Maintainability Engineering Requirements

The Maintainability Engineering Discipline

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Maintainability as a Figure of Merit (FOM)

The probability that a given maintenance action, for an item under given conditions of use, can be carried out within a stated time interval, when the maintenance is performed under stated conditions and using stated procedures and resources.

Maintenance Concept

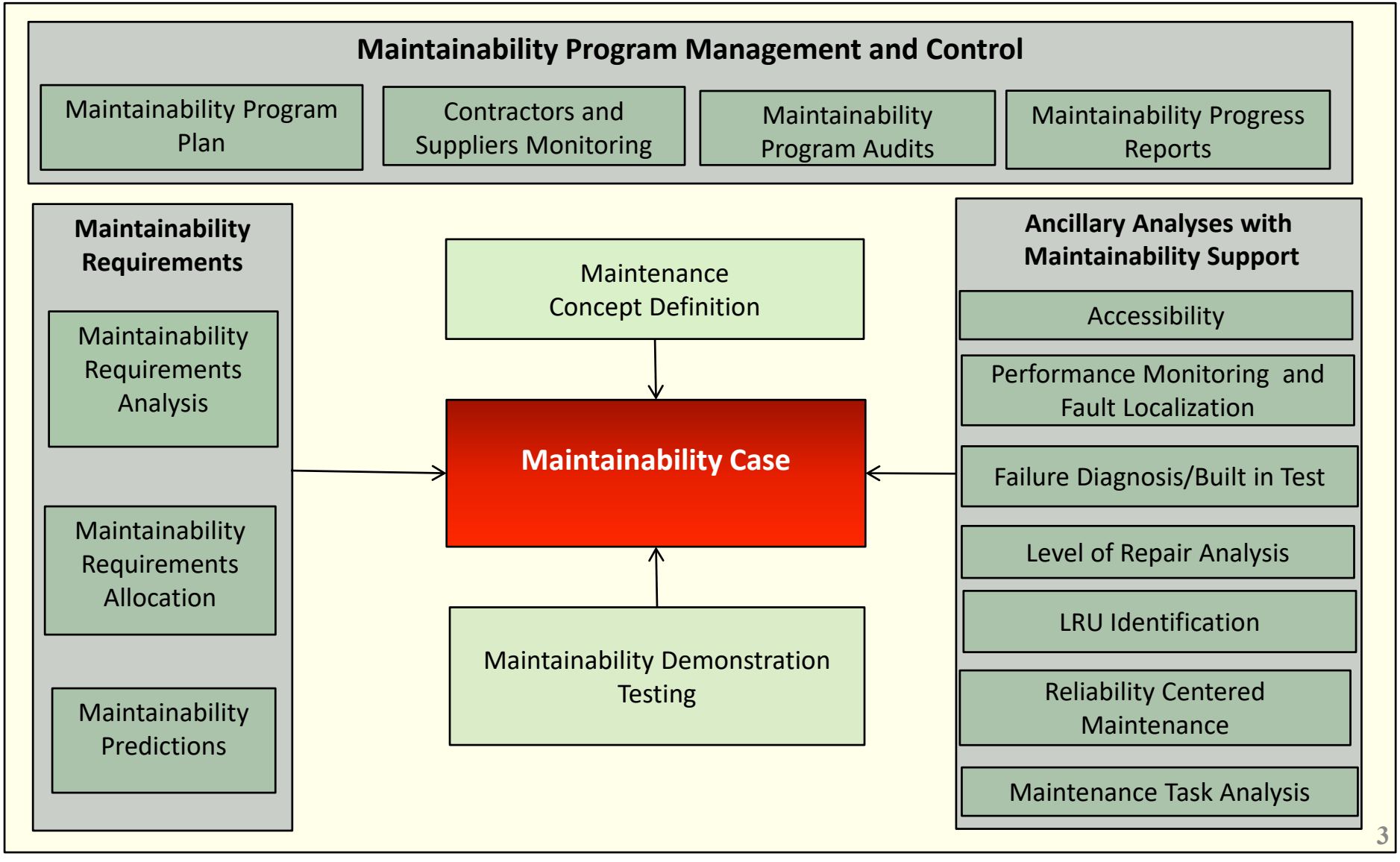
The Maintenance Concept is a brief description of maintenance considerations, constraints, and plans for operational support of the system/equipment under development. A preliminary Maintenance Concept is developed and submitted as part of the preliminary system operational concept for each alternative solution candidate by the operating command with the assistance of the implementing and supporting commands. The Maintenance Concept requirements are translated into system design and support requirements. As the system design activities are performed, the Maintenance Concept continues to shape system design decisions and detailed maintenance and product support requirements.

