THEMIS

Mission Requirements Document

THM-SYS-001

Revision A, July 2003

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DOCUMENT REVISION RECORD

Rev	Date	Description of Change	POC
Draft			
1	8/25/02	Began Drafting Mission Requirements from Proposal	PRH
2,3,4	4/23/03	Began Refining Mission Requirements from Concept Study Review (CSR)	ERT
5,6,7	5/25/03	Moved Mission Requirements into agreed-upon database format	ERT
8	5/28/03	Refined Mission Requirements from Instrument/Probe Internal Reviews (5/27, 5/28)	ERT
9a,9b	6/2/03	Added Scope, Flow, Definitions, Traceability, Trees Pages, and modified PB/PC subsystem requirements.	KSB
10	6/2/03	Added Rationale for Systems, IDPU Requirements.	ERT
11	6/3/03	Changed Level for many Mission Requirements from 2-System to 2-Space Seg.	KSB
12	6/7/03	Refined Mission Requirements from Science Requirements Review (6/3, 6/4)	ERT
13a	6/11/03	Implemented tools, incorporated all subsystem requirements, started linking subsystem req up to Mission. Highlighted changes in red text.	KSB
13b	6/12/03	Incorporated all changes from Swales internal reviews of Programmatic, Mission, PB, and subsystem requirements, started linking subsystem req up to Mission/Programmtic. Highlighted changes in red text. Changed Scope, Flow, and Definitions pages.	KSB
14	6/14/03	Red text changed to black text for accepted changes.	ERT
15	6/19/03	Refined Mission Requirements from Swales Requirements Review (6/17, 6/18)	ERT
16b	6/25/03	Updated PB/PC subsystems, and added Parent Ids.	KSB
16c	6/26/03	Refined Mission Requirements from Mission Requirements Dry Run Review (6/24, 6/25)	ERT
16d	7/1/03	Added Traceability Tree. Highlighted changes in red text.	ERT
16e	7/2/03	Changed requirements, titles, rationales (deleted text deleted, added text in red): IN.BOOM-1,2; PB-41, 42,44,45; PB.ACS-5, 6, 7, 8, 13, 14, 17, 18, 19; PB.CDH-28, 31, 39, 41; PB.Mec-6, 8, 9, 10, 11; PC-1, 2, 9; PC.Mec-1, 2, 6.	KSB
17	7/2/03	Added Ground Segment. Cover Page, Signiture Page. Small changes to traceability tree.	ERT
REV			**Approval**
A	7/8/03	First Release of Mission Requirements Document at System Requirements Review (SRR)	ERT

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Identifier	Description

1 Introduction

2 Mission Requirements Table

1.1 Scope

The THEMIS Mission Requirements Document (MRD) establishes the functional, performance and design requirements for the THEMIS Mission. It provides an official list of Level 2 (Space, Launch and Ground Segments) and Level 3/4 (Derived Instrument, Probe Bus, Probe Bus Carrier, Ground Based Observations, and Mission Operations down to the Subsystem Level) requirements. Level 1 Requirements (Science and Programmatic) are documented in *Program Level Requirements for the THEMIS Mission* and included here to illustrate requirement flow-down and trace-ability. Interface requirements are specified in Interface Control Documents (ICDs) between the space segment (*Instrument-to-Probe ICDs, Instrument-to-IDPU ICDs*); launch segment (*Probe-to-Launch Vehicle ICD*); and ground segment (*Probe-to-MOC ICD, MOC-to-SOC ICD*). Design verification and environmental test requirements are specified in the *THEMIS Verification and Environmental Test Specification*. Quality assurance and part selection requirements are documented in the *THEMIS Performance Assurance and Implementation Plan (PAIP)*.

1.2 Applicable Documents

Figure 1 shows the parent documents levied on the project from which mission requirements have been transferred or derived.

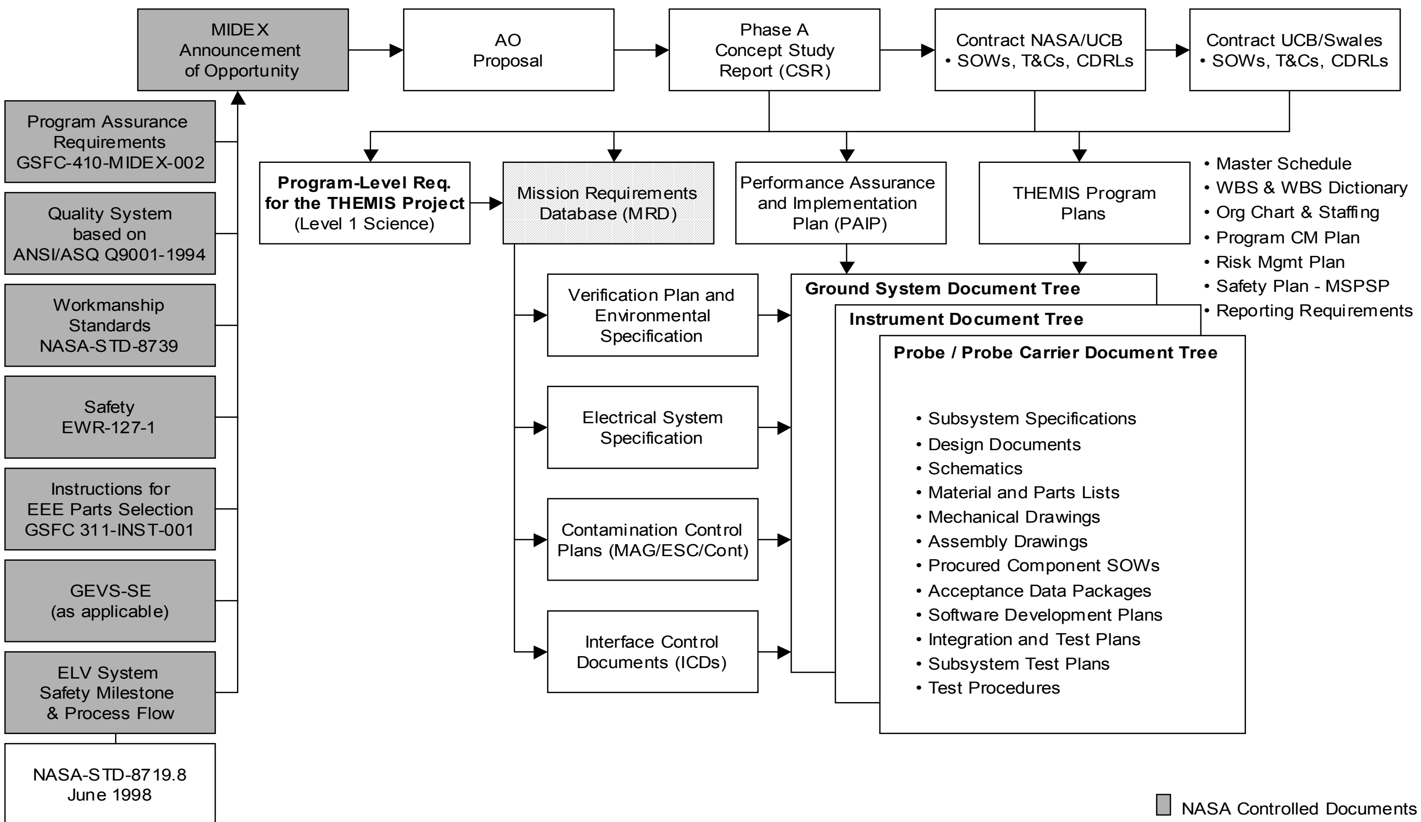

Figure 1: THEMIS Requirement Document Tree

1.3 Reference Documents

The following project documents are referenced in this MRD as separately binding documents.

THEMIS Magnetics Cleanliness Plan
THEMIS Contamination Control Plan
THEMIS Electrostatic Cleanliness Plan
THEMIS Performance Assurance and Implementation Plan
THEMIS Verification Plan and Environmental Test Specification
THEMIS Electrical System Specification
THEMIS Instrument-to-Probe ICDs
THEMIS Instrument-to-IDPU ICDs
THEMIS Probe-to-IDPU ICD
THEMIS Ground System ICDs (Space-to-Ground link, Ground Station, Data System)
Boeing Mission Specification for the THEMIS Mission
THEMIS Probe-to-Probe Carrier ICD
THEMIS Flight Software Specifications

1.4 Revisions

This Mission Requirements Document (MRD) shall be approved and signed by the authorized representatives of UCB and Swales. Each signatory is responsible for informing and obtaining concurrences from all cognizant members of their organization. The document shall become effective when signed by all relevant parties, and is binding on the organizations until mutually agreed upon revisions are released. Unsigned copies of this document are considered to be “Preliminary Only,” and subject to internal changes.

1.5 Approvals

Request for revisions to the MRD are made through a formal change process. UCB is responsible for oversight of revisions and will maintain documentation for all change requests. Any changes must be routed to the Mission System Engineer, who will obtain the necessary agreement from scientists and engineers (starting with those people on the signature page, but also including subsystem leads for any affected systems) before posting it as the official version. Changes are approved and signed by the authorized representatives of UCB and Swales.

1.6 Mission Science Objectives

The THEMIS (Time History of Events and Macroscale Interactions During Substorms) Mission, a NASA Middle Explorer (MIDEX) program, is aimed at understanding the onset and macroscale evolution of magnetospheric substorms. A substorm is an instability in the circulation of magnetic flux and plasma through the solar wind-magnetospheric system ultimately linked to the familiar auroral eruptions on Earth’s polar ionosphere. THEMIS will determine for the first time when and where in the magnetosphere substorms start, and how they evolve macroscopically. Specifically, THEMIS will:

· Establish when and where substorms start;
· Determine how the individual substorm components interact macroscopically;
· Determine how substorms power the aurora; and
· Identify how the substorm instability couples dynamically to local current disruption modes.

