THEMIS
Systems Engineering Management Plan (SEMP)

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Document Revision Record

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B	1/19/04	SC PDR RFA 5. Added project approach to controlling the use of dual measurement units (section 3.5). SC PDR RFA 7. Added Swales mass confidence factors (section 3.2).	
C	4/7/04	Minor updates to capture actual program implementation	
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Identifier	Description

1.0 INTRODUCTION

The THEMIS System Engineering Management Plan (SEMP) outlines the integrated Systems Engineering process for the *Time History of Events and Macroscale Interactions during Substorms* (THEMIS) Mission. The plan shall document the activities to be performed by the Systems Engineering Team at the University of California-Berkeley (UCB) Space Science Laboratory (SSL) and Swales Aerospace (Swales).

UCB has responsibility for management of the THEMIS program, including satisfaction of all cost, schedule, and technical performance requirements. UCB is responsible for the overall technical and business planning, organization, direction, control, and approval actions required to carry out the project. UCB is responsible for implementing the SEMP described here-in, and overseeing the Engineering team and the roles and responsibilities of team members. Systems Engineering at UCB consists of the Mission Systems Engineer (MSE) and Leads for each aspect of the overall mission (Electrical, Mechanical, Mission Operations, Ground Based Observations and Quality Assurance).

Swales provides the end-to-end management, design, development, manufacturing, integration, verification, and support equipment of the THEMIS Probe Bus and Probe Carrier. Systems Engineering at Swales is structured as an Integrated Product Team (IPT) environment. The organization consists of the Spacecraft Systems Engineering, the System Engineering Deputy, Launch Vehicle and Launch Site Systems Engineering and Subsystem Leads (Electrical, Mechanical, Thermal, and Guidance, Navigation and Control (GN&C)).

The Systems Engineering Team will update this SEMP at the end of each major project phase to ensure that it remains updated, accurate, and relevant to the ongoing systems engineering effort.

1.1 Document Scope

Systems Engineering combines the use of formal documentation and proven engineering practices to ensure all of the science objectives and performance requirements of the mission are realized. As such, the Systems Engineering Team is responsible for the overall management and integration of technical activities, and provides a variety of functions including:

- **Requirement Management (Section 2):** Establishing the overall framework and procedures for mission requirements identification, tracking, validation & verification. This function includes developing and maintaining requirement control documents, and verification matrices and plans.

- **Resource Management (Section 3):** Providing oversight of all technical resources; establishing processes that track and control allocations, contingencies and margins throughout the project lifecycle; and conducting analyses required to ensure allocations accurately assigned.

- **Technical Coordination (Section 4):** Coordinating the technical disciplines to ensure that the program meets all cost, schedule, and performance goals.

- **Technical Evaluation (Section 5):** Providing a structured evaluation process to assess technical progress and identify problems in a timely manner.

- **Reliability Engineering and Risk Management (Section 6):** Conducting reliability analyses (i.e Failure Modes and Effects Analyses) to assess the reliability of various aspects of the THEMIS systems; and developing and maintaining a comprehensive Risk Management Plan.

- **Integration and Test Activities (Section 7):** Providing support to all integration and test activities including: planning the integration and test flow; developing plans and procedures; and overseeing the execution of all activities.

The full range of systems engineering activities on the program, the organizations involved, and the methods of coordinating and integrating these activities, are presented in this document. Since discrete engineering functions are performed by a combination of various groups, the document is organized by the functions listed above rather than by organization.

1.2 Systems Engineering Team

The System Engineering Team is responsible for the technical coordination of the development & implementation effort over the entire lifecycle of the THEMIS project as well as the technical cohesiveness of all of the individual project elements. The major roles and responsibilities for each member on the System Engineering Team is listed below.

1.2.1 Mission Systems Engineer (MSE)

Ellen Taylor - UCB. The Mission Systems Engineer (MSE) leads the System Engineering Team and is responsible for the overall management and success of the THEMIS System Engineering effort. The MSE is responsible for facilitating the resolution of issues between the various members of the team as well as coordinating issues with Project Management. She is responsible for leading and coordinating the definition and development of the system requirements, resource budgets, system architecture, and operations concepts, as well as ensuring that these areas remain balanced and in agreement throughout the system lifecycle as part of an overall implementation approach. Specifically, the MSE is responsible for generating and maintaining the Mission Requirements Document (MRD) and related documents, and for generating and maintaining the SEMP. The MSE is ultimately responsible for requirements traceability, tracking, verification and validation. The MSE also provides contamination assessment and control support by evaluating the magnetic and electrostatic cleanliness contamination requirements. Specifically, she is responsible for defining, documenting, and implementing the THEMIS contamination control plans.

1.2.2 Spacecraft Systems Engineer (SSE)

Tom Ajluni - Swales. The Spacecraft Systems Engineer (SSE) is responsible for leading and coordinating the technical development of the THEMIS Probe Bus and Probe Carrier, including requirements, architecture design, and operations concept. He is the primary individual responsible for the development and maintenance of the Probe architecture and oversees all spacecraft trade studies and performance analyses leading to the spacecraft system architecture design and implementation. The SSE is responsible for the allocation and tracking of all Spacecraft technical resources. He is also responsible for technical oversight and maintenance of all spacecraft ICDs.

1.2.3 Systems Engineering Deputy (SED)

Kevin Brenneman - Swales. The Systems Engineering Deputy (SED) works closely with the MSE and SSE to define the development, verification and delivery requirements of the THEMIS Probes and all its components. The SED works to establish the tools and procedures used for requirements tracking and traceability. The SED will assemble the THEMIS Verification Plan/Matrix from the MRD, which identifies the verification requirements for the THEMIS Probes and all of their individual components. The SED will also work with the MSE and SSE to identify and target specific areas of the development effort that require additional scrutiny and oversight through the development and verification process. The SED will work with the relevant Subsystem Team Leads in these areas to provide oversight and assistance in the development and verification process.

1.2.4 Mission Operations Manager (MOM)

Manfred Bester - UCB. The Mission Operations Manager (MOM) is responsible for the operations concept development and verifying that it balances between the mission requirements and the system design architecture. In this capacity, the MOM works very closely with the spacecraft, instrument and ground segment teams to develop an operations concept that coordinates all of these system concepts into a cohesive whole. The MOM uses this ops concept in developing and leading the performance verification testing to ensure that the system is tested as it will fly. In addition, the MOM is responsible for ensuring Ground Station compatibility and maintaining the mission RF link budget.

1.2.5 Mechanical Systems Engineer (MechSE)

Paul Turin - UCB. The MechSE is responsible for the technical oversight of all THEMIS mechanical development activities. He will provide oversight for the mechanical development of all instruments, deployable booms and mechanisms, and the Probe Bus and Probe Carrier. The MechSE will maintain the system mass budget, providing monthly updates to the MSE and Project Management.

1.2.6 Instrument Electrical Engineer (IEE)

Peter Berg - UCB. The Instrument Electrical Engineer (IEE) is responsible for technical oversight and coordination of the Instrument electrical system. In this capacity, the IEE interfaces closely with all Instrument leads to provide technical inputs and oversight in the generation and maintenance of Instrument specifications and ICDs. Working closely with the MSE, the IEE is ultimately responsible for the electrical systems design of the Instrument Data Processing Unit (IDPU) to ensure technical cohesiveness of interfaces and resources.

1.2.7 Ground Based Observation Manager (GBO Manager)

Stu Harris - UCB. The Ground Based Observation Manager (GBO Manager) manages and oversees the weekly progress of the GBO task, including site selection and the development and test of the GBO instruments (ASI and Ground MAG). The GBO Manager is responsible for holding weekly meetings and periodically reporting to Project Management the status of the effort.

