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The A.I.T. Activities Flow in the System Engineering Process for a Multi-Application Satellite Platform

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ACRONYMS LIST

ABCL – As Built Configuration List

ADCL – As Designed Configuration List

AIT – Assembly Integration Test

AIV – Assembly Integration Verification

AR – Acceptance Review

CDR – Critical Design Review

CRR – Commissioning Readiness Review

DDF – Design Definition File

DJF – Design Justification File

ECSS – European Cooperation for Space Standardization

EGSE – Electrical Ground Support System

ELF – End of Life Review

FGSE – Fluidic Ground Support System

FRR – Facility Readiness Review/Flight Readiness Review

GSE – Ground Support System

ICD – Interface Control Document

IRD – Interface Requirement Document

LRR – Launch Readiness Review

MCR - Mission Close Out Review

MDD – Mission Description Document

MDR – Mission Description Review

MGSE – Mechanical Ground Support System

MP – Management Plan

MS – Mission Statement

PA – Product Assurance

ORR – Operational Readiness Review

PDR – Preliminary Design Review

PRR – Preliminary Requirements Review

PTRS – Preliminary Technical Requirements Specification

PTR – Post Test Review

QA – Quality Assurance

QR – Qualification Review

SRR – System Requirement Review

TB – Technical Budget

TP – Technology Plan

TRB –Test Review Board

TRS –Technical Requirement Specification

TRR – Test Readiness Review

1. ABSTRACT

The business function in charge of realizing the Space Segment Systems and their sub parts is the A.I.T Function. It deals with the planning and the execution of the Assembly, Integration and Testing activities. In the business context of Sitael s.p.a. that aims to the qualification of a modular satellite platform, suitable both for the realization of constellations and for the application in different missions, the thesis work aims to analyze the AIT activities flow.

The thesis work was conducted through a research work that allowed the comprehension of the dynamics that lead to the Space Project Development: the logic of the requirements allocation and verification in order to fulfill the stakeholders needs through the selected design solution, the product realization and testing activities and their planning in order to guarantee the in time validation and utilization of the space product.

The AIT activities are grafted on the overall activities structure in order to guarantee the definition of an efficient test program for the requirements verification and the development of the design solutions that respect the Integrability and Testability principles. These activities are related to the selection and development of tools like Facilities and Ground Support Equipment that enable the operational AIT activities through traceable and repeatable processes.

The internship carried out in Sitael s.p.a allowed the direct observation of the tasks performed by the AIT Function and the needs tied to the business objectives in order to realize the activities planning and to structure the division of roles respecting the real needs.

The result of this work is the macro-activities organizational Structure for AIT tasks, that respects rules settled by the European Cooperation for Space Standardization (ECSS) and the Business needs. The AIT macro-activities have been also divided into elementary tasks manageable for the analysis of input, output, employed resources and constraints, respecting the standardization of the IDEF 0 Business Process Modelling.

The activities have been organized in order to respect the milestones of a qualification campaign. The modular logic makes the activities flow adaptable for the AIT campaign tied to the different models foreseen (development, qualification and acceptance models). The activities time stream is adapted to the milestones and deliverable of the Space Mission respecting the iterative and recursive logic of the V-Model for System Engineering.

2. THE SYSTEM ENGINEERING DISCIPLINE

The technical effort necessary to transform requirements into a system solution is managed by an interdisciplinary approach defined "System Engineering" where the System is an integrated set of sub parts with a specified function that interact in order to accomplish an objective with a greater functionality. The elements of a systems are hardware, software, information but also human resources, facilities and other support elements.

In the perimeter of the Space Mission the concept of "system" could be used in a wide sense: for the Mission Level, that is the highest one, the "Space System" includes the Space Segment, Ground Segment and Launch Segment, where a Segment is defined as a combination of systems fulfilling a subset of objectives of a Space Mission.

The decomposition levels of a Segment are the following:

- Systems and Subsystems that, by a functional point of view, represent a set of interactive functions.
- Elements that, by a physical point of view, represent a combination of integrates equipment, components and parts.
- Equipment or unit that is an integrated set of parts and components accomplishing a specific function by a self-contained manufacturing, specification and use.
- Component or parts that is a set of material assembled by a specific process, that has a specific function evaluable by performance requirements.

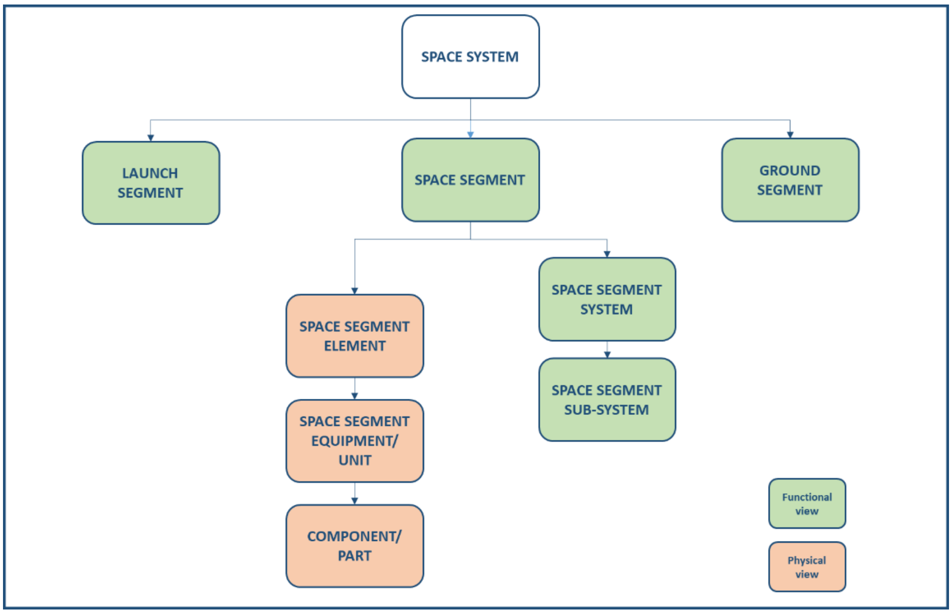

Figure 1 - Space System Breakdown

In The customer-supplier model, from the perspective of the considered element of the system, requirements are settled by the customer that is the next upper level of the system decomposition, and products are procured from the supplier at the next lower level.

Systems engineering is an integrative discipline, in which the contributions of many different disciplines are evaluated and balanced in order to produce a coherent integrated set of these disciplines with no one of them dominating the others.

The internal partition of System Engineering could be summarized by the following functions:
• requirement engineering that consist on requirement analysis, allocation, verification and maintenance.

• analysis performed to resolve requirements conflicts, to decompose and allocate requirements during the functional analysis and to provide trade studies for assessing risk, cost and planning factors.

• Design definition of system functional and physical architecture.

• Product realization tasks that lead, through implementation or integration process, to the product to be verified and transitioned to the next level.

• Verification activities, performed to demonstrate the conformity of the deliverable product to the specified requirements, including qualification and acceptance.

The boundary of the system engineering discipline is represented by the “Crosscutting Functions” that include product assurance and management. Management of a project includes the main objectives of managing the technical aspects, the project team, and the cost and schedule.

The **V-model** is a suitable graphical representation of the systems development lifecycle. It summarizes the main steps and corresponding deliverables of the project life cycle development, describing the activities to be performed to produce expected results.

The left side of the "V" represents the whole design activities that include the following steps:

- Definition of Stakeholders Expectations
- Definition of Requirements
- Definition of System Architecture
- Design Solution Definition

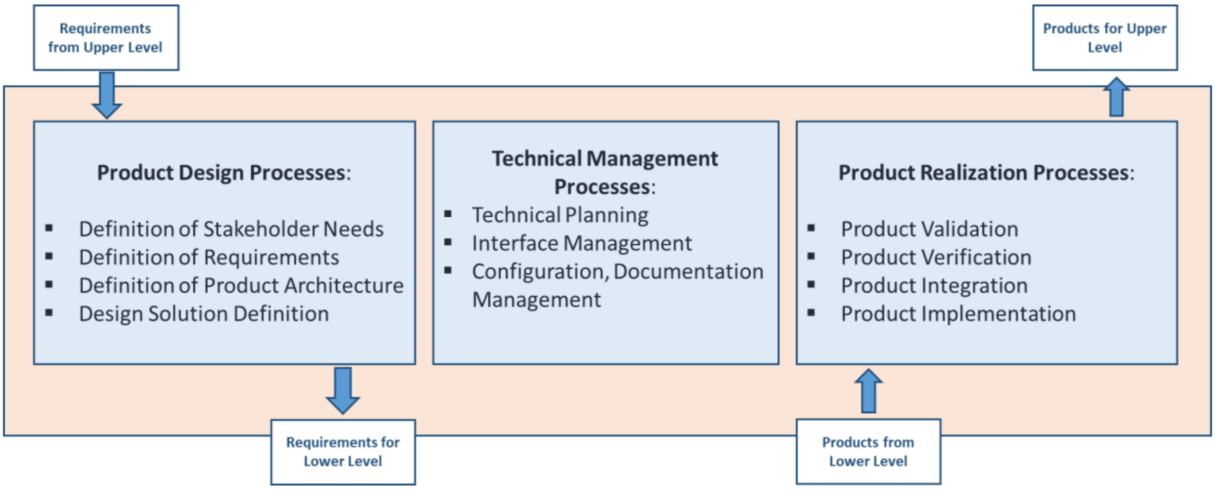

Figure 2 - The System Engineering Tasks

The right side of the "V" represents the whole product realization process, including the followings activities:

- Product Implementation
- Product Integration
- Product Verification
- Product Validation

Technical Management Process represents the whole "crosscutting activities", including the following tasks:

- Technical Planning
- Interface Management
- Configuration and Documentation/Information Management

The x-axis represents the time development of the activities, while the y-axis represents the level of detail of the activities based on the product decomposition level, with a top-down direction for the left side of the model and a bottom-up direction for the right side.

The design process defined by this model is applied to each product, from the top to the bottom of the system structure until the lowest products in the system structure branch can be only built, bought, or reused.

The product realization process is applied to each product in the system structure, starting from the lowest level and working up to the higher level integrated products. These processes are used to realize the design solution of each product, making it ready for the transition up to the next hierarchical level

Technical Management Processes establishes technical plans to manage communication across interfaces, and assess progress against the plans and requirements controlling the technical execution of the project through to completion, and aiding the decision-making process.

These processes are used both iteratively and recursively, where "iterative" is defined the application of the process to the same product to manage discrepancy or other variation from requirements, whereas "recursive" is defined as adding value to the system repeating the design process to the next lower layer of the system or repeating the realization process to the next upper layer till the end products.

The technical processes are applied recursively and iteratively to break down the preliminary concepts of the system reaching a level of detail sufficient to allow the technical team to implement the product from the input information.

This process is also repeated to the system structure in the next life cycle phase in order to increase maturity of the system definition and satisfy phase success criteria.

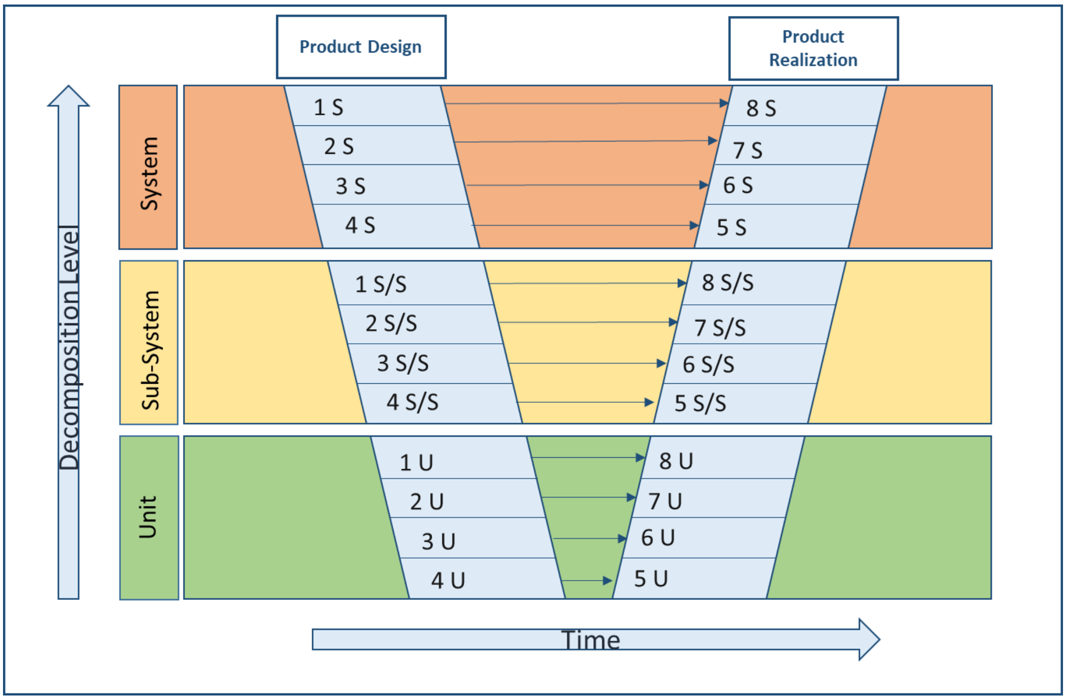

Figure 3 - The System Engineering 'V Model'

3. PROJECT DEVELOPEMENT PHASES DEFINITION

The life cycle of space projects is divided into seven Project Phases that are linked to the correspondent set of activities to perform at each product level in order to ensure the timely realization of the Space Mission. Each Phase is concluded by a specific review that verify the completion of the expected activities.

The typical phases are, as follows:

• Phase 0 - Mission analysis/needs identification

• Phase A - Feasibility

• Phase B - Preliminary Design Definition

• Phase C - Detailed Design Definition

• Phase D - Qualification and Production

• Phase E –Utilization

• Phase F – Disposal

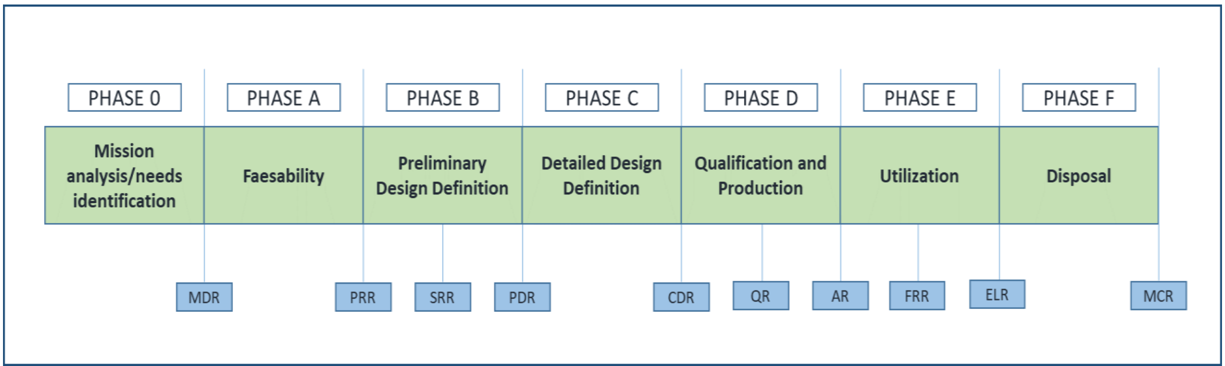

Figure 4 - Space Mission Phases

PHASE 0:

This phase is typically focused on establishing mission goals and formulating top-level system requirements and Concept of Operation. The demonstration of the feasibility, rather than optimality, is based on conceptual designs, limited in both depth and number of options, and economic studies support programmatic estimates.

During this phase the Mission Statement document is elaborated, containing mission needs, expected performance, mission operating constraints with respect to the physical and operational environment and safety goals. The associated review is the Mission Definition

Review (MDR) that has the aim to release the Preliminary Technical Requirements Specification (PTRS) and the Mission Statement (MS).

PHASE A:

During Phase A, the team effort focuses on analysis of the mission requirements and the mission architecture to compare against the identified needs, identifying levels of uncertainty and risks. Many alternatives through system and subsystem tradeoffs are considered in a process of iteration to seek out more cost-effective designs.

The project develops more definition in the system functional and performance requirements, top level system architecture and preliminary system requirements to next lower level. Conceptual design is developed including more engineering detail and technology development needs, allowing the identification of critical technologies for which pre-development activities are foreseen.

During Phase A, functions are allocated to items of hardware, software, personnel by establishing the function tree and various engineering and management plans are prepared for managing the project's following processes, such as verification and operations plans.

Verification approach is settled and documented in the verification plan, to be further elaborated during Phase B.

The associated review is the Preliminary Requirements Review (PRR). It confirms the programmatic feasibility of the system concept by releasing the preliminary management plan and preliminary engineering plan and confirm the technical feasibility of the system concepts releasing the technical requirements specification.

Phase B

During Phase B, activities are performed to establish an initial project baseline, which includes a formal flow down of the project-level performance requirements to a complete set of system and subsystem design specifications and corresponding preliminary designs.

Technical requirements become detailed enough to establish a realistic schedule and cost estimates for the project.

Phase B is where the top-level requirements and the requirements flowed down to the next level are finalized and placed under configuration control by the complete definition of the product and specification tree after the several changes due to the trade-off studies.

Establishment of baselines implies the beginning of configuration management procedures.

In Phase B the functionally complete preliminary design solution that meets mission goals and objectives is defined.

Engineering test items may be developed to obtains more data for further design work, and project risks are reduced by successful technology developments and demonstrations.

Phase B ends with a series of PDR that define the transition of requirements into designs solution and, almost all changes to the baseline will be refinements and not fundamental changes.

During PDR the final management plan, work breakdown structure, product assurance plan and engineering plan are delivered both with the updated reliability and safety assessment. Verification of the preliminary design of the selected concept and technical solutions against project and system requirements leads to the update of the risk assessment and the definition of the Development Configuration Baseline.

Phase C

During Phase C, a complete design is realized, hardware and software are produced to be further integrated. The scope and type of tasks, during this phase, are driven by the model philosophy selected for the project, as well as the verification approach adopted.

Engineering test units are built and tested to establish confidence with respect to the design functioning in the expected environments and pre-qualification activity of previously selected critical elements allows the qualification status of the critical processes and all design changes are tracked and controlled by the Configuration management and at each step of refinement of the final design corresponding integration and verification activities become more detailed.

Engineering analysis results are integrated into the design, and the manufacturing process and controls are defined and validated.

During CDRs, that follow the integration bottom-up sequence, the detailed design definition of the system at all levels of the customer-supplier chain is completed, including internal and external interfaces and their compatibility is documented by the issue of the preliminary User Manual and the assembly, integration and test planning for the system and its constituent parts is completed and released.

Phase D

During Phase D, activities are performed to assemble, integrate, test, and launch the system after the Flight Readiness Review (FRR). The activities conducted in this phase of the project, are planned since Phase A in order to consider all the requirements for testing and operations.

Phase D objective is to demonstrate, by the complete qualification testing of qualification models, that the system is capable of accomplishing the purpose for which it was created, and to perform the complete testing of flight models and associated ground support equipment, and the complete testing between the space and ground segment and the preparation of the acceptance data package.

During phase D three types of project reviews take place:

• The qualification review (QR) that confirms that the design meets the requirements with the accepted deviations and to verify that the verification record is complete at this and all lower levels in the customer-supplier chain. In case of production of recurring products, the QR is completed by a functional configuration verification that analyzes the first article configuration for reproducibility, in order to release the production master files and the series production go–ahead file.

• The acceptance review (AR) held at the end of the phase to judge the readiness of the product for delivery without workmanship errors and for subsequent operational use with the accepted waivers with the acceptance verification record completed at this and all lower levels in the customer-supplier chain, allowing the issue of the acceptance certificate.

During AR the product becomes available to the "as-built" verification against the "as designed" configuration.

• The operational readiness review (ORR), held at the end of the phase has the objectives of verify readiness of the operational procedures and to accept and release the ground segment for operations.

Phase E

The major tasks for this phase concern the activities at space and ground segment level in order to prepare and conduct the launch and early orbital operations, perform on-orbit verification activities and all on-orbit operations in order to achieve the mission objectives.

All ground segment activities are performed in order to support the mission till the disposal, defined by the finalized disposal plan.

The associated reviews are:

• Flight readiness review (FRR) conducted prior to launch to verify that the flight and ground segments including all supporting systems such as tracking systems, communication systems and safety systems are ready for launch.

•Launch readiness review (LRR) that is conducted just prior to launch to declare readiness for launch of the launch vehicle, the space and ground segments and all supporting systems, providing the authorization to proceed for launch.

•Commissioning result review (CRR) that is held at the end of the commissioning as part of the in-orbit stage verification. It allows declaring readiness for routine operations after the completion of a series of on-orbit tests designed to verify that all elements of the system are performing within the specified performance parameters.

•End of life review (ELR) to verify that the mission has completed its useful operation or service and to ensure that all on-orbit elements are configured to allow safe disposal.

Phase F

During the Phase F all the disposal activities foreseen by the Disposal Plan are performed and the evaluation of their adequately completion is assessed during the Mission Close Out Review (MCR).

The MDR involves only the project initiator, and the top level customer while all the other project reviews up to the AR are carried out by all level supplier in the customer-supplier chain. From the PRR to the PDR, the sequence of the reviews is “top down”, starting with the top level customer to the lowest level supplier. From the CDR to the AR, the sequence of reviews is “bottom up”, starting with the lowest level supplier up to the top level customer.

3.1 REQUIREMENT ENGINEERING

The Requirements Engineering is a recursive and iterative Process that transforms the stakeholder expectations into a complete set of product requirements later used to define a design solution for all the elements belonging to the Product Breakdown Structure (PBS).
Typical inputs needed for the requirements process include:

• Stakeholder Expectations: Needs, goals, objectives, constraints;

• Concept of Operations: It describes the system characteristics during the life cycle phases from an operational perspective and helps an understanding of the system goals, objectives, and constraints. It includes scenarios, use cases, design reference that enables to understand how the system will meet stakeholder expectations.

The top-level requirements are initially assessed to overview the technical problem to be solved and to establish the design constraints that limit how the system will be used, identifying elements that cannot be changed because already under design control, and elements that needs further trades analysis to converge to potential design solutions. The top level requirements identify external enabling systems with which the system should interact and establishing physical and functional interfaces.

A complete set of project requirements includes also the requirements decomposed and allocated down to design elements through the Product Breakdown Structure and those that cut across product boundaries.

Requirements can be functional, performance and interface requirements while crosscutting requirements include environmental, safety, human factors, design and construction standards.

An important part of requirements definition is the validation of the requirements against the stakeholder needs which means that the requirements are feasible, verifiable, technically correct, not redundant and satisfy stakeholders in order to proceed with the next process of Logical Decomposition and Design Solution Definition. The process for managing change in requirements should be established, documented in the project information repository, and communicated to stakeholders.

Logical decomposition is the process to create the set of detailed **functional requirements** to meet the stakeholder expectations identifying the aims to be achieved at each system level for a successful project.

Through Logical decomposition top-level requirements are allocates to the lowest levels of the project by the means of the **functional analysis that creates a system functional architecture**. The functional architecture of the system is the set of functions, sub-functions, their interfaces and the performance requirements to satisfy the requirements of the TS.

Functional analysis if performed through the following steps:

1. Transform top-level requirements into functions that should be performed to accomplish the requirements.
2. Decompose and allocate the functions to successive levels of the product breakdown structure.
3. Identify and describe functional and subsystem interfaces characteristics.

Each function is characterized by its inputs and outputs, failures and their consequence and interface requirements.

The process is repeated in a recursive and iterative way to analyze all the PBS levels foreseen by the baseline in order to recognize sub-functions as part of larger functional areas.

The functional architecture is the starting point for the function tree that is the document that describes the decomposition of the system and product capabilities into successive hierarchical level of functions and sub-functions.

The function tree is the starting point for the establishment of the Product Tree that is the breakdown of the physical architecture resulting by the physical analysis. The product tree is the breakdown of the project into successive levels of hardware and software products that perform the functions identified in the function tree.

The system architecture obtained by the functional analysis defines the underlying structure and relationships of hardware, software, support personnel, communications, operations needed to implement the project. The System architecture allows the partitioning of system elements and requirements to lower level functions enabling the accomplishment of design work. It enables the separated development of the elements, defining what the element is expected to do during its life cycle, and the relationship to each other, while ensuring that all element work together to achieve the top-level requirements.

From the logical decomposition and the allocation of functional requirements, a complete set of requirements related to the selected architecture and that were not initially baselined, flows down in the specification tree. All the requirements are allocated to the system architecture and functions.

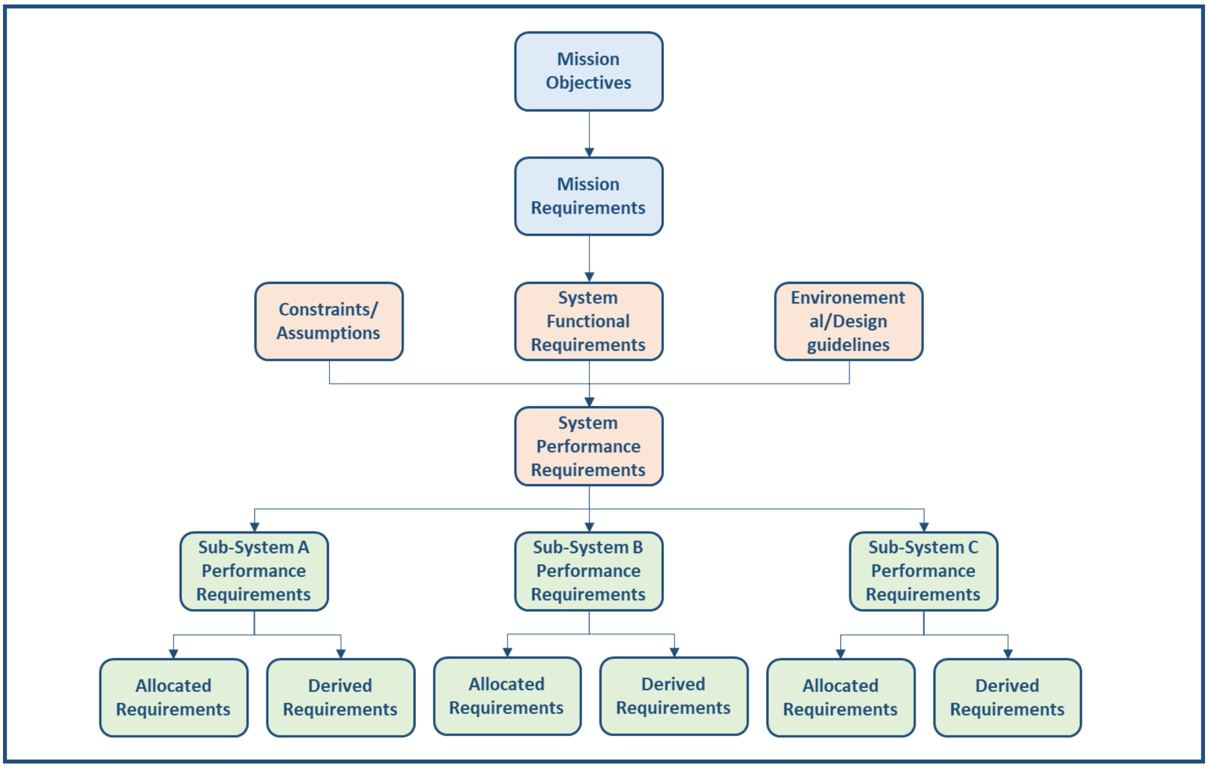

Figure 5 - The Requirements Flowdown

These requirements belong to the following types:

- Functional Requirements: define what the product shall perform, in order to conform to the needs of mission statement and to the requirements of the user.
- Mission Requirements: related to task, function, constraint, induced by the mission scenario.
- Environmental Requirements: related to a product or the system environment during its life cycle, including the natural and induced environments.
- Operational Requirements: related to the operational profiles and the utilization environment and events.
- Logistics related Requirements: considerations to ensure the support of a system for its life cycle including the constraints of maintenance, packaging, transportation, handling and storage, user documentation.
- Interface Requirements: related to the interconnection or relationship characteristics between the product and other items, including both functional and physical characteristics.
- Physical Requirements: ensure physical compatibility when it is not defined by the interface, design and construction requirements, or referenced drawings. This includes requirements related to mechanical characteristics, electrical isolation and chemical composition.

