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GLORY

Systems Engineering Management Plan (SEMP)-Rev A

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GLORY Systems Engineering Management Plan (SEMP) Signature Page

Prepared by:

Carey Lively
System Engineering Manager
GLORY
GSFC – Code 593

APPROVED BY:

Richard Burg
GLORY Project Manager

Goddard Space Flight Center
Greenbelt, Maryland

Change Record Page

Issue	Date	Pages Affected	Description
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Table of Contents

GLORY Systems Engineering Management Plan (SEMP) Signature Page i

Change Record Page ii

1.0 Introduction 1

1.1 Document Purpose and Scope 1
1.2 Document Structure 1
1.3 Applicable Documents 1
1.4 GLORY Background 2
1.5 Science Objectives 3
1.5.1 Aerosol Research 3
1.5.2 Total Solar Irradiance 4
1.6 Mission Architecture 5
1.7 Requirements Hierarchy 6
1.8 Program Master Schedule 8

2.0 Systems Engineering Management 9

2.1 Management Overview 9
2.2 Systems Engineering Team and Interactions 9
2.3 Systems Engineering Process Overview 10

3.0 Systems Engineering Development Activities 11

3.1 Concept Development 11
3.2 Requirements Development 12
3.3 Design 12
3.3.1 Architectural Design 12
3.3.2 Design and Development 12
3.4 Manufacturing and Refurbishment 13
3.5 Integration 13
3.6 Verification 13
3.7 Technical Decision Process Management 13
3.7.1 Technical Memos (TMs) 14
3.8 Requirement/Specification Management 14
3.8.1 Document Tree 14
3.9 Configuration Management (TBD) 14
3.9.1 Configuration Control 14
3.10 Risk Management 15
3.11 Mission Assurance Requirements 15
3.12 Review Plan 15
3.12.1 Project Reviews 15
3.12.1.1 Systems Requirements Review – S/C, TIM, APS – Informal 16
3.12.1.2 Mission System Requirements Review – Formal 16
3.12.1.3 Heritage Review – Spacecraft – Informal 16

3.12.1.4 System Requirements Review (SRR) 17
3.12.1.5 Preliminary Design Review – S/C, TIM, APS 17
3.12.1.6 Mission Preliminary Design Review – Formal 17
3.12.1.7 Mission Confirmation Review – Formal 18
3.12.1.8 Critical Design Review – Formal 18
3.12.1.9 Pre-Environmental Review – Formal 18
3.12.1.10 Flight Operations Review – Formal 18
3.12.1.11 Pre-Ship Review – Formal 18
3.12.1.12 Flight Readiness Review – Formal 18
3.12.1.13 Operational Readiness Review – Formal 19
3.12.1.14 Engineering Design and Peer Review – Informal 19
3.12.1.15 Status Review/Audit – Informal 19
3.13 Technical Meetings 19
3.13.1 Working Groups 19
3.13.2 Configuration Control Boards 20
3.13.3 Technical Interchange Meetings 20
3.13.4 Monthly Meetings 20
3.13.5 Quarterly Meetings 20
3.13.6 Weekly Telecons and Telecon Minutes 20

4.0 Systems Tasks and Analyses 20

4.1 Requirements Definition and Control 21
4.1.1 Mission Requirements Analysis 21
4.1.2 Requirements Allocation 21
4.1.2.1 Design Requirements 21
4.1.2.2 Operations Requirements 22
4.1.3 System/Subsystem Specifications 22
4.1.4 Traceability 22
4.1.4.1 Requirements Traceability Analysis 22
4.1.4.2 Requirements Traceability Database 23
4.2 System Definition 23
4.2.1 Systems Analysis/Trades 23
4.2.2 Fault Detection, Isolation, and Recovery (FDIR) Reliability 24
4.3 Interface Definition and Control 24
4.3.1 Space Segment to Launch Vehicle 24
4.3.2 Space Segment to Ground Segment 25
4.3.3 Internal Interfaces 25
4.4 Mission Analyses and Resource Allocation 25
4.4.1 Mass and Power 26
4.4.2 Propellant 26
4.4.3 Pointing (Alignment) 26
4.4.4 Command and Telemetry Allocations 26
4.4.5 Communications 26
4.4.6 Computer Processing 27
4.4.7 Data Management 27
4.4.8 Operational Performance 27
4.4.9 Critical Technical Performance Measures (TPM) (TBD) 27

4.4.10 Orbital Debris Analysis ... 29
4.5 Verification ... 29
4.5.1 Requirement Verification Overview ... 29
4.5.2 Verification Methodology ... 30
4.5.3 Verification Levels ... 30
4.5.4 Verification Overview ... 30
4.5.4.1 Verification Environment Specification ... 30
4.5.4.2 Verification Plans and Procedures ... 31
4.5.4.3 Verification Test Plan (VTP) ... 31
4.6 Integration and Test ... 31
4.6.1 Pre-Test Activities ... 31
4.6.2 Testing Activities ... 32
4.6.3 Post-Test Activities ... 32
4.7 Flight Operations and Ground Systems ... 33
4.7.1 Planning ... 33
4.7.2 Procedures ... 33
4.7.3 Training ... 34
4.7.4 Verification ... 34
4.7.5 Launch Operations ... 34
4.7.6 Launch Site Integration Planning ... 34
4.7.7 Post-Launch Mission Operations ... 35

5.0 Systems Technical Coordination ... 35

5.1 Engineering and Analyses ... 35
5.1.1 Subsystem Discipline Engineers ... 36
5.1.1.1 Mechanical ... 36
5.1.1.2 Thermal ... 36
5.1.1.3 Electrical Power ... 36
5.1.1.4 Command and Data Handling ... 36
5.1.1.5 RF ... 37
5.1.1.6 ACS ... 37
5.1.1.7 Propulsion ... 37
5.1.1.8 Software ... 37
5.1.1.9 Contamination ... 38
5.1.1.10 Ground Systems ... 38
5.2 Specialty Engineering ... 38
5.3 Reliability ... 38
5.4 Safety ... 38
5.5 Radiation ... 39
5.5.1 Total Dose Radiation ... 39
5.5.2 SEU and SEL ... 39
5.6 EMI/EMC ... 39
5.7 Project Management Support ... 39
5.8 External Organizations ... 40
5.9 Specifications ... 40
5.10 Integration and Test ... 40
5.10.1 Subsystem Integration ... 40

5.10.2 Software Integration 41
5.10.3 System Integration 41
5.10.4 Testing 41
5.10.5 Launch Site 42
5.11 Flight Operations and Ground Systems 42
6.0 Resource Requirements 43
Appendix List of Acronyms 44

List of Figures

Figure 1. GLORY Architecture Hierarchy 5
Figure 2. GLORY Specification Tree 7
Figure 3. GLORY Master Schedule 8

1.0 Introduction

1.1 Document Purpose and Scope

The GLORY Systems Engineering Management Plan (SEMP) defines the technical management approach to manage and execute GLORY Systems Engineering activities. The systems engineering plan is based on the foundations provided in NPG 7120.5A, NASA Program and Project Management Processes and Requirements and the guidelines in GSFC Systems Engineering Process. This SEMP describes how GLORY executes the systems engineering activities while enabling effective integration across mission elements.

This document covers the entire systems engineering life cycle of GLORY; however, the SEMP is an evolving document that will be updated to highlight the activities in the current mission phase. This initial release focuses on phase B through PDR and MCRR, while subsequent releases will provide details on activities associated with phase C/D and phase E, Operations.

The primary purpose will be to define the activities and roles and responsibilities of the (NASA) Government and the contractors systems engineering, and it will be a working document to document agreements and responsibilities.

1.2 Document Structure

The GLORY SEMP is structured to emphasize systems engineering activities in the context of the mission life cycle. As GLORY matures in the engineering life cycle, the focus of the systems engineering processes changes. This SEMP emphasizes the evolution of those processes across the critical mission phases as defined by project and engineering milestones.

1.3 Applicable Documents

- GLORY Level 1 Requirements.
- GLORY SMRD.
- GLORY Instrument/S/C ICD.
- APS/S/C.
- TIM/S/C.
- Cloud Camera/S/C.
- GLORY Element Performance Specifications.
- GLORY GDRD.
- Observatory SOW.
- TIM SOW.
- APS SOW.

- NASA Program and Project Management Processes and Requirements, NPG 7120.5A, NASA Procedures and Guidelines, April 3, 1998.
- GSFC Project Formulation, 700-PG-7120.2.2A, NASA Procedures and Guidelines, August 6, 1999.
- NASA Systems Engineering Handbook, National Aeronautics and Space Administration, June 1995.

1.4 GLORY Background

GLORY is a remote sensing spaceflight mission designed to 1) collect data on the chemical, microphysical, and optical properties, and spatial and temporal distributions of aerosols; and 2) continue collection of total solar irradiance data for the long-term climate record. The mission accomplishes these objectives by deploying two separate instruments aboard a low Earth orbit (LEO) satellite, the Aerosol Polarimetry Sensor (APS) and the Total Irradiance Monitor (TIM).

The APS collects global aerosol data based on along-track, sub-satellite polarimetric measurements taken within the solar reflective spectral region (0.4 to 2.4 microns). Measurements of spectral radiance are restricted to the sunlit portion of the orbit, and since clouds can have a significant impact on the quality of polarimetric measurements, an onboard cloud camera is used to distinguish between clear and cloud-filled scenes. The 3-year mission life (5-year goal) provides the minimum duration to observe seasonal and regional trends and characterize the evolution of aerosols during transient climate events (El Niño, volcanic eruptions, etc.)

The TIM collects high-accuracy, high-precision measurements of total solar irradiance (TSI) using an active cavity radiometer that monitors changes in incident sunlight to the Earth's atmosphere. Because the TIM is designed to operate nominally in a solar-viewing orientation, it is mounted on a gimbaled platform that accommodates targeting independent of the spacecraft's nadir viewing attitude. The TIM is a heritage-design instrument that was originally flown on the SORCE satellite in January 2003.

The GLORY satellite is flown in a nominal 824 km, Sun-synchronous orbit with a nominal descending node (north to south equatorial crossing) at 10:30 a.m. mean local time. This orbit was selected to coordinate observations made by the Visible Infrared Imaging Radiometer Suite (VIIRS) on the NPOESS Preparatory Project (NPP) satellite with the APS. From this altitude the APS scanning sensor generates along-track, multi-angle polarimetric measurements with a 5 km circular geometric instantaneous field of view (GIFOV). The sensor scans the Earth over a nominal field of view of ±50 degrees about nadir, collecting a minimum of 120 angular samples per revolution with overlap of the individual swaths.

The GLORY observatory consists of a spacecraft bus, cloud camera, APS, and TIM, and will be launched from the Western Test Range at Vandenberg Air Force Base (VAFB) aboard a Taurus 2110 launch vehicle. After the satellite has been placed into orbit, a 30-day in-orbit checkout begins. Verification of initial insertion parameters and early-orbit ephemeredes will be made using the NASA Flight Dynamics Facility. Normal science operations immediately follow successful checkout. During that period, science data collection takes place on a near-continuous basis, interrupted only by special operations and anomalies. Mission operations and control are performed through the Mission Operations Center (MOC) located at the mission operations support contractor facility.