1.2.8 Mission Assurance Manager (MAM)

Ron Jackson - UCB. The Mission Assurance Manager (MAM) is responsible for the day-to-day monitoring of product assurance to ensure the final product performs as designed and required. The MAM is responsible for the overall management, planning, reporting, and auditing of the performance assurance activities, which include both hardware and software quality assurance, and auditing the efforts of EEE parts control, materials and processes control, safety, and reliability. The MAM is also responsible for obtaining radiation analyses, evaluation and part assessment. This includes an assessment of the THEMIS radiation environment; determination of the radiation susceptibility of the THEMIS flight component parts lists; leading the radiation test regime required for any parts; and working with Product

Development Leads and the Parts Engineer to assess any implementation measures that need to be applied to mitigate radiation concerns. In addition, the MAM will serve as the Mission Safety Lead. Swales will have a safety lead who reports to the program with a direct line to the Swales director of QA. The Safety Organization will be spelled out in the Swales THEMIS Safety Plan. The Swales Safety manager is currently responsible for all Swales Industrial safety and will interface with the GSFC Safety Representative while we are at GSFC. Also the Swales Safety Manager will coordinate our Launch Site Safety Plan and documentation.

1.2.9 Parts Engineer (PE)

Jorg Fisher - UCB. The Parts Engineer (PE) is responsible for collecting the comprehensive flight parts lists of the THEMIS Probes to ensure that all flight components meet flight use and implementation requirements. In line with the THEMIS common-buy philosophy, the PE will create and maintain a comprehensive THEMIS Flight Parts database, which clearly lists, among other things, the following information for each flight part planned for use: parts qualification level and history, radiation characteristics, and parts use and criticality information. The PE will, where necessary, alert the System Engineering Team to parts application issues and make recommendations on alternate parts if necessary. The PE is also responsible for collecting and maintaining the comprehensive flight materials lists. The PE will create and maintain a comprehensive THEMIS Flight Materials database, which clearly lists all of the materials used, where they are used, and any use requirements and restrictions. Finally, the PE is responsible for the overseeing the development of flight assemblies, filling the configuration control role of assigning schematic and drawing numbers, tracking released versions and revisions, and maintaining tracking logs and change orders.

1.2.10 Scheduler

Daniele Meilhan - UCB. One of the key management tools required in the accomplishment of any project is that of scheduling. An accurate portrayal of the sequence of events and the pinpoint date or time for events helps all participants in the accomplishment of their task. 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.

1.2.11 Launch Vehicle and Launch Site Systems Engineering (LVS)

Michael McCullough – Swales. The Launch Vehicle and Launch Site Systems Engineer (LVS) works closely with the SED, MSE and SSE to insure that vehicle interfaces and capabilities meet mission objectives. As the THEMIS project single interface point to KSC, Boeing, and the Range he coordinates and controls mechanical and electrical interfaces, loads and payload accommodations including launch site processing and range safety.

1.2.12 Spacecraft Mechanical Lead Engineer (MLE)

Chris Lashley - Swales.

1.2.13 Spacecraft Electrical Lead Engineer (ELE)

Bob Krauter - Swales.

1.2.14 Guidance, Navigation and Control Lead (GN&C)

Richard Leboeuf - Swales.

1.2.15 Thermal

Rommel Zara - Swales.

1.2.16 Instrument and Subsystem Development Team Leads

Instrument and Subsystem Development Team Leads are the designated leads over the various functional discipline and development areas of the THEMIS Instrument Payload and Probe Bus. All of the PDLs are de facto members of the Systems Engineering Team and work with the Team in defining, developing, verifying and operating the THEMIS Probes. The Leads work with the MSE, SSE and SDE in developing and documenting the MRD Level 3 and Level 4 requirements. The Leads are responsible for the generation and maintenance of subsystem ICDs, as well as specifications for component procurements. Later in the project, they are responsible for ensuring their discipline area meets all requirements by providing performance verification plans and calibrations procedures as necessary.

1.3 System Overview

For reference and definition purposes, a brief description of the contents of the THEMIS Project is provided below. Nomenclature used to refer to the items making up this Project are taken from the NASA Systems Engineering Handbook, SP-6105, June 1995, page 3.

The overall THEMIS system is composed of four major segments as described below:

Flight Segment

The Flight Segment includes five THEMIS Probes and a Probe Carrier, together called the Probe Carrier Assembly (PCA). The Probe Carrier is the structure to which the Probes are mounted and released from. The Probes are comprised of the: Instrument Payload (five electric field and particle instruments and the instrument data processing and power distribution unit (IDPU) supporting the instruments); and the Probe Bus (support subsystems required for operation during the mission).

Launch Segment

The Launch Segment consists of the Delta II 2950-10 launch vehicle, and associated services, facilities, and properties needed to integrate the PCA onto the launch vehicle, and conduct pre-launch testing with the remainder of the ground system.

Ground Operations Segment

The Ground Operations segment includes all of the facilities needed to plan, schedule, execute, monitor, and maintain the health and safety of the Probes during the mission. Specific to the THEMIS mission, the Ground Operations Segment also includes the operations and maintenance of the Ground Based Observation (GBO) instruments.

Science Data Processing Segment

The Science Data Processing segment provides those facilities and equipment needed to receive, archive, and analyze science data obtained from the Probes and GBO instruments.

1.4 Reference Documents

The documents listed below are NASA documents used as references in the development of this SEMP.

Number	Title	Revision Date
410-MIDEX-002	MIDEX Program Assurance Requirements, Rev E	June 25, 2002
410-MIDEX-001	MIDEX Program Assurance Guidelines, Rev C	Nov 28, 1997
ANSI/AIAA R-020A-1999	American National Standard. Recommended Practice for Mass Properties Control for Satellite, Missiles and Launch Vehicles	August 23, 2000
NPG 7120.5 B	NASA Program and Project Management Processes and Requirements	Nov 21, 2002
SP-610S	NASA Systems Engineering Handbook	June 1995
NPG 8000.4	NASA Risk Management Procedures and Guidelines	April 25, 2002
GPG 7120.5	Systems Engineering NASA Goddard Space Flight Center	
GEVS-SE	General Environmental Verification Specification For STS & ELV Payloads, Subsystems, And Components, Rev A	June 1996
GPG 8700.6	Engineering Peer Reviews	Oct 16, 2001
GPG 7120.4	Risk Management, NASA Goddard Space Flight Center	Dec 7, 2001

2.0 REQUIREMENT MANAGEMENT

This portion of the SEMP describes the THEMIS life-cycle requirement management process. Requirement development, documentation, tracking, validation and verification occurs at each phase of the project as described below:

Phase A. Top-level mission requirements are developed and proposed in Phase A. The THEMIS Concept Study Report (CSR) provided the basic mission concept and outlines the top-level requirements imposed by science and programmatic objectives.

Phase B. Mission requirements are flown down to the subsystem level, formalized and documented early in Phase B. All elements of the CSR mission concept are reviewed by the development team to ensure requirements are well understood (down to the subsystem level), attainable and sufficient to meet mission objectives prior to preliminary design. Internal requirement reviews are held and attended by the System Engineering Team. For THEMIS, these reviews include: a Instrument Payload Internal Requirement Review, a Probe and Probe Carrier Internal Requirement Review, a Ground Based Observation Requirements Review, and a Science Requirements Review. From the CSR and these internal reviews, a Mission Requirements Database (MRD) is developed. The MRD is then reviewed by the development team and presented to NASA GSFC at the System Requirements Review (SRR). After the SRR, the MRD is put under configuration control. The attributes of the THEMIS MRD are described Section 2.1.