Maintainability Engineering

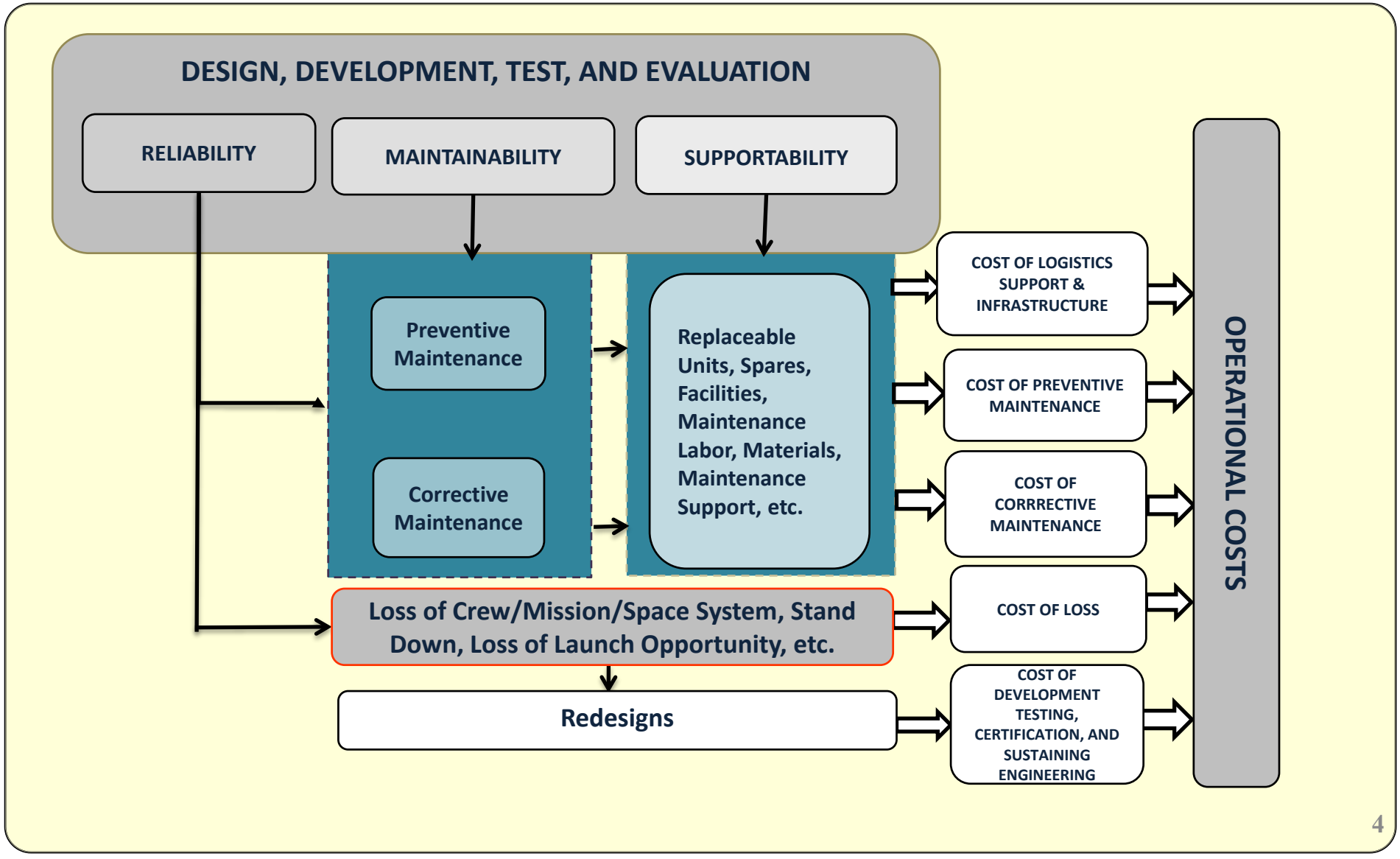
- **Why Maintainability Engineering?**
  - Maintainability Engineering is a design function.
  - Maintainability Engineering has important interfaces with and inputs to Reliability engineering, design engineering, maintenance planning, supportability engineering, and logistic support.
  - Maintainability analysis is critical to identify the design features and characteristics needed for time efficient processing, preventive and corrective maintenance, rapid fault detection and diagnosis, and retest/repair validation.
  - A Maintainability Program is required to improve operational readiness, reduce maintenance manpower needs, reduce life cycle cost, and provide data essential for project management.

Reliability and Maintainability Engineering is a critical design function and involves much more than just calculating probabilities and statistics.

