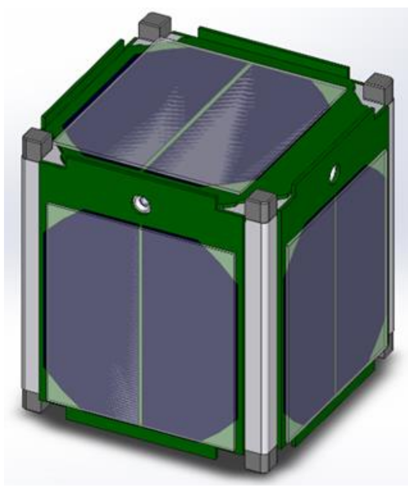
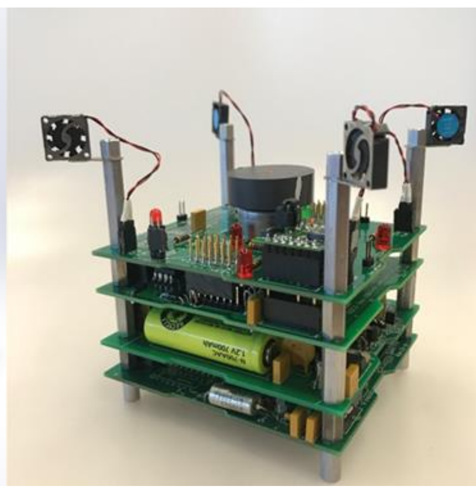
SYSTEMS ENGINEERING HANDBOOK

Tailored for Use by the USNA Small Satellite Program





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This handbook is adapted from the [NASA Systems Engineering Handbook Rev 2: NASA/SP-2016-6105 REV 2] and specifically tailored for use in the United States Naval Academy's Small Satellite Program. It is about a third of the size of the original NASA publication and it is specifically aimed at covering the most consequential systems engineering processes to increase the likelihood of success of undergraduate capstone teams endeavoring to conduct Small Satellite development projects with limited schedule, budget, and personnel resources.

Project Team Formation

One of the challenges of small-scale engineering development projects such as the capstone projects this handbook is made for is that a limited number of team members can leave members with multiple cumbersome responsibilities. Therefore, it is recommended that depending on the size of the project team, responsibilities and activities be allocated to the team members based on the schedule in Table 1.

Table 1 Recommended Schedule of Team Member Allocation

Role/Activity Team Size	Project Manager	Systems Engineer	Product Implementation	Product Integration	Product Verification	Product Validation	Product Transition	Technical Planning	Interface Management	Technical Risk Management	Technical Data Management
2	1	2	2	2	1	1	1	2	2	2	1
3	1	2	2	2	1	1	3	2	3	3	3
4	1	2	3	3	4	4	3	2	4	2	1
5	1	2	3	3	4	4	5	5	5	2	1
6	1	2	3	3	4	4	5	6	6	2	5
7	1	2	3	3	4	4	5	6	6	7	5
8	1	2	3	3	4	4	5	6	7	8	5
9	1	2	3	3	4	4	5	6	7	8	9
10	1	2	3	4	5	5	6	7	8	9	10
11+	1	2	3	4	5	6	7	8	9	10	11

List of Acronyms and Symbols

ADCS	Attitude Determination Control System
APRS	Automatic Packet Reporting System
ConOps	Concept of Operations
COTS	Commercial Off-the-Shelf
CPU	Central Processing Unit
CRM	Continuous Risk Management
DM	Data Management
EPS	Electrical Power System
FMEA	Failure Modes and Effects Analysis
GSE	Government-Supplied Equipment or Ground Support Equipment
HITL	Human-In-The-Loop
HWIL	Hardware-In-The-Loop
ICD	Interface Control Document/Drawing
ICP	Interface Control Plan
IDD	Interface Definition Document
IRD	Interface Requirements Document
ITAR	International Traffic in Arms Regulation
IWG	Interface Working Group
KDP	Key Decision Point
MBSE	Model Based Systems Engineering
MOE	Measure of Effectiveness
MOP	Measure of Performance
M&S	Modelling and Simulation
NASA	(U.S.) National Aeronautics and Space Administration

NGO	Needs, Goals, and Objectives
OTS	Off-the-Shelf
PBS	Product Breakdown Structure
PDR	Preliminary Design Review
QA	Quality Assurance
RIDM	Risk-Informed Decision-Making
RM	Risk Management
R&T	Research and Technology
SE	Systems Engineering
SEMP	Systems Engineering Management Plan
SWR	Standing Wave Ratio
T&E	Test and Evaluation
UFE	Unallocated Future Expenses
VHF	Very High Frequency
WBS	Work Breakdown Structure

1.0 Design Solution Definition

The Design Solution Definition Process is used to translate the high-level requirements derived from stakeholder expectations and the outputs of the Logical Decomposition Process into a design solution. This involves transforming the defined logical decomposition models and their associated sets of derived technical requirements into alternative solutions. These alternative solutions are then analyzed through detailed trade studies that result in the selection of a preferred alternative. This preferred alternative is then fully defined into a final design solution that satisfied the technical requirements. This design solution definition is used to generate the end product specifications that are used to produce the product verification. This process may be further refined depending on whether there are additional subsystems of the end product that need to be defined.

1.1 Process Description

The activities of the Design Solution Definition Process are described below.

1.1.1 Inputs

The inputs for this process are:

- **Technical Requirements:** These are the customer and stakeholder needs that have been translated into a complete set of validated requirements for the system, including all interface requirements.

- **Logical Decomposition Models:** Requirements are analyzed and decomposed by one or more different methods (e.g., function, time, behavior, data flow, states, modes, system architecture, etc.) in order to gain a more comprehensive understanding of their interaction and behaviors.

1.1.2 Process Activities

The process activities of the Design Solution Process are defined in detail below:

- **Define Alternative Design Solutions:** The realization of a system over its life cycle involves a succession of decisions among alternative courses of action. If the alternatives are precisely defined and thoroughly understood to be well differentiated in the cost-effectiveness space, then the systems engineer can make choices among them with confidence.

- **Create Alternative Design Concepts: O**nce it is understood what the system is to accomplish, it is possible to devise a variety of ways that those goals can be met. Sometimes, that comes about as a consequence of considering alternative functional allocations and integrating available subsystem design options, all of which can have technologies at varying degrees of maturity. Ideally, as wide a range of plausible alternatives as is consistent with the design organization's charter should be defined, keeping in mind the current stage in the process of successive refinement. When the bottom-up process is operating, a problem for the systems engineer is that the designers tend to become fond of the designs they create, so they lose their objectivity; the systems engineer should stay an "outsider" so that there is more objectivity. This is particularly true in the assessment of the technological maturity of the subsystems and components required for implementation. There is a tendency on the part of technology developers and project management to overestimate the maturity and applicability of a technology that is required to implement a design. This is especially true of "heritage" equipment. The result is that critical aspects of systems engineering are often overlooked.

- **Analyze Each Alternative Design Solution:** The technical team analyzes how well each of the design alternatives meets the system objectives (technology gaps, effectiveness, technical achievability, performance, cost, schedule, and risk, both quantified and otherwise). This assessment is accomplished through the use of trade studies. The purpose of the trade study process is to ensure that the system architecture, intended operations (i.e., the ConOps) and design decisions move toward the best solution that can be achieved with the available resources.

- **Select the Best Design Solution:** The technical team selects the best design solution from among the alternative design concepts, taking into account subjective factors that the team was unable to quantify, such as robustness, as well as estimates of how well the alternatives meet the quantitative requirements; the maturity of the available technology; and any effectiveness, cost, schedule, risk, or other constraints.

- **Increase the Resolution of the Design:** At each level of decomposition, the baselined derived (and allocated) requirements become the set of high-level requirements for the decomposed elements, and the process begins again. One might ask, "When do we stop refining the design?" The answer is that the design effort proceeds to a depth that is sufficient to meet several needs: the design should penetrate sufficiently to allow analytical validation of the design to the requirements and ConOps; it should also have sufficient depth to support cost and operations modeling and to convince a review team of a feasible design with performance, cost, and risk margins.

- **Fully Describe the Design Solution:** Once the preferred design alternative has been selected and the proper level of refinement has been completed, then the design is fully defined into a final design solution that will satisfy the technical requirements and ConOps. The design solution definition will be used to generate the end product specifications that will be used to produce the product and to conduct product verification. This process may be further refined depending on whether there are additional subsystems of the end product that need to be defined.

- **Verify the Design Solution:** Once an acceptable design solution has been selected from among the various alternative designs and documented in a technical data package, the design solution should next be verified against the system requirements and constraints. A method to achieve this verification is by means of a peer review to evaluate the resulting design solution definition.

- **Validate the Design Solution:** The validation of the design solution is a recursive and iterative process. Each alternative design concept is validated against the set of stakeholder expectations. The stakeholder expectations drive the iterative design loop in which a straw man architecture/design, the ConOps, and the derived requirements are developed. These three products should be consistent with each other and will require iterations and design decisions to achieve this consistency. Once consistency is achieved, functional analyses allow the study team to validate the design against the stakeholder expectations. A simplified validation asks the questions: Does the system work as expected? How does the system respond to failures, faults, and anomalies? Is the system affordable? If the answer to any of these questions is no, then changes to the design or stakeholder expectations will be required, and the process is started over again. This process continues until the system— architecture, ConOps, and requirements— meets the stakeholder expectations.

- **Identify Enabling Products:** Enabling products are the life cycle support products and services (e.g., production, test, deployment, training, maintenance, and disposal) that facilitate the progression and use of the operational end product through its life cycle. Since the end product and its enabling products are interdependent, they are viewed as a system. Project responsibility thus extends to responsibility for acquiring services from the relevant enabling products in each life cycle phase. When a suitable enabling product does not already exist, the project that is responsible for the end product can also be responsible for creating and using the enabling product.

- **Baseline the Design Solution:** Once the selected system design solution meets the stakeholder expectations, the study team baselines the products and prepares for the next life cycle phase. Because of the recursive nature of successive refinement, intermediate levels of decomposition are often validated and baselined as part of the process. In the next level of decomposition, the baselined requirements become the set of high-level requirements for the decomposed elements, and the process begins again.

1.1.3 Outputs

Outputs of the Design Solution Definition Process are described below:

- **The System Specification:** The system specification contains the functional baseline for the system that is the result of the Design Solution Definition Process. The system design specification provides sufficient guidance, constraints, and system requirements for the design engineers to begin developing the design.

- **The System External Interface Specifications:** The system external interface specifications describe the functional baseline for the behavior and characteristics of all physical interfaces that the system has with the external world. These include all structural, thermal, electrical, and signal interfaces, as well as the human-system interfaces.

- **The End-Product Specifications:** The end-product specifications contain the detailed build-to and code-to requirements for the end product. They are detailed, exact statements of design particulars, such as statements prescribing materials, dimensions, and quality of work to build, install, or manufacture the end product.

- **The End-Product Interface Specifications: T**he end-product interface specifications contain the detailed build-to and code-to requirements for the behavior and characteristics of all logical and physical interfaces that the end product has with external elements, including the human-system interfaces.

- **Initial Subsystem Specifications:** The end-product subsystem initial specifications provide detailed information on subsystems if they are required.

- **Enabling Product Requirements:** The requirements for associated supporting enabling products provide details of all enabling products. Enabling products are the life cycle support products, infrastructures, personnel, logistics, and services that facilitate the progression and use of the operational end product through its life cycle. They are viewed as part of the system since the end product and its enabling products are interdependent.

- **Product Verification Plan:** The end-product verification plan (generated through the Technical Planning Process) provides the content and depth of detail necessary to provide full visibility of all verification activities for the end product. Depending on the scope of the end product, the plan encompasses qualification, acceptance, prelaunch, operational, and disposal verification activities for flight hardware and software.

- **Product Validation Plan:** The end-product validation plan (generated through the Technical Planning Process) provides the content and depth of detail necessary to provide full visibility of all activities to validate the end product against the baselined stakeholder expectations. The plan identifies the type of validation, the validation procedures, and the validation environment that are appropriate to confirm that the realized end product conforms to stakeholder expectations.

- **Logistics and Operate-to Procedures:** The applicable logistics and operate-to procedures for the system describe such things as handling, transportation, maintenance, long-term storage, and operational considerations for the particular design solution.

1.2 Design Solution Definition Guidance

Refer to Section 4.4.2 in the NASA Expanded Guidance for Systems Engineering at Expanded Guidance for NASA SE NASA/SP-2016-6105-SUPPL for additional guidance on:

- technology assessment,

- human capability assessment, and

- integrating engineering specialties into the SE process.

2.0 Product Implementation

Product implementation is the first SE process encountered and begins the movement from the bottom of the product hierarchy up towards the Product Transition Process. This is where the plans, designs, analysis, requirements development, and drawings are realized into actual products.

Product implementation is used to generate a specified product of a project or activity through buying, making/coding, or reusing previously developed hardware, software, models, or studies to generate a product appropriate for the phase of the life cycle. The product should satisfy the design solution and its specified requirements.

The Product Implementation Process is the key activity that moves the project from plans and designs into realized products. Depending on the project and life-cycle phase within the project, the product may be hardware, software, a model, simulations, mockups, study reports, or other tangible results. These products may be realized through their purchase from commercial or other vendors, through partial or complete reuse of products from other projects or activities, or they may be generated from scratch. The decision as to which of these realization strategies or combination of strategies will be used for the products of this project will have been made earlier in the life cycle.

2.1 Process Description

The activities of the Product Implementation Process are described below.

2.1.1 Inputs

Inputs to the Product Implementation Process depend primarily on the decision about whether the end product will be purchased, developed from scratch, or formed by reusing part or all of products from other projects.

- **Inputs If Purchasing the End Product:** If the decision was made to purchase part or all of the products for this project, the end product design specifications are obtained from other applicable documents.

- **Inputs If Making/Coding the End Product:** For end products that will be made/coded by the technical team, the inputs will be the configuration-controlled design specifications, manufacturing plans, manufacturing processes, manufacturing procedures, and raw materials as provided to or purchased by the project.

- **Inputs Needed If Reusing an End Product:** For end products that will reuse part or all of products generated by other projects, the inputs may be the documentation associated with the product as well as the product itself. Care should be taken to ensure that these products will indeed meet the specifications and environments for this project. These would have been factors involved previously to determine the make/buy/reuse decision.

- **Enabling Products:** These would be any enabling products necessary to make, code, purchase, or reuse the product (e.g., drilling fixtures, production facilities, production lines, software development facilities, software test facilities, system integration and test facilities).

2.1.2 Process Activities

Implementing the product can take one of three forms:

1. Purchase/buy
2. Make/code
3. Reuse

These three forms will be discussed in the following subsections. This section describes what kind of inputs, outputs, and activities are performed during product implementation regardless of where in the product hierarchy or life cycle it is. These activities include preparing to conduct the implementation, purchasing/making/reusing the product, and capturing the product implementation work product. In some cases, implementing a product may have aspects of more than one of these forms (such as a build-to-print). In those cases, the appropriate aspects of the applicable forms are used.

2.1.2.1 Prepare to Conduct Implementation

Preparing to conduct the product implementation is a key first step regardless of what form of implementation has been selected. For complex projects, implementation strategy and detailed planning or procedures need to be developed and documented. For less complex projects, the implementation strategy and planning need to be discussed, approved, and documented as appropriate for the complexity of the project.

The documentation, specifications, and other inputs also need to be reviewed to ensure they are ready and at an appropriate level of detail to adequately complete the type of implementation form being employed and for the product life-cycle phase. For example, if the “make” implementation form is being employed, the design specifications need to be reviewed to ensure they are at a design-to level that allows the product to be developed. If the product is to be bought as a pure Commercial Off-the-Shelf (COTS) item, the specifications need to be checked to make sure they adequately describe the vendor characteristics to narrow to a single make/model of their product line.

Finally, the availability and skills of personnel needed to conduct the implementation as well as the availability of any necessary raw materials, enabling products, or special services should also be reviewed. Any special training necessary for the personnel to perform their tasks needs to be performed by this time. This is a key part of the Acceptance Data Package.

2.1.2.2 Purchase, Make, or Reuse the Product

Purchase the Product

In the first case, the end product is to be purchased from a commercial or other vendor. Design/purchase specifications will have been generated previously and provided as inputs. The technical team needs to review these specifications and ensure they are in a form adequate for the purchase. For major end products purchased from a vendor, the responsibilities of the Government and contractor team should be documented. This will define, for example, whether the project team expects the vendor to provide a fully verified and validated product or whether they will be performing those duties.

As the purchased products arrive, the technical team should assist in the inspection of the delivered product and its accompanying documentation. The team should ensure that the requested product was indeed the one delivered, and that all necessary documentation, such as source code, operator manuals, certificates of compliance, safety information, or drawings have been received.

The technical team should also ensure that any enabling products necessary to provide test, operations, maintenance, and disposal support for the product are also ready or provided as required.

Depending on the strategy and roles/responsibilities of the vendor, a determination/analysis of the vendor's verification and validation compliance may need to be reviewed. This may be done informally or formally as appropriate for the complexity of the product. For products that were verified and validated by the vendor, after ensuring that all work products from this phase have been captured, the product may be ready to enter the Product Transition Process to be delivered to the next higher level or to its final end user. For products that the technical team will verify and validate, the product will be ready for verification after ensuring that all work products for this phase have been captured.

Make/Code the Product

If the strategy is to make or code the product, the technical team should first ensure that the enabling products are ready. This may include ensuring all piece parts are available, drawings are complete and adequate, software design is complete and reviewed, machines to cut the material are available, interface specifications are approved, operators are trained and available, manufacturing and/or coding procedures / processes are ready, software personnel are trained and available to generate code, test fixtures are developed and ready to hold products while being generated, and software test cases are available and ready to begin model generation.

The product is then made or coded in accordance with the specified requirements, configuration documentation, and applicable standards. Throughout this process, the technical team should work to review, inspect, and discuss progress and status within the team and with higher levels of management as appropriate. Progress should be documented within the technical schedules. Peer reviews, audits, unit testing, code inspections, simulation checkout, and other techniques may be used to ensure the made or coded product is ready for the verification process. As production proceeds and components are produced, there is a need to establish a to review any nonconformance to specifications and disposition whether the components can be accepted, reworked, or scrapped and remade.

Reuse

If the strategy is to reuse a product that already exists, extreme care should be taken to ensure that the product is truly applicable to this project and for the intended uses and the environment in which it will be used. This should have been a major factor used in the decision strategy to make/buy/reuse. If the new environment is more extreme, requalification is needed for the component or system. Design factors of safety, margins, and other required design and construction standards should also be assessed. If the program/project requires higher factor of safety or margins, the component may not be useable or a modification may be required.

The documentation available (e.g., as-built documentation, user's guides, operations manuals, discrepancy reports, waivers and deviations) from the reuse product should be reviewed by the technical team so that they can become completely familiar with the product and ensure it will meet the requirements in the intended environment. Any supporting manuals, drawings, or other documentation available should also be gathered.

The availability of any supporting or enabling products or infrastructure needed to complete the fabrication, coding, testing, analysis, verification, validation, or shipping of the product needs to be determined. Supporting products may be found in product manufacturing plans, processes, and procedures. If any of these products or services are lacking, they will need to be developed or arranged for before progressing to the next phase.

A reused product often needs to undergo the same verification and validation as a purchased product or a built product. Relying on prior verification and validation should only be considered if the product's verification and validation documentation meets or exceeds the verification, validation, and documentation requirements of the current project and the documentation demonstrates that the product was verified and validated against equivalent requirements (including environments) and expectations. The savings gained from reuse is not necessarily from reduced acceptance-level testing of the flight products, but possibly elimination of the need to fully requalify the item (if all elements are the same, including the environment and operation), elimination of the need to specify all of the internal requirements such as printed circuit board specifications or material requirements, reduced internal data products, or the confidence that the item will pass acceptance test and will not require rework.

2.1.2.3 Capture Work Products

Regardless of what implementation form was selected, all work products from the make/buy/reuse process should be captured, including as-built design drawings, design documentation, design models, code listings, model descriptions, procedures used, operator manuals, maintenance manuals, or other documentation as appropriate.

2.1.3 Outputs

- **End Product for Verification:** Unless the vendor performs verification, the made/coded, purchased, or reused end product in a form appropriate for the life-cycle phase is provided for the verification process. The form of the end product is a function of the life-cycle phase and the placement within the system structure (the form of the end product could be hardware, software, model, prototype, first article for test, or single operational article or multiple production articles).

- **End Product Documents and Manuals:** Appropriate documentation is also delivered with the end product to the verification process and to the technical data management process. Documentation may include applicable as-built design drawings; close out photos; operation, user, maintenance, or training manuals; applicable baseline documents (configuration information such as as-built specifications or stakeholder expectations); certificates of compliance; or other vendor documentation.

- **Product Implementation Work Products:** Any additional work products providing reports, records, lesson learned, assumptions, and other outcomes of these activities.

The process is complete when the following activities have been accomplished:

- End products are fabricated, purchased, or reuse modules are acquired.

- End products are reviewed, checked, and ready for verification.

- Procedures, decisions, assumptions, anomalies, corrective actions, lessons learned, etc., resulting from the make/buy/reuse are recorded.

2.2 Product Implementation Guidance

Refer to Section 5.1.2 in the NASA Expanded Guidance for Systems Engineering at [Expanded Guidance for NASA SE NASA/SP-2016-6105-SUPPL] for additional guidance on:

- buying off-the-shelf products and
- the need to consider the heritage of products.

3.0 Product Integration

Product integration is a key activity of the systems engineer. Product integration is the engineering of the subsystem interactions and their interactions with the system environments (both natural and induced). Also in this process, lower-level products are assembled into higher level products and checked to make sure that the integrated product functions properly and that there are no adverse emergent behaviors. This integration begins during concept definition and continues throughout the system life cycle. Integration involves several activities focused on the interactions of the subsystems and environments. These include system analysis to define and understand the interactions, development testing including qualification testing, and integration with external systems (e.g., launch operations centers, space vehicles, mission operations centers, flight control centers, and aircraft) and objects (i.e., planetary bodies or structures). To accomplish this integration, the systems engineer is active in integrating the different discipline and design teams to ensure system and environmental interactions are being properly balanced by the differing design teams. The result of a well-integrated and balanced system is an elegant design and operation.

3.1 Process Description

The activities of the Product Integration Process are described below.

3.1.1 Inputs

- **Lower-level products to be integrated:** These are the products developed in the previous lower-level tier in the product hierarchy. These products will be integrated / assembled to generate the product for this product layer.

- **End product design specifications and configuration documentation:** These are the specifications, Interface Control Documents (ICDs), drawings, integration plan, procedures or other documentation or models needed to perform the integration including documentation for each of the lower-level products to be integrated.

- **Product integration-enabling products:** These would include any enabling products, such as holding fixtures, necessary to successfully integrate the lower-level products to create the end product for this product layer.

3.1.2 Process Activities

This subsection addresses the approach to the implementation of the Product Integration Process, including the activities required to support the process. The basic tasks that need to be established involve the management of internal and external interactions of the various levels of products and operator tasks to support product integration and are as follows:

3.1.2.1 Prepare to Conduct Product Integration

Prepare to conduct product integration by reviewing the product integration strategy/plan, generating detailed planning for the integration, and developing integration sequences and procedures; and determining whether the product configuration documentation is adequate to conduct the type of product integration applicable for the product life-cycle phase, location of the product in the system structure, and management phase success criteria.

3.1.2.2 Obtain Lower-Level Products for Assembly and Integration

Each of the lower-level products that is needed for assembly and integration is obtained from the transitioning lower-level product owners or a storage facility as appropriate. Received products should be inspected to ensure no damages occurred during the transitioning process.

3.1.2.3 Confirm That Received Products Have Been Validated

Confirm that the received products that are to be assembled and integrated have been validated to demonstrate that the individual products satisfy the agreed-to set of stakeholder expectations, including interface requirements. This validation can be conducted by the receiving organization or by the providing organization if fully documented or witnessed by the receiving representative.

3.1.2.4 Prepare the Integration Environment for Assembly and Integration

Prepare the integration environment in which assembly and integration will take place, including evaluating the readiness of the product integration-enabling products and the assigned workforce. These enabling products may include facilities, equipment jigs, tooling, and assembly/production lines. The integration environment includes test equipment, simulators, models, storage areas, and recording devices.

3.1.2.5 Assemble and Integrate the Received Products into the Desired End Product

Assemble and integrate the received products into the desired end product in accordance with the specified requirements, configuration documentation, interface requirements, applicable standards, and integration sequencing and procedures. This activity includes managing, evaluating, and controlling physical, functional, and data interfaces among the products being integrated.

Functional testing of the assembled or integrated unit is conducted to ensure that assembly is ready to enter verification testing and ready to be integrated into the next level. Typically, all or key representative functions are checked to ensure that the assembled system is functioning as expected. Formal product verification and validation will be performed in the next process.

3.1.2.6 Prepare Appropriate Product Support Documentation

Prepare appropriate product support documentation, such as special procedures for performing product verification and product validation. Drawings or accurate models of the assembled system are developed and confirmed to be representative of the assembled system.

3.1.2.7 Capture Product Integration Work Products

Capture work products and related information generated while performing the Product Integration Process activities. These work products include system models, system analysis data and assessment reports, derived requirements, the procedures that were used in the assembly, decisions made and supporting rationale, assumptions that were made, identified anomalies and associated corrective actions, lessons learned in performing the assembly, and updated product configuration and support documentation.