Subsystem interfaces and component requirements are further detailed in Phase B by way of Requirement Control Plans (Magnetics, Electrostatic Cleanliness, and Contamination) and Specifications (Verification and Environmental Test); Interface Control Documents (ICDs) between Subsystems and Institutions; System and Subsystem Specifications (SOWs, Instrument Specifications, etc); and Mission Plans and Policies (Performance Assurance Plan, Safety Plan, Risk Mitigation Plan, Peer Review Plan, etc). The requirement documents planned for THEMIS are further described in Section 2.2.

Phase C. Requirement verification plans are developed late in Phase B and early in Phase C. Development of a Mission Verification Matrix ensures a test or analysis is scheduled for all mission requirements in the MRD. The THEMIS verification process is described in Section 2.3.

Phase D. Requirements compliance and verification matrices are completed in Phase D. The MRD evolves into summary of test program as run, documenting the verification and compliance status of all requirements. This matrix provides direct trace-ability from requirements to test procedures and reports. Trace-ability and flow-down is an important part of the requirement process throughout all project phases and described further in Section 2.4.

2.1 Mission Requirement Database (MRD)

THEMIS mission requirements are tracked using an excel spreadsheet database tool, developed by SA. Each requirement in the database has a separate row with a unique ID. The MRD provides traceability from the top level (Level 1) science and programmatic requirements. The tool automatically provides direct trace-ability with the use of Parent and Child IDs for each requirement. Functional/Performance Requirements (Science, Mission Design and Operations based); Resource Requirements (Mass, Power, Data Allocations, etc.); Top-level Interface Requirements (Timing, Power Distribution, etc.); and Environmental Requirements (Thermal, Radiation, Contamination, etc.) are tracked explicitly in the Database. The MRD is composed of the following specific columns.

Attribute	Description
Organization	Identify which organization is responsible for generating this requirement
Owner	Identify which individual is responsible for verifying this requirement
WBS	WBS number, e.g. WBS-2.2.2 (for Probe Bus)
ID	Unique identification number, e.g. PB-356 (for Probe Bus) See Key below for a complete list
Level	Drivers (Level 1), System/Segment (Level 2), Element (Level 3), Subsystem (Level 4)
Title	Descriptive title
Statement	Requirement statement: "The _____shall provide___.", "The _____ shall weigh less than_____.", etc.)
Rationale	Explanation/context of requirement
Parent ID	ID of immediate higher level requirement
Source	Source of requirement (Design description document, Element Spec, analysis, best practice, etc.)
Child ID	ID of immediate lower level requirement
Status	TBD, TBR, Defined, Approved, Verified, Deleted
Verification method	Inspection / Analysis / Demonstration / Test : Description of type of test, if needed (i.e. a Verification Requirement)
Verification Procedure	Procedure in which the requirement is verified
Verification Result	Summarizes verification results
Change history	Change History

Table 2.1-1: THEMIS Mission Requirement Database Attributes

2.2 Level 2 and Level 3 Requirement Documents

Top-level mission requirements allocated to each mission segment in the MRD provide the starting point for additional control plans, ICDs, mission policy statements and subsystem specifications. These Level 2 and Level 3 Documents further allocate requirements down to the component level, as well as contain additional derived requirements as necessary to completely specify the design. The THEMIS Requirements Document Tree is provided in the Figure 2.2-1. The specific contents of these documents are further described below to illustrate the Systems Engineering requirement management and tracking process.

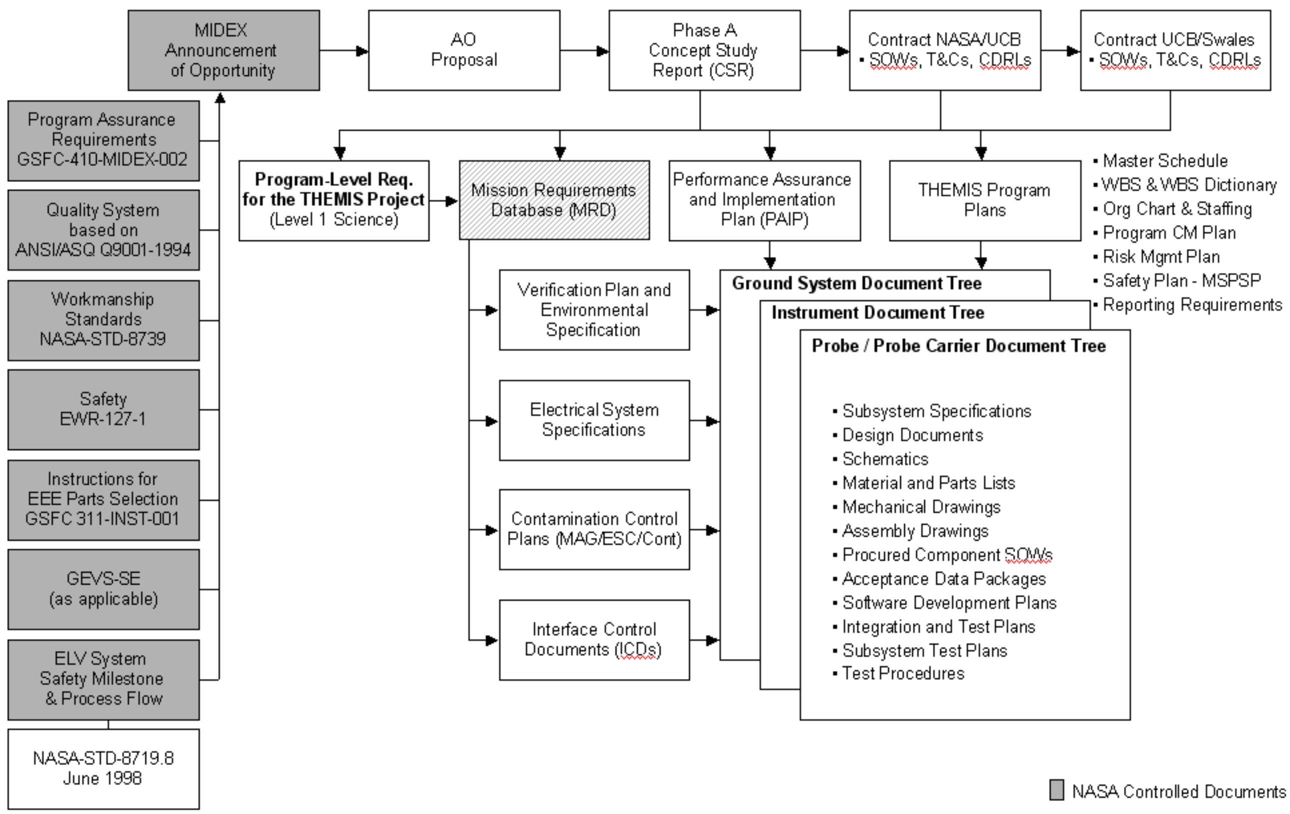

Figure 2.2-1: THEMIS Document Tree Flow-down

2.2.1 Requirement Control Plans and Specifications (Level 2)

Requirement Control Plans and Specifications provide detailed technical direction in specific areas of the project to ensure that the end-products will ultimately comply with the top-level mission requirement. These plans are extensions of the MRD and are controlled by the MSE. Table 2.1.1-1 provides requirement control plans and specifications that will be generated and maintained for THEMIS.

Number	Title	Responsible Org
THM-SYS-001	THEMIS Mission Requirements Document	UCB/Swales
THM-SYS-002	THEMIS Magnetics Cleanliness Spec and Design Guidelines	UCB
THM-SYS-003	THEMIS Electrostatic Cleanliness Specification	UCB
THM-SYS-004	THEMIS Contamination Control Plan	UCB

Table 2.1.1-1: THEMIS Requirement Control Plans and Specifications

The Electrical System Specifications are separately controlled documents at UCB and Swales. At UCB, all electrical interfaces and protocols are described in THM-IDPU-001 IDPU Backplane Specification. At Swales, the electrical interfaces are described in the BAU Specification.