Ground station contacts are nominally required once per day permitting single-shift support and minimizing overall spacecraft operations. Mission planning, routine state-of-health monitoring, and spacecraft commanding is accomplished by the spacecraft contractor with instrument command files provided electronically by the APS and TIM science operations centers (SOCs). The spacecraft is designed for automatic safing in the event of anomalies or critical failures.

A commercial ground station network is used for the GLORY mission with the primary terminal located in Fairbanks, Alaska, and backup located in northern Scandinavia, Norway. The ground station supports both low-rate S-band command and telemetry link and high-rate X-band return-only science downlink of 28 Mbps. A high-rate (2 Mbps) S-band science data backup downlink is also supported. The primary ground station provides sufficient coverage for all nominal mission operations and science downlinks plus additional passes for on-orbit activation and checkout, anomaly resolution, or additional science downlink, as required. The Space Network's geosynchronous Tracking and Data Relay Satellite System (TDRSS) provides communications support to the GLORY mission during early on-orbit and in contingency situations.

Science data are recorded at the ground system and routed to the science operations centers. Once received at the SOCs, calibration of the science data is performed and science data processing algorithms are applied. Retrieval of VIIRS and OMPS data from the NOAA Comprehensive Large-Array Data Stewardship System (CLASS) and science data from other sources is performed by the SOCs, as required, to generate the necessary data products. After resulting data products are validated and assessed for accuracy, by the science teams, final data products are archived and distributed to the user community by the NASA Distributed Active Archive Center (DAAC).

1.5 Science Objectives

The overall science objectives of the GLORY mission are 1) to perform aerosol research, and 2) to perform continued measurements of total solar irradiance.

1.5.1 Aerosol Research

Aerosols play a crucial role in climate and, interestingly, can contribute to both warming and cooling of the Earth's atmosphere. Black carbon aerosols can contribute to global warming by absorbing the Sun's radiation and re-radiating the Sun's energy as infrared radiation that is trapped by the Earth's atmosphere in much the same way that the windshield of an automobile contributes to a parked automobile heating up in summer sunlight. Sulfate aerosols, produced from the sulfur dioxide gas that spews out of a volcano or from the burning of sulfur-bearing fossil fuels, reflect the Sun's radiation out into space and typically cause cooling. Aerosols, unlike greenhouse gases, have a short lifetime in the atmosphere. After they are produced, they tend to mix with other agents, are transported up into the troposphere and then back down again, and are transported by the winds across continents, and within about a week they tend to disappear. Because of both natural and anthropogenic events, aerosols are constantly being replenished and the anthropogenic aerosols, since the beginning of the industrial age, have been increasing. Aerosol can also play a critical role in precipitation but again some species of aerosols may increase precipitation, while others may inhibit precipitation. While it is recognized that aerosols play a key role, because of the uncertainty of the composition of the aerosols in the atmosphere there remains great uncertainty in the effect that atmospheric aerosols have on climate and weather – hotter or cooler, more rain or less, etc.

In the framework of the Climate Change Research Initiative (CCRI) launched in June 2001 to study areas of uncertainty about global climate change, research on atmospheric concentrations and effects of aerosols is specifically identified as a top priority. One of the activities the CCRI calls out to support this research is improving observations for model development and applications from observing systems. To that end, the GLORY mission will deploy an instrument that will help understand the climate-relevant chemical, microphysical, and optical properties, and spatial and temporal distributions of human-caused and naturally occurring aerosols. Specifically, GLORY will be used to determine:

1. The global distribution of natural and anthropogenic aerosols (black carbons, sulfates, etc.) with accuracy, and coverage sufficient for reliable quantification of the aerosol effect on climate, the anthropogenic component of the aerosol effect, and the long-term change of the aerosol effect caused by natural and anthropogenic factors.
2. The direct impact of aerosols on the radiation budget and its natural and anthropogenic components.
3. The effect of aerosols on clouds and precipitation, and their natural and anthropogenic components.
4. The feasibility of improved measurements of black carbons and dust absorption to provide more accurate estimates of their contribution to the climate forcing function.

In addition to the aerosol science objectives, GLORY will be used to provide proof of concept and risk reduction for the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Aerosol Polarimetry Sensor.

1.5.2 Total Solar Irradiance

Total Solar Irradiance (TSI), together with the absorption and reflection of this radiation by the Earth's atmosphere, determines the global average temperature of the Earth. The climate of the Earth is directly affected by the balance between the intensity of the Sun and the response of the atmosphere. Changes in both the solar irradiance intensity and in the composition of the atmosphere can cause global climate change. Solar irradiance intensity is purely a natural phenomenon, while the composition of the atmosphere is strongly influenced by the byproducts of modern industrial societies. Over the past century the average temperature of the Earth has increased by about 0.5 degree Centigrade. Understanding whether the increase in temperature and the concomitant climate change are byproducts of natural events or whether the changes are caused by anthropogenic sources is of primary importance to the establishment of scientifically and economically effective policy.

The continued measurement of the TSI to determine the Sun's direct and indirect affects on Earth's climate, at current state-of-the-art accuracy and without temporal gaps in the dataset, composes the solar irradiance requirement for the GLORY mission. It is essential that there be no temporal gaps in the data, as any measured shift in the atmospheric temperature must be correlated with the solar irradiance.

1.6 Mission Architecture

GLORY is implemented as a hierarchical system comprised of three segments: A space segment, a ground segment, and a launch segment. Each segment is composed of elements that perform a major operational role or function of the system. Each element, in turn, is made up of a series of subsystems that perform key functions within an element, such as mechanical, attitude control, and electrical power.

Figure 1 illustrates the GLORY architecture hierarchy. The remainder of this document utilizes the following terminology when discussing the hierarchy of the GLORY architecture: Mission level, segment level, element level, and subsystem level.

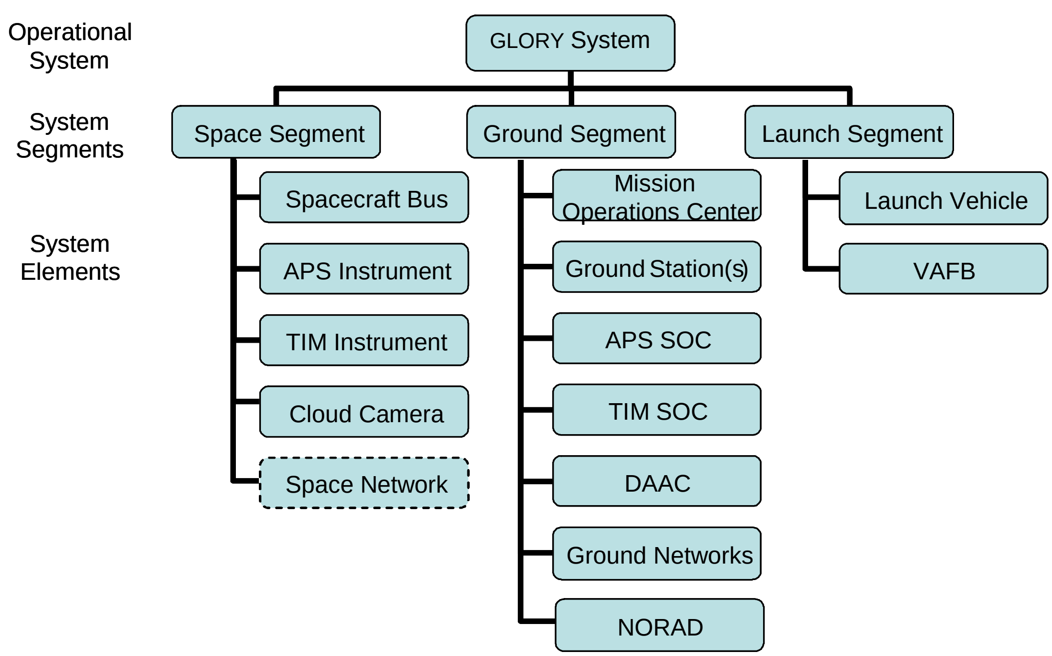

Figure 1. GLORY Architecture Hierarchy

1.7 Requirements Hierarchy

The GLORY systems engineering team generates mission requirements, with contractor support, through an iterative process that captures additional architecture detail with each engineering phase. The requirements interactions are organized according to the mission architecture described as follows.

- Level 1 requirements define the successful conduct of the mission. Level 1 requirements are negotiated with Headquarters and can be changed only with Headquarters approval.
- Mission (level 2) requirements define the requirements for the mission and meet the level 1 requirements. These requirements are contained in the SMRD, MAR, and Mission Concept.
- Element (level 3) requirements are the requirements at the element level, such as the spacecraft and instrument. The requirements for each segment are contained in a performance specification for each segment and ICDs between segments. The Observatory requirements are contained in the S/C performance specification and the GDRD. The instrument requirements are contained in a performance specification and the ICDs that flow from the SMRD and GDRD.
- Interface Control Documents (ICDs) define the interface requirements between segments and elements.
- Subsystem (level 4) requirements define the subsystem and components that meet the level 3 requirements and higher and the interactions between those components.

The specification tree for the GLORY Project is as follows in Figure 2.