Figure 2 shows the THEMIS baseline goals and objectives:

	Science Objective	Science Goal
Primary	Onset and evolution of substorm instability	Time history of auroral breakup, current disruption, and lobe flux dissipation at the substorm meridian by timing: • Onset time of auroral breakup, current disruption and reconnection within <10s. • Ground onset location within 0.5° in longitude and in space within $1R_E$.
		Macroscale interaction between current disruption and near-Earth reconnection.
		Coupling between the substorm current and the auroral ionosphere.
		Cross-scale energy coupling between the macroscale substorm instability and local processes at the current disruption site.
Secondary	At radiation belts: Production of storm-time MeV electrons	Source and acceleration mechanism of storm-time MeV electrons
Tertiary	At dayside: Control of solar wind-magnetosphere coupling by upstream processes	The nature, extent and cause of magnetopause transient events.

Figure 2: THEMIS Baseline Goals and Objectives

1.7 Mission and Instrument Description

The THEMIS science objectives are achieved by five space probes in high earth orbits (HEO) with similar perigee altitudes (1.16 to 1.5 earth radii, Re) and varying apogee altitudes (12.1 to 30 Re). The probes align within the plane of the substorm instability, providing plasma particle and field signatures at several locations in the Earth's magnetotail. Simultaneously, a dense network of ground observatories monitor auroral light and ionospheric currents to provide the time, location, and evolution of the auroral manifestation of the substorm.

The THEMIS probes are launched on a Delta II launch vehicle into a direct injection orbit close to the final science orbit of the 3 inner probes. An on-board hydrazine propulsion reaction control system (RCS) performs the placement of each probe into its final orbit. The probes are spin-stabilized with a passive thermal design. Power from body-mounted solar panels and a Li Ion battery is controlled by a direct energy transfer system. Instrument and probe components are mounted on a stiff base-plate within a composite bus structure. Science and housekeeping data is downlinked daily to the primary ground station at the University of California - Berkeley (UCB) through a low-rate S-band communication system.

Each Probe carries and Instrument Payload comprised of: an Electric Field Instrument (EFI); an Electrostatic Analyzer (ESA); a Solid State Telescope (SST); a FluxGate Magnetometer (FGM); and a Search Coil Magnetometers (SCM).

1.8 Mission Operation Concept

PRELAUNCH:

Configuration: All five probes mounted on the carrier installed on the vehicle.

Communications via hardline only, no RF. Probes monitored and communicated with one at time round robin style from a single set of remotely operated EGSE from KSC for prelaunch testing and to configure for liftoff. All launch operations are conducted locally from KSC. Ready for launch requires Go from probe console at KSC and Go from Mission Operations Center at UCB for TDRSS, BGS, USN/Perth and Operations Center.

LAUNCH AND ASCENT:

Configuration: Starts with all five probes mounted on the carrier, end with each probe on-orbit. Instruments and IDPU off, Probe in launch mode.

Each probe becomes autonomous at liftoff as the umbilical is separated. One designated probe will begin transmitting RF at 1 kbps upon fairing separation for reception by TDRSS to Mission Operations Center at UCB. The probes sense vehicle staging and initiate separation into a safe and stable configuration. UCB initiates communication with each probe one at a time round robin style to assess health and safety (the receivers in all five probes are always powered; only the transmitter needs to be turned on). Initial assessment focused on power system performance: battery DOD, array voltage and currents, etc. followed by other bus subsystems: propulsion system status, spin axis orientation, spin rate, sun angle, etc.

EARLY ORBIT OPERATIONS:

Configuration: Starts with each probe in the on orbit stowed configuration with the Instruments and IDPU off. Probes are spinning at approximately 15 rpm with the spin axis pointed normal to the plane of the ecliptic.

Each probe powers on the IDPU and instrument health assessed one at a time. Preliminary assignment to orbital slot is made. Thruster calibration occurs and both magnetometer and sun sensor data are telemetered to the Mission Operations Center to compute the on orbit attitude and all maneuvers.

Thruster Firing Mode: Dial down ESA high voltage, enable FDC, Transmitter ON, bus power negative

Communications Mode: Transmitter ON, bus power negative (battery discharging)

All Probes go through Delta-V maneuvers to align the constellation for the upcoming wedding season.

Once a probe is in the desired orbit the EFI deployment begins. Radial EFI’s are deployed in opposing pairs in steps interspersed with thruster firings to maintain proper spin rate. After all four radial wire booms are completely deployed the axial booms are deployed. All deployments occur only during ground contact.

MISSION OPERATIONS:

Configuration: Each probe has all instruments fully deployed and is in the desired target orbit for the next wedding season. Probes are spinning at approximately 15 rpm with the spin axis pointed within 10 degrees of normal to the plane of the ecliptic.

Probe Bus Avionics Unit (BAU) passes raw sun sensor data to IDPU for science assessment of spin rate and sun position. IDPU and BAU exchange routine housekeeping data. BAU passes commands from the ground to the IDPU.

Ephemeris comes from periodic two way Doppler ranging between BGS and the probe transponder with additional data from NORAD.

Each probe has at least a single pass per day scheduled to provide the mission operations team insight into ongoing health and safety and to downlink all engineering telemetry and any science data.

Expect Delta-V maneuvers for each probe several times a year for shadow avoidance and constellation alignment maintenance, especially for lunar perturbations on P1 and P2.

END OF LIFE:

Perform a depletion burn to expend all remaining propellant and minimize remaining orbital lifetime. Retract wire booms if possible to minimize potential for orbital debris.

1.9 Requirement Flow-down

Figure 3 illustrates the THEMIS requirement flow-down. All requirements are mapped to WBS level in the Requirements Table.

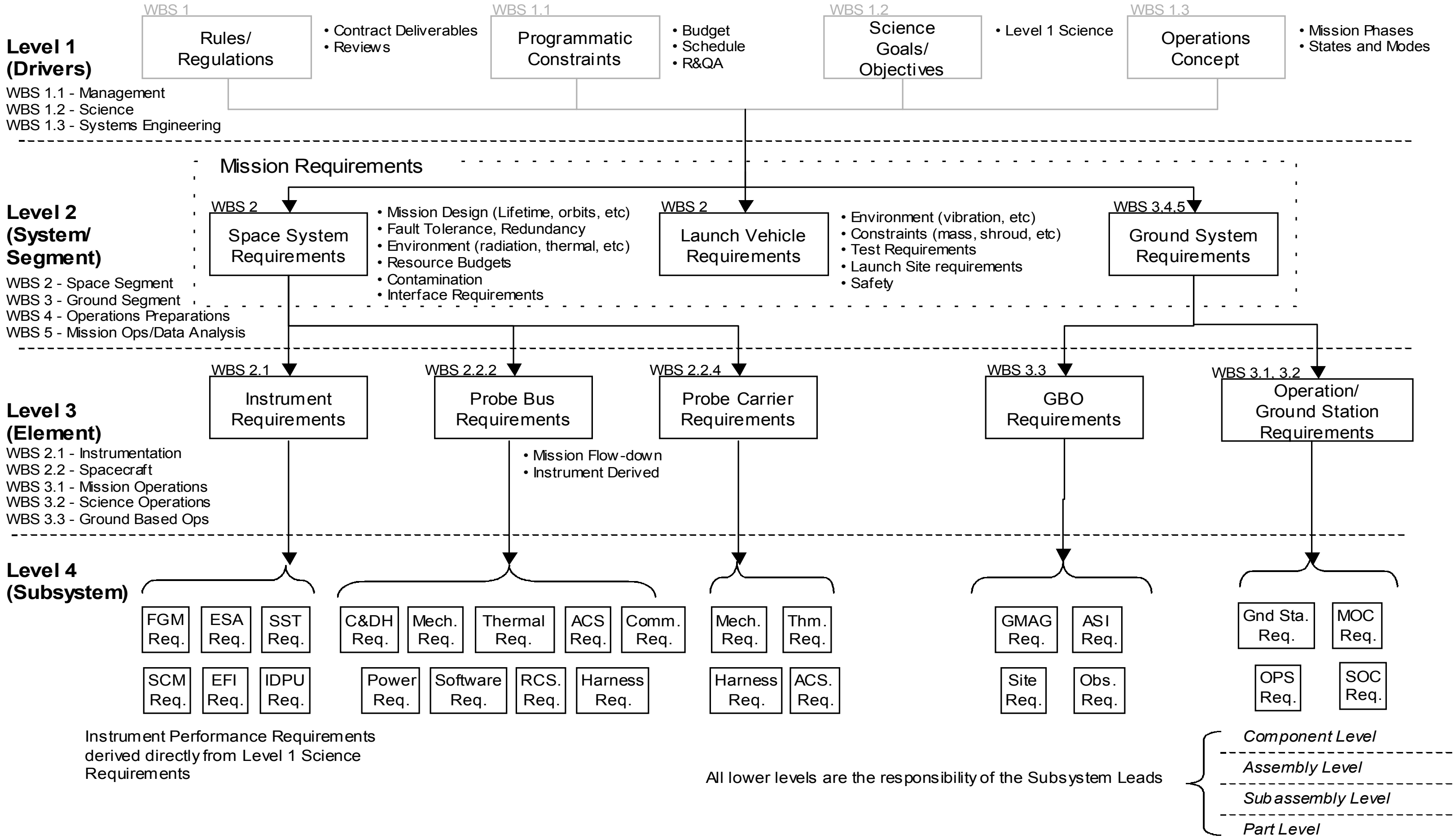

Figure 3: THEMIS Requirement Flow-down

1.10 Requirement Table Definition

The Requirements Table 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

Each Requirement has a specific ID number which adheres to the following key:

KEY: Requirements ID Labeling	
Prefix	**Definition**
S	Science (Drivers) Requirements
P	Progammatic/Rules/Operations (Drivers)
M	Mission (System/Segment)
IN	Instrument (Element)
PB	Probe Bus (Element)
PC	Probe Carrier (Element)
GS	Operation/Ground Station (Element)
GB	Ground Based Observatory (Element)