2.2.2 Interface Control Documents (Level 2)

Space Segment. Interface Control Documents between the various space segments of the project are identified in Table 2.2.2-1 below. Electrical and Software interfaces are principally covered under the Instrument-to-IDPU (Instrument Data Processor Unit) ICDs. Mechanical and Thermal interfaces are covered under the Probe-to-Instrument ICDs. The IDPU-to-Probe ICD covers both electrical and mechanical interfaces.

Number	Title	Organizations Involved	Release
THM-SYS-101	IDPU/ESA-to-Probe ICD	UCB/Swales	PDR
THM-SYS-102	Telecommand Format Specification	UCB/Swales	PDR
THM-SYS-103	IDPU-to-DFB ICD	UCB/LASP	PDR
THM-SYS-104	IDPU-to-BEB ICD	UCB	PDR
THM-SYS-105	ESA and SST I/F Specification	UCB	PDR
THM-SYS-106	FGM Interface Requirements Document	UCB/IWF	PDR
THM-SYS-107	SCM Interface Requirements Document	UCB/CETP	PDR
THM-SYS-108	Probe-to-EFI Spin Plane Booms (SPBs) ICD	UCB/Swales	PDR
THM-SYS-109	Probe-to-EFI Axial Booms ICD	UCB/Swales	PDR
THM-SYS-111	Probe-to-SST ICD	UCB/Swales	PDR
THM-SYS-112	Probe-to-FGM Mag Boom ICD	UCB/Swales	PDR
THM-SYS-113	Probe-to-SCM Mag Boom ICD	UCB/Swales	PDR

Table 2.2.2-1: THEMIS Space Segment Interface Control Documents (ICDs)

Space Segment to Launch Vehicle. The SSE is responsible for defining all launch vehicle interface requirements, monitoring the physical and electrical checkout of all interfaces, and ensuring 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 THEMIS Mission Specification, and then tracking and maintaining the Specification. Ensuring the correct flow of the Mission Spec interface, safety and verification requirements to the appropriate subsystem specifications is also critical. Key inputs to this process come from government safety documents and the launch vehicle users manual. The Mission Spec defines the verification requirements for the Probe Carrier Assembly-to-Launch Vehicle. Once the Mission Spec is completed and signed to establish agreement by all parties, the document is placed under formal configuration control by NASA Kennedy Space Center (KSC).

Space Segment to Ground Segment. Space to ground interfaces must be adequately specified to ensure proper Space Segment control and monitoring. These interfaces are defined by the Systems Engineering and specified in Space/Ground Interface Control Document. The MOM, MSE and SSE monitors the validation of ground hardware and software interfaces by direct ground station processing of Space Segment telemetry and commands as early as possible during Space Segment development. These tests enable resolution of any discrepancies with minimal schedule and financial impact. Space to Ground Segment and launch vehicle to ground station interface verification is included in the Space Segment Verification Plan. The interface parameters include appropriate RF interfaces, digital interfaces, and operations interfaces. In addition, because THEMIS is unique in that most of the attitude determination is done on the ground, additional ICDs are planned to clearly delineate the responsibilities of the ground based versus on-board attitude determination.

2.2.3 Mission Plans and Policies (Level 2)

Mission Plans and Policies cover quality assurance, risk mitigation, reliability analyses, and configuration control. These four areas are covered in the following project-level documents:

- THM-PA-001 Project Level Performance Assurance and Implementation Plan (PAIP)
- THM-SYS-007 Failure Modes Effects and Criticality Analysis (FMECA)
- THM-SYS-011 Configuration Management Plan (CMP)

2.2.4 Instrument/Subsystem Specifications (Level 3)

Instrument and Subsystem specifications (Level 3) are created as part of the overall project review process and documented in review package presentations. As part of the requirement flow-down process, presentations are checked by the MSE, ISE and SSE against higher level requirements and specifications. Design review presentations provide a description of how an instrument meets derived requirements, as well as providing an overview of the design for information purposes. The specification is created to address higher level requirements, and as such contains the information for creating the requirements for the next lower level subsystem/assembly/unit. These lower level requirements are then documented in component specifications (Actel specs) and vendor SOWs.

For the Instrument Data Processing Unit, each core function is covered in a specification:

- THM-LVPS-001 Low Voltage Power Supply Specification
- THM-PCB-001 Power Control Board Specification
- THM-DCB-001 Data Processing Unit Specification

2.3 Requirement Traceability

Requirements traceability is addressed specifically in the MRD by linking requirements to parent and child IDs. All requirements are traceable to the top level science, programmatic or mission requirements. Automatic traceability is provided by the SA Database Tool to identify all non-linking requirements which fail in two categories: lower-level requirements that do not trace directly to a higher-level requirement and high-level requirements that are not allocated to a lower level. Both of these situations may indicate non-compliance.

Non-linking lower-level requirements can indicate that higher-level requirements have not been fully defined. These requirements must be checked, making sure that they do not conflict with higher-level objectives or result in out-of-scope design work. Higher-level requirements that do not flow down to lower levels may indicate required system performance that has not been factored into the design specifications. In this case, the lower-level specifications are reviewed to ensure that they are responsive. If not, they are appropriately revised.

In addition, Traceability Trees are developed and provided in Appendix A of the MRD to ensure requirements have been appropriately and accurately flown-down to lower levels. The traceability trees also provide a map to Level 2 and 3 Documents, providing direct traceability to derived requirements.

2.4 Requirement Verification

This Requirement Verification section outlines the verification process, which ensures all end-item hardware and software products meet program requirements. The methodology and documents that define the THEMIS verification process are described below.

2.4.1 Requirement Verification Overview (Perf., Func. & Env.)

The MSE, SSE and SED are responsible for ensuring that the verification program addresses all requirements stated in the MRD and associated requirements documents (ICDs, Control Plans and Specifications). The verification process is in compliance with the MIDEX Assurance Requirements document, 410-MIDEX-001, -002 documents, and with the verification requirements of the General Environmental Verification Specification (GEVS-SE). The MSE, SSE and SED will utilize the fields for verification method, procedure, and result in the MRD (see Section 2.1) to ensure compliance with mission requirements. In addition, all Level 2 Requirement Documents shall include a verification matrix, containing the same criteria for derived requirements. All Level 2 and 3 requirements will demonstrate compliance to Level 1 requirements.

2.4.2 Verification Methodology

Verification of requirements is by inspection, analysis, demonstration, test, or some combination of these methods.

- Inspection. Inspection is the process of measuring, examining, gauging, or otherwise comparing an article or service with specified requirements. Inspection tasks include: establishing the inspection criteria; preparing inspection plans and procedures; implementing the inspection; and documenting the inspection results.
- Analysis. Analysis is defined as the mathematical or physical interpretation of simulation data or test data. Analysis tasks include: establishing the analysis objectives; preparing analysis plans; implementing the analysis; and documenting the analysis results.
- Test. Tests are defined as measurements made under fully controlled and traceable conditions using simulated environments and external stimuli, as well as those measurements of a system or equipment taken in the field in which actual or representative environments and external stimuli are used. Testing tasks include: establishing test objectives; preparing a test plan and procedure; implementing the test; and documenting the test results.

2.4.3 Verification Levels

The verification will be performed at one or more of the following verification levels: Assembly level, Subsystem level, Element level, or Space Segment level.

- Assembly. Assembly level refers to a completely integrated set if assemblies or sub-assemblies.
- Subsystem. Subsystems are any major assemblies, such as a propulsion module or a solar array. Testing at the Subsystem level is performed on fully integrated subsystems, which may be initially populated with some non-critical assembly simulators if needed.
- Element (probe or integrated instrument suite). Element level verification is conducted as subsystems are integrated onto the higher level assemblies, and is completed prior to Element integration into a Segment.