- Design Requirements: related to the imposed design and construction standards such as design standards, selection list of components or materials, interchangeability, safety or margins.
- Verification Requirements: related to the imposed verification methods, such as compliance to verification standards, usage of test methods or facilities.
- Product Assurance Requirements: are related to the relevant activities covered by the product assurance including reliability, availability, maintainability, safety, and quality assurance.
- Configuration Requirements: related to the composition of the product or its organization.

Each technical requirement shall be defined in quantifiable terms in order to describe a precise performance for each parameter with its tolerance, and a range of values within which the conformity to the requirement can be accepted. The method used to determine the required performance shall be indicated in order to avoid ambiguities and redundance and each technical requirement should be justified by the responsible of the technical requirement and should be under configuration management in order to backwards and forward trace the history, application, or location of a requirement by means of recorded identification finding the source from which it derives and to ensure that each level requirement is implemented at the appropriate phase of the design and that all requirements are implemented.

Technical Requirements tasks and Documents per Project Phase:

Technical Requirements for space project are frozen in the **Technical Requirements Specification** that is the starting point for the implementation of design and development of the proposed solution. The technical requirements specification presents the requirements to be met by the future solution, including compatibility with the intended purpose of the product and considering product related to other products, its associated constraints and environment, and the operational and performance features for each relevant situation of its life profile.

During Phase-0, considering the Customer-Supplier chain, the customer identifies and captures the user's needs or mission statements, associated environments and constraints and expresses these in terms of technical requirements and each individual technical requirement is structured, classified and justified. The customer assesses the entire set of technical requirements for correctness, consistency and suitability for the intended use to establish the preliminary TS and release it.

During Phase-A, the customer reviews the preliminary TS, identifies and proposes possible concepts and identifies the need for changes to the preliminary TS taking into account the limitations and possibilities induced by the selected preferred concepts. Then, he expresses the adjusted or new individual technical requirements, establishing the TS and releasing it.
During Phase-B, the customer can decide to update a few elements of hits TS and it is typically done as a result of the SRR.
The process described is applicable at each product decomposition level where the solution to be developed is for establishing a product level specification. The same process is used to settle down the lower-level specification but the process starts during phase A.

The specification tree document is delivered as part of the Design Definition File to define the hierarchical relationship of all technical requirements specifications for the different elements of a system or product while the Requirement Traceability Matrix defines the relationships between the requirements of a deliverable product defined by a technical requirements specification and the apportioned requirements of the product lower level elements in order to verify that all stated and derived requirements are allocated to system components and in order to determine the source of requirements by the backward trace.

3.2 DESIGN SOLUTION DEFINITION

The system design processes are interdependent, iterative and recursive processes performed through a multilayered set of suppliers and that result in a validated set of requirements and a design solution that satisfies a set of stakeholder expectations. There are four system design processes: development of stakeholder expectations, definition of technical requirements, logical decompositions, and design solutions definition.

During the first phase of the development of a space project, the System Engineering derives design oriented technical solutions responding to the input settled by the design-independent customer requirements through an iterative top-down process that trades off several design solutions with increasing level of detail.

The depth of the design characterization should allow analytical verification of the design that should be feasible and credible and should allow cost modeling and operational assessment.

3.2.1 Stakeholder Expectation

The system Design Process starts with the identification of Stakeholder and their expectations for which the product is realized. One key stakeholder is always the "costumer" that varies depending on the layer that is considered in the Product Breakdown Structure: at the topmost level, the customer is the organization that is purchasing the product, while for the next decomposition levels, the customer may be the leader of the team that needs the element to integrate it into a larger assembly.

Stakeholder's expectations identify **needs** related to the problem that the system is supposed to solve, **goals** that are an elaboration of the needs in a specific set of expectations for the system without a quantitative or measurable form, but that allow to assess if they have been achieved. The **Objectives** are specific target levels of outputs relate to a particular goal that the system must achieve. They should be measurable, quantifiable, and verifiable.

After the stakeholder expectations definition, the **Concept of Operations** is described. It establishes the expected behavior of the system by an operational point of view and provides an understanding of the stakeholders' expectations without addressing the design that will satisfy the needs. It describes behavioral characteristics and the interaction between people and the system, considering all aspects of operations including timelines, scenarios, operational facilities, integrated logistic support, description of human interaction and required, integration, test, and launch through disposal.

3.2.2 System and operation concept selection

During Phase 0 the system engineering performs an analysis of the Mission Statement document that contains all the stakeholder expectations and maintains this document for the final selected concept while the Mission Description Document (MDD) provides input for the later selection of the best concept meeting the mission statement (MS) in iteration with the preparation of the Preliminary Technical Requirements specification (PTS).
MDD is prepared in Phase 0 and Phase A for each possible concept and defines a concept that will satisfy the preliminary technical requirements specification, describing how the objectives, operation profile, major system events capabilities and performance standards are expected to be achieved. The MDD is a complete description of each mission concept and the related System Engineering Plan is created to evaluate the related system engineering effort while the Management Plan contains the evaluation of the associated programmatic aspects.
The **System Concept Report** assesses the different concepts from a technical, programmatic and risk point of view by a trade-off that includes weighting factors, followed by a system concept selection**.**
The system concept report shall be an instantiation of the trade-off report at system level in Phase 0 and Phase A.

3.2.3 Technology Assessment

After the **Mission Statement analysis,** the **functional analysis** is performed producing the **functional architecture**, and producing the **function tree** which satisfy the preliminary customer technical requirements specification. It is the starting point for the establishment of the system physical architecture, and it is a basic structure to **establish technical requirements specifications** for each project level.
As the system architecture is developed, its particulars become clearer but also harder to change allowing the definition of the Design Solution.
The purpose of systems engineering is to realize the Design Solution Definition in the most functional, safe, cost-effective final system working within the schedule boundaries.

The basic idea is that before the decisions are made, the alternatives should be iteratively assessed with respect to the maturity of the required technology.
The creation of alternative design is based on the assessment of potential capabilities offered by the changing state of technology. A continual interaction between the technology development process and the design process ensures that the design reflects the realities of the available technology.
Technology assessment should be done iteratively until requirements and available resources are aligned within an acceptable risk condition.
Basing on the system architecture is then possible to **identify candidate technologies**, assessing the availability of and need to develop new technologies and document them in the **Technology Matrix**.
The proposed technologies are assessed and confirmed in terms of availability and maturity according to TRL levels that represents the achieved status of development of a technology.
Level 1 to 9 are defined as follows:

- TRL1: Basic principles observed and reported.
- TRL2: Technology concept and application formulated.
- TRL3: Proof-of-concept performed.
- TRL4: Component and breadboard validated in the laboratory environment.
- TRL5: Component and breadboard validated in the relevant environment.
- TRL6: System and subsystem model tested in the relevant ground or space environment.
- TRL7: System prototype demonstrated in a space environment.
- TRL8: System completed and flight-qualified through test and demonstrated by ground or flight test.
- TRL9: System “flight-proven” through successful mission operations.

The selected technology leads the **physical analysis** to the **physical architecture**. Description of physical architecture of the product includes the arrangement of elements, their decomposition, internal and external interfaces, physical constraints, information necessary for its identification, manufacturing, utilization, support, configuration management and removal from service are settled out and issued in the **Design Definition File**.
The rationale for the selection of the design solution, and the demonstration that the design meets the baseline requirements are recorded in the **Design Justification File** that is a collection of all documentation that traces the evolution of the design during the development and

maintenance of the product and provides access to coherent and demonstrated information which can be used to support decision-making in the analysis of change requests for the management of non-conformances. It contains analysis and trade-off reports concerning the evaluation of alternative design solutions and the justification of the selection.

3.2.4 Analysis

Design activity is based on the definition of mathematical models with constraints, boundary condition and assumptions based on a simplification of the real conditions. These models help the designer to assess how the design fulfils requirements and gives an insight on how to improve the design. The mathematical model is the starting point for the conduction of analysis. It shall be demonstrated that the analysis tools used are adequate for the intended purpose, providing a justification of assumptions made in tools, methods, models and input data, considering the influence of tolerances whenever potentially critical. All analysis data shall be traceable, and the organization responsible for the analysis shall provide procedures to ensure data traceability during product life.

Analysis results are both the input for a preliminary verification of the product design and the input for the technical budget allocation and margins definition for the next lower level product. It could be necessary the validation of the mathematical model selected for the analysis, by testing activity conducted on development models included in the model philosophy definition in order to perform correlation analysis.

The test-analysis correlation considers summary of test predictions, test results and applicable correlation criteria, applying the correlation between test and analytical data. The subsequent activity is the updating and changes performed on the mathematical model to achieve the correlation criteria.

The Test Prediction (TP) document provides the analysis prediction of response of the tested article to the specified test environment and loads. The TP is essential for developing test procedures, for defining the specific parameters to be monitored during the test and for assessing and interpreting the test data.

3.2.5 Design Definition Output

Through the evaluation of Functional Architecture, Requirement allocation, Physical Architecture and the Technology selection by a tradeoff analysis, the best design meeting the requirements is chosen. For each technology or technological element, the model philosophy is defined basing on the assessment of the maturity status and of the criticality of the technology with respect to functions′ requirements. This is the starting point for the definition of verification methods and strategies, and the link to product assurance aspects, defining the necessary activities to be performed in order to complete the acquisition of each Technical Solution.

Verification activities are related to the identification of **key engineering parameters,** providing the **specified value of the parameter**, the supplier's **margin resulting by the allocation of the parameter** to the lower level products, establishing the influence of all types of environments applied during each life profile event on system and its elements in terms of nominal and extreme environmental conditions including all applicable operational phases and for all types of environment. This information is shared in the Technical Budget (TB).

The criteria for qualification and acceptance will be defined and a specific program to conform to the specified value in case of nonconformance will be proposed.

The System Engineering establishes the **design and test factors** and margins applicable for design. Test factors are applied to specified parameters to demonstrate margins with respect to these parameters (qualification and acceptance factors).

During design definition phase **constraints** will arise regarding:

- **Production activities**: restrictions on assembling sequences, procedures and testing modes, exclusion zones, manufacturing environmental conditions, and conditions for procurement will arise.

- **Transportation, handling and storage of the product**: allowable envelopes, restrictions on transportation and storage, exclusion zones, packaging, shock levels, temperature range, humidity level, cleanliness condition and dangerous materials. It is necessary to ensure that the environment seen by the flight hardware during transportation does not exceed the acceptance level. The design must respect the handling, storage and transportation constraints.

- **Maintenance activities and procedures**: operational allowable envelopes, accessibility, tooling, support materials, parts availability, and deliveries. The satellite design should guarantee the capability of performing inspection, maintenance and testing during AIT campaign and on-ground storage without the need to remove equipment or activate the complete satellite. The characteristics of maintenance activities are derived from the design.

- The design definition and the planning activity allow the **identification of long lead items** and the start of procurement activity.

-AIT activities: The design of the flight object shall provide direct access to connectors, test ports and fixation points for AIT operation, handling or transportation. Test points must be accessible without the need to disconnect flight harness of an item of equipment.

Constraints for assembly, testing and handling activity and the evaluation of product tree and interfaces requirements contribute to the definition of Ground Segment Equipment.

Design Documentation

Design Definition File (DDF): It details the as-designed configuration baseline of the system's products and is built up and updated under the responsibility of the team in charge of system engineering. It is the technical baseline for the production, assembly, integration, test, operations and maintenance of the product.

It is a collection of all documentation that establishes the system or product characteristics such as lower-level technical specifications, design and interface description, drawings, electrical schematics, specified constraints on materials, manufacturing, processes, and logistic.

The DDF presents the constraints on production activities that result by the design definition: operational allowable envelopes, restrictions on assembling sequences, procedures and testing modes, exclusion zones, manufacturing environmental conditions, and conditions for procurement, constraints for transportation and storage like exclusion zones, packaging, shock levels, temperature environments, humidity, cleanliness, regulations, and dangerous materials for maintainability. DDF includes:

The Technology plan (TP): The objective of the technology plan is to define the approach, procedures, resources and organization to evaluate the ability of a critical technology to meet the intended requirements. The objective of this plan is also to ensure effective preparation of the technologies necessary for a timely implementation of the system, in accordance to the requirements. It is established for each item of the function tree and highlights the technical requirements, and the critical technology of each item.

The TP contains the description of development activities for each technology, their interrelations for a timing acquisition and procurement of the technological elements.

The technical budget (TB): It defines the nature, measure, specified value, metrics requirements and current actual or computed value for each selected key engineering parameter concerning system's products. Examples of key engineering parameters are mass, communication links, power, and on-board computer memory capacity. The TB contain a chart of parameter history that presents the evolution of the parameter's value at the different design maturity steps for which the evaluation of the parameter is performed and list the documentation sources: analysis report and verification report.

The Design Justification File (DJF): It contains the evolution of the design resulting by the activities performed during the design process:

• Analysis and trade-off reports concerning the evaluation of alternative design solutions and the justification of the choice.

• All design verification activities result.

• Test Reports on engineering model, structural and thermal model and qualification model.

The DJF presents status of the design justification in response to requirements, with emphasis on the driving requirements that have a big impact on the system design, production and maintainability. The DJF shall present an overall system qualification status synthesis, including: the list of requirements which have not been met (non-conformances), including proposed actions, the list of all critical points, and how criticalities have been or are intended to be resolved, the identification of requirements which have not been justified yet, and associated risks analysis, with emphasis on those that can have an impact at system level.

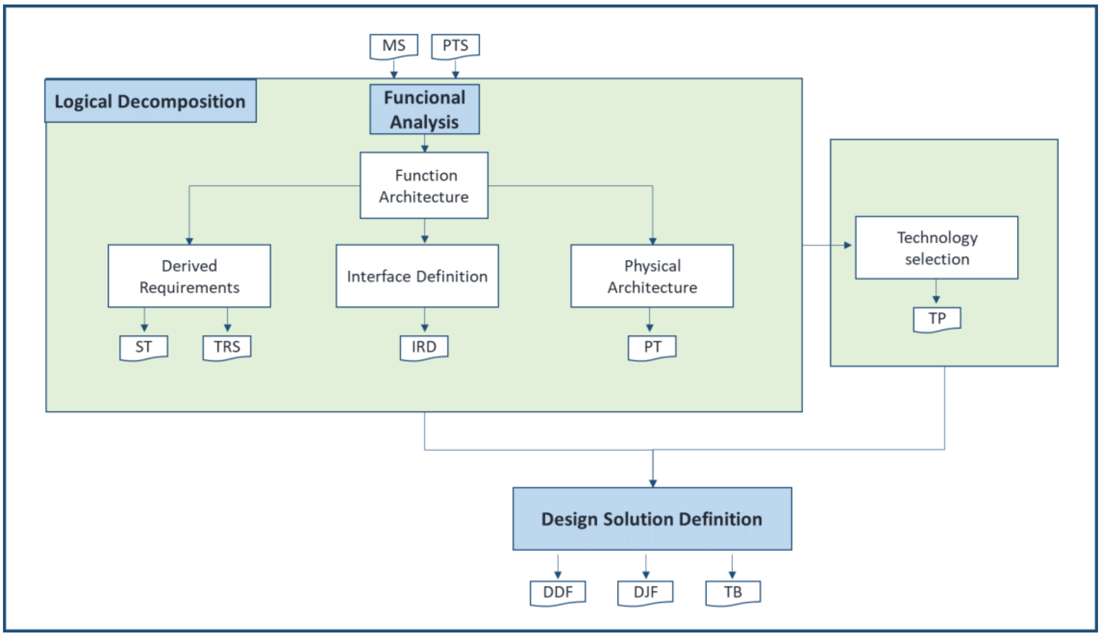

Figure 6 - Design Definition Tasks

3.3 PRODUCT REALIZATION

Realization process consists on the implementation or integration of product performed before the verification and validation activity in order to allow the transition of the end product for use it at the next level of the system structure or to realize the end product ready for its utilization.

3.3.1 Product Implementation

Product implementation is the first task in the bottom-up process for the realization of the end product. During this step actual products are realized basing on plans, analysis, requirements, designs and drawings. Product implementation is used to procure the product of a project or supporting activity in order to satisfy the design solution and its specified requirements through three types of activities:

- Purchasing from commercial or vendors.
- Making from a new design.
- Reusing products developed during other projects or during previous activities of the same project.

For complex products to integrate a combination of these three strategies can be used basing on the assessment of Decision Analysis Process.

With the aim of Making Products by the technical team, the inputs will be the configuration-controlled design specifications including constraints for selected raw materials, manufacturing plans, processes and procedures. The design specifications need to be reviewed to ensure they allow the product to be developed and the availability of all piece parts, the availability of personnel and their training level and skills, the availability of enabling tools and facilities and other support services should also be reviewed to guarantee the actual capability of making the product.

The technical team should work with the quality organization to review, inspect, and discuss progress and status, documented within the technical schedules, with the team and with higher levels of management as appropriate. As production of components proceeds any nonconformance to specifications has to be find out and reviews in order to assess whether the components can be accepted, reworked, or scrapped and remade.

Inputs needed to reuse end product consist in the product itself and all the associated documentation that describes specifications, the design, the as built configuration, user and operations manuals, discrepancy reports, waivers and deviations, manufacturing processes and procedures and the environment for which it has been qualified, with the aim to assess the readiness of the product for the phase of the life cycle or the need to perform upgrade in the design factors of safety, margins, and other required design and construction standards and delta qualification activity.

If the product will be bought as a Commercial Off-the-Shelf (COTS) item, the Design to purchase specifications resulting by the requirements development process, need to be checked and provided as input to the vendor, to make sure they adequately describe the vendor characteristics to narrow to a single model.

The technical team needs to work with the acquisition team to ensure the accuracy of the purchase order and to ensure that adequate documentation, certificates of compliance, or other specific needs are requested from the vendor, assessing the possibility of a product provided as a fully verified product or could be verified by the internal technical team.

The technical team should work as a reviewer of the technical information during the selection of the vendor that best meets the design requirements for acceptable cost and schedule and considering the Product assurance requirements that will guide the inspection of the delivered product and its accompanying documentation. The team should ensure that the requested product corresponds to the one delivered, and that the necessary documentation have been received.

For every selected implementation form, all work products from the make, buy or reuse process should be captured, including as-built design drawings, design documentation, design models, model descriptions, procedures used, operator and maintenance manuals, or other appropriate documentation.

Unless the vendor performs verification, the made, purchased, or reused end product, in a form appropriate for the life cycle phase, is provided for the verification process together with the Documentation for the technical data management process. Documentation includes as-built design drawings, operation, user, maintenance, or training manuals, applicable baseline documents such as as-built specifications and configuration information, certificates of compliance.

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

3.3.2 Product Integration

Product integration is the activity that aims at the realization of the final Product through the interactions of its lower level products and the verification of the proper functioning of each one in the articulated functional architecture of the overall system.

Assembly is a pre-requisite for integration by physically combining parts, components, equipment or segment elements to form a larger entity.

Even if the physical integration of mechanical, software and EEE products is performed during the top down phase of the "V Model" Engineering System, integration activities start during the the Project development

Integration of products guides the requirements derivation and allocation ensuring the compatibility between requirements, their justification and forward and backward traceability in the requirement specification tree. This analysis enables the effective operation of the product respecting the technical and environmental constraints.

The definition of logical, thermo-mechanical, fluidic, electrical and data interface enables the logical connection between parts and the definition of interface requirements and design solution represents the system interaction pathway.

System interactions is a guiding principle of the design process in order to maintain a balance between the subsystems performance that optimizes the system performance in an elegant and efficient design.

Development models and test of components, assemblies and systems is a key means to achieve confidence about system interactions, and the evaluation of feasibility of integration procedures including human in the loop evaluations, and environmental interaction.

Several teams of system engineering are included in the definition phase to balance the design activities and their collaboration ensures the final interaction between parts and the correct time planning of the many activities to be performed to accomplish the integration. These activities are planned and described in a logical way in the Integration Plan that includes the layout of tests that occur during the integration phase.

The execution activities of integration foreseen during the development phase are detailed in an integration process that includes the procurement of the enabling technology like mechanical, fluidic, electric, optical Ground Support Systems, and technical instrumentation, the availability of facilities and related systems that allow the performance of integration and test of the product and the skills, training and certification needed by the integration operators.

These enabling technology and services are also included in the development of the functional, product and specification tree. They contribute to the definition of interface and their configuration depends on the selected design solution. The detailed utilization of these enabling technology and skills during the integration process is detailed in the integration procedures that list every action to be conducted to obtain the end product as a result of the integrability constraints considered during the development phase.

In order to guarantee the correct integration, the verification and validation of the Lower Level Product Implemented to be integrated and their documentation is a key prerequisite. The documentation includes Design Descriptions and Drawings, user Manuals, storage, handling and transportation constraints and procedures and the Configuration Documentation, fundamental to maintain the coherent traceability in the following Configuration Documentation of the end product.

Functional testing of the assembled or integrated unit is conducted to check key functions and to ensure that assembly is ready for the subsequent formal verification and testing activities and for the integration into the next level.

Work products, including reports, records of product integration activities and facility reports, system and component documentation describing sequences for selected assemblies and assumptions that were made, identified anomalies and associated corrective actions, lessons learnt in performing the assembly, updated product configuration and support documentation are properly compiled and stored.

3.4 PRODUCT VERIFICATION

The objective of verification is to demonstrate, through a dedicated process, that the deliverable product whether built, coded, bought, or reused, meets the specified requirements. The steps of Verification activities are as follows:

- the qualification of design and performance, as meeting the specified requirements at the specified levels
- the demonstration of the acceptance for use of the product that agrees with the qualified design, and its freedom from workmanship defects;
- the confirmation of product integrity and performance level at particular steps of the project life cycle and the ability of the overall system to fulfil mission requirements.

Product verification is the means to demonstrate that the product has been correctly built and that the design solution respects the requirements specification and that the end product respects the design solution without defects. Verification process does not provide the evidence of the product fulfilling the customer needs and expectation. This latter demonstration is accomplished by Validation activity.

2.4.1 Verification Tasks

The verification process activities consist of planning, execution, reporting, control and closeout.

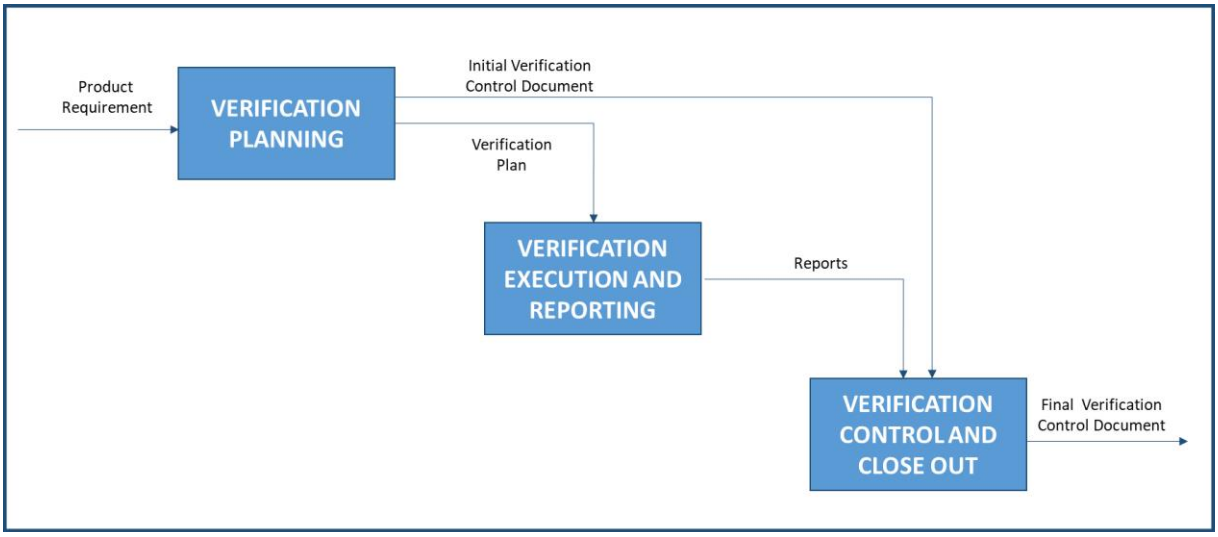

Figure 7 - Verification Tasks

The project manager and systems engineer should work with the verification engineering (AIV) to develop the verification approach and plan the activities with the aid of Quality Assurance (QA) personnel for the execution activities and the AIT engineering and management for the tasks concerning testing activity.
Verification planning includes the definition of:

Verification Approach that identifies "Which" are the products and requirements subject of the verification process and verification objectives and "How" to verify them by considering the methods stated in the technical specification, "When" to implement by applying the chosen verification strategy. These steps are generally conducted in an iterative process based on technical, cost and schedule considerations and the verification approach should be tailored to the project it supports.
Verification Strategy, defined for each requirement to be verified, represents the combination of the selected verification methods for the different verification levels at the applicable verification stages.
Verification methods that specifies if the compliance to the requirements will be verified by one or more of the following verification methods: analysis, review of design test and inspection.
Verification by analysis consists of performing theoretical or empirical evaluation using techniques like statistical and qualitative design analysis, modelling and computational simulation and verification by similarity. Analysis is generally used when development models are not available for testing activities.

Verification by Review-of design consists of using approved records like design documents and reports, technical descriptions, and engineering drawings or evidence by the verification performed on development models that unambiguously shows that the requirement is met. Demonstrations by review of design can involve the use of physical models but it is differentiated from testing because of the lack of detailed data acquisition.

Verification by Test consist of the direct measurement of product performance and functions under representative simulated environments. The analysis of data derived from testing is an integral part of the test and the results are included in the test report. The test programme is prepared for each product and is foreseen in coordination with the integration flow even to check quality and status of the in-progress configuration and interfaces.

Verification by Inspection consists of visual determination of physical characteristics like constructional features, hardware conformance to document drawing or workmanship requirements, physical conditions, software code respecting coding standards.

Verification Levels

The verification is performed incrementally at different product decomposition levels and the number and type of verification levels depends upon the complexity and characteristics of the project. Typical space product verification levels are equipment, subsystem, element, segment and overall system.

Verification Stages

Verification is performed on the basis of project specificity at the appropriate stages:

1. qualification
2. acceptance
3. pre-launch
4. in-orbit
5. post-landing.