3.1.3 Outputs

The following are typical outputs from this process and destinations for the products from this process:

- **Integrated product(s)** with all system interactions identified and properly balanced.
- **Documentation and manuals** including system analysis models, data, and reports supporting flight-readiness rationale and available for future analysis during the operation of the system in the mission-execution phase.
- **Work products**, including reports, records, and non-deliverable outcomes of product integration activities; integration strategy document; assembly/check area drawings; system/component documentation sequences and rationale for selected assemblies; interface management documentation; personnel requirements; special handling requirements; system documentation; shipping schedules; test equipment and drivers' requirements; emulator requirements; and identification of limitations for both hardware and software.

4.0 Product Verification

The Product Verification Process is the first of the verification and validation processes conducted on an end product. As used in the context of the systems engineering common technical processes, a product is one provided by either the Product Implementation Process or the Product Integration Process in a form suitable for meeting applicable life-cycle phase success criteria. Realization is the act of implementing, integrating, verifying, validating, and transitioning the end product for use at the next level up of the system structure or to the customer. At this point, the end product can be referred to as a "realized product" or "realized end product."

Product verification proves that an end product (whether built, coded, bought, or reused) for any element within the system structure conforms to its requirements or specifications. Such specifications and other design description documentation establish the configuration baseline of that product, which may have to be modified at a later time. Without a verified baseline and appropriate configuration controls, such later modifications could be costly or cause major performance problems.

4.1 Process Description

There are several methods of verification, described in the figure below.

Methods of Verification

- **Analysis**: The use of mathematical modeling and analytical techniques to predict the suitability of a design to stakeholder expectations based on calculated data or data derived from lower system structure end product verifications. Analysis is generally used when a prototype; engineering model; or fabricated, assembled, and integrated product is not available. Analysis includes the use of modeling and simulation as analytical tools. A model is a mathematical representation of reality. A simulation is the manipulation of a model. Analysis can include verification by similarity of a heritage product.
- **Demonstration**: Showing that the use of an end product achieves the individual specified requirement. It is generally a basic confirmation of performance capability, differentiated from testing by the lack of detailed data gathering. Demonstrations can involve the use of physical models or mockups; for example, a requirement that all controls shall be reachable by the pilot could be verified by having a pilot perform flight-related tasks in a cockpit mockup or simulator. A demonstration could also be the actual operation of the end product by highly qualified personnel, such as test pilots, who perform a one-time event that demonstrates a capability to operate at extreme limits of system performance, an operation not normally expected from a representative operational pilot.
- **Inspection**: The visual examination of a realized end product. Inspection is generally used to verify physical design features or specific manufacturer identification. For example, if there is a requirement that the safety arming pin has a red flag with the words "Remove Before Flight" stenciled on the flag in black letters, a visual inspection of the arming pin flag can be used to determine if this requirement was met. Inspection can include inspection of drawings, documents, or other records.
- **Test**: The use of an end product to obtain detailed data needed to verify performance or provide sufficient information to verify performance through further analysis. Testing can be conducted on final end products, breadboards, brassboards, or prototypes. Testing produces data at discrete points for each specified requirement under controlled conditions and is the most resource-intensive verification technique. As the saying goes, "Test as you fly, and fly as you test."

The activities of the Product Verification Process are described below.

4.1.1 Inputs

Key inputs to the process are:

- **The product to be verified:** This product will have been transitioned from either the Product Implementation Process or the Product Integration Process. The product will likely have been through at least a functional test to ensure it was assembled correctly. Any supporting documentation should be supplied with the product.
- **Verification plan:** This plan will have been developed previously and baselined before entering this verification.

- **Specified requirements baseline:** These are the requirements that have been identified to be verified for this product. Acceptance criteria should have been identified for each requirement to be verified.

- **Enabling products:** Any other products needed to perform the Product Verification Process. This may include test fixtures and support equipment.

4.1.2 Process Activities

This subsection addresses the approach to the implementation of the Product Verification Process, including the activities required to support the process. There are five major activities in the Product Verification Process: (1) prepare to conduct product verification; (2) perform verification; (3) analyze verification results; (4) prepare a product verification report; and (5) capture work products generated during the verification activities. These tasks are described as follows:

4.1.2.1 Product Verification Preparation

In preparation for verification, the verification plan and the specified requirements are collected, reviewed, and confirmed. The product to be verified is obtained along with any enabling products, such as those representing external interfacing products and support resources (including personnel) that are necessary for verification. Procedures capturing detailed step-by-step activities and based on the verification type and methods are finalized and approved. Development of procedures typically begins during the design phase of the project life cycle and matures as the design is matured. The verification environment is considered as part of procedure development. Operational scenarios are assessed to explore all possible verification activities to be performed. The final element is preparation of the verification environment; e.g., facilities, equipment, tools, measuring devices, and climatic conditions.

4.1.2.2 Perform Product Verification

The actual act of verifying the end product is performed as spelled out in the plans and procedures, and conformance is established with each specified product requirement. The verification lead should ensure that the procedures were followed and performed as planned, the verification-enabling products and instrumentation were calibrated correctly, and the data were collected and recorded for required verification measures.

4.1.2.3 Analyze Product Verification Results and Report

As the verification activities are completed, the results are collected and analyzed. The data are analyzed for quality, integrity, correctness, consistency, and validity. Any verification discrepancies (anomalies, variations, and out-of-compliance conditions) are identified and reviewed to determine if there is a nonconforming product not resulting from poor verification conduct, procedure, or conditions. If possible, this analysis is performed while the test/analysis configuration is still intact. This allows a quick turnaround in case the data indicates that a correction to the test or analysis run needs to be performed again.

4.1.2.4 Capture Product Verification Work Products

Verification work products take many forms and involve many sources of information. The capture and recording of verification results and related data is a very important, but often underemphasized, step in the Product Verification Process. Verification results, peer review reports, anomalies, and any corrective action(s) taken should be captured, as should all relevant results from the application of the Product Verification Process (related decisions, rationale for the decisions made, assumptions, and lessons learned).

4.1.3 Outputs

Key outputs from the process are:

- **Verified product ready for validation:** After the product is verified, it will next pass through the Product Validation Process.

- **Product verification results:** Results from executed procedures are passed to technical assessment.
- **Product verification report(s):** A report shows the results of the verification activities. It includes the requirement that was to be verified and its bidirectional traceability, the verification method used, and reference to any special equipment, conditions, or procedures used. It also includes the results of the verification, any anomalies, variations or out-of-compliance results noted and associated corrective actions taken.
- **Product verification work products:** These include discrepancy and nonconformance reports with identified correction actions; updates to requirements compliance documentation; changes needed to the procedures, equipment or environment; configuration drawings; calibrations; operator certifications; and other records.

5.0 Product Validation

The Product Validation Process is the second of the verification and validation processes conducted on an implemented or integrated end product. While verification proves whether "the product was done right," validation proves whether "the right product was done." In other words, verification provides objective evidence that every "shall" statement in the requirements document or specification was met, whereas validation is performed for the benefit of the customers and users to ensure that the system functions in the expected manner when placed in the intended environment. This is achieved by examining the products of the system at every level of the product structure and comparing them to the stakeholder expectations for that level. A well-structured validation process can save cost and schedule while meeting the stakeholder expectations.

5.1 Process Description

There are several methods of validation, described in the figure below.

Methods of Validation

- **Analysis**: The use of mathematical modeling and analytical techniques to predict the suitability of a design to stakeholder expectations based on calculated data or data derived from lower system structure end product verifications. Analysis is generally used when a prototype; engineering model; or fabricated, assembled, and integrated product is not available. Analysis includes the use of modeling and simulation as analytical tools.
  A model is a mathematical representation of reality. A simulation is the manipulation of a model.
- **Demonstration**: Showing that the use of an end product achieves the stakeholder expectations as defined in the NGOs and the ConOps. It is generally a basic confirmation of behavioral capability, differentiated from testing by the lack of detailed data gathering. Demonstrations can involve the use of physical models or mockups; for example, an expectation that controls are readable by the pilot in low light conditions could be validated by having a pilot perform flight-related tasks in a cockpit mockup or simulator under those conditions.
- **Inspection**: The visual examination of a realized end product. Inspection is generally used to validate the presence of a physical design features or specific manufacturer identification. For example, if there is an expectation that the safety arming pin has a red flag with the words "Remove Before Flight" stenciled on the flag in black letters, a visual inspection of the arming pin flag can be used to determine if this expectation has been met.
- **Test**: The use of an end product to obtain detailed data needed to determine a behavior, or provide sufficient information to determine a behavior through further analysis. Testing can be conducted on final end products, breadboards, brassboards, or prototypes.

The activities of the Product Validation Process are described below.

5.1.1 Inputs

Key inputs to the process are:

- **End product to be validated:** This is the end product that is to be validated and which has successfully passed through the verification process.
- **Validation plan:** This plan would have been developed previously and baselined prior to entering this process. This plan may be a separate document.
- **Baselined stakeholder expectations:** These would have been developed for the product at this level previously. It includes the needs, goals, and objectives as well as the baselined and updated concept of operations and MOEs.
- **Any enabling products:** These are any special equipment, facilities, test fixtures, applications, or other items needed to perform the Product Validation Process.

5.1.2 Process Activities

This subsection addresses the approach to the implementation of the Product Validation Process, including the activities required to support the process. The Product Validation Process demonstrates that the end product satisfies its stakeholder expectations within the intended operational environments, with validation performed by anticipated operators and/or users whenever possible. The method of validation is a function of the life-cycle phase and the position of the end product within the system structure. There are five major steps in the validation process: (1) preparing to conduct validation, (2) conduct planned validation (perform validation), (3) analyze validation results, (4) prepare a validation report, and (5) capture the validation work products.

5.1.2.1 Product Validation Preparation

To prepare for performing product validation, the appropriate set of expectations against which the validation is to be made should be obtained. Other documentation such as the ConOps may be useful. The product to be validated, as well as the appropriate enabling products and support resources with which validation will be conducted should be collected. Enabling products includes those representing external interfacing products and special test equipment. Support resources include personnel necessary to support validation and operators. Procedures, capturing detailed step-by-step activities and based on the validation type and methods are finalized and approved. Development of procedures typically begins during the design phase of the project life cycle and matures as the design is matured. The validation environment is considered as part of procedure development. Operational scenarios are assessed to explore all possible validation activities to be performed. The final element is preparation of the validation environment; e.g., facilities, equipment, software, and climatic conditions.

5.1.2.2 Perform Product Validation

The act of validating the end product is performed as spelled out in the validation plans and procedures, and the conformance established to each specified stakeholder expectation shows that the validation objectives were met. Validation differs from qualification testing. Validation testing is focused on the expected environments and operations of the system where as qualification testing includes the worst-case loads and environmental requirements within which the system is expected to perform or survive. The verification lead should ensure that the procedures were followed and performed as planned, the validation-enabling products and instrumentation were calibrated correctly, and the data were collected and recorded for required validation measures.

5.1.2.3 Analyze Product Validation Results

Once the validation activities have been completed, the results are collected and the data are analyzed to confirm that the end product provided will supply the customer's needed capabilities within the intended environments of use, validation procedures were followed, and enabling products and supporting resources functioned correctly.

The data are also analyzed for quality, integrity, correctness, consistency, and validity, and any unsuitable products or product attributes are identified and reported.

5.1.2.4 Prepare Report and Capture Product Validation Work Products

Validation work products take many forms and involve many sources of information. The capture and recording of validation-related data is a very important, but often underemphasized, step in the Product Validation Process. Validation results, deficiencies identified, and corrective actions taken should be captured, as should all relevant results from the application of the Product Validation Process (related decisions, rationale for decisions made, assumptions, and lessons learned).

5.1.3 Outputs

Key outputs of validation are:

- **Validated end product:** This is the end product that has successfully passed validation and is ready to be transitioned to the next product layer or to the customer.
- **Product validation results:** These are the raw results of performing the validations.
- **Product validation report:** This report provides the evidence of product conformance with the stakeholder expectations that were identified as being validated for the product at this layer. It includes any nonconformance, anomalies, or other corrective actions that were taken.
- **Work products:** These include procedures, required personnel training, certifications, configuration drawings, and other records generated during the validation activities.

6.0 Product Transition

The Product Transition Process is used to transition a verified and validated end product that has been generated the customer at the next level in the system structure for integration into an end product or, for the top-level end product, transitioned to the intended end user. The form of the product transitioned will be a function of the product life-cycle phase success criteria and the location within the system structure of the WBS model in which the end product exists. The systems engineer involvement in this process includes ensuring the product being transitioned has been properly tested and verified/validated prior to being shipped to the next level stakeholder/customer.

6.1 Process Description

The activities of the Product Transition Process are described below.

6.1.1 Inputs

Inputs to the Product Transition Process depend primarily on the transition requirements, the product that is being transitioned, the form of the product transition that is taking place, and the location to which the product is transitioning. Typical inputs are described below.

- **The end product or products to be transitioned:** The product to be transitioned can take several forms. It can be a subsystem component, system assembly, or top-level end product. It can be hardware, analytical models, or software. It can be newly built, purchased, or reused. A product can transition from a lower system product to a higher one by being integrated with other transitioned products. This process may be repeated until the final end product is achieved. Each succeeding transition requires unique input considerations when preparing the validated product for transition to the next level.
- **Documentation including manuals, procedures, and processes that are to accompany the end product:** The documentation required for the Product Transition Process depends on the specific end product; its current location within the system structure; and the requirements identified in various

agreements, plans, or requirements documents. Typically, a product has a unique identification (i.e., serial or version number) and may have a pedigree (documentation) that specifies its heritage and current state. Pertinent information may be controlled using a configuration control process or work order system as well as design drawings and test reports. Documentation often includes proof of verification and validation conformance. A COTS product would typically contain a manufacturer's specification or fact sheet. Documentation may include operations manuals, installation instructions, and other information.

- **Product transition-enabling products, including packaging materials; containers; handling equipment; and storage, receiving, and shipping facilities:** Product transition-enabling products may be required to facilitate the implementation, integration, evaluation, transition, training, operations, support, and/or retirement of the transition product at its next higher level or for the transition of the final end product. Some or all of the enabling products may be defined in transition-related agreements, system requirements documents, or project plans. In some cases, product transition-enabling products are developed during the realization of the product itself or may be required to be developed during the transition stage.

6.1.2 Process Activities

Transitioning the product can take one of two forms:

- The delivery of lower system end products to higher ones for integration into another end product; or
- The delivery of the final end product to the customer or user that will use it in its operational environment.

In the first case, the end product is one of perhaps several other pieces that will ultimately be integrated together to form the item. In the second case, the end product is for final delivery to the customer. For example, the end product might be one of several circuit cards that will be integrated together to form the final unit that is delivered. Or that unit might also be one of several units that have to be integrated together to form the final product.

Product transition activities include preparing to conduct the transition; making sure the end product, all personnel, and any enabling products are ready for transitioning; preparing the site; and performing the transition including capturing and documenting all work products.

6.1.2.1 Prepare to Conduct Transition

The first task is to identify which of the two forms of transition is needed: (1) the delivery of lower system end products to higher ones for integration into another end product; or (2) the delivery of the final end product to the customer or user that will use the end product in its operational environment. The form of the product being transitioned affects transition planning and the kind of packaging, handling, storage, and transportation that is required. The customer and other stakeholder expectations, as well as the specific design solution, may indicate special transition procedures or enabling product needs for packaging, storage, handling, shipping / transporting, site preparation, installation, and/or sustainability. These requirements need to be reviewed during the preparation stage.

6.1.2.2 Prepare the Site to Receive the Product

For either of the forms of product transition, the receiving site needs to be prepared to receive the product. Here the end product is stored, assembled, integrated, installed, used, and/or maintained as appropriate for the life-cycle phase, position of the end product in the system structure, and customer agreement.

6.1.2.3 Prepare the Product for Transition

Whether transitioning a product to the next room for integration into the next higher assembly, or for final transportation across the country to the customer, care should be taken to ensure the safe transportation of the product. The requirements for packaging, handling, storage, training, and transportation should have been identified during system design. Preparing the packaging for protection, security, and prevention of deterioration is critical for products placed in storage or when it is necessary to transport or ship between and within organizational facilities or between organizations by land, air, and/or water vehicles. Particular emphasis needs to be on protecting surfaces from physical damage, preventing corrosion, eliminating damage to electronic wiring or cabling, shock or stress damage, heat warping or cold fractures, moisture, and other particulate intrusion that could damage moving parts.

6.1.2.4 Transition the Product

The end product is then transitioned (i.e., moved, transported, or shipped) with required documentation to the customer based on the type of transition required, e.g., to the next higher-level item in the product hierarchy for product integration or to the end user. Documentation may include operations manuals, installation instructions, and other information. The end product is finally installed into the next higher assembly or into the customer/user site using the preapproved installation procedures.

6.1.2.5 Capture Product Transition Work Products

Other work products generated during the transition process are captured and archived as appropriate. These may include site plans, special handling procedures, training, certifications, videos, inspections, or other products from these activities. A checklist can be valuable for documenting transition work products and for preparing for delivery.

6.1.3 Outputs

- **Delivered end product with applicable documentation:** This may take one of two forms:

    1. **Delivered end product for integration to next level up in system structure:** This includes the appropriate documentation. The form of the end product and applicable documentation are a function of the life-cycle phase and the placement within the system structure. (The form of the end product could be hardware, software, model, prototype, first article for test, or single operational article or multiple production articles.) Documentation includes applicable draft installation, operation, user, maintenance, or training manuals; applicable baseline documents (configuration baseline, specifications, and stakeholder expectations); and test results that reflect completion of verification and validation of the end product.

    2. **Delivered operational end product for end users:** The appropriate documentation is to accompany the delivered end product as well as the operational end product appropriately packaged. Documentation includes applicable final installation, operation, user, maintenance, or training manuals; applicable baseline documents (configuration baseline, specifications, stakeholder expectations); and test results that reflect completion of verification and validation of the end product. If the end user will perform end product validation, sufficient documentation to support end user validation activities is delivered with the end product.

- **Work products from transition activities to technical data management:** Work products could include the transition plan, site surveys, measures, training modules, procedures, decisions, lessons learned, corrective actions, etc.

- **Realized enabling end products to appropriate life-cycle support organization:** Some of the enabling products that were developed during the various phases could include fabrication or integration specialized machines; tools; jigs; fabrication processes and manuals; integration processes and manuals; specialized inspection, analysis, demonstration, or test equipment; tools; test stands; specialized packaging materials and containers; handling equipment; storage-site environments; shipping or transportation vehicles or equipment; specialized courseware; instructional site environments; and delivery of the training instruction. For the later life-cycle phases, enabling products that are to be delivered may include specialized mission control equipment; data collection equipment; data analysis equipment; operations manuals; specialized maintenance equipment, tools, manuals, and spare parts; specialized recovery equipment; disposal equipment; and readying recovery or disposal site environments.

7.0 Technical Planning

The Technical Planning Process establishes a plan for applying and managing each of the common technical processes that will be used to drive the development of system products and associated work products. This process also establishes a plan for identifying and defining the technical effort required to satisfy the project objectives and life-cycle phase success criteria within the cost, schedule, and risk constraints of the project.

This effort starts with the technical team conducting extensive planning early in the program. With this early planning, technical team members will understand the roles and responsibilities of each team member, and can establish cost and schedule goals and objectives. From this effort, the Systems Engineering Management Plan (SEMP) and other technical plans are developed and baselined. Once the SEMP and technical plans have been established, they should be synchronized.

This is a recursive and iterative process. Early in the life cycle, the technical plans are established and synchronized to run the design and realization processes. As the system matures and progresses through the life cycle, these plans should be updated as necessary to reflect the current environment and resources and to control the project's performance, cost, and schedule. At a minimum, these updates will occur at every Key Decision Point (KDP). However, if there is a significant change in the project, such as new stakeholder expectations, resource adjustments, or other constraints, all plans should be analyzed for the impact of these changes on the baselined project.

7.1 Process Description

The activities of the Technical Planning Process are described below.

7.1.1 Inputs

Input to the Technical Planning Process comes from all stakeholders as outputs from the other common technical processes. Initial planning utilizing external inputs from the project to determine the general scope and framework of the technical effort will be based on known technical and programmatic requirements, constraints, policies, and processes. Throughout the project's life cycle, the technical team continually incorporates results into the technical planning strategy and documentation and any internal changes based on decisions and assessments generated by the other SE processes or from requirements and constraints mandated by the project.

- **Project Technical Effort Requirements and Project Resource Constraints:** The program/project plan provides the project's top-level technical requirements, the available budget allocated to the program/project from the program, and the desired schedule to support overall program needs. Although the budget and schedule allocated to the program/project serve as constraints, the technical team generates a technical cost estimate and schedule based on the actual work required to satisfy the technical requirements. Discrepancies between the allocated budget and schedule and the technical team's actual cost estimate and schedule should be reconciled continuously throughout the life cycle.

- **Agreements, Capability Needs, Applicable Product Life-Cycle Phase:** The program/project plan also defines the applicable life-cycle phases and milestones, as well as any internal and external agreements or capability needs required for successful execution. The life-cycle phases and programmatic milestones provide the general framework for establishing the technical planning effort and for generating the detailed technical activities and products required to meet the overall milestones in each of the life-cycle phases.

- **Applicable Policies, Procedures, Standards, and Organizational Processes:** The program/project plan includes all programmatic policies, procedures, standards, and organizational processes that should be adhered to during execution of the technical effort. The technical team should develop a technical approach that ensures the program/project requirements are satisfied and that any technical procedures, processes, and standards to be used in developing the intermediate and final products comply with the policies and processes mandated in the program/project plan.

- **Prior Phase or Baseline Plans**: The latest technical plans (either baselined or from the previous life-cycle phase) from other processes should be used in updating the technical planning for the upcoming life-cycle phase.

- **Replanning Needs:** Technical planning updates may be required based on results from technical reviews conducted in the Technical Assessment Process, issues identified during the Technical Risk Management Process, or from decisions made previously.

7.1.2 Process Activities

Technical planning as it relates to systems engineering is intended to define how the project will be organized, structured, and conducted and to identify, define, and plan how the common technical processes will be applied in each life-cycle phase for all levels of the product hierarchy within the system structure to meet product life-cycle phase success criteria. A key document capturing and updating the details from the technical planning process is the SEMP.

The SEMP is a subordinate document to the project plan. The project plan defines how the project will be managed to achieve its goals and objectives within defined programmatic constraints. The SEMP defines for all project participants how the project will be technically managed within the constraints established by the project. The SEMP also communicates how the systems engineering management techniques will be applied throughout all phases of the project life cycle.

Technical planning should be tightly integrated with the Technical Risk Management Process (see Section 6.4) to ensure corrective action for future activities will be incorporated based on current issues identified within the project.

Technical planning, as opposed to program or project planning, addresses the scope of the technical effort required to develop the system products. While the project manager concentrates on managing the overall project life cycle, the technical team, led by the systems engineer, concentrates on managing the technical aspects of the project. The technical team identifies, defines, and develops plans for performing engineering functions. Additional planning includes defining and planning for the appropriate technical reviews, audits, assessments, and status reports and determining crosscutting engineering discipline and/or design verification requirements.

This section describes how to perform the activities contained in the Technical Planning Process. The initial technical planning at the beginning of the project establishes the technical team members; their roles and responsibilities; and the tools, processes, and resources that will be utilized in executing the technical effort. In addition, the expected activities that the technical team will perform and the products it will produce are identified, defined, and scheduled. Technical planning continues to evolve as actual data from completed tasks are received and details of near-term and future activities are known.

7.1.2.1 Technical Planning Preparation

For technical planning to be conducted properly, the processes and procedures that are needed to conduct technical planning should be identified, defined, and communicated. As participants are identified, their roles and responsibilities and any training and/or certification activities should be clearly defined and communicated.

Once the processes, people, and roles and responsibilities are in place, a planning strategy may be formulated for the technical effort. A basic technical planning strategy should address the following:

- The communication strategy within the technical team and for up and out communications;
- Identification and tailoring of procedural requirements that apply to each level of the PBS structure;
- The level of planning documentation required for the SEMP and all other technical planning documents;
- Identifying and collecting input documentation;
- The sequence of technical work to be conducted, including inputs and outputs;
- The deliverable products from the technical work;
- How to capture the work products of technical activities;
- How technical risks will be identified and managed;
- The tools, methods, and training needed to conduct the technical effort;
- The involvement of stakeholders in each facet of the technical effort;
- The entry and success criteria for milestones, such as technical reviews and life-cycle phases;
- The identification, definition, and control of internal and external interfaces;
- The identification and incorporation of relevant lessons learned into the technical planning;

- The team's approach to capturing lessons learned during the project and how those lessons will be recorded;

- The approach for technology development and how the resulting technology will be incorporated into the project;

- The identification and definition of the technical metrics for measuring and tracking progress to the realized product;

- The criteria for make, buy, or reuse decisions and incorporation criteria for Commercial Off-the-Shelf (COTS) software and hardware;

- The plan to identify and mitigate off-nominal performance;

- The "how-tos" for contingency planning and replanning;

- The plan for status assessment and reporting;

- The approach to decision analysis, including materials needed, skills required, and expectations in terms of accuracy; and

- The plan for managing the human element in the technical activities and product.

By addressing these items and others unique to the project, the technical team will have a basis for understanding and defining the scope of the technical effort, including the deliverable products that the overall technical effort will produce, the schedule and key milestones for the project that the technical team should support, and the resources required by the technical team to perform the work.

A key element in defining the technical planning effort is understanding the amount of work associated with performing the identified activities. Once the scope of the technical effort begins to coalesce, the technical team may begin to define specific planning activities and to estimate the amount of effort and resources required to perform each task. Historically, many projects have underestimated the resources required to perform proper planning activities and have been forced into a position of continuous crisis management in order to keep up with changes in the project.