- Segment (probe or integrated instrument suite). Segment level verification is performed as the Elements are integrated onto the Segment, and is completed on a completely integrated Segment (probe carrier assembly).

2.4.4 Documents

The verification and testing processes at each level (for performance, functionality, and environments) are specified in the THEMIS Verification Plan and Environmental Test Specification, Calibration Plans, and Comprehensive 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, Assurance Requirements, as well as design specifications. The MRD and Verification Matrices included as appendices in subsequent requirements documents will be used to ensure that all pertinent requirements are reflected in the verification plans and specifications.

- Verification Plan and Environment Test Specification. The MSE and SED are responsible for the generation of the Verification Plan and Environmental Test 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; and Thermal and thermal vacuum test profiles including hot and cold soak durations, transitions, etc.

- Calibration Plans & Procedures. The calibration plans and procedures identity the overall approach to accomplishing performance verification. Included in any plan shall be the overall approach of the calibration program, descriptions of the configuration of the test item, test objectives, facilities, safety considerations, organization responsibilities, as well as descriptions of what will be contained in the each test procedure document.

- Comprehensive Test Plan. MSE and SSE, along with I&T, are responsible for the generation of the Comprehensive Test Plan. The purpose of the Comprehensive Test Plan is to ensure that the Instrument Payload and Probe Bus are 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 Probe, from assemblies to integrated Probe Carrier Assembly 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 Calibration Plans.

3.0 RESOURCE MANAGEMENT

The MSE is responsible for establishing, implementing, and maintaining resource budgets for the THEMIS Mission. Specific tasks associated with this activity are maintaining budgets of critical resources, tracking subsystem resource allocations, determining resource margins, developing and maintaining various resource databases, and monitoring and releasing contingencies. Under this directive, the MSE, SSE and SED are also responsible for identifying growth paths and maintaining margins to accommodate planned growth with minimum design impact, as well as taking corrective action if necessary.

3.1 Resource Allocations

Mass, Power, Data, Link Margin and DeltaV resources are allocated at the System level for the Probe, Probe Carrier, and Instrument Payload in the MRD. The MRD also indicates all Elements and Subsystems shall comply with System Resource Table allocations (THM-SYS-008 THEMIS Mass Resource Budget, THM-SYS-009 THEMIS Power Resource Budget, and THM-SYS-010 THEMIS Data Budget). Subsystem allocations are then used to generate lower level assembly or part allocations, which are tracked by Subsystem engineers.

Pointing error contributions are allocated in the SWALES THEMIS Error Budgets. Command and telemetry allocations are tracked in the Command and Telemetry Lists. Data throughput, processor utilization and memory allocations are documented in the UCB Data Control Board (DCB) and SWALES Command and Data Handling (C&DH) Specifications.

Allocations are based on a Current Best Estimate (CBE) + Contingency estimated during Phase A. The sum of allocations is less than the available resource (or system capability) providing a Program Managers Margin held at UCB. CBEs are updated monthly and tracked in the System Resource Tables. SWALES reports Probe Bus and Probe Carrier resources in monthly reports to UCB. UCB combines these reports with Instrument Payload CBEs to produce a system total. This total is then provided to NASA GSFC in the Project Management monthly report.

Since CBEs change with design maturity, the MSE may assess the allocations against "bottom-up" engineering estimates by the development team and recommend allocation changes when justified. These changes require formal approval via the Configuration Control Board (CCB) process, and are reflected in a revision to the appropriate System Resource Table or Document. (See Section 4 for the Configuration Control Process).

3.2 Contingency Criteria

Contingency (also called reserve) is defined as a percentage of resource (e.g., mass or power) added to an estimate as a provision for uncertainty. Contingency is based on the level of maturity of the item, thusthe Current Best Estimate x %contingency is called the mature estimate. For UCB and the Instrument Development team, each item is identified as being in one of the following groups and the appropriate %contingency applied:

1. Concept: 25%
2. Design: 15%
3. Prior Build: 7.5%
4. Fabrication: 4%
5. Flight Build: 2%

For Swales (consistent with prior project experience), each item is identified as being in one of the following groups and the %contingency applied:

1. Rough estimate based on Basic concept: 25%
2. Conceptual estimate based on sketches, description experience, or finite element model: 18%
3. Pre-released drawing values: 10%
4. Released drawing values: 5%
5. Actual measured weight of flight unit: 0.2%

In monthly reports, contingency% is determined by the Current Best Estimate (CBE) and the initial allocation. Contingency is re-evaluated at key milestones, such as major project reviews, the successful development and test of an Engineering Test Unit (ETU), or completion of a detailed analysis. Contingency% that does not meet the appropriate maturity level will trigger a review of the design, resulting in either modification to the proposed hardware design, reallocation of available resources, or release of program margin.

3.3 Margin Description

Program Managers margin is defined as the amount of resource remaining when an estimate plus the associated contingencies are subtracted from the available quantity. Margin is calculated at the Element/Subsystem level. For mass margin, the launch vehicle lift capability is used as the Probe Carrier Assembly (PCA) available resource, and a “not-to-exceed” Probe wet mass is used as the Delta-V propellant mass plus Probe dry mass available resource. For power margin, the Probe EOL solar array capability is used. Margin% is represented by the equation:

Margin% = [(Available Resource - (Maximum Expected)) / (Maximum Expected)] x 100%

where Maximum Expected is equivalent to the Estimate + Contingency.

Margin% that doesn’t meet the following Margin Schedule will trigger a project level risk mitigation plan, resulting in possible descope of mission objectives.

1. Phase A Concept: > 30%
2. Preliminary Design Review (PDR): > 20%
3. Conceptual Design Review (CDR): > 15%
4. Pre-Environmental Review (PER): > 10%
5. Pre-Ship Review (PSR): 2% to 5%

Including contingency, this schedule is consistent with guidelines historic NASA project trends. Page 62 of the NASA Systems Engineering Handbook, SP-6105, 1995, says "As an example, spacecraft dry mass tends to grow during Phases C and D by as much as 25 to 30 percent." The JPL guidelines say that from the Phase B start to launch, total mass and power growth ranged from 20% to 48%. The AIAA Recommended Practice (R-020A-1999) doesn't give mass growth by phase, but by type of calculation, and for a "Layout" has 12-30% growth allowance.

3.4 Equipment Databases

The MSE, SSE and SED are responsible for developing and maintaining equipment lists to track assembly resource requirements and properties to aid in assessing subsystem margins and contingencies. The lists are used to track engineering changes, compare the engineering estimates with allocated quantities, assess resource margins and contingencies, and provide a baseline assembly description for engineering analysis.

At a minimum, the following data are tracked in equipment lists: Quantity, mass estimate and contingency, allocated mass, orbit average power and contingency, allocated orbit average power, peak power, power draw by mode, voltage and current draw, and heat dissipation. The lists are updated monthly and represents the latest engineering estimates of assembly resources. This information is then grouped by subsystem and used as input to the System Resource Tables for higher level margin and contingency tracking in THM-SYS-008 THEMIS Mass Budget and THM-SYS-009 THEMIS Power Budget.

3.5 Resource Analyses

Specific resource analyses provide the bases for allocations and ensure appropriate system architecture and design. Analyses include mass properties, power analysis, propellant, pointing error contributions, commands and telemetry, communications bandwidth, processor use, and other performance parameters.

To preclude any confusion as to units of measurement during design, development, test and operation, all analysis shall clearly state the measurement unit. All interface drawings between UCB and Swales shall clearly state dual measurement units (SI and English).