The Maintainability Engineering Case



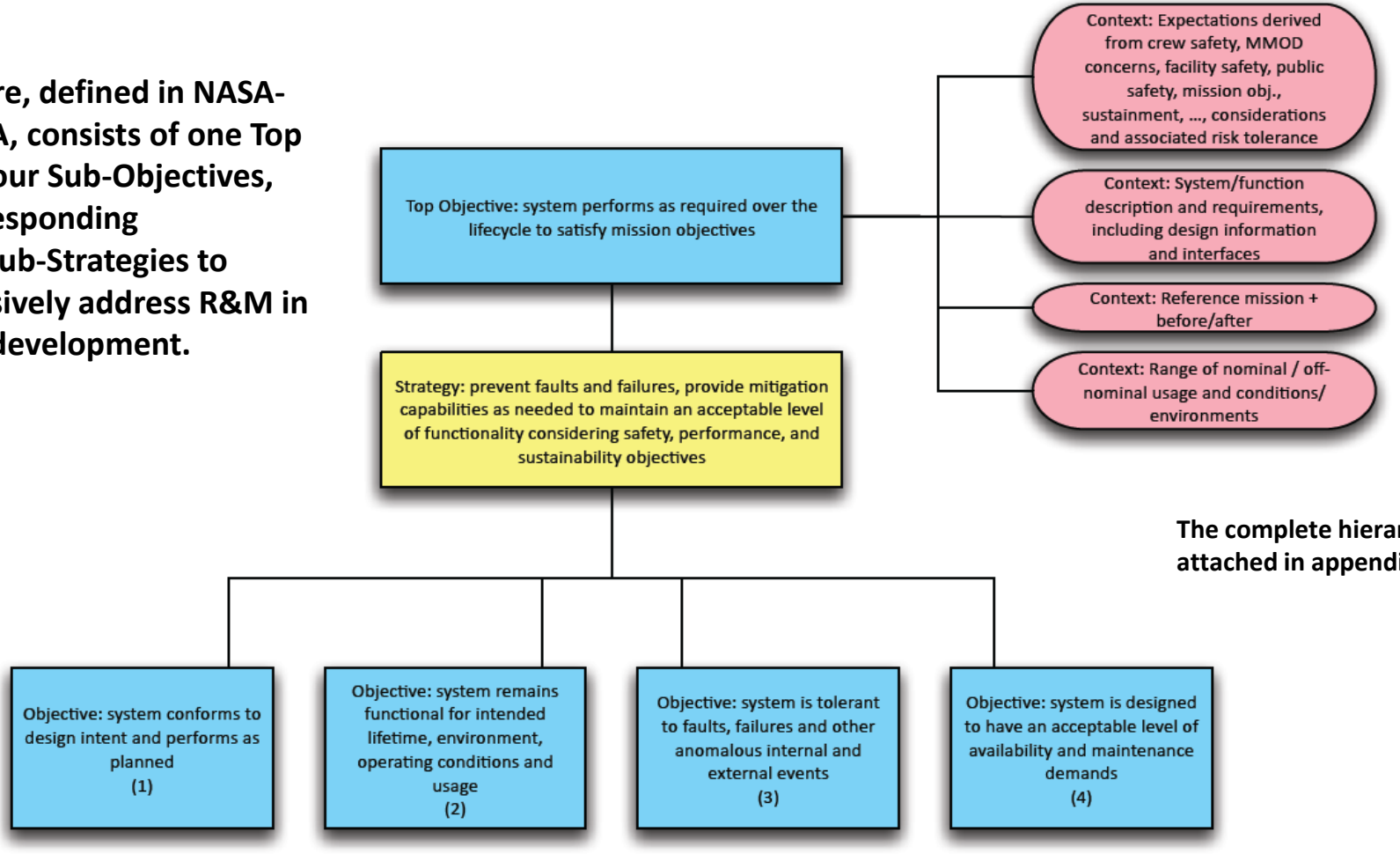
Why R&M Engineering?
Relationship to Affordability



