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**Office of Exploration Systems**  
NASA Headquarters  
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Washington, D.C.

## **Code T**

# **Office of Exploration Systems Enterprise**

# **Project Constellation Work Breakdown Structure**

This WBS will evolve over the life cycle of Project Constellation. This version establishes the framework for more detailed versions that will include the contractor WBSs that will be established as contracts are awarded. No architecture solutions have been selected and this WBS is intended to have the flexibility to accommodate any architecture selected. Any exceptions identified will be corrected and changed in future releases.

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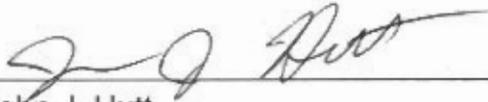
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Project Constellation Work Breakdown Structure

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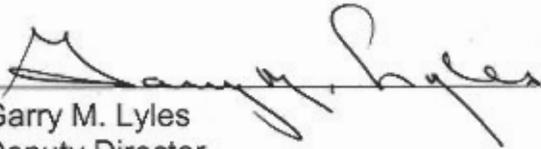


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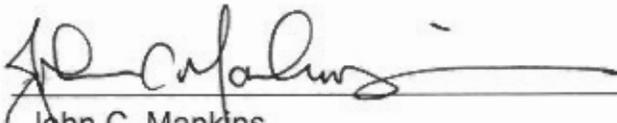
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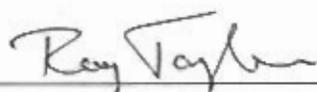
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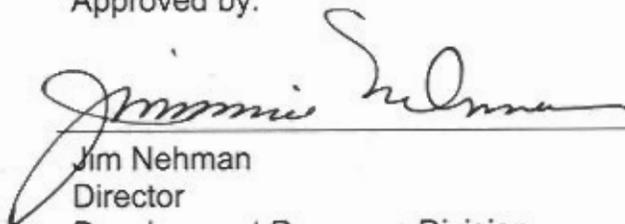


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## **i Introduction to WBS Dictionary**

### **i.i Goals and Objectives**

The goals and objectives for the WBS are to provide a backbone framework for work management. The WBS structure supports management tools to assist in Earned Value Management (EVM), Requirements Flow-down, Risk Management, Integrated Product Team Formulation, and Simulation Based Acquisition. It provides the back bone for EVM by establishing the structure by which schedule development and resource loading can occur. It eventually becomes aligned with the NASA UPN codes and supports development of the basis for Program Operating Plan Development.

Requirements flow down is supported by establishing “parent-child” relationships through a system hierarchical decomposition of the hardware elements. Risk Management is supported by providing a thorough assessment of all activities required to achieve the end item throughout the life cycle of its existence.

The structure’s categorical alignment to system of systems products assist in clearly defining fundamental systems necessary to provide capabilities in order to achieve a defined mission. It also provided for a framework in which simulation modeling and integration tools are developed.

### **i.ii Approach**

The WBS is centered on a “System of Systems” focus. The structure is to achieve capabilities in which a mission can be formulated from the building block identified in this work. Each system of systems becomes integral to the total mission. The desire is to have capabilities that can be mixed and matched as missions and capability allow.

An approach for the WBS development is centered on formulating a functional template that can be replicated throughout the system of systems products to capture the work required throughout the products life cycle. The template incorporates the lower level decomposition based on the system hierarchical structure listed below. The intent is to provide consistency and discipline throughout. For example is there are certain functions that are not performed for certain hardware elements then that number will be held in reserve. A desire to provide a disciplined format for easy of tracking and visibility was achieved by having a consistent numbering schema. The structure template is applied consistently throughout such that systems engineering is always a .2 regardless what level it is applied.

The structural template that was applied to this work breakdown is organized around fundamental cross cutting functions to yield a capability (product). The upper level functions such as management, systems engineering, and Safety & Mission Assurance provide guidance and oversight of products. Being that we have a collection of systems, mission objectives can be met by aggregating the appropriate capabilities necessary to meet the mission needs. At the early stage of WBS development it is important to maintain generic language until a time when functional decomposition can be completed.

The structures format also considered implementation in a relational database environment such that it can interface with multiple management, analysis, and Program Integration tools such as wINSIGHT, Doors, Active Risk Manager and etc.

### **i.iii System Hierarchy**

The hierarchical description of the system provides a disciplined decomposition such that requirements flow. This WBS categorizes the system in a hierarchy description per the following levels of decomposition within the overall system architecture Per NASA SP-6105.

- Tier 1 Enterprise Elements (Constellation System of System Capabilities)
- Tier 2 System (Crew Transport, Surface Systems)
- Tier 3 Segment (Crew Exploration Vehicle, Launch Vehicle, Ground Segment)
- Tier 4 Element (Booster Element)
- Tier 5 Subsystem (Booster Main Engine, Booster MPS)
- Tier 6 Assembly (Thrust Chamber Assembly; turbo pump Assembly, etc.)

### **i.iv Template**

The template below is the generic example is applied to the system hierarchy flow above.

- System Product
  - Management
  - Systems Engineering
  - Safety and Mission Assurance
  - Technology Maturation
  - Development (Integration Function at the Higher Levels)
  - Operations (Integration Function at the Higher Levels)
  - Next lower Tier of product 1
    - Management
    - Systems Engineering
    - Safety and Mission Assurance
    - Technology Maturation
    - Development
    - Operations
    - Next Tier of sub products
  - Next lower Tier of product 2
  - Next lower Tier of product (n)

## **1.0 Enterprise Management**

With respect to Constellation, this element encompasses all the work required to organize, plan, lead, and control the activities assigned to the Office of Explorations Systems Enterprise. This includes establishing Enterprise policy for security, external relations, procurement, legal, human resources and EEO, legislative affairs, public affairs, and Education and Public Engagement; planning and integration with other NASA enterprises and HQ codes, other Federal agencies, and international partners; and coordination of activities associated with the acquisition strategy, program and business authorizations, budget analysis and allocation.

## **2.0 Systems Engineering and Integration**

With respect to Constellation, this element is the Enterprise level for systems engineering. It includes the efforts of establishing and directing an integrated engineering effort for the Enterprise. This item includes but is not limited to the process, methods and tools for engineering including those that support simulation based acquisition; effort associated with the integration of Office of Exploration Systems Enterprise activities with those of other enterprises; development of System of Systems requirements for Exploration Systems and the overall campaign for exploration of space based on Agency provided requirements and science objectives; and development and implementation of the overall OExS configuration management and risk management programs; and definition of applicable standards and policies to be implemented.

### **2.1 Management and Administration**

With respect to Constellation, scope includes the work to set policy for the enterprise overall systems engineering effort. It includes enterprise guidance for required reviews and associated plans, the systems engineering management plan, systems engineering reports, supportability strategy, program/project requirements documents, and system description documents. This element provides stakeholder representation in all phases of the SoS life cycle. Includes the work associated with reduction in total ownership cost planning and support at the enterprise level. Scope includes the identification of applicable Standards and Specifications for OExS programs and projects. Scope includes the coordination of concurrent engineering across the OExS Tier one elements where appropriate.