3.5.1 Mass Properties Analyses

In addition to tracking unit and subsystem weights, The MSE, SSE and SED are responsible for ensuring all analyses having to do with system mass properties are completed, including:

1. Centers of gravity of all components
2. Dynamic and/or static imbalance (Probe and Probe Carrier Assembly)
3. Spin-to-transverse moment of inertia ratio
4. Max.-to-min. transverse moment of inertia variation
5. Deployed moments of inertia
6. Moment on the Probe Carrier separation system interface
7. Probe Carrier separation analysis

3.5.2 Power Analyses

The SSE and ELE are responsible for ensuring power levels and usage is summarized for all operating modes by unit and subsystem (including battery charging and distribution losses). This includes:

1. Beginning-of-life (BOL) and end-of-life (EOL)
2. Eclipse and sunlight operations
3. Nominal and worst case operating conditions
4. Transfer orbit and operational orbit
5. Peak and steady state load operation
6. Safe State operations

3.5.3 Propellant

The MSE and GN&C Lead supports the development and maintenance of the maneuver calculator and propellant budget. The propellant budgets reflect changes in satellite mass properties, thruster performance, and/or mission Delta-V requirements. The propulsion subsystem configuration is reviewed, and operational strategies are developed that minimize propellant usage. The propellant budget is used as an input to the mass allocation process.

3.5.4 Pointing (Alignment)

The allowable contribution of the Probe Bus to instrument pointing error, antenna pointing errors (antenna look angle analysis), and attitude sensor pointing error is allocated by the GN&C Lead. The GN&C Lead also works with mechanical and thermal subsystem engineers to develop and maintain an integrated alignment plan, assess the effect of attitude disturbances (thermal transients, thrusters, mechanisms, solar /magnetic torques), and develop strategies to minimize their impacts. The instruments contributions to instrument pointing error and attitude disturbances is assessed cooperatively between the Spacecraft Bus and Instrument Payload leads.

3.5.5 Command and Telemetry Allocations

MSE, SSE and ELE analyzes the requirements for commands and telemetry in order to allocate commands and housekeeping telemetry to Instruments and Subsystems. The allocations are maintained in the Command and Telemetry Lists. These lists must include all information for each command or telemetry point, such as:

1. Mnemonic, title, description, channel number, format
2. Telemetry channel type (analog, bilevel, serial)
3. Command type (low-level pulse, high-level pulse, serial)
4. Indication of hazardous and critical commands

3.5.6 Communications

The MOM and SSE 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 the fidelity of the analysis is increased to reflect details of the Space and Ground Segment properties.

3.5.7 Processing

Key processor parameters tracked by the MSE and SSE include memory, throughput, and bus bandwidth utilization. Processor resource management involves maintenance of adequate spare Random Access Memory (RAM) and Programmable Read Only Memory (PROM).

3.5.8 Data Management

The MOM oversees data management for 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.

4.0 TECHNICAL COORDINATION

The objective of Technical Coordination is to bring all of the technical groups on the program toward a unified baseline mission design that can be verified. This effort involves: coordinating communication between the subsystem leads or technical teams as required (Technical Communication Coordination);

ensuring the baseline design is appropriately captured in easy to find, accurate and up-to-date documentation (Configuration Management); and informing team members of baseline changes in a structured and controlled manner (Configuration Control).

4.1 Technical Communication Coordination

Technical Meetings are divided into two major categories: working groups and technical exchange meetings. Working groups are dedicated towards specific aspects of the program where consistent and frequent contact is required to accomplish a certain aspect of the Project. Technical exchange meetings are scheduled on an ad hoc basis depending to aid in general communication between team members.

4.1.1 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. A member of the Systems Engineering Team is assigned to lead each of the meetings. The Lead is responsible for providing an agenda, distributing minutes from the meetings, and tracking action items. Table 4.1.1-1 provides the THEMIS Working Groups, identifying organizations involved, the Lead and how frequently the meeting occurs. The table does not include Management meetings held routinely between UCB/GSFC and UCB/Swales.

Meeting	Organizations Involved	Lead	Occurrence
UCB/Probe Bus Systems	UCB/Swales	MSE	Weekly
UCB/Probe Bus Mechanical	UCB/Swales	MechSE	Bi-Weekly
UCB/FGM and SCM	UCB/IWF/CETP	PM	Bi-Weekly
UCB/GBO	UCB/Un	GBO Manager	Weekly
UCB IDPU/EFI, SST and ESA	UCB/LASP	PM	Weekly
UCB Magnetics	UCB/Swales/UCLA	MSE	Bi-Weekly
UCB Instrument Meetings (EFI, SST, ESA)	UCB	Inst. Leads	Weekly
UCB Science Operations (SCISOC)	UCB	PI	Weekly
UCB Mission Operations (MOC)	UCB	MOM	Weekly
Swales Subsystem Status	Swales	SSE	Weekly
Swales Launch Vehicle Meeting	Swales/UCB/KSC	GN&C	Bi-Weekly

Table 4.1.1-1: THEMIS Working Meetings

4.1.2 Technical Exchange Meetings

Technical Exchange Meeting (TEM) provides a forum for additional technical discussions required from time to time. Systems Engineering schedules a TEM 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 support from across the program as required. The meetings are informal and minutes are distributed over e-mail.

4.2 Configuration Management

Configuration Management (CM) includes managing the content and release of technical information, including technical memos, requirement documents, interface documents, schematics, and drawings. The

THEMIS Mission CM process is briefly described here as an outline of the process as related to Systems Engineering. UCB's CM process is documented in *THM-SYS-011 Configuration Management Plan* and SA's CM process is documented in the *Swales THEMIS Configuration Control Plan*.

4.2.1 Document Revision Process

The THEMIS document revision process maintains history and protect against uncoordinated/ unauthorized change. The title page of all system documents shall include the Title, Assigned Document Number, Revision Letter, Revision Date, and Appropriate Signatures. The introduction of all system documents shall include a Document Revision List; a Distribution List; and a TBD/TBR List.

The Document Revision List provides the date, revision letter, and short description of the changes since the last revision. The Distribution List provides the name, affiliation, and e-mail of all team members that formally receive the document for review and comment. Changes to the document are brought to the attention of all users by the formal distribution of a revised document. (Drafts are passed freely between members. Suggested changes are typically provided to the author using the 'Track Changes' Tool provided in Microsoft Word). The TBD (To Be Determined)/TBR (To Be Resolved) List provides a tabulation of all the information required in the document. The list includes the responsible organization and date that resolution is due. TBR/TBD logs are reviewed at the release of each new revision to determine the status of each item and identify any roadblocks to resolution of the TBRs/TBDs.

4.2.2 Configuration Accounting System

UCB will implement a configuration accounting system using PDMWorks™. The PDMWorks™ database contains all released drawings. The PDMWorks™ accounting process is further described in *THM-SYS-011 Configuration Management Plan*.

4.3 Configuration Control

Program changes resulting from the identification of problem areas, or from changes in requirements or interfaces need to be managed in order to control the technical baseline (Level 1,2 or 3). The change process used by Systems Engineering shall involve an Impact Assessment (IA) followed by a formal approval process. The IA is attached a System Change Notice (SCN) and submitted to the Configuration Control Board (CCB) for approval. Systems Engineering controls and monitors the documentation, review, and approval of design changes. The MSE is the chief reviewer of all recommended technical changes, and must approve system design changes prior to implementation. *THM-SYS-001 Configuration Management Plan* provides detailed descriptions of these documents (IA, SCN, PFR) and the CCB process.

5.0 TECHNICAL EVALUATION

The Technical Evaluation section introduces the approach used to accurately evaluate the technical status of the project. The MSE uses various levels of reviews to establish how well the project execution is progressing, to identify problem areas, and to communicate technical status to Project Management. By continually and accurately evaluating technical progress, deviations or problems can be flagged in a timely fashion, and system trades can be quickly identified and conducted to minimize program impact.