NASA R&M Objectives Structure

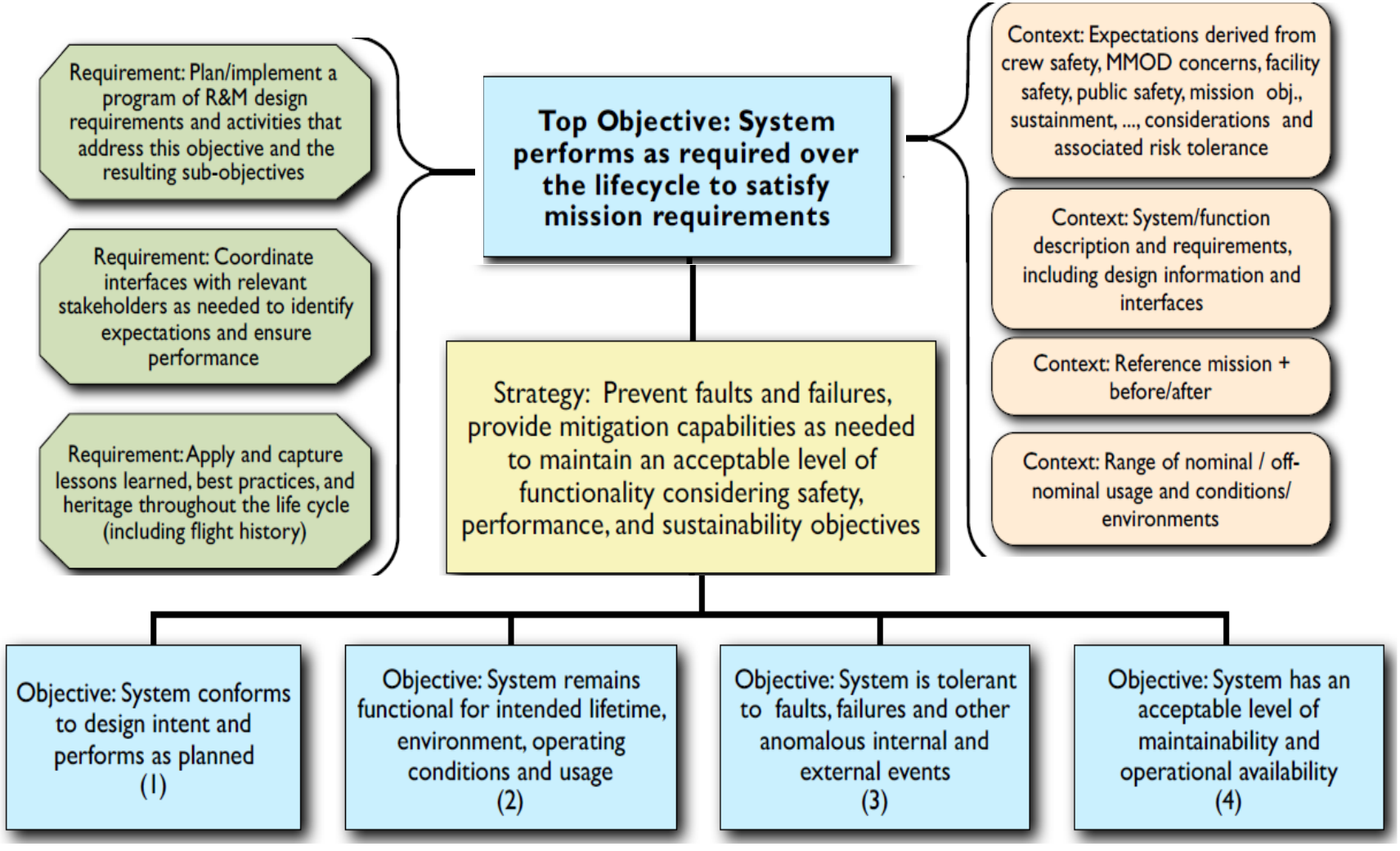
R&M Objectives Structure – Top-Level

This structure, defined in NASA-STD-8729.1A, consists of one Top Objective, four Sub-Objectives, and 46 corresponding Strategies/Sub-Strategies to comprehensively address R&M in design and development.