Identifying Facilities

The planning process also includes identifying the required facilities, laboratories, test beds, and instrumentation needed to build, test, launch, and operate a variety of commercial and Government products. A sample list of the kinds of facilities that might be considered when planning is illustrated in Table 7.1-1.

Table 7.1-1 Examples of Types of Facilities to Consider during Planning

Communications & Tracking Labs	Models & Simulation Labs	Thermal Chambers
Power Systems Labs	Prototype Development Shops	Vibration Labs
Propulsion Test Stands	Calibration Labs	Radiation Labs
Mechanical/Structures Labs	Biological Labs	Animal Care Labs
Instrumentation Labs	Space Materials Curation Labs	Flight Hardware Storage Areas
Human Systems Labs	Electromagnetic Effects Labs	Design Visualization
Guidance and Navigation Labs	Materials Labs	Wiring Shops
Robotics Labs	Vacuum Chambers	NDE Labs
Software Development Environment	Mission Control Center	Logistics Warehouse
Meeting rooms	Training Facilities	Conference facilities
Education/Outreach centers	Server farms	Project documentation centers

7.1.2.2 Define the Technical Work

The technical effort should be defined commensurate with the level of detail needed for the life cycle phase. When performing the technical planning, realistic values for cost, schedule, and labor resources should be used. Whether extrapolated from historical databases or from interactive planning sessions with the project and stakeholders, realistic values should be calculated and provided to the project team. Contingency should be included in any estimate and should be based on the complexity and criticality of the effort. Contingency planning should be conducted. The following are examples of contingency planning:

- Additional, unplanned-for software engineering resources are typically needed during hardware and systems development and testing to aid in troubleshooting errors/anomalies. Frequently, software engineers are called upon to help troubleshoot problems and pinpoint the source of errors in hardware and systems development and testing (e.g., for writing additional test drivers to debug hardware problems). Additional software resources should be planned into the project contingencies to accommodate inevitable component and system debugging and avoid cost and schedule overruns.

- Hardware-In-the-Loop (HWIL) should be accounted for in the technical planning contingencies. HWIL testing is typically accomplished as a debugging exercise where the hardware and software are brought together for the first time in the costly environment of HWIL. If upfront work is not done to understand the messages and errors arising during this test, additional time in the HWIL facility may result in significant cost and schedule impacts. Impacts may be mitigated through upfront planning, such as making appropriate debugging software available to the technical team prior to the test, etc.

- Similarly, Human-In-The-Loop (HITL) evaluations identify contingency operational issues. HITL investigations are particularly critical early in the design process to expose, identify, and cost-effectively correct operational issues—nominal, maintenance, repair, off-nominal, training, etc.—in the required human interactions with the planned design. HITL testing should also be approached as a debugging exercise where hardware, software, and human elements interact and their performance is evaluated. If operational design and/or performance issues are not identified early, the cost of late design changes will be significant.

7.1.2.3 Schedule, Organize, and Budget the Technical Effort

Once the technical team has defined the technical work to be done, efforts can focus on producing a schedule and cost estimate for the technical portion of the project. The technical team should organize the technical tasks according to the project WBS in a logical sequence of events, taking into consideration the major project milestones, phasing of available funding, and timing of the availability of supporting resources.

Scheduling

Products described in the WBS are the result of activities that take time to complete. These activities have time precedence relationships among them that may be used to create a network schedule explicitly defining the dependencies of each activity on other activities, the availability of resources, and the receipt of receivables from outside sources. Use of a scheduling tool may facilitate the development and maintenance of the schedule.

Scheduling is an essential component of planning and managing the activities of a project. The process of creating a network schedule provides a standard method for defining and communicating what needs to be done, how long it will take, and how each element of the project WBS might affect other elements. A complete network schedule may be used to calculate how long it will take to complete a project; which activities determine that duration (i.e., critical path activities); and how much spare time (i.e., float) exists for all the other activities of the project.

"Critical path" is the sequence of dependent tasks that determines the longest duration of time needed to complete the project. These tasks drive the schedule and continually change, so they should be updated. The critical path may encompass only one task or a series of interrelated tasks. It is important to identify the critical path and the resources needed to complete the critical tasks along the path if the project is to be completed on time and within its resources. As the project progresses, the critical path will change as the critical tasks are completed or as other tasks are delayed. This evolving critical path with its identified tasks needs to be carefully monitored during the progression of the project.

Network scheduling systems help managers accurately assess the impact of both technical and resource changes on the cost and schedule of a project. Cost and technical problems often show up first as schedule problems. Understanding the project's schedule is a prerequisite for determining an accurate project budget and for tracking performance and progress. Because network schedules show how each activity affects other activities, they assist in assessing and predicting the consequences of schedule slips or accelerations of an activity on the entire project.

For additional information on scheduling, refer to NASA Scheduling Management Handbook, NASA/SP-2010-3403.

Budgeting

Budgeting and resource planning involve establishing a reasonable project baseline budget and the capability to analyze changes to that baseline resulting from technical and/or schedule changes. The project's WBS, baseline schedule, and budget should be viewed as mutually dependent, reflecting the technical content, time, and cost of meeting the project's goals and objectives. The budgeting process needs to take into account whether a fixed cost cap or fixed cost profile exists. When no such cap or profile exists, a baseline budget is developed from the WBS and network schedule. This specifically involves combining the project team and other resource needs with the appropriate costs and other financial and programmatic factors to obtain cost element estimates. For student-lead projects, there may or may not be direct labor costs associated with project tasks. The elements of cost include:

- Direct labor costs,

- Overhead costs,

- Other direct costs (travel, data processing, etc.),
- Subcontract costs,
- Material costs,
- Equipment costs,
- General and administrative costs,
- Cost of money (i.e., interest payments, if applicable),
- Fee (if applicable), and
- Contingency (Unallocated Future Expenses (UFE)).

7.1.2.4 Prepare the SEMP and Other Technical Plans

Systems Engineering Management Plan

The SEMP is the primary, top-level technical management document for the project and is developed early in the Formulation Phase and updated throughout the project life cycle. The SEMP is driven by the type of project, the phase in the project life cycle, and the technical development risks and is written specifically for each project or project element. While the specific content of the SEMP is tailored to the project, the recommended content is discussed in Appendix C. It is important to remember that the main value of the SEMP is in the work that goes into the planning.

The technical team, working under the overall project plan, develops and updates the SEMP as necessary. The technical team works with the project manager to review the content and obtain concurrence. This allows for thorough discussion and coordination of how the proposed technical activities would impact the programmatic, cost, and schedule aspects of the project. The SEMP provides the specifics of the technical effort and describes the technical processes that will be used, how the processes will be applied using appropriate activities, how the project will be organized to accomplish the activities, and the cost and schedule associated with accomplishing the activities.

The physical length of a SEMP is not what is important. This will vary from project to project. The plan needs to be adequate to address the specific technical needs of the project. It is a living document that is updated as often as necessary to incorporate new information as it becomes available and as the project develops through the Implementation Phase. The SEMP should not duplicate other project documents; however, the SEMP should reference and summarize the content of other technical plans.

The systems engineer and project manager should identify additional required technical plans based on the project scope and type. If plans are not included in the SEMP, they should be referenced and coordinated in the development of the SEMP. Other plans, such as system safety, probabilistic risk assessment, and an HSI Plan also may be planned for and coordinated with the SEMP. If a technical plan is a stand-alone, it should be referenced in the SEMP. Depending on the size and complexity of the project, these may be separate plans or they may be included within the SEMP. Once identified, the plans can be developed, training on these plans established, and the plans implemented. Examples of technical plans in addition to the SEMP are listed in Appendix D.

The SEMP should be developed prior to beginning project execution. In developing the SEMP, the technical approach to the project's life cycle is developed. This determines the project's length and cost. The development of the programmatic and technical management approaches requires that the key project personnel develop an understanding of the work to be performed and the relationships among the various parts of that work. Refer to Sections 6.1.2.1 and 6.1.1.2 on WBSs and network scheduling, respectively. The SEMP then flows into the project plan to ensure the proper allocation of resources including cost, schedule, and personnel.

The SEMP's development requires contributions from knowledgeable programmatic and technical experts from all areas of the project that can significantly influence the project's outcome. The involvement of recognized experts is needed to establish a SEMP that is credible to the project manager and to secure the full commitment of the project team.

Role of the SEMP

The SEMP is the rule book that describes to all participants how the project will be technically managed. The technical team on the project should have a SEMP to describe how it will conduct its technical management. Since the SEMP is unique to a project, it should be updated for each significant programmatic change or it will become outmoded and unused and the project could slide into an uncontrolled state. The project team should have its SEMP developed before attempting to prepare an initial cost estimate since activities that incur cost, such as technical risk reduction and human element accounting, need to be identified and described beforehand. The SEMP describes the technical content of the project, the potentially costly risk management activities, and the verification and validation techniques to be used, all of which should be included in the preparation of project cost estimates. The project SEMP is the senior technical management document for the project; all other technical plans should comply with it. The SEMP should be comprehensive and describe how a fully integrated engineering effort will be managed and conducted.

Verification Plan

The verification plan is developed as part of the Technical Planning Process and is baselined at PDR. As the design matures throughout the life cycle, the plan is updated and refined as needed. The task of preparing the verification plan includes establishing the method of verification to be performed, dependent on the life-cycle phase; the position of the product in the system structure; the form of the product used; and the related costs of verification of individual specified requirements. The verification methods include analyses, inspection, demonstration, and test. In some cases, the complete verification of a given requirement might require more than one method. For example, to verify the performance of a product may require looking at many use cases. This might be accomplished by running a Monte Carlo simulation (analysis) and also running actual tests on a few of the key cases. The verification plan, typically written at a detailed technical level, plays a pivotal role in bottom-up product realization.

A phase product can be verified recursively throughout the project life cycle and on a wide variety of product forms. For example:

- Simulated (algorithmic models, virtual reality simulator);

- Mockup (plywood, brassboard, breadboard);

- Concept description (paper report);
- Engineering unit (fully functional but may not be same form/fit);
- Prototype (form, fit, and function);
- Design verification test units (form, fit, and function is the same, but they may not have flight parts);
- Qualification units (identical to flight units but may be subjected to extreme environments); and
- Flight units (end product that is flown, including protoflight units).

Types of Hardware

- **Breadboard:** A low fidelity unit that demonstrates function only without considering form or fit in the case of hardware or platform in the case of software. It often uses commercial and/or ad hoc components and is not intended to provide definitive information regarding operational performance.
- **Brassboard:** A medium fidelity functional unit that typically tries to make use of as much operational hardware/software as possible and begins to address scaling issues associated with the operational system. It does not have the engineering pedigree in all aspects, but is structured to be able to operate in simulated operational environments in order to assess performance of critical functions.
- **Engineering Unit:** A high fidelity unit that demonstrates critical aspects of the engineering processes involved in the development of the operational unit. Engineering test units are intended to closely resemble the final product (hardware/software) to the maximum extent possible and are built and tested so as to establish confidence that the design will function in the expected environments. In some cases, the engineering unit will become the final product, assuming proper traceability has been exercised over the components and hardware handling.
- **Prototype Unit:** The prototype unit demonstrates form, fit, and function at a scale deemed to be representative of the final product operating in its operational environment. A subscale test article provides fidelity sufficient to permit validation of analytical models capable of predicting the behavior of full-scale systems in an operational environment.
- **Qualification Unit:** A unit that is the same as the flight unit (form, fit, function, components, etc.) that will be exposed to the extremes of the environmental criteria (thermal, vibration, etc.). The unit will typically not be flown due to these off-nominal stresses.
- **Protoflight Unit**: In projects that will not develop a qualification unit, the flight unit may be designated as a protoflight unit and a limited version of qualification test ranges will be applied. This unit will be flown.

Verification of the end product—that is, the official "run for the record" verification where the program/project takes credit for meeting a requirement—is usually performed on a qualification, protoflight, or flight unit to ensure its applicability to the flight system. However, with discussion and approval from the program/project and systems engineering teams, verification credit may be taken on lower fidelity units if they can be shown to be sufficiently like the flight units in the areas to be verified.

Any of these types of product forms may be in any of these states:

- Produced (built, fabricated, manufactured, or coded);

- Reused (modified internal non-developmental products or OTS product); or

- Assembled and integrated (a composite of lower-level products).

The conditions and environment under which the product is to be verified should be established and the verification should be planned based on the associated entrance/exit criteria that are identified.

Procedures should be prepared to conduct verification based on the method (e.g., analysis, inspection, demonstration, or test) planned. These procedures are typically developed during the design phase of the project life cycle and matured as the design is matured. Operational use scenarios are thought through in order to explore all possible verification activities to be performed.

> Note: The final, official verification of the end product should be on a controlled unit. Typically, attempting to "buy off" a "shall" on a prototype is not acceptable; it is usually completed on a qualification, flight, or other more final, controlled unit.

As appropriate, project risk items are updated based on approved verification strategies that cannot duplicate fully integrated test systems, configurations, and/or target operating environments. Rationales, trade space, optimization results, and implications of the approaches are documented in the new or revised risk statements as well as references to accommodate future design, test, and operational changes to the project baseline.

Validation Plan

The validation plan is one of the work products of the Technical Planning Process and is generated to validate the end product against the baselined stakeholder expectations. This plan can take many forms. The plan describes the total Test and Evaluation (T&E) planning from development of lower-end through higher-end products in the system structure and through operational T&E into production and acceptance. It may combine the verification and validation plans into a single document, especially for smaller project efforts. (See Appendix E for a sample Verification and Validation Plan outline.)

The methods of validation include test, demonstration, inspection, and analysis. While the name of each method is the same as the name of the methods for verification, the purpose and intent as described above are quite different.

Planning to conduct the product validation is a key first step. The method of validation to be used (e.g., analysis, demonstration, inspection, or test) should be established based on the form of the realized end product, the applicable life-cycle phase, cost, schedule, resources available, and location of the system product within the system structure.

An established set or subset of expectations or behaviors to be validated should be identified and the validation plan reviewed (an output of the Technical Planning Process, based on design solution outputs) for any specific procedures, constraints, success criteria, or other validation requirements. The conditions and environment under which the product is to be validated should be established and the validation should be planned based on the relevant life-cycle phase and associated success criteria identified. The Decision Analysis Process should be used to help finalize the planning details.

It is important to review the validation plans with relevant stakeholders and to understand the relationship between the context of the validation and the context of use (human involvement). As part of the planning process, validation-enabling products should be identified and scheduling and/or acquisition should be initiated.

Procedures should be prepared to conduct validation based on the method planned; e.g., analysis, inspection, demonstration, or test). These procedures are typically developed during the design phase of the project life cycle and matured as the design is matured. Operational and use-case scenarios are thought through in order to explore all possible validation activities to be performed.

Validation is conducted by the user/operator or by the developer. Systems-level validation may be performed by an acquirer testing organization. For those portions of validation performed by the developer, appropriate agreements should be negotiated to ensure that validation proof-of-documentation is delivered with the product.

Regardless of the source (buy, make, reuse, assemble and integrate) and the position in the system structure, all realized end products should be validated to demonstrate/confirm satisfaction of stakeholder expectations. Variations, anomalies, and out-of-compliance conditions, where such have been detected, are documented along with the actions taken to resolve the discrepancies. Validation is typically carried out in the intended operational environment or a relevant environment under simulated or actual operational conditions, not necessarily under the tightly controlled conditions usually employed for the Product Verification Process.

Environments

- **Relevant Environment:** Not all systems, subsystems, and/or components need to be operated in the operational environment in order to satisfactorily address performance margin requirements or stakeholder expectations. Consequently, the relevant environment is the specific subset of the operational environment that is required to demonstrate critical "at risk" aspects of the final product performance in an operational environment.
- **Operational Environment:** The environment in which the final product will be operated. In the case of space flight hardware/software, it is space. In the case of ground-based or airborne systems that are not directed toward space flight, it is the environments defined by the scope of operations. For software, the environment is defined by the operational platform.

Validation of phase products can be performed recursively throughout the project life cycle and on a wide variety of product forms. For example:

- Simulated (algorithmic models, virtual reality simulator);
- Mockup (plywood, brassboard, breadboard);
- Concept description (paper report);
- Engineering unit (functional but may not be same form/fit);
- Prototype (product with form, fit, and function);

- Design validation test units (form, fit, and function may be the same, but they may not have flight parts);

- Qualification unit (identical to flight unit but may be subjected to extreme environments); and

- Flight unit (end product that is flown).

Any of these types of product forms may be in any of these states:

- Produced (built, fabricated, manufactured, or coded);

- Reused (modified internal non-developmental products or off-the-shelf product); or

- Assembled and integrated (a composite of lower-level products).

> Note: The final, official validation of the end product should be for a controlled unit. Typically, attempting final validation against the ConOps on a prototype is not acceptable: it is usually completed on a qualification, flight, or other more final, controlled unit.

> Note: In planning for validation, consideration should be given to the extent to which validation testing will be done. In many instances, off-nominal operational scenarios and nominal operational scenarios should be utilized. Off-nominal testing offers insight into a system's total performance characteristics and often assists in identifying the design issues and human-machine interface, training, and procedural changes required to meet the mission goals and objectives. Off-nominal testing as well as nominal testing should be included when planning for validation.

For additional information on technical plans, refer to the following appendices of this document and to Section 6.1.1.2.4 of the NASA Expanded Guidance for Systems Engineering at Expanded Guidance for NASA SE NASA/SP-2016-6105-SUPPL:

- Appendix A Integration Plan Outline
- Appendix E Verification and Validation Plan Outline
- Appendix C SEMP Content Outline
- Appendix D Technical Plans
- Appendix F Interface Requirements Document Outline
- Appendix G CM Plan Outline
- Appendix H HSI Plan Outline
- Appendix I Concept of Operations Outline

7.1.2.5 Obtain Stakeholder Commitments to Technical Plans

Stakeholder Roles in Project Planning

To obtain commitments to the technical plans from the stakeholders, the technical team should ensure that the appropriate stakeholders, including subject domain experts, have a method to provide inputs and to review the project planning for implementation of stakeholder interests.

During the Formulation Phase, the roles of the stakeholders should be defined in the project plan and the SEMP. Review of these plans and the agreements from the stakeholders to the content of these plans constitutes buy-in from the stakeholders to the technical approach. It is essential to identify the stakeholders and get their concurrence on the technical approach.

Later in the project life cycle, stakeholders may be responsible for delivering products to the project. Initial agreements regarding the responsibilities of the stakeholders are key to ensuring that the project technical team obtains the appropriate deliveries from stakeholders.

For university project teams, stakeholders may be instructors or professors, project sponsors, or local subject matter experts just to name a few.

Stakeholder Involvement in Defining Requirements

The identification of stakeholders is one of the early steps in the systems engineering process. As the project progresses, stakeholder expectations are flowed down and specific stakeholders are identified for all of the primary and derived requirements. A critical part of the stakeholders' involvement is in the definition of the technical requirements. As requirements and the ConOps are developed, the stakeholders will be required to agree to these products. Inadequate stakeholder involvement leads to inadequate requirements and a resultant product that does not meet the stakeholder expectations. Status on relevant stakeholder involvement should be tracked and corrective action taken if stakeholders are not participating as planned.

Stakeholder Support Forums

During development of the project plan and the SEMP, forums are established to facilitate communication and document decisions during the life cycle of the project. These forums include meetings, working groups, decision panels, and control boards. Each of these forums should establish a charter to define the scope and authority of the forum and identify necessary voting or nonvoting participants. Ad hoc members may be identified when the expertise or input of specific stakeholders is needed when specific topics are addressed. It is important to ensure that stakeholders have been identified to support the forum.

7.1.2.6 Capture Technical Planning Work Products

The work products from the Technical Planning Process should be managed as required. Some of the more important products of technical planning (i.e., the WBS, the SEMP, and the schedule, etc.) are kept under current throughout the project life cycle. Additional products are captured such as trade studies, cost estimates, technical analyses, reports, and other important. Work products, such as meeting minutes and correspondence (including e-mail) containing decisions or agreements with stakeholders also should be retained and stored in project files for later reference.

7.1.3 Outputs

Typical outputs from technical planning activities are:

- **Technical work cost estimates, schedules, and resource needs**: e.g., funds, workforce, facilities, and equipment (to the project) within the project resources;

- **Product and process measures:** Those needed to assess progress of the technical effort and the effectiveness of processes (to the Technical Assessment Process);

- **SEMP and other technical plans:** Technical planning strategy, WBS, SEMP, HSI Plan, V&V Plan, and other technical plans that support implementation of the technical effort (to all processes; applicable plans to technical processes);

- **Technical Planning Process work products:** Includes products needed to provide reports, records, and non-deliverable outcomes of process activities.

The resulting technical planning strategy constitutes an outline, or rough draft, of the SEMP. This serves as a starting point for the overall Technical Planning Process after initial preparation is complete. When preparations for technical planning are complete, the technical team should have a cost estimate and schedule for the technical planning effort. The budget and schedule to support the defined technical planning effort can then be negotiated with the project manager to resolve any discrepancies between what is needed and what is available. The SEMP baseline needs to be completed. Planning for the update of the SEMP based on programmatic changes needs to be developed and implemented. The SEMP needs to be approved by the appropriate level of authority.

7.2 Technical Planning Guidance

Refer to Section 6.1.2 in the NASA Expanded Guidance for Systems Engineering at Expanded Guidance for NASA SE NASA/SP-2016-6105-SUPPL for additional guidance on:

- Work Breakdown Structure (WBS),
- cost definition and modeling, and
- lessons learned.

Additional information on the WBS can also be found in NASA Work Breakdown Structure Handbook, NASA/SP-2016-3403/REV1. NASA/SP-2010-3404, NASA Work Breakdown Structure Handbook and on costing in the NASA Cost Estimating Handbook.

8.0 Interface Management

The definition, management, and control of interfaces are crucial to successful programs or projects. Interface management is a process to assist in controlling product development when efforts are divided among parties (e.g., Government, contractors, geographically diverse technical teams, etc.) and/or to define and maintain compliance among the products that should interoperate.

The basic tasks that need to be established involve the management of internal and external interfaces of the various levels of products and operator tasks to support product integration. These basic tasks are as follows:

- Define interfaces;

- Identify the characteristics of the interfaces (physical, electrical, mechanical, human, etc.);

- Ensure interface compatibility at all defined interfaces by using a process documented and approved by the project;

- Strictly control all of the interface processes during design, construction, operation, etc.;
- Identify lower-level products to be assembled and integrated (from the Product Transition Process);
- Identify assembly drawings or other documentation that show the complete configuration of the product being integrated, a parts list, and any assembly instructions (e.g., torque requirements for fasteners);
- Identify end-product, design-definition-specified requirements (specifications), and configuration documentation for the applicable work breakdown structure model, including interface specifications, in the form appropriate to satisfy the product life-cycle phase success criteria; and
- Identify product integration-enabling products (from existing resources or the Product Transition Process for enabling product realization).

8.1 Process Description

The activities of the Interface Management Process are described below.

8.1.1 Inputs

Typical inputs needed to understand and address interface management would include the following:

- **Interface Requirements:** These include the internal and external functional, physical, and performance interface requirements developed previously for the product(s).
- **Interface Change Requests:** These include changes resulting from program or project agreements or changes on the part of the technical team.

Other inputs that might be useful are:

- **System Description:** This allows the design of the system to be explored and examined to determine where system interfaces exist.
- **System Boundaries:** Documented physical boundaries, components, and/or subsystems, which are all drivers for determining where interfaces exist.
- **Organizational Structure:** Decisions on which organization will dictate interfaces, particularly when there is the need to jointly agree on shared interface parameters of a system. The program and project WBS will also provide organizational interface boundaries.
- **Boards Structure:** Defined board structure that identifies organizational interface responsibilities.

8.1.2 Prepare or Update Interface Management Procedures

These procedures establish the interface management responsibilities, what process will be used to maintain and control the internal and external functional and physical interfaces (including human), and how the change process will be conducted. Training of the technical teams or other support may also be required and planned.

8.1.3 Conduct Interface Management during System Design Activities

During project formulation, the ConOps of the product is analyzed to identify both external and internal interfaces. This analysis will establish the origin, destination, stimuli, and special characteristics of the interfaces that need to be documented and maintained. As the system structure and architecture emerges, interfaces will be added and existing interfaces will be changed and should be maintained. Thus, the Interface Management Process has a close relationship to other areas during this period.

8.1.4 Conduct Interface Management during Product Integration

During product integration, interface management activities would support the review of integration and assembly procedures to ensure interfaces are properly marked and compatible with specifications and interface control documents. The interface management process has a close relationship to verification and validation. Interface control documentation and approved interface requirement changes are used as inputs to the Product Verification Process and the Product Validation Process, particularly where verification test constraints and interface parameters are needed to set the test objectives and test plans. Interface requirements verification is a critical aspect of the overall system verification.

8.1.5 Conduct Interface Control

Typically, an Interface Working Group (IWG) establishes communication links between those responsible for interfacing systems, end products, enabling products, and subsystems. The IWG has the responsibility to ensure accomplishment of the planning, scheduling, and execution of all interface activities. An IWG is typically a technical team with appropriate technical membership from the interfacing parties. The IWG may work independently or as a part of a larger change control board.

8.1.6 Capture Work Products

Work products include the strategy and procedures for conducting interface management, rationale for interface decisions made, assumptions made in approving or denying an interface change, actions taken to correct identified interface anomalies, lessons learned and updated support and interface agreement documentation.

8.1.7 Outputs

Typical outputs needed to capture interface management would include:

- **Interface control documentation.** This is the documentation that identifies and captures the interface information and the approved interface change requests. Types of interface documentation include the Interface Requirements Document (IRD), Interface Control Document/Drawing (ICD), Interface Definition Document (IDD), and Interface Control Plan (ICP). These outputs will then be maintained and approved and become a part of the overall technical data package for the project.