Technical reviews are divided into two major categories: project reviews and peer reviews. Major Project Reviews are significant milestones in the project and are conducted by the Independent Integrated Review

Team (IIRT). More detailed project reviews covering key technical aspects of major segment of the project such as the spacecraft bus design are conducted prior to the System Level Project Reviews. Peer Reviews are held with independent experts to ready the technical team and critically evaluate the design.

5.1 Project Reviews

The technical progress of the program must be assessed at key milestones to ascertain readiness to transition into the next program phase. These reviews are event driven activities, that is, the technical progress milestones require that certain specific tasks must be completed prior to the conduct of the review. The MSE, along with Project Management, collects and reviews the documentation that demonstrates the technical progress planned for the milestone, and submits the materials as a data package to the review team prior to the review. IIRT is responsible for the agenda, organization, and conduct of the review as well as obtaining closure on any action items and corrective actions. The MSE acts as recorder, noting all comments and questions that are not adequately addressed during the presentations. Requests for Actions (RFAs) are collected at the end of the review and logged.

The following Project Reviews are held in accordance with the MIDEX GPG 8700.4E, “Integrated Independent Reviews”. For more detailed definitions and guidance on the following definitions, refer to MIDEX Program Assurance Guidelines. For all reviews below, a review team independent from the THEMIS organization will coordinate, chair, provide independent reviewers, and provide technical evaluation and issue actions items.

- System Requirements Review (SRR): 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, and that the System specifications are sufficient to meet the project objectives.

- Preliminary Design Reviews (PDRs): A comprehensive, technical review 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.

- Confirmation Review: A formal review that provides the authority for the mission to proceed to Phase C.

- Critical Design Reviews (CDRs): 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, Elements, and Segment CDRs.

- Pre-Environmental Review (PER): A formal technical review of the System that establishes functional compliance with all technical requirements prior to exposure to environmental testing.

- Mission Operations Review (MOR): A formal review to determine the state of readiness of the Ground Segment to support the System operations functions.

- Pre-Ship Review (PSR): 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 preflight activities planned for the launch site and other support areas.

- Mission Readiness Review (MRR): A formal review to determine the overall readiness of the System for launch.

5.2 Peer Reviews

The THEMIS Peer Review process follows the guidelines and checklist provided in NASA GPG-8700.6 Engineering Peer Reviews. Subsystem Peer Reviews are typically held prior to major project reviews. Details of the THEMIS Peer Reviews are contained in CDRL II: THEMIS Engineering Peer Review Plan.

5.3 Systems Trades

After detailed technical evaluation of a design (either at a review or as a natural occurrence during the design process), system-level trades may be conducted. The trades assess proposed changes to the System/Subsystem configuration or architecture often suggested during the review process. Results are used to update and detail system performance and design requirements allocations as necessary. Trade analyses should consider:

1. Assessment of technical and development risks
2. Effects on operations
3. Impact on verification
4. Effects on programmatics
5. Predicted performance

All major trade analyses will be documented in an informal Engineering Memo (EM) format and provided to the CCB for consideration. The EM will identify the subject, tradeoff considerations, and results. Trade recommendations will address technical, cost, and schedule impacts to the program.

6.0 RELIABILITY ENGINEERING and RISK MANAGEMENT

This section provides an overview of the analyses and other tasks that supports the Systems Engineering reliability engineering and risk management functions.

6.1 Reliability Engineering

Systems Engineering reliability analysts provides an estimate of the mission lifetime probability of success. If reliability falls below the specified levels, the MSE, SSE and SED suggest design changes that improve the reliability at minimum cost. Tradeoffs also suggest means of reliability improvement for modest use of weight, power, schedule or other resources. THEMIS shall follow the reliability evaluation process shown here:

1. Establish reliability criteria for the System
2. Gather reliability data for parts/subassemblies/assemblies
3. Specify Space Segment operating modes for the purposes of reliability modeling, which will be part of the Fault Tree Analysis (FTA)

4. Support Subsystem/Reliability Engineers in calculating and evaluating reliabilities based on design complexity, operational use, parts count, parts type, and parts failure rates. This information will be used in the Probabilistic Risk Assessment (PRA). This effort can involve:
    - Electronic parts stress derating analyses
    - Worst case circuit analyses
    - Mechanical device stress analyses
    - Thermal analyses
    - Life limiting wearout analyses defining operational constraints for each unit and evaluating margins
    - Test failure (if applicable) identification, investigation, documentation, reporting, and corrective action definition
5. Perform initial Failure Modes and Effects Analyses (FMEAs) by determining critical unit failures at interfaces between each unit (their input/output) and determining existing levels of function redundancy
6. Complete system level analyses, identify the lowest reliability parts/assemblies, and define means of eliminating susceptibility
7. Evaluate and select design changes with the lowest system impact to increase reliability, if needed
8. Perform risk assessment, and with Project concurrence, make decision on design change
9. If Yes, modify the design to account for low reliability areas
10. Perform tests to verify design (e.g. mechanism life cycle testing)
11. Finalize FMEA results, showing current design meets the criteria
12. Identify telemetry to monitor low reliability areas
13. For Ground Segment equipment, incorporate results into the sparing requirements and maintenance facility requirements.

6.1.1 Fault Detection, Isolation, and Recovery

Reliability Engineering also defines the Fault Detection, Isolation, and Recovery (FDIR) strategy and requirements, using heritage designs as much as possible. These will become the bases for development and implementation of Element and Subsystem FDIR. The FDIR system concept will be documented and controlled.

6.2 Risk Management

Risk Management is performed to identify the risk areas early in the program, developed plans to reduce this risk and implemented these plans. The Risk Management Plan for THEMIS is documented inTHEMIS Continuous Risk Management Plan, CDRL 5. The Risk Management Plan document will be used to maintain the specifics of the risk management effort and will also document the products. Risk Management is conducted in four phases: Risk Assessment, Risk Analysis, Risk Planning, and Risk Plan Implementation and Tracking. The MSE, ISE and SSE are responsible for the implementation of the Risk Management process. Project Management is responsible for reporting to the Program Office the highest risks and the status of contingency or mitigation efforts.

6.2.1 Risk Assessment

The first phase, Risk Assessment, uses a survey to identify potential risk elements. The surveys are conducted across the project to provide comprehensive coverage of the program. The Assessment process examines the number of components, their technical maturity, and their complexity, and produces a ranking of the risk each item contributes to the program. These rankings are broken out into Low, Moderate, and High risk groupings, where a few, highly mature and simple components are the lowest risk, and the opposite is high. The assessments are rolled up by Systems Engineering, taking account of independent and dependent risk items which is necessary to avoid cascading problems.

6.2.2 Risk Analysis

Risk Analysis entails the quantification of specific failure modes contributing risk to the program, and the exploration of potential solutions. Data relating to each risk item shall be collected, detailing the rationale for its being a risk and the impacts to the program if that particular failure occurs, including any dependencies of one risk on another. Alternative design solutions are investigated, with Systems Engineering providing oversight with regard to requirements. The results of this effort are combined with the cost and schedule impacts to arrive at a set of possible alternative solutions. The alternatives are evaluated based on risk minimization, cost, schedule and impact to other subsystems to determine the best candidates for implementing.

6.2.3 Risk Planning

The third phase of the Risk Management process, Risk Planning, encompasses the planning of response and abatement strategies to minimize overall program risk. The best solution(s) identified from analysis shall be presented to the program office for final decision. Selected solutions shall be incorporated into abatement plans for High Risk failure modes to proactively mitigate the risk; response plans shall be developed for Moderate risk elements to be activated if a failure develops.