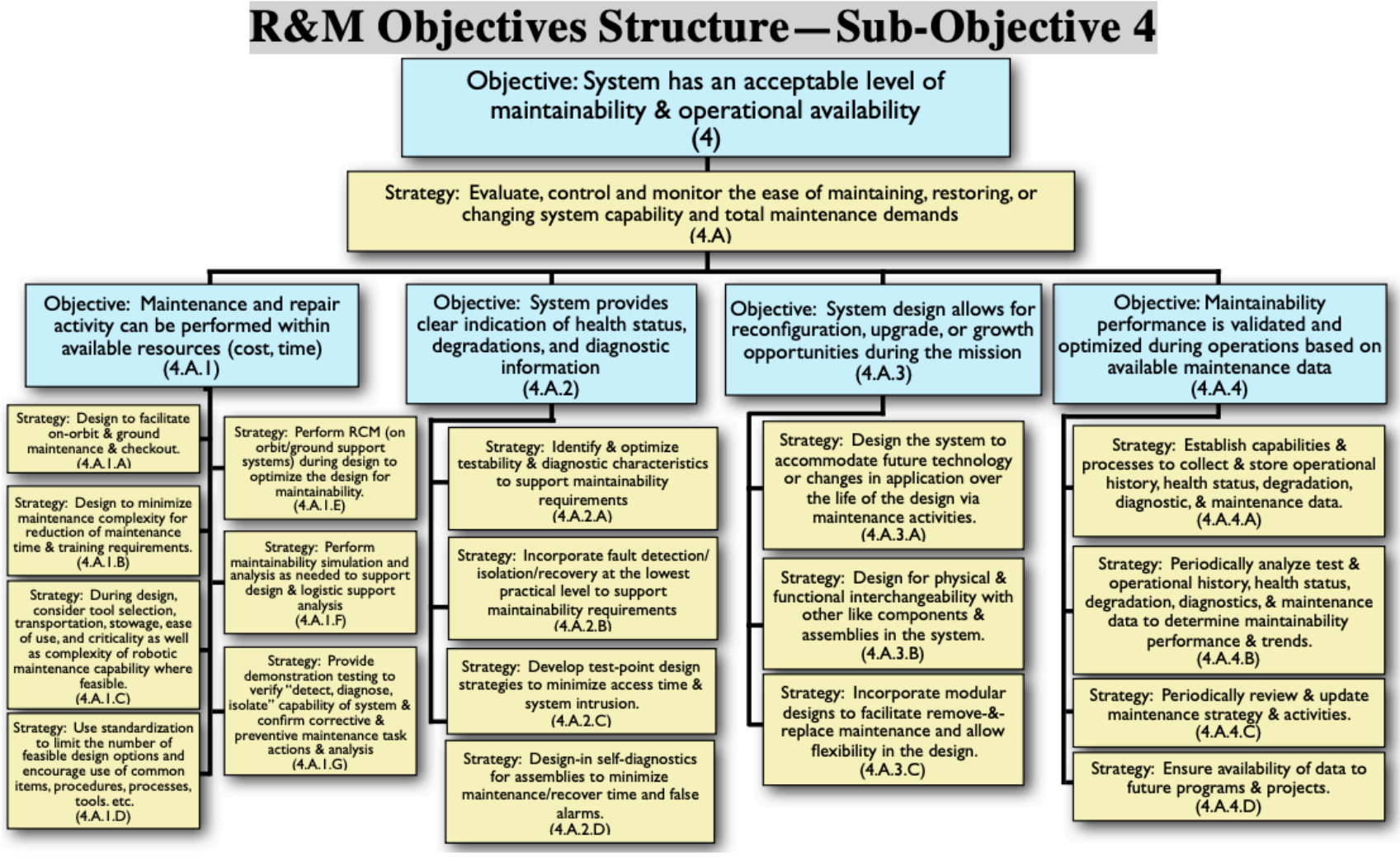


The complete hierarchy is attached in appendix to the plan

NASA NASA-STD-8729.1A: Objectives Hierarchy



NASA NASA-STD-8729.1A: Objectives Hierarchy



NASA NASA-STD-8729.1A: Objectives Hierarchy

NASA-STD-8729.1A—2017-06-13

			Scope						
		Evidence	Human Space Flight	Class A	Class B	Class C	Class D	Research and Technology	Ground Based Systems
4.A	Strategy: Evaluate, control, and monitor the ease of maintaining, restoring, or changing system capability and total maintenance demands								
4.A.1	Objective: Maintenance and repair activity can be performed within available resources (cost, time)								
4.A.1.A	Strategy: Design to facilitate on-orbit and ground maintenance and check out	Design for maintainability techniques (Accessibility Analysis, Maintenance Task Analysis, Maintainability Demonstration, Process FMEA, 'Level of technician' analysis, Consumables Catalog/Limited Life Items)	Preform Maintainability Analysis consistent with the concept of Operations and Maintainability Plan					Scope the same as Class D for TRL level 3 hardware and above	Design system to support the maintenance concept and comply with Maximum downtime and availability requirements
4.A.1.B	Strategy: Design to minimize maintenance complexity for reduction of maintenance time and training requirements	Level of repair analysis, maintainability models, maintenance activities block diagrams, Maintainability Demonstration, Process FMEA 'Level of technician' analysis, Training Plan and Material Requirements for modularity/interoperability	Preform Maintainability Analysis consistent with the Concept of Operations and Maintenance Plan and design to minimize crew workload and training requirements if applicable					Scope the same as Class D for TRL level 3 hardware and above	
4.A.1.C	Strategy: During design, consider tool selection, transport, stowage, ease of use, and criticality as well as complexity of robotic maintenance capability where feasible	Level of repair analysis, maintainability models, maintenance activities block diagrams, Maintainability Design Check sheets, Process FMEA	Verify the design complies with the maintainability design requirements					Verify the design complies with maintainability design requirements (if they exist)	
4.A.1.D	Strategy: Use standardization to limit the number of feasible design options and encourage the use of common items, procedures, processes, tools, etc.	Level of repair analysis, maintainability models, maintenance activities block diagrams, Logistics/sparing analysis, Maintenance manual	Verify the design complies with the maintainability design requirements					Verify the design complies with maintainability design requirements (if they exist)	
4.A.1.E	Strategy: Perform RCM (on orbit/ground support systems) during design to optimize the design for maintainability	RCM Decision Logic Tree, RCM Analysis, Reliability Maintainability and Availability Analysis	Verify the design complies with the maintainability design requirements					Verify the design complies with maintainability design requirements (if they exist)	
4.A.1.F	Strategy: Perform maintainability simulation and analysis as needed to support design and logistic support analysis	Level of repair analysis, maintainability models, maintenance activities block diagrams, Maintainability Demonstration, RMA Analysis, Monte Carlo simulation for predicting MMH	Perform Maintainability Analysis consistent with the Maintainability Plan, Supportability Plan, and crew workload requirements if applicable					Scope the same as Class D for TRL level 3 hardware and above	
4.A.1.G	Strategy: Provide demonstration testing to verify 'detect, diagnose, isolate' capability of systems and confirm corrective and preventive maintenance task actions and analysis	Results of demonstration test which verify expected results from: testability demonstration plan, testability analysis, FMEA/CIL, Maintainability Demonstration	Test to lowest level necessary to verify Testability requirements and Mean and Maximum time to Repair Requirements					Verify the design complies with maintainability design requirements (if they exist)	