Note: All labels below are at the Subsystem level	
IN.DPU	Instrument Data Processing Unit
IN.EFI	Electric Field Instrument
IN.ESA	Electrostatic Analyzer
IN.SST	Solid State Telescope
IN.FGM	Fluxgate Magnetometer
IN.SCM	Search Coil Magnetometer
PB.Com	PB Communications
PB.ACS	PB Attitude Control System
PB.RCS	PB Reaction Control System
PB.EPS	PB Electrical Power System
PB.CDH	PB Command & Data Handling
PB.FSW	PB Flight Software
PB.Mec	PB Mechanical Systems
PB.Thm	PB Thermal Systems
PB.Hrn	PB Harnesses
PC.Mec	PC Mechanical Systems
PC.Thm	PC Thermal Systems
PC.Hrn	PC Harnesses
GS.STN	GB Ground Station
GS.MOC	GB Mission Operations Center
GS.OPS	GB Operations
GS.SOC	GB Science Operations Center
GB.ASI	GB All Sky Instrument
GB.MAG	GB Ground Magnetometer
GB.OBS	GB Observatory
GB.GnS	GB Ground Site

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Science Requirements (S-#)								
UCB	VA	WBS 1.2	S-1	1-Drivers	Substorm Onset Time	Determine substorm onset time and substorm meridian magnetic local time (MLT) using ground ASIs (one per MLT hr) and MAGs (two per MLT hr) with t_res<30s and dMLT<1 degree respectively, in an 8hr geographic local time sector including the US.	*Primary Science Objective - Onset and evolution of substorm instability. Science Goal 1: Time History of auroral breakup, current disruption (CD), and lobe flux dissipation at the substorm meridian*	N/A
UCB	VA	WBS 1.2	S-2	1-Drivers	Current Disruption Onset Time	Determine current disruption onset time with t_res<30s, using two near-equatorial (within 2Re of magnetic equator) probes, near the anticipated current disruption site (~8-10 Re). Current disruption onset is determined by remote sensing the expansion of the heated plasma via superthermal ion flux measurements at probes within +-2Re of the measured substorm meridian and the anticipated altitude of the current disruption.	*Primary Science Objective: Onset and evolution of substorm instability. Science Goal 1: Time History of auroral breakup, current disruption (CD), and lobe flux dissipation at the substorm meridian*	N/A
UCB	VA	WBS 1.2	S-3	1-Drivers	Reconnection Onset Time	Determine reconnection onset time with t_res<30s, using two near-equatorial (within 5Re of magnetic equator) probes, bracketing the anticipated reconnection site (20-25Re). Reconnection onset is determined by measuring the time of arrival of superthermal ions and electrons from the reconnection site, within dY=+-2Re of the substorm meridian and within <10Re from the anticipated altitude of the reconnection site. In addition, dawn-dusk DC electric field measurements and energetic ion finite gyroradius-technique determination of the velocity of the expanding plasma sheet boundary are required to determine the actual distance to the reconnection site (with dE/E=10% or 1mV/m accuracy whichever is larger, and dV/V=10% or dV=50km/s whichever is larger, respectively).	*Primary Science Objective: Onset and evolution of substorm instability. Science Goal 1: Time History of auroral breakup, current disruption (CD), and lobe flux dissipation at the substorm meridian*	N/A
UCB	VA	WBS 1.2	S-4	1-Drivers	Simultaneous Observations	Obtain simultaneous observations of: substorm onset and meridian (ground), current disruption onset and reconnection onset for >10 substorms in the prime observation season (September-April). Given an average 3.75hr substorm recurrence in the target tail season, a 2Re width of the substorm meridian, a 1Re requirement on probe proximity to the substorm meridian (of width 2Re) and a 20Re width of the tail in which substorms can occur, this translates to a yield of 1 useful substorm event per 18.75hrs of probe alignments, i.e, a requirement of >188hrs of four-probe alignments within dY=+-2Re.	*Primary Science Objective: Onset and evolution of substorm instability. Science Goal 1: Time History of auroral breakup, current disruption (CD), and lobe flux dissipation at the substorm meridian*	
UCB	VA	WBS 1.2	S-5	1-Drivers	Ion and Electron Fluxes	Use the SST to measure near the ecliptic plane (within +-30degrees) the superthermal ion and electron fluxes (30-100keV) at t_res<30s.	*Primary Science Objective: Onset and evolution of substorm instability. Science Goal 1: Time History of auroral breakup, current disruption (CD), and lobe flux dissipation at the substorm meridian*	N/A
UCB	VA	WBS 1.2	S-6	1-Drivers	Earthward Ion Flows	Track between probes the earthward ion flows (400km/s) from the reconnection site and the tailward moving rarefaction wave in the magnetic field, and ion plasma pressure (motion at 1600km/s) with sufficient precision (dV/V=10% or V within 50km/s whichever is larger, dB/B=10%, or B within 1nT whichever is larger, dP/P=10%, or P within 0.1nPa whichever is larger) to ascertain macroscale coupling between current disruption and reconnection site during >10 substorm onsets (>188hrs of four-probes aligned within dY of +-2Re).	*Primary Science Objective: Onset and evolution of substorm instability. Science Goal 2: Macroscale interaction between current disruption (CD), and near-Earth reconnection (RX)*	N/A
UCB	VA	WBS 1.2	S-7	1-Drivers	Pressure Gradients	Determine the radial and cross-current-sheet pressure gradients(anticipated dP/dR, dP/dZ ~0.1nPa/Re) and ion flow vorticity/deceleration with probe measurement accuracy of 50km/s/Re, over typical inter-probe conjunctions in dR and dZ of 1Re, each during >10 onsets. The convective component of the ion flow is determined at 8-10Re by measurements of the 2D electric field (spin-plane to within +-30degrees of ecliptic, with dE/E=10% or 1mV/m accuracy whichever is larger) assuming the plasma approximation at t_res<30s.	*Primary Science Objective: Onset and evolution of substorm instability. Science Goal 2: Macroscale interaction between current disruption (CD), and near-Earth reconnection (RX)*	N/A
UCB	VA	WBS 1.2	S-8	1-Drivers	Cross-Current-Sheet Change	Determine the cross-current-sheet current change near the current disruption region (+-2Re of meridian, +-2Re of measured current disruption region) at substorm onset from a pair of Z-separated probes using the planar current sheet approximation with relative (interprobe) resolution and interorbit (~12hrs) stability of 0.2nT.	*Primary Science Objective: Onset and evolution of substorm instability. Science Goal 2: Coupling between the substorm current and the auroral ionosphere*	N/A

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
UCB	VA	WBS 1.2	S-9	1-Drivers	MHD	Obtain measurements of the Magneto-Hydrodynamic (MHD) and non-MHD parts of the plasma flow through comparisons of ion flow from the ESA detector and ExB flow from the electric field instrument, at the probes near the current disruption region, with t_res<10s.	*Primary Science Objective: Onset and evolution of substorm instability. Science Goal 2: Coupling between the substorm current and the auroral ionosphere*	N/A
UCB	VA	WBS 1.2	S-10	1-Drivers	Cross-tail pairs	Determine the presence, amplitude, and wavelength of field-line resonances, Kelvin-Helmholz waves and ballooning waves on cross-tail pairs (dY=0.5-10Re) with t_res<10s measurements of B, P and V for >10 substorm onsets.	*Primary Science Objective: Onset and evolution of substorm instability. Science Goal 3: Cross-scale energy coupling between macroscale substorm instability and local processes at the current disruption site.*	N/A
UCB	VA	WBS 1.2	S-11	1-Drivers	Cross-field current instabilities	Determine the presence of cross-field current instabilities (1-60Hz), whistlers and other high frequency modes (up to 600Hz) in 3D electric and magnetic field data on two individual probes near the current disruption region for >10 substorm events.	*Primary Science Objective: Onset and evolution of substorm instability. Science Goal 3: Cross-scale energy coupling between macroscale substorm instability and local processes at the current disruption site.*	N/A
UCB	VA	WBS 1.2	S-12	1-Drivers	Radiation Belt Science	Goal: Determine the source and acceleration mechanism of storm-time MeV electrons (at radiation belts)	*Secondary Science Objective: At radiation belts, production of storm-time MeV electrons.*	N/A
UCB	VA	WBS 1.2	S-13	1-Drivers	Dayside Science	Goal: Determine the nature, extent and cause of magnetopause transient events (on dayside)	*Tertiary Science Objective: At dayside, control of solar wind-magnetosphere coupling by upstream processes.*	N/A
Science Data Requirements								
UCB	VA	WBS 1.2	S-14	2-Ground Segment	Science Data Management	The THEMIS Principal Investigator shall be responsible for initial analysis of the data, its subsequent delivery to an appropriate data repository, the publication of scientific findings, and communication of results to the public.		N/A
UCB	VA	WBS 1.2	S-15	2-Ground Segment	Science Data Validation	The THEMIS Principal Investigator shall be responsible for collecting housekeeping, and ancillary information necessary to validate and calibrate the scientific data prior to depositing it in a NASA approved data repository.		N/A
UCB	VA	WBS 1.2	S-16	2-Ground Segment	Data Dissemination Time	The time required to complete this process shall be the minimum necessary to provide accurate scientific data to the science community and the general public.		N/A
UCB	VA	WBS 1.2	S-17	2-Ground Segment	Data Dissemination Restrictions	The THEMIS science data base shall be made available to the science community without restrictions or proprietary data rights of any kind.	*NASA Requirement.*	N/A
UCB	VA	WBS 1.2	S-18	2-Ground Segment	Science Data Analysis Software	Science analysis software shall be developed by the PI team and integrated into the NASA approved data repository.		N/A
UCB	VA	WBS 1.2	S-19	2-Ground Segment	Equal-Access	The PI team and the science community shall have equal on-line access to this software.		N/A
UCB	VA	WBS 1.2	S-20	2-Ground Segment	Data Management Plan	The THEMIS Project shall develop a data management plan to address the total activity associated with the flow of science data, from acquisition, through processing, data product generation and validation, to archiving and preservation. The data management plan shall be delivered no later than the THEMIS Critical Design Review		N/A