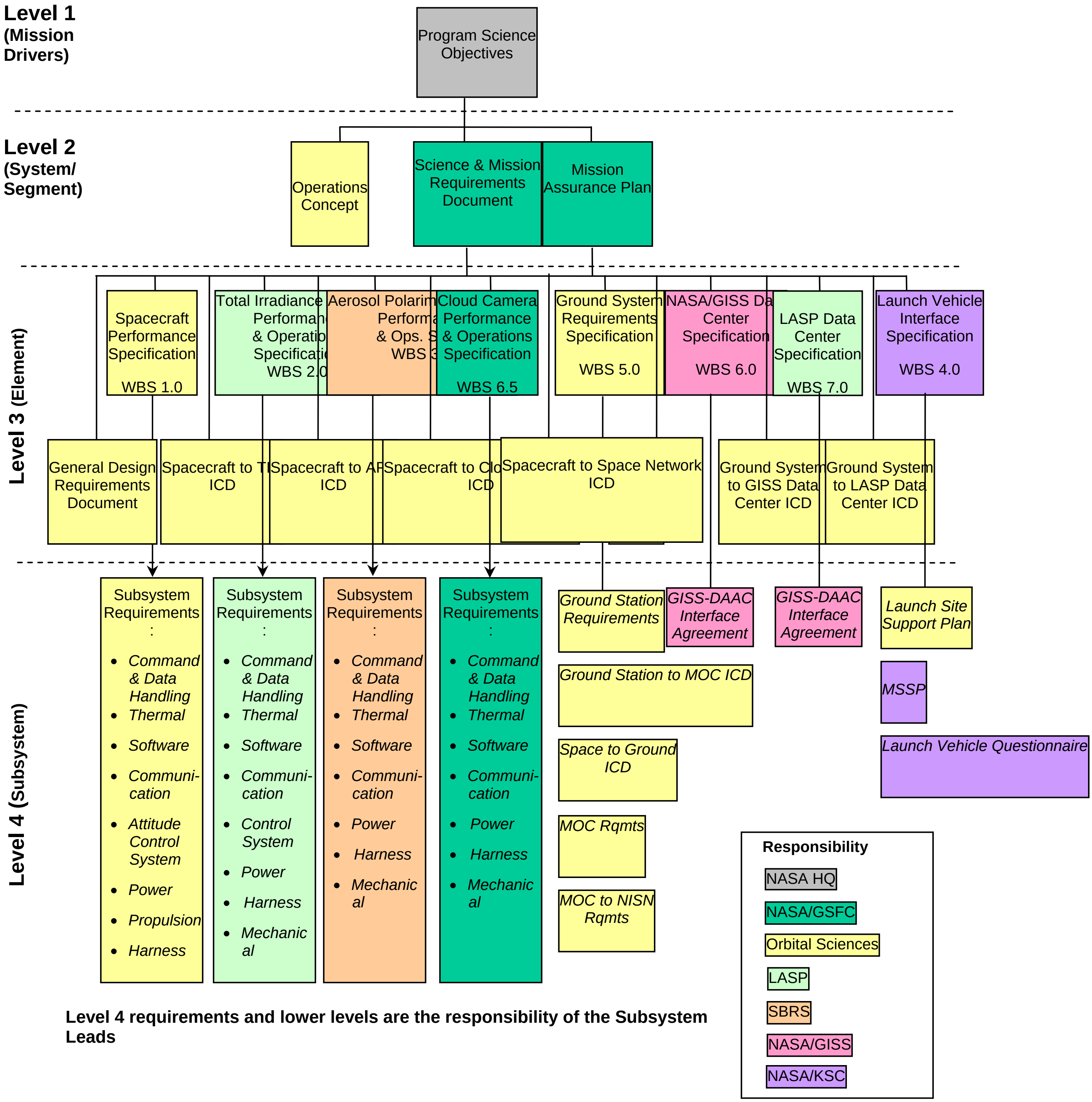

Figure 2. GLORY Specification Tree

1.8 Program Master Schedule

The GLORY mission life cycle will be executed in accordance with NPG 7120.5A, Program and Project Management Processes and Requirements. GLORY utilizes a project schedule to assist in schedule analysis and monthly reporting to GSFC Center management. The schedule identifies key milestones that are agreed upon between the Project Manager and GSFC Center management prior to schedule baseline. Project management will maintain the master schedule and will provide to systems engineering the schedule and milestones associated with all systems engineering activities. This schedule will be updated at regular intervals or as needed by project management; however, the schedule presented becomes the planning schedule for program development.

The major program schedule becomes the foundation for planning the systems engineering milestones and reviews given in the GLORY project schedule (see Figure 3). Systems engineering will adapt as this program schedule is changed by the Project.

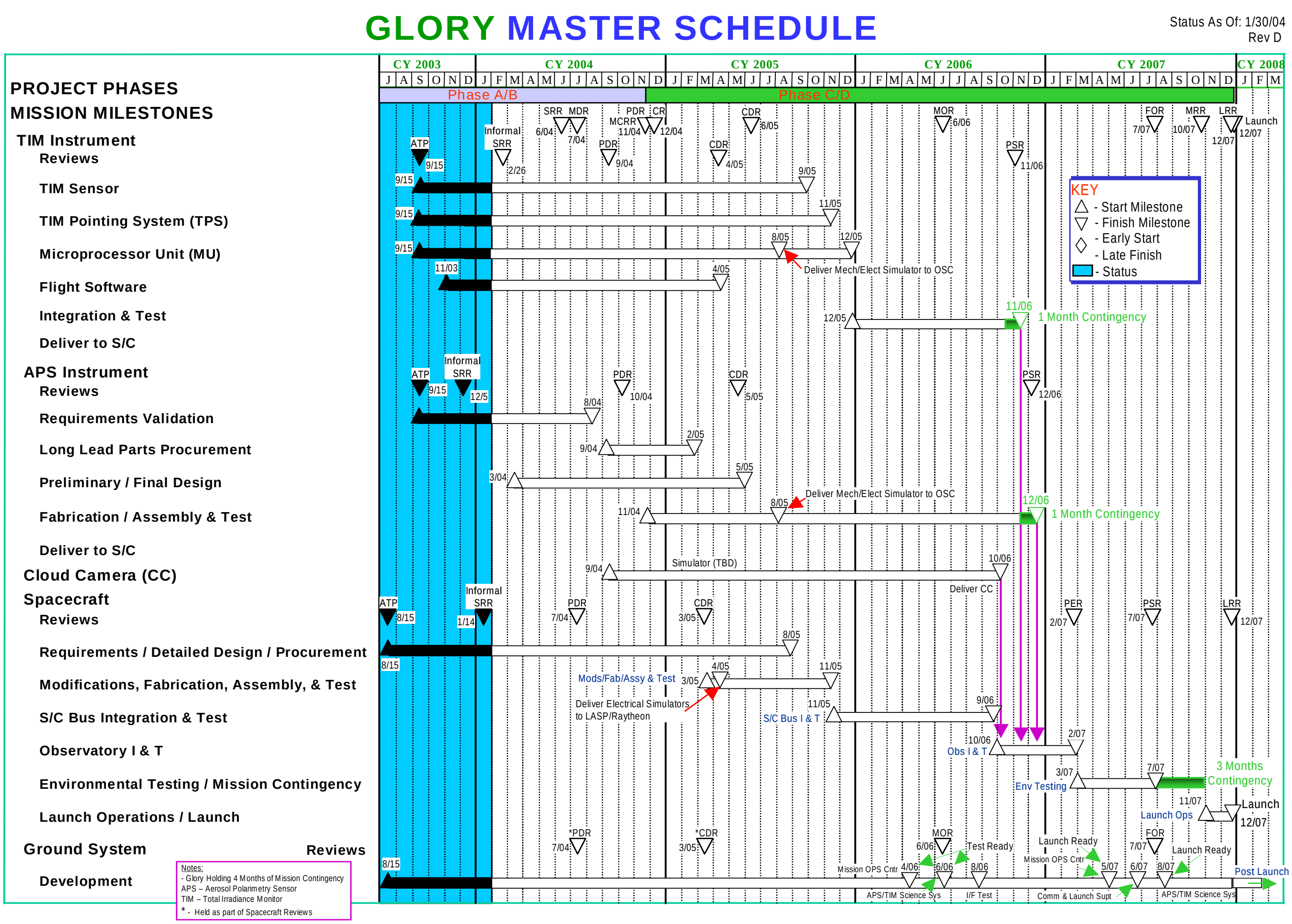

Figure 3. GLORY Master Schedule

2.0 Systems Engineering Management

The Systems Engineering Management section serves as an introduction to the project's approach to managing the technical effort and the controls used to accurately assess the technical status of the project.

2.1 Management Overview

Within NASA, the GLORY project office is responsible to the EOS Program Office. The GLORY project organization has ultimate responsibility for management of GLORY, including satisfaction of all cost, schedule, and technical performance requirements. The GLORY office is responsible for the overall technical and business planning, organization, direction, integration, control, and approval actions required to carry out the project.

The systems engineering manager reports directly to the program manager. He is responsible for implementing the Systems Engineering Management Plan described herein, and oversees the engineering team and the roles and responsibilities of team members. The engineering organization is responsible for the development of the design solutions that meet the cost, schedule, and technical performance requirements established by the project office.

2.2 Systems Engineering Team and Interactions

Systems engineering focuses on communications among the engineering teams and is firmly based on the foundations provided in NPG 7120.5A, NASA Program and Project Management Processes and Requirements, as evident through clear definition of system analysis, defined interfaces with project planning activities, and established project evaluation guidelines. This SEMP describes how GLORY executes the systems engineering activities while enabling effective integration across mission elements.

The GLORY systems engineering team consists of the mission SE manager, mission systems engineer, and contractor systems engineers; spacecraft SE and instrument SEs; and other supporting engineering team members. This section highlights their roles, responsibilities, and interactions.

The mission SE manager is the overall technical systems engineering manager and is responsible to the Government for the overall technical integrity of the program. The mission SE manager and the mission systems engineer work with the project scientist and systems engineering team to define mission architecture and top-level requirements. The systems engineering team ensures that the GLORY system meets the science objectives and level 1 requirements of the project. The SE manager and the mission systems engineer interfaces with the spacecraft SE, the science community, and the GLORY Instrument SE to ensure science objectives are accurately captured in the requirements.

Element SEs are responsible for the technical integrity of each element identified in Figure 1, with exception of the launch elements. NASA Kennedy Space Center (KSC) is responsible for the launch vehicle (LV) segment. This interface will be handled by the mission SE manager. The element SEs are responsible for element-specific systems engineering activities throughout the mission life cycle, including element and subsystem requirements development, verification, and validation; architecture integration; interface definition; and fabrication. Each element SE is responsible for the definition of performance requirements of the elements from higher-level requirements, and the verification of requirements at the element level. The spacecraft SE is responsible for the observatory-level requirements and the flow-down of S/C requirements to the instrument elements. Mission systems engineering is responsible for specifying the performance requirements imposed on the instrument by the science community as approved by the project.

The Primary Spacecraft SE (Orbital) is responsible for all technical aspects of the primary spacecraft element, including spacecraft hardware, software, and spacecraft I&T and observatory I&T. The primary spacecraft SE also coordinates with the instrument programs (APS and TIM) SE and the Cloud Camera (CC) to ensure that the S/C design requirements for the instruments are established and the instruments meet the S/C imposed design criteria through the ICD and GDRD.

The Instrument Project (APS and TIM) SEs are responsible for all technical aspects of the instrument subsystems, including instrument hardware and software, instrument ground support equipment, and instrument verification. The mission SE and the instrument (APS and TIM) SEs will coordinate as a team with the science community to ensure that the science objectives are captured in the instrument requirements. It is the responsibility of the mission SE to manage this interface and ensure that the requirements are accurate. The Cloud Camera is treated as a vendor item with no changes.

The (mission operations, TBD) SE is responsible for all technical aspects of the mission operations system element, including the MOC, space-to-ground data transport, and terrestrial data transport. The (mission operations, TBD) SE also coordinates operations preparations and maintenance.

The mission contractor (Orbital) is responsible for the mission requirements and the implementation of the ground operations segment.

2.3 Systems Engineering Process Overview

Three categories of activities are performed across the life cycle of the mission: Systems engineering development activities, systems engineering support activities, and engineering management and control activities.

Systems engineering development activities are those activities that are executed by the GLORY systems engineering team. The GLORY systems engineering team iterates these activities across all mission life cycle phases. The emphasis of the activities matures as the mission proceeds through the life cycle, while the systems engineering processes continue to be executed.

Systems engineering development activities include the following:

- Concept development.
- Requirements development.
- Architecture design.
- Bus refurbishment.
- New hardware/software development.
- Integration.
- Verification.
- Operations.

Systems engineering support activities are executed in every life cycle phase in support of the systems engineering activities, and include the following:

- Trade studies.
- Peer reviews.
- Design reviews.
- Reliability assessment.
- Mission analysis.

Engineering management activities are cross-cutting support processes used to track engineering activities across the entire life cycle, and include the following:

- Risk management support.
- Engineering configuration management and problem reporting.
- Project management support.

3.0 Systems Engineering Development Activities

The following sections provide additional detail on the focus of the GLORY systems engineering team during the mission life cycle.