Model philosophy

The verification by test is implemented on the selected models. The selection of the different models for every verification level is defined as the "Model philosophy" that is chosen through an iterative process that aims at the optimization of number of physical models and the selection of their characteristics in order to achieve confidence in the product verification with the shortest planning and a suitable weighting of costs and risks.

The assessment of the best model philosophy is guided by the selection of the critical requirements and the confidence with respect to the design and the relative mathematical model and analysis. The close out of these requirements allows the successive design definition activity. The different models for a product are designed with an overview to the final flight product but focusing on the requirements to be verified. Some design requirements (in terms of configuration, redundant parts, materials and process) are relaxed.

The model philosophy planning defines the program of design, verification, testing, definition of GSE: different models activities are conducted in parallel for some aspects, spending more efforts for the prior models to be developed.

The different models foreseen for the development of the space product are:

Engineering model: that is representative of the flight model physical characteristics and function usually without high reliability parts or full redundancy and it is used for functional and failure effect verification. The engineering model is used for validation of test facilities, GSE and associated procedures.

Structural-thermal model: that is a model structurally and thermally representative of the flight model used for qualification of the structural design. The results of the verification activities on the STM are provided for the correlation analysis of the mathematical models. The STM could be used for the validation of test facilities, GSE, and associated procedures. It consists of a representative structure, with dummies and representative mechanical parts of the flight equipment and subsystems.

Engineering qualification model, fully reflects the flight model design except for the employment of parts standard during functional, performance and EMC verification. Functional and performance qualification includes failure detection, isolation and recovery and for redundancy management procedure verification. The engineering qualification model may also be used for environmental testing applying the qualification model rules.

Qualification model, which completely reflects the flight model design. It is used for complete functional and environmental qualification testing of newly designed hardware or when a delta qualification is performed for modification of a qualified design. The qualification model is usually not used for flight, since it is over tested.

Flight model: is the end product intended for flight, subjected to functional and environmental acceptance testing.

The verification process activities are performed at different product decomposition levels and in different stages, following the bottom-up strategy and applying a combination of different verification methods. The verification by test is performed on different physical models respecting the selected model philosophy.

The Verification Control Board monitors the execution of Verification activities and controls the Verification results recorded in the verification matrix. The process is completed when the

VCD declares the product as verified against the requirements by the achievement of associated verification objectives. A waiver or modification of requirements are identified when the compliance of requirements is demonstrated as non-achievable.

Verification Documentation and activities for Project Phase

The Verification Plan contains the verification approach, the model philosophy for the product matrix and the verification strategies for the verification of the requirements. It contains the test, inspection, analysis and review-of-design programme with the relevant activity sheets and planning, the selected verification tools, the verification control methodology and the involved documentation, and the approach for verification management and organization. It is the master document to conduct the verification activity and it is the input for the activity of the Assembly Integration and Testing activity.

The **Verification Control Document** includes the Verification Matrix that lists the requirements to be verified with the selected methods in the applicable stages at the defined levels and is used to provide traceability between the verification activity planned and the actually verification of the requirements during phase C, D and E.

3.5 SPACE PROJECT MANAGEMENT

The project management represents the overall responsibility for managing the project team in order to ensure that the project delivers a technically correct system within established cost and schedule.

3.5.1 Project and Planning Implementation

Project planning and implementation process involves all of the activities to plan the execution of a space project at all levels of the customer-supplier chain in a coordinated, efficient and structured manner. It is a project wide activity that receives inputs and ensures co-operation of all project disciplines.

Project planning activity starts in the first phase of the project development by settling of Purpose and Objectives of the project in the Mission Statement which includes key performance parameters and technical and programmatic constraints to be applied to the project.

The subsequent assessment concerns **availability of technology** and the possibility to reuse existing products or the need to develop new ones. The result of these assessment, has a significant impact on cost budgeting and schedule definition, and is a guide principle in the assessment of the suitability of existing resources, skills and facilities or the need of upgrades. This is the starting point for the next technical and programmatic risk assessment.

Taking into account the results of all this assessment **The development approach** and **Project** Deliverables are defined by the customer and supplier to comply with the mission statement, requirements and constraints.

In order to plan the project activities, the first step is the definition of the Project Breakdown Structure that divides the overall project tasks into manageable element and create a common understanding between all actors.

The Work Breakdown Structure is than derived from the product tree including support functions and associated services and used for the management of cost, technical aspects and schedule of the project. The overall project is divided into work packages, with an increasing levels of detail and including tasks related to manufacturing, assembly, integration and test of all product parts. Any **Work package** of the WBS can be measured and managed for planning, resource requirements, budget and duration.

This structure is used as the base for creating the project chronological planning of work, organizing the project into **sequential phases** which include all project specific reviews and decision milestones.

The establishment of the **organizational structure for implementing a project** is a key factor for an efficient management approach. It is settled at the overall system level by the coordination of all internal teams and external support function, but also at each level of the customer-supplier chain, as an independent project team containing all necessary disciplines within the team structure. The project organizational structure must include all disciplines necessary to implement the project with their functions and their relationships and interfaces. All project actors have the roles of suppliers and customers, and their organizational structures foresee both roles. The organizational structure allocates the individual roles and responsibilities, define the necessary authority within the internal project structure and towards project external interfaces and describes the communication tools essential to ensure interaction between all project teams.

3.5.2 Configuration Management

Configuration management tasks belong to the project management process and interfaces with system engineering, product assurance and production function to allow the record between functional and physical characteristics of products and their design and operational requirements throughout the entire life cycle of the product supporting project organization and schedule.

Configuration management allows to know and control the evolution of the technical characteristic of the product that is settled in the documentation during the development phase, providing traceability of the modification. Configuration management ensure the correspondence between products and their documentation that describes the as-built configuration baseline, including all the discrepancies and non-conformances rose during production activity. Interface Management is the Configuration management subpart that guarantees the consistency of the internal and external interfaces.

The configuration management requirements for a project are settled by the customer in order to be applied to the supplier that produces a Configuration Management Plan responding to his customer's requirements in all the customer-supplier chain level. The Configuration Management Plan establish also the CM manager that is the responsible of the implementation of configuration management and information-documentation management activities within the programme team.

Implementation of configuration management comprises the following steps:

• **Configuration identification** that consists in the selection of configuration items between products belonging to the product tree that will be identified by a unique identification, represented through the item identification code, allowing the easy management of hardware or software items.

A configuration item is defined by its design documentation, procurement specification, interface control document, or standard for off-the-shelf (OTS) products.

Configuration identification provides the basis for traceability during product evolution and changes since it is used to describe configuration characteristics even if it is note fully defined.

The approved status of requirements and design at project milestones, including the documentation that describes product's characteristics is defined as "Configuration Baseline" that is applicable to hardware and software and represents the point of departure for following evolution of design activity.

• **Mission objective baseline** is established at PRR and is based on the approved functional specification that establishes the system's purpose, constraints, environments, operational and performances capabilities for each phase of the life cycle.

• **Functional configuration baseline** is established at SRR to establishes the system's characteristics in terms of technical requirements, criteria and corresponding levels of qualification and acceptance and the definition of the preliminary design for all the functional requirements.

• **Development configuration baseline** is established at PDR based on approved product's characteristics in terms of technical requirements, design constraints, and their verification conditions.

• **Design baseline** is established at CDR based on the approved design and related documentation.

• **Product configuration baseline** is established at QR/AR for prototypes based on the approved documentation that contains all the functional and physical characteristics required for production, acceptance, operation, support and disposal. The log book is established at end of the acceptance review and is maintained during utilization phase till the disposal of the product.

Configuration baseline includes the documents agreed with Customer, such as:

• the functional specification;

• the technical specification;

• procurement specification for OTS items;

• standardization document;

•engineering drawings (e.g. interface control drawings, parts and assembly drawings, and installation drawings) and associated lists;
• the interface control document;
• the configuration items data list;
• the user/maintenance manual;
• test specifications;
• test procedures;
• applicable engineering changes;
• applicable deviations.

• **Configuration control**: Configuration control is the means to allow controlled and traceable changes, deviations and waivers to agreed configuration baselines, including their released and approved documentation.
Each Baselines established at the conclusion of each technical review is the starting point for configuration control:

- Mission objective baseline at PRR is the starting point of configuration control for functional specifications.
- Functional configuration baseline at SRR is the starting point for system technical specifications.
- Development configuration baseline at PDR is the starting point of configuration control for product technical specifications and Interface Control Document and the freezing of performance and design requirements of Engineering Model.
- Design baseline at CDR is the starting point of configuration control of the product design for PFM/FM model manufacturing for qualification activity.
- Product configuration baseline at QR/AR is the starting point of configuration control of the qualified product. After the Qualification Review starts the configuration control of the User Manual and at the conclusion of the Acceptance Review starts the configuration control of the Logbook.

The configuration control process prevents the degradation of product capability due to changes. The involvement of all actors for analysis and decision process of changes is guaranteed and only authorized changes and deviation are implemented, verified and recorded.

Change control procedures are applied following the establishment of the first baseline and can be started by the customer through a change request and followed by a reply from the supplier or proposed by the supplier that use a change proposal followed by a response from the customer.
The change assessment covers technical, programmatic and operational impacts on all affected products through analysis and review defined by procedures. Each project actor involved in the change process can assess any request or proposal for a change to a configuration baseline, and the disposition of change is a prerogative of the Configuration Control Board that is convened by the configuration manager at each project levels and consists of permanent representatives of all project disciplines necessary for the review and evaluation of changes.

• **Configuration status accounting** is conducted through the delivery of the Configuration Item Data List that is a document that reports the design status of each configuration item. The document is delivered at the PDR and it is maintained during the lifecycle of the product as a departure point for the control of following changes of performance, design and manufacturing. The CIDL is the starting point for the preparation of the As Built Configuration List that reports the as-built and as-tested status for each serial number of product CI. The CIDL is used as a reference to identify any difference between the ABCL and the CIDL that is referred to Non conformity and Request for wavers.

• **Configuration Verification** allows the inspection of the analyzed product to compare the "as-built" configuration and "as designed" configuration. Configuration of functional and performance characteristics are verified at qualification review while configuration of physical and nominal performance characteristic is verified at AR.

3.5.3 Information and documentation management

Information and documentation management is the process, applied throughout the life cycle of the project, that allows timely creation, collection, review, delivery, storage, and archiving of project information by using electronic repository.
Information and documentation management allows the accessibility, availability, reliability and security of information to all the actors of the project through defined means of access, and related methods and procedures.
It is a support tool for project reporting in accordance with the project needs.

There are four steps for Information and documentation management:

• **Creation and revision** of documents containing preliminary information that could not be considered fully complete to make cession or bind agreements.

• **Review activity:** defined by a review cycle and a control process settled by each actor to ensure the timely revision and approval confirmation by signatures of all the required customer and supplier. The completion of the review cycle and the obtained approval for the information and documentation allows their delivery.

• **Delivery** of Information and documentation uses Technical Data Package to share the required knowledge. The method, format and schedule for the required information delivery are settled in the Configuration Management Plan.

• **Storage** and retrieval is the step that allows the availability of information and documentation to the authorized project members throughout the entire project life cycle, storing them in its preliminary format for being later updated throughout the project life cycle.

• **Archiving** and retrieval is the step that ensure the preservation and access control to the documentation by authorized personnel after their delivery and approval.

3.5.4 Interface Definition and Management

The definition, management, and control of interfaces are crucial for the correct development of the space Product.

The interface management process is applied at all levels of the supplier-customer chain and involves both external and internal interfaces to support product integration.

The customer is the responsible for the definition, development and verification of the interface while all the parties involved in the 'interface end' definition, design and development are defined as interface actors.

Once functional, logical and physical decomposition is defined, the Interface Identification starts with the identification of the responsibility at each level of the customer-supplier chain.

The identified interfaces are compiled into a list that identifies the involved suppliers and contains references to the applicable technical documentation.

The output of the interface identification process is documented in an Interface Identification Document (IID) that is updated by the references to Interface Requirement Document (IRD) and Interface Control Document (ICD) when they are produced.

Following the interfaces identification, each customer derives the requirements for each interface from the higher level requirements and the system architecture.

The interface requirement defines the functional, performance, electrical, environmental, human, and physical requirements that exist at a common boundary between two or more products. These requirements are documented in **IRD** and they are subject to the verification process defined for the other requirements.
Interface definition leads to the design solution that ensures compatibility between interactive products. Interface definition is the result of the design activities performed by the customer who is responsible for the interface as a whole and by the suppliers who are responsible for their interface ends. The **Interface Control Document (ICD)** reports the interface definition after an iterative process, with a decreasing number of modifications over time.
Since the issue of the ICD, interface control is formalized by two steps: controlled ICD that reflects an evolving interface definition from supplier preliminary design to the final one and frozen ICD signed by the interface responsible and all the involved actors, to reflect acceptance. A Change Request, generated by the interface responsible is used to support the Interface Change Management process.
Identification of assembly drawings and instructions, parts list, and a complete documentation that shows the configuration and information about the product to integrate and about the of the end-product, design requirements, including interface specifications to satisfy the product life cycle phase success criteria is fundamental for the successful design and integration of interfaces.

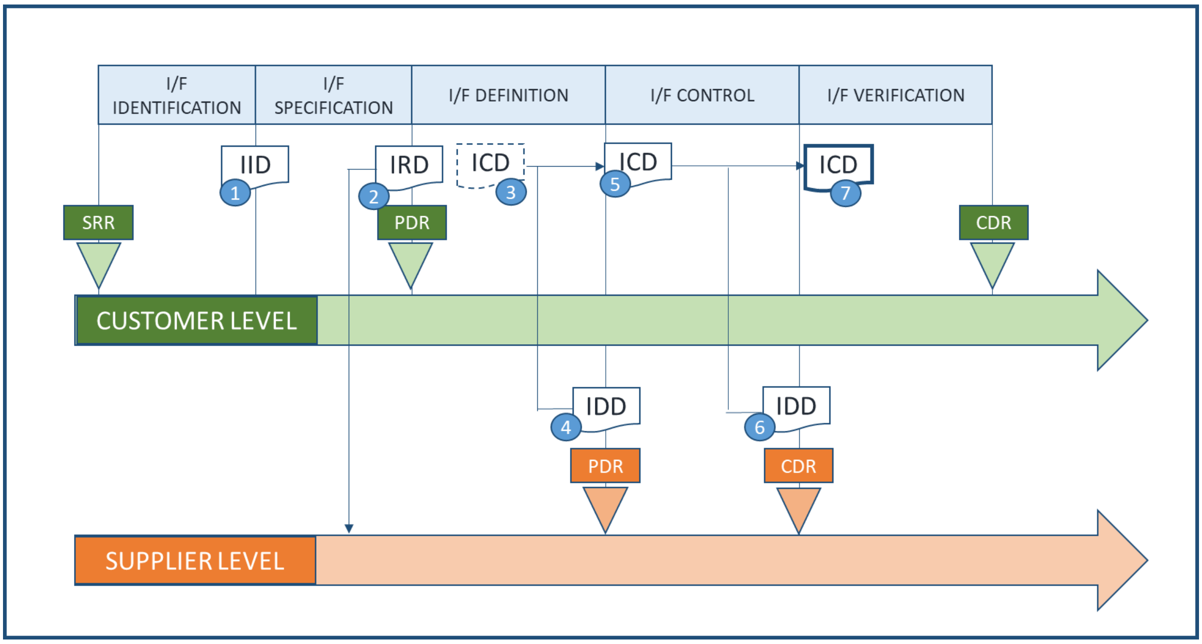

Figure 8 - Interface Management Process

3.6 PRODUCT ASSURANCE PRINCIPLES

The objective of Product Assurance is to ensure safety, availability and reliability of space products accomplishing their defined mission during the life time. The management of Product Assurance is set inside the management of the project in order to obtain the timely identification of critical aspects potentially detrimental for safety and mission success, and the effective prevention of any adverse consequence. This objective is achieved by the performance of audits for non-conformances detection and management, the support to risk management activities in coordination with the Project Management, the support to configuration management and documentation data control.

The supplier prepares and implements the PA Plan that settles the activities to be performed in order to comply with the customer PA requirements and identifies the personnel responsible for performing PA management and disciplines in collaboration with risk and configuration management, engineering, procurement of products and AIV aspects for the verification activity.

PA activities are reported in the PA report that includes status of PA reviews, Audits and MIPs, audits for Procurement activity, Waiver requests, Non conformity, Critical items risks mitigation, Qualification status of items and processes, indicate inspection performance during the incoming, integration, tests, storage and shipment activities.

The PA manager ensure that the Qualification programme is implemented and that the Qualification Status List correctly reports the results of qualification activities and the qualification status achieved by every configuration item at every decomposition level.

The PA manager is the professional figure that verify the suitability of drawings, plans, specifications, procedures and changes during Configuration Control Boards. He controls the definition and timely release of the as designed status prior to manufacturing and the definition of the as-built documentation reflecting the approved modifications in order to be compliant to the delivered end item.

3.6.1 Nonconformity management

A nonconformity is the non-fulfilment of any operational, functional, technical, reliability, maintainability requirement and any changes or deviations from approved qualification or

acceptance test procedures. A nonconformity could be classified as major if it has an impact in the areas of safety of people or equipment.
When a nonconformance is detected it is analyzed by the project PA to identify its extent and cause and it is documented by a NCR completed by the supplier.
The NCR is than submitted to the internal Nonconformance Review Board that includes core members from the Project PA and Engineering that investigates the causes and consequences of the nonconformance supported by documentation such as (Failure Mode Effects and Critical Analysis) FMECA, CIL, DJF and reports NRB results of the investigation in the nonconformance report.

After the assessment of causes and consequences, the nonconformance is classified as minor or major: Minor Nonconformance are then disposed by the return of nonconforming procured items to the supplier, the "as-is" use, rework, repair or scrap while Major nonconformance are submitted to the customer NRB by a major nonconformance report that includes proposed disposition. The customer NRB reflects the same steps of the internal NRB to decide on the need to perform complementary investigations of causes and consequences.

An objective of the NRB is the selection of corrective actions that will eliminate the causes of the nonconformity and Preventive actions that will avoid the occurrence of the nonconformance on similar items. Typical actions implemented by the supplier involve changes to tools, equipment, facilities, processes, materials, drawings, specifications, or procedures and as all actions are performed and verified, the supplier PA representative closes-out the nonconformance and informs the customer.

3.6.2 Quality Assurance

The objective of Quality Assurance management is to ensure that mission definition, design, development and production activities for space systems respects the QA programme and requirements that are specified through the implementation of adequate methods and procedures.
The QA function ensures the implementation of the following activities during all phases of project development:

- critical-items control
- nonconformity control

- acceptance authority media control
- traceability
- metrology and calibration
- handling, storage and preservation.

The QA Plan describes the activities to be performed by the supplier to assure the quality of the product by settling quality assurance requirements for design and verification, procurement, manufacturing, assembly and integration, testing, acceptance and delivery, and QA requirements for Ground Support Equipment.

QA requirements applicable to the space product regards:

• **Inspectability** that is the ability of an item of being inspected and leads to the definition of acceptance or rejection criteria of inspected items and the definition of tolerance for dimensional inspection performance of component that have to be accessible for inspection.

• **Producibility** that is the ability of an item of being producible thanks to design simplification and standardization, reduction of part types and number and selection of preferred materials and processes, standardization of interfaces and tolerance build-up methods. Manufacturing, assembly, inspections are simplified and the design criteria are consistent with the capability of manufacturing processes.

• **Testability** that is the ability of an item of being tested through the definition of test requirements, including acceptance or rejection criteria. The accessibility of parts for testing activity, the definition of design techniques that facilitates fault detection, the identification of test points, and the modularity of the product are requirements that guarantee the testability.

• **Traceability** that ensures the bidirectional relationship between products and associated documentation. Data relating to personnel and equipment involved in procurement, manufacturing, inspection, test, assembly, integration and operations activities have to be traced.

4. SITAEL COMPANY AND BUSINESS MISSION

SITAEL S.p.A. belongs to the Angel Group, that is an holding of high-tech companies that deals with Transportation and Aerospace technologies.

SITAEL space activities are integrated to realize the Design, Development and Production of Small Satellites, Advanced Electric Propulsion Systems, Earth Observation and Science Payloads, Platform and Payload Avionics.

SITAEL develops turn-key solutions that facilitates the access to space services and applications through Smart Microsatellite In-house designed and produced after the complete analysis of the mission in the Low Earth Orbit, in order to reduce the costs of access to space.

SITAEL is equipped with tools for the design and development of software and electronics and their testing and manufacturing. Some examples are Clean Rooms, Test Facility suitable for Green Propellant Rocket, Environmental and Mechanical, Vacuum and Thermal-Vacuum Test, Micro-propulsion and Aerothermodynamics Laboratory.

These facilities and the personnel who work in the correspondent tasks are located in different Italian areas: Mola di Bari, Pisa, Forlì and Rome.

After the demonstrated skills in the Development of units for space application, the Business Mission developed with the aim of realize a Complete Satellite Product Line.

The Satellites developed are smart, modular, scalable, with all-electric platforms (weight from 50 Kg to 300 Kg) suitable for a wide range of missions and applications: Earth Observation, Telecom, In orbit Demonstration and Validation, Science research.

The design of Platform, subsystems, and Payload or their selection is performed by the System Engineering Team, the AIV Engineering plans and control the overall verification activities and the AIT Function performs products Assembly, Integration and Testing activities.

The strategy used to accomplish with the objective of a Complete Satellite Product line includes the development of four Satellites:

- ESEO
- UHETSAT
- STRIVING
- PLATINO

The **ESEO** mission, started in 2018 to take pictures of Earth, measure radiation levels of the Low Earth Orbit, and test technologies for future missions. It is currently completed, with the validation of the SITAEL S-50 platform (50kg including the payload), the smallest within the products portfolio.

Figure 9 - ESEO Satellite

Figure 10 - UHETSAT Satellite

µHETSAT represents the first applications of a Hall Effect thruster onboard a microsatellite platform with the goal of orbit raising capability by using SITAEL HT100 low power Electric Propulsion System and SITAEL S-75 micro-satellite platform.

The aim of the STRIVING project is to realize the Proof of Concept missions by integrated service by the in-orbit verification and validation of new payload technologies. STRIVING-1 mission will fly on a SITAEL S-75 platform and will embark multiple payloads from European companies.

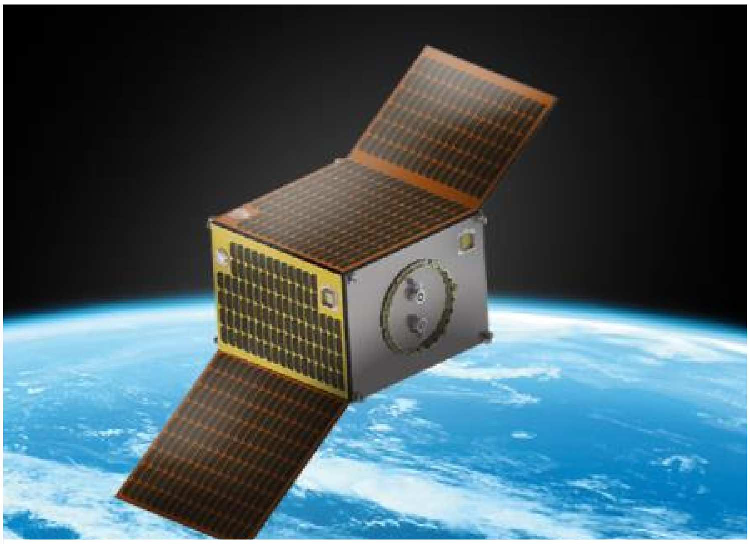

Figure 11 - STRIVING Satellite

PLATiNO-1 mission will validate the PLATiNO platform embarking a Micro-SAR payload operating in passive mode during the first phase at 619km and in active mode during a second phase at 410km by the orbit transfer performed by the use of SITAEL HT100 Electric Thruster and validating the platform orbit maneuvering capabilities.

Figure 12 - PLATINO Satellite

Figure 13 - PLATINO 2 Satellite

PLATiNO-2 mission will validate PLATiNO multi-applicability feature with the platform embarking a Thermal Infrared payload developed by Leonardo and SITAEL, to acquire images for territories control and protection service (monitoring of waters, glaciers, vegetation pollution, energy consumption in urban areas) from a low earth orbit (less than 400 Km). PLATiNO-2 will be equipped with the magnetically shielded HT 100, an improved version of SITAEL electric thruster.

These different Satellites reflect the different achievement in the technical and technological development and tough they are foreseen to perform mission with different objectives, the develop and production of the next Satellite will be based on the awareness of Design and processes developed and qualified for previous Satellite.

4.1 Consideration after ESEO program completion

During ESEO Program, SITAEL developed the fully redundant satellite platform and performed the integration and testing of the whole spacecraft, including the integration of the payloads and subsystems.

The test campaign performed on ESEO was developed with a model philosophy that includes an Elegant Breadboard (EBB) and the Proto-flight models (PFM). The EBB was implemented with COTS components resembling the satellite functions and interfaces to face qualification tests, including environmental test. A set of electrical and functional confidence tests were successfully completed.

Envelope and mass measurement, including the mechanical interface check were performed. Signals on electrical interfaces, Power consumption measurement, over-voltage protection circuit activation were verified. Functional and Performance test, interface check for redundant lines were performed.

The approach used for the AIT campaign of ESEO included the participation of the Engineering team that developed the design solution together with the test procedure, with the collaboration of the Test Engineering Function that executed part of the test campaign within the foreseen models.

During the successive development of the µHETsat the limits of that approach arose. The expansion of the company business imposed the necessity to allocate an increasing number of personnel in order to conduct the two programs in parallel.

By the experience made on ESEO and to fulfill the tasks required for the expansion of the company business the need to separate the Engineering team that defines the requirement specifications and the team that performs the tests arose, in order to guarantee:

- Repeatability: The integration and test process need to be repeatable, especially for the development of recurrent models. This characteristic is guaranteed by the standardization of test specifications and procedures for integration and testing activities and by the selection of the documentation to be adequately draft, shared and stored in order to trace requirements to the verification activity.
- Objectivity: It is a fundamental approach to be taken to define "how" the requirement will be tested and to produce the related test procedure.

The involvement of an AIT team distinct from the Design Team allows the external point of view and the elimination of the risk of an excessive involvement of the team during the verification activities.

- Testability and Integrability: These fundamental characteristics of the products to be integrated and tested are guaranteed by the selection of the appropriate interfaces and physical and functional features of the product to ensure the correct configuration of the product respecting the most common and standardized integration and test processes. This awareness is tightly tied to the know how coming from the direct experience in the matter of integration and testing activities.
- "Test early and often" principle: The selection of a model philosophy that includes the adequate number of models is a fundamental prerequisite to verify the capability of the design to fulfill the requirements and to discover defects as soon as possible. This is the results of a general view over the overall testing plan, resulting by a
- Programmatic view: it is the base for the identification of the activity flow and for the assessment of tools that enable these activities in a provisional way. This is a fundamental aspect for the selection of Ground Support Equipment, able to fulfill tasks related not only to the temporary AIT activities but also to the next activities, in a modular and recurrent philosophy.
- Cost and Timely optimization: it is a driving requirement for the accomplishment of program that doesn't aim only to the technological development and demonstration but also to the commercial objectives of competitiveness and reliability.

These considerations are the departure point for practical assessment about the features of the new AIT Team and the basic rules to be observed by a useful AIT Process.