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Programmatic Requirements (P-#)								
UCB	PRH	WBS 1.1	P-1	1-Drivers	Cost Constrained	The THEMIS mission shall be cost capped per Program-Level Requirements (Level1)	*Program Requirement - Single Cost Cap for the Mission*	N/A
UCB	PRH	WBS 1.1	P-2	1-Drivers	Schedule	THEMIS shall be launched no later than March 2007	*Program Requirement - Schedule Cost Cap.*	N/A
Reliability and Quality Assurance - Electrical								
UCB	RJ	WBS 1.1	P-3	1-Drivers	MIDEX Program Assurance	The implementation of Program Assurance shall follow the the Performance Assurance and Implementation Plan (PAIP), which shall be compliant with GSFC-410-MIDEX-002 Rev E 6/25/02 standards	*Program Requirement.*	N/A
UCB	RJ	WBS 1.1	P-4	1-Drivers	Parts Selection (Grade)	GSFC 311-INST-001 Grade 3 parts shall be used with selective up-screening to Grade 2 for key items in critical sub-systems	*Program Requirement.*	P-3
UCB	RJ	WBS 1.1	P-5	1-Drivers	Part Derating	Parts shall be derated to GSFC PPL-22, Appendix B, or Mil-STD-975 H, Appendix A standards	*Program Requirement*	P-3
UCB	RJ	WBS 1.1	P-6	1-Drivers	Workmanship	THEMIS workmanship standards shall be compliant with the PAIP. Solder - NASA STD-8739.3; Cable, Harness and Wiring Interconnects - NASA STD-8739.2; Conformal Coating and Staking - NASA STD-8739.1; Printed Wiring Board Design - NHB 5300.4 (3K) or NASA STD-S-312-003 Rev B.	*Program Requirement. Addresses MIDEX SR&QA requirement to invoke hi-reliability workmanship standards. Should reference workmanship standard documents here.*	P-3
UCB	RJ	WBS 1.1	P-7	1-Drivers	Quality System	The THEMIS quality system shall be based on ANSI/ASQ Q9001-1994	*Program Requirement*	P-3
Reliability and Quality Assurance - Mechanical								
UCB	RJ	WBS 1.1	P-8	1-Drivers	Mil or NASA Standards	All mechanical components shall be designed to Mil or NASA Standards when applicable	*Best Practice*	N/A
UCB	RJ	WBS 1.1	P-9	1-Drivers	Units	All Units (SI, English) shall be clearly documented.	*There will be different units used by different organizations, due to the status of tools currently available.*	P-8
UCB	RJ	WBS 1.1	P-10	1-Drivers	Design Loads	All mechanical components shall be designed using the limit loads specified in the Verification Plan and Environmental Test Requirements Document	*GEVS-SE will be used to develop Test Requirements Document*	P-8
UCB	RJ	WBS 1.1	P-11	1-Drivers	Safety Factors	All nonpressurized metallic mechanical components shall be designed to meet NASA-STD-5001. All pressurized components shall be designed to meet MIL-STD-1522 and EWR 127-1.	*Cover uncertainty in design, analysis and materials*	P-8
UCB	RJ	WBS 1.1	P-12	1-Drivers	NDE	All weldments, bonded joints and composite materials shall be 100% inspected per the inspection criteria in: Mil-STD-2219 (TBR), MSFC-SPEC-522	*Detect structural defects and minimize the risk of fracture*	P-8
UCB	RJ	WBS 1.1	P-13	1-Drivers	Stress Corrosion Cracking	Materials shall be selected from Table 1 of MSFC-STD-3029 for sensitivity to stress-corrosion cracking	*Minimizes fracture risk*	P-8
UCB	RJ	WBS 1.1	P-14	1-Drivers	Composites	All composite structures shall be proof tested to 1.25 X limit loads	*GEVS-SE requirement*	P-8
UCB	RJ	WBS 1.1	P-15	1-Drivers	Dissimilar Metals	Dissimilar metals in contact in the presence of electrolyte shall be avoided where possible. If not possible, interfaces shall be protected from galvanic corrosion by the use of appropriate coatings.	*Avoid corrosion and possible contamination of instruments (particularly optics)*	P-8
Reliability and Quality Assurance - Software								
UCB	RJ	WBS 1.1	P-16	1-Drivers	Flight Software Assurance	All Flight Software shall meet the assurance requirements for IV&V, per TBD. Required for the following flight subsystems: IDPU FSW (UCB); Bus Avionics Unit FSW (Hammers); Mission Operations Software	*Program Requirement.*	N/A
Safety								
UCB	RJ	WBS 1.1	P-17	1-Drivers	Launch Site Safety	The THEMIS Project shall meet all safety requirements	*Program Requirement.*	N/A
UCB	RJ	WBS 1.1	P-18	1-Drivers	Launch Site Safety	The THEMIS Project shall meet requirements of EWR 127-1	*EWR 127-1 provides the overriding design and test requirements for payloads using the Eastern Range*	P-17
UCB	RJ	WBS 1.1	P-19	1-Drivers	Launch Vehicle Safety	The THEMIS Project shall meet requirements of the launch vehicle contractor	*The Launch Vehicle contractor, at their discretion impose additional safety requirements*	P-17
UCB	RJ	WBS 1.1	P-20	1-Drivers	NASA Safety	The THEMIS Project shall meet requirements of KHB 1710.2	*Payloads processed through NASA facilities must meet the requirements of KHB 1710.2*	P-17
Risk and Anomaly Reporting								
UCB	PRH	WBS 1.1	P-21	1-Drivers	Anomaly Tracking and Reporting	UCB shall manage and track to closure Problem/Failure Reports (PFRs) from all probe bus, ground system and instrument activities	*Program Decision on Anomaly Tracking Process*	N/A
UCB	PRH	WBS 1.1	P-22	1-Drivers	Risk Tracking and Reporting	Risk shall be tracked in project-level database. Top 10 risks shall be listed in monthly status reports to the Explorers office.	*Program Decision on Risk Tracking Process. Risk Management responsibilities include: Resources; Schedules and Milestones; Risk Identification; Risk analysis, assessment and mitigation; Criteria for categorizing and ranking to probability and consequences; Role of decision making, formal reviews, status reporting; Documenting risk products and actions.*	N/A

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Mission Requirements (M-#)								
Lifetime and Radiation								
UCB	ERT	WBS-1.3	M-1	2-Space/Ground Segment	Mission Lifetime	The THEMIS operational system shall be designed for at least a two-year lifetime.	*Sufficient to achieve baseline science requirements - allows for two full tail seasons, ensuring conjunction time >188 hrs per year (dY first year, dZ second year).*	S-4
UCB	ERT	WBS-1.3	M-2	2-Space Segment	Orbital Debris Requirement	THEMIS shall meet the NASA orbital debris guidelines of re-entry in NASA Safety Standard (NSS) 1740.14	*Required per NASA guidelines (re-entry in <25 yrs and debris footprints <8 m2)*	N/A
UCB	ERT	WBS-1.3	M-3	2-Space Segment	Total Dose Radiation	THEMIS shall be designed for a total dose environment of 33 krad/year (66 krad total) (TBR)	*Survival in predicted radiation environment - based on dose/depth curve calculations indicating 33 krad TID behind 5mm Al for a 1 year mission (includes a RDM of 2 for uncertainty of model and variability of environment).*	M-1
UCB	ERT	WBS-1.3	M-4	2-Space Segment	SEE Radiation	THEMIS shall be Single Event Effect (SEE) tolerant and immune to destructive latch-up.	*Operability in radiation environment. Protection occurs on several levels: Parts, Local Circuit Protection, Scrubbing, Reset.*	M-1
Fault Tolerance								
UCB	ERT	WBS-1.3	M-5	2-Space/Ground Segment	Fault Tolerance	To the maximum extent possible, THEMIS shall be designed to be single fault tolerant and still meet minimum mission success criteria	*Project guidelines direct the design of the most robust and fault tolerant system within the constraints of allocated resources. Reflects accepted design practice commensurate with mission scope; use of redundancy; and probe system design promoting graceful degradation in the event of an anomaly or failure.*	N/A
UCB	ERT	WBS-1.3	M-6	2-Space Segment	Probe Redundancy	THEMIS Probes 3 or 4 shall be capable of replacing any other probe during the minimum mission	*Allows for failure of one probe and still meet minimum mission success*	M-5
UCB	ERT	WBS-1.3	M-7	2-Space Segment	Probe Safe-Hold Power	Each Probe shall have a viable safe-hold mode after carrier separation (i.e. power-positive, thermally safe, able to communicate with ground throughout orbit).	*Allows for anomaly investigation and correction from the ground. Safe-hold mode will be fully defined early in the design process.*	N/A
UCB	ERT	WBS-1.3	M-8	2-Space Segment	Failure Detection and Correction	THEMIS shall implement Failure Detection and Correction (FDC)	*Allows for autonomy in detecting and correcting faults.*	N/A
Mission Design								
UCB	ERT	WBS-1.3	M-9	2-Space Segment	Space Mission Design	THEMIS shall perform science observations with identical probes in multiple period, near-equatorial orbits (five probes required for baseline science, four probes required for minimum)	*Supports science requirements - multiple spacecraft allows probes to simultaneously measure substorm signatures over long distances along the magnetotail.*	S-2
UCB	ERT	WBS-1.3	M-10	2-Space Segment	Unique ID	Each THEMIS Probe shall have a unique ID that can not be changed on-orbit	*All probes share the same frequency. Required to contact one probe at a time*	M-9
UCB	ERT	WBS-1.3	M-11	2-Space/Ground Segment	Ground Based Observations	The THEMIS probe conjunctions shall be coordinated with ground-based observations during prime geotail season	*Fundamental part of science mission – space-based observations coordinated with ground-based observations to aid in determining the onset of substorms*	S-1
UCB	ERT	WBS-1.3	M-12	2-Space/Ground Segment	Orbital Plan	The selected orbital plan shall achieve greater than 188 hours of four-probe conjuctions during the prime tail observation season (September to April)	*Number of hours of conjuctions required by Level 1 Science.*	S-4
UCB	ERT	WBS-1.3	M-13	2-Launch/Space Segment	Initial Injection Altitude	THEMIS Probes shall be launched into a transfer orbit with the following characteristics: apogee 12 +/- 0.38 Re; perigee 1.1 +/- 0.5Re ; inclination 9 +/- 0.5°; RAAN of 330 +/- 7 deg; and argument of perigee of 0 +/-5 deg (all parameters TBR)	*This is near the final science orbit of the 3 inner probes, and thus minimizes the fuel required to place all probes into their final desired science orbits*	M-12
UCB	ERT	WBS-1.3	M-14	2-Space Segment	Probe Science Altitudes	The THEMIS probes shall ascend to the following approximate science orbits prior to the first-year tail observation season: 1.5x30.9 Re, 7deg inclination (P1); 1.2x19.8 Re, 7deg inclination (P2); 1.2x12.1 Re, 9deg inclination (P3, P4); and 1.1x9.8 Re, 4deg inclination (P5). P5 raised to 1.1x13.2 Re orbit after tail season.	*Approximate orbital elements, sufficient to design system. Supports science requirements and ops concept - choice of periods results in multi-point conjunctions at apogee, allowing probes to simultaneously measure substorm signatures over long distances along the magnetotail, while simplifying ground communication scheduling.*	M-12
UCB	ERT	WBS-1.3	M-15	2-Space Segment	Conjuction Optimization	Upon ascent, and twice during the first- and second-year tail observation seasons, the orbital phase of P1 and P2 shall be adjusted to optimize the amount and quality of conjuctions.	*Ensures science requirements are met.*	M-12
UCB	ERT	WBS-1.3	M-16	2-Space Segment	Eclipse Constraint	The selected date of tail observation season shall satisfy the requirement for eclipse duration (<180 minutes), conjuctions with GBO's and aggregate amount of conjunction hours.	*System design decision selected to constrain orbit trades and optimization in consideration of probe power and thermal constraints.*	M-12
UCB	ERT	WBS-1.3	M-17	2-Space Segment	De-Orbit Constraint	All probes shall perform end-of-mission maneuvers to place themselves in orbits that ensure re-entry within 25 years.	*Required by NASA orbital debris guidelines*	M-2
UCB	ERT	WBS-1.3	M-18	2-Space Segment	Minimal Fuel	THEMIS shall require the minimal fuel possible to place probes in desired orbits	*Accomodates small probe design consistent with total launch capability. Drives manuever planning, axial thrusting, no re-orientation of spin axis, etc.*	M-14