3.1 Concept Development

The GLORY systems engineering team, including the GLORY mission SE with the observatory SE and other element SEs, is responsible for the development of the GLORY operations concept. The preliminary operations concept developed during the study phase will be evolved as further engineering and management decisions are made. The instrument contractors will make inputs into the operational concepts to meet the science and instrument requirements. The mission SE uses these inputs to continually modify and refine the Operations Concept and generate the baseline operations concept to be reviewed at the SRR.

3.2 Requirements Development

The mission SE is responsible for producing the Mission (level 2) requirements. The mission SE monitors progress and ensures that cross-functional impacts are examined and addressed within the team. These requirements are flowed down to each element through level 3 requirements. The level 3 requirements at the observatory level are flowed down to instrument-level requirements through ICDs and the GDRD generated at the observatory level and approved by NASA. The level 1 , 2, and 3 requirements will be reviewed at the SRR.

The observatory SE (contractor) is responsible for determining preliminary resource budgets for the observatory, including the instrument budgets (allocations). The mission SE is responsible for approval of these budgets. Preliminary resource budgets will be completed for review at the SRR.

The observatory SE (contractor) is also responsible for development of the instrument interface descriptions and the environmental design requirements for the instruments.

The mission SE is responsible for the performance requirements of the instruments as determined by the science requirements. The mission SE is responsible for coordinating with the project scientist and the science community and capturing these requirements in documentation. The mission SE will be responsible for the verification of the requirements in cooperation with the instrument and project scientist.

3.3 Design

3.3.1 Architectural Design

The architectural design has been developed in the study phase by the observatory contractor and will be the baseline design. The architecture will be evolved by the SE team and modified to meet new requirements and will be approved by the mission SE.

3.3.2 Design and Development

The spacecraft SE will be responsible for defining the environmental design requirements for the instruments, as well as the interface requirements. These will be documented through the GDRD and the ICD for each instruments. The mission SE will be responsible for reviewing all requirements in the GDRD and recommending approval disposition by NASA. NASA will be responsible for insuring the performance requirements are defined for the instrument and the validation of these requirements is accomplished. This review and approval will be accomplished with the support of discipline engineers from AETD.

3.4 Manufacturing and Refurbishment

The mission is structured around using an existing VCL bus and making the necessary modification to the bus to accommodate the GLORY scientific requirements and a separate Taurus 2110 launch vehicle with different environmental requirements from the previously proposed launch vehicle design of the Athena. The bus has been in storage and will be refurbished and necessary modifications identified to meet the Taurus requirements and the new science and instrument requirements. This will be proposed by the government and approved by NASA.

3.5 Integration

The bus will be checked and re-qualified for use with the GLORY mission. The bus will undergo a number of tests, and analysis will be performed to ensure that the bus is suitable for the GLORY mission. The necessary improvements will be proposed by the contractor. The mission SE manager will be responsible for the review and approval of the proposed qualification and modifications to the hardware and software. The contractor is responsible for defining these modifications. The contractor is responsible for defining the environments through test to be placed on the instruments. The contractor is responsible for providing the environmental requirements and interface requirements to the instrument providers. The contractor is responsible for integrating the instruments into the S/C and testing the integrated observatory. The mission SE manager is responsible for monitoring the work and insuring the technical integrity of the work. The FAM is responsible for ensuring that the quality requirements are met.

3.6 Verification

The mission SE and the spacecraft SE are responsible for developing a verification strategy that defines the methods that will be used to verify lower-level requirements to higher-level requirements, design to requirements, build to design, and perform operational validation. The verification plan is due at PDR.

3.7 Technical Decision Process Management

The technical decision process controls and monitors the documentation, review, and approval of design recommendations. The systems engineers are the chief reviewers of all recommended technical changes, and must approve all design changes prior to implementation. This section describes how proposed design changes are reflected in appropriate documentation, and reviewed and approved in a procedure consistent with the status (released or unreleased) of the document containing the design information (e.g., specification or drawing).

3.7.1 Technical Memos (TMs)

All technical design descriptions and all analyses, models, trade studies, and recommendations that support recommended design implementations and changes are documented in technical memo format. The TM requires approval from systems engineering before release. All TMs are maintained in the project library, and are updated as appropriate using a revision sheet contained in each memo to reflect changes in the design or add analytical detail. Although TMs supply supporting rationale and justification for the technical design or design changes, they do not in themselves authorize changes or necessarily reflect baseline information.

3.8 Requirement/Specification Management

3.8.1 Document Tree

Systems engineering maintains the GLORY project specification tree (see Figure 2), which delineates the flow of the program technical requirements and design specifications. Both Government and contractor requirements and specifications are included. The summary presented in this section is not intended to show all documentation, but rather to highlight the documentation hierarchy and requirements flow. This tree should include all program hardware and software, be consistent with project or team member deliverables, and present a logical path for the flow-down of all requirements from system to subsystem or assembly levels.

3.9 Configuration Management (CM)

Configuration management (CM) is an engineering function that is supported by all PMO and engineering organizations. The primary control maintained at the project will be requirements control. The level 2 requirements will be controlled by a control board composed of the PM, SE manager, and mission SE.

Contractor team members will maintain their own CM systems. NASA shall have full visibility into the contractor team member's CM system for informational and communication purposes. NASA will attend FRBs at the contractor team's plant on an ad hoc basis and monitor all changes.

NASA will maintain a CM system to manage NASA-controlled documents. This will be documented in a PM CM Plan.

3.9.1 Configuration Control

SE will participate in configuration control at the project level as defined by the PM.

3.10 Risk Management

Risk management is performed to identify the risk areas early in the program, develop plans to reduce this risk, and implement these plans. The Risk Management Plan for GLORY will be documented in TBD. The Risk Management Plan document will be used to maintain the specifics of the risk management effort and will be based on the NASA standard risk management process. Systems engineering will assist in defining the risks and assessing the impact of risk on system development.

3.11 Mission Assurance Requirements

Part of the systems engineering function is assuring that the final product performs as required. The mission assurance function is the role of the FAM supported by SEs. The systems engineering team will assist the FAM in the conduct of MA. The Mission Assurance Requirements (MAR) are defined in the S/C and Instrument MARs.

3.12 Review Plan

Technical reviews are divided into two major categories: Major formal project reviews, and engineering design peer reviews. Major formal project reviews are the key technical milestones of the program, conducted by the project and chaired by the quality organization (Code 300). They cover the major segments and elements of the project and culminate in a formal mission design review.

Project reviews and engineering design peer reviews are informal and focus on one subsystem or sub-element.

3.12.1 Project Reviews

The technical progress of the program must be assessed at key milestones to ascertain readiness to transition into the next program phase. A formal review schedule for the project is defined in the MAR. Clarification of the review purpose and role of systems engineering is defined herein. Systems engineering organizes a team composed of discipline engineers to review subsystem elements and ensure the viability of each subsystem. Systems engineering is responsible for reviewing the content of the review, as well as obtaining closure on any action items and corrective actions.

The following project reviews are held in accordance with the MAR and the GLORY Project Plan. A review team for the project will be organized, which includes all discipline engineers.

The major formal reviews chaired by the Government will have an external independent team from NASA to provide an independent technical evaluation of the project. SE will support this review team as required. These reviews are listed below chronologically. A summary definition will be included and more detailed requirements will be added as the program develops.

3.12.1.1 Systems Requirements Review – S/C, TIM, APS – Informal

A review will be held to provide an initial assessment of the requirements and the ability of the VCL bus to meet the requirements.

The preliminary SRR focuses on the mission (level 2) requirements. The objective of the SRR is to confirm that the mission-level requirements are compatible with the current mission objectives. The SRR ensures that the mission objectives and level 2 requirements have been successfully flowed down to segment and element level 3 requirements and that the mission concept is compatible.

3.12.1.2 Mission System Requirements Review – Formal

The Mission SRR will be performed after all SRRs have concluded at the element level, and it will be the final approval of the level 2 and level 3 requirements for the project.

The following documents are required for review and approval at the SRR:

- Mission Operations Concept Document.
- S/C and Instrument Design Concept.
- Observatory Concept.
- S/C Bus History and Refurbishment Status.
- SMRD.
- GDRD.
- Functional Element Architecture Diagrams.
- Preliminary Element Interface Descriptions.
- Selected Trade Study Results.
- Verification Strategy (with emphasis on Bus Refurbishment).
- Major Open Issues.

3.12.1.3 Baseline Review – Spacecraft – Informal

This review will be held at the end of the VCL bus integration testing phase and will be a review to establish the status of all subsystems and their prior verification. An assessment of the modifications necessary to meet the GLORY mission will be conducted.

3.12.1.4 System Requirements Review (SRR)

The SRR is a technical review of the mission requirements, as well as requirements at the system level, to demonstrate that the requirements at the system level meet the mission objectives, that the mission-level requirements have been flowed down to the system specifications, and all elements and systems are sufficient to meet project objectives.

3.12.1.5 Preliminary Design Review – S/C, TIM, APS

Preliminary design reviews (PDRs) are comprehensive, technical reviews of the preliminary design showing that it meets all system requirements with acceptable risk, is adequately defined, and can be verified. All elements are covered in this series of reviews, which cover assembly or subsystems, elements, and segment PDRs, which will culminate in a mission design review and an approval for detail design.

3.12.1.6 Mission Preliminary Design Review – Formal

PDRs are held to demonstrate that the preliminary design meets all system requirements with acceptable risk. Element specific PDRs are held prior to the overall mission PDR covering all the elements from a mission perspective. Following completion of the SRR, the mission SE and the element SEs determine which elements require a PDR.

Each of the element SEs is responsible for coordinating the element PDR. The objective of the PDR is to demonstrate that the preliminary design is sufficient to proceed to detailed design. The Element SE demonstrates that the appropriate design option has been selected by presenting key trade study analyses and results. The PDR verifies that all mission (level 2) requirements have been successfully flowed down to the element (level 3) and subsystem (level 4) requirements and that interface requirements are sufficiently defined. The PDR also demonstrates that the verification methods have been appropriately defined and that all risks have been identified and mitigated, as necessary.

The following documents are required for review and approval at the PDR:

- Element (Level 3) and Subsystem (Level 4) Requirements Documents.
- ICDs.
- Baseline Mission Architecture.
- Verification Requirements Matrix.
- Baseline Resource Budgets.
- Cost Estimates.
- Reliability Program Plan.

Each PDR consists of a formal presentation of the materials listed above. Following completion of the Mission PDR, the project proceeds to confirmation review (MCR) to gain approval to proceed to the implementation phase. The MCR is a Center-level review and is discussed in the GPM Formulation Plan.

3.12.1.7 Mission Confirmation Review – Formal

A mission confirmation review will be conducted in conjunction with the PDR to allow management to assess the readiness of the mission to continue. The mission confirmation review is the gate to phase B implementation.

3.12.1.8 Critical Design Review – Formal

A CDR is a comprehensive, technical review of the complete system design in full detail, showing that all problems have been resolved, and that the design is sufficiently mature to proceed to manufacturing. All elements are covered in this series of reviews, which cover assembly or subsystems, element, and segment CDRs and will culminate in a mission design review.