### **2.2 Enterprise Integration**

With respect to Constellation, this element encompasses all the effort required to establish enterprise policy and planning and integration with other NASA enterprises and HQ codes, and within the Office of Exploration (OExS) elements. This element includes coordination with external agencies such as the Department of Defense (DoD), the Department of Energy (DOE), Environmental Protection Agency (EPA) and the Federal Aviation Administration (FAA). Activity includes policy for security, environmental protection, planetary protection, external relations, procurement, legal, human resources, Equal Employment Opportunity Commission (EEOC), legislative affairs, and public affairs. This element encompasses all the effort required to develop an internal review plan and support external reviews as required. This element includes all the work required to negotiate requirements with the science community and direct inclusion in mission analysis provided by the requirement development function.

### **2.3 Campaign and Mission Definition**

With respect to Constellation, this task includes integration of science objectives with exploration systems and establishes top level concept of operations. Activity includes design of mission scenarios with supporting trade studies and analysis. This element contains the effort for planning specific missions required to meet exploration goals, including definition of all required precursor missions to support human exploration missions, and

associated operations concepts. This effort establishes top level decision analysis criteria and mission needs statements. Trade studies are implemented to determine optimum combination of mission objectives. Analysis includes supportability, definition of robustness and flexibility needs, user requirements, cost and schedule needs. Scope includes developing a top level cost and schedule definition, establishing initial design margins, analyses and trade studies, and establishing key performance parameters. System of systems level requirements are generated and programmatic requirements are identified (cost, schedule, institutional/national/international constraints, mission classifications) and documented.

#### **2.4 Configuration Management**

With respect to Constellation, this element captures the efforts for managing the enterprise configuration items including the campaign, mission and top level system of systems (SoS) requirements and enterprise level documentation. Scope involves the planning, organization, integration, support, and monitoring functions for tracking changes, conducting change board reviews, and maintaining configuration documentation to include decision support data for the enterprise level configuration items. This element includes management of document configuration for enterprise configuration items and establishes policy and standards for the all OExS configuration management activities.

#### **2.5 Risk Management**

With respect to Constellation, this element will implement risk management at the Enterprise level and coordinate risk management for the system of systems and their constituent projects that comprise Exploration. This element includes the overarching coordination of the identification, analysis, planning, tracking and control for risk reduction at the Enterprise level. These processes shall be applied to the technical, schedule and cost aspects of the Enterprise. It includes oversight and insight in the planning and conducting of project/demonstrations and trade analysis to reduce the risk of the overall program. With respect to Constellation, overall policy for risk management for the Exploration Enterprise shall be established in this element. This shall include the preparation for base-lining of a risk management plan documenting the implementation approach to risk management at the Enterprise level and risk management policy at the system of systems level and below. Risk management plans for the constituent system of systems will be monitored for compliance with Enterprise-level risk management policy.

#### **2.6 Simulation Based Acquisition**

With respect to Constellation, this element addresses the work to formulate the requirements for the tools and integration of the tools needed to support all of the OExS WBS elements and the realization of the SBA requirements into products and processes in support to OExS.

#### **2.7 Space Logistics**

With respect to Constellation, this element encompasses all the work required to develop strategy and direct Enterprise campaign and mission ground and space supportability engineering and integrated logistics support efforts to provide mission sustainability. Efforts include supportability analyses and integrated logistics support management and engineering concepts and techniques that are integral to system design and development of support infrastructures. This element identifies supportability factors for mission risk and life cycle cost that include sustainability, interoperability, obsolescence, and standardization. Strategy development includes total life cycle system management (TLCSM) and performance based logistics (PBL) sustainability concepts. Work includes oversight and insight for efforts to minimize the logistics footprint and reduce life cycle cost. This element coordinates closely with the reliability and maintainability disciplines to provide more effective, affordable, operationally-ready systems through increased reliability, maintainability, and supportability.

### **3.0 Safety and Mission Assurance**

With respect to Constellation, this element includes the technical and management efforts for developing and implementing across the Office of Exploration Systems unique policy for the safety and mission assurance function in the disciplines of safety, environment, reliability, maintainability, supportability assurance, quality assurance, and operations. This effort includes an independent review and assurance function over the design, development, supportability assurance, review, and verification of OExS systems. It is to provide oversight of the S&MA Program Management functions with support to the Program/System panels, approve Constellation S&MA policies, guidelines and plans, and conduct review and approval of S&MA deviations and waivers. This element shall also have an IA (Independent Assessment) task.

### **4.0 Constellation (System of Systems)**

This element encompasses all the work required to develop the necessary systems and conduct operations supporting human and robotic exploration missions to Earth orbit, the Moon, and beyond.

#### **4.1 System Management**

This element encompasses all the work required to organize, plan, lead, and control all facets of the activities required to develop and operate Constellation system of systems. This effort includes leading the overall Project Constellation business and administrative management functions including establishing and maintaining an earned value management system for determining budget requirements, conducting analysis, and controlling allocation; all activities associated with developing and executing the acquisition and procurement strategy; workforce requirements and utilization; integrated master plan and schedule (IMP/IMS) development, execution, and assessment; and information management and dissemination.

##### **4.1.1 Business Management**

This element encompasses all coordination activities associated with the acquisition strategy, system of systems authorizations, budget analysis and allocation, system workforce utilization, and integrated program assessment measurement.

##### **4.1.2 Information Management**

This element encompasses the effort required to disseminate required information to system of systems stakeholders. Additionally, this element encompasses the effort required to develop a Project Constellation communication and reporting plan and respond to unexpected requests for information.

##### **4.1.3 Administrative**

This element encompasses the effort required to facilitate the system of systems management operations including human resources, staff assignments, and security. Etc.

##### **4.1.4 Requirements Management**

This task provides support to manage programmatic cost, schedule and scope trade offs.

##### **4.1.5 Acquisition Management**

This element encompasses all the effort required to develop an acquisition strategy plan for Project Constellation. Additionally, solicitation planning, solicitation development, source selection, contract administration, and contract closeout efforts are included here.

#### **4.1.6 Comprehensive Risk Management**

This element encompasses all the effort required to prioritize technical and programmatic risks associated with the system of systems. Technical risks are recommended by the systems engineering including identification, analysis, and planning and costs. Work includes approval and funding of risk mitigation plans, tracking of mitigation progress and status reporting to system stakeholders.

#### **4.1.7 Supportability and Integrated Logistics Support Management**

This element encompasses all the effort for engineering and support considerations necessary to assure the effective, sustainable, and economical support of a system for its total life cycle. It is an integral part of all other aspects of system acquisition and operation. Work includes development of supportability strategy and establishing and leading a management team with representation from system integrated logistics support activities.

### **4.2 Systems Engineering**

Implementation of processes necessary to separate elements of the system of systems into manageable work elements and allow those elements to be readily integrated into the final product that meets its intended capability. These processes include requirements formulation, decomposition and prioritization, configuration and data management, and risk assessment. The requirements include both technical requirements along with funding and schedule needed to enable these technical requirements. The effort also includes decomposition of requirements to technologies that must be matured prior to system acquisition. This includes performing operations studies and analyses producing operations metrics across system elements, developing operations life cycle cost assessments, developing, integrating, and assessing integrated operations schedules.