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Resource Budgets								
UCB	ERT	WBS-1.3	M-19	2-Space Segment	Delta V Allocation	THEMIS maneuvers shall be optimized to not exceed a Delta-V of 566m/s +15% contingency (TBR) (for limiting case P1)	*Design decision based on current best estimate of Delta-V plus some contingency for design margin. Fixing number allows sizing of propellant tanks.*	M-22
UCB	ERT	WBS-1.3	M-20	2-Space Segment	Propellant margin at launch	All THEMIS Probes shall have (TBD) propellant margin at launch	*Allows for operational errors, possible anomalies after launch. Acceptable propellant margin at launch will be considered in trade-off when sizing tanks considering significant Delta-V contingency and acceptable dry mass margin.*	M-22
UCB	ERT	WBS-1.3	M-21	2-Space	Dry Mass Allocation	No THEMIS Probe shall exceed a dry mass of 70.8kg	*Rationale: 62.0 kg CBE + 14.4% contingency*	M-22
UCB	ERT	WBS-1.3	M-22	2-Space Segment	Design Mass	Each THEMIS Probe shall be designed to accommodate a 82kg (TBR) dry mass, Delta-V of 650m/s (TBR), and a (TBD) propellant margin at launch	*System design allocation accommodates dry mass 62.0kg CBE + 14.4% contingency (not-to-exceed 70.8kg) plus 20.0% Program Margin; and delta-V 566m/s + 15% contingency (not-to-exceed 650m/s) plus 15.0% propellant margin at launch. Sizes propellant tanks.*	M-29
UCB	ERT	WBS-1.3	M-23	2-Space Segment	Power Allocation	No THEMIS Probe shall exceed an on-orbit power draw of 29.24 W	*Rationale: 24.5 W CBE + 19.3% contingency*	M-24
UCB	ERT	WBS-1.3	M-24	2-Space Segment	Design On-orbit Average Power	The Probe power system shall be designed to accommodate an EOL on-orbit average power of 41.5W.	*Rationale: System design allocation is 24.5 W CBE + 19.3% contingency (not-to-exceed 29.24W) plus 41.9% Program Margin. Sizes solar array area and battery capacity.*	M-29
UCB	ERT	WBS-1.3	M-25	2-Space Segment	Design Eclipse, Peak Power	Each Probe shall be designed to achieve electrical energy balance over an orbit assuming a 30 minute transmitter power on time and a 180 minute eclipse.	*Electrical power system must be sized to accommodate peak and on-orbit power loads (eclipse, downlink, etc). Defines eclipse and transmitter on time.*	M-1
UCB	ERT	WBS-1.3	M-26	2-Space Segment	Data Volume On-board	Each THEMIS Probe shall be designed to accomodate 750 Mbits/orbit (uncompressed) Instrument science and housekeeping data and 87 Mbits/orbit Probe Bus housekeeping data.	*Reflects expected instrument data rate collected over an orbit for all mission modes (survey and burst); and expected probe data rate (1kpbs) collected for P3,4,5 (1 day orbit). Drives need to reduce probe data rate for P1 (4 day orbit) and P2 (2 day orbit).*	M-50
UCB	ERT	WBS-1.3	M-27	2-Space Segment	Data Storage	THEMIS shall be capable of storing 1 orbit + 1 days worth of Instrument and Probe Bus data.	*Provides contingency if ground station pass is missed.*	M-29
UCB	ERT	WBS-1.3	M-28	2-Space Segment	Thermal	THEMIS shall survive and perform as designed under worst-case thermal conditions	*Ensures thermal survivability. Drives thermal design to meet component temperature limits.*	M-1
UCB	ERT	WBS-1.3	M-29	2-Space Segment	Program Margin	All resource budgets (mass, power, data) shall show sufficient positive margin at each project milestone	*Sufficient margins are evaluated at each major review and addressed in Risk Mitigation Plan. Mass and Power resources are considered 'high' risk (triggering risk mitigation plan) if they don't meet the margin schedule.*	N/A
Contamination								
UCB	ERT	WBS-1.3	M-30	2-Space Segment	SCM Sensitivity	AC magnetic noise radiated by the Probe and the other instruments shall not exceed 10pT/Hz^1/2 @ 10Hz and 1pT/Hz^1/2 at 1kHz at the SCM sensor	*Sensitivity of SCM*	N/A
UCB	ERT	WBS-1.3	M-31	2-Space Segment	FGM Sensitivity	DC magnetic noise radiated by the Probe and the other instruments shall not exceed 1nT at the FGM sensor	*Sensitivity of FGM*	N/A
UCB	ERT	WBS-1.3	M-32	2-Space Segment	Magnetic Cleanliness Document	All THEMIS elements shall comply with the Magnetics Cleanliness standard described in the THEMIS Magnetics Cleanliness Plan.	*Adherence to document ensures residual and induced magnetic fields does not corrupt mission science*	M-30
UCB	ERT	WBS-1.3	M-33	2-Space Segment	EFI Sensitivity	Quasi-DC voltages produced by the Probe and the other instruments shall not affect the quality of the EFI measurement	*Sensitivity of EFI*	N/A
UCB	ERT	WBS-1.3	M-34	2-Space Segment	Electrostatic Cleanliness	All THEMIS elements (Instruments, Probe) shall comply with the THEMIS Electrostatic Cleanliness (ESC) Plan	*Adherence to document mitigates potential of contaminating quasi-DC voltages affecting quality of EFI measurement.*	M-33
UCB	ERT	WBS-1.3	M-35	2-Space Segment	ESA Molecular Contamination	The molecular contamination of the ESA sensor shall be less than 0.01 ug/cm^2 (TBR). Particulate level TBD.	*ESA Contamination*	N/A
UCB	ERT	WBS-1.3	M-36	2-Space Segment	SST Molecular Contamination	The molecular contamination of the SST sensor shall be less than 0.1 ug/cm^2 (TBR). Particulate level TBD.	*SST Contamination*	N/A
UCB	ERT	WBS-1.3	M-37	2-Space Segment	Contamination Control Plan	All THEMIS Elements shall comply with the THEMIS Contamination Control Plan	*Adherence to document ensures contamination of sensitive portions of the Probes by condensables and particulates does not prevent the ESA and SST from meeting its performance requirements*	M-35
Interface Requirements								