5. AIT BUSINESS FUNCTION

The Assembly, Integration and Test (AIT) Business Function is a set of different skilled technical teams involved in the assembly, integration and testing activity within the space programme.

Even if assembly, integration and test are performed during the ascending branch of the V model for System Engineering the activities are technically defined and scheduled during the descending phase as soon as the design development reaches increasing levels of detail.

By this perspective the AIT personnel collaborate to the System Engineering and to the AIV personnel during the design development activity, contribute to the realization of the crosscutting management tasks and operate during the execution of the activities of assembly integration and test in collaboration with the Space Test Centre and the related facilities, instrumentation and tools.

In order to fulfill the several tasks under the responsibility of the AIT Function, Sitael company presents the following Structure:

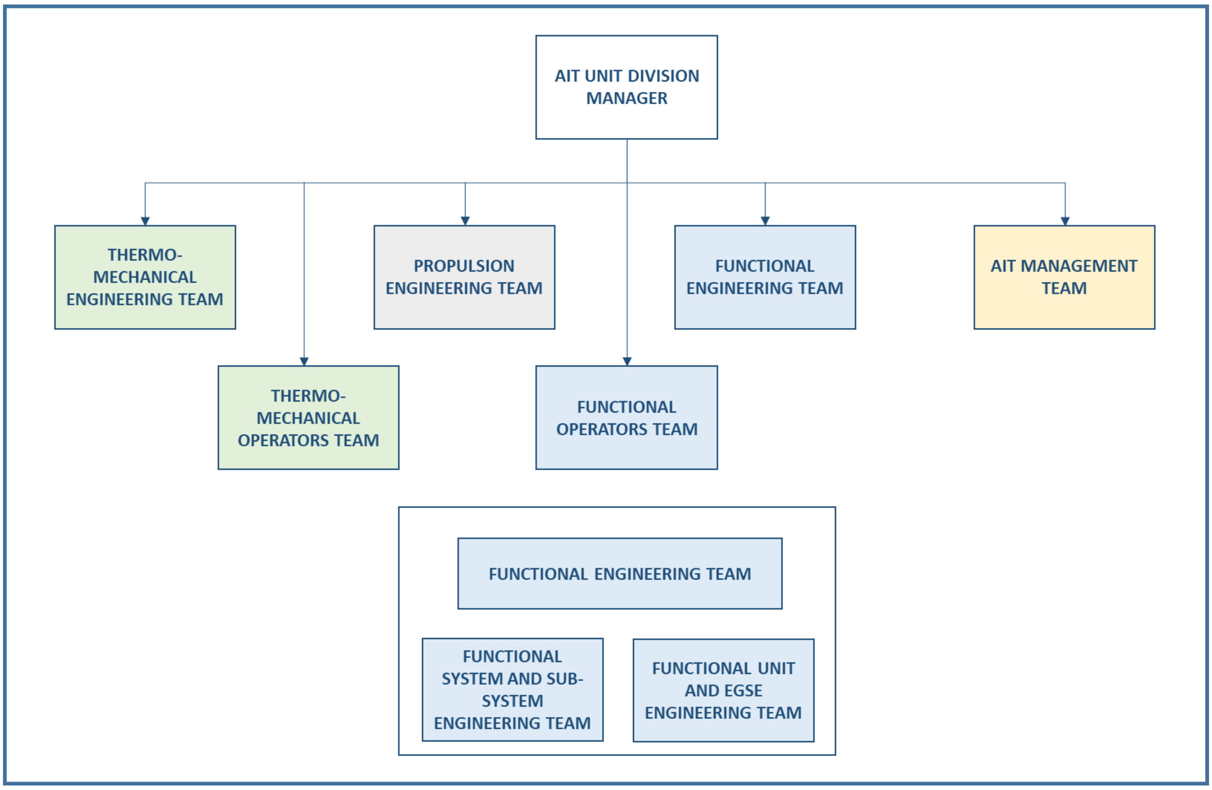

Figure 14 - AIT Structure

The distribution of roles and responsibilities within the AIT Technical teams is customized to fulfill technical needs and required skills and to respect constraints derived from the location of the different facility in different areas.

The first parameter is based on the technical characteristics of the integration and test campaign that could be tied to mechanical aspects or to electrical ones. Following this distinction, the teams are further organized with respect to the nature of the tasks that could be operative or tied to the definition and supervision of the operations.

The management team is responsible for the planning, scheduling and coordination of the overall AIT activities.

The second parameter is based on the distinction of the verification level and the support equipment management activity.

The third parameter is based on the nature of the subsystem to integrate and test and the related technical skills.

As a consequence of these considerations the personnel is grouped into the Thermo-mechanical and Functional Teams and for each one of these branches the personnel is divided into operational and Engineering teams.

The Functional Engineering AIT Team is further divided into Subsystem Functional Engineering AIT that has the responsibility for the integration and test campaign at Subsystem and System level and Unit and GSE Functional Engineering team that is responsible for the integration and test campaign of products at unit level and for the procurement of the EGSE useful for functional operations at all the verification levels.

In order to define the activities concerning the integration and test of the Propulsion Subsystem and the related enabling technology the Propulsion AIT has been created in Pisa where the facility for the management of the electrical propulsion developed by Sitael is sited.

Functional System and Subsystem AIT:

It is a team of Engineers that defines functional, electrical and RF test phases within the AIT Plan. It develops sequences and procedures for Functional, Electrical and RF Test, and Electrical Integration at System and Subsystem level, coordinating and overseeing the integration and test execution and evaluating and post-processing test results. AIT Functional

S and S/S Engineer, as a process engineer, defines and contributes to improve a standard set of AIT Procedures and Processes and define test harness and setup.

The responsible of the team attends customer meeting (TRR, PTR, TRB) and contribute to the handle of anomalies and non-conformances evaluation, attending the Nonconformance Review Boards. The responsible also supports AIV and Engineering teams in the planning of System and Subsystem test, having the VCD as an input and aids Engineering teams in the definition of test requirements and specification and for the post processing and evaluation of test results. He collaborates with the AIT management in the coordination of resources and overall AIT authority tasks.

Thermo-mechanical AIT:

It is a team of engineers responsible for the preparation of the procedures for the mechanical integration of Spacecraft units, Modules and all mechanical elements, in compliance with delivered documentation. The team is also in charge of the preparation of the handling and transportation procedure and of Thermal and Mechanical Environmental Test Procedure and setup definition. The team responsible is in charge of the coordination and supervision of all thermo-mechanical activities, supporting AIV and Engineering team for the definition of test Program and requirements and for the evaluation of test results. He is responsible for the design, development, qualification and operation of the MGSE and the related documentation. He also oversees the activities relevant to modification or finalization of the thermal/mechanical configuration performed by companies or entities external to AIT. He attends customer meeting and supervises activity related to anomalies in the Thermo-Mechanical AIT aspects and processes aiding the AIT management in the coordination of resources and overall AIT authority tasks.

Propulsion AIT:

It is a team of engineers responsible for the preparation of integration and test procedures for the Propulsion Subsystem, whose test campaign is planned by AIV and System Engineering with the contribute of the AIT Propulsion team leader that subsequently manages this latter topic within the AIT Plan. The team is responsible for the definition and procurement of the test setup and of MGSE and FGSE necessary to perform handling, integration and test campaign of the Propulsion Subsystem. The technical discussion concerning these latter topics is conducted in collaboration with the Thermo-mechanical team. The team responsible attends

Project Reviews and Technical Documents Review. He collaborates with the AIT Manager for the authority and resources management tasks.

Thermo-Mechanical, Functional Operation AIT:

These are two distinct teams of highly skilled operators in charge of the operational activities respectively, the first for the mechanical integration and Thermo-mechanical test campaign, the second for the electrical integration and electrical functional test. These teams are in charge for the handling of the product to integrate and test, the realization of the setup, the completion of the work items' activity and for the fill out of the reports and documentation following the step by step procedure. The team is responsible for the first detection of non-conformance during the operation and of the identification of procedure variation. The responsible of the team organizes through a daily management the work of the team and oversees the operations and the proper state of the equipment and instrumentation useful for the team work. He trains the team and organizes class for the achievement of the required certification.

AIT Master Planner:

This team consists of AIT Managers and AIT Planners. An AIT Manager is foreseen for every space programme in order to conduct the management tasks of activity planning and resources allocation and their coherent coordination, in order to ensure the satisfaction of the contractual technical requirements. The AIT Manager guarantees coordination and liaison within the teams involved in the AIT activities, as well as within the AIT function and the external business functions and the external services to ensure a clear communication about the update of activity planned and executed activities for a timely and optimized completion of the programme. The AIT Manager supervises the configuration control of the items to test and integrate and of the related support Equipment and Instrumentation. He defines and control the AIT Documentation as guidelines for the integration and testing activities. The AIT Manager selects the personnel from all the previous teams to create the program/project AIT teams to fulfill the related technical effort, including the AIT Planners that are responsible for the Scheduling of the AIT activities planned by the AIT Manager and for the management of the planning for the providing of materials and services, needed for the completion of the AIT activities.

In case of production of totally recurring models to create a constellation of satellites, based on the qualified design and production process, the AIT Managers and Planners will manage the project with greater autonomy carrying out the action related to the provision of the qualified product constituting the satellite or its qualified and recurring subparts in case of projects that foresee delta qualification.

AIT unit division Manager

He is the head off all the activities in charge of the AIT. He implements organizational measures for the continuous improvement of business process with focus on the AIT activities. He is the figure that ensures a coherent AIT approach to all the programs and supervises the AIT Manager of the specific program in the project allocation of personnel over activities. The AIT unit division manager provide the feasibility assessment by the AIT point of view for the feasibility of the overall project. He manages the budget prevision and allocation for the AIT related tasks with a provisional approach. He manages the Technical and Programmatic risks evaluation with the support of the AIT Manager and the responsible of every operational and engineering AIT teams. He reports the issues related to the AIT processes and the interrelation with the other internal business functions and the external companies. The AIT unit division Manager is in charge to the management of the internal Facilities for the AIT campaign, carrying out the supervision on the Test Space Center.

5.1 Business Process Modelling Language: IDEF0-IDEF3

IDEF0 is a functional modeling tool developed through the Air Force's Integrated Computer Aided Manufacturing (ICAM) program and it is used to represent the activity or process oriented framework of a system. It is a technique suitable for the structured analysis and engineering of business processes such as the development of manufacturing systems, organizational change implementation and project management.

The IDEF0 functional model includes five elements:

- Boxes that represent the process activities.
- Arrows flowing into the left side that represent inputs.
- Arrows flowing out the right side that represent outputs.
- Arrows flowing into the top that represent constraints or controls over the activities.
- Arrows flowing into the bottom that represent the employed resources.

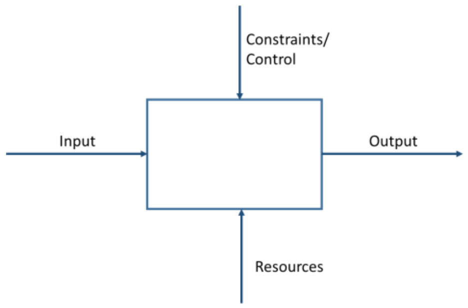

Figure 15 - Idef 0 Elements

The activities flow resulted by the IDEF0 modelling does not represent the chronological sequence of events, it rather focuses on the relation and feedback between actions into successive level of decomposition.

The first layer could be broken down into further levels in order to take into account the additional knowledge gained through the inclusion of all necessary activities. The initial versions of the diagram consist of boxes that correspond to the concept of what have to be done. The step-by-step development with feedback and changes leads to the complete description of the process till the desired level.

The formalism imposed by IDEF0 leads to the partition of the models into parts defined by interfaces and developed independently. These parts must be consistent and allow to interact each other for being integrated into the overall model.

This characteristic, together with the ability to specify explicit feedback between activities makes IDEF0 usefulness in the development of activities that can occur concurrently or iteratively and for the description of sequence in which tasks accomplished could be variable depending on a specific implementation.

IDEF3 (Process-Centered Views) is a Process Description Method that decompose the process into sub processes starting from a scenario and leading to a level that allows allocation of specific resources available in the execution environment.
The IDEF3 model can be related to the activities described by the IDEF0 model, to describe the temporal, logical, conventional, or natural constraints between them in a time-dependent fashion.
The IDEF3 model includes some symbols that allow the univocal understanding of the process:

- Boxes that represent the Unit of Behavior (UOB) with the reference to the IDEF0 diagram
- Simple precedence Arrows that represent the temporal precedence between instance, the source action must be completed before the start of the successive action.
- Constrained precedence links that any instance of the source UOB must be followed by an instance of the destination UOB.
- Object Flow Link indicate that there is an object that is common to both processes, the destination UOB must follow the source UOB even if it is not completed.
- Asynchronous And Junction: all the preceding/following UOB must complete/start
- Synchronous And Junction: all the preceding/following UOB must complete/start in the same time
- Asynchronous Or Junction: one or all the preceding/following UOB must complete/start
- Synchronous Or Junction: one or all the preceding/following UOB must complete/start in the same time
- Exclusive Or Junction: only one of the preceding/following UOB must complete/start.

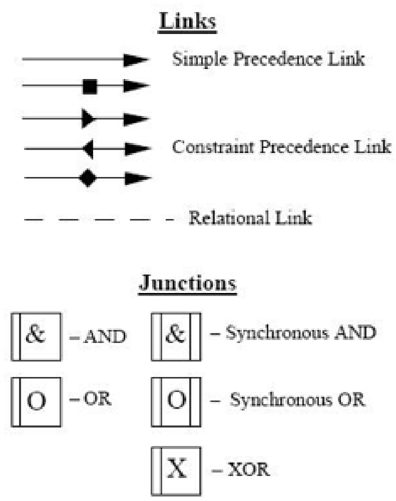

Figure 16 - Idef 3 elements

5.2 AIT MACRO-ACTIVITIES

The following organization of the activities in charge of the AIT Function derives from the definition of Work Packages in the Work Breakdown Structure of the Platino Project.

It defines the perimeter of the AIT responsibility and the support activity that the AIT personnel share with the other internal Business Function and the external ones. Basing on this organization the AIT tasks are related to different Level of Decomposition of the Space System: unit and subsystem whose design is developed and qualified by Sitael, Platform and the overall Satellite, including the different development model foreseen for each product. The AIT Function has the responsibility for the complete definition of the mechanical, electrical and fluidic GSE and for the complete definition of operations and testing activities prior launch.

In order to accomplish these objectives, the AIT Function is involved into process of different nature such as:

- Support to the System Engineering and AIV internal business functions, and to the launch service in order to ensure the Integrability, Testability and Repeatability of the development Space Product at different levels of decomposition.

- Accomplishment of the crosscutting objectives of planning of the operative activities of Assembly, Integration and Test of the specimens and flight products, contributing to their configuration control and evaluating the technical and programmatic risks related to these tasks and ensuring the timely achieving of the program aims and schedule.

- Guarantee of the feasibility of the Assembly, Integration and Testing activity by the definition of Support Equipment, Instruments, Facility, and services such as procurement of required material and definition of transportation and storage of the products.

- Complete Design Development, Verification and Validation of the Ground Support Equipment respecting the programmatic and technical needs and constraints coming from the integration and test programme.

- Completion of the integration and testing activities for development specimen, the qualification campaign and the acceptance campaign for development project and the fulfillment of the purpose of the serial production of recurring models based on a qualified design.

In order to accomplish these aims the overall AIT process have been divided into five macro activities that could be considered as self-standing:

1. AIT PLAN Definition
2. AIT Facility Management
3. GSE Management
4. Assembly Integration and Testing Activity Execution
5. AIT Management

All these complex tasks have been decomposed into subsequent decomposition levels: the first level represents their role into the overall space project where AIT is, by a general point of view, the supplier for the production and verification by test of the different models against the selected requirements respecting the test requirements and constraints. This level allows also the general definition of the external interface between the AIT Function and the other Business Function and External actors.

The following decomposition derives from the need to create a logical interrelation between the project level and the intermediated levels that allow the allocation of the activities in the space project development over the time, respecting the milestones till the level that includes elementary activities.

Elementary activities are those considered for the allocation of roles and responsibility within the AIT perimeter and the definition of the interdependences between the activities and the coordination of the interdependences. This level ensures that all the aspects of the AIT job are covered by the analysis and that the flow of activities over the time corresponds to the ever increasing level of depth of the development of the programme.

Each activity in every decomposition level is defined by the inputs that it need to be performed, by the outpust that it is expected to produce and by the constraints to the performance of the activities. The inputs are mostly referred to the information and documentation that contains the full characteristics of the requirements and the design related to the product to be integrated and tested. Other important inputs are the Management plan that guides the actions by the definition of milestones and their required baseline.

The constraints are represented by the plans related to the product and quality assurance, legal regulation and other normative adopted by specific nation. The progress state related to the activities later planned or carried out, and the availability of required materials and services represent the most common control over the activities.

The activities are then considered in their temporal flow that is derived from advices defined by the ECSS that describe the technical and programmatic achievement in the overall knowledge for the definition of the product and programme and the regulations stated by the ECSS in terms of documentation and products to be delivered.

In order to manage the different level of decomposition of the space product and in order to respect the inner iterative and recursive nature of the V Model for the Space Product Engineering, the overall process is standardized to be applicable in every layer of the product decomposition from the Satellite level to the unit level.

The baseline for the organization of the activities in a complete process is based on the development of the qualification campaign of a Qualification Model, followed by the acceptance campaign of the Flight Model. The inclusion of activities related to other specimen, such as Engineering Models, represents a temporal optimization of the development philosophy and the moving up of some activities in order to complete the verification of these specimens and to reach more confidence in the design definition.

The process is defined in a way to be adaptable, through a simplification, carried out by the selection of the activities related to the production, test and provision of qualified product to be integrated, to fulfill the programmatic requirements of a foreseen production of totally recurring Satellites.

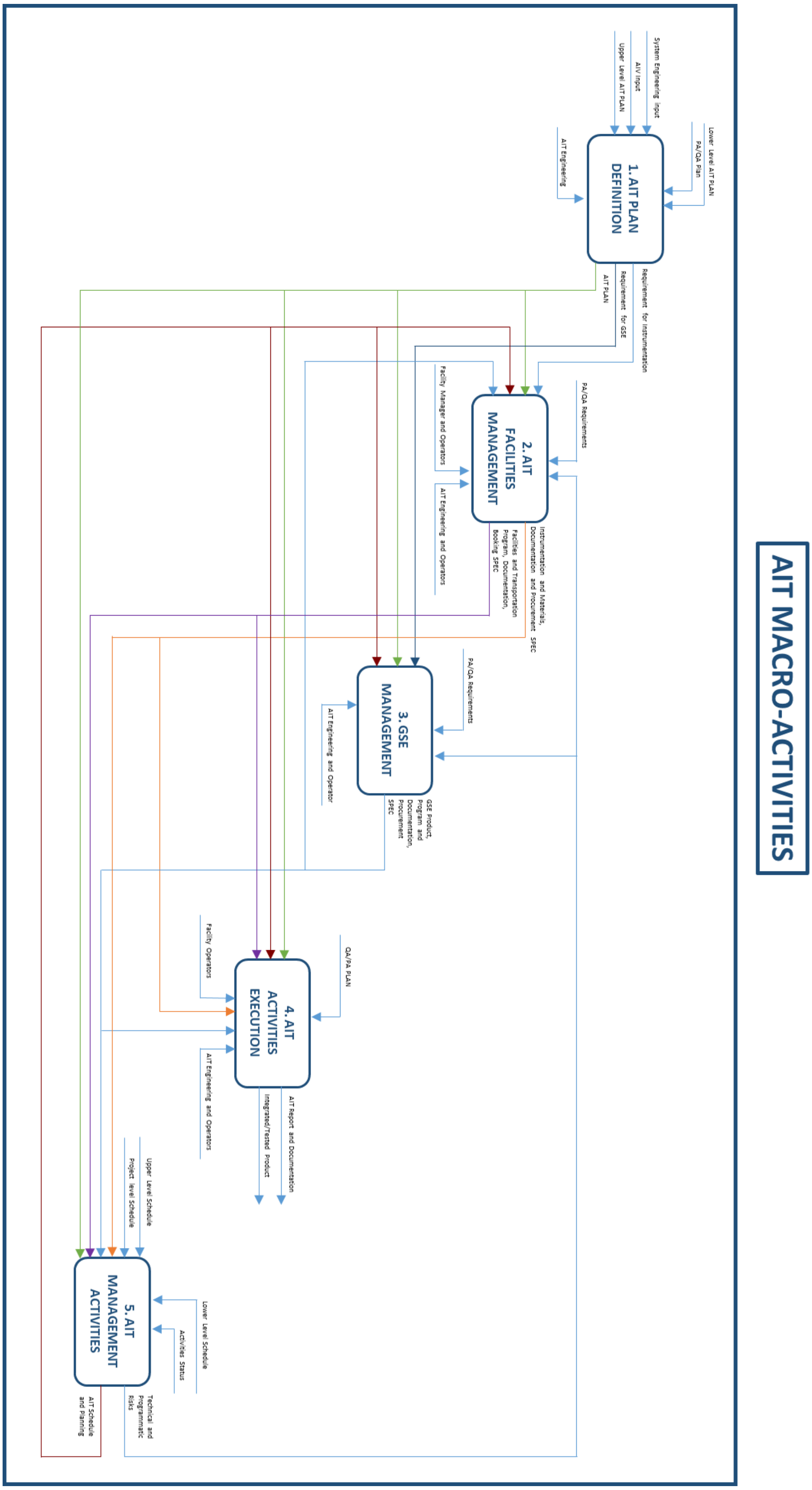

Figure 17 - AIT Macro Activities

5.3 AIT PLAN Definition

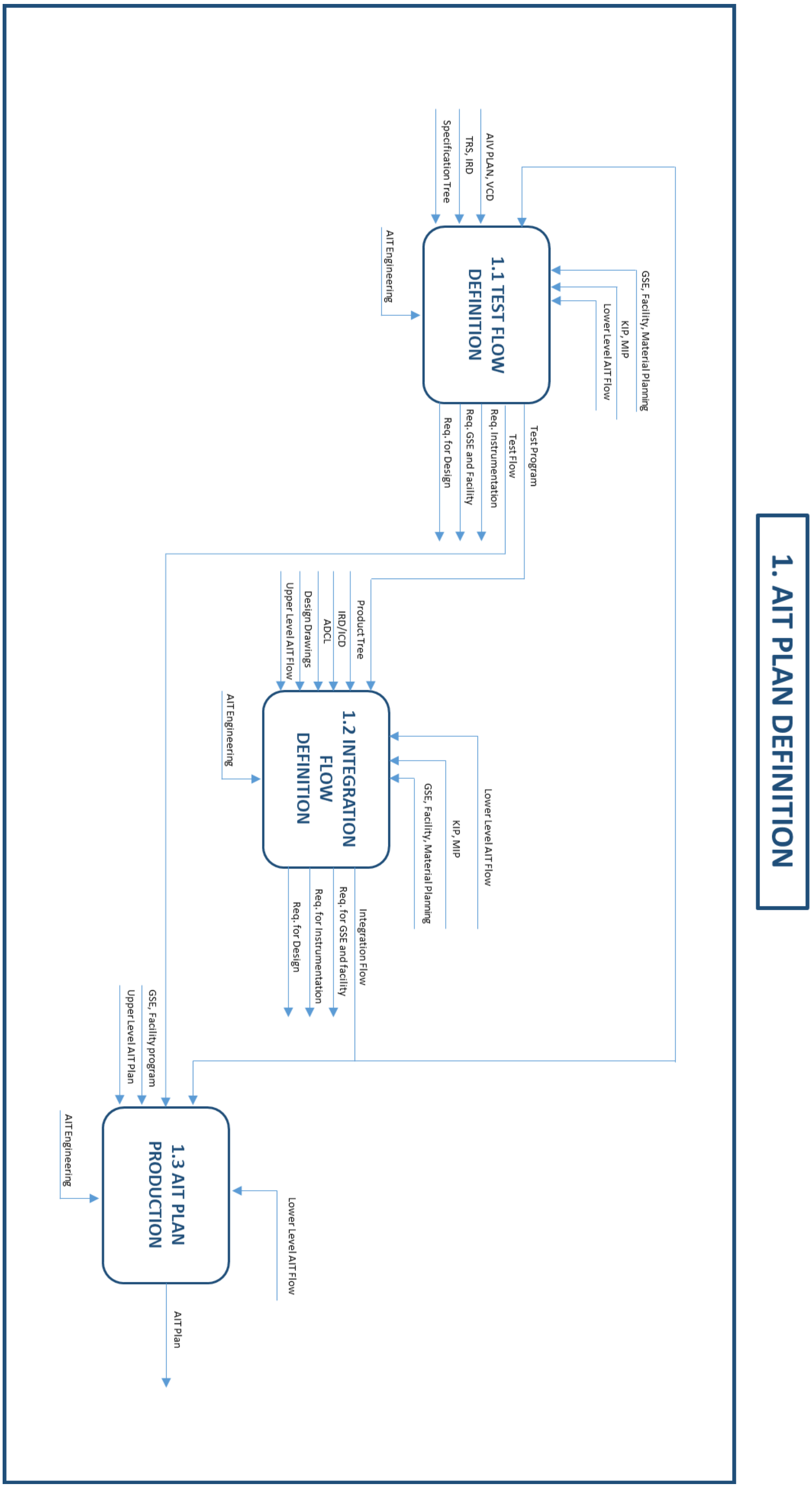

Figure 18 - AIT PLAN Definition, lev. 1 (idef0)