- **Approved interface requirement changes.** After the interface requirements have been baselined, they should be managed to identify the need for changes, evaluate the impact of the proposed change, document the final approval/disapproval, and update the requirements documentation/tool/database. For interfaces that require approval from all sides, unanimous approval is required. Changing interface requirements late in the design or implementation life cycle is more likely to have a significant impact on the cost, schedule, or technical design/operations.

- **Other work products.** These work products include the strategy and procedures for conducting interface management, the rationale for interface decisions made, the assumption made in approving or denying an interface change, the actions taken to correct identified interface anomalies, the lessons learned in performing the interface management activities, and the updated support and interface agreement documentation.

8.2 Interface Management Guidance

Refer to Section 6.3.2 in the NASA Expanded Guidance for Systems Engineering at [Expanded Guidance for NASA SE NASA/SP-2016-6105-SUPPL] for additional guidance on:

- interface requirements documents,
- interface control documents,
- interface control drawings,
- interface definition documents,
- the interface control plans, and
- interface management tasks.

9.0 Technical Risk Management

The Technical Risk Management Process is one of the crosscutting technical management processes. Risk is the potential for performance shortfalls, which may be realized in the future, with respect to achieving explicitly established and stated performance requirements. The performance shortfalls may be related to institutional support for mission execution or related to any one or more of the following mission execution domains:

- Safety
- Technical
- Cost
- Schedule

Systems engineers are involved in this process to help identify potential technical risks, develop mitigation plans, monitor progress of the technical effort to determine if new risks arise or old risks can be retired, and to be available to answer questions and resolve issues. The following is guidance in implementation of risk management in general. Thus, when implementing risk management on any given program/project, the responsible systems engineer should direct the effort accordingly. The idea is to tailor the risk management process so that it meets the needs of the individual program/project being executed.

Risk is characterized by three basic components:

1. The scenario(s) leading to degraded performance with respect to one or more performance measures (e.g., scenarios leading to injury, fatality, destruction of key assets; scenarios leading to exceedance of mass limits; scenarios leading to cost overruns; scenarios leading to schedule slippage);

2. The likelihood(s) (qualitative or quantitative) of those scenario(s); and

3. The consequence(s) (qualitative or quantitative severity of the performance degradation) that would result if the scenario(s) was (were) to occur.

Uncertainties are included in the evaluation of likelihoods and consequences.

Scenarios begin with a set of initiating events that cause the activity to depart from its intended state. For each initiating event, other events that are relevant to the evolution of the scenario may (or may not) occur and may have either a mitigating or exacerbating effect on the scenario progression. The frequencies of scenarios with undesired consequences are determined. Finally, the multitude of such scenarios is put together, with an understanding of the uncertainties, to create the risk profile of the system.

This "risk triplet" conceptualization of risk is illustrated in Figures 9.0-1 and 9.0-2.

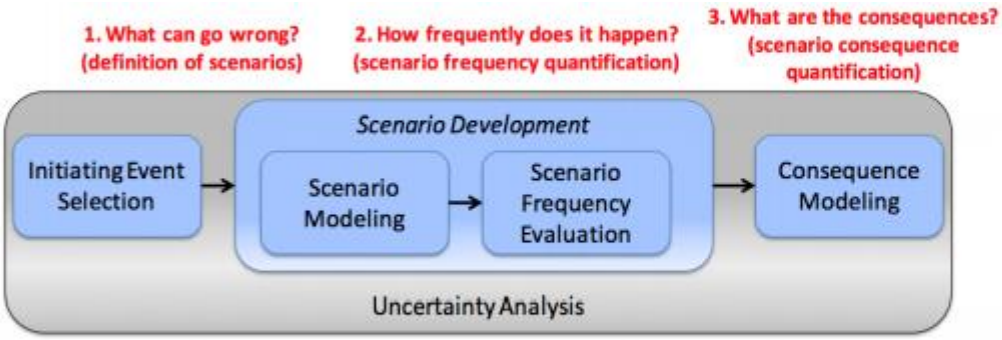


Figure 9.0-1 Risk Scenario Development *(Source: NASA/SP-2011-3421)*

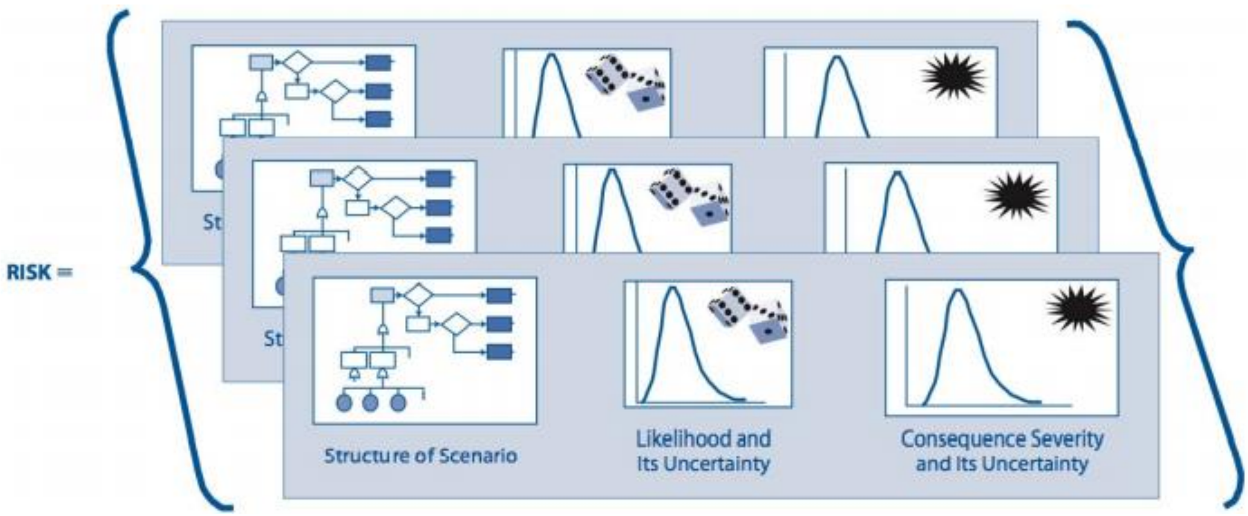


Figure 9.0-2 Risk as an Aggregate Set of Risk Triplets

Undesired scenario(s) might come from technical or programmatic sources (e.g., a cost overrun, schedule slippage, safety mishap, health problem, malicious activities, environmental impact, or failure to achieve a needed scientific or technological objective or success criterion). Both the likelihood and consequences may have associated uncertainties.

- Key Concepts in Risk Management **Risk:** Risk is the potential for shortfalls, which may be realized in the future with respect to achieving explicitly-stated requirements. The performance shortfalls may be related to institutional support for mission execution, or related to any one or more of the following mission execution domains: safety, technical, cost, schedule. Risk is characterized as a set of triplets:
  - The scenario(s) leading to degraded performance in one or more performance measures.
  - The likelihood(s) of those scenarios.
  - The consequence(s), impact, or severity of the impact on performance that would result if those scenarios were to occur.

  Uncertainties are included in the evaluation of likelihoods and consequences.
- **Cost Risk:** This is the risk associated with the ability of the program/project to achieve its life-cycle cost objectives and secure appropriate funding. Two risk areas bearing on cost are (1) the risk that the cost estimates and objectives are not accurate and reasonable; and (2) the risk that program execution will not meet the cost objectives as a result of a failure to handle cost, schedule, and performance risks.
- **Schedule Risk:** Schedule risks are those associated with the adequacy of the time estimated and allocated for the development, production, implementation, and operation of the system. Two risk areas bearing on schedule risk are (1) the risk that the schedule estimates and objectives are not realistic and reasonable; and (2) the risk that program execution will fall short of the schedule objectives as a result of failure to handle cost, schedule, or performance risks.
- **Technical Risk:** This is the risk associated with the evolution of the design and the production of the system of interest affecting the level of performance necessary to meet the stakeholder expectations and technical requirements. The design, test, and production processes (process risk) influence the technical risk and the nature of the product as depicted in the various levels of the PBS (product risk).
- **Programmatic Risk:** This is the risk associated with action or inaction from outside the project, over which the project manager has no control, but which may have significant impact on the project. These impacts may manifest themselves in terms of technical, cost, and/or schedule.
- **Scenario:** A sequence of credible events that specifies the evolution of a system or process from a given state to a future state. In the context of risk management, scenarios are used to identify the ways in which a system or process in its current state can evolve to an undesirable state.

9.1 Risk Management Process Description
The activities of the Risk Management Process are described below.

9.1.1 Inputs
The following are typical inputs to risk management:

- **Project Risk Management Plan:** The Risk Management Plan is developed under the Technical Planning Process and defines how risk will be identified, mitigated, monitored, and controlled within the project.

- **Technical Risk Issues:** These will be the technical issues identified as the project progresses that pose a risk to the successful accomplishment of the project mission/goals.

- **Technical Risk Status Measurements:** These are any measures that are established that help to monitor and report the status of project technical risks.

- **Technical Risk Reporting Requirements:** Includes requirements of how technical risks will be reported, how often, and to whom.

Additional inputs that may be useful:

- **Other Plans and Policies:** Systems Engineering Management Plan, form of technical data products, and policy input to metrics and thresholds.

- **Technical Inputs:** Stakeholder expectations, concept of operations, imposed constraints, tracked observables, current program baseline, performance requirements, and relevant experience data.

9.1.2 Prepare a Strategy to Conduct Technical Risk Management

This strategy would include documenting how the program/project risk management plan will be implemented, identifying any additional technical risk sources and categories not captured in the plan, identifying what will trigger actions and how these activities will be communicated to the internal and external teams.

9.1.3 Identify Technical Risks

On a continuing basis, the technical team will identify technical risks including their source, analyze the potential consequence and likelihood of the risks occurring, and prepare clear risk statements for entry into the program/project risk management system. Coordination with the relevant stakeholders for the identified risks is included.

9.1.4 Conduct Technical Risk Management

The risk management approach described in this guide entails two complementary processes: Risk-Informed Decision Making (RIDM) and Continuous Risk Management (CRM). RIDM is intended to inform direction-setting systems engineering (SE) decisions (e.g., design decisions) through better use of risk and uncertainty information in selecting alternatives and establishing baseline performance requirements.

CRM is then used to manage risks over the course of the development and implementation phases of the life cycle to assure that requirements related to safety, technical, cost, and schedule are met. In the past, RM was considered equivalent to the CRM process; now, RM is defined as comprising both the RIDM and CRM processes, which work together to assure proactive risk management as programs and projects are conceived, developed, and executed. Figure 9.1-1 illustrates the concept.

Figure 9.1-1 Risk Management as the Interaction of Risk-Informed Decision Making and Continuous Risk Management *(Source: NASA/SP-2011-3422)*

9.1.5 Prepare for Technical Risk Mitigation

This includes selecting the risks that will be mitigated and more closely monitored, identifying the risk level or threshold that will trigger a risk mitigation action plan, and identifying for each risk which stakeholders will need to be informed that a mitigation/contingency action is determined as well as which organizations will need to become involved to perform the mitigation/contingency action.

9.1.6 Monitor the Status of Each Technical Risk Periodically

Risk status will need to be monitored periodically at a frequency identified in the risk plan. Risks that are approaching the trigger thresholds will be monitored on a more frequent basis. Reports of the status are made to the appropriate program/project management or board for communication and for decisions whether to trigger a mitigation action early. Risk status will also be reported at most life-cycle reviews.

9.1.7 Implement Technical Risk Mitigation and Contingency Action Plans as Triggered

When the applicable thresholds are triggered, the technical risk mitigation and contingency action plans are implemented. This includes monitoring the results of the action plan implementation and modifying them as necessary, continuing the mitigation until the residual risk and/or consequence impacts are acceptable, and communicating the actions and results to the identified stakeholders. Action plan reports are prepared and results reported at appropriate boards and at life-cycle reviews.

9.1.8 Capture Work Products

Work products include the strategy and procedures for conducting technical risk management; the rationale for decisions made; assumptions made in prioritizing, handling, and reporting technical risks and action plan effectiveness; actions taken to correct action plan implementation anomalies; and lessons learned.

9.1.9 Outputs

Following are key risk outputs from activities:

- **Technical Risk Mitigation and/or Contingency Actions:** Actions taken to mitigate identified risks or contingency actions taken in case risks are realized.

- **Technical Risk Reports:** Reports of the technical risk policies, status, remaining residual risks, actions taken, etc. Output at the agreed-to frequency and recipients.

- **Work Products:** Includes the procedures for conducting technical risk management; rationale for decisions made; selected decision alternatives; assumptions made in prioritizing, handling, and reporting technical risks; and lessons learned.

9.2 Risk Management Process Guidance

For additional guidance on risk management, refer to NASA RIDM Handbook NASA/SP-2010-576 and NASA Risk Management Handbook NASA/SP-2011-3422.

10.0 Technical Data Management

The Technical Data Management Process is used to plan for, acquire, access, manage, protect, and use data of a technical nature to support the total life cycle of a system. Data Management (DM) includes the development, deployment, operations and support, eventual retirement, and retention of appropriate technical, to include mission and science, data beyond system retirement.

Key aspects of DM for systems engineering include:

- Application of policies and procedures for data identification and control,
- Timely and economical acquisition of technical data,
- Assurance of the adequacy of data and its protection,
- Facilitating access to and distribution of the data to the point of use,
- Analysis of data use,
- Evaluation of data for future value to other programs/projects, and
- Process access to information written in legacy software.

The Technical Data Management ensures all information about the project is safe, known, and accessible. Changes to information under Technical Data Management need to be managed by identifying who can make changes to each type of technical data.

10.1 Process Description

The activities of the Technical Data Management Process are described below.

10.1.1 Inputs

The inputs for this process are:

- **Technical data products to be managed:** Technical data, regardless of the form or method of recording and who has generated the data during the life cycle of the system being developed. (Electronic technical data should be stored with sufficient metadata to enable easy retrieval and sorting.)

- **Technical data requests:** External or internal requests for any of the technical data generated by the program/project.

10.1.2 Prepare for Technical Data Management Implementation

The recommended procedure is that the DM plan to be a standalone plan. DM issues are usually of sufficient magnitude to justify a separate plan. The plan should cover the following major DM topics:

- Identification/definition/management of data sets.

- Control procedures—receipt, modification, review, and approval.

- Guidance on how to access/search for data for users.

- Data exchange formats that promote data reuse and help to ensure that data can be used consistently throughout the system, family of systems, or system of systems.

- Data rights and distribution limitations such as export-control Sensitive But Unclassified (SBU).

- Storage and maintenance of data, including master lists where documents and records are maintained and managed.

Prepare a technical data management strategy. This strategy can document how the program / project data management plan will be implemented by the technical effort or, in the absence of such a program-level plan, be used as the basis for preparing a detailed technical data management plan, including:

- ➢ Items of data that will be managed according to program/project or organizational policy, agreements, or legislation;

- ➢ The data content and format;

- ➢ A framework for data flow within the program/project and to/from contractors including the language(s) to be employed in technical effort information exchanges;

- ➢ Technical data management responsibilities and authorities regarding the origin, generation, capture, archiving, security, privacy, and disposal of data products;

- ➢ Establishing the rights, obligations, and commitments regarding the retention of, transmission of, and access to data items; and

- Relevant data storage, transformation, transmission, and presentation standards and conventions to be used according to program/project or organizational policy, agreements, or legislative constraints.

- Obtain strategy/plan commitment from relevant stakeholders.

- Prepare procedures for implementing the technical data management strategy for the technical effort and/or for implementing the activities of the technical data management plan.

- Establish a technical database(s) to use for technical data maintenance and storage or work with the program/project staff to arrange use of the program/project database(s) for managing technical data.

- Establish data collection tools, as appropriate to the technical data management scope and available resources.

- Establish electronic data exchange interfaces in accordance with applicable standards.

Train appropriate stakeholders and other technical personnel in the established technical data management strategy/plan, procedures, and data collection tools, as applicable.

Data Identification/Definition

Each program/project determines data needs during the life cycle. Data types may be defined in standard documents. The standard description is modified to suit program/project-specific needs. Below are the different types of data that might be utilized within a program/ project:

- **Data**
    - "Data" is defined in general as "recorded information regardless of the form or method of recording." However, the terms "data" and "information" are frequently used interchangeably. To be more precise, data generally should be processed in some manner to generate useful, actionable information.

    - "Data," as used in SE DM, includes technical data; computer software documentation; and representation of facts, numbers, or data of any nature that can be communicated, stored, and processed to form information.

    - Data include that associated with system development, modeling and simulation used in development or test, test and evaluation, installation, parts, spares, repairs, usage data required for product sustainability, and source and/or supplier data.

    - Data specifically not included in Technical Data Management would be data relating to general workforce operations information, communications information (except where related to a specific requirement), financial transactions, personnel data, transactional data, and other data of a purely business nature.

- **Information:** Information is generally considered as processed data. The form of the processed data is dependent on the documentation, report, review formats, or templates that are applicable.

- **Technical Data Package:** A technical data package is a technical description of an item adequate for supporting an acquisition strategy, production, engineering, and logistics support. The package defines the required design configuration and procedures to ensure adequacy of item performance. It consists of all applicable items such as drawings, associated lists, specifications, standards, performance requirements, quality assurance provisions, and packaging details.

- **Technical Data Management System:** The strategies, plans, procedures, tools, people, data formats, data exchange rules, databases, and other entities and descriptions required to manage the technical data of a program/project.

10.1.3 Collect and Store Data

Subsequent activities collect, store, and maintain technical data and provide it to authorized parties as required. Some considerations that impact these activities for implementing Technical Data Management include:

- Requirements relating to the flow/delivery of data to or from a party should be specified in the technical data management plan.

- Responsibility for data inputs into the technical data management system lies solely with the originator or generator of the data.

- The availability/access of technical data lies with the author, originator, or generator of the data in conjunction with the manager of the technical data management system.

- The established availability/access description and list should be baselined and placed under configuration control.

- For new programs/projects, a digital generation and delivery medium is desired. Existing programs/projects should weigh the cost/benefit trades of digitizing hard copy data.

Data Collection Checklist

- Have the frequency of collection and the points in the technical and technical management processes when data inputs will be available been determined?
- Has the timeline that is required to move data from the point of origin to storage repositories or stakeholders been established?
- Who is responsible for the input of the data?
- Who is responsible for data storage, retrieval, and security?
- Have necessary supporting tools been developed or acquired?

Tables 10.1-1a and 10.1-1b define the tasks required to capture technical data.

10.1.4 Provide Data tot Authorized Parties

All data deliverables should include distribution statements and procedures to protect all data that contain critical technology information, as well as to ensure that limited distribution data, intellectual property data, or proprietary data are properly handled during systems engineering activities. This injunction applies whether the data are hard copy or digital.

Table 10.1-1a Technical Data Tasks

Description	Tasks	Expected Outcomes
Technical data capture	Collect and store inputs and technical effort outcomes from the technical and technical management processes, including: results from technical assessments; descriptions of methods, tools, and metrics used; recommendations, decisions, assumptions, and impacts of technical efforts and decisions; lessons learned; deviations from plan; anomalies and out-of-tolerances relative to requirements; and other data for tracking requirements Perform data integrity checks on collected data to ensure compliance with content and format as well as technical data checks to ensure there are no errors in specifying or recording the data. Report integrity check anomalies or variances to the authors or generators of the data for correction. Prioritize, review, and update data collection and storage procedures as part of regularly scheduled maintenance.	Sharable data needed to perform and control the technical and technical management processes is collected and stored. Stored data inventory.
Technical data maintenance	Implement technical management roles and responsibilities with technical data products received. Manage database(s) to ensure that collected data have proper quality and integrity; and are properly retained, secure, and available to those with access authority. Periodically review technical data management activities to ensure consistency and identify anomalies and variances. Review stored data to ensure completeness, integrity, validity, availability, accuracy, currency, and traceability. Perform technical data maintenance, as required. Identify and document significant issues, their impacts, and changes made to technical data to correct issues and mitigate impacts. Maintain, control, and prevent the stored data from being used inappropriately. Store data in a manner that enables easy and speedy retrieval. Maintain stored data in a manner that protects the technical data against foreseeable hazards, e.g., fire, flood, earthquake, etc.	Records of technical data maintenance. Technical effort data, including captured work products, contractor-delivered documents, and acquirer-provided documents are controlled and maintained. Status of data stored is maintained to include: version description, timeline, and security classification.

Table 10.1-1b Technical Data Tasks (cont'd)

Description	Tasks	Expected Outcomes
Technical data/ information distribution	Maintain an information library or reference index to provide technical data availability and access instructions. Receive and evaluate requests to determine data requirements and delivery instructions. Process special requests for technical effort data or information according to established procedures for handling such requests. Ensure that required and requested data are appropriately distributed to satisfy the needs of the acquirer and requesters in accordance with the agreement, program/project directives, and technical data management plans and procedures. Ensure that electronic access rules are followed before database access is allowed or any requested data are electronically released / transferred to the requester. Provide proof of correctness, reliability, and security of technical data provided to internal and external recipients.	Access information (e.g., available data, access means, security procedures, time period for availability, and personnel cleared for access) is readily available. Technical data are provided to authorize requesters in the appropriate format, with the appropriate content, and by a secure mode of delivery, as applicable.
Data management system maintenance	Implement safeguards to ensure protection of the technical database and of *en route* technical data from unauthorized access or intrusion. Establish proof of coherence of the overall technical dataset to facilitate effective and efficient use. Maintain, as applicable, backups of each technical database. Evaluate the technical data management system to identify collection and storage performance issues and problems; satisfaction of data users; risks associated with delayed or corrupted data, unauthorized access, or survivability of information from hazards such as fire, flood, earthquake, etc. Review systematically the technical data management system, including the database capacity, to determine its appropriateness for successive phases of the Defense Acquisition Framework. Recommend improvements for discovered risks and problems: Handle risks identified as part of technical risk management. Control recommended changes through established program / project change management activities.	Current technical data management system. Technical data are appropriately and regularly backed up to prevent data loss.

10.1.5 Outputs

Outputs include timely, secure availability of needed data in various representations to those authorized to receive it. Major outputs from the Technical Data Management Process include the following:

- **Form of Technical Data Products:** How each type of data is held and stored such as textual, graphic, video, etc.

- **Technical Data Electronic Exchange Formats:** Description and perhaps templates, models or other ways to capture the formats used for the various data exchanges.

- **Delivered Technical Data:** The data that were delivered to the requester. Other work products generated as part of this process include the strategy and procedures used for technical data management, request dispositions, decisions, and assumptions.

10.2 Technical Data Management Guidance

Refer to Section 6.6.2 in the NASA Expanded Guidance for Systems Engineering at Expanded Guidance for NASA SE NASA/SP-2016-6105-SUPPL for additional guidance on:

- data security and
- ITAR.

11.0 Technical Assessment

Technical assessment is the crosscutting process used to help monitor technical progress of a program/project through periodic technical reviews and through monitoring of technical indicators such as MOEs, MOPs, Key Performance Parameters (KPPs), and TPMs. The reviews and metrics also provide status information to support assessing system design, product realization, and technical management decisions.

11.1 Process Description

The activities of the Technical Assessment Process are described below.

11.1.1 Inputs

The inputs for this process are:

- **Technical Plans:** These are the planning documents that will outline the technical reviews/ assessment process as well as identify the technical product/process measures that will be tracked and assessed to determine technical progress. Examples of these plans are the program (or project) plan, SEMP (if applicable), review plans (which may be part of the program or project plan), ILS plan, and EVM plan (if applicable). These plans contain the information and descriptions of the program/project's alignment with and contribution to Agency strategic goals, its management approach, its technical approach, its integrated cost and schedule, its budget, resource allocations, and its risk management approach.

- **Technical Process and Product Measures:** These are the identified technical measures that will be assessed or tracked to determine technical progress. These measures are also referred to as MOEs, MOPs, KPPs, and TPMs. They provide indications of the program/project's performance in key management, technical, cost (budget), schedule, and risk areas.

- **Reporting Requirements:** These are the requirements on the methodology in which the status of the technical measures will be reported with regard to management, technical cost (budget), schedule, and risk. The requirements apply internally to the program/project and are used externally by the Centers and Mission Directorates to assess the performance of the program or project. The methodology and tools used for reporting the status will be established on a project-by-project basis.

11.1.2 Process Activities

The process activities of the Technical Assessment Process are described below:

- **Prepare Strategy for Conducting Technical Assessments:**

- **Assess Technical Work Productivity and Product Quality and Conduct Progress Reviews:**

- **Capture Work Products:**

11.1.3 Outputs

Typical outputs of the Technical Assessment Process include the following:

- **Assessment Results, Findings, and Recommendations:** This is the collective data on the established measures from which trends can be determined and variances from expected results can be understood. Results then feed into the Decision Analysis Process where corrective action may be necessary.

- **Technical Review Reports/Minutes:** This is the collective information coming out of each review that captures the results, recommendations, and actions with regard to meeting the review's success criteria.

- **Other Work Products:** These would include strategies and procedures for technical assessment, key decisions and associated rationale, assumptions, and lessons learned.

11.2 Technical Assessment Guidance

Refer to Section 6.7.2 in the NASA Expanded Guidance for Systems Engineering at [Expanded Guidance for NASA SE NASA/SP-2016-6105-SUPPL] for additional guidance on:

- the basis of technical reviews,
- audits,
- Key Decision Points,
- other reviews,
- status reporting and assessment.