3.12.1.9 Pre-Environmental Review – Formal

This is a formal technical review of the system that establishes functional compliance with all technical requirements prior to environmental testing. A pre-environmental review will be performed for each element.

3.12.1.10 Flight Operations Review – Formal

This is a formal review to determine the state of readiness of the ground segment to support the system operations functions.

3.12.1.11 Pre-Ship Review – Formal

Pre-ship review is a technical and programmatic review prior to shipment of the space segment to the launch site to demonstrate the system has verified all requirements. The technical review will concentrate on past system performance during functional and environmental testing. The programmatic review will emphasize pre-flight activities planned for the launch site and other support areas.

3.12.1.12 Flight Readiness Review – Formal

This formal review determines the overall readiness of the system for launch.

3.12.1.13 Operational Readiness Review – Formal

This formal review determines that the system is ready to transition into an operational mode.

3.12.1.14 Engineering Design and Peer Review – Informal

These reviews are held as required for the engineering activities and subcontractor/vendor design and development activities. They will be held for each element prior to the major element PDR and CDR. These reviews will be held of each major subsystem as well as system. These reviews will be informal and will consist of the subsystem engineers assigned to each subsystem and systems engineering.

3.12.1.15 Status Review/Audit – Informal

Weekly and daily program and status reviews are held to assess progress and current status, and identify outstanding issues that require resolution.

3.13 Technical Meetings

Technical meetings are different from reviews in that all participants are involved in the project, whereas reviews are presentations to persons outside of the project. Technical meetings are divided into three major categories: working groups, boards, and technical exchange meetings. Technical working groups are dedicated towards specific aspects of the program where significant and frequent contact among various contractors and Government teams is required in order to accomplish a certain aspect of the project. Boards are composed of specialized individuals in a particular discipline, formed to oversee and monitor that developments or changes in that area. Technical exchange meetings are scheduled on an ad hoc basis, depending on the pace of the program, to aid in general communication between team members.

3.13.1 Working Groups

Working groups provide a structured technical exchange on a common set of topics that require formalized scheduling and conduct to arrive at technical agreement on requirements, interfaces, and performance. Each working group has a particular area of responsibility and topics. Systems engineering dedicates an individual to each working group to act on behalf the systems engineer/manager and act as a point of contact for other team members. Minutes from the meetings shall be distributed, identify action item status, and be used by the systems engineer/manager to track progress. Potential working groups are Space/Ground Interface, Launch Operations Interface, Science, and ICD.

3.13.2 Configuration Control Boards

A configuration control board will be maintained for control of the SMRD at the mission level, which will include the PM, the SM, and the mission SE. Each contractor will maintain a configuration control board according to their contractor procedures with NASA attendance and notification of meetings.

3.13.3 Technical Interchange Meetings

Additional technical discussions will be required from time to time, and the technical interchange meeting (TIM) provides a forum for meeting these needs. Systems engineering schedules a TIM based on the needs of the program and at the request of any team member for a particular set of topics. Systems engineering conducts the meeting using whatever support from across the program may be required.

3.13.4 Monthly Meetings

The systems engineering team shall support monthly meetings to review documentation orally and graphically from the S/C, APS, and TIM contractor's monthly reports. These meetings will provide GSFC management with a means to monitor and direct the contractor effort through status provided by this monthly report.

3.13.5 Quarterly Meetings

The systems engineer shall support quarterly meetings with the S/C, APS, and TIM contractors to review documentation orally and graphically provided through the contractor's quarterly reports.

3.13.6 Weekly Telecons and Telecon Minutes

The mission systems engineering team shall support weekly meetings with the S/C, APS, and TIM contractors to allow the GSFC team, through weekly information, to evaluate the contractor's status at the close of business for the preceding week's activity. The weekly telecon is intended to be timely but informal and should summarize the past week's status and planned activities.

4.0 Systems Tasks and Analyses

This section provides an overview of the analyses and other tasks that support the systems engineering management functions previously described. Systems engineering is responsible for the end-to-end definition, technical analysis, planning, monitoring, and organizing required to ensure that all segments meet the requirements of the project. This effort includes deriving requirements for element, subsystem, and assembly design; trades and analyses to define the system architecture and interfaces; allocating system resources; evaluating reliability and possible failures; establishing compliance with system requirements; and preparing for operations. Additional trades and analyses covering multiple subsystems and/or specialty areas are performed as required to assess system performance and evaluate design alternatives. The major system analysis tasks are described below.

4.1 Requirements Definition and Control

This portion of the SEMP describes the technical approach for all system requirements. The goal is to create a comprehensive and traceable set of technical requirements specifying all aspects of the mission design. This goal is achieved by:

- Allocating top-level requirements to progressively lower levels.
- Flowing subsystem/assembly capabilities up to higher level requirements for evaluation.
- Maintaining traceability of requirements up and down the requirements/specification tree.
- Incorporating verification methods and checking with each requirement.

This approach provides a logical top-down flow of program technical requirements while allowing for existing technologies to be used, as well as bottom-up verification. The goal is to control risk, address the operational aspects, and allow for system growth. To fulfill these goals, systems engineering will check and review all lower-level specifications.

4.1.1 Mission Requirements Analysis

Mission-level requirements are documented in a Level 2 Requirements document SMRD. These requirements have been flowed down from GLORY studies and agreements with NASA Headquarters and will be documented in the GLORY Level 1 Requirements document.

4.1.2 Requirements Allocation

Mission requirements will be allocated to each mission segment based on the mission requirements analysis. Team member requirements are documented in the SMRD, flowed down to each segment and element, and documented as indicated in the document tree.

4.1.2.1 Design Requirements

Design requirements for each segment will be derived from mission requirements as necessary. NASA-level requirements in the SMRD and general NASA design criteria will be supplemented by contractor best practices to produce the necessary design requirements.

4.1.2.2 Operations Requirements

Operations requirements will be determined at a level as needed to determine the design and specify the operational concepts. Operations concepts will be developed and documented as necessary to perform phase B design.

4.1.3 System/Subsystem Specifications

System specifications for each segment will provide a description of how the system or subsystem meets the requirements, as well as provide an overview of the design for information purposes. This should include requirements flow-down; system configurations or architectures; functional capabilities; block diagrams; performance predictions; and weight, power, and reliability allocations.

Subsystem specifications (level 3) are created as part of the requirements flow-down process, and as such are iterated along with the higher-level requirements and specifications. Each subsystem specification is created to address a higher level of requirements, and as such contains the information for creating the requirements for the next lower level subsystem/assembly/unit. Where a limited selection of assemblies are available to fulfill a requirement, the assembly most closely matched will be selected. Any changes to higher-level requirements resulting from this will be evaluated and documented.

4.1.4 Traceability

Requirements traceability is crucial in determining that all program requirements are addressed in the design. Requirements will be traced from the SMRD Level 2 Requirements document down through the levels of performance specifications and verification plans and specifications.

4.1.4.1 Requirements Traceability Analysis

A requirements/specification tree will be created to trace all requirements, specifications, and ICDs back to the GLORY SMRD Level 2 Requirements document. The general organization is described in Section 3.13. Requirements traceability analysis links requirements and tracks their flow up and down the specification tree.

4.1.4.2 Requirements Traceability Database

A requirements traceability database is maintained to trace requirements between the following specifications:

- SMRD.
- GDRD.
- Mission Assurance Requirements (MAR).
- Segment ICDs.
- Element Performance Specification.
- S/C/Instrument interface Specification.

Each requirements document or specification is loaded into the DOORS system. Each requirement is tracked by its unique ID and references the document in which it appears. Once the database has been loaded with each document, links are established between individual requirements in the various documents. These links allow the database user to determine how each requirement tracks between documents. Top-level requirements will be traced to the element and subsystem level requirements using this database. Derived requirements will be traced to their source documentation. In addition to the above documents, subsystem lead engineers are responsible for tracing their assembly specification requirements to higher-level documents, and justifying any derived requirements.

4.2 System Definition

The synthesis of the system design requires that systems engineering define a hardware and software architecture that has simple testable interfaces, supports maximum parallel development effort, and provides early recognition of problems through an integrated test program. The following tasks are performed to help define the overall system architecture and operational concept.

4.2.1 Systems Analysis/Trades

System-level trades are conducted with the goal of optimizing the system architecture. The trades assess proposed changes to the system/subsystem configuration or architecture, and to the requirements. Results will be used to update and detail system performance and design requirements allocations as necessary.

Each analysis will be documented in an engineering memo (EM), which will identify the subject, tradeoff considerations, and results. This EM will provide the rationale for the requirement, and will be used as a reference for verification. Trade recommendations will address technical, cost, and schedule impacts to the program.

4.2.2 Fault Detection, Isolation, and Recovery (FDIR) Reliability

A preliminary estimate of the reliability of the GLORY system has been made by the S/C contractor. This estimate will be refined as the project progresses. Tradeoffs will be performed on modifications to the systems to meet the goals or improve on the system. Selected redundancy or product improvements will be considered to improve on the system reliability. Calculations will be performed by the S/C contractor and instrument contractors, and mission systems engineering will review proposed improvements and make recommendations to the project for approval. Tradeoffs will be proposed relative to reliability, cost, and other impacts to the project for approval.

Failure modes and effects analyses (FMEAs) and critical item lists (CILs) will be performed by the contractors and reviewed by mission systems engineering. These studies will be the basis of the development of an FDIR for the mission.

The systems engineering team will define the fault detection, isolation, and recovery strategy and requirements. Heritage designs will be referenced. These will become the bases for development and implementation of element and subsystem FDIR. The FDIR system concept will be documented and controlled.

A reliability requirement has been established by the project and defined in the SMRD and will be used as a goal.

4.3 Interface Definition and Control

Systems engineering is responsible for defining and controlling all external and internal interfaces. Primary space segment external interfaces include those with the launch vehicle and ground segment, while internal interfaces can be between any number of components, such as bus to instrument or bus to recorder. Primary ground segment external interfaces include those with the space segment and data product users, while internal interfaces can be between components such as the ground station and the data processing center. The creation of interface definition and control documents shall be the product of this effort, and shall be used for control and design and integration efforts.

4.3.1 Space Segment to Launch Vehicle

Mission systems engineering will be responsible for coordinating with NASA KSC and the launch vehicle provider to define all launch vehicle interface requirements, monitor the physical and electrical checkout of all interfaces, and ensure a thorough launch site integration and test plan. Critical systems engineering tasks are working with the launch contractor systems engineering team and subsystems leads to create the ICD, and then tracking and maintaining the ICD. Ensuring the correct flow of the ICD interface, safety, and verification requirements to the appropriate subsystem specifications is also critical. Key inputs to this process come from the launch vehicle interface specification, Government safety documents, and the launch vehicle users manual. The ICD also defines the verification requirements for the observatory/launch vehicle interface.

4.3.2 Space Segment to Ground Segment

Space-to-ground interfaces must be adequately specified in appropriate ICDs. These interfaces will be the responsibility of the ground system manager. Systems engineering will work with the GSM to ensure that all interface requirements are defined and integrated in the design of the elements.