#### **4.2.1 Engineering Management**

Scope includes the work required to manage and administer the Systems Engineering for the Constellation's overall system architecture, definition, and engineering functions and establishes the standards and specifications which are to apply to Constellation and all lower tier work. Leads the SoS systems engineering team and manages the SoS action-item list. Also includes SoS engineering document development tasks such as the project review plans, the Systems Engineering Management Plan (SEMP), systems engineering reports, SoS requirements documents, and architecture description documents. This element provides stakeholder representation in all phases of the SOS life cycle. Includes the work necessary for organizational implementation for Integrated Product Teams (defining how IPTs will be setup, executed and dissolved). It addresses the work necessary to support the Integrated Management (or Master) Plan (IMP) and Integrated Master Schedule (IMS) (identifies key events, milestones, reviews, all integrated technical tasks, and risk reduction activities) along with other progress measurement tools to track major reviews progress, programmatic technical performance, etc. It includes the work associated with reduction in total ownership cost planning and support (cost control, cost reduction, invest to modernize planning, and assurance that life cycle costs are implemented as co-equal to performance in acquisition). This element also addresses the work necessary to develop lessons learned, modify processes based on performance metrics, and record accomplishments.

#### **4.2.2 Requirements Formulation**

This element provides analysis of system of systems requirements and documenting the resultant requirements. It comprises requirements analysis including trade studies, and documenting requirements specifications. It includes the successive refinement of decomposition (partitioning) of system of systems requirements into allocated and derived requirements, appropriately assigned to lower-level system products. This task documents verification and compliance requirements at the system of systems level. This task provides key performance

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parameters and operational thresholds and objectives shall be derived and tracked. Scope includes the definition, execution, and documentation of trade studies for desired and practical trade-offs among stated requirements (user requirements, design, program schedule, functional, performance and life-cycle costs); scope includes trades at various levels of functional or physical detail to support requirements, functional decomposition, /allocation, and design alternative decisions, or as specifically designed, to support the decision needs of the systems engineering process. The level of detail of a study is commensurate with cost, schedule, performance, and risk impacts. The system of systems design has to ensure that the final integrated architecture meets interface requirements and is balanced (performance balanced with cost, schedule, and effectiveness requirements).

#### **4.2.3 Configuration and Data Management**

This element captures the efforts for managing the overall configuration of the system of systems flight and ground systems throughout the development, implementation, and operations. Scope involves the planning, organization, integration, support, and monitoring functions for tracking changes, conducting change board reviews, and maintaining configuration documentation to include decision support data. This element includes management of document configuration at the system of systems level and establishes policy and standards for the system level configuration management activities.

#### **4.2.4 Risk Identification and Analysis**

This element includes the overarching identification and analysis for risk reduction at the Project Constellation level. These processes shall be applied to the technical, schedule and cost aspects of the system of systems. It includes oversight and insight in the planning and conducting of project/demonstrations for the identification of risk, and trade analysis to reduce the risk of the overall program. Additionally, this element includes training in, and execution of, specialized risk identification techniques that are performed on an as needed basis for activities under Constellation. Also includes identification of risk mitigation task requirements, resources, and schedule

#### **4.2.5 Verification, Validation and Acceptance Planning**

This element encompasses the effort required to plan the verification, validation and acceptance of the Constellation elements to ensure that they meet the requirements and can execute the mission objectives as intended. Scope involves assurance that all supporting system elements are ready to support end to end tests, definition of key system test plans for completeness and ability to meet goals, review of key test scripts for timing and order of execution of command sequences. The validation, verification and acceptance work is planned for each level of the “system” as it is “reintegrated in design” from the bottoms up (the right half of the systems engineering “vee”). This work includes verification that the requirements are met, interfaces requirements are met and controlled, interoperability requirements are addressed, each requirement has a corresponding verification item and methods necessary to perform the verification is identified, and the test plans necessary to conduct the V,V and A is accomplished. Scope includes the work to develop the Test and Evaluation Master Plan (TEMP).

#### **4.2.6 Integrated Logistics Support**

A composite effort of all the engineering, supportability analysis, planning, and support considerations necessary to assure the effective, sustainable, and economical support of the SoS systems for their life cycle. It is an integral part of all other aspects of system acquisition and operation. Provides oversight and insight to Constellation elements.

### **4.3 Safety and Mission Assurance**

With respect to Constellation, this element includes the technical and management efforts for developing and implementing across the Office of Exploration Systems unique policy for the safety and mission assurance

function in the disciplines of safety, environment, reliability, maintainability, supportability assurance, quality assurance, and operations. This effort also includes an independent review and assurance function over the design, development, review, and verification of OExS systems.

#### **4.3.1 Management and Administration**

With respect to Constellation, lead and manage the overall mission assurance effort and provide the primary mission assurance interface to other enterprise divisions. Includes approval of necessary plans and procedures to guide and direct the mission assurance functions through all phases of the initiative, from design through disposal. This effort provides sufficient review for certification of flight worthiness.

#### **4.3.2 Safety and Mission Assurance Integration**

With respect to Constellation, this element includes the technical and management efforts necessary for integrating safety and mission assurance functions across all systems required to complete an exploration mission. Includes development of necessary plans and procedures to guide and direct the integrated mission assurance functions through all phases of the initiative, from design through disposal. Ensures continuity across all lower level S&MA (Safety and Mission Assurance) functions and approval of top level enterprise, S&MA elements by supporting the risk management process, development of S&MA requirements, and contract Request for Proposals (RFPs), Scopes of Work (SOWs), and Source Evaluation Boards (SEBs).

##### **4.3.2.1 Safety and Mission Assurance Panels**

This element includes the technical and management efforts necessary for the operation of Programmatic S&MA Panels

###### **4.3.2.1.1 Safety Review Panel (SRP)**

Develop Program Level System Safety policies and review and approve element System Safety Plans, documents, and process waivers and deviations (for approval by Code Q and the ITA). In addition, this element includes support for the development of the Constellation System Safety Plan and Flight Readiness Review (FRR) documentation

###### **4.3.2.1.2 Reliability, Maintainability and Supportability (RMS) Panel**

Review and approve RMS requirements, reports and analyses. Also, to process waivers and deviations to RMS requirements.

#### **4.3.3 System Safety**

With respect to Constellation, includes the technical and management effort necessary to ensure the overall safety and protection of flight and ground personnel, general public, flight/ground hardware, software and facilities through all phases of the initiative, including over(in)sight of contracted efforts. It includes the implementation of requirements for and ensuring the adequacy of safety plans, hazards analyses, safety non-compliance disposition, and safety assessment, reports, and reviews of flight/ground/planetary hardware and software element, and operations plans and range safety. Element includes development of Constellation level hazard analysis guideline and Constellation integrated hazard analyses (HAs) based on inputs from Constellation element HAs.

#### **4.3.4 Safety, Health and Environment Assurance (SHEA)**

With respect to Constellation, this element includes the efforts necessary for providing occupation (industrial) safety and health and environmental assurance function for all aspects of the initiative. This effort includes providing for regulatory assurance function related to Occupation (Industrial) Safety and Health and Environmental Protection on Earth.

##### **4.3.4.1 Occupational (Industrial) Safety**

Element includes insight function necessary for assuring Constellation elements across OExS comply with federal or state Occupational Safety regulations.

##### **4.3.4.2 Occupational Health**

Element includes insight function necessary for assuring Constellation elements across OExS comply with federal or state Occupational Health regulations.

##### **4.3.4.3 Environmental Protection**

Element includes insight function necessary for assuring Constellation elements across OExS comply with federal or state environmental regulations.

##### **4.3.4.4 Contingency (Mishap Reporting) Plan**

Element includes development and maintenance of the Constellation level Mishap Reporting Plan.

#### **4.3.5 Reliability and Maintainability**

With respect to Constellation, this element includes the technical and management efforts necessary for assuring reliability and maintainability for all aspects of the initiative.