NASA NASA-STD-8729.1A: Objectives Hierarchy

NASA-STD-8729.1A—2017-06-13

			Scope						
		Evidence	Human Space Flight	Class A	Class B	Class C	Class D	Research and Technology	Ground Based Systems
4.A	Strategy: Evaluate, control, and monitor the ease of maintaining, restoring, or changing system capability and total maintenance demands								
4.A.2	Objective: System provides clear indication of health status, degradations, and diagnostic information								
4.A.2.A	Strategy: Identify and optimize the testability and diagnostics characteristics to support the maintainability requirements	testability demonstration plan and results, testability analysis, MTA, I&T Reports, Ambiguity Analysis	Test to lowest level necessary to address fault detection requirements					Verify that design meets fault detection requirements (if they exist)	To Lowest level necessary to address maximum time to repair requirements and availability requirements
4.A.2.B	Strategy: Incorporate fault detection/isolation/recovery at the lowest practical level to support the maintainability requirements	testability demonstration plan and results, testability analysis, FMEA/CIL, MTA	Test to lowest level necessary to address fault detection requirements						
4.A.2.C	Strategy: Develop test-point-design strategies to minimize access time and system intrusion	testability demonstration plan and results, testability analysis, FMEA/CIL, MTA	Minimize downtime to lowest level necessary to address mean-time-to-repair requirements					Verify that design meets mean-time-to-repair requirements and false alarm rates (if they exist)	
4.A.2.D	Strategy: Design-in self-diagnostics for assemblies to minimize maintenance/recovery time and false alarms	testability demonstration plan and results, testability analysis, MTA, FMEA/CIL	Test to lowest level necessary to address mean-time-to-repair requirements and verify false alarm rates						
4.A.3	Objective: System design allows for reconfiguration, upgrade, or growth opportunities during the mission								
4.A.3.A	Strategy: Design the system to accommodate future technology or changes in application over the design life via maintenance activities	Maintenance Concept, Maintainability Design Check sheets, Recapitalization Analysis (Tech refresh), Requirements for modularity/interoperability, Material and Processes Control Plan	Verify the design complies with the maintainability design requirements	Verify system growth opportunities have been considered during System design				Scope the same as Class D for TRL level 3 hardware and above	To Lowest level necessary to address maximum time to repair requirements and availability requirements
4.A.3.B	Strategy: Design for physical and functional interchangeability with other like components and assemblies in the system	Maintenance Concept, Maintainability Design Check sheets, Requirements for modularity/interoperability, Material and Processes Control Plan, Standard Interface Requirement Document	Verify the design complies with the maintainability design requirements	Verify system growth opportunities have been considered during System design				Scope the same as Class D for TRL level 3 hardware and above	
4.A.3.C	Strategy: Incorporate modular designs to facilitate remove-and-replace maintenance and allow flexibility in the design	Maintenance Concept, Maintainability Design Check sheets, Maintainability Demo, Requirements for modularity/interoperability, Material and Processes Control Plan	Verify the design complies with the maintainability design requirements	Verify system growth opportunities have been considered during System design				Scope the same as Class D for TRL level 3 hardware and above	