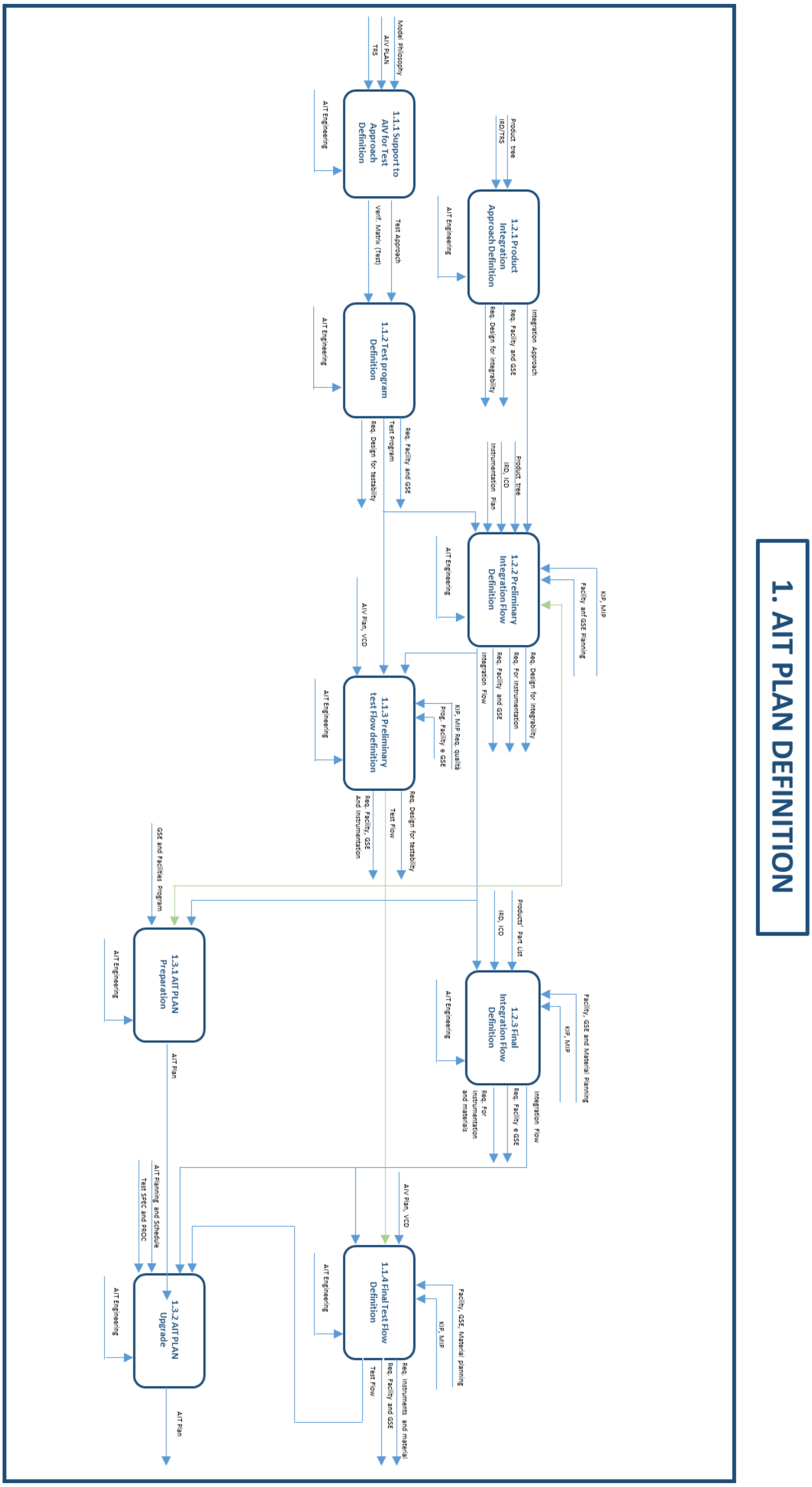

Figure 19 - AIT PLAN Definition, Lev.2 (idef0)

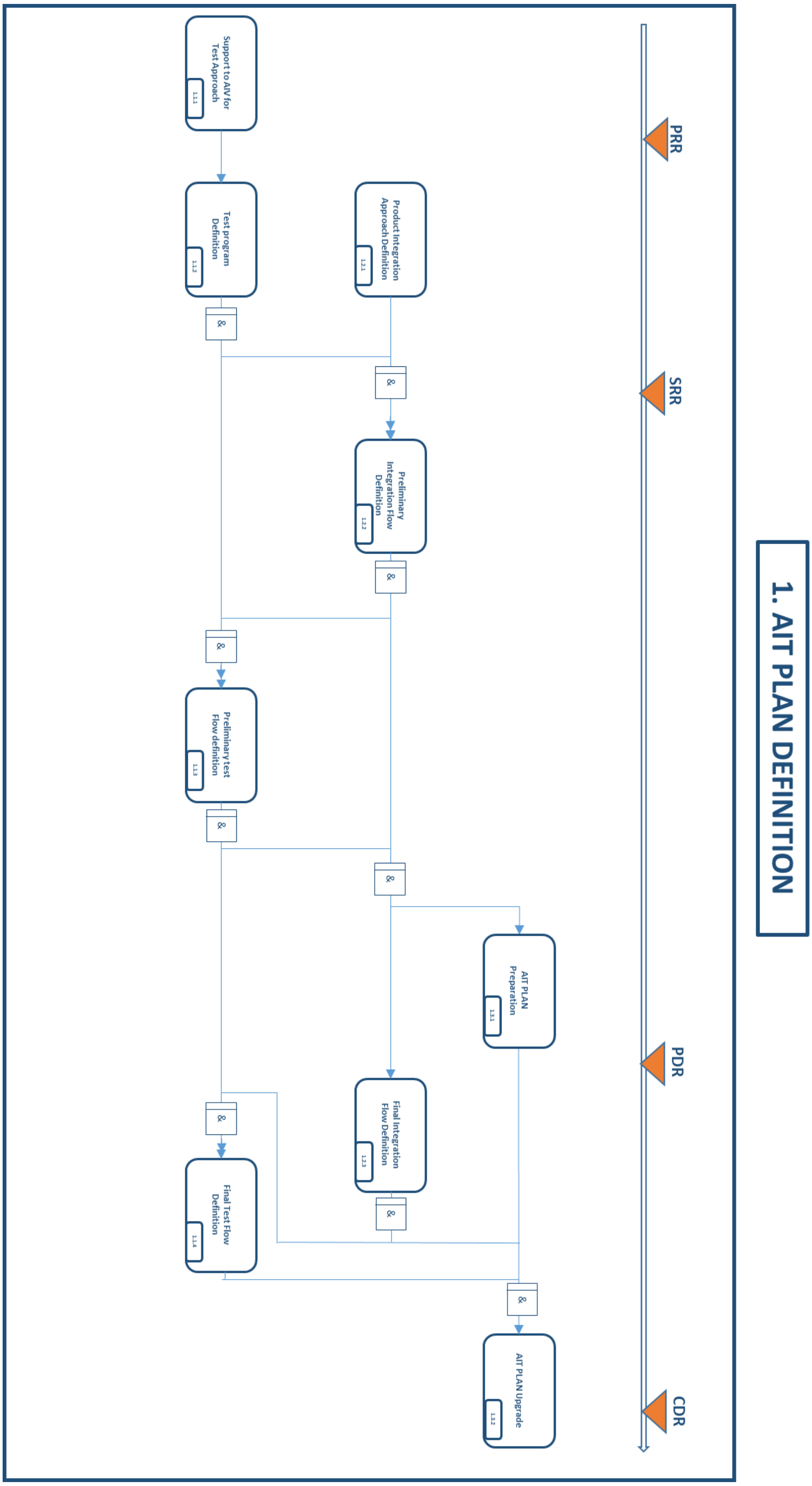

Figure 20 - AIT PLAN Definition, lev. 2 (idef 3)

1. AIT PLAN Definition

The definition of the AIT PLAN is the macro-activity that includes the definition of the Test Flow and the Integration Flow and the delivery of the AIT Plan, that is the Master Plan that leads all the tasks related to the AIT Campaign for a Space Program. These activities are performed during the project definition phase, following the project development, to program the realistic flow of the activities during the process of the product realization. The actors involved in this activity are the AIT Engineering teams with the aids of the AIT Operators that bring theire experience about the most practicall aspects. The integration flow and the test flow merge into a singol AIT Flow that includes both the activities. The need to separete the two flows derives by the different skills and resources that are involved in the flow definition. The activities concerning the thermomechanical, the propulsion and the Electrical aspects are carried out by the tree different AIT Engineering Teams: their evaluations and choices meet in the final AIT flow.

This activities involve the AIT team in the constant collaboration with the System Engineering, the AIV Engineering and the Launch Service Provider, as soon as it is selected.

1.1 Test Flow Definition

The definition of the test flow for a verification level is an iterative process carried out from Phase A to Phase C by the acquisition of successive levels of detail about the requirements to be tested, by the deepened awereness about the tools to be used and by the more realistic definition of the AIT and Program Schedule. The Definition of the Test flow is thightly tied to the activities of System Engineering and AIV Engineering, for which AIT represents the supplier of the testing activities. In order to define a Test flow coherent with the overall verification activities the AIT engineering needs the input of the Technical Requirement Specification, the AIV Plan and the Verification Control Document, respecting their development phases over the time. The outputs of this activities are the characteristics for the GSE, Facilities and Instrumentation that will be further used for the AIT Campaign and whose program, together with the AIT flow further developed for the next verification level, represent a control over the preliminary decisions made. The definition of the test flow is reached by a sequence of activities:

- Support to AIV for Test Approach Definition
- Test Program Definition
- Preliminary Test Flow
- Detailed Test Flow

1.1.1 Support to AIV for Test Approach Definition

This acrivity is carried out during phase A by the AIT Engineering that supports the AIV Engineering in the definition of the verification approach concerning testing activities. The aim of the activity is the selection of the model philosophy for each verification level, the efficient strategy to reuse test models for being further integrated in sucessive verification level considering the preliminary Product Tree, the thecnology selection and the related TRL. This activity allows the preliminary selection of the type of test that will be performed for the Qualification and Acceptance Campaign for each verification level together with the definition of the test strategy, that is the selection of the verification stage, level and model for each requirement of the TRS. The AIT Engineering, by the assessment of the documentation such as Product Tree, TRS, Verification Plan, helps the assessment of the best strategy, and the trade off between the different verification method for each requirement basing on the experience on previous AIT caimpaign.

1.1.2 Test Program Definition

During the phase B the more accurate development of the product tree and the organization of the specification tree by the allocation and derivation of the requirements to all the product of the breakdown structure, allow the completion of the verification strategy for all the requirement and for all the verification levels. The AIT Engineering carries on its support activity ensuring that all the requirement will be covered by the verification activities without redundancy and supports design activities to ensure the quality principle of testability. The completion of the verification strategy, by the end of the phase B, allowes the definition of a coherent Test Programme encompassing each verification stage and level to implement the verification by testing that will be performed incrementally at different product decomposition levels. The test program is decomposed in blocks that include one or more tests and that are defined basing on the item under test, the facility and tools. Typical test blocks for space segment elements includes:

- **Functional and performance test**: Functional tests verify the complete function of the space product under the specified environment conditions and in all operational modes and for all the redundant chains; Performance tests verify the space product performances conformance with the performances specification under the specified environment.

- **Mechanical tests**: This test block includes the Physical Properties Measurements like dimension and interfaces, mass, Center of Gravity, Momentum of Inertia, Static, Spin or Transient Acceleration Tests, Sinusoidal and Random vibration test, Shock test, Structural Integrity test like Leak test and Proof Pressure Test
- **Electrical/RF Test**: Electrical tests includes Electro Magnetic Compatibility Test, Magnetic Test, Electro Static Discharge Test, Passive Intermodulation Test, Multipaction Test, Radio Frequency Test.
- **Thermal Test**: Thermal Test could be Thermal vacuum and thermal ambient test according to the environment where the product will operate.
- **General Test**: Other General Test that could be selected are the Life test, Burn-in test, Humidity Test, Audible Noise test.

For each test block the test readiness review, the post-test review and the test review board are foreseen. The more accurate definition of the test program represents the input for the general definition of the characteristics of GSE, Facilities and Instrumentation that will allow the AIT program execution. It is a fundamental input even for the integration flow, for each product at each level, that will consider the tests to be performed during the integration activity and the related constraints and needs.

1.1.3 Preliminary Test Flow Definition

During the second part of the Phase B, having in input the preliminary Integration flow of the product, the detailed verification strategy and test programme contained in the Verification Matrix and AIV Plan, considering the programme established for the GSE and Facility as a constraints, the preliminary Test Flow is settled with a sequence tailored to the specific space product for each project, considering the combination of all required tests specified for each type at which the product belongs.

The test sequence is defined taking into account test applicability that reflects the principle "Test as you fly", basing on the combination of the environments encountered during flight and the need to identify defects and unusual or unexpected behavior as early as possible in the test sequence. General rules for the definition of the test flow are defined by the ECSS manual:

- The execution of Performance Test and Full Functional Test is foreseen at the beginning and at the end of the test program under ambient conditions for judging the integrity of the space segment equipment thought the overall test flow and during the thermal test block.

- Reduced Functional Test is foreseen before and after each environmental test block and before and after transportation to verify the integrity of the space product.

The definition of the AIT Flow must respect the expected Mandatory Inspection Point and the Key Inspection Point included in the Product Assurance program.

The test flow resulting by this activity represents a control over the preliminary integration flow and provide more needs and constraints for the definition of the GSE, the selection of the test Facilities and the requirements for the instrumentation useful for the test setup configuration.

1.1.4 Detailed Test Flow Definition

This activity is carried out during the Phase C in order to determine the final test flow that will be based on the definition of the final Integration Flow for the product whose design is subjected to its frozen process. The definition of the final test flow is even based on contingent aspects related to the procurement of GSE and material under the responsibility of the AIT Function, to the availability of the test Facilities and to the availability of product to be tested that is an input that the AIT receives from the project manager responsible for that product.

1.2.1 Product Integration approach definition

This activity is performed during the first part of the phase B when the product tree is settled with an adequate level of confidence about all the decomposition level for the product. The definition of the technical requirements including the interface requirements is the major input for this activity that lead to the preliminary definition of the modality of the integration and the high level characteristics of the related enabling technology like GSE, Facilities and instrumentation. During this phase the AIT Engineering gives its support to the System Engineering for the definition of the requirements for integrability of the products, especially for the aspects concerning the interfaces requirements.

1.2.2 Preliminary Integration Flow definition

The Preliminary Integration Flow is settled during the second part of the Phase B when the requirements for all the level are defined together with their verification strategy. The test program established for every product is an aspect to be evaluated during the definition of the Integration Flow because of the constraints related to the integration sequence and the needs related to the accessibility of the measurement points. In order to define an Integration Flow coherent with this necessity, the instrumentation plan with the instruments and the sensor that will be arranged during the integration flow and whose removal won't be possible, it's a required information. During this phase the preliminary design solution definition for the different chosen technology is carried on together with the definition of the interface design. This is a crucial step to be executed with the assessment of the AIT Engineering and the Operators advices in order to ensure the possibility to integrate the product in a feasible manner. During these steps the requirements for the GSE and facility became more clear although their program represents a constraint for the flow itself. Another constraint for the definition of the integration flow is the Mandatory Inspection Point and Key Inspection Point defined by the Product Assurance. Inspection over integration are planned at the points of the flow that guarantees the exploitation of correct processes and the prevention of costly non-conformances. Critical characteristics are inspected respecting the critical-item control program. MIPs are selected when the maximum visibility is given and when the next step of the integration flow makes the item inaccessible for inspection or when a failure of the product integrated in the higher assembly determines the damage of the overall assembly.

1.2.3 Final integration Flow definition

The final integration flow is obtained during the Phase C by a series of modification carried out on the preliminary test flow considering the assessment of the Preliminary Test Flow and the evaluation of the more detailed definition of the test condition and needs. During this phase the configuration part list describing the product to be integrated configuration with the frozen internal and external interfaces is a fundamental input for the realization of the integration flow. Other contingent aspect that could limit the integration sequence is the availability of GSE, facilities, materials whose provision is described by the related plans drafted by the AIT Planners and the availability of the product to be integrated reported by the project manager responsible for that product.

1.3.1 AIT PLAN preparation

The AIT plan is the master plan for AIT process of the space products. It contributes, together with the verification plan, to the demonstration of how the requirements will be verified by inspection and test. It describes the overall AIT activities, their management, organization and schedule, the related verification GSE, facilities, instrumentation and the required documents to be produced and their content.

The AIT Plan indicates the responsibilities within the project team, the relation to product assurance, quality and configuration control for tasks with respect to AIT that include: anomaly handling, change control, safety, and cleanliness.

The AIT Plan is prepared by the AIT Manager in charge for the program, for the different verification levels, by the detailed description of the activities at that level and foreseeing the activities for lower level aspects.

The AITP could be considered as complementary to the verification plan: while the Verification Plan focuses on “what will be verified”, the AIT Plan focuses on “How it will be verified by test”. The verification plan is a prerequisite and an input to the preparation of the AIT Plan.

The first issue of the AIT Plan is baselined for the phase B when the information about the AIT Program and Flow, together with the selection of the GSE program and the Facility characteristics reach a sufficient level of accuracy.

1.3.2 AIT PLAN upgrade

The first version of the AIT Plan is then refined with minor modification and completed by more details during the following phases, till the completion of the test campaign.

The updated AIT Plan contains the planning associated to the AIT activities and includes the test matrix that contains the link between each test and its test specification, test procedure, test blocks and hardware model. The upgraded AIT Plan includes dedicated activity sheets that describes the activity including the tools and GSE to be used, the expected duration of the activity, and the relevant safety or operational constraints and the description of the logistics and major transportations.

The AITP shall describe the responsibilities within the project team, the relation to product assurance, quality control and configuration control (tasks with respect to AIT) as well as the responsibility sharing with external partners. Tasks with respect to AIT include for example, anomaly handling, change control, safety, and cleanliness.

5.4 AIT Facilities Management

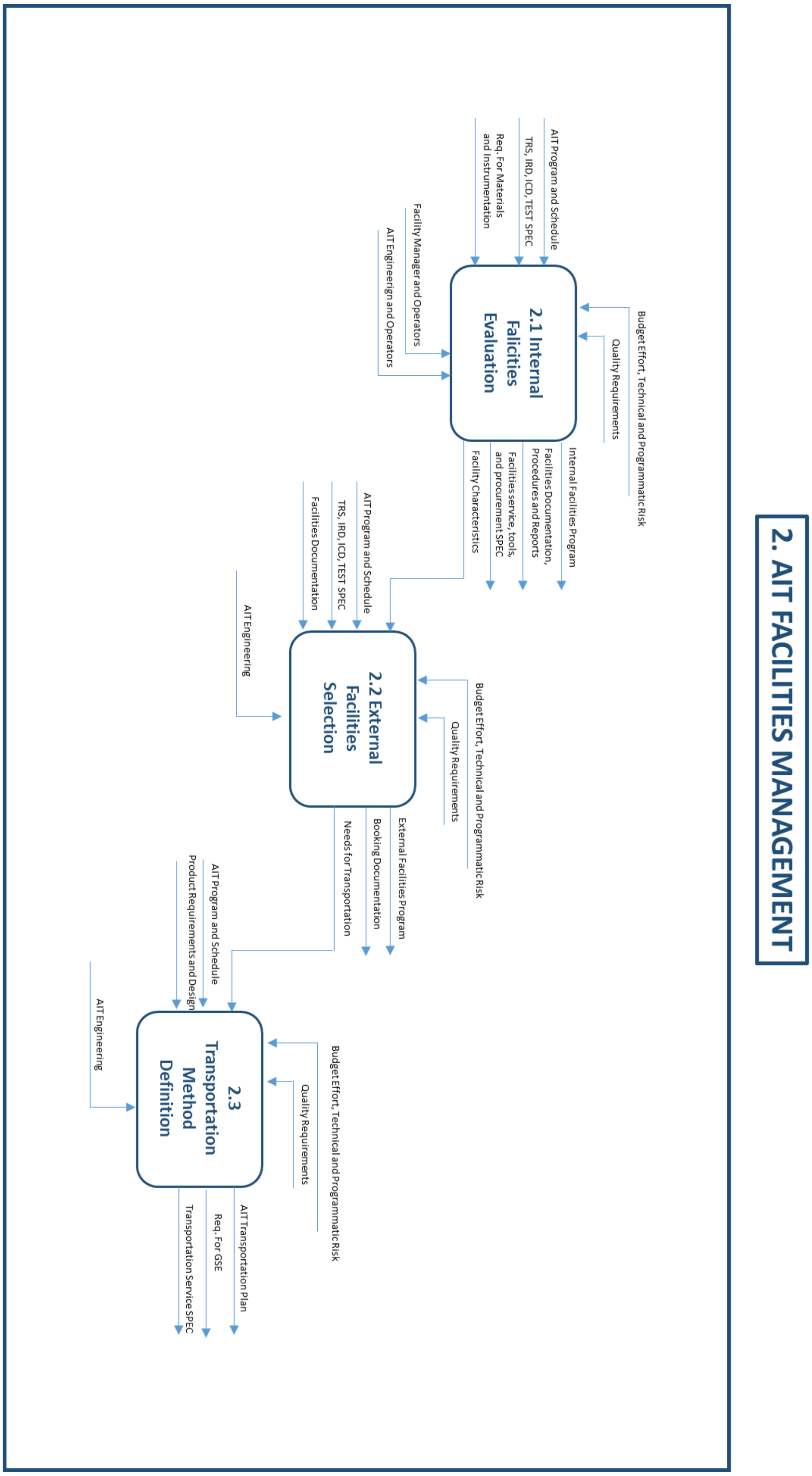

Figure 21 - AIT Facilities Management, lev. 1 (idef 0)

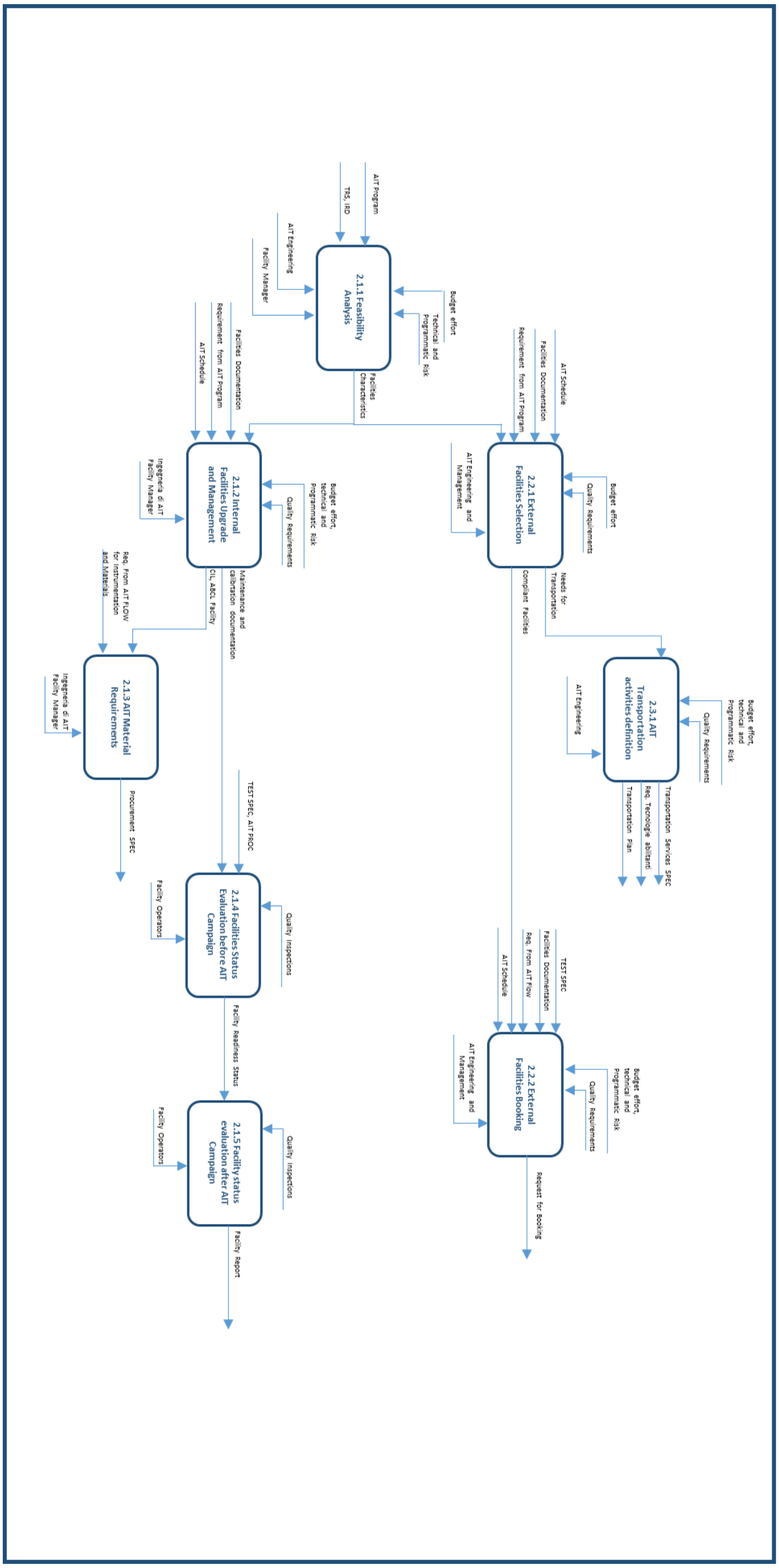

Figure 22 - AIT Facilities Management, lev. 2 (idef 0)

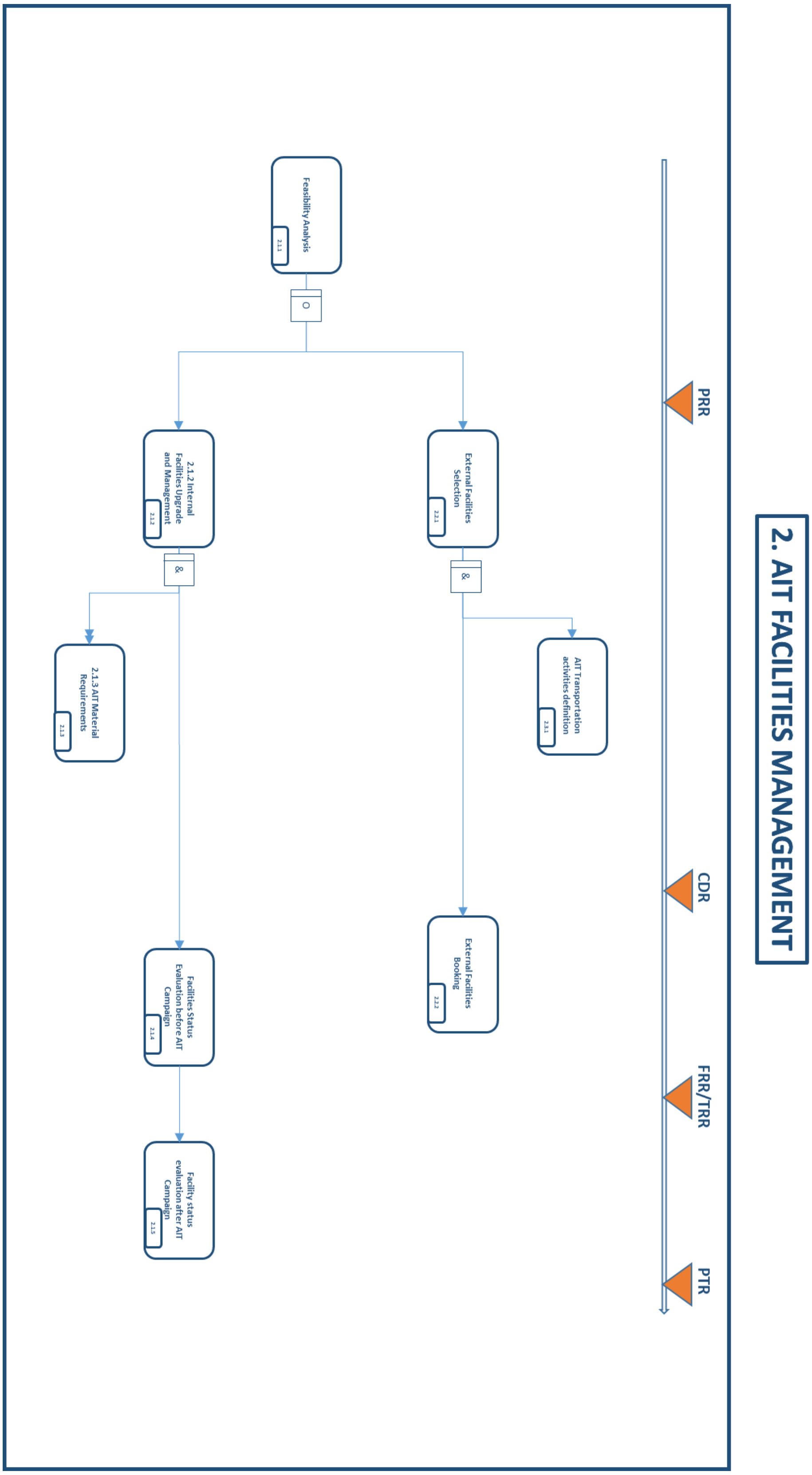

Figure 23 - AIT Facilities Management, lev. 2 (idef 3)

2. AIT Facilities management

The overall AIT campaign is tightly tied to the availability of the appropriate facilities, where the test facility is the technical plant that provides the simulated conditions for testing products for space applications. The facility includes test connections and instrumentation necessary to perform the test campaign, maintained and operated by qualified test personnel. The space test Center is the complete entity that provides, maintains, and operates the facilities.