6.2.4 Risk Plan Implementation and Tracking

The products of the planning effort will be continuously reviewed and updated by the MSE as the program progresses. This will ensure that the issues highlighted reflect the current design approach, allow an assessment of the effectiveness of any abatement plans, and trigger implementation of any response or abatement plans. Swales will implement a risk management plan and database at the probe bus and carrier level and report top level risks to UCB for tracking at the mission level.

7.0 INTEGRATION AND TEST COORDINATION

7.1 Integration Activities

Integration and Test 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 the Probe Carrier Assembly (PCA) design can be easily integrated and tested. In the implementation phase this includes planning, directing and implementing the test and integration processes for the Instrument Payload, the Probes and the PCA.

7.1.1 Subsystem Integration

MSE and SSE has the responsibility for ensuring that all unit and subsystem testing satisfies program requirements. MSE and SSE review all subsystem test plans and procedures to ensure that all specification requirements will be verified and reviews results along with the Subsystem lead. Subsystem Integration begins when the first integrated test of one or more assemblies.

7.1.2 Software Integration

Integration of all the Mission software within the Project is performed by the Software Engineers, in coordination with the Mission Operations Manager for Ground Software. 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 probe ELE 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.

7.1.3 System Integration

During system integration, MSE and SEE have the responsibility for assuring that all lower level testing satisfied program requirements, and that the systems integration process incorporates all testing which cannot be performed during system testing. Prior to Subsystem integration, the MSE and SSE review the hardware status along with relevant Subsystem personnel. This meeting is held for all flight hardware and test equipment. The MSE and SSE are responsible for leading the review of any open discrepancies, liens, non-conformance reports, failure reports, or waivers etc, and determination of action to be taken to resolve these items prior to System Integration. The hardware status and as-built condition should be reviewed and compared with the design, will all discrepancies reconciled, and any test data should be reviewed and made available for system level testing comparison. System Integrated begins with the

7.2 Test Activities

7.2.1 Pre-Test Activities

The MSE, SSE and SED bear 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, as well as verifying that it is accounted for in the system level comprehensive test plan. 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.

The MSE and SSE prepare or review all test plans and procedures. For test plans this responsibility includes verifying that the planned tests will meet project requirements, provide the necessary data for design/ performance verification, be conducted under the proper environmental conditions, and ensure 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.

7.2.2 Testing Activities

During testing, the SSE or designee 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, The SSE also 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, the SSE makes sure that all procedure paragraphs are run unless deviations have been agreed to.

7.2.3 Post Test Activities

The SSE 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. For any test anomaly, the test director logs the test anomaly, and, when appropriate, generates a special test request. The SSE and SED are 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, the response is one of the following:

1. If the anomaly is due to the as-built configuration being different than the as-designed, but there is no adverse performance, a discrepancy is recorded in a Discrepancy 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 Performance-As-Run 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 Problem 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. The MSE, SSE, and SED are 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:

1. 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
2. Reviewing corrective action plans including approval or repeat testing, considering expected benefit versus schedule impact
3. When an PFR causes a unit to be reworked, reviewing and approving the unit reacceptance test plan, defining retest required at the system level$_1$ and defining any required process, material, or facility changes
4. Examining need for retrofit of already assembled, tested, or delivered hardware

7.3 Launch Operation Activities

Launch operations begin with shipment of the PCA to the launch site; continue through integration, final testing, fueling, and encapsulation; and ends 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. The SSE or designee 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.

7.3.1 Planning

The SSE or SED writes the launch site support plan, which is coordinated with NASA, the launch vehicle contractor, and 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 PCA, and meets the PCA 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 PCA requirements as needed.

7.3.2 Procedures

The SSE and SED review launch site test procedures to verify the testing validates the readiness of the PCA for launch. Launch site testing also verifies the integrity of the PCA following shipment. Responsibilities for launch site test procedure review include:

- Assure that procedures scheduled for the launch site have been rehearsed prior to shipment
- Generate the requirements for special launch site test procedures to confirm proper integration of the PCA prior to launch
- Assure that all launch vehicle interfaces have been properly validated prior to integration of the PCA with the launch vehicle

7.3.3 Checklist

Final PCA integration at the launch site is the responsibility of the Spacecraft Systems Engineer (SSE). The SSE’s checklist indicates operations, in chronological order, that must occur before launch. The Systems Engineering Team reviews the checklist to assure that all required events are listed and signs off the completed checklist before launch. The checklist must include the following, listed in sequential order:

- All mechanical operations
- All testing or check-outs to be performed w/ procedures
- Installation of all flight items
- Removal of all non-flight items
- Critical clearance measurements to be taken
- Final inspections to be performed

7.3.4 Launch Site Testing

Launch site testing parallels the earlier test and integration program, and require MSE and SSE participation. Specific responsibilities include:

1. Overseeing integration and system validation to: ensure testing is adequate to detect adverse effects of shipment, verify proper satellite functioning, launch compatibility, and readiness; and evaluate trends and test data to determine possible hardware degradation
2. Overseeing hazardous operations such as fuel loading by checking calculations, measurements, and handling anomalies
3. Overseeing launch vehicle integration, resolving anomalies that may occur, and completing final inspection of the PCA following installation of final close-outs and encapsulation within the launch vehicle fairing
4. Preparing for launch operations by: conducting the Launch Readiness Review based on successful completion of all test and integration activities; supporting checkout of voice and data links for launch; determining readiness of ground stations to support pre- and post-launch activities; and verifying on-pad readiness of satellite for launch including telemetry functions, battery state of charge, and environmental readiness

7.3.5 Data Analysis

Launch site testing provides that last test data prior to launch which must be carefully evaluated by the MSE and SSE to establish satellite readiness for launch. Specific responsibilities for launch site test data analysis include:

1. Comparison of launch site test data with previously taken trend data to verify that no hardware degradation has occurred
2. Document relevant launch site test results for possible use during mission operations.

7.3.6 Launch Day Rehearsals and Operations

The Systems Engineering Team will participate in launch day rehearsals and launch operations. The MSE will be the focal point for the Systems Engineering Team and will report launch readiness to the THEMS Project Manager.

Launch site testing provides that last test data prior to launch which must be carefully evaluated by the MSE and SSE to establish satellite readiness for launch. Specific responsibilities for launch site test data analysis include:

7.4 Flight Operations & Ground Systems

The Flight Operations and Ground Systems function is to plan all Phase E activities. The MOM provides Ground Segment requirements, defines the test and verification program and performs system level analyses to predict performance and verify the design modifications meet the System requirements. The MOM also provides the early operations planning and technical support to operations from launch to the completion of all on-orbit and ground tests.

7.4.1 Planning

The MOM prepares key operations planning documents for the operations concept, 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 for spares, i.e. on site or buy as needed.

7.4.2 Procedures

All 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 telemetry responses. The MOM supports the Subsystem and Test Engineers in developing the procedures based on command sequences which have been verified from subsystem tests, and includes these procedures in the operating manual. Operations procedures should also identify all 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.

7.4.3 User Interface Management

The MOM's role in the User Interface for the Ground Segment is to ensure that the system will be adequate to meet all the Ground Segment requirements. The interface to the Ground Systems should be user friendly, with information in known units, with access to the databases for all operators, and be hosted on reliable platforms. The MSE reviews and approve all operations manuals and handbooks documenting the functions and characteristics of the Space and Ground Segment hardware and software.

7.4.4 Training

The MOM's 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.

7.4.5 Verification

The MOM defines the verification program in the Operations Test 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.

7.5 Post Launch

The MOM is responsible for the development of the launch and early orbit mission plan that describe 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. The MOM 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, the MSE produces the 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.