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
UCB	ERT	WBS-1.3	M-38	2-Space Segment	Electrical System Specification (TBR)	All hardware shall meet the general electrical system requirements documented in the THEMIS Electrical System Specification.	*Document provides electrical design guidelines to alleviate interface problems during system integration*	N/A
UCB	ERT	WBS-1.3	M-39	2-Space/Ground/	ICD development	All THEMIS Elements shall be compatible per their ICDs	*Adherence to ICDs ensures electrical, mechanical, thermal, etc. interface requirements are met*	N/A
Test Requirements								
UCB	ERT	WBS-1.3	M-40	2-Space/Ground	Performance Verification	All THEMIS components shall verify mission performance requirements are met per the Verification Plan and Environmental Test Specification.	*Supports mission science - verifies performance is as expected prior to launch.*	N/A
UCB	ERT	WBS-1.3	M-41	2-Space/Ground Segment	Environments	All THEMIS components shall survive and function prior, during and after exposure to the launch and space environments described in the Verification Plan and Environmental Test Specification.	*Adherence to document ensures all elements are subjected to expected launch and space environments as part of a comprehensive test program*	M-1
UCB	ERT	WBS-1.3	M-42	2-Space Segment	Integration and Testing	All THEMIS components shall be sufficiently testable during all levels of integration and test.	*Ensures system function and performance. Drives subsystem design to include integrated test capabililiy.*	M-41
Launch Vechicle								
UCB	ERT	WBS-1.3	M-43	2-Launch/Space	Launch Vehicle	The THEMIS Probe Carrier Assembly (5 Fueled Probes plus Probe Carrier) shall be compatible with a Delta II 2925-10	*Provides sufficient performance capability and reliability to place THEMIS Probes into the desired initial parking orbit*	N/A
UCB	ERT	WBS-1.3	M-44	2-Launch/Space Segment	Launch Window	Within the schedule cap (March 2007), the THEMIS launch date shall not be restricted	*System is sized to allow launch any day of the year. A launch date of August 2006 plus or minus 2 months is preferred in accordance with schedule and minimum time to prime observation season. Launch period would allow time to commission the probes prior to the operational period starting in December 2006. The launch window is*	
UCB	ERT	WBS-1.3	M-45	2-Launch/Space	Launch Vehicle Lift Capability	The THEMIS Probe Carrier Assembly (5 Fueled Probes plus Probe Carrier) shall not exceed 807kg.	*Preliminary estimate of Delta 2925-10 lift capability*	M-43
UCB	ERT	WBS-2.0	M-46	2-Space Segment	PCA Fundamental Frequency	The fundamental frequency of the Probe Carrier Assembly (Probe Carrier + 5 Fueled Probes) in launch configuration shall be greater than 15 Hz in lateral and 35 Hz in axial.	*Delta II requirement*	M-43
UCB	ERT	WBS-1.3	M-47	2-Space Segment	PCA CG Location	The CG location of the Probe Carrier Assembly (Probe Carrier + 5 Fueled Probes) shall be within TBD of the PCA centerline.	*Delta II requirement. Affects spin balance, bending moment, and dynamic balance*	M-43
Ground Station								
UCB	ERT	WBS-1.3	M-48	2-Ground/Space Segment	Ground Station Compatibility	THEMIS shall be compatible with BGS, USN, TDRSS, and NASA/GN	*Ensures data downlink requirements during operations phase are met with dedicated ground station (BGS), secondary (USN) and back-up (NASA/GN). TDRSS provides continuous coverage as needed during launch, early operations phase, maneuvers and potential anomalous*	N/A
UCB	ERT	WBS-1.3	M-49	2-Ground/Space	Frequency and Format	THEMIS shall be S-Band, CCSDS-compatible and COP-1 compatible	*Provides a standard to simplify back-up by other stations*	N/A
UCB	ERT	WBS-1.3	M-50	2-Ground/Space Segment	Data Volume Downlinked	THEMIS Probes shall be capable of downlinking all stored data for each Probe: 325 Mbits/orbit science and instrument HK data (assumes x2 compression) plus 87 Mbits/orbit Probe HK data.	*Reflects expected data volume.*	M-56
UCB	ERT	WBS-1.3	M-51	2-Ground/Space	Regularity of Downlink	THEMIS Probes shall be capable of downlinking minimum housekeeping data from all probes at least once a day.	*Operational Goal. Safe-guards against anomaly going unnoticed.*	M-7
UCB	ERT	WBS-1.3	M-52	2-Ground/Space	Transmitter on time	THEMIS Probes shall be capable of downlinking all data within 30 minutes per day per probe (maximum transmitter on time).	*Reflects power generation capabilities of body mounted solar arrays. Affects thermal and required data rates.*	M-25
UCB	ERT	WBS-1.3	M-53	2-Ground/Space	Receive Commands at Maximum Altitude	THEMIS Probes shall be capable of receiving ground commands to maximum altitude (apogee of 30RE)	*Desire to communicate with probe at anytime (no black-out)*	M-7
UCB	ERT	WBS-1.3	M-54	2-Ground/Space	Provide Telemetry to Maximum Altitude	THEMIS Probes shall provide housekeeping telemetry downlink capability from maximum altitude (apogee of 30RE)	*Desire to know state of probe at any time (no black-out)*	M-7
UCB	ERT	WBS-1.3	M-55	2-Ground/Space	Uplink data rate	THEMIS Probes shall be capable of receiving commands at an uplink data rate of 1 kbps	*Baseline uplink rate*	M-56
UCB	ERT	WBS-1.3	M-56	2-Ground/Space	Link Margin	The S-Band uplink and downlink shall have a link margin of ≥ 3dB at all points in the orbit through all mission phases	*Ensures a stable and reliable RF communications path. Design driven by limiting cases. Drives need for variable downlink rates*	M-29
UCB	ERT	WBS-1.3	M-57	2-Ground/Space	Bit Error Rate (BER)	The THEMIS link analysis shall assume a 10E-6 BER downlink and 10E-7 BER uplink	*Downlink BER minimizes error rate of data recovered after transmission and recovery at ground station. Uplink BER (along with*	M-56
UCB	ERT	WBS-1.3	M-58	2-Ground Segment	Orbital Knowledge	Probe orbits shall be known to an accuracy of 10km at Perigee and 100km at Apogee.	*Adequate for ground station antenna pointing. Meets Science Requirement.*	N/A
UCB	ERT	WBS-1.3	M-59	2-Ground/Space	Probe Health and Safety	The THEMIS Ground System shall monitor and take appropriate action to maintain the health and safety of the Probes		N/A
UCB	ERT	WBS-1.3	M-60	2-Ground/Space Segment	Orbit & Attitude Management	The THEMIS Ground System shall calculate and propagate all orbit and attitude parameters necessary for orbit maintenance and attitude control of each Probe.	*Design decision to simplify Probe Bus design, given that the spinning probes are highly stable once fully deployed and spinning.*	N/A

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Instrument - General (IN-#)								
UCB	ERT	WBS-1.3	IN-1	3-Element	Mission Lifetime	The Instrument Payload shall be designed for at least a two-year lifetime.	*Flow-down*	M-1
UCB	ERT	WBS-1.3	IN-2	3-Element	Total Dose Radiation	The Instrument Payload shall be designed for a total dose environment of 33 krad/year (66 krad total) (TBR)	*Flow-down*	M-3
UCB	ERT	WBS-1.3	IN-3	3-Element	SEE Radiation	The Instrument Payload shall be Single Event Effect (SEE) tolerant and immune to destructive latch-up.	*Flow-down*	M-4
UCB	ERT	WBS-1.3	IN-4	3-Element	Safe-hold Mode	Each Instrument Payload shall have an autonomous safe state after carrier separation.	*Flow-down*	M-7
UCB	ERT	WBS-1.3	IN-5	3-Element	Failure Detection and Correction	The Instrument Payload shall implement Failure Detection and Correction (FDC)	*Flow-down*	M-8
UCB	ERT	WBS-1.3	IN-6	3-Element	System Mass Budget	The Instrument Payload shall not exceed a mass of 23.6 kg.	*Ensures limiting mass constraint (deltaV to place probes in required orbits) is met with system margin. Not-to-exceed is CBE of 21kg with 12.8% contingency.*	M-21
UCB	ERT	WBS-1.3	IN-7	3-Element	Allocated Mass Budget	No component of the Instrument Payload shall exceed the allocated mass budget in Table M1	*Reflects estimated mass plus contingency based on level of design fidelity.*	IN-6
UCB	ERT	WBS-1.3	IN-8	3-Element	System Power Budget	The Instrument Payload shall require less than 14.7 W (on-orbit average)	*Ensures limiting power constraint (probe power generation and storage capability at mission end-of-life) is met with system margin. Not-to-exceed is CBE of 12.1W with 21.6% contingency.*	M-23
UCB	ERT	WBS-1.3	IN-9	3-Element	Allocated Power Budget	No component of the Instrument Payload shall exceed the allocated power budget in Table P1	*Reflects estimated power plus contingency based on level of design fidelity.*	IN-8
UCB	ERT	WBS-1.3	IN-10	3-Element	Allocated Data Budget	The Instrument Payload shall not exceed the allocated data budget of 750Mbits/orbit (uncompressed)	*Sufficient to achieve baseline science objectives*	M-26
UCB	ERT	WBS-1.3	IN-11	2-Ground/Space	Uplink data rate	The Instrument Payload shall be compatible with an uplink data rate of 1 kbps	*Baseline uplink rate*	M-55
UCB	ERT	WBS-1.3	IN-12	3-Element	Data Storage	The Instrument Payload shall be capable of storing 1 orbit + 1 days worth of Instrument Science and housekeeping data.	*Flow-down*	M-27
UCB	ERT	WBS-1.3	IN-13	3-Element	Survival Temperature	The Instrument Payload shall survive the temperature ranges provided in Table XX in the ICD	*Provides component limits for Probe thermal design*	M-28
UCB	ERT	WBS-1.3	IN-14	3-Element	Operating Temperature	The Instrument Payload shall perform as designed within the temperature ranges provided in Table XX in the ICD	*Provides component limits for Probe thermal design*	M-28
UCB	ERT	WBS-1.3	IN-15	3-Element	Cold Start	The Instrument Payload shall be able to cold start at TBD	*Provides component limits for Probe thermal design*	M-28
UCB	ERT	WBS-1.3	IN-16	3-Element	Magnetic Cleanliness Document	All Instrument Payload shall comply with the Magnetics Cleanliness standard described in the THEMIS Magnetics Cleanliness Plan.	*Flow-down*	M-32
UCB	ERT	WBS-1.3	IN-17	3-Element	Electrostatic Cleanliness	The Instrument Payload shall comply with the THEMIS Electrostatic Cleanliness (ESC) Plan	*Flow-down*	M-34
UCB	ERT	WBS-1.3	IN-18	3-Element	Contamination Control Plan	The Instrument Payload shall comply with the THEMIS Contamination Control Plan	*Flow-down*	M-37
UCB	ERT	WBS-1.3	IN-19	3-Element	Electrical System Specification	All Instruments shall meet the general electrical system requirements documented in the THEMIS Electrical System Specification.	*Flow-down*	M-38
UCB	ERT	WBS-1.3	IN-20	3-Element	ICD	The Instrument Payload shall be compatible per the IDPU-Instrument ICD	*Flow-down. Defines where interfaces are documented.*	M-39
UCB	ERT	WBS-1.3	IN-21	3-Element	ICD	The Instrument Payload shall be compatible per the IDPU-Probe Bus ICD	*Flow-down. Defines where interfaces are documented.*	M-39
UCB	ERT	WBS-1.3	IN-22	3-Element	ICD	The Instrument Payload shall be compatible per the Instrument-Probe ICDs	*Flow-down. Defines where interfaces are documented.*	M-39
UCB	ERT	WBS-1.3	IN-23	3-Element	Performance Verification	The Instrument Payload shall verify performance requirements are met per the Verification Plan and Environmental Specification.	*Flow-down*	M-40
UCB	ERT	WBS-1.3	IN-24	3-Element	Fields Ground Support Equipment	The EFI, SCM, FGM, and DFB GSE shall support the intercalibration of the combined fields system.	*Supports instrument performance verification*	IN-23
UCB	ERT	WBS-1.3	IN-25	3-Element	Environments	The Instrument Payload shall survive and function prior, during and after exposure to the environments described in the Verification Plan and Environmental Specification.	*Flow-down*	M-41
UCB	ERT	WBS-1.3	IN-26	3-Element	Integration and Testing	All Instruments shall be testable during all levels of integration and test	*Flow-down*	M-42
UCB	ERT	WBS-1.3	IN-27	3-Element	Component Stiffness	All Instrument Payloadmstructural components shall be designed to have a minimum fundamental frequency of 75 Hz (goal) in the stowed configuration.	*Design goal. Implemented to avoid coupling between component and Probe / Probe Carrier dynamics. Mass model will be required if below goal.*	M-46