4.3.3 Internal Interfaces

Element systems engineering defines and controls the interfaces between each subsystem (including bus, payload, and ground terminal subsystems) to ensure compatible designs. Systems Engineering assures that all users of a particular subsystem or system resource meet interface requirements and provide proper protection to prevent a single failure from causing satellite failure. Subsystem and payload interfaces must be clearly defined by joint agreement with systems engineering. All interface requirements are defined early in the program in specifications. Changes are brought to the attention of all users by distribution of updated specifications. Systems engineering is responsible for working interface conflicts to arrive an equitable solution for both sides.

4.4 Mission Analyses and Resource Allocation

The resource analyses activities allocate and track critical segment resources to elements, subsystems, and assemblies. These resources include mass, power, propellant, pointing error contributions, commands and telemetry, communications bandwidth, processor use, and other performance parameters.

Mission systems engineering will be responsible for coordinating the analyses of the spacecraft/observatory/instrument requirements that fully establish, define, maintain, and control resource allocations. The SE will coordinate with the contractor and ensure that the requirements and guidelines for the resource budgets are defined. The SE will review all budgets established by the contractor and forward reports to the project manager. Resource budgets shall be established by the contractor for mass and mass properties, angular momentum, disturbance torque, power, radio frequency transmission channels, alignment, pointing control, pointing knowledge, pointing stability, on-board processor resources, and propellant capacities. Margins for each resource shall be established, and resource tracking against the budget shall be maintained and reported monthly.

4.4.1 Mass and Power

Launch vehicle lift analyses and observatory power profile analyses are performed by systems engineering in order to allocate mass and power to the space segment elements and subsystems. These analyses make use of the space segment equipment database and assess how changes in assembly mass and power estimates impact lift and power margins. Power margins are assessed for all mission phases and system modes.

4.4.2 Propellant

Mission systems engineering works with the S/C system engineers to support the development and maintenance of the propellant budget. Systems engineering maintains propellant budgets to reflect changes in satellite mass properties, thruster performance, and/or mission requirements.

4.4.3 Pointing (Alignment)

The allowable contribution of the spacecraft bus to instrument pointing error, any antenna pointing errors (gimbal accuracy, performance changes over time, and attitude sensor error), and solar array pointing error is allocated by systems engineering. Systems engineering also works with mechanical and thermal subsystem engineers to develop and maintain the space segment alignment plan, to assess the effect of attitude disturbances (thermal transients, thrusters, mechanisms, and solar/magnetic torques) on the space segment system, and to develop strategies to minimize their impacts. The instrument contribution to instrument pointing error and attitude disturbances is assessed cooperatively between the spacecraft bus and instrument element leads.

4.4.4 Command and Telemetry Allocations

Systems engineering analyzes the space segment requirements for commands and telemetry in order to allocate commands and telemetry to elements and subsystems. The allocations are maintained in the command and telemetry lists.

4.4.5 Communications

Systems engineering maintains link margin calculations for both command and telemetry, with margin allocated based on project maturity. As the design matures, margins are replaced with measured/actual values, and fidelity of analysis is increased to reflect details of the space and ground segment respective properties.

4.4.6 Computer Processing

Key tracking parameters of the space segment processor(s) include memory, throughput, and bus bandwidth utilization. Processor resource management involves maintenance margins on memory and processor and communication throughput.

4.4.7 Data Management

Data Management effects both the space and ground segments, and deals with data flow and storage. In the space segment, this effects the selection of memory sizing and communications, both internal and space to ground. In the ground segment, this affects the choice of ground stations, data lines, and storage devices.

4.4.8 Operational Performance

Comparisons of predicted overall system performance with specified performance and design requirements is an integral part of systems engineering. These comparisons provide systems engineers with visibility into performance trends and system capabilities. This visibility enables the balancing of performance and design allocations within the system, and ensures system compatibility with project objectives.

4.4.9 Critical Technical Performance Measures (TPM) (TBD)

Critical TPMs are selected by the mission systems engineering team and reviewed by the contractor team. Parameter selection is based on the measures of system effectiveness, impact to system performance, and appropriate technical attributes of the program. Definition of the input data types, formats, and schedules required to support these analyses will be established by agreement with the team members as appropriate. After agreement within the systems engineering team on the TPM and the frequency of reporting and approval by the project, mission systems engineering maintains constant monitoring of the TPM status.

Systems engineering defines alternatives and mitigation plans for areas falling short of full performance, and assesses impacts of potential risks. The project office has full visibility into this process through the technical metrics used to assess progress. System impact of any change is determined, trends are generated and corrective action, where required, is implemented in a mitigation plan.

A preliminary list of performance metrics is included herein and will be updated as appropriate.

Monthly TIM technical performance metrics are as follows:

- Mass margin.
- Volume.
- Power demand, margin.
- Data rate (orbit average peak).
- Software lines of code (SLOC).
- Processor loading/memory margins.
- Document completion vs. assigned (including mechanical drawings).

Other items that will be tracked on an as-needed basis are as follows:

- Volume margin.
- Cg and inertias.
- Natural frequency (instrument).
- Reliability.
- Pointing control/error.
- Performance/interface requirements verified (later in the program).

Monthly APS instrument metrics are as follows:

- Mass.
- Volume, Cg.
- Power demand.
- Data rate (peak, average).
- SNR (radiometric precision).
- Radiometric accuracy.
- Polarimetric accuracy.
- Polarimetric precision.
- EOL SWIR temperature.
- Reliability.
- Document completion (vs. assigned, including mechanical drawings).
- Problem failure reports logged/closed.
- Performance/interface requirements verified (later in the SE cycle).
- Action item processing (open vs. total).

Monthly spacecraft bus metrics are as follows:

- Mass margin (summary including bus, instruments/instrument accommodation, propellant, and LV lift margin).
- Power margin (peak and orbital average, and summary of bus and instruments vs. EOL availability; +5 V margin is an issue that also needs to be tracked).
- Software lines of code.
- Processor loading/memory margin (CDH, ADACS, PIP, ROM/RAM).

- Downlink data volume margin (in terms of required vs. available D/L volume, SSR margin).
- Document status (completed vs. assigned, including mechanical drawings).
- Problem failure reports logged/closed.

Other items that will be tracked on an as-needed basis are as follows:

- Commands/day (bus and instruments).
- Volume margin (vs. fairing).
- Cg and inertias.
- Natural frequency (bus and instrument).
- RF margins.
- Propellant margin (% remaining for science).
- Reliability.
- Pointing control and knowledge budget.
- Performance/interface requirements verified (later in the program).

4.4.10 Orbital Debris Analysis

An orbital debris analysis will be performed by the S/C contractor and reviewed by mission systems engineering. A report will be generated to fulfill the requirements of NASA Safety Standard 1740.14 and will be reviewed by GSFC experts.

4.5 Verification

The verification section outlines the verification process, which assures that the program requirements have been met in the hardware and software products. The documents that define the verification process are described.

4.5.1 Requirement Verification Overview

Systems engineering is responsible for ensuring that the verification program addresses all technical requirements stated in all specifications and interface control documents. The verification process must be in compliance with the Mission Assurance Requirements (MAR) document, and with the verification requirements of the General Environmental Verification Specification (GEVS-SE). Systems engineering utilizes the fields for verification method, compliance, and verification in the requirements traceability database to ensure compliance with program requirements and design specifications. All element design specifications shall include a verification matrix.

4.5.2 Verification Methodology

Systems engineering ensures that the design specifications contain the appropriate verification methods. Verification is by inspection, analysis, demonstration, test, or some combination of these methods.

4.5.3 Verification Levels

Systems engineering ensures that verification of the design requirements is being performed at the appropriate level. The verification will be performed at one or more of the following verification levels: Assembly level, subsystem level, element level, or space segment level. Systems engineering will ensure that the required level of testing is established at each level consistent with the requirements and the mission assurance requirements.

4.5.4 Verification Overview

The verification and testing processes at each level are specified in their respective design requirements, environmental requirements, verification plans, and the test plan documents. Low-level documents (subsystem or assembly levels) are the responsibility of the lead subsystem engineers. These documents aid in ensuring that the verification program adequately validates the design and complies with the requirements of the requirements document and the performance assurance requirements, and design specifications will be used to ensure that all pertinent requirements are reflected in the verification plans and specifications.

4.5.4.1 Verification Environment Specification

Mission systems engineering will work with the S/C contractor, LV provider, and NASA KSC to develop the verification environment specification. This document defines the environmental test tolerance limits at each level of assembly. It stipulates the parameters associated with each of the environmental tests and analyses required by the verification plans. These parameters include test conditions (i.e., temperature, humidity and cleanliness), environmental levels, durations, functional operations, safety and contamination precautions, instrumentation, and procedure/report requirements. These parameters apply to the following tests described in the specification:

- Shock test requirements.
- Radiation levels.
- Acoustic excitation levels.
- Qualification and acceptance vibration test levels.
- Electromagnetic test levels.
- Thermal and thermal vacuum test profiles to include hot and cold soak durations, transitions, etc.

Performance or design requirements that require verification, along with the proposed method of verification, are stipulated in the appropriate performance specifications. These environments will be captured in the Orbital GDRD, the S/C-to-instrument ICDs, and the MAR.

4.5.4.2 Verification Plans and Procedures

The verification and test plans identify the overall approach to accomplishing verification, establish requirements for each level of verification, establish verification methods, describe the verification process, and dictate what shall be included in the verification test procedures. The plans are necessary for all levels of assembly, including assembly, subsystem, element, and segment, although one high-level plan can be used to cover several lower level verification tests. They define the tests, analyses, inspections, and/or demonstrations that collectively verify that the hardware, software, and support equipment meet design and performance requirements, and are suitable for flight/operations or flight/operations support. Included in any plan shall be the overall approach of the verification program, descriptions of the configuration of the test item, test objectives, facilities, safety considerations, organization responsibilities, and descriptions of what will be contained in the each test procedure document.

4.5.4.3 Verification Test Plan (VTP)

Systems engineering, along with the contractors and the I&T organizations, is responsible for the generation of the VTP. The purpose of the VTP is to ensure that the segment is completely functionally tested and ready for environmental tests. It is also used as part of the validation process during environmental tests. This plan combines all test plans associated with the segment, from assemblies to integrated segment level. It identifies test flows, test descriptions, test setups, test parameters, and test methods, and is based on the tests identified in the lower-level verification plans.

4.6 Integration and Test

4.6.1 Pre-Test Activities

Systems engineering bears the primary responsibility for ensuring that the test requirements flow down to the implementing areas and that these requirements are fulfilled. Specific responsibilities include checking for and reviewing the performance verification matrices in each specification, as well as verifying that it is accounted for in the system-level specification. Systems engineering must also generate test requirements for each test that will be conducted, including external and major internal interfaces. The test requirements should identify the required test data, the conditions under which those data are to be gathered, the pass/fail criteria, and the required accuracy of the test.

Systems engineering prepares or reviews all test plans and procedures. For test plans, this responsibility includes verifying that the planned tests will meet project requirements; providing the necessary data for design/performance verification; conducting the planned test under the proper environmental conditions; and ensuring that all provisions of the project test plan are fully implemented during unit, subsystem, and system test. For procedures, systems engineering works with the test and subsystem engineers to ensure that the procedure is consistent with the system test requirements and that all critical or hazardous commands are flagged and protected with the proper safeguards. In addition, they must ensure that pass/fail criteria are specified for all data to be taken, that sufficient data is being taken to satisfy the requirements for performance verification, and that all command sequences are checked and correct.