The assessment of the facilities is one of the most important evaluation to be performed during the first phase of the space project development because it implicates great limit on the budget effort and allocation, and because of the programmatic and technical risks related to the AIT Schedule and therefore to the overall program schedule. This macro-activity includes:

2.1 Internal Facilities evaluation
2.2 External Facilities selection
2.3 Transportation method definition

The possibility to perform the integration and test campaign within the internal facilities or in the external ones coexists for a space program and even for the specific space project and products. The choice is made on the basis of the needs related to the test program, the availability of the structures and the technical requirements of the space product and to the requirements to be respected during the AIT Campaign.

The necessity to perform the activities in external facilities impose the selection of the appropriate transportation method and the related enabling technologies.

These activities are carried out through the collaboration of the AIT Engineering team responsible for the technical aspects tied to the integration and testing activities, the AIT Manager responsible for the programmatic aspects that discuss with both internal and external Facility Management and technicians.

2.1.1 Feasibility Analysis

This activity is carried out during the overall feasibility evaluation of the space program (Phase A). The assessment is based on mission requirements, high level technical requirements including interface requirements, physical characteristics of the product to be integrated and tested and the functional requirements that are baselined during the phase A. All these requirements determine features and constraints for functional and physical characteristics of facilities, Ground Support Equipment and other enabling technologies that the facility should be equipped with in order to conduct the AIT campaign. Other input necessary for this evaluation is the test programme that underlines the need for facility suitable for Electro Magnetic Compatibility, Radio Frequency test, Environmental tests and thermal or thermal vacuum chamber. These evaluations allow to establish the readiness of existing resources or the necessity of an implementation strategy in order to conduct assembly, integration and testing activities. Other output of the assessment could be the necessity for the selection of external facilities. This activity is conducted by the AIT Engineering Teams that settle the facilities requirements related to the integration and test campaign, the AIT Management that evaluates the programmatic risks related to the AIT activities and with the collaboration of the Programme management that establish the Budget limits.

2.1.2 Internal Facilities upgrade and management

As a result of the feasibility analysis it could be necessary an upgrade activity related to the existing facility. It will be customized on the basis of the technical requirements settled by the system engineering for the space programme and by the requirements settled by the AIT Engineering for the AIT activities. The evaluation is made by the Facility Manager on the basis of the analysis of the documentation that describes the configuration and the functions of the facility technology, with the technical support of the AIT Engineering. The space test Centre is responsible for the configuration control. It produces a configuration item list and the as built configuration for each test facility and associated equipment like software, critical items and items under maintenance control. Every configured item is described by the applicable documents, drawings and identification data.

The management of the Internal facilities includes the implementation of metrology and calibration tasks, respecting the proper programme and schedule, and providing the traceability of calibration by the unbroken chain of activities performed to link the measurement results to the standards used to perform the calibration. The calibration plan includes the identification of the equipment to be calibrated, the calibration activity and his periodicity, the applicable specification.

The Facility Manager is also responsible for the execution of tasks related to the maintenance plan for test facilities, environmental monitoring, and software used during the test process and for the facility risk assessment.

Another task necessary for the performance of the integration and test campaign within the internal facility is the definition of skills and qualification necessary for both facility and AIT Operators. On the basis of the test programme and integration method and related selected tools the AIT Operators Responsible identifies the required competence, training and authorizations necessary to perform the AIT campaign complying with the applicable safety requirements and organizes training class to allow the timely availability of the personnel for the integration and test reviews.

The Facility Manager is also responsible of the specified environmental and cleanliness condition throughout the test process in order to preserve the test specimen and equipment. With this aim the space test center establishes, the environmental control programme for temperature, relative humidity and differential pressure, and the other parameters specified by the customer like the light level, electromagnetic radiation, magnetic cleanliness, vibration, acoustic environment to ensure conformance with the level specified by the specifications.

2.1.3 AIT Material Requirements

This activity starts after the definition of the AIT Flow, during the Phase B, when a sufficient level of accuracy is reached in the definition of the test campaign. The AIT Engineering team define the characteristics of the test setup and integration instruments including test software, fixture, jigs, sensors, torque wrenches, cables, savers and other consumable materials, identifying the long lead procurement items that need to be timely procured. The AIT Engineering teams are in charge to produce the procurement specification for these materials included in the AIT Billet of Material correspondent to the different AIT activities. The required materials must be compared to the instruments stored under the responsibility of the Facility Manager and in case of lack of material the requirement for purchase is made by the AIT Planners that manage the procurement of the missing materials and maintain the Material Requirement Planning. During the phase C when the modality of integration and test becomes more clear with the delivery of test specification and the integration and test procedures, the configuration for the setup if frozen and the test levels and the required measurement accuracy the need for other materials arises with an upgrade of the Material Requirement planning following the same steps.

2.2.1 External Facilities Selection

After the evaluation of the mission requirements and the high level technical characteristics, the necessity to conduct part of the AIT campaign in external facilities can arise. During the phase A, the design definition of the space product is not so advanced to allow accurate technical assessment but it is necessary to adopt a provisional view to assess if the physical characteristics, together with the functional and performance behavior to verify by test, will require the shipment of specimens in external facilities. This prevision has to be timely assessed because of the increase of cost effort and consequences on the schedule. For the correct selection of test facilities for the test campaign, the documented description of infrastructures including functional performance, general arrangement drawings and interface definition, the identification of standards for maintenance and calibration of items and the assessment of risks related to customer supplied products and the related processes are fundamental input to be examined. The selection of facilities compliant with the requirements is conducted by the AIT Engineering team by the supervision of the Product Assurance in order to respect the quality requirements and by the approval of the Programme and Project Managers for the budget and programmatic aspects.

The selection of the launch vector and the launch site is another fundamental aspect for the definition of the AIT activities. As soon as the choice is made the AIT engineering teams support the System Engineering Team during the meeting with the Launch provider to ensure the coherent interface of the space product with the launcher and the definition of the useful GSE and the associated handling procedure.

2.3.1 AIT Transportation Activities Definition

As soon as the external facilities and the launch site are selected, the transportation activities are planned and the mode of transport are selected by a trade-off of technical requirements, cost effort and programmatic aspects. The AIT Transportation Plan is managed by the AIT Planner for the planning and subsequent schedule of the related activities and for the booking request of the related services. The goods are classified in different categories:

P1- Critical products for transportation: goods that exceed the legal standard transport envelope or product defined as "critical for transport" in the Configuration Item List of the project and reusable transports containers for these goods;
P2- Products of specific care: items sensible to environmental conditions and items for which the defined packaging has not proven its capability to protect them against the risks of standard transports;
P3- Other products;
For each type of transported good a corresponding transportation category is defined:

T1- Critical transports, which are escorted dedicated transports;

T2- Dedicated transports, which are door to door pick-up and delivery of the item;

T3- Standard transports;

The Configuration Item List and the constraints settled by the requirements of the product, the product assurance requirements and the legal regulation, a risk analysis for P1 and P2 products are the input required by the AIT Engineer that write the specification for transport service selection and booking.

The definition of the mode of transportation and the planning of the transportation is a fundamental input for the definition of the GSE and the other enabling technologies and for the definition of packing and handling procedure.

2.2.2 External Facilities Booking

During phase C the design characteristics of the products is frozen and the test specification and procedures are delivered. The definition of the test points and level, the instrumentation plan and the frozen interfaces allow the final selection and booking of the external facilities. The AIT program and schedule are a fundamental input to be considered. The quality assurance requirements are a fundamental control for the evaluation of risk related to the handling procedures to be performed by the AIT Operators. The request for booking is made by the AIT Planners that maintain the Facility Plan encompassing the AIT activities execution.

The external facility must demonstrate the compatibility of the test processes with the infrastructure, the test facilities, the test execution, and the applicable test procedures specifying the requirements for any verification and validation of test processes, equipment and personnel.

2.1.4 Facility Status Evaluation before AIT Campaign

The Space test Centre maintains procedures to verify the test planning, test preparation, test execution and test related hardware and infrastructures in order to meet customer requirements. All phases of the testing process and related servicing are identified in cooperation with engineering, AIT, quality and safety assurance staff with the aim to assess the risks of the test process. Every activity must be performed under controlled conditions and by methodologies agreed by the quality and safety representative.

The Space Test Centre personnel establish procedures for the assessment of readiness of test facility and set-up. The test facility status is verified before each test by the AIT Operators that control facility configuration for the test, test facility data handling, measurement equipment calibration, environmental and cleanliness status, maintenance and safety status.

The personnel qualification and availability together with the GSE readiness status are verified and the Facility Readiness Report is prepared and shared by the Facility Manager during the Facility Readiness Review and the subsequent Test Readiness Review.

2.1.5 Facility status evaluation after AIT Campaign

During the AIT campaign the Facility Operators have the responsibility for the management of the tools that belong to the facilities and for the storage of the related data. The space test center monitors the status of the test set-up and documentation during the different phases of the test process, and maintains records of this status.

All testing activities performed by the Facilities operators are documented in test reports that includes the description of the method or procedure, derived results and measurement units, uncertainty and confidentiality level together with data that allow the traceability of the operators involved and their actions.

The accuracy of test instrumentation is verified by the application of the calibration procedures, and the anomalies of test instrumentation detected at the firs calibration cycle after test are reported.

The Facility operators present the preliminary test facility data during the Post Test Review sharing test facility data packages, non-conformances and dispositions, demonstration that test facility data meet customer requirements, and the status of the facilities, GSE and Instrumentation after the AIT Campaign.

5.5 Ground Support Equipment Management

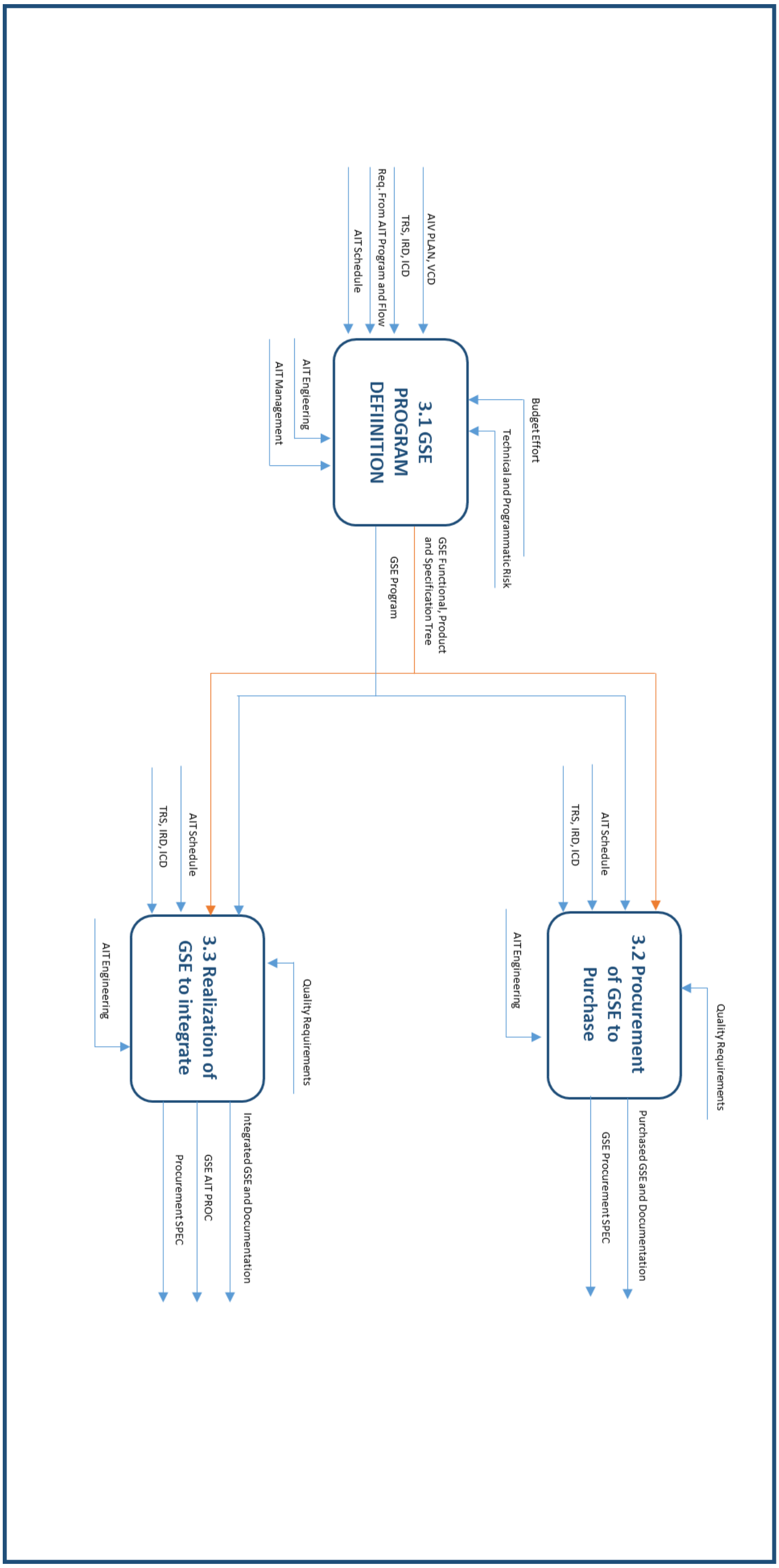

Figure 24 - GSE Management, lev.1 (idef 0)

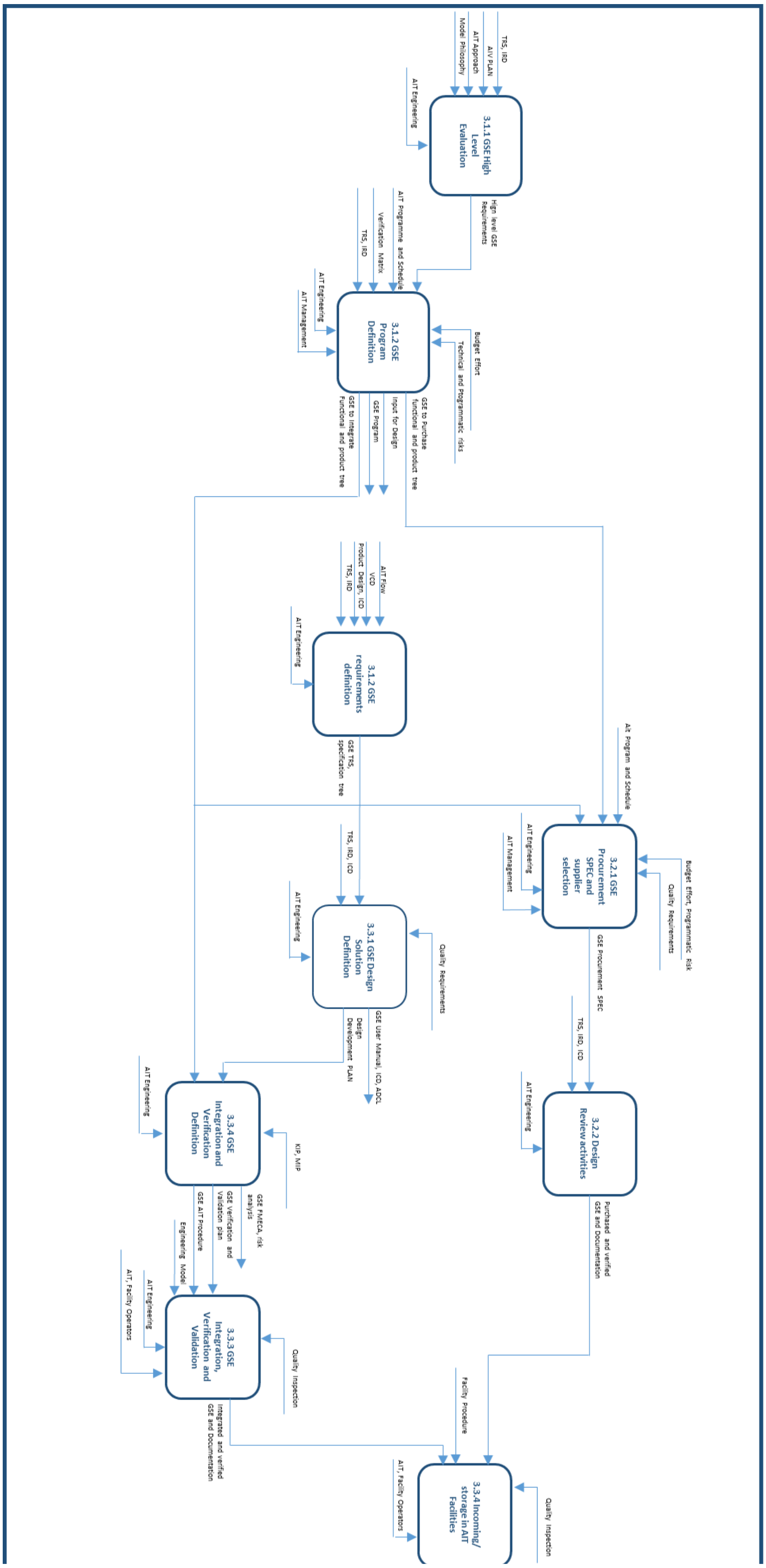

Figure 25 - GSE Management, lev. 2 (idef 0)

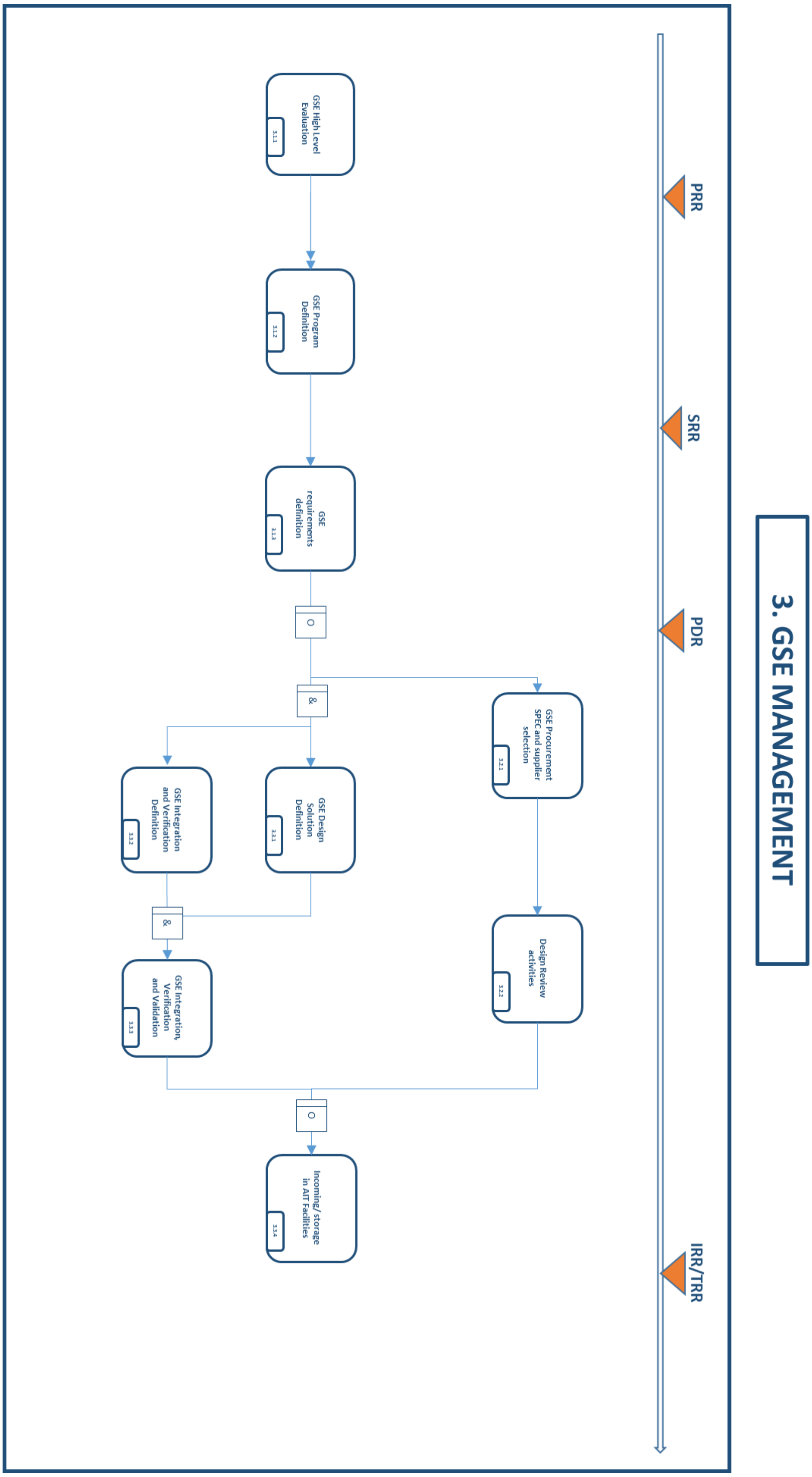

Figure 26 - GSE Management, lev. 2 (idef 3)

The Ground Support Equipment (GSE) are equipment provided to allow the correct handling and operation of the satellite during all activities of the manufacturing, assembly, integration, testing, handling, transportation and storage cycles. They include all hardware and software required to support AIT activities at every levels of integration, up to and including preparation and testing at the launch site. They allow functional testing to demonstrate flight readiness of the integrated system without causing any failure or damage to the product.

The GSE can be classified, according to their functional designations as:

- Servicing Ground Support Systems: they supply electrical power or fluids to the flight hardware or their associated GSE. They are capable to store, transfer, pressurize, purify propellants and other fluids required by the flight hardware.
- Checkout and test GSE: they are used during the test and functional check of flight hardware functions and performances. They are capable to monitor the specimen response to stimulation and to evaluate the test results.
- Handling and transportation GSE: they are used for the movement and support of flight hardware. Typical types of equipment for this category are slings, trolleys, transport containers, support stands, hoisting device.
- Auxiliary GSE: they are devices required to align, access, protect, and calibrate flight hardware. Some examples are protective devices, access stands, alignment or calibration hardware.
- Umbilical GSE: they directly interface with flight hardware for transfer of fluids, electrical power, or electronic signals to or from the flight element.

They can be further classified on the basis of the test block and of the type of product for which they will be used as: Mechanical GSE (MGSE) provided by the Thermo-mechanical AIT, Electrical GSE (EGSE) provided by the Functional Unit and GSE AIT, and Fluidic GSE (FGSE), provided by the Propulsion AIT.

The teams collaborate for the definition of the program and characteristics of the GSE that are a fundamental input for the production of the AIT procedure for the AIT Campaign of specimen and flight products.

The overall activities related to the provision of the GSE for a qualification and acceptance campaign of a space product can be classified as:

1. GSE Program definition

2. Procurement of GSE to purchase
3. Realization of GSE to integrate

3.1.1 GSE high level evaluation

During the phase A, the feasibility analysis conducted by the AIT Manager by the supervision of the AIT Division Manager and in collaboration with the AIT Engineering Responsible is based on the selection of the characteristics of tools needed for the AIT Campaign completion. These tools include AIT Facilities and the Ground Support Systems. During this phase the functional requirements baselined and the derived product tree, the definition of the concept of operation for the program and the preliminary technical requirements allow the selection of the high level characteristics for the GSE that will be required for the AIT Campaign. This evaluation allows the preliminary assessment of the existing equipment, the definition of the programmatic constraints and the preliminary budget and resources allocation for the related activities.

3.1.2 GSE Program Definition

The development of the GSE hardware and software program is tied to the selection of the most cost-effective philosophy that can guarantee the timely provision of the equipment for the AIT campaign and the maximum utilization of the minimum amount of equipment without degrading the testing activity. The GSE program could be optimized by foreseeing the reuse of subsets of equipment at different levels of testing. With this philosophy hardware and software are reused from subsystem to system testing and Payload testing up to spacecraft testing. A modular GSE approach allows also an easier correlation of test results from one level to another, the maximum similarity of the operator interface from one level of test to another, and the Maximum reuse of equipment and software. All GSE interfaces are designed to be fully compatible with integration and test facilities. To achieve the most effective designs, a system-oriented approach is implemented to enable the maximum re-use of equipment.

The subsequent iterations in the GSE definition reflect the decomposition level of the overall space product and results in successive refinements of the functional characteristics that the equipment will supply. The functional requirements and all the derived and allocated technical and interface requirements need to be organized in a programmatic view in order to respect the timeline of the integration and testing activities up to the launch, considering all the verification level for all the verification models foreseen by the Model Philosophy. The Verification Plan with the model philosophy, the Verification Control Document with the Verification Matrix, the Technical Requirements Specification and the Interface Requirement Document are the fundamental input for the definition of the GSE program and high level requirement. The results of this activity conducted during the first part of the Phase B is the definition of the program for the GSE, and basing on the space product functional tree (with frozen functional specification) and the correspondent product tree and specification tree, the GSE functional tree and a preliminary product tree is prepared.

3.1.3 GSE Requirements Definition

During the Phase B the technical requirements of all the decomposition level of the space product are defined to be subjected to the configuration control. During this phase the AIT Engineering teams support the System Engineering team in the refinement of the interface requirements and design in order to allow the correct interaction between the space product to be integrated and tested and the related GSE. The frozen TRS are then an input for the AIT Engineering to complete the definition of the technical, design, interface specification for the GSE.

The criteria for the definition of the GSE requirements are based on a common collection of requirements useful for all the GSE in order to respect quality and safety aspects and other specific criteria determined by the responsible design organization. The Thermo-Mechanical AIT is responsible for the definition of MGSE, The Functional Unit and GSE AIT Team is responsible for the definition of EGSE and the Propulsion AIT Team is responsible for the definition of FGSE. These team are responsible for the selection of the customized requirements for the GSE, in consultation with the other involved AIT Engineering teams, the System Engineering that is the final costumer for the Verification and Integration campaign of the product, the Launch Provider in order to ensure the final handling and integration of the Space Product on the Launcher and the AIT Operators that are the final users of the GSE. The Technical Requirement Specification are delivered during PDR and they are subjected to the configuration control as stated in the Program Management Plan.

Design, production, delivery and maintenance requirements for GSE are defined and implemented to allow testability, availability, safety, life duration, operability and ability to interface as necessary with space products in a safe way.
The function tree and correspondent product tree and specification tree for the GSE are produced to guaranty traceability and to maintain the configuration control for the GSE product.

Basing on the trade-off analysis between programmatic aspects, related to the AIT and Programme Schedule, technical risk evaluation, resources allocation and budget effort, conducted by the AIT Manager with the support of the AIT Engineering Responsible and with the constraints of the Program Management, the GSE to be purchased by external supplier and the GSE to be Designed and Integrated by the AIT Engineering and Operators are selected.