##### **4.3.5.1 Reliability**

With respect to Constellation, this element includes the tasks necessary to ensure the overall reliability of the systems. Implement requirements for and ensure adequacy of reliability analyses, reliability/risk assessments/tradeoffs, coordination between government and contractor reliability teams, and requirements compliance. Element includes development and maintenance of Integrated Constellation Reliability documents including Integrated Reliability Policy, FMEA/CIL Guideline, Probabilistic Risk Assessment (PRA) Guideline, Problem Reporting and Corrective Actions (PRACA) Guideline, and Integrated FMEA/CIL Design Verification

##### **4.3.5.2 Maintainability**

With respect to Constellation, this element includes the review/performance of those tasks necessary to ensure the overall maintainability of the systems. Implement requirements for and ensure adequacy of maintainability analyses, maintenance/replacement tradeoffs, coordination between government and contractor maintainability teams, and requirements compliance. Includes development and maintenance of the Integrated Constellation Maintainability and Supportability assurance documents including Integrated Constellation Maintainability Policy, Supportability Insight Plan, and an Integrated Logistics Support Plan which includes support to the logistics element responsible for this Plan and is necessary to assure reliability and maintainability elements have been integrated.

#### **4.3.6 Quality Engineering and Assurance**

With respect to Constellation, this element includes the technical and management efforts necessary for assuring establishment, management, and maintenance of the overall quality system for system hardware and software. Implement requirements for and ensure adequacy of product assurance requirements/plans; performing inspections and audits; monitoring quality; and maintaining oversight of the procurement, design review, manufacturing, testing/verification, and validation efforts, including provisions for over(in)sight of contracted efforts for all aspects of the initiative.

With respect to Constellation, this element includes the technical and management efforts necessary for assuring establishment, management, and maintenance of the overall quality of system hardware. Ensure adequacy and implementation of product assurance requirements/plans; performing inspections and audits; monitoring quality; and maintaining oversight of the procurement, design review, manufacturing, testing/verification, and validation efforts, including provisions for over(in)sight of contracted efforts for all aspects of the initiative.

##### **4.3.6.1 Hardware Quality Assurance**

With respect to Constellation, this element includes the technical and management efforts necessary for assuring establishment, management, and maintenance of the overall quality of system hardware. Ensure adequacy and implementation of product assurance requirements/plans; performing inspections and audits e.g., NEQA); monitoring quality; and maintaining oversight of the procurement, design review, manufacturing, testing/verification, and validation efforts, including provisions for over(in)sight of contracted efforts for all aspects of the initiative. This includes development and maintenance of a Constellation Quality Policy and Constellation NASA Engineering Quality Audit (NEQA) Plan

##### **4.3.6.2 EEE Parts**

With respect to Constellation, the technical and management efforts necessary for assuring establishment, management, and maintenance of parts control programs. Ensure adequacy and implementation of the establishment and maintenance of parts lists, review and issuance of alerts/advisories, parts control, part test/qualification/screening programs, parts testing activities, and test reporting including provisions for over(in)sight of contracted efforts for all aspects of the initiative. Includes development and maintenance of the Constellation EEE Parts Program Plan

#### **4.3.7 Software Safety and Product Assurance**

Includes effort necessary to ensure that software developed meets overall safety requirements for the protection of flight and ground personnel, general public, flight/ground hardware, software and facilities through all phases of the initiative, including over(in)sight of contracted efforts. Ensure adequacy and implementation of software safety plans, hazards analyses, safety non-compliance disposition, and safety assessment, reports, and reviews of flight/ground/planetary software element and operations plans and range safety. Includes development and maintenance of the Constellation Software Quality Plan

The technical and management efforts necessary for assuring mission requirements and system design changes are carried forward across software life cycle phases of the operations system to includes Software Independent Verification and Validation (IV&V) after development.

#### **4.3.8 Operations Safety and Mission Assurance**

With respect to Constellation, this element includes the technical and management efforts necessary for assuring performance of flight/ground/planetary operations processes and procedures. Ensure adequacy and implementation of operational procedures, flight rules, checklists, and guidelines, including pre and post operation checkout and monitoring of real time operations.

#### **4.3.9 Operational Safety and Mission Assurance**

This element includes the technical and management efforts necessary for assuring performance of flight/ground/planetary operations processes and procedures. Ensure adequacy and implementation of operational procedures, flight rules, checklists, and guidelines, including pre and post operation checkout and monitoring of real time operations.

#### **4.3.10 Crew Survival**

This element provides for the effort necessary to ensure the use of all available mechanisms including abort, safe haven, escape, emergency egress, and rescue. It also ensures that all design efforts have established, assessed, and documented agency requirements for an acceptable life cycle cumulative probability of safe Crew and passenger return for all missions over the life of all Constellation programs and projects. The element also ensures that all critical flight systems are designed in compliance to agency Human-Rating Requirements and Guidelines for Space Flight Systems to preclude a catastrophic safety risk to the flight Crew.

#### **4.3.11 Nuclear Safety**

TBD if within Constellation or in Prometheus or both - (This element includes the effort necessary to ensure the overall safety and protection of flight and ground personnel, the general public, flight/ground hardware, software and facilities through all phases of the initiative when nuclear material is present. Ensure adequacy and implementation of safety plans, hazards analyses, safety non-compliance disposition, and safety assessment, reports, and reviews of nuclear hardware elements and operations plans and compliance with Federal law and regulations. This also includes participation in the Inter-agency Nuclear Safety Review Panel (INSRP).

### **4.4 Technology Integration**

This element provides for the integration of technology maturation needs and plans across the Project Constellation system of systems. This activity includes technical risk mitigation requirements and tasks identified in the risk management process and technology maturation tasks needed to support trade study decisions for system requirements and design solutions.

### **4.5 Development Integration**

Encompasses the effort required to integrate the system of systems to verify requirements provided in WBS element 4.2. These activities include work necessary to design, analyze, and integrate physical interfaces and functional capabilities for verification in the development phase. Activity includes development of assembly drawings, interface control drawings and specifications, and assembly and test documentation of the integrated system of systems flight and ground hardware and software. Assembly, integration, and test of the system of systems are performed in this element to meet verification and validation requirements and to ensure integrated system can execute the mission objectives as intended. Scope involves assurance that all supporting system

elements are ready to support end to end tests, review of key system test plans for completeness and ability to meet goals, review of key test scripts for timing and order of execution of command sequences.

#### **4.6 Integrated Operations**

This element focuses on the integration of the SoS operations and provides the planning, directing, controlling, and execution of an integrated operations effort to meet SoS mission objectives. This element encompasses operations integration and analysis activities, integrated logistics support, consolidated operations implementation to support an integrated SoS mission and provides insight into operations common or multi-use systems to provide a balanced and integrated operations capability. This effort also includes integration of NASA's operational expertise in the design and development of Constellation SoS focusing the expertise on each system and horizontally across the program to ensure integrated operations capability across the system. The Integrated Operations activity also includes assessing the schedule and cost control for operation and sustainment of the mission operations activities throughout the system life cycle and producing operations metrics to ensure the most efficient and effective operations throughout the life of the system

##### **4.6.1 Operations Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the operations at the system so systems level.

##### **4.6.2 Operations Planning**

This area performs operations integration and analysis across the enterprise system by evaluating the enterprise mission and operations planning, processes, tools, facilities and systems to promote and ensure consistency, compatibility, and efficiency across the enterprise.