12.0 THE PSAT1U CUBESAT

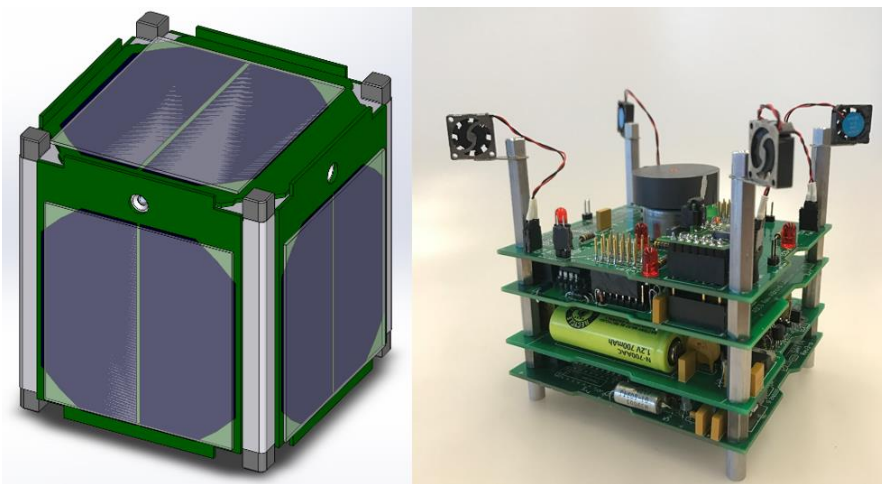
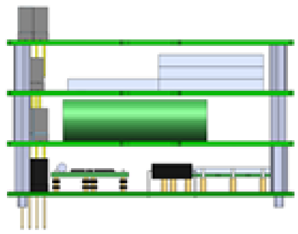


Figure 12.0-1 The PSAT1U CubeSat

The mission of the PSAT1U project is to develop a 1U CubeSat educational satellite to expand on the launch opportunities and mission capabilities of previous student-built 1.5U satellites. The design, depicted in Figure 12.0-1, reduces total cost through innovative engineering solutions without sacrificing overall performance and capabilities. PSAT1U provides an engineering model for future students to use as well as a standard design to be replicated by other academic institutions and their various payloads. The PSAT1U Baseline Model is an MBSE representation of the satellite and is depicted in Appendix J.

PSAT1U's satellite design specifications are in Figure 12.0-2. As seen in the figure, the satellite is designed for a maximum mass of 1500 g within the 1U frame. The specific dimensions of the structure itself, as well as the satellite's board organization, are shown in Figure 12.0-3. PSAT1U retains the capability to host a variety of payloads on its top payload board. The Electrical Power System (EPS) and physical layout of the satellite are designed with the goal of remaining flexible and providing all necessary power to whatever payload might be placed on board for flight.



Satellite Specifications	
Mass	Max: 1500 g
Size	1.0 U
Power Generation	2.85 W in Sunlight
ADCS	Magnetotorquers
Comms VHF (data)	145.825 MHz (Uplink & Downlink)

Figure 12.0-2 PSAT1U Satellite Design Specifications

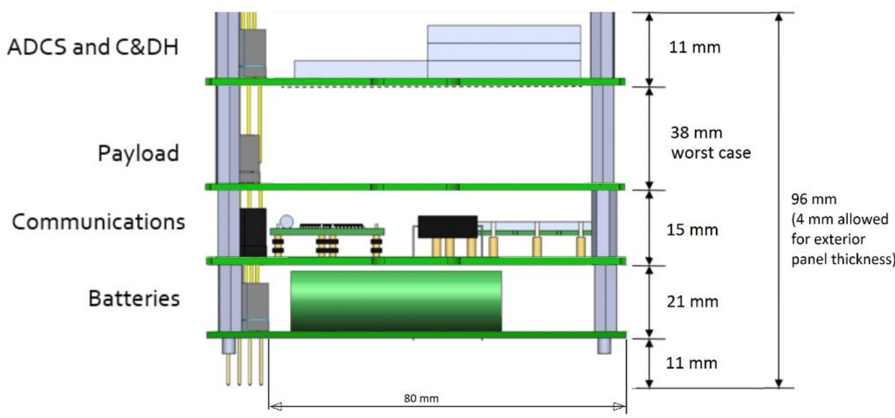


Figure 12.0-3 PSAT1U Board Organization Dimensions

12.1 Electrical Power System

Utilizing a 1U footprint, the PSAT1U spacecraft must make efficient use of its small volume without sacrificing overall performance and capabilities. The largest impact in using this small footprint when compared to larger CubeSat Class satellites is a reduction in the potential solar panel collection area. In order to address this challenge, the Electrical Power System (EPS) design is based on only two Sol Aero ZTJ solar cells per side, as shown in Figure 12.1-1 below.

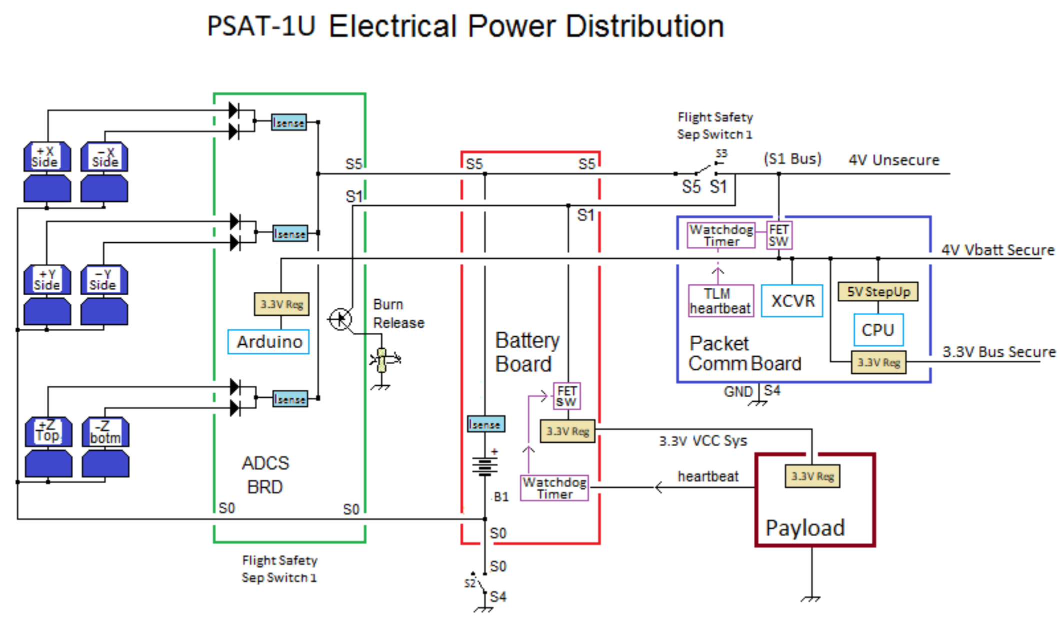


Figure 12.1-1 PSAT1U Electrical Power System Design Diagram

PSAT1U utilized ZTJ solar cells, rather than the very expensive UTJ solar cells used in other CubeSats built at the United States Naval Academy. While the UTJ cells offer predictable performance due to their high cost and quality control, the ZTJ cells offer similar performance at one-tenth of the cost. The ZTJ cells are factory-seconds that do not include cover glass. Instead, the design calls for the thicker microscope coverglass at 1% of the cost and the added mass is insignificant.

NiCd batteries have over 50 years of space heritage and survivability and offer the best lifetime survivability and reliability compared to Lithium-ion batteries. Lithiums offer more power in a smaller battery cell, but are much less forgiving of abuse and require complex battery management systems per cell to prevent hazards and failures. Single errors in charging or discharge can destroy the cell permanently. On the other hand, NiCd's can survive occasional overcharge and complete discharge without damage. NiCd batteries are also traditionally used in USNA CubeSats due to their reliability and low cost. PSAT1U's battery board design is shown in Figure 12.1-2.

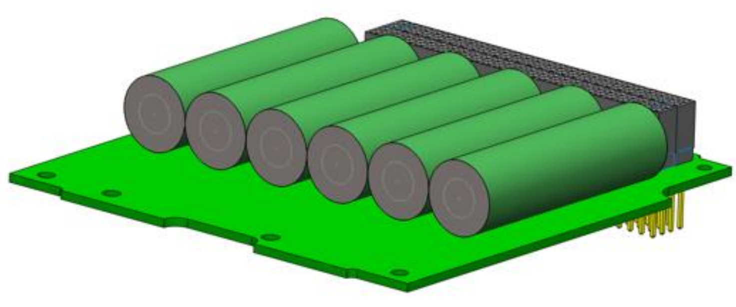


Figure 12.1-2 PSAT1U Battery Board Design

Radiation-induced upsets and glitches can cause errors in spacecraft processors. In order to combat this, PSAT1U has two secure power circuits and watchdog timers. One is on the communications board that will reset the communicationss Central Processing Unit (CPU) and cycle power in the event of any lockup that stops its routine as shown in Figure 12.1-3.

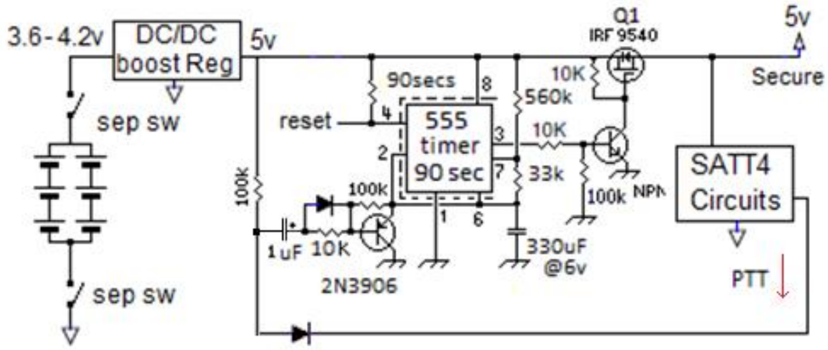


Figure 12.1-3 Watchdog Timer Circuit Diagram

The main power bus for critical optional payload boards is the 5V secure line. It is made secure by the second watchdog timer on the battery board that can cycle power off and back on if there is a payload processor failure. A processor failure is assured if the optional payload CPU fails to toggle the heartbeat periodically. This secure payload bus supplies critical voltage to the other boards and is independent from the power to the communcations board, named the SATT4.

Additionally, a 4V unsecure bus will also stem from the battery board to deliver unregulated and unsecure power to the ADCS board and communications board circuits that only need raw power or that do not need the reset possibility.

The overall power budget for PSAT1U is displayd in Figure 12.1-4.

Load	Voltage	Ipk	Duty Cycle	Normal (mA)	StdBy (mA)	ALL ON (mA)
SATT4 RX (StdBy)	5	60	90%	54	54	OFF
SATT4 RX	3.3	120	10%	12	OFF	120
SATT4 TX Tlm	4	750	2%	15	15	750
SATT4 TX users	4	750	4%	30	OFF	OFF
Arduino CPU On	3.3	5	10%	1	OFF	5
Arduino CPU Sleep	3.3	2	90%	2	2	OFF
Payload StdBy	3.3	-	-	-	-	-
Payload OP	3.3	-	-	-	-	-
Totals				113	71	946

Solar Current per Panel =	503.085	mA
Average Current from geometry =	712.55	mA
Current Margin StdBy)* =	432.085	mA
Current Margin (Normal)* =	390.085	mA
*Margin Calculated Assuming Single Panel Power Production (minimum)		

Time (min)
Eclipse: 30
Daylight: 60

Avg Capacity Produced Per Orbit =	599.55	mAh
Avg Capacity Consumed Per Orbit	56.5	mAh
Capacity Margin	543.05	mAh

Figure 12.1-4 PSAT1U Power Budget

12.2 Attitude Determination Control System (ADCS)

The ADCS depends on sun vector inputs from all solar panels and the ADCS CPU is also used to read solar panel current from each panel. Therefore, the ADCS board serves as the central connection point for the solar side panel connectors which contain all of these signals and power. To facilitate these requirements, the ADCS board was placed at the top of the stack so that the connections to all of the side panels can be made last during assembly. Serving as the connection point between the ZTJ solar cells and the battery board, the ADCS board sums the current from all the solar panels to power the rest of the EPS system.

Figure 12.2-1 shows the side panel for PSAT1U and highlights the embedded torquer coils. The coils are present on both sides of the panel, and each face of the satellite is populated with a panel. Each torquer coil is designed to provide a maximum of 1.43×10^{-7} Nm of torque. With four coils in total, the maximum torque available for the spacecraft is 5.74×10^{-7} Nm. All attitude control will be performed by these coils.

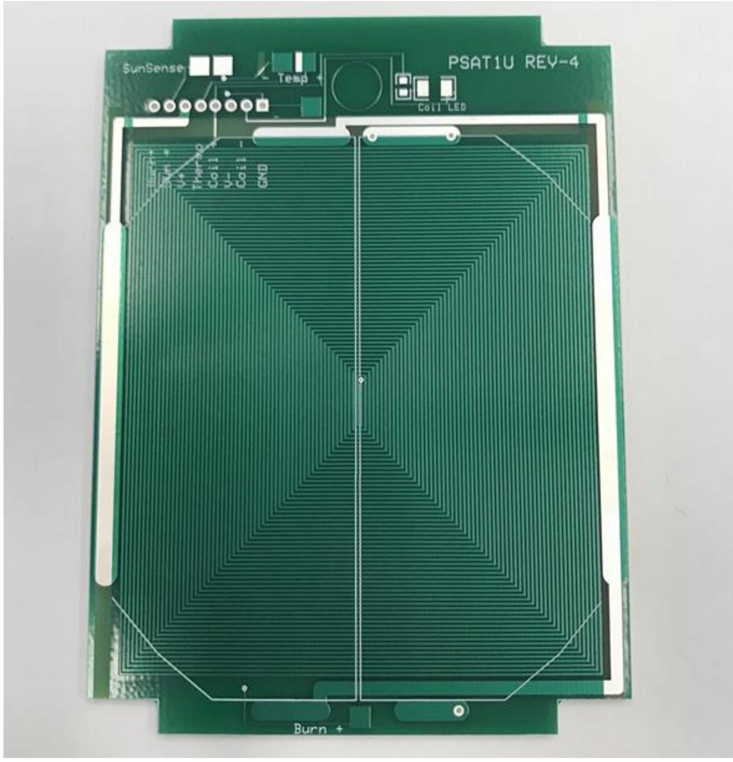


Figure 12.2-1 PSAT1U Side Panel with Torquer Coils

Magnetometers and sun sensors fulfill all attitude determination roles on PSAT1U. These standard components are the same ones used on previous USNA CubeSats. The ADCS board is shown below in Figure 12.2-2.

Figure 12.2-2 ADCS Board Model

12.3 Communications System

PSAT1U has a communications board with a 1.5-Watt Automatic Packet Reporting System (APRS) transceiver capable of operating in the 2-meter amateur radio band. The board can be programmed with two separate operating configurations with the goal of enabling or disabling user digipeating (packet relay) and switching the uplink receiver to a separate frequency if needed for a payload experiment. The communications board, named the SATT4, is displayed in Figure 12.3-1.

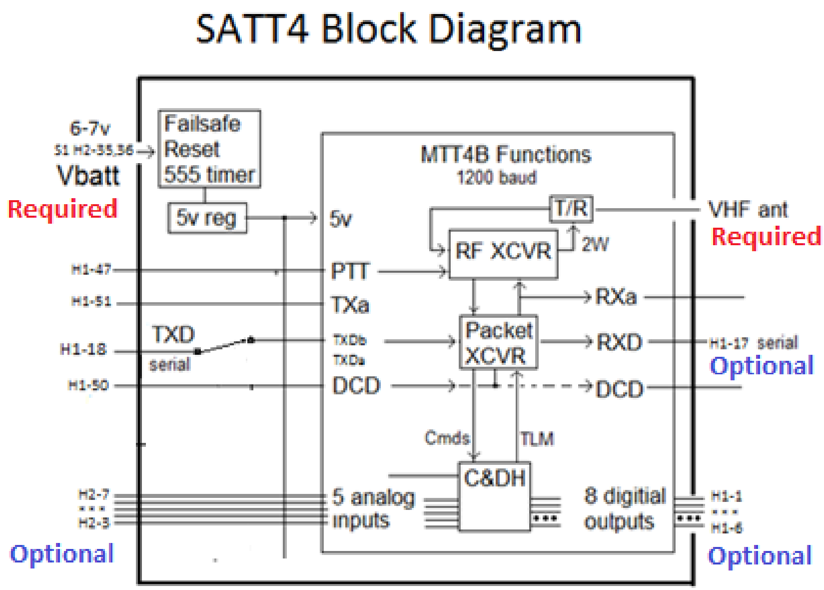


Figure 12.3-1 Communications Board Block Diagram

Operating with the SATT4 communications board, uplink and downlink will occur at a frequency of 145.825 MHz. A VHF wire antenna was designed to facilitate communication at this frequency and achieve a Standing Wave Ratio (SWR) as close to ideal as possible. The antenna design is 724.5 mm in length. An EZNEC software model for PSAT1U's antenna design is shown in Figure 12.3-2.

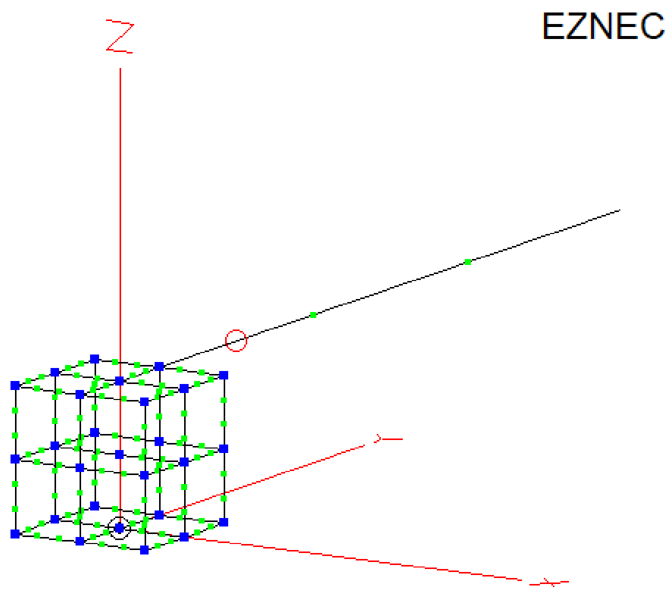


Figure 12.3-2. PSAT1U Antenna Design

The downlink and uplink link budgets for PSAT1U are included below in Tables 12.3-1 and 12.3-2.

Table 12.3-1 PSAT1U Link Budget Downlink

PSAT1U VHF Downlink

Overhead Scenario (30° El)		Horizon Scenario (10° El)	
Frequency (MHz)	145.825	Frequency (MHz)	145.825
Altitude (km)	600.00	Altitude (km)	600.00
Elevation (deg)	30.00	Elevation (deg)	10.00
Range (km)	1075.19	Range (km)	1932.24
Space Loss (dB)	-136.35	Space Loss (dB)	-141.44
$Power_{Transmitter\ of\ Satellite}$ (dBW)	1.76	$Power_{Transmitter\ of\ Satellite}$ (dBW)	1.76
$Gain_{Transmitter\ Antenna}$ (omni) (dB)	0.00	$Gain_{Transmitter\ Antenna}$ (omni) (dB)	0.00
$Gain_{Receiver\ Antenna}$ (dB) (Mobile Users)	5.00	$Gain_{Receiver\ Antenna}$ (dB) (Mobile Users)	5.00
Incidental Losses (dB)	3.00	Incidental Losses (dB)	3.00
P_r (dBW)	-132.59	P_r (dBW)	-137.68
P_r (dBm)	-102.59	P_r (dBm)	-107.68
Rx Threshold USNA & Users (dBm)	-116.00	Rx Threshold USNA & Users (dBm)	-116.00
Margin for User (dBm)	**13.41**	Margin for User (dBm)	**8.32**
Rx Command Link Antenna Gain (dBi)	15.00	Rx Command Link Antenna Gain (dBi)	15.00
Margin Command Link (dBm)	**28.41**	Margin Command Link (dBm)	**23.32**

Table 12.3-2 PSAT1U Link Budget Uplink

PSAT1U VHF Uplink

Overhead Scenario (30° El)		Horizon Scenario (10° El)	
Frequency (MHz)	145.825	Frequency (MHz)	145.825
Altitude (km)	600.00	Altitude (km)	600.00
Elevation (deg)	30.00	Elevation (deg)	10.00
Range (km)	1075.19	Range (km)	1932.24
Space Loss (dB)	-136.35	Space Loss (dB)	-141.44
$Power_{Transmitter\ of\ User}$ (dBW)	7.00	$Power_{Transmitter\ of\ User}$ (dBW)	7.00
$Gain_{Transmitter\ Antenna}$ (dB) (Mobile Users)	5.00	$Gain_{Transmitter\ Antenna}$ (dB) (Mobile Users)	5.00
$Gain_{Receiver\ Antenna}$ (dB)	0.00	$Gain_{Receiver\ Antenna}$ (dB)	0.00
Incidental Losses (dB)	3.00	Incidental Losses (dB)	3.00
P_r (dBW)	-127.35	P_r (dBW)	-132.44
P_r (dBm)	-97.35	P_r (dBm)	-102.44
Rx Threshold Satellite (dBm)	-110.00	Rx Threshold Satellite (dBm)	-110.00
Margin Users (dBm)	**12.65**	Margin Users (dBm)	**7.56**
Rx Command Link Antenna Gain (dBi)	15.00	Rx Command Link Antenna Gain (dBi)	15.00
Margin Command Link (dBm)	**22.65**	Margin Command Link (dBm)	**17.56**

As seen in the budgets, the link margins are favorable in both the downlink and uplink scenarios. In the horizon scenarios for VHF downlink and uplink, users are predicted to experience 8.32 dB and 7.56 dB margins respectively.

12.4 Payload

PSAT1U possesses the ability to host a variety of different payloads, depending on the mission objective. In this way, the CubeSat was specifically designed to be a modular architecture with well understood interfaces to allow practitioners to concentrate on payload design for their particular application. The payload board resides at the top of PSAT 1U's structure, as displayed in Figure 12.0-3.

PSAT1U is able to host payloads within certain physical and electrical specifications. Payloads must have a mass less than 567 g. Any payload must have a volume no greater than 247 cm^3. Specifically, payloads are allowed a maximum height of 4.0 cm, maximum width of 8.0 cm, and maximum depth of 7.7 cm. Payloads should operate within the available on-orbit average power of 1.92 W, operating at a voltage of 5V during daylight.

Appendix A: Integration Plan Outline

1 Purpose

The integration plan defines the integration and verification strategies for a project interface with the system design and decomposition into the lower-level elements.[3] The integration plan is structured to bring the elements together to assemble each subsystem and to bring all of the subsystems together to assemble the system/product. The primary purposes of the integration plan are: (1) to describe this coordinated integration effort that supports the implementation strategy, (2) to describe for the participants what needs to be done in each integration step, and (3) to identify the required resources and when and where they will be needed.

2 Questions/Checklist

- Does the integration plan include and cover integration of all of the components and subsystems of the project, either developed or purchased?
- Does the integration plan account for all external systems to be integrated with the system (for example, communications networks, field equipment, other complete systems owned by the government or owned by other government agencies)?
- Does the integration plan fully support the implementation strategy, for example, when and where the subsystems and system are to be used?
- Does the integration plan mesh with the verification plan?
- For each integration step, does the integration plan define what components and subsystems are to be integrated?
- For each integration step, does the integration plan identify all the needed participants and define what their roles and responsibilities are?
- Does the integration plan establish the sequence and schedule for every integration step?
- Does the integration plan spell out how integration problems are to be documented and resolved?

3 Integration Plan Contents

Title Page

The title page should follow the NASA procedures or style guide. At a minimum, it should contain the following information:

- INTEGRATION PLAN FOR THE [*insert name of project]* AND [*insert name of organization]*

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[3] The material in this appendix is adapted from Federal Highway Administration and CalTrans, *Systems Engineering Guidebook for ITS, Version 2.0.*

- *Contract number*
- *Date that the document was formally approved*
- *The organization responsible for preparing the document*
- *Internal document control number, if available*
- *Revision version and date issued*

1.0 Purpose of Document

This section gives a brief statement of the purpose of this document. It is the plan for integrating the components and subsystems of the project prior to verification.

2.0 Scope of Project

This section gives a brief description of the planned project and the purpose of the system to be built. Special emphasis is placed on the project's deployment complexities and challenges.

3.0 Integration Strategy

This section tells the reader what the high-level plan for integration is and, most importantly, why the integration plan is structured the way it is. The integration plan is subject to several, sometimes conflicting, constraints. Also, it is one part of the larger process of build, integrate, verify, and deploy, all of which should be synchronized to support the same project strategy. So, for even a moderately complex project, the integration strategy, which is based on a clear and concise statement of the project's goals and objectives, is described here at a high but all-inclusive level. It may also be necessary to describe the analysis of alternative strategies to make it clear why this particular strategy was selected.

The same strategy is the basis for the build plan, the verification plan, and the deployment plan. This section covers and describes each step in the integration process. It describes what components are integrated at each step and gives a general idea of what threads of the operational capabilities (requirements) are covered. It ties the plan to the previously identified goals and objectives so the stakeholders can understand the rationale for each integration step. This summary-level description also defines the schedule for all the integration efforts.

4.0 Phase 1 Integration

This and the following sections define and explain each step in the integration process. The intent here is to identify all the needed participants and to describe to them what they have to do. In general, the description of each integration step should identify the following:

- *The location of the activities.*
- *The project-developed equipment and software products to be integrated. Initially this is just a high-level list, but eventually the list should be exact and complete, showing part numbers and quantity.*
- *Any support equipment (special software, test hardware, software stubs, and drivers to simulate yet-to-be-integrated software components, external systems) needed for this integration step. The same support equipment is most likely needed for the subsequent verification step.*

- *All integration activities that need to be performed after installation, including integration with onsite systems and external systems at other sites.*
- *A description of the verification activities, as defined in the applicable verification plan, that occur after this integration step.*
- *The responsible parties for each activity in the integration step.*
- *The schedule for each activity.*

5.0 Multiple Phase Integration Steps (1 or N steps)

This and any needed additional sections follow the format for Section 3.0. Each covers each step in a multiple-step integration effort.