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Electric Field Instrument (IN.EFI)								
EFI Science Requirements								
UCB	JB	WBS-2.1.2	IN.EFI-1	4-Subsystem	Science Objective: 2D E-Field	The EFI shall determine the electric field in 2D (spin plane) with one spin period time resolution the times of onset at 8-10RE (<10sec	*Determines the electric field associated with plasma convective motion at times of onset*	S-7
UCB	JB	WBS-2.1.2	IN.EFI-2	4-Subsystem	Science Objective: Dawn/Dusk E-Field	The EFI shall determine the dawn/dusk electric field over one spin period at 18-30RE (<10sec required)	*Determines distance to the reconnection site (along with SST measurements).*	S-3
UCB	JB	WBS-2.1.2	IN.EFI-3	4-Subsystem	Science Objective: 3D E-Field	The EFI shall measure the 3D wave electric field in the frequency range 1-600Hz at the times of onset at 8-10RE.	*Determines the electric component of waves at frequencies below the lower hybrid frequency through whistler branch during times of onset.*	S-11
UCB	JB	WBS-2.1.3	IN.EFI-4	4-Subsystem	Science Objective: Radiation Belt	The EFI shall measure the electric components of the waves up to the electron cyclotron frequency	*Waves may be responsible for the electron acceleration in the radiation belt*	S-12
EFI Instrument Performance Requirements								
UCB	JB	WBS-2.1.2	IN.EFI-5	4-Subsystem	Time Resolution	The EFI shall measure the 2D (on the spin plane) DC E-field with a 10 second time resolution.	*Time resolution required to meet Level 1 Science Requirements*	IN.EFI-1
UCB	JB	WBS-2.1.2	IN.EFI-6	4-Subsystem	Frequency Range	The EFI shall measure the 3D AC E-field from 1- 4kHz.	*1-6Hz for low-frequency modes, up to 4kHz for whistler branch (cyclon frequency)*	IN.EFI-3
UCB	JB	WBS-2.1.2	IN.EFI-7	4-Subsystem	Spacecraft Potential	The EFI shall measure the Spacecraft Potential with a time resolution better than the spin rate (3 seconds).	*Spin time resolution required for ESA to compute moments on-board. Probe potential measurement needed for quality EFI data on ground.*	IN.ESA-1
UCB	JB	WBS-2.1.2	IN.EFI-8	4-Subsystem	DFT Spectra Range	The EFI DFT Spectra Range shall be 16Hz - 4kHz, with df/f~25%		IN.EFI-3
UCB	JB	WBS-2.1.2	IN.EFI-9	4-Subsystem	DC Resolution	The EFI shall measure the DC signals of amplitude up to 300mV/m with 16 bit digitization	*Sufficient dynamic range and resolution to measure the spacecraft potential and E-Field.*	IN.EFI-1
UCB	JB	WBS-2.1.2	IN.EFI-10	4-Subsystem	AC Resolution	The EFI shall measure the AC signals of amplitude up to 100mV/m with 16 bit digitization		IN.EFI-3
UCB	JB	WBS-2.1.2	IN.EFI-11	4-Subsystem	Noise Level	The EFI noise level shall be below 10^-4 mV/m/sqrt(Hz) at 4kHz [TBR].	*Sets noise floor.*	IN.EFI-4
UCB	JB	WBS-2.1.2	IN.EFI-12	4-Subsystem	High Frequency Log Power	The EFI HF RMS (Log power) measurement shall cover 100-500 kHz with a minimum time resolution of spin rate. (on-board triggers)	*Provides on-board triggers to catch onsets simultaneously on all probes.*	IN.DPU-15
UCB	JB	WBS-2.1.2	IN.EFI-13	4-Subsystem	Accuracy	The EFI shall achieve an accuracy better than 10% or 1mV/m in the SC XY components during times of onset.		IN.EFI-1
Electrostatic Analyzer (IN.ESA)								
ESA Science Requirements								
UCB	CC	WBS-2.1.3	IN.ESA-1	4-Subsystem	Science Objective: Partial Moments	The ESA shall obtain partial moments of the 3D plasma electron and ion distributions with one spin period time resolution in the magnetotail plasma sheet (<10sec required)	*Provides interprobe timing studies to help determine current disruption onset time*	S-3
UCB	CC	WBS-2.1.3	IN.ESA-2	4-Subsystem	Science Objective: Velocity/Pressure	The ESA shall measure differences in velocity and ion pressure between probes in the magnetotail plasma sheet	*Provides an estimate of the scale size of transport, the size and strength of flow vortices and the pressure gradient*	S-7
UCB	CC	WBS-2.1.3	IN.ESA-3	4-Subsystem	Science Objective: Distributions	The ESA shall measure, at one spin resolution, ion and electron distributions that are associated with the current disruption process (<10sec required)	*Identifies sources of free energy and evidence of acceleration processes*	S-11
UCB	CC	WBS-2.1.3	IN.ESA-4	4-Subsystem	Science Objective: Dayside Science	The ESA shall be capable of measuring ion moments and differences of those moments in the magnetosheath and solar wind	*Dayside Science*	S-13
ESA Instrument Performance Requirements								
UCB	CC	WBS-2.1.3	IN.ESA-5	4-Subsystem	Energy Range	The ESA shall measure ions and electrons over an energy range of 0.01-30 keV	*Provides low part of energy range required for Level 1 Science Requirements.*	IN.ESA-1
UCB	CC	WBS-2.1.3	IN.ESA-6	4-Subsystem	Energy Resolution	The ESA energy sampling resolution, dE/E, shall be better than 25% FWHM for ions and electrons	*Resolution adequate for science.*	IN.ESA-1
UCB	CC	WBS-2.1.3	IN.ESA-7	4-Subsystem	Energy Flux	The ESA shall be capable of measuring ion and electron energy flux of 10^4 to 10^9 keV/cm^2/s/Str/keV	*Expected flux levels in the magnetotail plasma sheet*	IN.ESA-1
UCB	CC	WBS-2.1.3	IN.ESA-8	4-Subsystem	Dayside Energy Flux	The ion ESA geometric factor shall be attenuated in the solar wind to avoid saturation.	*Solar wind ion measurement requires attenuated geometric factor and finer energy steps.*	IN.ESA-4
UCB	CC	WBS-2.1.3	IN.ESA-9	4-Subsystem	Partial Moment Contribution	The ESA shall supply partial energy moments at one spin time resolution.	*Identifies ESA's contribution to partial moments (medium energy). Data is combined with SST measurements to compute plasma particle*	IN.ESA-1
UCB	CC	WBS-2.1.3	IN.ESA-10	4-Subsystem	Angular Resolution (Elevation x Azimuth)	The ESA shall have a 180 degree elevation field of view with a minimum angular resolution of 22.5 degrees.	*Angular resolution sufficient for science. ESA will have a FOV of 11.25 degrees. Drives stability of 5.6 degree requirement.*	IN.ESA-1
UCB	CC	WBS-2.1.3	IN.ESA-11	4-Subsystem	Dayside Angular Resolution	To resolve the solar wind, the ESA shall have a field of view with enhanced resolution of approximately 6 degrees	*Solar wind ion measurement requires attenuated geometric factor and finer energy steps.*	IN.ESA-4
UCB	CC	WBS-2.1.3	IN.ESA-12	4-Subsystem	4pi Steradian FOV	The ESA shall produce measurements of particle distributions over the entire 4pi steradian field of view in one spin period.	*ESA Particle distribution data must be spin sectored over a spin period. Drives need for spin pulse.*	IN.ESA-1
UCB	CC	WBS-2.1.3	IN.ESA-13	4-Subsystem	ESA Calibration	ESA calibration shall ensure <20% relative flux uncertainty (not including statistical uncertainty) over the ranges defined above.		IN.ESA-2