##### **4.6.2.1 Ground Operations Integration**

This element captures the overall ground processing integration and coordination across the enterprise to ensure commonality and standardization. Ground processing includes the activities required to prepare a mission for flight including vehicle processing; maintenance and refurbishment; assembly, test, and check-out; integrated testing, launch operations; and recovery operations. This element also captures the coordination of launch site processing ground systems including facilities, support equipment, and check-out equipment.

##### **4.6.2.2 Mission Operations Integration**

This element provides operations integration activities for the Exploration Missions which includes the mission control facility, operations software, training, simulation, communications, flight certification, flight operations, and support and disposal through the crew transport system life cycle.

##### **4.6.2.3 Surface Operations Integration**

This element captures the overall surface operations integration and coordination across the enterprise to ensure commonality and standardization. Surface operations includes the activities performed on the lunar and planetary surface including servicing, maintenance, repair, handling, surface preparations, and environmental issues (e.g. electrostatic properties of dust).

#### **4.6.3 Consolidated Systems Operations**

This element captures the operations implementation activities to be performed after the transition of an element from the design and development phase to the operations phase in support of a SoS mission. The transition to the operations phase will occur once the hardware has met documented criteria and reached an appropriate maturity

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level. The activities to be included in this element are mission integration, ground processing, mission operations, and lunar/planetary surface operations. Common and multi-use facilities operations and maintenance activities will be captured in 4.11 and unique operations will be defined for each project in WBS elements 4.7-4.12 during the development phase prior to the operational phase.

#### **4.6.3.1 Mission Integration**

This element provides the analysis and integration of ground, flight and surface operations planning, preparation and execution for the SoS through all phases of operations, including the necessary ground facilities, equipment, systems and software. This element ensures that the enterprise mission and operations planning, processes, tools, facilities and systems are implemented efficiently across the enterprise. This element implements the environmental compliance initiatives for ground, flight, and surface operations. Also, included in this element are the definition, preparation, and conduct of mission readiness reviews

#### **4.6.3.2 Ground Processing**

This element captures the ground processing operations that will occur after the hardware elements have transitioned from the design and development phase to an operations phase. This includes, but is not limited to; launch operations, landing and recovery operations, receiving and inspection, assembly and checkout, maintenance and refurbishment, turnaround, integrated testing, payload/cargo processing and integration, transportation, training and simulation, operations logistics, and ground infrastructure operations and maintenance.

#### **4.6.3.3 Mission Operations**

##### **4.6.3.3.1 Certification**

Prepare, coordinate, and conduct mission operations system validation tests to demonstrate the capability and readiness of the mission operations system to operate and support the Exploration Missions. Provide the mission operations V&V system engineer a process which assures the mission operations system is ready and capable of safely carrying out its intended purpose. Prepare the test plan and provide test reports.

##### **4.6.3.3.2 Training and Simulation**

This element provides resources to perform training and certification of crew and operations personnel for the Exploration Missions. This includes lesson and training material development, mock-ups, trainers, simulators, facilities, and supporting software; preparation, planning, and coordination for incorporation of the trainers into the training flow; conduct of operations training, rehearsals, and tests. Tasks also include preparing the operations training plan and producing training reports. Training will occur both prior to and during flight operations

##### **4.6.3.3.3 Logistics**

This element captures the operations logistics activities for the flight operations once the hardware has been transitioned from the design and development phase to the operations phase. Activities included in this element are logistics management and integration, logistics engineering, maintenance and supply support, parts sparing (including flight hardware), government property management, and government furnished services.

##### **4.6.3.3.4 Flight Operations**

The technical and management efforts to direct and control the mission operation activities associated with an Exploration Mission on-board operations. Includes support of systems engineering efforts that define and document the flight operations requirements; plans, procedures, and tools to satisfy requirements; and training,

test, and certification plans. This activity supports the flight operations of the Exploration Missions with communication, commanding, controlling, data analysis, and anomaly resolution and contingency planning capabilities.

#### **4.6.3.3.5 Retirement Disposal**

The activity associated with planning for and executing the disintegration of the mission operations complex and disposal of the associated assets consistent with ITAR and NEPA restrictions.

#### **4.6.3.4 Surface Operations**

Integrated operations during the planetary surface mission phase.

#### **4.6.3.5 Communications**

### **4.7 Crew Transport Systems**

This effort includes the work to develop and operate the systems required for Crew transportation from the surface of the Earth, to Earth Orbit, from Earth orbit to orbit around and/or the surface of the Moon or Mars, or other destinations (asteroids, Mars moons, etc), and for safe return to Earth. These systems will be evolved in spirals with unique spiral systems identified.

#### **4.7.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

#### **4.7.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

#### **4.7.3 Reserved**

#### **4.7.4 Reserved**

#### **4.7.5 Development Spiral Integration**

Ensures that development phase activities for crew transport systems are coordinated across spirals. Ensures that development lessons learned are documented and passed to follow-on spirals systems engineering.

#### **4.7.6 Operations Spiral Integration**

Ensures that operations phase activities for crew transport systems is coordinated across spirals. Ensures that operations lessons learned are documented and passed to follow-on spirals systems engineering.

#### **4.7.7 Crew Transport Spiral I**

For the given system of systems spiral, the work to develop and operate the systems required for Crew transportation from the surface of the Earth, to Earth Orbit, from Earth orbit to orbit around and/or the surface of the Moon or Mars, or other destinations (asteroids, Mars moons, etc), and for safe return to Earth.

##### **4.7.7.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

**4.7.7.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

**4.7.7.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level

**4.7.7.4 Reserved**

**4.7.7.5 Development**

For the given system of systems spiral, the effort required to evolve the system from requirements to product solutions. These activities include work necessary to design, analyze, prototype, manufacture/produce or acquire, assemble, integrate and test and verify requirements.

**4.7.7.6 Operations**

For the given system of systems spiral, the operations activities for the given system product level

**4.7.7.7 Crew Transport Ground Systems (Spiral I)**

The work to develop and operate unique crew transport ground systems for the given system of systems spiral

**4.7.7.8 Crew Exploration Vehicle (Spiral I)**

The work required to develop and operate the Crew Exploration Vehicle. This element includes the crew compartment from earth's surface to the crew destination system. Also includes the required servicing systems for life support, communications, navigation, power, and minor maneuvering capability.

**4.7.7.9 Launch Vehicle (Spiral I)**

Work required to develop and operate the crew transport launch vehicles for the given system of systems spiral  
Includes all vehicle elements required to accelerate and navigate the CEV to the earth orbit insertion point.

**4.7.7.10 IVA Systems (Spiral I)**

Work required to develop and operate flight suits and crew protection systems while performing duties inside the spacecraft.

**4.7.7.11 EVA System (Spiral I)**

Work required to develop and operate systems for all extravehicular activity during exploration missions. Effort includes delivery and operation of space suit systems, airlock systems, and in-space EVA tools and mobility aids.

**4.7.8 Crew Transport Spiral II**

For the given system of systems spiral, the work to develop and operate the systems required for Crew transportation from the surface of the Earth, to Earth Orbit, from Earth orbit to orbit around and/or the surface of the Moon or Mars, or other destinations (asteroids, Mars moons, etc), and for safe return to Earth.