Appendix B: Creating the Validation Plan with a Validation Requirements Matrix

Note: See appendix I for an outline of the Verification and Validation Plan. The matrix shown here (Table E-1) is appendix D in that outline.

When developing requirements, it is important to identify a validation approach for how additional validation evaluation, testing, analysis, or other demonstrations will be performed to ensure customer/sponsor satisfaction.

There are a number of sources to draw from for creating the validation plan:

- ConOps
- Stakeholder/customer needs, goals, and objectives documentation
- Rationale statements for requirements and in verification requirements
- Lessons learned database
- System architecture modeling
- Test-as-you-fly design goals and constraints
- SEMP, HSIP, V&V plans

Validation products can take the form of a wide range of deliverables, including:

- Stakeholder evaluation and feedback
- Peer reviews
- Physical models of all fidelities
- Simulations
- Virtual modeling
- Tests
- Fit-checks
- Procedure dry-runs
- Integration activities (to inform on-orbit maintenance procedures)
- Phase-level review solicitation and feedback

Particular attention should be paid to the planning for life cycle phase since early validation can have a profound impact on the design and cost in the later life-cycle phases.

Table E-1 shows an example validation matrix.

Table E-1 Validation Requirements Matrix

Validation Product #	Activity	Objective	Validation Method	Facility or Lab	Phase	Performing Organization	Results
Unique identifier for validation product	*Describe evaluation by the customer/ sponsor that will be performed*	*What is to be accomplished by the customer/ sponsor evaluation*	*Validation method for the requirement (analysis, inspection, demonstration, or test)*	*Facility or laboratory used to perform the validation*	*Phase in which the verification/ validation will be performed*[a]	*Organization responsible for coordinating the validation activity*	*Indicate the objective evidence that validation activity occurred*
1	Customer/ sponsor will evaluate the candidate displays	1. Ensure legibility is acceptable 2. Ensure overall appearance is acceptable	Test	xxx	Phase A	xxx	TPS 123456

a. Example: (1) during product selection process, (2) prior to final product selection (if COTS) or prior to PDR, (3) prior to CDR, (4) during box-level functional, (5) during system-level functional, (6) during end-to-end functional, (7) during integrated vehicle functional, (8) during on-orbit functional.

Appendix C: SEMP Content Outline

J.1 SEMP Content

The Systems Engineering Management Plan (SEMP) is the foundation document for the technical and engineering activities conducted during the project. The SEMP conveys information to all of the personnel on the technical integration methodologies and activities for the project within the scope of the project plan. SEMP content can exist as a stand-alone document or, for smaller projects, in higher-level project documentation.

The SEMP provides the specifics of the technical effort and describes what technical processes will be used, how the processes will be applied using appropriate activities, how the project will be organized to accomplish the activities, and the resources required for accomplishing the activities. The SEMP provides the framework for realizing the appropriate work products that meet the entry and success criteria of the applicable project life-cycle phases to provide management with necessary information for assessing technical progress.

Because the SEMP provides the specific technical and management information to understand the technical integration and interfaces, its documentation and approval serve as an agreement within the project of how the technical work will be conducted. The SEMP communicates to the team itself, managers, customers, and other stakeholders the technical effort that will be performed by the assigned technical team.

The technical team, working under the overall program/project plan, develops and updates the SEMP as necessary. The technical team works with the project manager to review the content and obtain concurrence. The SEMP includes the following three general sections:

1. Technical program planning and control, which describe the processes for planning and control of the engineering efforts for the design, development, test, and evaluation of the system.
2. Systems engineering processes, which include specific tailoring of the systems engineering process as described in the NPR, implementation procedures, trade study methodologies, tools, and models to be used.
3. Engineering specialty integration describes the integration of the technical disciplines' efforts into the systems engineering process and summarizes each technical discipline effort and cross references each of the specific and relevant plans.

The SEMP outline in this appendix is guidance to be used in preparing a stand-alone project SEMP. The level of detail in the project SEMP should be adapted based on the size of the project. For a small project, the material in the SEMP can be placed in the project plan's technical summary, and this annotated outline should be used as a topic guide.

Some additional important points on the SEMP:

- The SEMP is a living document. The initial SEMP is used to establish the technical content of the engineering work early in the Formulation Phase for each project and updated as needed throughout the project life cycle. Table J-1 provides some high level guidance on the scope of SEMP content based on the life-cycle phase.

- Project requirements that have been tailored or significant customization of SE processes should be described in the SEMP.
- For multi-level projects, the SEMP should be consistent with higher-level SEMPs and the project plan.
- For a technical effort that is contracted, the SEMP should include details on developing requirements for source selection, monitoring performance, and transferring and integrating externally produced products to NASA.

J.2 Terms Used

Terms used in the SEMP should have the same meaning as the terms used in the NPR 7123.1, Systems Engineering Processes and Requirements.

J.3 Annotated Outline

Title Page

Systems Engineering Management Plan

(Provide a title for the candidate program/project and designate a short title or proposed acronym in parenthesis, if appropriate.)

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______________________________	__________
Designated Governing Authority/Technical Authority	Date
______________________________	__________
Program/Project Manager	Date
______________________________	__________
Chief Engineer	Date
______________________________	__________
	Date
______________________________	__________
	Date

By signing this document, signatories are certifying that the content herein is acceptable as direction for engineering and technical management of this program/project and that they will ensure its implementation by those over whom they have authority.

1.0 Purpose and Scope

This section provides a brief description of the purpose, scope, and content of the SEMP.

- *Purpose: This section should highlight the intent of the SEMP to provide the basis for implementing and communicating the technical effort.*
- *Scope: The scope describes the work that encompasses the SE technical effort required to generate the work products. The plan is used by the technical team to provide personnel the information necessary to successfully accomplish the required task.*
- *Content: This section should briefly describe the organization of the document.*

2.0 Applicable Documents

This section of the SEMP lists the documents applicable to this specific project and its SEMP implementation. This section should list major standards and procedures that this technical effort for this specific project needs to follow. Examples of specific procedures to list could include procedures for hazardous material handling, crew training plans for control room operations, special instrumentation techniques, special interface documentation for vehicles, and maintenance procedures specific to the project.

3.0 Technical Summary

This section contains an executive summary describing the problem to be solved by this technical effort and the purpose, context, and products to be developed and integrated with other interfacing systems identified.

Key Questions
1. What is the problem we're trying to solve?
2. What are the influencing factors?
3. What are the critical questions?
4. What are the overall project constraints in terms of cost, schedule, and technical performance
5. How will we know when we have adequately defined the problem?
6. Who are the customers?
7. Who are the users?
8. What are the customer and user priorities?
9. What is the relationship to other projects?

3.1 System Description

This section contains a definition of the purpose of the system being developed and a brief description of the purpose of the products of the product layer of the system structure to which this SEMP applies. Each product layer includes the system end products and their subsystems and the supporting or enabling products and any other work products (plans, baselines) required for the development of the system. The description should include any interfacing systems and system products, including humans with which the system products will interact physically, cognitively, functionally, or electronically.

3.2 System Structure

This section contains an explanation of how the technical portion of the product layer (including enabling products, technical cost, and technical schedule) will be developed, how *the resulting product layers will be integrated into the project portion of the WBS, and how the overall system structure will be developed. This section contains a description of the relationship of the specification tree and the drawing tree with the products of the system structure and how the relationship and interfaces of the system end products and their life cycle-enabling products will be managed throughout the planned technical effort.*

3.3 Product Integration

This section contains an explanation of how the products will be integrated and describes clear organizational responsibilities and interdependencies and whether the organizations are geographically dispersed or managed across Centers. This section should also address how products created under a diverse set of contracts are to be integrated, including roles and responsibilities. This includes identifying organizations—intra-and inter-NASA, other Government agencies, contractors, or other partners—and delineating their roles and responsibilities. Product integration includes the integration of analytical products.

When components or elements will be available for integration needs to be clearly understood and identified on the schedule to establish critical schedule issues.

3.4 Planning Context

This section contains the programmatic constraints (e.g., NPR 7120.5) that affect the planning and implementation of the common technical processes to be applied in performing the technical effort. The constraints provide a linkage of the technical effort with the applicable product life-cycle phases covered by the SEMP including, as applicable, milestone decision gates, major technical reviews, key intermediate events leading to project completion, life-cycle phase, event entry and success criteria, and major baseline and other work products to be delivered to the sponsor or customer of the technical effort.

3.5 Boundary of Technical Effort

This section contains a description of the boundary of the general problem to be solved by the technical effort, including technical and project constraints that affect the planning. Specifically, it identifies what can be controlled by the technical team (inside the boundary) and what influences the technical effort and is influenced by the technical effort but not controlled by the technical team (outside the boundary). Specific attention should be given to physical, cognitive, functional, and electronic interfaces across the boundary.

A description of the boundary of the system can include the following:

- *Definition of internal and external elements/items involved in realizing the system purpose as well as the system boundaries in terms of space, time, physical, and operational.*
- *Identification of what initiates the transitions of the system to operational status and what initiates its disposal is important. General and functional descriptions of the subsystems inside the boundary.*
- *Current and established subsystem performance characteristics.*
- *Interfaces and interface characteristics.*
- *Functional interface descriptions and functional flow diagrams.*
- *Key performance interface characteristics.*
- *Current integration strategies and architecture.*

- *Documented Human System Integration Plan (HSIP)*

3.6 Cross References

This section contains cross references to appropriate nontechnical plans and critical reference material that interface with the technical effort. It contains a summary description of how the technical activities covered in other plans are accomplished as fully integrated parts of the technical effort.

4.0 Technical Effort Integration

This section describes how the various inputs to the technical effort will be integrated into a coordinated effort that meets cost, schedule, and performance objectives.

The section should describe the integration and coordination of the specialty engineering disciplines into the systems engineering process during each iteration of the processes. Where there is potential for overlap of specialty efforts, the SEMP should define the relative responsibilities and authorities of each specialty. This section should contain, as needed, the project's approach to the following:

- *Concurrent engineering*
- *The activity phasing of specialty engineering*
- *The participation of specialty disciplines*
- *The involvement of specialty disciplines,*
- *The role and responsibility of specialty disciplines,*
- *The participation of specialty disciplines in system decomposition and definition*
- *The role of specialty disciplines in verification and validation*
- *Reliability*
- *Maintainability*
- *Quality assurance*
- *Integrated logistics*
- *Human engineering*
- *Safety*
- *Producibility*
- *Survivability/vulnerability*
- *National Environmental Policy Act (NEPA) compliance*
- *Launch approval/flight readiness*

The approach for coordination of diverse technical disciplines and integration of the development tasks should be described. For example, this can include the use of multidiscipline integrated teaming approaches—e.g., an HSI team—or specialized control boards. The scope and timing of the specialty engineering tasks should be described along with how specialty engineering disciplines are represented on all technical teams and during all life-cycle phases of the project.

4.1 Responsibility and Authority

This section describes the organizing structure for the technical teams assigned to this technical effort and includes how the teams will be staffed and managed.

Key Questions
1. What organization/panel will serve as the designated governing authority for this project?
2. How will multidisciplinary teamwork be achieved?
3. What are the roles, responsibilities, and authorities required to perform the activities of each planned common technical process?
4. What should be the planned technical staffing by discipline and expertise level?
5. What is required for technical staff training?
6. How will the assignment of roles, responsibilities, and authorities to appropriate project stakeholders or technical teams be accomplished?
7. How are we going to structure the project to enable this problem to be solved on schedule and within cost?
8. What does systems engineering management bring to the table?

The section should provide an organization chart and denote who on the team is responsible for each activity. It should indicate the lines of authority and responsibility. It should define the resolution authority to make decisions/decision process. It should show how the engineers/engineering disciplines relate.

The systems engineering roles and responsibilities need to be addressed for the following: project office, user, Contracting Officer's Representative (COR), systems engineering, design engineering, specialty engineering, and contractor.

4.2 Contractor Integration

This section describes how the technical effort of in-house and external contractors is to be integrated with the NASA technical team efforts. The established technical agreements should be described along with how contractor progress will be monitored against the agreement, how technical work or product requirement change requests will be handled, and how deliverables will be accepted. The section specifically addresses how interfaces between the NASA technical team and the contractor will be implemented for each of the 17 common technical processes. For example, it addresses how the NASA technical team will be involved with reviewing or controlling contractor-generated design solution definition documentation or how the technical team will be involved with product verification and product validation activities.

Key deliverables for the contractor to complete their systems and those required of the contractor for other project participants need to be identified and established on the schedule.

4.3 Analytical Tools that Support Integration

This section describes the methods (such as integrated computer-aided tool sets, integrated work product databases, and technical management information systems) that will be used to support technical effort integration.

5.0 Common Technical Processes Implementation

Each of the 17 common technical processes will have a separate subsection that contains a plan for performing the required process activities as appropriately tailored. (See NPR 7123.1 for the process activities required and tailoring.) Implementation of the 17 common technical processes *includes (1) the generation of the outcomes needed to satisfy the entry and success criteria of the applicable product life-cycle phase or phases identified in D.4.4.4, and (2) the necessary inputs for other technical processes. These sections contain a description of the approach, methods, and tools for:*

- *Identifying and obtaining adequate human and nonhuman resources for performing the planned process, developing the work products, and providing the services of the process.*
- *Assigning responsibility and authority for performing the planned process (e.g., RACI matrix, [http://en.wikipedia.org/wiki/Responsibility_assignment_matrix]), developing the work products, and providing the services of the process.*
- *Training the technical staff performing or supporting the process, where training is identified as needed.*
- *Designating and placing designated work products of the process under appropriate levels of configuration management.*
- *Identifying and involving stakeholders of the process.*
- *Monitoring and controlling the systems engineering processes.*
- *Identifying, defining, and tracking metrics and success.*
- *Objectively evaluating adherence of the process and the work products and services of the process to the applicable requirements, objectives, and standards and addressing noncompliance.*
- *Reviewing activities, status, and results of the process with appropriate levels of management and resolving issues.*

This section should also include the project-specific description of each of the 17 processes to be used, including the specific tailoring of the requirements to the system and the project; the procedures to be used in implementing the processes; in-house documentation; trade study methodology; types of mathematical and/or simulation models to be used; and generation of specifications.

Key Questions	
1.	*What are the systems engineering processes for this project?*
2.	*What are the methods that we will apply for each systems engineering task?*
3.	*What are the tools we will use to support these methods? How will the tools be integrated?*
4.	*How will we control configuration development?*
5.	*How and when will we conduct technical reviews?*
6.	*How will we establish the need for and manage trade-off studies?*
7.	*Who has authorization for technical change control?*
8.	*How will we manage requirements? interfaces? documentation?*

6.0 Technology Insertion

This section describes the approach and methods for identifying key technologies and their associated risks and criteria for assessing and inserting technologies, including those for *inserting critical technologies from technology development projects. An approach should be developed for appropriate level and timing of technology insertion. This could include alternative approaches to take advantage of new technologies to meet systems needs as well as alternative options if the technologies do not prove appropriate in result or timing. The strategy for an initial technology assessment within the scope of the project requirements should be provided to identify technology constraints for the system.*

Key Questions
1. How and when will we insert new of special technology into the project?
2. What is the relationship to research and development efforts? How will they support the project? How will the results be incorporated?
3. How will we incorporate system elements provided by others? How will these items be certified for adequacy?
4. What facilities are required?
5. When and how will these items be transitioned to be part of the configuration?

7.0 Additional SE Functions and Activities

This section describes other areas not specifically included in previous sections but that are essential for proper planning and conduct of the overall technical effort.

7.1 System Safety

This section describes the approach and methods for conducting safety analysis and assessing the risk to operators, the system, the environment, or the public.

7.2 Engineering Methods and Tools

This section describes the methods and tools that are not included in the technology insertion sections but are needed to support the overall technical effort. It identifies those tools to be acquired and tool training requirements.

This section defines the development environment for the project, including automation, simulation, and software tools. If required, it describes the tools and facilities that need to be developed or acquired for all disciplines on the project. It describes important enabling strategies such as standardizing tools across the project, or utilizing a common input and output format to support a broad range of tools used on the project. It defines the requirements for information management systems and for using existing elements. It defines and plans for the training required to use the tools and technology across the project.

7.3 Specialty Engineering

This section describes engineering discipline and specialty requirements that apply across projects and the WBS models of the system structure. Examples of these requirement areas would include planning for safety, reliability, human factors, logistics, maintainability, quality, operability, and supportability. It includes estimates of staffing levels for these disciplines and incorporates them with the project requirements.

7.4 Technical Performance Measures

a. This section describes the TPMs that have been derived from the MOEs and MOPs for the project. The TPMs are used to define and track the technical progress of the systems *engineering effort. The performance metrics need to address the minimally required TPMs as defined in NPR 7123.1. These include:*

1. *Mass margins for projects involving hardware [SE-62].*
2. *Power margins for projects that are powered [SE-63].*
3. *Review Trends including closure of review action documentation (Request for Action, Review Item Discrepancies, and/or Action Items as established by the project) for all software and hardware projects [SE-64].*

b. *Other performance measure that should be considered by the project include:*

- *Requirement trends (percent growth, TBD/TBR closures, number of requirement changes);*
- *Interface trends (percent ICD approval, TBD/TBR burndown, number of interface requirement changes);*
- *Verification trends (closure burndown, number of deviations/waivers approved/open);*
- *Software-unique trends (number of requirements per build/release versus plan);*
- *Problem report/discrepancy report trends (number open, number closed);*
- *Cost trends (plan, actual, UFE, EVM, NOA);*
- *Schedule trends (critical path slack/float, critical milestone dates); and*
- *Staffing trends (FTE, WYE).*

Key Questions
1. *What metrics will be used to measure technical progress?*
2. *What metrics will be used to identify process improvement opportunities?*
3. *How will we measure progress against the plans and schedules?*
4. *How often will progress be reported? By whom? To whom?*

7.5 Heritage

This section describes the heritage or legacy products that will be used in the project. It should include a discussion of which products are planned to be used, the rationale for their use, and the analysis or testing needed to assure they will perform as intended in the stated use.

7.6 Other

This section is reserved to describe any unique SE functions or activities for the project that are not covered in other sections.

8.0 Integration with the Project Plan and Technical Resource Allocation

This section describes how the technical effort will integrate with project management and defines roles and responsibilities. It addresses how technical requirements will be integrated with the project plan to determine the allocation of resources, including cost, schedule, and personnel, and how changes to the allocations will be coordinated.

Key Questions
1. *How will we assess risk? What thresholds are needed for triggering mitigation activities? How will we integrate risk management into the technical decision process?*

2.	*How will we communicate across and outside of the project?*
3.	*How will we record decisions?*
4.	*How do we incorporate lessons learned from other projects?*

This section describes the interface between all of the technical aspects of the project and the overall project management process during the systems engineering planning activities and updates. All activities to coordinate technical efforts with the overall project are included, such as technical interactions with the external stakeholders, users, and contractors.

9.0 Compliance Matrices

Appendix H.2 in NPR 7123.1A is the basis for the compliance matrix for this section of the SEMP. The project will complete this matrix from the point of view of the project and the technical scope. Each requirement will be addressed as compliant, partially compliant, or noncompliant. Compliant requirements should indicate which process or activity addresses the compliance. For example, compliance can be accomplished by using a Center process or by using a project process as described in another section of the SEMP or by reference to another documented process. Noncompliant areas should state the rationale for noncompliance.

Appendices

Appendices are included, as necessary, to provide a glossary, acronyms and abbreviations, and information published separately for convenience in document maintenance. Included are: (1) information that may be pertinent to multiple topic areas (e.g., description of methods or procedures); (2) charts and proprietary data applicable to the technical efforts required in the SEMP; and (3) a summary of technical plans associated with the project. Each appendix should be referenced in one of the sections of the engineering plan where data would normally have been provided.

Templates

Any templates for forms, plans, or reports the technical team will need to fill out, like the format for the verification and validation plan, should be included in the appendices.

References

This section contains all documents referenced in the text of the SEMP.

Table J-1 Guidance on SEMP Content per Life-Cycle Phase

SEMP Section	SEMP Subsection	Pre-Phase A KDP A	Phase A KDP B		Phase B KDP C	Phase C KDP D		Phase D KDP E		Phase E KDP F	Phase F
		MCR	SRR	SDR/MDR	PDR	CDR	SIR	ORR	MRR/FRR	DR	DRR
Purpose and Scope		Final	Final	Final	Final	Final	Final	Final	Final	Final	Final
Applicable Documents		Initial	Initial	Initial	Final	Final	Final	Final	Final	Final	Final
Technical Summary		Final	Final	Final	Final	Final	Final	Final	Final	Final	Final
System Description		Initial	Initial	Initial	Final	Final	Final	Final	Final	Final	Final
System Structure	Product Integration	Define thru SDR timeframe	Define thru SDR timeframe	Define thru SDR timeframe	Define thru SIR	Define thru SIR	Define thru SIR	Define sustaining thru end of program	Define sustaining thru end of program	Define sustaining thru end of program	Define sustaining thru end of program
	Planning Context	Define thru SDR timeframe	Define thru SDR timeframe	Define thru SDR timeframe	Define thru SIR	Define thru SIR	Define thru SIR	Define sustaining thru end of program	Define sustaining thru end of program	Define sustaining thru end of program	Define sustaining thru end of program
	Boundary of Technical Effort	Initial	Initial	Initial	Final	Final	Final	Final	Final	Final	Final
	Cross References	Initial	Initial	Initial	Final	Final	Final	Final	Final	Final	Final
Technical Effort Integration	Responsibility and Authority	Define thru SDR timeframe	Define thru SDR timeframe	Define thru SDR timeframe	Define thru SIR timeframe	Define thru SIR timeframe	Define thru SIR timeframe	Define sustaining Roles and Responsibilities through end of program	Define sustaining Roles and Responsibilities through end of program	Define sustaining Roles and Responsibilities through end of program	
	Contractor Integration	Define acquisitions needed		Define insight/ oversight through SIR timeframe				Define sustaining insight/ oversight through end of program			
	Support Integration	Define acquisitions needed		Define insight/ oversight through SIR				Define sustaining insight/ oversight through end of			

SEMP Section	SEMP Subsection	Pre-Phase A KDP A	Phase A KDP B		Phase B KDP C	Phase C KDP D		Phase D KDP E		Phase E KDP F	Phase F
		MCR	SRR	SDR/MDR	PDR	CDR	SIR	ORR	MRR/FRR	DR	DRR
				timeframe				program			
Common Technical Processes Implementation		Processes defined for Concept Development and Formulation		Processes defined for the Design Phase		Processes added for the integration and Operations Phase		Update Operations processes. Define close out processes and sustaining engineering processes			
Technology Insertion		Define technologies to be developed		Define decision process for on ramps and off ramps of technology efforts				Define technology sustaining effort through end of program.			
Additional SE Functions and Activities	System Safety	Define process through CDR						Define sustaining Roles and Responsibilities through end of program			
	Engineering Methods and tools	Define process through CDR						Define sustaining Roles and Responsibilities through end of program			
	Specialty Engineering	Define process through CDR						Define sustaining Roles and Responsibilities through end of program			
Integration with the Project Plan and Technical Resource Allocation		Define through SDR timeframe			Define through SIR	Define through SIR	Define through SIR	Define sustaining through end of program	Define sustaining through end of program	Define sustaining through end of program	Define sustaining through end of program
Compliance		Initial	Initial	Initial	Final	Final	Final	Final	Final	Final	Final

SEMP Section	SEMP Subsection	Pre-Phase A KDP A	Phase A KDP B		Phase B KDP C	Phase C KDP D		Phase D KDP E		Phase E KDP F	Phase F
		MCR	SRR	SDR/MDR	PDR	CDR	SIR	ORR	MRR/FRR	DR	DRR
Matrix (Appendix H.2 of SE NPR)											
Appendices		As required	As required	As required	As required	As required	As required	As required	As required	As required	As required
Templates		As required	As required	As required	As required	As required	As required	As required	As required	As required	As required
References		As required	As required	As required	As required	As required	As required	As required	As required	As required	As required

Appendix D: Technical Plans

The following table represents a typical expectation of maturity of some of the key technical plans developed during the SE processes. This example is for a space flight project. Requirements for work product maturity can be found in the governing PM document (i.e., NPR 7120.5) for the associated type of project.

Table K-1 Example of Expected Maturity of Key Technical Plans

Plan	Pre-Phase A	Phase A		Phase B	Phase C		Phase D		Phase E	Phase F	Ref. Page
	MCR	SRR	SDR/ MDR	PDR	CDR	SIR	ORR	MRR/ FRR	DR	DRR	
Systems Engineering Management Plan	P	B	U	U	U	U	U	U	U	U	
Risk Management Plan	A	B	U	U	U						
Integrated Logistics Support Plan	A	P	P	B	U						
Technology Development Plan	B	U	U	U							
Review Plan	P	B	U	U	U	U	U	U	U	U	
Verification and Validation Plan	A	A	P	B	U						
Integration Plan			P	B	U						
Configuration Management Plan		B	U	U							
Data Management Plan		D	U	U							
Human Systems Integration Plan		B	U	U	U						
Software Management Plan		P	B	U							
Reliability and Maintainability Plan			P	B	U						
Mission Operations Plan						P	B	U			
Project Protection Plan			P	B	U	U	U	U	U	U	
Decommissioning Plan			A					B	U		
Disposal Plan			A					B	U	U	

A= Approach B = Baseline P = Preliminary U = Update

Appendix E: Verification and Validation Plan Outline

Sample Outline

The Verification and Validation (V&V) Plan needs to be baselined after the comments from PDR are incorporated. In this annotated outline, the use of the term "system" is indicative of the entire scope for which this plan is developed. This may be an entire spacecraft, just the avionics system, or a card within the avionics system. Likewise, the term "end item", "subsystem" or "element" is meant to imply the lower-level products that, when integrated together, will produce the "system." The general term "end item" is used to encompass activities regardless of whether the end item is a hardware or software element.