3.2.1 GSE Procurement SPEC and supplier selection

For the procurement of GSE to be purchased the AIT Engineering Team responsible for the GSE will produce the Procurement specification that will be delivered during the Phase C after the freezing process of GSE Technical Requirements during the PDR. The procurement specification includes all the requirements that will be respected by the GSE Purchased, together with the selected verification method for each requirement. Procurement documents identify validation and receiving inspection requirements and define the list of countries where the GSE is intended to be used along the project development life cycle in order to guarantee that GSE will be certified, conform to all customer rules, EC rules and national laws of the countries where the GSE is intended to be used.
The AIT Engineering Team, in coordination with the quality assurance selects the GSE supplier assessing the suppliers demonstrated ability to conform to requirements, through previous supply of similar items, certification covering similar design, production and quality standards.

3.2.2 Design Review activities

After the selection of the GSE Provider, the AIT Engineering team behaves as a customer for the Design solution definition. The team supports the provider to ensure the respect of the requirements and to communicate the refinement to the design of the space product occurring during Phase C that involves consequences on the Design of the GSE. The AIT Engineering team is the customer for the Design review of the GSE and after the CDR, the frozen hardware and software design of the GSE is an input for the AIT Engineering team for the production of the integration and test procedure for the specimen AIT campaign that will employ the GSE.
The GSE provider is also responsible for the manufacturing, integration and verification activities for the GSE that will be delivered with all the related documentation such as: User Manual, Verification and Validation Report.

3.3.1 GSE Design Solution Definition

Design and verification standards are set to fit with the level of complexity of the GSE to be developed taking into account the development risks into the GSE Design Development Plan. The GSE design configuration is controlled by the definition of the configuration item list and the As Design Configuration List. The Team in charge of the Design Solution Definition, is responsible even for the production of the design documentation like the Interface Control Document, the User Manual that must document the ready for use criteria (such as functional check, visual inspection, maintenance status, validity of certification), Maintenance Requirements, and the Storage Plan for the GSE. History of MGSE is recorded in its log book that should be available to the user at the place of the GSE to record activity such as repairs, maintenance operations, Non-conformance Report and modifications of the GSE. After the definition of the GSE Architecture and layout the team is responsible for the procurement of the unit and technology to be integrated. This is an input for the AIT Planner that will manage the procurement and the Material Requirement Plan concerning the GSE production. All GSE with hazardous configuration are identified in order to implement specific risk mitigation devices defined by risk analysis and implemented to avoid reaching the unsafe conditions.

Prior to the use of GSE the design authority performs analysis and document it in a report, including interfaces, performances, safety factors, as designed and as built documentation.

3.3.4 GSE Integration and verification Definition

The AIT Engineering team responsible for the Design development of the GSE defines also the integration, verification and validation plan for the GSE, ensuring that the verification method and process are tailored to the complexity of the item to be verified, to the criticality of the function to be implemented by the GSE and to the inherent criticality of the item itself. The FMECA or the risk analysis are AIT tasks that allow the definition of the verification criteria.
Encompassing the operational needs and the selected method for the GSE requirements verification, the functional and performance test procedures and the validation procedures are prepared by the AIT Engineering team.

3.3.3 GSE Integration and verification Execution

The GSE are integrated and verified with the same process described for the integration and verification of the space product. The difference between the two flows lie to the different responsible for the start of Production: the responsible for the production of models for development project is the project manager whereas and responsible for the GSE production is the AIT Manager. The responsibility for the procurement of the products to be integrated is a program manager task for the space product, whereas the AIT Planners maintain the Material Requirement Planning for the GSE Production.

After the integration, verification and validation activities of the GSE the Inspection and Verification Report and the Validation report is prepared by the AIT Operators and delivered by the Integration/Test readiness review in order to be employed for the AIT Campaign.

3.2.2 Incoming/ storage in AIT Facilities

After the incoming activities of the GSE executed by the AIT and Facility Operators in collaboration with the Product Assurance that inspect the products, the GSE are stored in the Facility. The storage configuration and activities for the GSE are defined by the Storage Plan, that contains all the information for storage and de-storage activities. It is issued by the internal or external supplier as part of the User Manual during the CDR.

The storage period and the identified periodic inspection and testing are defined by the storage plan and recorded in the GSE log book.

5.6 AIT Activities Execution

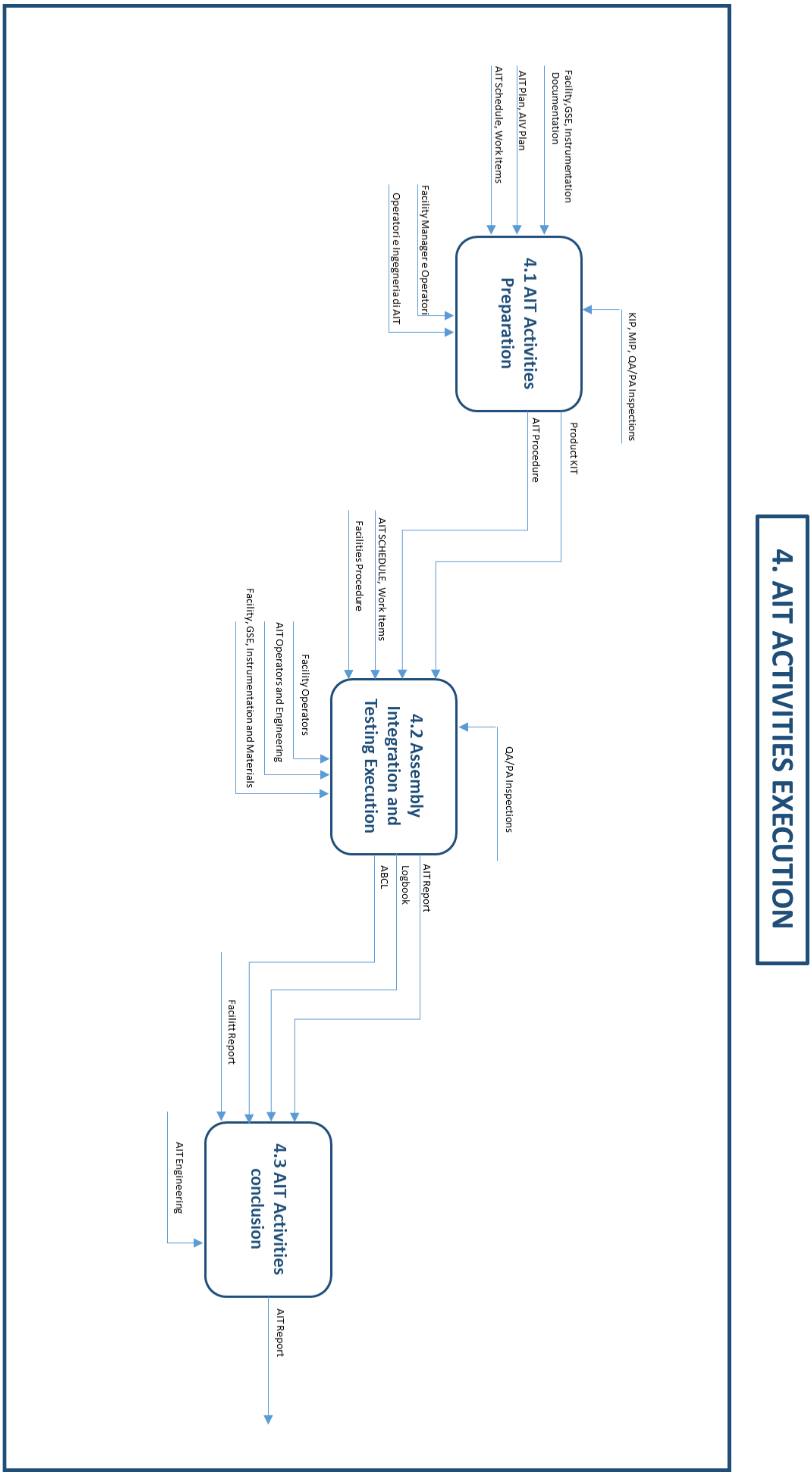

Figure 27 - AIT Activities Execution, lev. 2 (idef 0)

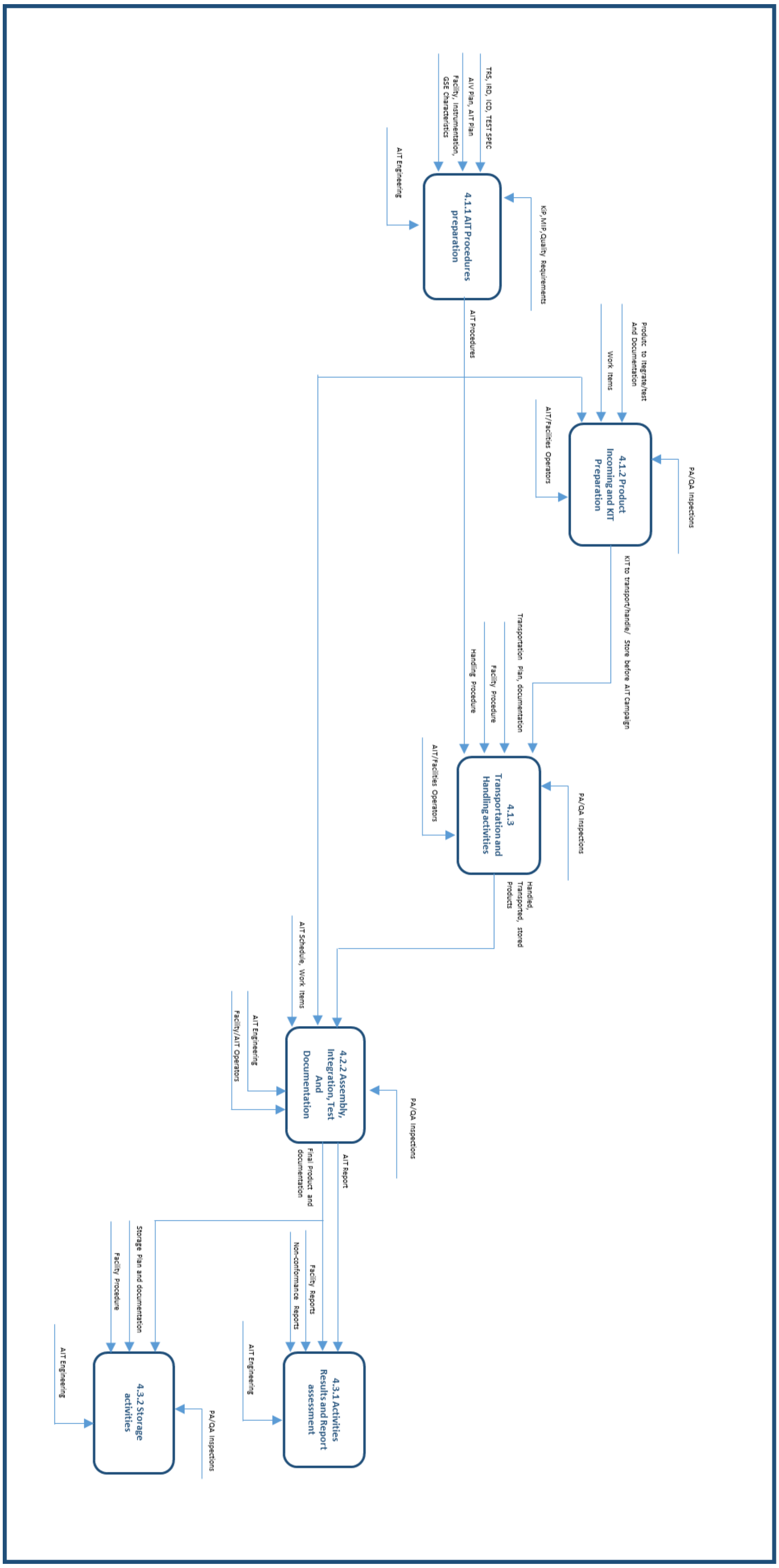

Figure 28 - AIT Activities Execution, lev.2 (idef 0)

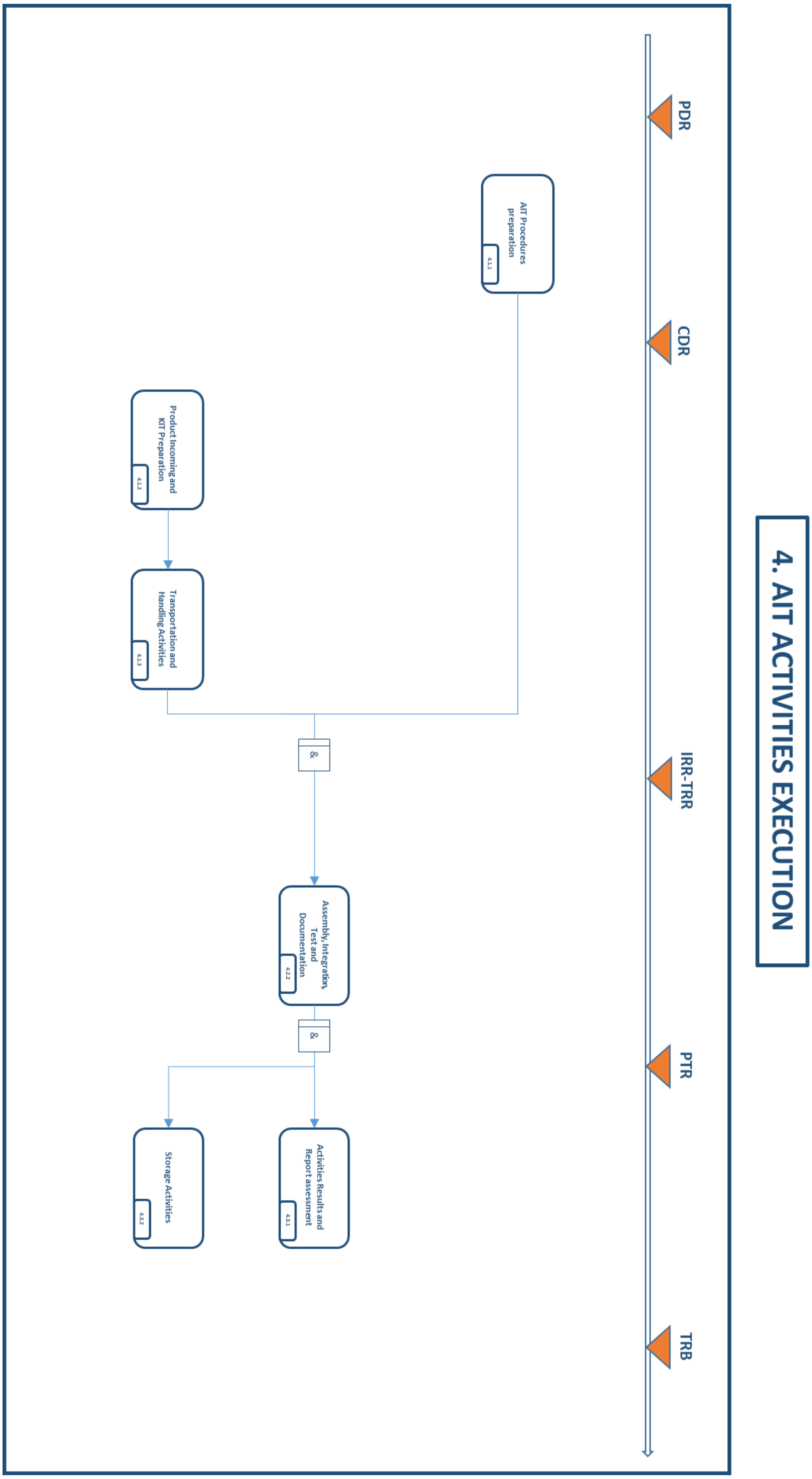

Figure 29 - AIT Activities Execution, lev. 2 (idef 3)

4.1.1 AIT Procedures Preparation

Procedures capturing detailed step-by step assembly, integration and testing activities are prepared by the AIT Engineering Team. Procedures draft begins during the design phase of the project life cycle and their details mature as the design is developed and frozen. They are completed during the phase C and delivered during the Critical Design Review to be further finalized through the Review Item Description Process and to be approved by the customer during the Integration and Test Readiness Review.

Preparation of the AIT Procedures represents the final part of the process that define "How" the product will be integrated and "How" the selected requirements will be verified by testing activities during the integration flow in agreement with the relevant AITP.
The AIT Procedures contain the activity objective and the step-by-step actions to be performed by the operators in the selected facility and by the employment of the selected tools and GSE to complete the integration and test respecting the design and functional constraints contained in the applicable documentation, without inducing defects to the product.
The functional and design characteristics of the selected GSE and Facilities are used to determine the integration and test procedures. The collaboration and the information sharing between the AIT Engineering Team that provides the GSE and the team that develops the AIT procedure is a crucial element for the planning of the AIT activities.

Test procedure

In order to complete the test procedures, that are prepared for each test to be conducted at each verification level, input from Design Engineering are needed such as: test sequence, pass-fail criteria, test conditions, test levels and durations, test tolerances and accuracy in measurement, and test points.
Test conditions are established using the environment predicted by the previous mission data and by analytical prediction, adding the proper margins. The verification environment is considered as part of procedure development respecting the settled Cleanliness and Contamination condition.

Every Test is performed simulating the mission envelope and the differences of the specimen behavior, due to the limit encountered in the environment reproduction, shall be accounted for in the test levels and duration.
Levels and duration are set by the ECSS for Qualification, Acceptance and Protoflight Testing.

- Qualification testing are performed on dedicated qualification models, that fully represent the function tested, to verify that the design and manufacturing technique fulfil specification requirements, providing the evidence that the space product performs in accordance with the requirements in the intended environments and margins. Upon achievement of qualification, the design is not further modified, the flight product manufacturing is authorized and the Verification Control Document is closed-out. The qualification level and duration overstress the specimen that is not reusable as flight model.
- Acceptance testing are performed to provide evidence that the space product performs in accordance with the selected requirements in the intended environments with the specified acceptance margins. Acceptance testing are performed on each flight product, built from the same design file and integration process used for the qualified product, to ensure freedom from workmanship defects and flawed materials. The acceptance program is performed, after the conclusion of the qualification program. The acceptance duration and levels are such as to subject the flight model to less stress that the qualification tests.
- Protoflight testing is the combination of the qualification and acceptance testing objectives on the first flight model to provide the evidence that the space product performs in accordance with the selected requirements in the intended environments with the specified qualification margins and to confirm its readiness for delivery and usage, being free from workmanship defects and flawed materials. The general approach for protoflight test is to select levels as qualification levels and durations as acceptance durations.

Test tolerances bands are the allowable ranges within which the test parameters can vary. Test tolerances and Test accuracies are specified in the test error budgets and are related to the confidence level of the measurement instruments. It is an input for the definition of the test setup and the proper measuring equipment that the AIT Engineering will select and provide for the AIT activities.

This information is described in the Test Specification that is the document that details the test requirements applicable to any major testing activity, defining the purpose of the test, the test approach, the test sequence and the related success criteria and test results derived by the analysis conducted. The Test Specification are frozen and delivered during the Critical Design Review in order to book the Test Facilities but its content must be shared with the AIT

Engineering as soon as it is developed in order to allow the accurate definition of the test setup and the test step by step procedure.

Assembly and Integration Procedure

Assembly and Integration Procedures represent the culmination of the synergical activity of the Design Engineering and the AIT that ensure the Assembly and Integration feasibility during the definition of product configuration.

The production of space products shall ensure that the structure, and all parts, can be manufactured in the way intended to conform to the quality, reliability and reproducibility requirements.

Input documentation for the production of Assembly and Integration Procedure includes: Part and Assembly Drawings, Specifications of parts and materials with related information, constraints and limit to take into account during the assembly and integration process, Interface requirements and Interface Control Document, As Designed Configuration with the List of Components.

The Assembly and Integration Procedures contains the description of the items to be integrated, the tools and Ground Support Equipment that will be used and the requirements and conditions related to the proper facility. The step by step procedures that will be used as the “as run” procedure during the Assembly and Integration activities must consider the inspection and test verification that will be performed during the product integration as defined by the AIT Flow in order to describe the intermediate configuration step of the final product.

Integration processes are qualified during the qualification campaign.

4.1.2 Product Incoming and KIT Preparation

The product implemented by the lower decomposition level to be integrated in a more complex assembly and further tested are subjected to the incoming process in order to verify the product configuration and the lack of defect and flawed materials. The incoming and inspection activities are performed by the Product Assurance delegate in collaboration with the Facility Operators respecting the Facility procedures.

Once inspected the products are picked up by the AIT Operators to compose the suitable kit for the assembly integration and testing activities. This activity needs as input the Work Item document produced by the AIT planners that contains the list of configured products and instrumentation to be used during the selected activities.

In case the kit is prepared to be transported to the external Facility or to the Launch Site, the kit containing the products and the suitable GSE and proper instrumentation are packaged as described by the transportation documentation.
If the AIT activities will be conducted within the internal facility, the prepared kit is stored in the identified facility's storage area to be further employed for the setup preparation

4.1.3 Handling and Transportation activities

Every transportation activity and handling operation of space hardware is conducted respecting the handling procedures. These procedures are prepared by the AIT Engineering, considering the product to be handled/transported and the selected GSE, as stated by the AIT and Transportation Plan. These procedures describe the hardware configuration, and the step by step action to be taken by the authorized personnel, within the safety perimeter to avoid critical and hazardous operations.
Before the execution of any move of the space hardware, the product assurance witnesses the item-by-item visual inspection to ensure that all the involved devices are safely attached and to confirm the Ready for use criteria for GSE.

Before the transport activity the person responsible for all transport activities is defined, item and associated hardware pre transport testing are performed without anomaly that can prevent the transport. The Transport Responsible organize the activities of configuration control, inspection, packaging and preservation of the item and the related documentation. The accompanying documentation include the handling, packing or unpacking and the safety procedures.

4.2.2 Assembly, Integration, Test and Documentation

The assembly, integration and test programme is performed incrementally at different product decomposition levels and the number and type of testing levels reflects the complexity of the project and the requirements settled in the Verification Plan.

The Integration Readiness Review and the Test Readiness Review take place before the start of the integration and testing activity to verify that all conditions allow to proceed with the integration and test. Documentation like AIT Plan and schedule, test specification and item under test configuration, AIT Procedures with the setup, approved measurement point plan, Kip and MIP have to be available and suitable, including contingency and emergency procedures to limit hazard conditions. During this review the facilities readiness report and environmental condition together with the GSE readiness report and instrumentation maintenance and calibration status, personnel qualification and availability, are delivered and the qualification or acceptance data package of lower level items is verified. The AIT Responsible for the test attend the review together with the Facility Manager, the authority responsible for the test, the product assurance manager and the project engineer and launcher authority for tests related to launcher interface. The output of the IRR and TRR is the decision to proceed with the integration and test or not.

The assembly integration and test operation are performed through the cooperation of the skilled AIT Operators and Facilities operators: the first are responsible for the handling operations and for the assembly and integration of the specimen to respect the right configuration, while the Facility Operators manage the facility instruments and technologies. They have the responsibility to prepare the proper setup, respecting and the configuration indicated by the AIT procedures and reporting the variation.

The input for the complete and correct execution of the activities is the management documentation such as: The Work Items that encompasses the AIT activities into manageable blocks, the AIT Procedures for each Assembly Integration and Test included in the Work Item and the AIT Schedule that organize the day by day activities to be performed in order to respect the project milestones.

The operators perform the actions stated by the step by step procedures employing the selected instrument and verifying that the action results reflect the success criteria. In case of defects or deviation from the expected behavior are observed the Operators annotate them and inform the AIT Engineering and the PA/QA Responsible that allows the activities progression or the non-conformance opening.

The PA/QA representative defines the way to monitor the performance of assembly, integration and testing activities, to ensure the adherence to the test procedures, and to manage any deviation. The PA/QA identifies the steps that need to be overseen and this are indicate in the AIT procedures.

Having in input the as designed configuration the AIT Operators produce the as built configuration.

Configuration Control of the Spacecraft will be established under the responsibility of the AIT Quality Control, in order to trace the evolution of the As-Built status of the spacecraft with the progress of the AIT activities, as well as the mechanical and electrical configurations temporarily implemented for specific test purposes.
The configuration records will allow reconstructing the spacecraft configuration in terms of installed equipment and GSE during each operation, to verify the compliance with respect to the design and to identify and justify all deviations. The configuration control is implemented by defining and maintaining the following as built registers: Product installation status list, Software configuration records, GSE application, Declared Material List and Processes List, Non Conformance Status List, Open Works List.

During the execution of the activity, the steps of the procedure are checked out as soon as they are performed, and all data or measurement results are filled-in as required. The filled-in copy of the procedure will become the “As-Run” procedure that became part of the test report. Any deviation from the procedure activities is annotated into the attached Procedure Variation Sheet. Test report contains also the scope and description of the test, and the setup configuration and includes the test results with supporting data, including facility reports and the post processing made by the AIT Engineering responsible for the test. The test report is then supplied to the AIV and System Engineering for the final considerations for the requirement verification close-out including deviations, non-conformances and failures.

The AIT Responsible attends the Post test review and the Post Integration review together with product assurance representative, project engineer and launcher authority for tests related to launcher interface. These review take place to formally declare the integration and testing activities completed and to allow the release of the final product and the breaking of the test configuration to set free the facility for further activity. During The PIR/PTR test data acquisition and the conformance of the performed activities, including NCR, to the specification, the procedure and the AIT Plan are verified.
The post activities status of GSE and facility and the final product configuration is reviewed basing on inspection and cleanliness report.

4.3.1 Activities Results and Report assessment

As the testing activities are completed, the results are collected and analyzed for quality, correctness, consistency, and validity. The out-of-compliance conditions are identified and reviewed to determine if there is a nonconforming resulting from poor verification, procedure, or activity conditions. In order to conduct this analysis, the test configuration must be recorded. A Test Review Board is held by the product assurance representative, the project engineering, the AIT Responsible, the Facility or launcher authority for tests related to launcher interface, to review all results. The activities completeness and test achievement of objectives is then concluded after the evaluation of the test documentation and results contained in the AIT and Facility Report, Inspection report, the NCR reports.
The compliance with the test specification, and AIT Plan and the post-test status of GSE and Specimen is assessed to verify the compliance of the item under test to the requirement and to obtain the lessons learned.

4.3.2 Storage activities

The storage activities for the qualified specimen and accepted models are conducted by the facilities operators supported by the AIT Operators following the requirements and constraints settled in the Storage Plan delivered by the product supplier and agreed by the Facility Manager. The Storage Plan for the final Product containing all the information for storage and de-storage activities is prepared by the Design Engineering and issued during the Preliminary Design Review and frozen by the end of the phase C.

The Storage Plan integrates the requirements settled in the User Manuals of the lower-level equipment to identify the proper storage condition for the intermediate configuration of the product during the integration and test process.

The Pre-storage review is conducted during the Qualification Review and during the Acceptance Review to agree the storage time, the storage configuration and documentation tools, support equipment, facilities condition and the inspection and testing activities to be conducted during the storage period. All activities performed by the Facilities Operators with the support of the AIT Operators during storage period, are recorded in the log book in order to guarantee the traceability of the product configuration and state.