#### **4.7.8.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

#### **4.7.8.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

#### **4.7.8.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level.

#### **4.7.8.4 Reserved**

#### **4.7.8.5 Development**

For the given system of systems spiral, the effort required to evolve the system from requirements to product solutions. These activities include work necessary to design, analyze, prototype, manufacture/produce or acquire, assemble, integrate and test and verify requirements.

#### **4.7.8.6 Operations**

For the given system of systems spiral, the operations activities for the given system product level

#### **4.7.8.7 Crew Transport Ground Systems (Spiral II)**

The work to develop and operate unique crew transport ground systems for the given system of systems spiral

#### **4.7.8.8 CEV (Spiral II)**

The work required to develop and operate the Crew Exploration Vehicle. This element includes the crew compartment from earth's surface to the crew destination system. Also includes the required servicing systems for life support, communications, navigation, power, and minor maneuvering capability.

#### **4.7.8.9 Launch Vehicle (Spiral II)**

Work required to develop and operate the crew transport launch vehicles for the given system of systems spiral. Includes all vehicle elements required to accelerate and navigate the CEV to the earth orbit insertion point.

#### **4.7.8.10 IVA Systems (Spiral II)**

Systems required to meet system level requirements for flight suits and crew protection while performing duties inside the spacecraft.

#### **4.7.8.11 EVA Systems (Spiral II)**

Systems required to meet system level requirements for all extravehicular activity during exploration missions. Effort includes delivery and operation of space suit systems, airlock systems, and in-space EVA tools and mobility aids.

#### **4.7.8.12 In-Space Transportation Systems (Spiral II)**

Work required to develop and operate systems required provide propulsion of the Crew Exploration Vehicle beyond earth orbit to the destination vicinity. Includes orbit insertion and orbit transfer beyond the capability of the CEV and Launch Vehicle

### **4.7.9 Crew Transport Spiral III**

For the given system of systems spiral, the work to develop and operate the systems required for Crew transportation from the surface of the Earth, to Earth Orbit, from Earth orbit to orbit around and/or the surface of the Moon or Mars, or other destinations (asteroids, Mars moons, etc), and for safe return to Earth.

#### **4.7.9.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

#### **4.7.9.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

#### **4.7.9.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level

#### **4.7.9.4 Reserved**

#### **4.7.9.5 Development**

For the given system of systems spiral, the effort required to evolve the system from requirements to product solutions. These activities include work necessary to design, analyze, prototype, manufacture/produce or acquire, assemble, integrate and test and verify requirements.

#### **4.7.9.6 Operations**

For the given system of systems spiral, the operations activities for the given system product level

#### **4.7.9.7 Crew Transport Ground Segment (Spiral III)**

The work to develop and operate unique crew transport ground systems for the given system of systems spiral

#### **4.7.9.8 CEV (Spiral III)**

The work required to develop and operate the Crew Exploration Vehicle. This element includes the crew compartment from earth's surface to the crew destination system. Also includes the required servicing systems for life support, communications, navigation, power, and minor maneuvering capability.

#### **4.7.9.9 Launch Vehicle (Spiral III)**

Work required to develop and operate the crew transport launch vehicles for the given system of systems spiral  
Includes all vehicle elements required to accelerate and navigate the CEV to the earth orbit insertion point.

#### **4.7.9.10 IVA Systems (Spiral III)**

Systems required to meet system level requirements for flight suits and crew protection while performing duties inside the spacecraft.

#### **4.7.9.11 EVA System (Spiral III)**

Systems required to meet system level requirements for all extravehicular activity during exploration missions. Effort includes delivery and operation of space suit systems, airlock systems, and in-space EVA tools and mobility aids.

#### **4.7.9.12 In-Space Transportation Systems (Spiral III)**

Work required to develop and operate systems required provide propulsion of the Crew Exploration Vehicle beyond earth orbit to the destination vicinity. Includes orbit insertion and orbit transfer beyond the capability of the CEV and Launch Vehicle

#### **4.7.9.13 Ascent / Descent Systems (Spiral III)**

Systems required to meet system level requirements for last stage Earth to Orbit propulsion and in-space propulsion to and from the Moon and Mars. This effort includes delivery and operation of propulsion stages.

### **4.7.10 Crew Transport Spiral IV**

For the given system of systems spiral, the work to develop and operate the systems required for Crew transportation from the surface of the Earth, to Earth Orbit, from Earth orbit to orbit around and/or the surface of the Moon or Mars, or other destinations (asteroids, Mars moons, etc), and for safe return to Earth.

#### **4.7.10.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

#### **4.7.10.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level.

#### **4.7.10.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level

#### **4.7.10.4 Reserved**

#### **4.7.10.5 Development**

For the given system of systems spiral, the effort required to evolve the system from requirements to product solutions. These activities include work necessary to design, analyze, prototype, manufacture/produce or acquire, assemble, integrate and test and verify requirements.

#### **4.7.10.6 Operations**

For the given system of systems spiral, the operations activities for the given system product level

#### **4.7.10.7 Crew Transport Ground Segment (Spiral IV)**

The work to develop and operate unique crew transport ground systems for the given system of systems spiral

#### **4.7.10.8 CEV (Spiral IV)**

The work required to develop and operate the Crew Exploration Vehicle. This element includes the crew compartment from earth's surface to the crew destination system. Also includes the required servicing systems for life support, communications, navigation, power, and minor maneuvering capability.

#### **4.7.10.9 Launch Vehicle (Spiral IV)**

Work required to develop and operate the crew transport launch vehicles for the given system of systems spiral. Includes all vehicle elements required to accelerate and navigate the CEV to the earth orbit insertion point.

#### **4.7.10.10 IVA Systems (Spiral IV)**

Systems required to meet system level requirements for flight suits and crew protection while performing duties inside the spacecraft.

#### **4.7.10.11 EVA System (Spiral IV)**

Systems required to meet system level requirements for all extravehicular activity during exploration missions. Effort includes delivery and operation of space suit systems, airlock systems, and in-space EVA tools and mobility a

#### **4.7.10.12 In-Space Transportation Systems (Spiral IV)**

Work required to develop and operate systems required provide propulsion of the Crew Exploration Vehicle beyond earth orbit to the destination vicinity. Includes orbit insertion and orbit transfer beyond the capability of the CEV and Launch Vehicle

#### **4.7.10.13 Ascent / Descent Systems (Spiral IV)**

Work required to develop and operate systems that enable crew access and departure to and from the surface of planetary bodies

### **4.8 Cargo Transport Systems**

This effort includes the work to develop and operate the systems required for transportation of cargo required to enable combined human and robotic exploration missions. Includes cargo transfer from the surface of the Earth, to Earth Orbit, from Earth orbit to orbit around and/or the surface of the Moon or Mars, or other destinations (asteroids, Mars moons, etc), and for safe return to Earth if necessary. These systems will be evolved in spirals with unique spiral systems identified.

#### **4.8.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

#### **4.8.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

#### **4.8.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level

**4.8.4 Reserved**

**4.8.5 Development Spiral Integration**

Ensures that development phase activities for cargo transport systems are coordinated across spirals. Ensures that development lessons learned are documented and passed to follow-on spirals systems engineering.

**4.8.6 Operations Spiral Integration**

Ensures that operations phase activities for cargo transport systems is coordinated across spirals. Ensures that operations lessons learned are documented and passed to follow-on spirals systems engineering.