The various sections are intended to move from the high-level generic descriptions to the more detailed. The sections also flow from the lower-level items in the product layer to larger and larger assemblies and to the completely integrated system. The sections also describe how that system may be integrated and further verified/validated with its externally interfacing elements. This progression will help build a complete understanding of the overall plans for verification and validation.

1.0 Introduction

1.1 Purpose and Scope

This section states the purpose of this Verification and Validation Plan and the scope (i.e., systems) to which it applies. The purpose of the V&V Plan is to identify the activities that will establish compliance with the requirements (verification) and to establish that the system will meet the customers' expectations (validation).

1.2 Responsibility and Change Authority

This section will identify who has responsibility for the maintenance of this plan and who or what board has the authority to approve any changes to it.

1.3 Definitions

This section will define any key terms used in the plan. The section may include the definitions of verification, validation, analysis, test, demonstration, and test. See appendix B of this handbook for definitions of these and other terms that might be used.

2.0 Applicable and Reference Documents

2.1 Applicable Documents

These are the documents that may impose additional requirements or from which some of the requirements have been taken.

2.2 Reference Documents

These are the documents that are referred to within the V&V Plan that do not impose requirements, but which may have additional useful information.

3.0 System Description

3.1 System Requirements Flowdown

This section describes where the requirements for this system come from and how they are flowed down to subsystems and lower-level elements. It should also indicate what method will be used to perform the flowdown and bidirectional traceability of the requirements: spreadsheet, model, or other means. It can point to the file, document, or spreadsheet that captures the actual requirements flowdown.

3.2 System Architecture

This section describes the system that is within the scope of this V&V Plan. The description should be enough so that the V&V activities will have the proper context and be understandable.

3.3 End Item Architectures

This section describes each of the major end items (subsystems, elements, units, modules, etc.) that when integrated together, will form the overall system that is the scope of this V&V Plan.

3.3.1 System End Item A

This section describes the first major end item/subsystem in more detail so that the V&V activities have context and are understandable.

3.3.n System End Item n

Each end item/subsystem is separately described in a similar manner as above.

3.4 Ground Support Equipment

This section describes any major ground-support equipment that will be used during the V&V activities. This may include carts for supplying power or fuel, special test fixtures, lifting aids, simulators, or other type of support.

3.5 Other Architecture Descriptions

This section describes any other items that are important for the V&V activities but which are not included in the sections above. This may be an existing control center, training facility, or other support.

4.0 Verification and Validation Process

This section describes the process that will be used to perform verification and validation.

4.1 Verification and Validation Management Responsibilities

This section describes the responsibilities of key players in the V&V activities. It may include identification and duty description for test directors/conductors, managers, facility owners, boards, and other key stakeholders.

4.2 Verification Methods

This section defines and describes the methods that will be used during the verification activities.

4.2.1 Analysis

Defines what this verification method means (See appendix B of this handbook) and how it will be applied to this system.

4.2.2 Inspection

Defines what this verification method means (See appendix B of this handbook) and how it will be applied to this system.

4.2.3 Demonstration

Defines what this verification method means (See appendix B of this handbook) and how it will be applied to this system.

4.2.4 Test

Defines what this verification method means (See appendix B of this handbook) and how it will be applied to this system. This category may need to be broken down into further categories.

4.2.4.1 Qualification Testing

This section describes the test philosophy for the environmental and other testing that is performed at higher than normal levels to ascertain margins and performance in worst-case scenarios. Includes descriptions of how the minimum and maximum extremes will be determined for various types of tests (thermal, vibration, etc.), whether it will be performed at a component, subsystem, or system level, and the pedigree (flight unit, qualification unit, engineering unit, etc.) of the units these tests will be performed on.

4.2.4.2 Other Testing

This section describes any other testing that will be used as part of the verification activities that are not part of the qualification testing. It includes any testing of requirements within the normal operating range of the end item. It may include some engineering tests that will form the foundation or provide dry runs for the official verification testing.

4.3 Validation Methods

This section defines and describes the methods to be used during the validation activities.

4.2.1 Analysis

Defines what this validation method means (See appendix B of this handbook) and how it will be applied to this system.

4.2.2 Inspection

Defines what this validation method means (See appendix B of this handbook) and how it will be applied to this system.

4.2.3 Demonstration

Defines what this validation method means (See appendix B of this handbook) and how it will be applied to this system.

4.2.4 Test

Defines what this validation method means (See appendix B of this handbook) and how it will be applied to this system. This category may need to be broken down into further categories such as end-to-end testing, testing with humans, etc.)

4.4 Certification Process

Describes the overall process by which the results of these verification and validation activities will be used to certify that the system meets its requirements and expectations and is ready to be put into the field or fly. In addition to the verification and validation results, the certification package may also include special forms, reports, safety documentation, drawings, waivers, or other supporting documentation.

4.5 Acceptance Testing

Describes the philosophy of how/which of the verification/validation activities will be performed on each of the operational units as they are manufactured/coded and are readied for flight/use. Includes how/if data packages will be developed and provided as part of the delivery.

5.0 Verification and Validation Implementation

5.1 System Design and Verification and Validation Flow

This section describes how the system units/modules will flow from manufacturing/coding through verification and validation. Includes whether each unit will be verified/validated separately, or assembled to some level and then evaluated or other statement of flow.

5.2 Test Articles

This section describes the pedigree of test articles that will be involved in the verification/validation activities. This may include descriptions of breadboards, prototypes, engineering units, qualification units, protoflight units, flight units, or other specially named units. A definition of what is meant by these terms needs to be included to ensure clear understanding of the expected pedigree of each type of test article. Descriptions of what kind of test/analysis activities will be performed on each type of test article is included.

5.3 Support Equipment

This section describes any special support equipment that will be needed to perform the verification/validation activities. This will be a more detailed description than is stated in Section 3.4 of this outline.

5.4 Facilities

This section identifies and describes major facilities that will be needed in order to accomplish the verification and validation activities. These may include environmental test *facilities, computational facilities, simulation facilities, training facilities, test stands, and other facilities as needed.*

6.0 End Item Verification and Validation

This section describes in detail the V&V activities that will be applied to the lower-level subsystems/elements/end items. It can point to other stand-alone descriptions of these tests if they will be generated as part of organizational responsibilities for the products at each product layer.

6.1 End Item A

This section focuses in on one of the lower-level end items and describes in detail what type of verification activities it will undergo.

6.1.1 Developmental/Engineering Unit Evaluations

This section describes what kind of testing, analysis, demonstrations, or inspections the prototype/engineering or other types of units/modules will undergo prior to performing official verification and validation.

6.1.2 Verification Activities

This section describes in detail the verification activities that will be performed on this end item.

6.1.2.1 Verification by Testing

This section describes all verification testing that will be performed on this end item.

6.1.2.1.1 Qualification Testing

This section describes the test environmental and other testing that is performed at higher than normal levels to ascertain margins and performance in worst-case scenarios. It includes what minimum and maximum extremes will be used on qualification tests (thermal, vibration, etc.) of this unit, whether it will be performed at a component, subsystem, or system level, and the pedigree (flight unit, qualification unit, engineering unit, etc.) of the units these tests will be performed on.

6.1.2.1.2 Other Testing

This section describes all other verification tests that are not performed as part of the qualification testing. These will include verification of requirements in the normal operating ranges.

6.1.2.2 Verification by Analysis

This section describes the verifications that will be performed by analysis (including verification by similarity). This may include thermal analysis, stress analysis, analysis of fracture control, materials analysis, Electrical, Electronic, and Electromechanical (EEE) parts analysis, and other analyses as needed for the verification of this end item.

6.1.2.3 Verification by Inspection

This section describes the verifications that will be performed for this end item by inspection.

6.1.2.4 Verification Demonstration

This section describes the verifications that will be performed for this end item by demonstration.

6.1.3 Validation Activities

6.1.3.1 Validation by Testing

This section describes what validation tests will be performed on this end item.

6.1.3.2 Validation by Analysis

This section describes the validation that will be performed for this end item through analysis.

6.1.3.3 Validation by Inspection

This section describes the validation that will be performed for this end item through inspection.

6.1.3.4 Validation by Demonstration

This section describes the validations that will be performed for this end item by demonstration.

6.1.4 Acceptance Testing

This section describes the set of tests, analysis, demonstrations, or inspections that will be performed on the flight/final version of the end item to show it has the same design a the one that is being verified, that the workmanship on this end item is good, and that it performs the identified functions properly.

6.n End Item n

In a similar manner as above, a description of how each end item that makes up the system will be verified and validated is made.

7.0 System Verification and Validation

7.1 End-Item Integration

This section describes how the various end items will be assembled/integrated together, verified and validated. For example, the avionics and power systems may be integrated and tested together to ensure their interfaces and performance is as required and expected prior to integration with a larger element. This section describes the verification and validation that will be performed on these major assemblies. Complete system integration will be described in later sections.

7.1.1 Developmental/Engineering Unit Evaluations

This section describes the unofficial (not the formal verification/validation) testing / analysis that will be performed on the various assemblies that will be tested together *and the pedigree of the units that will be used. This may include system-level testing of configurations using engineering units, breadboard, simulators, or other forms or combination of forms.*

7.1.2 Verification Activities

This section describes the verification activities that will be performed on the various assemblies.

7.1.2.1 Verification by Testing

This section describes all verification testing that will be performed on the various assemblies. The section may be broken up to describe qualification testing performed on the various assemblies and other types of testing.

7.1.2.2 Verification by Analysis

This section describes all verification analysis that will be performed on the various assemblies.

7.1.2.3 Verification by Inspection

This section describes all verification inspections that will be performed on the various assemblies.

7.1.2.4 Verification by Demonstration

This section describes all verification demonstrations that will be performed on the various assemblies.

7.1.3 Validation Activities

7.1.3.1 Validation by Testing

This section describes all validation testing that will be performed on the various assemblies.

7.1.3.2 Validation by Analysis

This section describes all validation analysis that will be performed on the various assemblies.

7.1.3.3 Validation by Inspection

This section describes all validation inspections that will be performed on the various assemblies.

7.1.3.4 Validation by Demonstration

This section describes all validation demonstrations that will be performed on the various assemblies.

7.2 Complete System Integration

This section describes the verification and validation activities that will be performed on the systems after all its assemblies are integrated together to form the complete integrated system. In some cases this will not be practical. Rationale for what cannot be done should be captured.

7.2.1 Developmental/Engineering Unit Evaluations

This section describes the unofficial (not the formal verification/validation) testing / analysis that will be performed on the complete integrated system and the pedigree of the units that will be used. This may include system-level testing of configurations using engineering units, breadboard, simulators, or other forms or combination of forms.

7.2.2 Verification Activities

This section describes the verification activities that will be performed on the completely integrated system

7.2.2.1 Verification Testing

This section describes all verification testing that will be performed on the integrated system. The section may be broken up to describe qualification testing performed at the integrated system level and other types of testing.

7.2.2.2 Verification Analysis

This section describes all verification analysis that will be performed on the integrated system.

7.2.2.3 Verification Inspection

This section describes all verification inspections that will be performed on the integrated system.

7.2.2.4 Verification Demonstration

This section describes all verification demonstrations that will be performed on the integrated system.

7.2.3 Validation Activities

This section describes the validation activities that will be performed on the completely integrated system.

7.2.3.1 Validation by Testing

This section describes all validation testing that will be performed on the integrated system.

7.2.3.2 Validation by Analysis

This section describes all validation analysis that will be performed on the integrated system.

7.2.3.3 Validation by Inspection

This section describes the validation inspections that will be performed on the integrated system.

7.2.3.4 Validation by Demonstration

This section describes the validation demonstrations that will be performed on the integrated system.

8.0 Program Verification and Validation

This section describes any further testing that the system will be subjected to. For example, if the system is an instrument, the section may include any verification/validation that the system will undergo when integrated into its spacecraft/platform. If the system is a spacecraft, the section may include any verification/validation the system will undergo when integrated with its launch vehicle.

8.1 Vehicle Integration

This section describes any further verification or validation activities that will occur when the system is integrated with its external interfaces.

8.2 End-to-End Integration

This section describes any end-to-end testing that the system may undergo. For example, this configuration would include data being sent from a ground control center through one or more relay satellites to the system and back.

8.3 On-Orbit V&V Activities

This section describes any remaining verification/validation activities that will be performed on a system after it reaches orbit or is placed in the field.

9.0 System Certification Products

This section describes the type of products that will be generated and provided as part of the certification process. This package may include the verification and validation matrix and results, pressure vessel certifications, special forms, materials certifications, test reports or other products as is appropriate for the system being verified and validated.

Appendix A: Acronyms and Abbreviations

This is a list of all the acronyms and abbreviations used in the V&V Plan and their spelled-out meaning.

Appendix B: Definition of Terms

This section is a definition of the key terms that are used in the V&V Plan.

Appendix C: Requirement Verification Matrix

The V&V Plan needs to be baselined after the comments from PDR are incorporated. The information in this section may take various forms. It could be a pointer to another document or model where the matrix and its results may be found. This works well for large projects using a requirements tracking application. The information in this section could also be the requirements matrix filled out with all but the results information and a pointer to where the results can be found. This allows the key information to be available at the time of baselining. For a smaller project, this may be the completed verification matrix. In this case, the V&V Plan would be filled out as much as possible before. See appendix D for an example of a verification matrix.

Appendix D: Validation Matrix

As with the verification matrix, this product may take various forms from a completed matrix to just a pointer for where the information can be found. Appendix E provides an example of a validation matrix.

Appendix F: Interface Requirements Document Outline

1.0 Introduction

1.1 Purpose and Scope

State the purpose of this document and briefly identify the interface to be defined. (For example, "This IRD defines and controls the interface(s) requirements between ______ and ______.")

1.2 Precedence

Define the relationship of this document to other program documents and specify which is controlling in the event of a conflict.

1.3 Responsibility and Change Authority

State the responsibilities of the interfacing organizations for development of this document and its contents. Define document approval authority (including change approval authority).

2.0 Documents

2.1 Applicable Documents

List binding documents that are invoked to the extent specified in this IRD. The latest revision or most recent version should be listed. Documents and requirements imposed by higher-level documents (higher order of precedence) should not be repeated.

2.2 Reference Documents

List any document that is referenced in the text in this subsection.

3.0 Interfaces

3.1 General

In the subsections that follow, provide the detailed description, responsibilities, coordinate systems, and numerical requirements as they relate to the interface plane.

3.1.1 Interface Description

Describe the interface as defined in the system specification. Use tables, figures, or drawings as appropriate.

3.1.2 Interface Responsibilities

Define interface hardware and interface boundary responsibilities to depict the interface plane. Use tables, figures, or drawings as appropriate.

3.1.3 Coordinate Systems

Define the coordinate system used for interface requirements on each side of the interface. Use tables, figures, or drawings as appropriate.

3.1.4 Engineering Units, Tolerances, and Conversion.

Define the measurement units along with tolerances. If required, define the conversion between measurement systems.

3.2 Interface Requirements

In the subsections that follow, define structural limiting values at the interface, such as interface loads, forcing functions, and dynamic conditions. Define the interface requirements on each side of the interface plane.

3.2.1 Mass Properties

Define the derived interface requirements based on the allocated requirements contained in the applicable specification pertaining to that side of the interface. For example, this subsection should cover the mass of the element.

3.2.2 Structural/Mechanical

Define the derived interface requirements based on the allocated requirements contained in the applicable specification pertaining to that side of the interface. For example, this subsection should cover attachment, stiffness, latching, and mechanisms.

3.2.3 Fluid

Define the derived interface requirements based on the allocated requirements contained in the applicable specification pertaining to that side of the interface. For example, this subsection should cover fluid areas such as thermal control, O_2 and N_2, potable and waste water, fuel cell water, and atmospheric sampling.

3.2.4 Electrical (Power)

Define the derived interface requirements based on the allocated requirements contained in the applicable specification pertaining to that side of the interface. For example, this subsection should cover various electric current, voltage, wattage, and resistance levels.

3.2.5 Electronic (Signal)

Define the derived interface requirements based on the allocated requirements contained in the applicable specification pertaining to that side of the interface. For example, this subsection should cover various signal types such as audio, video, command data handling, and navigation.

3.2.6 Software and Data

Define the derived interface requirements based on the allocated requirements contained in the applicable specification pertaining to that side of the interface. For example, this subsection should cover various data standards, message timing, protocols, error detection/correction, functions, initialization, and status.

3.2.7 Environments

Define the derived interface requirements based on the allocated requirements contained in the applicable specification pertaining to that side of the interface. For example, cover the dynamic envelope measures of the element in English units or the metric equivalent on this side of the interface.

3.2.7.1.a Electromagnetic Compatibility

Define the appropriate electromagnetic compatibility requirements. For example, the end-item-1-to-end-item-2 interface shall meet the requirements [to be determined] of systems requirements for electromagnetic compatibility.

3.2.7.1.b Electromagnetic Interference

Define the appropriate electromagnetic interference requirements. For example, the end-item-1-to-end-item-2 interface shall meet the requirements [to be determined] of electromagnetic emission and susceptibility requirements for electromagnetic compatibility.

3.2.7.1.c Grounding

Define the appropriate grounding requirements. For example, the end-item-1-to-end-item-2 interface shall meet the requirements [to be determined] of grounding requirements.

3.2.7.1.d Bonding

Define the appropriate bonding requirements. For example, the end-item-1-to-end-item-2 structural/mechanical interface shall meet the requirements [to be determined] of electrical bonding requirements.

3.2.7.1.e Cable and Wire Design

Define the appropriate cable and wire design requirements. For example, the end-item-1-to-end-item-2 cable and wire interface shall meet the requirements [to be determined] of cable/wire design and control requirements for electromagnetic compatibility.

3.2.7.2 Acoustic

Define the appropriate acoustics requirements. Define the acoustic noise levels on each side of the interface in accordance with program or project requirements.

3.2.7.3 Structural Loads

Define the appropriate structural loads requirements. Define the mated loads that each end item should accommodate.

3.2.7.4 Vibroacoustics

Define the appropriate vibroacoustics requirements. Define the vibroacoustic loads that each end item should accommodate.

3.2.7.5 Human Operability

Define the appropriate human interface requirements. Define the human-centered design considerations, constraints, and capabilities that each end item should accommodate.

3.2.8 Other Types of Interface Requirements

Define other types of unique interface requirements that may be applicable.

Appendix G: CM Plan Outline

A comprehensive Configuration Management (CM) Plan that reflects efficient application of configuration management principles and practices would normally include the following topics:

- General product definition and scope
- Description of CM activities and procedures for each major CM function
- Organization, roles, responsibilities, and resources
- Definitions of terms
- Programmatic and organizational interfaces
- Deliverables, milestones, and schedules
- Subcontract flow down requirements

The documented CM planning should be reevaluated following any significant change affecting the context and environment, e.g., changes in suppliers or supplier responsibilities, changes in diminishing manufacturing sources/part obsolescence, changes in resource availabilities, changes in customer contract, and changes in the product. CM planning should also be reviewed on a periodic basis to make sure that an organization's application of CM functions is current.

For additional information regarding a CM Plan, refer to SAE EIA-649, Rev. B.

Appendix H: HSI Plan Content Outline

R.1 HSI Plan Overview

The Human Systems Integration (HSI) Plan documents the strategy for and planned implementation of HSI through a particular program's/project's life cycle. The intent of HSI is:

- To ensure the human elements of the total system are effectively integrated with hardware and software elements,
- To ensure all human capital required to develop and operate the system is accounted for in life-cycle costing, and
- To ensure that the system is built to accommodate the characteristics of the user population that will operate, maintain, and support the system.

The HSI Plan is specific to a program or project and applies to NASA systems engineering per NPR 7123.1, NASA Systems Engineering Processes and Requirements. The HSI Plan should address the following:

- Roles and responsibilities for integration across HSI domains;
- Roles and responsibilities for coordinating integrated HSI domain inputs with the program team and stakeholders;
- HSI goals and deliverables for each phase of the life cycle;
- Entry and exit criteria with defined metrics for each phase, review, and milestone;
- Planned methods, tools, requirements, processes, and standards for conducting HSI;
- Strategies for identifying and resolving HSI risks; and
- Alignment strategy with the SEMP.

The party or parties responsible for program/project HSI implementation—e.g., an HSI integrator (or team)—should be identified by the program/project manager. The HSI integrator or team develops and maintains the HSI Plan with support from and coordination with the project manager and systems engineer.

Implementation of HSI on a program/project utilizes many of the tools and products already required by systems engineering; e.g., development of a ConOps, clear functional allocation across the elements of a system (hardware, software, and human), and the use of key performance measurements through the life cycle to validate and verify HSI's effectiveness. It is not the intent of the HSI Plan or its implementation to duplicate other systems engineering plans or processes, but rather to define the uniquely HSI effort being made to ensure the human element is given equal consideration to hardware/software elements of a program/project.

R.2 HSI Plan Content Outline

Each program/project-specific HSI Plan should be tailored to fit the program/project's size, scope, and purpose. The following is an example outline for a major program; e.g., space flight or aeronautics.

1.0 Introduction

1.1 Purpose

This section briefly identifies the ultimate objectives for this program/project's HSI Plan. This section also introduces the intended implementers and users of this HSI Plan.

1.2 Scope

This section describes the overall scope of the HSI Plan's role in documenting the strategy for and implementation of HSI. Overall, this section describes that the HSI Plan:

- *Is a dynamic document that will be updated at key life-cycle milestones.*
- *Is a planning and management guide that describes how HSI will be relevant to the program/project's goals.*
- *Describes planned HSI methodology, tools, schedules, and deliverables.*
- *Identifies known program/project HSI issues and concerns and how their resolutions will be addressed.*
- *Defines program/project HSI organizational elements, roles, and responsibilities.*
- *May serve as an audit trail that documents HSI data sources, analyses, activities, trade studies, and decisions not captured in other program/project documentation.*

1.3 Definitions

This section defines key HSI terms and references relevant program/project-specific terms.

2.0 Applicable Documents

This section lists all documents, references, and data sources that are invoked by HSI's implementation on the program/project, that have a direct impact on HSI outcomes, and/or are impacted by the HSI effort.

3.0 HSI Objectives

3.1 System Description

This section describes the system, missions to be performed, expected operational environment(s), predecessor and/or legacy systems (and lessons learned), capability gaps, stage of development, etc. Additionally, reference should be made to the acquisition strategy for the system; e.g., if it is developed in-house within NASA or if major systems are intended for external procurement. The overall strategy for program integration should be referenced.

Note that this information is likely captured in other program/project documentation and can be referenced in the HSI Plan rather than repeated.

3.2 HSI Relevance

At a high level, this section describes HSI's relevance to the program/project; i.e., how the HSI strategy will improve the program/project's outcome. Known HSI challenges should be described along with mention of areas where human performance in the system's operations is predicted to directly impact the probability of overall system performance and mission success.

HSI Relevance

Key Points

- *Describe performance characteristics of the human elements known to be key drivers to a desired total system performance outcome.*
- *Describe the total system performance goals that require HSI support.*
- *Identify HSI concerns with legacy systems; e.g., if operations and logistics, manpower, skill selection, required training, logistics support, operators' time, maintenance, and/or risks to safety and success exceeded expectations.*
- *Identify potential cost, schedule, risk, and trade-off concerns with the integration of human elements; e.g., quantity and skills of operators, maintainers, ground controllers, etc.*

4.0 HSI Strategy

4.1 HSI Strategy Summary

This section summarizes the HSI approaches, planning, management, and strategies for the program/project. It should describe how HSI products will be integrated across all HSI domains and how HSI inputs to program/project systems engineering and management processes contribute to system performance and help contain life-cycle cost. This section (or Implementation Summary, Section 6 of this outline) should include a top-level schedule showing key HSI milestones.

HSI Strategy

Key Points

- *Identify critical program/project-specific HSI key decision points that will be used to track HSI implementation and success.*
- *Identify key enabling (and particularly, emerging) technologies and methodologies that may be overlooked in hardware/software systems trade studies but that may positively contribute to HSI implementation; e.g., in the areas of human performance, workload, personnel management, training, safety, and survivability.*
- *Describe HSI products that will be integrated with program/project systems engineering products, analyses, risks, trade studies, and activities.*
- *Describe efforts to ensure HSI will contribute in critically important Phase A and Pre-Phase A cost-effective design concept studies.*
- *Describe the plan and schedule for updating the HSI Plan through the program / project life cycle.*

4.2 HSI Domains

This section identifies the HSI domains applicable to the program/project including rationale for their relevance.

HSI Domains

Key Points

- *Identify any domain(s) associated with human performance capabilities and limitations whose integration into the program/project is likely to directly affect the probability of successful program/project outcome.*
- *An overview of processes to apply, document, validate, evaluate, and mitigate HSI domain knowledge and to integrate domain knowledge into integrated HSI inputs to program/project and systems engineering processes.*

5.0 HSI Requirements, Organization, and Risk Management

5.1 HSI Requirements

This section references HSI requirements and standards applicable to the program/project and identifies the authority that invokes them; e.g., the NASA Procedural Requirements (NPR) document(s) that invoke applicability.