NASA NASA-STD-8729.1A: Objectives Hierarchy

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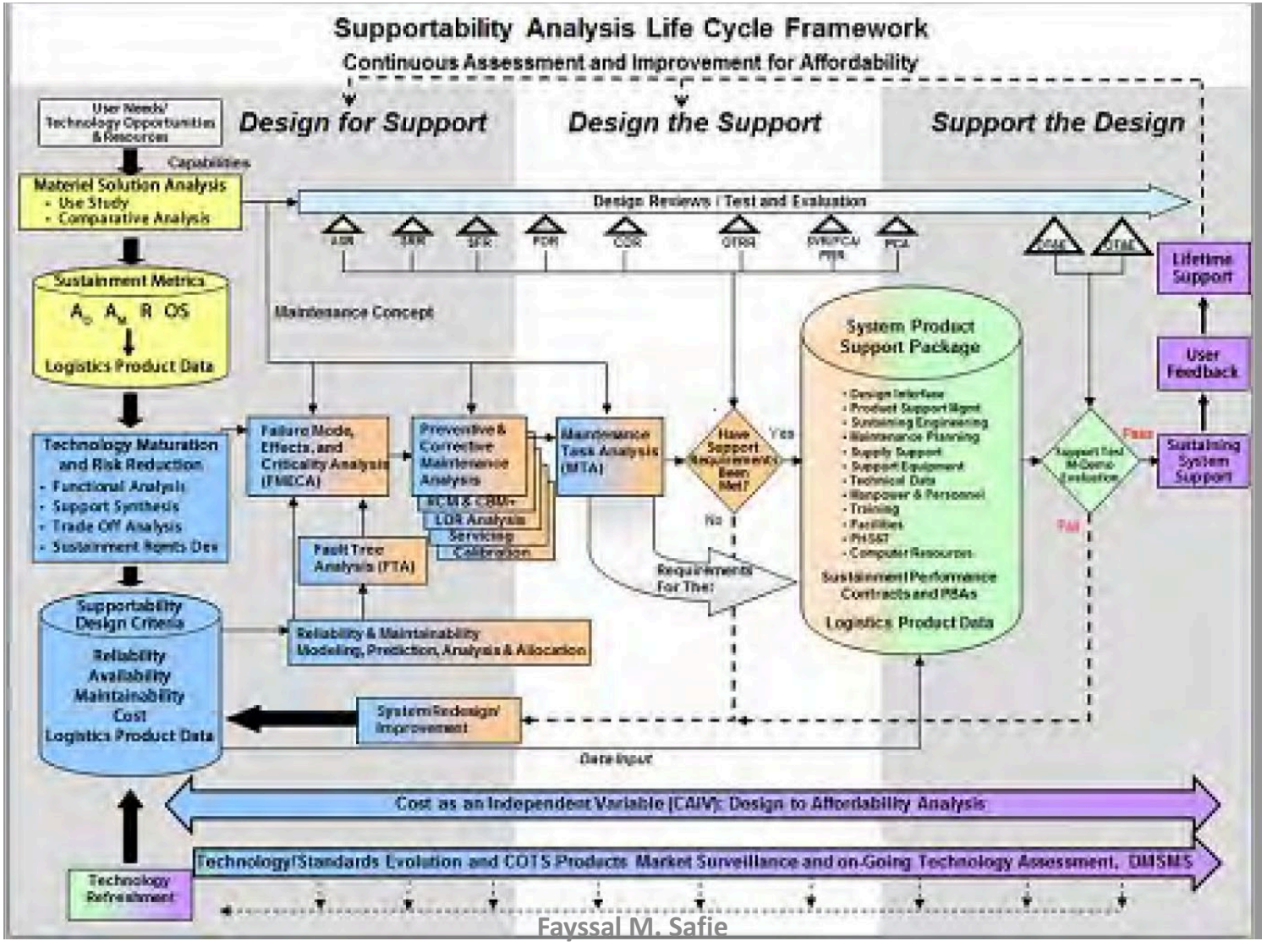
NASA-STD-8729.1A—2017-06-13

			Scope						
		Evidence	Human Space Flight	Class A	Class B	Class C	Class D	Research and Technology	Ground Based Systems
4.A	Strategy: Evaluate, control, and monitor the ease of maintaining, restoring, or changing system capability and total maintenance demands								
4.A.4	Objective: Maintainability performance is validated and optimized during operations based on available maintenance data								
4.A.4.A	Strategy: Establish capabilities and processes to collect and store operational history, health status, degradation, diagnostic, and maintenance data	Maintainability Program Plan, Maintenance Database, FRACAS	Collect and analyze all necessary maintenance data under actual operations conditions to verify that the system's maintainability requirements are met.					Verify compliance with maintainability design requirements (if they exist)	Collect and analyze all necessary maintenance data under actual operations to verify that the system's maintainability requirements are met
4.A.4.B	Strategy: Periodically analyze test and operational history, health status, degradation, diagnostic, and maintenance data to determine maintainability performance and trends	Maintainability Program Plan, Maintenance Database, FRACAS	Collect and analyze all necessary maintenance data under actual operations conditions to verify that the system's maintainability requirements are met.					Verify compliance with maintainability design requirements (if they exist)	
4.A.4.C	Strategy: Periodically review and update maintenance strategy and activities	Maintainability Program Plan, FRACAS	Collect and analyze all necessary maintenance data under actual operations conditions to verify that the system's maintainability requirements are met.					Verify compliance with maintainability design requirements (if they exist)	
4.A.4.D	Strategy: Ensure availability of data to future programs and projects	Maintainability Program Plan, FRACAS, Lessons Learned, Insertion of data into some NASA-wide database	Collect and analyze all necessary maintenance data under actual operations conditions to verify that the system's maintainability requirements are met.					Verify compliance with maintainability design requirements (if they exist)	