**4.8.7 Reserved**

**4.8.8 Cargo Transport Spiral II**

For the given spiral, includes the work to develop and operate the systems required for transportation of cargo required to enable combined human and robotic exploration missions

**4.8.8.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

**4.8.8.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

**4.8.8.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level

**4.8.8.4 Reserved**

**4.8.8.5 Development**

For the given system of systems spiral, the effort required to evolve the system from requirements to product solutions. These activities include work necessary to design, analyze, prototype, manufacture/produce or acquire, assemble, integrate and test and verify requirements.

**4.8.8.6 Operations**

For the given system of systems spiral, the operations activities for the given system product level.

**4.8.8.7 Cargo Transport Ground Systems (Spiral II)**

This element includes the cargo transport unique parts of the physical system that do not fly as part of a mission. The complex of equipment, HW, SW, and facilities required to assemble, integrate, test, monitor, and operate the Cargo Transportation System during flight simulations, rehearsals, and flight operations and the support necessary to operate and maintain it. Includes the computers, communications, operating systems, and networking equipment needed to interconnect and host the mission operations system SW. May include

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spacecraft and instrument test-beds post-launch; flight SW development equipment, or interfaces to such capability if provided by corresponding spacecraft or instrument areas.

**4.8.8.8 Cargo Module (Spiral II)**

Includes work required to develop and operate systems necessary to transfer exploration mission payloads to their destinations

**4.8.8.9 Cargo Launch Vehicle (Spiral II)**

Work required to develop and operate the cargo transport launch vehicles for the given system of systems spiral  
Includes all vehicle elements required to accelerate and navigate the cargo to the earth orbit insertion point.

**4.8.8.10 In-Space Cargo Transportation Systems (Spiral II)**

Work required to develop and operate systems necessary to transfer cargo beyond the capability of the launch vehicle

**4.8.9 Cargo Transport Spiral III**

For the given spiral, includes the work to develop and operate the systems required for transportation of cargo required to enable combined human and robotic exploration missions

**4.8.9.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

**4.8.9.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

**4.8.9.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level

**4.8.9.4 Reserved**

**4.8.9.5 Development**

For the given system of systems spiral, the effort required to evolve the system from requirements to product solutions. These activities include work necessary to design, analyze, prototype, manufacture/produce or acquire, assemble, integrate and test and verify requirements.

**4.8.9.6 Operations**

For the given system of systems spiral, the operations activities for the given system product level.

#### **4.8.9.7 Cargo Transport Ground Systems (Spiral III)**

This element includes the cargo transport unique parts of the physical system that do not fly as part of a mission. The complex of equipment, HW, SW, and facilities required to assemble, integrate, test, monitor, and operate the Cargo Transportation System during flight simulations, rehearsals, and flight operations and the support necessary to operate and maintain it. Includes the computers, communications, operating systems, and networking equipment needed to interconnect and host the mission operations system SW. May include spacecraft and instrument test-beds post-launch; flight SW development equipment, or interfaces to such capability if provided by corresponding spacecraft or instrument areas.

#### **4.8.9.8 Cargo Module (Spiral III)**

Includes work required to develop and operate systems necessary to transfer exploration mission payloads to their destinations

#### **4.8.9.9 Cargo Launch Vehicle (Spiral III)**

Work required to develop and operate the cargo transport launch vehicles for the given system of systems spiral. Includes all vehicle elements required to accelerate and navigate the cargo to the earth orbit insertion point.

#### **4.8.9.10 In-Space Cargo Transportation Systems (Spiral III)**

Work required to develop and operate systems necessary to transfer cargo beyond the capability of the launch vehicle

#### **4.8.9.11 Ascent / Descent Systems (Spiral III)**

Work required to develop and operate systems that enable cargo delivery and removal to and from the surface of planetary bodies

### **4.8.10 Cargo Transport Spiral IV**

For the given spiral, includes the work to develop and operate the systems required for transportation of cargo required to enable combined human and robotic exploration missions

#### **4.8.10.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

#### **4.8.10.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

#### **4.8.10.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level

**4.8.10.4 Reserved**

**4.8.10.5 Development**

For the given system of systems spiral, the effort required to evolve the system from requirements to product solutions. These activities include work necessary to design, analyze, prototype, manufacture/produce or acquire, assemble, integrate and test and verify requirements.

**4.8.10.6 Operations**

For the given system of systems spiral, the operations activities for the given system product level.

**4.8.10.7 Cargo Transport Ground Systems (Spiral IV)**

This element includes the cargo transport unique parts of the physical system that do not fly as part of a mission. The complex of equipment, HW, SW, and facilities required to assemble, integrate, test, monitor, and operate the Cargo Transportation System during flight simulations, rehearsals, and flight operations and the support necessary to operate and maintain it. Includes the computers, communications, operating systems, and networking equipment needed to interconnect and host the mission operations system SW. May include spacecraft and instrument test-beds post-launch; flight SW development equipment, or interfaces to such capability if provided by corresponding spacecraft or instrument areas.

**4.8.10.8 Cargo Module**

Includes work required to develop and operate systems necessary to transfer exploration mission payloads to their destinations

**4.8.10.9 Cargo Launch Vehicle (Spiral IV)**

Work required to develop and operate the cargo transport launch vehicles for the given system of systems spiral. Includes all vehicle elements required to accelerate and navigate the cargo to the earth orbit insertion point.

**4.8.10.10 In-Space Cargo Transportation Systems (Spiral IV)**

Work required to develop and operate systems necessary to transfer cargo beyond the capability of the launch vehicle

**4.8.10.11 Ascent / Descent Systems (Spiral IV)**

Work required to develop and operate systems that enable cargo delivery and removal to and from the surface of planetary bodies

**4.9 Surface Systems**

This effort includes development of systems required for human exploration of the surface of the Moon, Mars, and other bodies (i.e. asteroids or the moons of Mars). This element may include Crew habitats, logistics modules (i.e. supplies, power, resource processing), surface mobility systems, intra/extra-vehicular suit systems, and the required systems to provide power, life support, radiation protection, thermal control, and communications. This element also includes all required unique support systems to test, process, certify, and operate Surface Systems.

#### **4.9.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

#### **4.9.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

#### **4.9.3 Reserved**

#### **4.9.4 Reserved**

#### **4.9.5 Development Spiral Integration**

Ensures that development phase activities for the surface systems are coordinated across spirals. Ensures that development lessons learned are documented and passed to follow-on spirals systems engineering.

#### **4.9.6 Operations Spiral Integration**

Ensures that operations phase activities for the surface systems is coordinated across spirals. Ensures that operations lessons learned are documented and passed to follow-on spirals systems engineering

#### **4.9.7 Reserved**

#### **4.9.8 Reserved**

#### **4.9.9 Surface Systems Spiral III**

#### **4.9.10 Surface Systems Spiral IV**

### **4.10 In-Space Systems**

The work required to develop and operate in-space systems supporting combined human and robotic exploration of the Moon, Mars, and other bodies (i.e. asteroids and the moons of Mars). This element may include logistics modules (i.e. supplies, fuel); communication, navigation, and reconnaissance systems to support operations. Space Systems also includes the required systems to provide communications, command, and control, power, thermal control, and propulsion for orbit maintenance and maneuvering, and docking. This element also includes all required unique support systems to test, process, certify, and operate In-Space Systems.

#### **4.10.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

#### **4.10.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

**4.10.3 Reserved**

**4.10.4 Reserved**

**4.10.5 Development Spiral Integration**

Ensures that development phase activities for the In-Space systems are coordinated across spirals. Ensures that development lessons learned are documented and passed to follow-on spirals systems engineering.