5.7 AIT MANAGEMENT

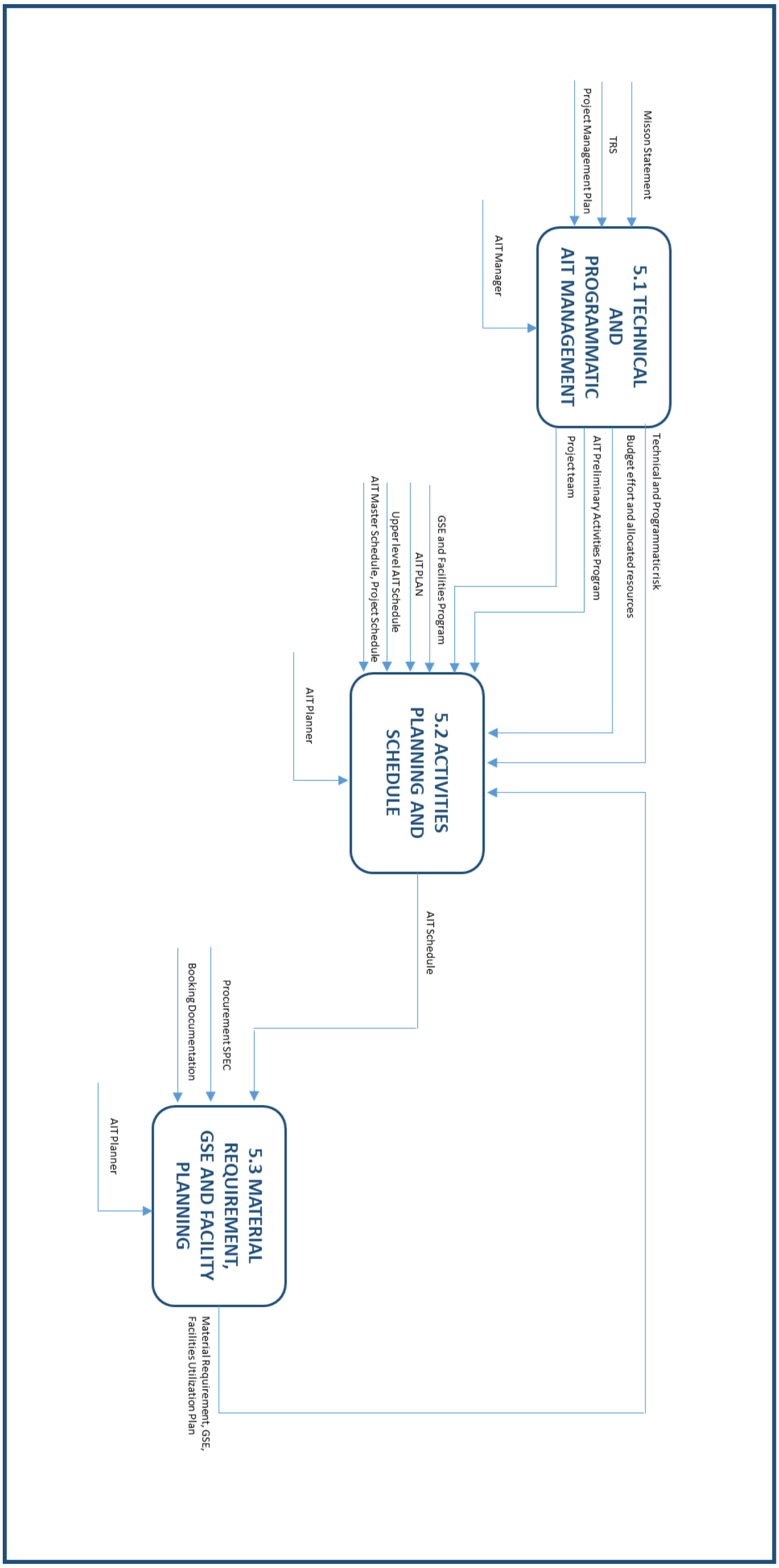

Figure 30 - AIT Management activities, lev. 1 (idef 0)

5. AIT MANAGEMENT ACTIVITIES

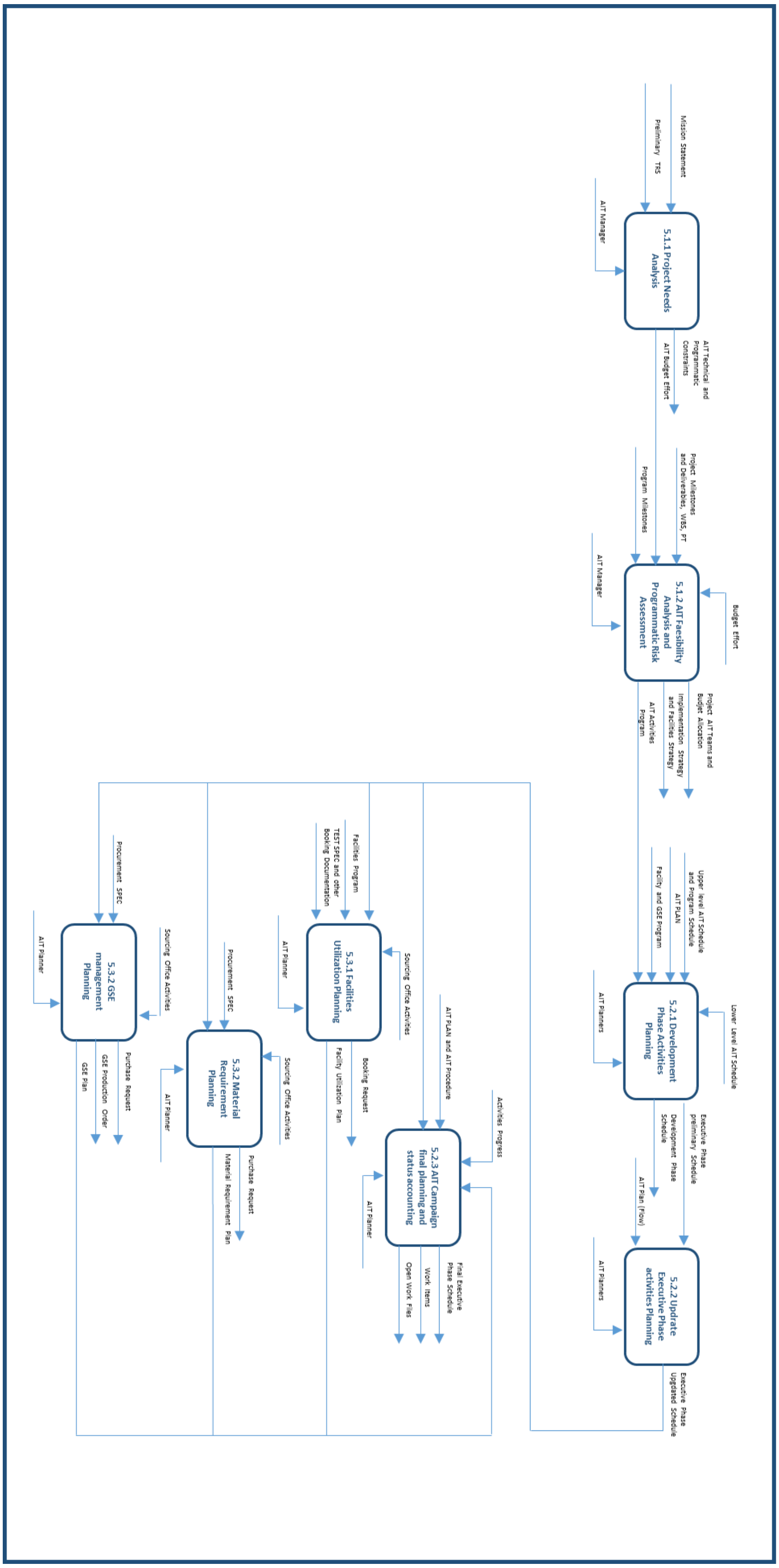

Figure 31 - AIT Management Activities, lev.2 (idef 0)

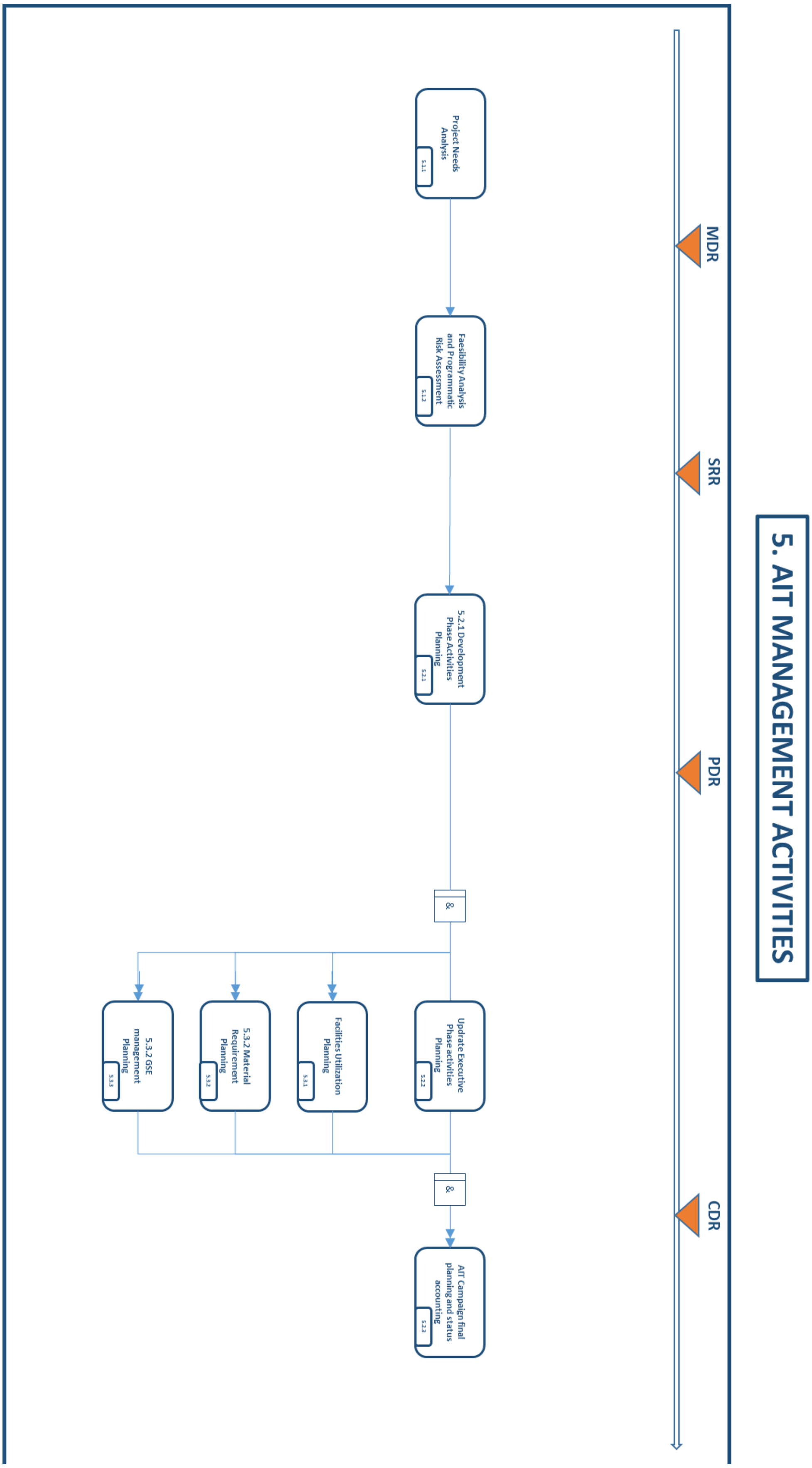

Figure 32 - AIT Management Activities, lev. 2 (idef 3)

The AIT management activities are performed by the Management team composed by the AIT Manager in charge for the specific program and several AIT Planner in charge for the overall programs. The management tasks include:

- **Technical and Programmatic AIT Management:** the programmatic organization of the technical activities with their risk assessment in order to set the implementation and program philosophy for the AIT Campaign, GSE, facilities and other related services. These activities are tied to the program and project management whose plan represent the input and constraints for the AIT decisions.
- **Activities Planning and Schedule:** the planning and schedule of the AIT activities encompass the planning for the development phase and the parallel development of the preliminary planning and schedule for the operative phase that became the final schedule after the iterative process and the accounting of the status of the activities and through the:
- **Material Requirement, GSE and Facility Planning:** the planning of the materials, tools and logistic services to provide for the AIT Campaign execution is a fundamental requirement for the effective scheduling of the activities and for the efficient execution of the activities respecting constraints, delivery and milestones.
- **Configuration and Documentation Management**: the control and status accounting for the setup and product integrated and tested configuration together with the management of the AIT Documentation is a task of the AIT Management that implements the control respecting the requirements stated in the Project Management Plan.

5.1.1 Program Needs Analysis

During the Phase 0 the mission goals, Concept of Operation and the Preliminary Requirements Specification for the system are developed. The AIT Manager in charge for the specific program, assesses the AIT general program and the general needs for tools and facilities, in order to evaluate the feasibility of the program and a preliminary budget effort for the AIT Activities with the technical support of the AIT Engineering Responsible and the supervision of the AIT Division Manager. This evaluation is carried out through a series of meeting with the other Internal Business Functions and the Final Customers and through the analysis of the documentation of previous or similar programs.

5.1.2 AIT Feasibility analysis and Programmatic Risk Assessment

During the Phase A, the feasibility analysis concerning the AIT tasks is conducted by the AIT Manager through the evaluation of the characteristics of AIT facilities, GSE and personnel in order to ensure the cost-effective general activities program related to the GSE Program and the facility program suitable for the preliminary AIT campaign. This preliminary organization of AIT activities is based on the product and work breakdown structures received as input by the Program Management and to the decomposition of the manageable work packages that are used by the AIT Manager to estimate the personnel resources to place and to create the Program/Project AIT Team.
During the Phase A and first part of the Phase B taking into account the program milestones and the delivery objectives the AIT Manager is responsible for the coordination of the multidisciplinary team that analyze the technical and programmatic risk related to the facility and GSE strategy. Taking into account the budget and program constraints and the technical resources the procurement method of new enabling technology by purchasing or by internal development is selected to be the most cost-effective and the less risky.

5.2.1 Development Phase Activities Planning

The planning of the activities during the Development Phase is based on the freezing of the tasks in charge of the AIT as established by the work breakdown structure and by the definition of the AIT Flows for the different product and the related facilities and GSE programs. The development of the activities planning allows the development of the activities schedule that encompasses the different AIT Flows and the program schedule. The activities scheduling follows a top down flow opposite to the bottom up operative flow. This implies that the planning and schedule concerning the Executive AIT Phase, could be at first only a preliminary draft. After the successive iterations and activities status accounting they became the final plans and schedule.
The preliminary plans and schedule for the executive phase allow the definition of plans and schedule for the development phase by the backward definition of the activities that will allow the performance of the AIT Campaign.

5.2.2 Executive Phase activities planning

The updated schedule for the executive phase is prepared and shared by the Critical Design Review when the AIT Program is completed, reviewed and finally accepted to be performed during the successive phase.

The working AIT schedule is implemented following internal company process, lessons learnt and best practices. Due to the parallelism of different models foresee by the model philosophy, the AIT schedule is broken down into a set of independent MS Project files. The different files will be combined via a Master File in order to create the AIT Master Schedule. The AIT Manager is responsible to ensure coherency and coordination of the AIT schedule with the expectation settled into the overall Project schedule. With this aim the constant information sharing between the AIT Manager and the Program Manager is mandatory.

For each model to be developed, following the model philosophy, the AIT schedule is structured following the AIT flow. During this phase, the lowest level of task listed in the AIT schedule consist in sub-activity with a granularity of half a day.

5.3.1/5.3.2/5.3.3 Facility utilization/ Material Requirement/GSE Planning

The AIT Planners are in charge to create and maintain the planning for the material, facilities and GSE provision. They represent the enabling tools for the AIT Campaign and their timely procurement represent a successful factor for the technical and programmatic aims. These planning allow the translation between the temporary execution phase schedule and the final one that take in account the needs coming from the contingent availability and of material, technology and logistic services, potential delays due to the procurement activities and possible constraints related to the arising non-conformances.

The production of these planning activities starts as soon as the respective programs are established by the AIT Manager, following the needs stated by the AIT Engineering teams to fulfill the requirements verification. The AIT Planners are in charge to start the procurement activities by the production of purchase and booking requests and to submit them to the sourcing office. The AIT planners monitor the purchasing and expediting activities and reports the activities status to the AIT Manager in order to optimize the activities flow.

The delay propagation is avoided by the early identification of long lead procurement items and services. Their procurement is brought forward in order to align their incoming with the activities schedule.

5.2.3 AIT Campaign execution and status accounting

Once phase D starts, the schedule is rewritten based on procedure structure. The first level of summary tasks will remain the same as in phase C based on the distribution of activities defined in the AIT Flow but the granularity of activities shown at this stage of the project reaches fractions of an hour.

The control of the AIT activities is carried out from several documents under AIT responsibility: AIT plans, Logbooks, AIT schedule, Work items, Status lists and from regular meetings, key points, inspections, and reviews.

The logbook also records the work progress and all events occurred during the tasks execution. All the AIT tasks status will be reported in the AIT weekly report.

Periodic meetings with different granularity are held with the objectives of reporting the activities performed and of confirming the planned tasks execution and reviewing the status of inputs to AIT activities weeks ahead of the planned activity date such as Specifications, Procedures, Test software, Availability of GSE, Availability of facilities, Hardware delivery forecast.

A single AIT task might be further broken down in a flow of elementary activities, performed by different teams or in different timeframe and whose flow will constitute the overall activity subject of the task. Each of those elementary activities is described in terms of sequence of operations and applicable documentation in the Work Item produced in the form of a high level procedure, exhaustively covering the activity to be performed, where all operations are listed as macro-steps, with references to AIT procedures or GSE Manuals for step-by-step execution. The Work Item also indicates all the pre-requisites to be verified before starting each of the macro-steps, as well as to highlight possible hazards and precautions to be observed in the execution of the described activity.

Once started, the Work Item remains open until all steps in the main document or in the called in procedures have been completed.

The AIT planners track the open work in order to be sure that these postponed activities are not forgotten maintaining the Open work files that identify the tasks which could not be carried out as planned, detail the reason of their postponement and the necessary conditions for their execution, verifying open work status at any time.

Development Models

The need to produce Development Models derives from the necessity of the Design Engineering to reach a higher level of confidence in the developed design. This awareness limits the technical and economic risk related to the performance of verification activities on costly specimens and prevents the occurring of design changes later than expected.

These models are foreseen in the model philosophy proposed by AIV and System Engineering as Input to AIT.
The possibility to perform tests on such products implies the anticipation of the AIT Campaign Execution block that must be conducted during phase C.
The activity block must be performed in parallel to the activity planned for the qualification model to allow the design freezing within the CDR.
At the same time, the AIT Management activities related to the Facility Utilization, GSE and material procurement planning are anticipated in order to perform the integration and testing activities of these models.
The contribution of AIT concerns the ability to anticipate the GSEs procurement. The GSE can be initially provided with the specific functions necessary to verify the requirements on the Development Models and then implemented to meet the qualification campaign requirements.
In this case, for an effective planning of the activities related to AIT, it is necessary a timely planning of the activities within the Verification Plan by AIV engineering and a timely definition of the requirements by the System Engineering.

Assembly Integration and Test of Recurring Products

After the qualification campaign of the developed design and following the Qualification Review, a functional configuration verification allows to define the item as reproducible and to release the Production Master File to carry out the serialized production.
In this case the AIT Management team becomes responsible for opening and managing the production order.
To the material planning activity described in the previous AIT Management flow, the procurement of the parts to be integrated in the final product is added. This activity is in charge of the Project Manager for the procurement of parts to be qualified.
The AIT Planners Manage the operating budget for the production order without the Project Manager constraints.
The activities linked to the AIT campaign are repeated with the same logic used for the qualification campaign and take advantage of the production processes and of the integration and test procedures previously qualified to carry out an acceptance test campaign. This documentation and all the tools necessary for the integration and qualification campaign are prepared for being available for the Acceptance IRR and TRR.

6. CONCLUSION

The development process of a Space Program is the result of the coordinated work of different actors, both internal and external to the Company, that collaborate in order to achieve the objectives set, in the established time and with the most convenient economic effort.

In particular, the AIT Business Function realizes the Space Segment System and its sub-parts through the assembly and integration activities and collaborates to the requirements verification through the test activity on the Flight Model and all the previous Development Models.

In the perimeter of the space program that, starting from the ESEO project will lead to the realization of the Platinum Project, the AIT of Sitael s.p.a. will participate to the realization of the Qualification and Acceptance Campaign of the Platino Platform.

The latter is a multi-application platform suitable both for the realization of constellations of recurrent platforms both for the specialization of the model to be adapted to different missions.

The work of the AIT will concern the different decomposition levels of the Space Product: units, subsystems and systems, and the procurement of assembly, integration and testing enabling tools.

The Business Expansion objectives have placed the need to move from the "Test Engineering" Business Function that carried out the testing activities planned by the Design Engineering to a broad and organized AIT Business Function that actively collaborates to the planning of integration and testing activities giving a technical, programmatic and practical contribution.

The direct experience in the Company has brought out the need to organize in a coherent flow the activities in charge of the AIT.

In order to respect the iterative and recursive nature that characterizes the Space Project development process and consequently the AIT activities process, the activities are not considered in a linear time flow but rather through the relationships that exist between modular activities related to the verification level (unit, subsystem, system).

This organization takes into account decisions made in previous phases that become inputs for subsequent levels, and takes into account the increased accuracy achieved in subsequent phases through controls and constraints on the activities of higher levels.

In order to respect the concatenated logic of the activities and to allow a simple representation the IDEF 0 modeling methodology has been chosen. It allows to detail the activities characteristics respecting the coherence between several representation levels.

The first organizational level is based on the grouping of activities by nature and objective into five macro-activities:

- AIT PLAN DEFINITION: this macro-activity groups the activities that lead to the definition of the integration and test program to be carried out on the different levels of decomposition for the various products foreseen through support activities to AIV, System Engineering and Design Engineering and to the drafting of the AIT PLAN.
- AIT FACILITIES MANAGEMENT: this macro activity groups together the activities inherent to the management of internal facilities and the selection of external facilities that are compliant with test requirements and quality standards.
- GSE MANAGEMENT: this macro activity groups together activities related to the definition of requirements, configuration, design and procurement of Ground Support Equipment necessary to carry out integration and testing activities in compliance with the requirements of the integration and testing process.
- AIT CAMPAIGN EXECUTION: this macro-activity groups together the operational activities of the integration and test flow from the incoming of the products to be integrated, to the fully verified product ready to be delivered accompanied by the documentation and reports.
- AIT MANAGEMENT: this macro-activity groups the management activities in charge of the AIT teams, the materials and services procurement and the activity scheduling.

The macro-activities have been decomposed in elementary activities in order to analyze the needs tied to the single activities and to divide the responsibilities according to the team skills. It is possible to define the activities flow respecting the input and output flow of information, documentation and products respecting the time flow suggested by the ECSS and highlighting in the possible occurring limits.

The macro activities have been detailed as follows:

AIT Plan Definition: It includes all the collaboration activities of the AIT Function with System Engineering and AIV Engineering.

In the requirements engineering process, requirements are derived and allocated starting from the high level requirements to make a traceable chain that links each requirement to the stakeholder needs to be met and that defines the verification program of the various requirements.

The AIT participation contributes to the optimization of the test program that, respecting the model philosophy, became effective (covers all the requirements) and efficient (avoids the

overlap between activities and the possibility of breaking down an already integrated product to perform further tests).
Through the activity of the AIT engineering teams, the integration flow for the different product decomposition levels is also defined.
It is the starting point for the definition of the facilities, Ground Support System and product configuration that will form the setup for the testing activities to be performed during the integration flow.
The realization of this activity creates the necessity of a constant and effective communication between the AIT, the system engineering and the design engineering so that in the trade-off that characterizes the first phases of definition of the product space, the AIT is constantly informed of the resulting variations.
In particular, the documents needed as input for the AIT are the Technical Requirement Specification and the functional, specifications and product tree, the AIV Plan that keeps track of the total verification approach and the Verification Control Document that keeps track of the stage, level and model on which the verification of a specific requirement will take place.
Evaluating the documentation delivery period, some inputs and outputs document are frozen and published during the same review. For this reason, it is necessary to formalize the communication process both for the adopted solutions and for the changes made by System Engineering and AIV in order to avoid unnecessary work and delays for AIT tasks.
AIT Facility Management: includes the management activities of the Test Space Centre and the facility implementation to meet the results of the feasibility analysis.
The test space center activities include the maintenance and calibration planning for instrumentation and training of the facility operators who collaborate with the AIT operators during the AIT campaign execution.
In the business context of Sitael, the activities inherent to the Test Space Centre are carried out by personnel belonging to the AIT. It highlights the need for a clear division of tasks and responsibilities in order to maintain a dual point of view during the test activity.
It is important to ensure objectivity during AIT campaign to meet quality requirements and to ensure the different point of view in the facility report and AIT operators report to demonstrate that the testing activity meets the specifications and evaluate the test results and all non-conformities that occur during the activity.
This macro-activity includes also the definition AIT Campaign blocks to be carried out in external facilities. This activity sees the AIT engineering interfacing with the external facilities representative for the evaluation of the documents attesting the facility configuration in order

to guarantee the correspondence between the facility interfaces with product and GSEs interfaces.
GSE Management: This macro-activity encompasses all the activities of defining the functionality, configuration and design of the GSEs, developed in a timely manner to carry out the procurement.
The taks related to the GSEs is a design activity that starts with the definition of the requirements in accordance with the characteristics of the product to be integrated and tested, the objectives of the tests, and the characteristics of the integration and testing process.
The main documental inputs are the Design Definition File, Technical Requirement Specification, Interface Requirement Document and Interface Control Document. These documents freeze the requirements and characteristics of the product and allow the definition of how to interface with it.
During these activities the constant updating and sharing of information in a timely manner between AIT, AIV and System Engineering, allow to ensure the integrability, testability and the possibility to handle products within the selected facility. The information sharing between the AIT teams allows the production of AIT procedures related to the selected GSE.
AIT CAMPAIGN EXECUTION: The macro activity concerning the conduction of the integration and testing campaign has been modeled thinking about the timing, the activities and the inputs and outputs necessary for a qualification campaign.
The anticipation of some activities allows to ensure integration and testing of development products foreseen by the model philosophy in order to achieve greater confidence in the design that will be subsequently qualified.
The flow of activity is thought in such way to be conformed, through some simplifications and variations of responsibility for some activities, to the eventual production of previously qualified model.
In the context of the business objectives, the AIT flow for the qualification campaign must be organized and documented in a standardizable, repeatable and configuration controlled way. It allows the possibility of reconstructing the events chain in case of defects or non-conformities, and the possibility of obtaining engineered and qualified processes, described by procedures and reports that can subsequently employed for a serialized production.
AIT MANAGEMENT: this macro-activity includes the planning and scheduling of AIT activities, to ensure their coordination with the program needs and the constraints imposed by the materials and services procurement. The responsibilities are shared by the AIT management and the program/project management for the evaluation of technical and programmatic risks

that lead to the selection of the most effective and economically advantageous strategies and for an organization of all the activities that allows to respect the expected delivery times.

The result of this work is therefore represented by the analysis of individual AIT activities, their orchestration in a structure that respects the business logic and standardization of ECSS and the evaluation of potential criticalities, to be subsequently implemented in business procedures.
In this way it will be possible to test the effectiveness of such organization through the control of process indicators and proceed to the optimization of AIT Process.

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