4.6.2 Testing Activities

During testing, systems engineering observes all tests in progress to allow for near-real-time evaluation of test data so that minor anomalies can be addressed immediately. Following the conclusion of a test, systems engineering checks that all data points are either within the expected range or noted as a test anomaly. They also compare the data against previous test results to see if unfavorable trends exist, and verify that there is sufficient data for requirements verification. In preparation for sign-off of the test procedure, systems engineering makes sure that all procedure paragraphs are run unless deviations have been agreed to.

4.6.3 Post-Test Activities

Systems engineering must determine the source of each anomaly or failure. The evaluation must distinguish between problems with flight hardware, system test equipment, test software, operator error, or procedure error. The test director logs any test anomaly, and when appropriate, generates a special test request. Systems engineering is responsible for acting on these anomaly reports to define correction procedures and ensure satisfactory resolution. If the problem proves to be test equipment or procedure related, the anomaly is categorized as non-flight and corrective action is taken by test engineering. If the problem is with the flight equipment, systems engineering responds in one of three ways:

1. If the anomaly is due to the as-built configuration being different than the as-designed, but there is no adverse performance, a vehicle discrepancy is recorded in the log.
2. If the result is not due to any failure or discrepancy but is simply the result of inaccurate prediction of the expected test results, the correct performance signature is recorded in the signature and constraints log.
3. If the anomaly results from a failure, a failure report is written and the unit removed for repair. The appropriate lead subsystem engineer then manages the failure report close-out process, ensuring proper action to correct the failure and revalidate performance.

Test failures are documented by failure reports (PFRs). Closure of the PFR indicates that an explanation of the cause of the failure has been discovered and that a corrective action has been determined. Systems engineering is involved in all phases of this process, helping performance assurance with the analysis and documentation of the problem, participating in failure review board meetings, and approving the closure of all PFRs. Specific systems engineering responsibilities include the following:

- Tracking each PFR until a cause and corrective action can be determined and reviewing open PFRs periodically for possible association with new anomalies or failures.
- Reviewing corrective action plans including approval or repeat testing, considering expected benefit versus schedule impact.
- When an PFR causes a unit to be reworked, reviewing and approving the unit re-acceptance test plan; defining retest required at the system level; and defining any required process, material, or facility changes.
- Examining need for retrofit of already assembled, tested, or delivered hardware.
- Documenting and tracking the PFR will be maintained by the contractors; however, the mission systems engineer will monitor and review as necessary. The FRB will be maintained at the contractors; however, the mission systems engineering manager will monitor the boards and be an ad hoc member. The MSE will attend critical FRBs as defined to be all class 1 changes. (Put in definition.)

4.7 Flight Operations and Ground Systems

The flight operations and ground systems function is to plan all phase E activities. Systems engineering provides ground segment requirements, defines the test and verification program, and performs system-level analyses to predict performance and verify that the design modifications meet the system requirements. Systems engineering also provides the early operations planning and technical support to operations from launch to the completion of all on-orbit and ground tests.

4.7.1 Planning

Systems engineering prepares key operations planning documents for the operations concept and training, and flight support, maintenance, repairs, and spares. Planning for the operations concept early in the program ensures system capabilities, constraints, and mission requirements are appropriately blended in the operations plans, which guide the creation of the operations procedures. A plan for supporting the system checkout phase is necessary for an orderly transition to full operations. Long-term planning for the ground segment equipment requires a plan for handling maintenance, repairs, and spares (i.e., on site or procure as needed).

4.7.2 Procedures

All observatory operations are run according to procedures developed in accordance with the operations plan and verified in advance. Operations procedures identify in chronological order all required commands and identify expected observatory telemetry responses. Systems engineering supports the subsystem and test engineers in developing the procedures based on command sequences that have been verified from subsystem tests, and includes these procedures in the operating manual. Operations procedures should also identify all observatory constraints associated with each command procedure. On-orbit checkout and testing should be comprehensive enough to verify proper functioning of all primary and redundant flight and ground equipment.

4.7.3 Training

Systems engineering supports operations in the conduct of classroom and console training of all ground personnel in the operations of the system. Training should include all operations phases, as well as transitions between phases. Collocating development engineers with operations personnel is one method of transferring knowledge of the space segment operations in an informal manner to the operations team.

4.7.4 Verification

Systems engineering defines the verification program in the ground performance and verification plan. The plan identifies the key telecommunications performance requirements for the ground segment and the specific verification tests to be performed. The plan defines the acceptance test requirements as well as the on-orbit performance verification tests.

4.7.5 Launch Operations

Launch operations begin with shipment of the observatory to the launch site; continue through integration, final testing, fueling, and encapsulation; and end with launch. Final integration of the system and installation on the launch vehicle represent critical events that must be performed properly according to written and rehearsed procedures. Systems engineering is present during all testing and integration events and reviews all test data since launch site testing is the final-chance demonstration of proper system performance.

4.7.6 Launch Site Integration Planning

Systems engineering writes the launch site integration plan, which is negotiated with NASA, the launch vehicle contractor, and the NASA launch vehicle procurement center. This plan describes the services provided by the launch vehicle contractor at the launch site, guides the creation of all launch site procedures involving the observatory, and meets the observatory launch processing requirements. Systems engineering also generates the launch site test plans to perform the final space segment checkout, as well as verification of any remaining observatory requirements as needed.

4.7.7 Post-Launch Mission Operations

Systems engineering is responsible for the development of the launch and early orbit mission plan that describes the orbital plan from launch to stable operations in orbit following deployments and acquisition of stable attitude control. They are responsible for the planning of all orbital activities and all interfaces with team members. Systems engineering supports all preparation for nominal operations through planning, compatibility demonstrations, interface tests, rehearsals, and the post-launch activities.

Following completion of the initial mission operations and the handover normal operations, systems engineering produces a test report that documents the results of the system performance evaluation. The report contains a summary of all significant data including as-run procedures, an event time line, a data summary with comparison to pre-flight results, anomaly descriptions and resolutions, and recommendations for future changes.

5.0 Systems Technical Coordination

The objective of technical coordination is to bring all of the technical groups on the program together in a unified mission design effort. Systems engineering is responsible for the coordination of the technical aspects of each segment development, and for the overall segment system concept and architecture. This involves coordinating between the subsystem or technical leads, as well as with all other systems engineers or engineering managers in each participating organization.

In the technical integration effort, systems engineering also ensures compatibility of each element or subsystem with all external interfaces that support it, such as integration and test equipment. Systems engineers also ensure compatibility between the mission segments, such as during flight simulations or ground operations training.

5.1 Engineering and Analyses

Systems engineering provides the end-to-end project support to ensure proper design development, assess risk of the resulting concept, and predict the performance of the system. They work with the engineering disciplines to verify that the reliability, quality, safety, and logistics aspects of the program are fully integrated into the design, as well as analyze for environmental and for verification test conditions. They provide support during all phases of the verification test program in order to meet the requirements in a cost-effective and timely manner. Finally, they work with the ground segment and operations engineers to define the operations concept, user interface, and on-orbit checkout requirements.

5.1.1 Subsystem Discipline Engineers

Discipline engineers are matrixed to the subsystems engineers from their discipline or skill groups. In this way, they continue to interact with engineers within their technical disciplines while supporting the project, and are able to coordinate strategies, tools, and best practices. These engineers perform the subsystem design and analysis work and support engineering trades and analyses. Their responsibilities include subsystem architectures and analyses, assembly specifications and drawings, generating assembly test plans and procedures, and following the subsystem through integration and test. These disciplines include the following sections (5.1.1.1 to 5.1.1.10).

5.1.1.1 Mechanical

Mechanical engineering conducts detailed structural analysis of the observatory on orbit and during launch. The analysis is performed using structural models created to match the design, which are also provided to the launch vehicle contractor for coupled loads analyses. The models are used to evaluate design changes for strengthening, stiffening, and/or weight reduction where needed, and are updated to match test data once it becomes available.

Tracking the mass properties model of the observatory throughout the development process is another critical role of mechanical engineering. Systems engineering is involved in coordinated mass allocations with all other subsystems from program start.

5.1.1.2 Thermal

Thermal analysis begins during the early design phase to establish the interface requirements and specific design requirements. The thermal analysis supports definition of hardware finish and mounting interfaces, predicts temperature excursions for typical scenarios, supports performance analyses with worst-case operating conditions, provides predictions for thermal vacuum tests, and predicts on-orbit thermal conditions for operations.

5.1.1.3 Electrical Power

This analysis determines the power required to operate the observatory, as well as the size of the electrical power subsystem. This analysis also establishes the expected values for power measurement tests at the subsystem level and determines performance margins through worst-case circuit analysis. The analysis is updated as the design matures to accurately reflect power usage and to maintain margins.

5.1.1.4 Command and Data Handling(C&DH)

The C&DH system

5.1.1.5 RF

RF engineering performs analysis on the communications subsystems to establish RF link budget performance predictions, verify correct requirements allocation, predict spurious signal impact on performance, ensure electromagnetic compatibility, and establish minimum performance margins through worst-case circuit analysis.

5.1.1.6 ACS

Systems engineering works with the controls engineers to establish initial requirements and verify the performance and stability of the attitude control subsystem. The model inputs include results from the dynamics models and the satellite mass properties. Systems engineering verifies these inputs to ensure that the proper configuration is used. This model is used to evaluate pointing budgets for instruments and communication antennas. The performance of components and subsystems as measured during test are used to update the performance predictions.

5.1.1.7 Propulsion

NASA will review all propulsion design and confirm the ability of the system to meet performance and safety requirements. Propulsion experts will be used to review all propulsion elements.

5.1.1.8 Software

Software engineering with systems engineering support prepares the software management and development plan that describes the requirements, analysis, design, coding, integration, testing, documentation, storage, handling, and organization responsibility for flight, test, and deliverable ground operations software. The plan describes software standards and procedures; development tools, techniques, and methodologies specific to each area of software development; and a development schedule. The plan also describes formal configuration control including configuration audits, change management through version description documents, and quality evaluation of the code.

Systems engineering is responsible for the requirements addressing the design, development, integration and test of all space and ground segment software for the project. During all software development (flight, test/support, and ground), software is modularized into basic processes and then into modules until individual coding blocks are identified. Systems engineering reviews the structured development process, the interfaces, and the means of transition between all modules, as well as manages the formal design review as part of the standard review process. Systems engineering ensures that the software standards for documentation, validation, and maintenance are followed during software development, and that adequate testing is conducted to validated.

5.1.1.9 Contamination

Engineers review all materials for outgassing and offgassing properties, suggesting alternatives where required. The design layout is constrained to avoid locating optical sensors near thruster or other sources of contaminants. Also, interior venting is arranged to direct products away from any radiator or other sensitive surfaces. Systems engineering coordinates resolution of contamination issues with the subsystem engineers to arrive at the best solution.

5.1.1.10 Ground Systems

Ground system engineers perform the selection, installation, and test of all hardware and software required to perform the function of the ground segment. Ground system simulations can provide information on the optimum system configuration, as well as validate the software elements within the ground terminal over the range of expected mission scenarios. Simulations can also provide computer-loading estimates, allow testing of timelines for various operations scenarios, and provide early identification and resolution of problem areas. Systems engineering works with these engineers to ensure that all the requirements will be met, and that the operations concept is consistent with the planned ground system design.