**4.10.6 Operations Spiral Integration**

Ensures that operations phase activities for the In-Space systems are coordinated across spirals. Ensures that operations lessons learned are documented and passed to follow-on spirals systems engineering.

**4.10.7 In Space Spiral I**

For the given system of systems spiral, the work required to develop and operate in-space systems supporting combined human and robotic exploration of the Moon, Mars, and other bodies (i.e. asteroids and the moons of Mars).

**4.10.7.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

**4.10.7.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

**4.10.7.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level

**4.10.7.4 Reserved**

**4.10.7.5 Development**

For the given system of systems spiral, the effort required to evolve the system from requirements to product solutions. These activities include work necessary to design, analyze, prototype, manufacture/produce or acquire, assemble, integrate and test and verify requirements.

**4.10.7.6 Operations**

For the given system of systems spiral, the operations activities for the given system product level.

**4.10.7.7 In Space Communication and Navigation Systems (Spiral I)**

Systems required to meet system level requirements for communication and navigation during transit to and from and at the Moon and Mars

#### **4.10.8 In Space Spiral II**

For the given system of systems spiral, the work required to develop and operate in-space systems supporting combined human and robotic exploration of the Moon, Mars, and other bodies (i.e. asteroids and the moons of Mars).

#### **4.10.9 In Space Spiral III**

For the given system of systems spiral, the work required to develop and operate in-space systems supporting combined human and robotic exploration of the Moon, Mars, and other bodies (i.e. asteroids and the moons of Mars).

#### **4.10.10 In Space Spiral IV**

For the given system of systems spiral, the work required to develop and operate in-space systems supporting combined human and robotic exploration of the Moon, Mars, and other bodies (i.e. asteroids and the moons of Mars).

### **4.11 Ground Systems**

This effort includes development and operations of common and multi-use facilities /systems such as a mission control center, communication networks, processing infrastructure, etc. supporting human exploration and supporting Crew missions as well as robotic precursor missions. This element includes all common and multi-use facilities/systems that do not fly as part of a mission in the support of Mission Operations. The complex of equipment, HW, SW, and facilities/systems required to assemble, integrate, test, and monitor the Exploration Missions systems during flight simulations, rehearsals, and flight operations and the support necessary to operate and maintain it. Includes the computers, communications, operating systems, and networking equipment needed to interconnect and host the mission operations system SW. May include spacecraft and instrument test beds, post-launch flight SW development equipment, or interfaces to such capability. This element also includes all required unique support systems to test, process, certify, and operate the common ground systems.

#### **4.11.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

#### **4.11.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

#### **4.11.3 Reserved**

#### **4.11.4 Reserved**

#### **4.11.5 Development Spiral Integration**

Ensures that development phase activities for the ground systems are coordinated across spirals. Ensures that development lessons learned are documented and passed to follow-on spirals systems engineering.

#### **4.11.6 Operations Spiral Integration**

Ensures that operations phase activities for the ground systems are coordinated across spirals. Ensures that operations lessons learned are documented and passed to follow-on spirals systems engineering

#### **4.11.7 Ground Systems Spiral I**

For the given system of systems spiral, the work required to develop and operate the ground systems as part of the integrated system of systems

##### **4.11.7.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

##### **4.11.7.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

##### **4.11.7.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level

##### **4.11.7.4 Reserved**

##### **4.11.7.5 Development**

For the given system of systems spiral, the effort required to evolve the system from requirements to product solutions. These activities include work necessary to design, analyze, prototype, manufacture/produce or acquire, assemble, integrate and test and verify requirements.

##### **4.11.7.6 Operations**

For the given system of systems spiral, the operations activities for the given system product level.

##### **4.11.7.7 Ground Processing Facilities and Systems (Spiral I)**

##### **4.11.7.8 Launch Facilities and Systems (Spiral I)**

##### **4.11.7.9 Mission Control Facilities and Systems (Spiral I)**

##### **4.11.7.10 Training/Simulation Facilities and Systems (Spiral I)**

##### **4.11.7.11 Communications Facilities and Systems (Spiral I)**

#### **4.11.8 Ground Systems Spiral II**

For the given system of systems spiral, the work required to develop and operate the ground systems as part of the integrated system of systems

##### **4.11.8.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

**4.11.8.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

**4.11.8.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level

**4.11.8.4 Reserved**

**4.11.8.5 Development**

For the given system of systems spiral, the effort required to evolve the system from requirements to product solutions. These activities include work necessary to design, analyze, prototype, manufacture/produce or acquire, assemble, integrate and test and verify requirements.

**4.11.8.6 Operations**

For the given system of systems spiral, the operations activities for the given system product level.

**4.11.8.7 Ground Processing Facilities and Systems (Spiral II)**

**4.11.8.8 Launch Facilities and Systems (Spiral II)**

**4.11.8.9 Mission Control Facilities and Systems (Spiral II)**

**4.11.8.10 Training/Simulation Facilities and Systems (Spiral II)**

**4.11.8.11 Communications Facilities and Systems (Spiral II)**

**4.11.9 Ground Systems Spiral III**

For the given system of systems spiral, the work required to develop and operate the ground systems as part of the integrated system of systems

**4.11.9.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

**4.11.9.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

**4.11.9.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level

**4.11.9.4 Reserved**

**4.11.9.5 Development**

For the given system of systems spiral, the effort required to evolve the system from requirements to product solutions. These activities include work necessary to design, analyze, prototype, manufacture/produce or acquire, assemble, integrate and test and verify requirements.

**4.11.9.6 Operations**

For the given system of systems spiral, the operations activities for the given system product level.

**4.11.9.7 Ground Processing Facilities and Systems (Spiral III)**

**4.11.9.8 Launch Facilities and Systems (Spiral III)**

**4.11.9.9 Mission Control Facilities and Systems (Spiral III)**

**4.11.9.10 Training/Simulation Facilities and Systems (Spiral III)**

**4.11.9.11 Communications Facilities and Systems (Spiral III)**

**4.11.10 Ground Spiral IV**

For the given system of systems spiral, the work required to develop and operate the ground systems as part of the integrated system of systems

**4.11.10.1 System Management**

This element encompasses all the work required to plan, lead, organize, and control all facets of the development and operations at the given system level.

**4.11.10.2 Systems Engineering**

Systems Engineering functions (as described in element 4.2) applied at the given system level

**4.11.10.3 Safety and Mission Assurance**

For the given system of systems spiral, the safety and mission assurance functions (as described in element 4.3) applied at the given system level

**4.11.10.4 Reserved**

**4.11.10.5 Development**

For the given system of systems spiral, the effort required to evolve the system from requirements to product solutions. These activities include work necessary to design, analyze, prototype, manufacture/produce or acquire, assemble, integrate and test and verify requirements.

**4.11.10.6 Operations**

For the given system of systems spiral, the operations activities for the given system product level.

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- 4.11.10.7 Ground Processing Facilities and Systems (Spiral IV)**
- 4.11.10.8 Launch Facilities and Systems (Spiral IV)**
- 4.11.10.9 Mission Control Facilities and Systems (Spiral IV)**
- 4.11.10.10 Training/Simulation Facilities and Systems (Spiral IV)**
- 4.11.10.11 Communications Facilities and Systems (Spiral IV)**

**4.12 Robotic Precursor Systems**

Work required to develop and operate fully robotic systems that satisfy exploration objectives before initiation of combined human and robotic missions