HSI Requirements

Key Points

- *Describe how HSI requirements that are invoked on the program/project contribute to mission success, affordability, operational effectiveness, and safety.*
- *HSI should include requirements that influence the system design to moderate manpower (operators, maintainers, system administrative, and support personnel), required skill sets (occupational specialties with high aptitude or skill requirements), and training requirements.*
- *Define the program/project-specific HSI strategy derived from NASA-STD-3001, NASA Space Flight Human-System Standard, Volume 2: Human Factors, Habitability, and Environmental Health, Standard 3.5 [V2 3005], "Human-Centered Design Process", if applicable.*
- *Capture the development process and rationale for any program/project-specific requirements not derived from existing NASA standards. In particular, manpower, skill set, and training HSI requirements/goals may be so program/project-specific as to not have NASA parent standards or requirements.*
- *Identify functional connections between HSI measures of effectiveness used to verify requirements and key performance measures used throughout the life cycle as indicators of overall HSI effectiveness.*

5.2 HSI Organization, Roles, and Responsibilities

In this section, roles and responsibilities for program/project personnel assigned to facilitate and/or manage HSI tasks are defined; e.g., the HSI integrator (and/or team if required by NPR 8705.2). HSI integrator/team functional responsibilities to the program are described in *addition to identification of organizational elements with HSI responsibilities. Describe the relationships between HSI integrator/team, stakeholders, engineering technical teams, and governing bodies (control boards).*

5.2.1 HSI Organization

- *Describe the HSI management structure for the program/project and identify its leaders and membership.*
- *Reference the organizational structure of the program (including industry partners) and describe the roles and responsibilities of the HSI integrator/team within that structure. Describe the HSI responsible party's relationship to other teams, including those for systems engineering, logistics, risk management, test and evaluation, and requirements verification.*
- *Provide the relationship of responsible HSI personnel to NASA Technical Authorities (Engineering, Safety, and Health/Medical).*
- *Identify if the program/project requires NASA- (Government) and/or contractor-issued HSI Plans, and identify the responsible author(s). Describe how NASA's HSI personnel will monitor and assess contractor HSI activities. For contractor-issued HSI Plans, identify requirements and processes for NASA oversight and evaluation of HSI efforts by subcontractors.*

5.2.2 HSI Roles & Responsibilities

- *Describe the HSI responsible personnel's functional responsibilities to the program / project, addressing (as examples) the following:*
  - *developing HSI program documentation;*
  - *validating human performance requirements;*
  - *conducting HSI analyses;*
  - *designing human machine interfaces to provide the level of human performance required for operations, maintenance, and support, including conduct of training;*
  - *describing the role of HSI experts in documenting and reporting the results from tests and evaluations.*
- *Define how collaboration will be performed within the HSI team, across program / project integrated product teams and with the program/project manager and systems engineer.*
- *Define how the HSI Plan and the SEMP will be kept aligned with each other.*
- *Define responsibility for maintaining and updating the HSI Plan through the program/project's life cycle.*

5.3 HSI Issue and Risk Processing

This section describes any HSI-unique processes for identifying and mitigating human system risks. HSI risks should be processed in the same manner and system as other program / project risks (technical, programmatic, schedule). However, human system risks may only be recognized by HSI domain and integration experts. Therefore, it may be important to document any unique procedures by which the program/project HSI integrator/team *identifies, validates, prioritizes, and tracks the status of HSI-specific risks through the program/project risk management system. Management of HSI risks may be deemed the responsibility of the program's/project's HSI integrator/team in coordination with overall program/project risk management.*

- *Ensure that potential cost, schedule, risk, and trade-off concerns with the integration of human elements (operators, maintainers, ground controllers, etc.) with the total system are identified and mitigated.*
- *Ensure that safety, health, or survivability concerns that arise as the system design and implementation emerge are identified, tracked, and managed.*
- *Identify and describe any risks created by limitations on the overall program/project HSI effort (time, funding, insufficient availability of information, availability of expertise, etc.).*
- *Describe any unique attributes of the process by which the HSI integrator/team elevates HSI risks to program/project risks.*
- *Describe any HSI-unique aspects of how human system risk mitigation strategies are deemed effective.*

6.0 HSI Implementation

6.1 HSI Implementation Summary

This section summarizes the HSI implementation approach by program/project phase. This section shows how an HSI strategy for the particular program/project is planned to be tactically enabled; i.e., establishment of HSI priorities; description of specific activities, tools, and products planned to ensure HSI objectives are met; application of technology in the achievement of HSI objectives; and an HSI risk processing strategy that identifies and mitigates technical and schedule concerns when they first arise.

HSI Implementation

Key Points

- *Relate HSI strategic objectives to the technical approaches planned for accomplishing these objectives.*
- *Overlay HSI milestones—e.g., requirements definition, verification, known trade studies, etc.—on the program/project schedule and highlight any inconsistencies, conflicts, or other expected schedule challenges.*
- *Describe how critical HSI key decision points will be dealt with as the program / project progresses through its life cycle. Indicate the plan to trace HSI key performance measures through the life cycle; i.e., from requirements to human/system functional performance allocations, through design, test, and operational readiness assessment.*
- *Identify HSI-unique systems engineering processes—e.g., verification using human-in-the-loop evaluations—that may require special coordination with program/project processes.*
- *As the system emerges, indicate plans to identify HSI lessons learned from the application of HSI on the program/project.*
- *Include a high-level summary of the resources required.*

6.2 HSI Activities and Products

In this section, map activities, resources, and products associated with planned HSI technical implementation to each systems engineering phase of the program/project. Consideration might be given to mapping the needs and products of each HSI domain by program/project phase. Examples of HSI activities include analyses, mockup/prototype human-in-the-loop evaluations, simulation/modeling, participation in design and design reviews, formative evaluations, technical interchanges, and trade studies. Examples of HSI resources include acquisition of unique/specific HSI skill sets and domain expertise, facilities, equipment, test articles, specific time allocations, etc.

When activities, products, or risks are tied to life-cycle reviews, they should include a description of the HSI entrance and exit criteria to clearly define the boundaries of each phase, as well as resource limitations that may be associated with each activity or product (time, funding, data availability, etc.). A high-level, summary example listing of HSI activities, products, and known risk mitigations by life-cycle phase is provided in Table R.2-1.

Table R.2-1 HSI Activity, Product, or Risk Mitigation by Program/Project Phase

Life-Cycle Phase	Phase Description	Activity, Product, or Risk Mitigation
Pre-Phase A	*Concept Studies*	*ConOps (Preliminary--to include training, maintenance, logistics, etc.)*
Phase A	*Concept & Technology Development*	*HSI Plan (baseline)* *ConOps (initial)* *HSI responsible party(ies) and/or team identified before SRR* *Develop mockup(s) for HSI evaluations* *Crew Workload Evaluation Plan* *Functional allocation, crew task lists* *Validation of ConOps (planning)*
Phase B	*Preliminary Design & Technology Completion*	*HSI Plan (update)* *ConOps (baseline)* *Develop engineering-level mockup(s) for HSI evaluations* *Define crew environmental and crew health support needs (e.g., aircraft flight decks, human space flight missions)* *Assess operator interfaces through task analyses (for, e.g., aircraft cockpit operations, air traffic management, spacecraft environments, mission control for human space flight missions)* *Human-in-the-loop usability plan* *Human-rating report for PDR*
Phase C	*Final Design & Fabrication*	*HSI Plan (update)* *First Article HSI Tests* *Human-rating report for CDR*
Phase D	*System Assembly, Integ. & Test, Launch & Checkout*	*Human-rating report for ORR* *Validation of human-centered design activities* *Validation of ConOps*
Phase E	*Operations & Sustainment*	*Monitoring of human-centered design performance*
Phase F	*Closeout*	*Lessons learned report*

6.3 HSI Plan Update

The HSI Plan should be updated throughout the program/project's life-cycle management and systems engineering processes at key milestones. Milestones recommended for HSI Plan updates are listed in appendix G of NPR 7123.1, NASA Systems Engineering Processes and Requirements.

HSI Plan Updates

Key points to be addressed in each update

- *Identify the current program/project phase, the publication date of the last iteration of the HSI Plan, and the HSI Plan version number. Update the HSI Plan revision history.*
- *Describe the HSI entrance criteria for the current phase and describe any unfinished work prior to the current phase.*
- *Describe the HSI exit criteria for the current program/project phase and the work that must be accomplished to successfully complete the current program/project phase.*

Appendix I: Concept of Operations Annotated Outline

This Concept of Operations (ConOps) annotated outline describes the type and sequence of information that should be contained in a ConOps, although the exact content and sequence will be a function of the type, size, and complexity of the project. The text in italics describes the type of information that would be provided in the associated subsection. Additional subsections should be added as necessary to fully describe the envisioned system.

Cover Page

Table of Contents

1.0 Introduction

1.1 Project Description

This section will provide a brief overview of the development activity and system context as delineated in the following two subsections.

1.1.1 Background

Summarize the conditions that created the need for the new system. Provide the high-level mission goals and objective of the system operation. Provide the rationale for the development of the system.

1.1.2 Assumptions and Constraints

State the basic assumptions and constraints in the development of the concept. For example, that some technology will be matured enough by the time the system is ready to be fielded, or that the system has to be provided by a certain date in order to accomplish the mission.

1.2 Overview of the Envisioned System

This section provides an executive summary overview of the envisioned system. A more detailed description will be provided in Section 3.0

1.2.1 Overview

This subsection provides a high-level overview of the system and its operation. Pictorials, graphics, videos, models, or other means may be used to provide this basic understanding of the concept.

1.2.2 System Scope

This section gives an estimate of the size and complexity of the system. It defines the system's external interfaces and enabling systems. It describes what the project will encompass and what will lie outside of the project's development.

2.0 Documents

2.1 Applicable Documents

This section lists all the documents, models, standards or other material that are applicable and some or all of which will form part of the requirements of the project.

2.2 Reference Documents

This section provides supplemental information that might be useful in understanding the system or its scenarios.

3.0 Description of Envisioned System

This section provides a more detailed description of the envisioned system and its operation as contained in the following subsections.

3.1 Needs, Goals and Objectives of Envisioned System

This section describes the needs, goals, and objectives as expectations for the system capabilities, behavior, and operations. It may also point to a separate document or model that contains the current up-to-date agreed-to expectations.

3.2 Overview of System and Key Elements

This section describes at a functional level the various elements that will make up the system, including the users and operators. These descriptions should be implementation free; that is, not specific to any implementation or design but rather a general description of what the system and its elements will be expected to do. Graphics, pictorials, videos, and models may be used to aid this description.

3.3 Interfaces

This section describes the interfaces of the system with any other systems that are external to the project. It may also include high-level interfaces between the major envisioned elements of the system. Interfaces may include mechanical, electrical, human user/operator, fluid, radio frequency, data, or other types of interactions.

3.4 Modes of Operations

This section describes the various modes or configurations that the system may need in order to accomplish its intended purpose throughout its life cycle. This may include modes needed in the development of the system, such as for testing or training, as well as various modes that will be needed during it operational and disposal phases.

3.5 Proposed Capabilities

This section describes the various capabilities that the envisioned system will provide. These capabilities cover the entire life cycle of the system's operation, including special capabilities needed for the verification/validation of the system, its capabilities during its intended operations, and any special capabilities needed during the decommissioning or disposal process.

4.0 Physical Environment

This section should describe the environment that the system will be expected to perform in throughout its life cycle, including integration, tests, and transportation. This may include expected and off-nominal temperatures, pressures, radiation, winds, and other atmospheric, space, or aquatic conditions. A description of whether the system needs to operate, tolerate with degraded performance, or just survive in these conditions should be noted.

5.0 Support Environment

This section describes how the envisioned system will be supported after being fielded. This includes how operational planning will be performed and how commanding or other uploads will be determined and provided, as required. Discussions may include **how** *the envisioned system would be maintained, repaired, replaced, it's sparing philosophy, and how future upgrades may be performed. It may also include assumptions on the level of continued support from the design teams.*

6.0 Operational Scenarios, Use Cases and/or Design Reference Missions

This section takes key scenarios, use cases, or DRM and discusses what the envisioned system provides or how it functions throughout that single-thread timeline. The number of scenarios, use cases, or DRMs discussed should cover both nominal and off-nominal conditions and cover all expected functions and capabilities. A good practice is to label each of these scenarios to facilitate requirements traceability; e.g., [DRM-0100], [DRM-0200], etc.

6.1 Nominal Conditions

These scenarios, use cases, or DRMs cover how the envisioned system will operate under normal circumstances where there are no problems or anomalies taking place.

6.2 Off-Nominal Conditions

These scenarios cover cases where some condition has occurred that will need the system to perform in a way that is different from normal. This would cover failures, low performance, unexpected environmental conditions, or operator errors. These scenarios should reveal any additional capabilities or safeguards that are needed in the system.

7.0 Impact Considerations

This section describes the potential impacts, both positive and negative, on the environment and other areas.

7.1 Environmental Impacts

Describes how the envisioned system could impact the environment of the local area, state, country, worldwide, space, and other planetary bodies as appropriate for the systems intended purpose. This includes the possibility of the generation of any orbital debris, potential contamination of other planetary bodies or atmosphere, and generation of hazardous wastes that will need disposal on earth and other factors. Impacts should cover the entire life cycle of the system from development through disposal.

7.2 Organizational Impacts

Describes how the envisioned system could impact existing or future organizational aspects. This would include the need for hiring specialists or operators, specialized or widespread training or retraining, and use of multiple organizations.

7.3 Scientific/Technical Impacts

This subsection describes the anticipated scientific or technical impact of a successful mission or deployment, what scientific questions will be answered, what knowledge gaps will be filled, and what services will be provided. If the purpose of this system is to improve *operations or logistics instead of science, describe the anticipated impact of the system in those terms.*

8.0 Risks and Potential Issues

This section describes any risks and potential issues associated with the development, operations or disposal of the envisioned system. Also includes concerns/risks with the project schedule, staffing support, or implementation approach. Allocate subsections as needed for each risk or issue consideration. Pay special attention to closeout issues at the end of the project.

Appendix A Acronyms

This part lists each acronym used in the ConOps and spells it out.

Appendix B Glossary of Terms

The part lists key terms used in the ConOps and provides a description of their meaning.

Appendix J: PSAT1U Baseline Model

The PSAT1U Baseline Model is an MBSE representation of the satellite. The baseline model is unique in that it defines all of the important subsystems, components, and interfaces of the PSAT1U, but leaves the payload and mission specific modules undefined. This allows a user to understand the payload design space in clear terms. In this way, a practitioner can apply their mission application and the components associated with it to the baseline model to create their own mission specific model.

The model was developed using CAMEO Systems Modeler MBSE Software V19.0. Each predefined architecture package or template was created to represent a corresponding system or subsystem on the physical PSAT1U satellite design. As an example, Section 10, the overall Architecture Hierarchy of the PSAT1U Baseline Model is depicted in Figure J.1-1.

The Architecture Hierarchy encompasses all of the subsystems, subsystem components and ground system components along with the domain, enterprise and segment packages.

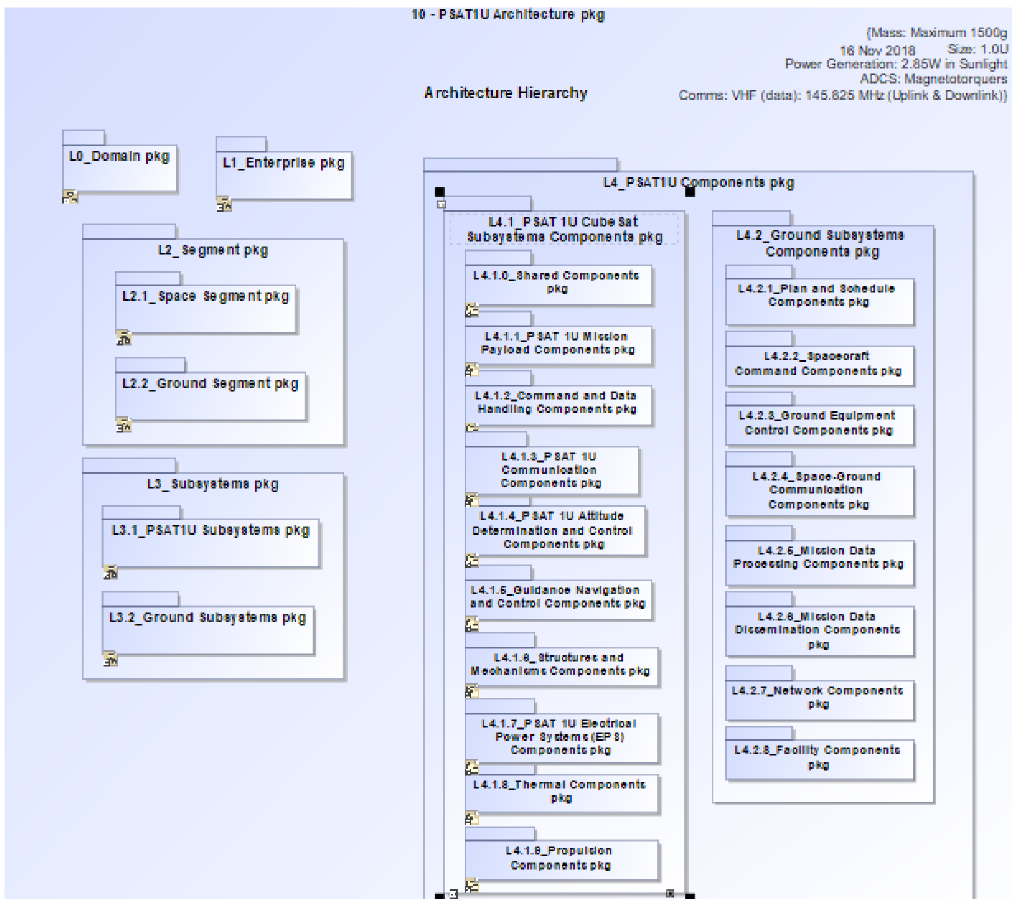

Figure J.1-1 PSAT1U Baseline Model Architecture Hierarchy

From within the Architecture Hierarchy, any of the Subsystem Structures Packages can be accessed and critical information and interfaces can be reviewed and understood. Figure J.1-2, for example, represents the ADCS Subsystem Block Definition Diagram and its relationships with other parts of the structures package and shared components. In turn, more information and relationships are contained within each instance of a subsystem or component.

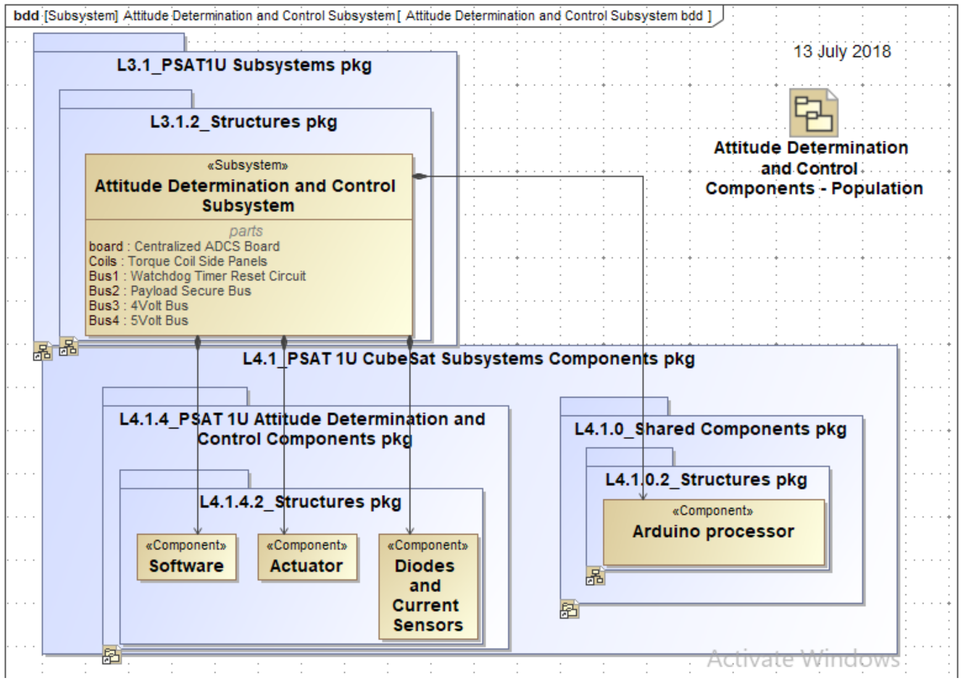

Figure J.1-2 ADCS Subsystem Block Definition Diagram

Figure J.1-3 is the package diagram describing the Electrical Power System for the spacecraft. In it, each of the main component parts are described and further details and specifications of those parts are also available. Within the specification for the EPS, pertinent information such as the as-designed power budget (Figure J.1-4) is also available.

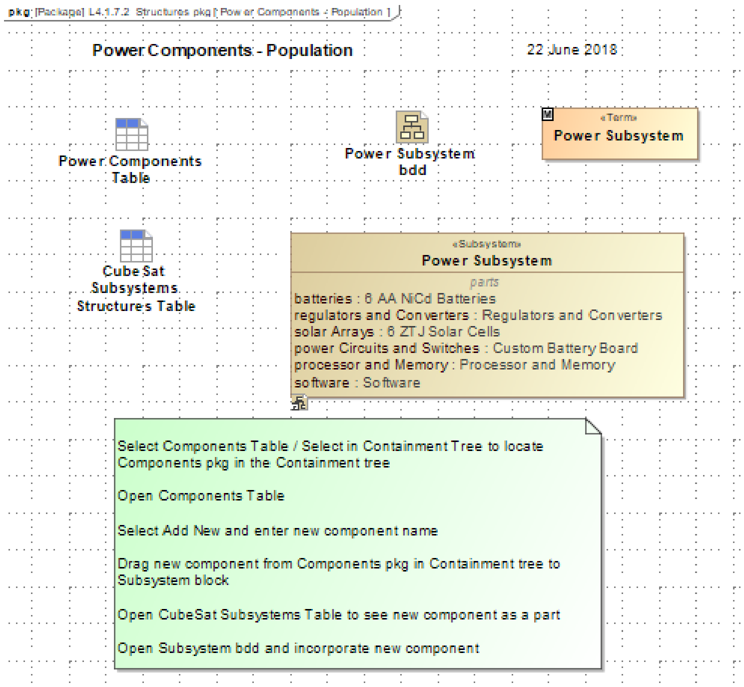

Figure J.1-3 Electrical Power System Package Diagram

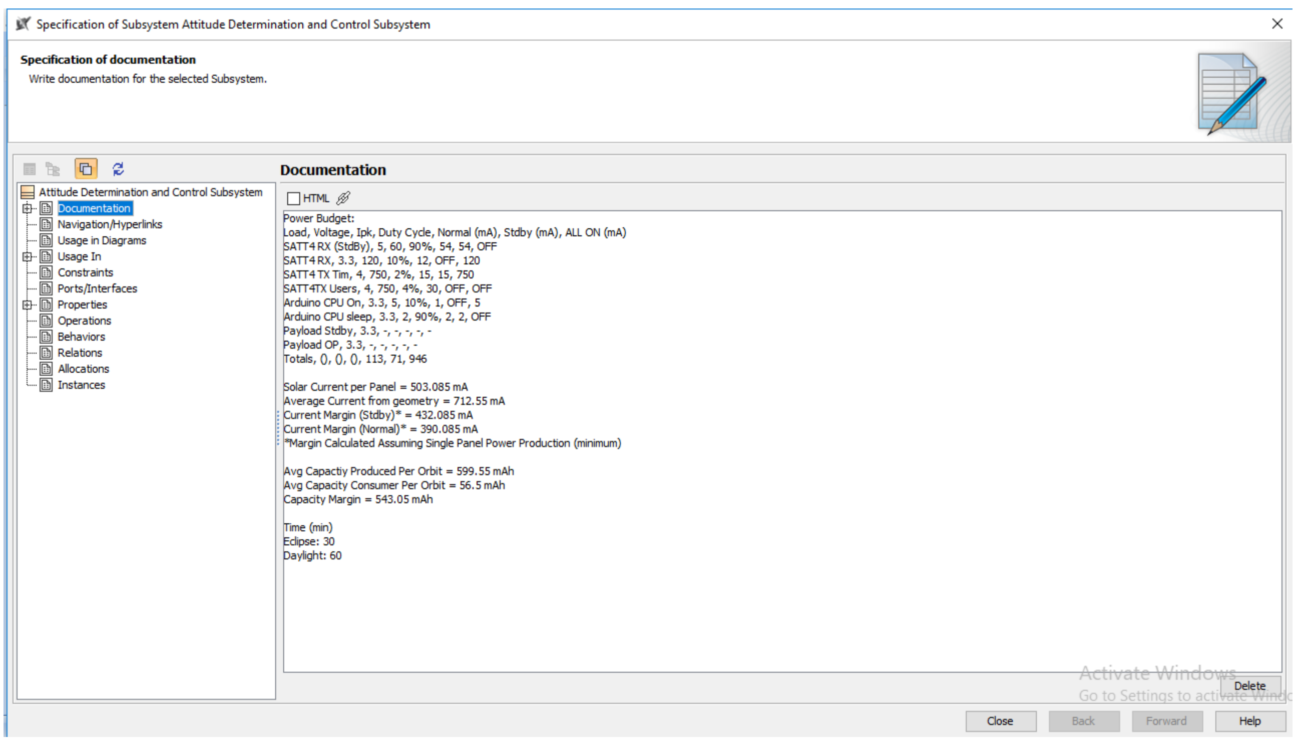

Figure J.1-4 Specification for Electrical Power System including Power Budget Information