guides as necessary to assure ease of ORU/LRU installation and removal.

2. Reach envelopes, crew load/forces, and general work constraints for EVA, IVA and '1-G' maintenance tasks shall be defined.

3. General accessibility criteria for each ORU/LRU shall include minimum sweep clearances between interface tools and hardware structures, and connector clearance constraints. Replacement of an ORU/LRU shall be accomplished without removal of other ORUs/LRUs.

4. Accessibility criteria for planned maintenance activity shall include clearance envelopes for those activities where access to an opening for an ORU/LRU maintenance activity is required.

5. System thermal design criteria shall provide for ORU/LRU replacement or maintenance in a manner which will preclude degradation or damage to any other ORU/LRU subsystem, or component.

6. Requirements shall be defined for handling provisions of ORUs/LRUs so as to simplify handling and minimise the likelihood of mishandling equipment.

7. Tooling and hardware items shall be designed for commonality, standardisation and interchangeability to ensure the minimum number of items.

8. ORU/LRU fasteners shall be selected to minimise accessibility time consistent with good design practice.

9. The ORU/LRU surface structure shall be so designed that no safety hazard is created during the removal, replacement, test or checkout of any ORU during an EVA or IVA maintenance activity, or LRU in '1-G' environment. Design criteria shall include minimum radii requirements, surface finish requirements, and special requirements for protective mechanisms where indicated.

Additionally the design shall include caution/warnings for mission or safety critical ORUs/LRUs.