Supportability Analysis Life Cycle Framework
Continuous Assessment and Improvement for Affordability
Design for Support
Design the Support
Support the Design
User Needs/ Technology Opportunities & Resources
Capabilities
Materiel Solution Analysis
• Use Study
• Comparative Analysis
Design Reviews / Test and Evaluation
ASR
SRR
SFR
PDR
CDR
OTRR
SVR/FCA/ PRR
PCA
IOAR
FOAR
Lifetime Support
User Feedback
Sustaining System Support
Sustainment Metrics
A_O A_M R OS
Logistics Product Data
Maintenance Concept
Technology Maturation and Risk Reduction
• Functional Analysis
• Support Synthesis
• Trade Off Analysis
• Sustainment Rqmts Dev
Failure Mode, Effects, and Criticality Analysis (FMECA)
Preventive & Corrective Maintenance Analysis
RCM & CBM+
LOR Analysis
Servicing
Calibration
Maintenance Task Analysis (MTA)
Have Support Requirement(s) Been Met?
Yes
No
Requirements For The:
Fault Tree Analysis (FTA)
System Product Support Package
• Design Interface
• Product Support Mgmt
• Sustaining Engineering
• Maintenance Planning
• Supply Support
• Support Equipment
• Technical Data
• Manpower & Personnel
• Training
• Facilities
• PHS&T
• Computer Resources
Sustainment Performance Contracts and PBAs
Logistics Product Data
Pass
Fail
Supportability Design Criteria
Reliability
Availability
Maintainability
Cost
Logistics Product Data
Reliability & Maintainability Modeling, Prediction, Analysis & Allocation
System Redesign/ Improvement
Data Input
Cost as an Independent Variable (CAIV): Design to Affordability Analysis
Technology/Standards Evolution and COTS Products Market Surveillance and on-Going Technology Assessment. DMSMS
Technology Refreshment

Tailoring Process

- **Purpose**: Ensure oversight of Agency requirements and provide Centers and Project Managers with the authority and flexibility to complete their tasks.

- **Definition**: The process of assessing the applicability of requirements and evaluating potential compliance to generate a set of specific requirements for the project.

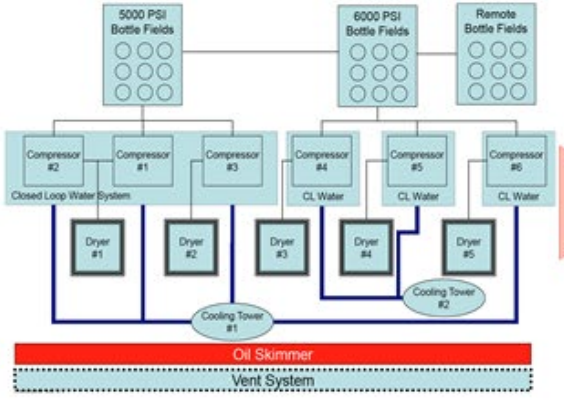
Success Stories

Reliability, Availability, Maintainability (RAM), and Affordability Study of the Langley Research Center (LaRC) Compressed Air Facility:

- A RAM study of the aging LaRC compressor facility was conducted to determine merits of continuing to refurbish the Compressor Station's infrastructure or immediately begin a campaign to replace the compressors.
- As a result of the study, a repair by replacement strategy and investment plan was developed and provided by LaRC.
- The plan was well received and was used as the bases to proceed and refurbish the facility to achieve sustainable operations through significant improvements in Reliability, availability, and the probability of meeting the air demand with acceptable investment cost that should translate into sustained cost savings.

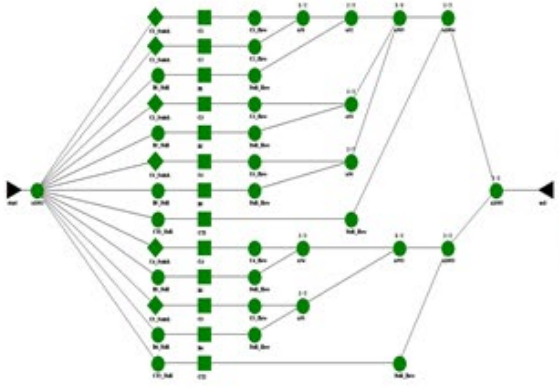
Aging Facility

Low Reliability
Low Availability
High Maintenance Cost



RAM Evaluation and Analysis

RAPTOR Monte-Carlo Simulation



Replacement Strategy

High Reliability
High Availability
Low Sustainment Cost

Challenges

- Creating the “Design for R&M” environment to support the Agency ambitious safety and affordability goals.
- Providing young R&M engineers adequate training and support to fill the gap created by staff attrition.
- Having the right mix of R&M engineering skills to support:
  - Technology development environment.
  - Reliability, Maintainability and Supportability (RMS) for long duration manned missions beyond LEO.
- Creating an integrated RMS operating analysis environment.
- Embedding R&M engineers in the design community.
- Establishing a centralized database for R&M analysis and predictions.