5.2 Specialty Engineering

Systems engineering also supports coordination of the specialty engineering disciplines into the overall design process. Particular emphasis is placed on integrating these functions with the technical program due to the importance of incorporating specialty requirements early in the program to avoid redesign and rework.

5.3 Reliability

The reliability of the system will be determined by systems engineering with inputs from the discipline engineers on their systems. The reliability analysis will be used to confirm the system meets the reliability goals and will be used in tradeoffs on system selection. The NASA engineers will review and support these analyses and confirm the acceptance of the system to meet system requirements.

5.4 Safety

Systems engineering will coordinate the safety analyses and ensure the program meets all safety requirements.

5.5 Radiation

5.5.1 Total Dose Radiation

Engineers are responsible for modeling and analyzing survivability as a function of total radiation dose received during the on-orbit life of the observatory. The analysis uses location of individual units, observatory structural configuration, and location of sensitive components to predict total dose mapping from the typical environment. This analysis is used to determine any localized shielding requirements to ensure that adequate total dose margins are maintained. A radiation environment will be determined by the GSFC radiation analysis and coordinated with the contractors by SE.

5.5.2 SEU and SEL

Engineers review parts for single-event upset (SEU) and single-event latchup (SEL) sensitivity, selecting those with high linear transfer threshold and suggesting alternatives to acceptably minimize the probability of mission disruption. Systems engineering monitors SEU tests to define susceptibility for new parts.

5.6 EMI/EMC

Systems engineering specifies space segment electromagnetic compatibility (EMC) in the power users specification. Systems engineering performs EMC analyses and monitors EMC tests according to the environmental specification.

Systems engineering also monitors the electromagnetic interference (EMI) testing according to the EMI test plan. Monitoring of unit-level design and test helps minimize system-level problems. Any sensitive units are rechecked at the system level, and all safety margins are measured.

5.7 Project Management Support

Systems engineering ensures that requirements and design concepts are properly reflected in the specifications, ICDs, and plans generated by the project management offices (PMOs) at each of the team member organizations. Systems engineering provides support to each PMO by:

- Supporting development of and reviewing all specifications, ICDs, and plans.
- Coordinating internal meetings and reviews.
- Providing systems engineering analysis support.
- Obtaining technical input to systems engineering trades and analysis from the various groups.

Frequent staff meetings, attended by PMO and engineering representatives, are used to maintain program communication and provide a forum to address technical status and issues. Effective and accurate communication between engineering and program management is essential to solving problems in a timely manner and efficiently allocating resources to the areas most in need.

5.8 External Organizations

Systems engineering is responsible for the overall coordination and technical integration of the external interfaces required to support each segment/element/subsystem. These typically include the space segment providers, the launch vehicle organizations (NASA project office, contractor, launch site operators, etc.), the ground network, the data processing organizations, and possibly the TDRSS organization. Systems engineering coordination support includes ICDs, meetings, schedules, technical support, status updates, and verification.

5.9 Specifications

Add text.

5.10 Integration and Test

Integration and test (I&T) is responsible for the physical integration and testing of the space segment and for the planning of all launch-site activities. In the preliminary and detail design phases of the program, I&T participation ensures an observatory design that is easily and cost-effectively integrated and tested. In the implementation phase, this includes planning, directing, and implementing the test and integration processes for the observatory. Systems engineering serves as the interface between the I&T team and the design team to ensure that neither imposes overly costly or technically difficult constraints on the other.

5.10.1 Subsystem Integration

Systems engineering has the responsibility for assuring that all unit and subsystem testing satisfies program requirements. Systems engineering reviews all unit and subsystem test specifications, plans, and procedures to assure that all specification requirements will be verified following the testing, and reviews results along with the subsystem lead.

5.10.2 Software Integration

Integration of all the mission software within the project is performed by the software systems engineers, in coordination with the software engineers. The major software items to be integrated into the project are:

- Flight software.
- Ground support equipment (GSE) software.
- Software development facility.
- Operations support software.

Software integration ensures that these items work together and within the confines of the rest of the system. The software integration tasks performed by systems engineering include flow-down and derivation of requirements to support the software activities, ensuring that the various software groups are interfacing with design engineering, and coordinating all technical and organizational interfaces.

5.10.3 System Integration

During system integration, systems engineering has the responsibility for assuring that all lower-level testing satisfies program requirements, and that the systems integration process incorporates all testing that cannot be performed during observatory testing. Prior to subsystem integration into the element, systems engineering reviews the hardware status along with relevant subsystem personnel. This meeting should be held for all flight hardware and test equipment. Systems engineering is responsible for leading the review of any open discrepancies, liens, nonconformance reports, failure reports, or waivers, and determines actions to be taken to resolve these items. The hardware status and as-built condition should be reviewed and compared with the design, all discrepancies should be reconciled, and any test data should be reviewed and made available for element- or system-level testing comparison. Procedures required to test and verify the observatory system at the launch site are also developed as part of this effort.

5.10.4 Testing

Systems engineering provides support to test engineers during formal acceptance at the subsystem, element, and segment levels. This includes certification that all required testing and paperwork is in order. During testing, systems engineering supports the test and subsystem engineers in the creation and review of test procedures. They also review test results, address anomalies, sign off on completed procedures, and organize investigations into anomalies and failures. The most important part of the testing process is the comparison of each test result with the performance requirements. Test engineers prepare detailed test procedures, perform subsystem compatibility and system performance tests, and prepare test reports.

Systems engineering approves the test procedures, reviews the other system integration and test activities, and prepares performance assessment reports for the project reviews. Systems engineering reviews, coordinates, and approves the analysis and demonstrations for verification of items that cannot be verified through the test program. Systems engineering also evaluates the possible effect of open liens on performance and operations, and is responsible for their resolution.

In preparation for shipping to the launch site, the match-mate test is performed, in which the observatory and the launch vehicle adapter are physically mated and the mechanical and electrical interfaces are verified. The observatory is mechanically configured in the launch configuration as close as possible for this test.

5.10.5 Launch Site

Launch-site operations tasks performed by I&T include inspecting the adapter interface geometry and verification of the electrical interface, establishing interfaces between the observatory and all launch site facilities, and planning and generating procedures for all launch site activities. These tests consist of electrical interface verifications conducted at each stage of the observatory/launch vehicle build beginning with observatory-to-adapter mate and umbilical functional tests, and ending with the on-pad interface verification. Once on-pad, the observatory-to-launch-vehicle RF compatibility is tested before the launch countdown. During pre-launch operations, systems engineering supports in the checkout of voice and data links for launch, determines readiness of the ground stations, and verifies the on-pad readiness of the satellite including telemetry functions, battery state of charge, and environmental readiness.

5.11 Flight Operations and Ground Systems

Systems engineering coordinates all ground segment elements needed to support the space segment in flight and to deliver all data products to the end user. Systems engineering involvement begins with the definition of the operations concept concurrent with the requirements definition effort. The concept needs to strike a balance between design complexity and operating complexity, since both have cost and schedule impacts. Systems engineering works with the space segment subsystem leads in the planning for the space segment in-flight operations; deriving space segment operating rules, procedures, and constraints; health and safety telemetry monitoring and recovery from failures; payload operation planning; and resource availability.

Work with the ground segment leads involves planning for the design, development, installation, checkout, operations, and maintenance of all required ground equipment for managing all data products from the space segment. Systems engineering analyzes the roles of all ground segment elements and their interactions to ensure that the ground segment requirements are compatible with the space segment. This support also includes review of ground system requirements documentation, participation in data system and operations meetings, and the review of ground system design concepts. Systems engineering also provides support to develop and design the training system for the ground teams.

6.0 Resource Requirements

The systems engineering effort will be accomplished with a personnel support level of one NASA and two contractor support personnel for phases B and C/D.

Subsystem support shall require a level of two NASA FTEs to support phases B and C/D.

Appendix List of Acronyms

ADACS – Attitude Determination and Control System?
AETD – Applied Engineering and Technology Directorate
APS – Aerosol Polarimetry Sensor

C&DH – Command and Data Handling
CC – Command and controll
CCRI – Climate Change Research Initiative
CDR – Critical Design Review
Cg – Center of Gravity
CIL – Critical Items List
CLASS – Comprehensive Large-Array Data Stewardship System
CM – Configuration Management

D/L – Downlink
DAAC – Distributed Active Archive System
DOORS – Data Object-Oriented Repository System

EM – Engineering Memo
EMC – Electromagnetic Compatibility
EMI – Electromagnetic Interference
EOL Beginning of Life
EOS – Earth Observation System

FAM – Flight Assurance Manager
FDIR – Fault Detection, Isolation, and Recovery
FMEA – Failure Modes and Effects Analysis
FRB – Failure Review Board
FTE – Full-Time Employee

GDRD –General design Requirements Document
GEVS-SE – General Environmental Verification Specification, Systems Engineering
GIFOV – Geometric Instantaneous Field of View
GIS – Geographical Information System
GISS – Goddard Institute for Space Science
GLORY – GLORY Project
GPM – Global Positioning Monitor
GPS-Global Position System
GSE – Ground Support Equipment
GSFC – Goddard Space Flight Center
GSM – Ground Systems Manager

I&T – Integration and Test
ICD – Interface Control Document

ID – Identification

KSC – NASA Kennedy Space Center

LASP – Laboratory for Atmospheric and Space Physics
LEO – Low-Earth Orbit
LV – Launch Vehicle

MAR – Mission Assurance Requirements
MCR – Mission Confirmation Review
MCRR – Mission Confirmation Review
MOC – Mission Operations Center
MSSP – ???

NASA – National Aeronautics and Space Administration
NISN – ????
NOAA – National Oceanic and Atmospheric Administration
NPG – NPG project
NPOESS – National Polar-Orbiting Operational Environmental Satellite System
NPP – NPOESS Preparatory Project

OMPS – Ozone Mapper and Profiler System

PDR – Preliminary Design Review
PFR – Problem Failure Report
PIP – Payload Integration Processor
PM – Project Manager
PMO – Project Management Office

RF – Radio Frequency
ROM/RAM – Read-Only Memory/Random-Access Memory

S/C – Spacecraft
SE – Systems Engineer
SEL – Single-Event Latchup
SEMP – Systems Engineering Management Plan
SEU – Single-Event Upset
SLOC – Software Lines of Code
SM – Systems Manager
SMRD –Systems Mission Requirements Document
SN – Signal to Noise Ratio
SNR – Signal-to-Noise Ratio
SOC – Science Operations Center
SORCE – Solar Radiation and Climate Experiment
SOW – Statement of Work
SRR – System Requirements Review

TBD/TBR – To Be Determined/To Be Resolved
TDRSS – Tracking and Data Relay Satellite System
TIM – Total Irradiance Monitor or Technical Interchange Meeting
TM – Technical Memo
TPM – Technical Performance Measures
TSI – Total Solar Irradiance

VAFB – Vandenberg Air Force Base
VCL – Vegetation Canopy Lidar
VIIRS – Visible Infrared Imaging Radiometer Suite
VTP – Verification Test Plan