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Solid State Telescope (IN.SST)								
SST Science Requirements								
UCB	DL	WBS-2.1.4	IN.SST-1	4-Subsystem	Science Objective: Disruption Boundary Speed	The SST shall perform measurements of the tailward-moving current disruption boundary speed using the finite gyroradius technique	*Helps to determine current disruption onset time*	S-2
UCB	DL	WBS-2.1.4	IN.SST-2	4-Subsystem	Science Objective: Time-of-Arrival	The SST shall measure the time-of-arrival of superthermal ions and electrons of different energies emanating from the reconnection region (<10 seconds required)	*Helps to determine reconnection onset time*	S-3
UCB	DL	WBS-2.1.4	IN.SST-3	4-Subsystem	Science Objective: Partial Moments	The SST shall obtain partial moments of the plasma electron and ion distributions with one spin period time resolution in the magnetotail plasma sheet (<10sec required)	*Provides interprobe timing studies to help determine current disruption onset time*	S-3
UCB	DL	WBS-2.1.4	IN.SST-4	4-Subsystem	Science Objective: Distributions	The SST shall measure, at one spin resolution, ion and electron distributions that are associated with the current disruption process (<10sec required)	*Identifies sources of free energy and evidence of acceleration processes*	S-2
UCB	DL	WBS-2.1.4	IN.SST-5	4-Subsystem	Science Objective: Radiation Belt Science	The SST shall measure energetic electron fluxes as close to Earth as 6RE geocentric, at all local times.	*Radiation Belt Science. Requirement achieved by nominal (baseline science) design.*	S-12
UCB	DL	WBS-2.1.4	IN.SST-6	4-Subsystem	Science Objective: Dayside Science	The SST shall measure energetic ions in the solar wind, at the magnetopause and in the magnetosheath.	*Dayside Science. Requirement achieved by nominal (baseline science) design.*	S-13
SST Instrument Performance Requirements								
UCB	DL	WBS-2.1.4	IN.SST-7	4-Subsystem	Energy Range	The SST shall measure energetic particles over an energy range of 30-300keV for ions and 30-100keV for electrons found in the magnetotail plasma sheet .	*Provides high part of energy range required for Level 1 Science Requirements. Magetotail region 9-30Re. Large dynamic range of flux requires multiple geometric factors.*	IN.SST-1
UCB	DL	WBS-2.1.4	IN.SST-8	4-Subsystem	Energy Resolution	The SST energy sampling resolution, dE/E, shall be better than 30% for ions and electrons.	*Resolution adequate for science.*	IN.SST-1
UCB	DL	WBS-2.1.4	IN.SST-9	4-Subsystem	Energy Flux	The SST shall be capable of measuring differential energy flux in the range from: 10^2 to 5x10^6 for ions; 10^3-10^7 for electrons (keV/cm2-s -st- keV) whilst providing adequate counts within a 10 second interval. (TBR)	*Expected flux levels in the magnetotail plasma sheet*	IN.SST-1
UCB	DL	WBS-2.1.4	IN.SST-10	4-Subsystem	Angular Resolution (Elevation)	The SST shall measure over 90 degrees in elevation with a minimum resolution of 45 degrees.	*Resolution sufficient for science.*	IN.SST-1
UCB	DL	WBS-2.1.4	IN.SST-11	4-Subsystem	Angular Resolution (Azimuth)	The SST shall have an azimuthal resolution of 45 degrees.	*Resolution sufficient for science.*	IN.SST-1
UCB	DL	WBS-2.1.4	IN.SST-12	4-Subsystem	Partial Moment Contribution	The SST shall supply the high energy partial moments at one spin time resolution	*Identifies SST's contribution to partial moments high energy). Data is combined with ESA measurements to compute plasma particle moments.*	IN.SST-3
UCB	DL	WBS-2.1.4	IN.SST-13	4-Subsystem	SST Calibration	SST calibration shall ensure <20% relative flux uncertainty over the ranges defined above.		IN.SST-1

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Fluxgate Magnetometer (IN.FGM)								
FGM Science Requirements								
IWF	WM	WBS-2.1.5	IN.FGM-1	4-Subsystem	Science Objective: Magnetic Field	The FGM shall measure DC and low frequency perturbations of the magnetic field	*Supports the following mission goals: 1. Measure time wave and structure propagation between probes; and 2. Information on plasma currents based on instantaneous magnetic field differences on two or more probes, separated by >0.2 RE*	S-2
FGM Instrument Performance Requirements								
IWF	WM	WBS-2.1.5	IN.FGM-2	4-Subsystem	Absolute Stability	The absolute stability of the FGM shall be less than 1nT	*Sufficient precision required by Level 1*	IN.FGM-1
IWF	WM	WBS-2.1.5	IN.FGM-3	4-Subsystem	Relative Stability	The relative stability of the FGM shall be less than 0.2nT/12hrs	*Interprobe resolution and interorbit (12hrs) stability of 0.2nT required by Level 1 Science*	IN.FGM-1
IWF	WM	WBS-2.1.5	IN.FGM-4	4-Subsystem	Resolution	The FGM digital resolution shall be less than 0.1nT	*Ensures stability measurements are obtained*	IN.FGM-1
IWF	WM	WBS-2.1.5	IN.FGM-5	4-Subsystem	Noise Level	The FGM noise level @ 1Hz shall be less than 0.03nT/sqrt(Hz)	*Sets noise floor*	IN.FGM-1
IWF	WM	WBS-2.1.5	IN.FGM-6	4-Subsystem	Science Range	The FGM science range shall exceed 0-1000nT		IN.FGM-1
IWF	WM	WBS-2.1.5	IN.FGM-7	4-Subsystem	Frequency Range	The FGM frequency range shall exceed DC-1 Hz	*Problem to find the right compromise between telemetry rate, aliasing errors, and spin period interferences.*	IN.FGM-1
Search Coil Magnetometer (IN.SCM)								
SCM Science Requirements								
CETP	BdIP	WBS-2.1.6	IN.SCM-1	4-Subsystem	Science Objective: Magnetic components	SCM shall provide a critical test for the role of waves at substorm onset, in various models (together with EFI).	*SCM shall identify low-frequency wave mode in current disruption region at times of onset at 8-10 Re. SCM shall identify wave mode, in diffusion during times of onset. SCM shall determine direction of k-vector on all probes, at times of onsets. SCM shall provide a survey of wave activity at various probe locations.*	S-11
CETP	BdIP	WBS-2.1.6	IN.SCM-2	4-Subsystem		Deleted	*N/A*	N/A
SCM Instrument Performance Requirements								
CETP	BdIP	WBS-2.1.6	IN.SCM-3	4-Subsystem	Frequency Range	SCM shall measure the 3D AC B-field from 1 Hz to 4kHz	*1-128Hz for low-frequency modes, up to 4kHz for whistler branch*	IN.SCM-1
CETP	BdIP	WBS-2.1.6	IN.SCM-4	4-Subsystem	Sensitivity	The SCM sensitivity shall be better than 1pT/Hz^1/2 @10Hz , and 0.1 pT/Hz^1/2 @1 kHz.		IN.SCM-1
CETP	BdIP	WBS-2.1.6	IN.SCM-5	4-Subsystem	Spectral measurements	The SCM DFT spectral range shall be in the range 16Hz to 4 kHz, transmitted as 32 steps with df/f ~ 25%.		IN.SCM-1
CETP	BdIP	WBS-2.1.6	IN.SCM-6	4-Subsystem	Calibration	The transfer function of the SCM sensors (amplitude &phase) shall be known with an accuracy better than 5%.	*Transfer function will be well calibrated on the ground (in a quite site), and calibrated in flight (once/day).*	IN.SCM-1
CETP	BdIP	WBS-2.1.6	IN.SCM-7	4-Subsystem	Orthogonal Sensors	On each spacecraft the 3 magnetic antennas, shall be held orthogonal by a structure procured by CETP.		IN.SCM-1
Boom Requirements (IN.BOOM)								
UCB	DP	WBS-2.1.5.2 WBS-2.1.6.3	IN.BOOM-1	4-Subsystem	Mag Boom Repeatability	Mag Boom deployment shall be repeatible to 1 degree	*Number are 3 sigma. Accuracy in knowledge of SCM and FGM magnetic axis must be better than 1 degree. Probe Dynamic Balance.*	IN.SCM-1
UCB	DP	WBS-2.1.5.2 WBS-2.1.6.3	IN.BOOM-2	4-Subsystem	Mag Boom Stability	Mag Boom stability shall be better than 0.1 degree	*Specifically, the FGM and SCM mounts shall be stable with respect to their respective Mag Boom bus mounts to within 0.1 degrees, 3 sigma*	PB-43
UCB	DP	WBS-2.1.5.2 WBS-2.1.6.3	IN.BOOM-3	4-Subsystem	Mag Boom Stiffness	Mag Boom deployed stiffness shall be greater than 0.75Hz	*Flexible Body Passive Spin Stability (>1.5x Spin Rate)*	PB.ACS-1
UCB	DP	WBS-2.1.5.2 WBS-2.1.6.3	IN.BOOM-4	4-Subsystem	Mag Boom Deployment	Mag Boom shall be designed to be deployed between 0 and 15 RPM	*Boom Deployment Strength Design Margins*	PB-46
UCB	DP	WBS-2.1.2	IN.BOOM-5a	4-Subsystem	EFI Boom Stability	Deployed EFI Axials shall be repeatible and stable to $\Delta\theta$ = 1 degree and $\Delta L/L$ = 1%	*Required by EFI Science and Probe Dynamic Balance*	IN.EFI-13
UCB	DP	WBS-2.1.2	IN.BOOM-5b	4-Subsystem	EFI Boom Stability	Deployed EFI Radials shall be repeatible and stable to $\Delta\theta$ = 1 degree and $\Delta L/L$ = 1%	*Required by EFI Science and Probe Dynamic Balance*	IN.EFI-13
UCB	DP	WBS-2.1.2	IN.BOOM-6	4-Subsystem	EFI Axial Boom Deployment	EFI Axial Booms shall be designed to be deployed between 0 and 25 RPM	*Boom Mechanism Design Margin*	PB-46
UCB	DP	WBS-2.1.2	IN.BOOM-7	4-Subsystem	EFI Radial Boom Deployment	EFI Radial Booms shall be designed to be deployed between 2 and 25 RPM	*Boom Mechanism Design Margin*	PB-47
UCB	DP	WBS-2.1.2	IN.BOOM-8	4-Subsystem	EFI Axial Boom Stiffness	EFI Axial Booms deployed stiffness shall be greater than 0.75Hz	*Flexible Body Passive Spin Stability (>1.5x Spin Rate)*	PB.ACS-1

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Instrument Data Processing Unit (IN.DPU)								
Data Rates								
UCB	ISE	WBS-2.1.1	IN.DPU-1	4-Subsystem	Command Interface	The IDPU DCB shall receive commands from the C&DH Subsystem via a 38.4 kbaud bi-directional serial interface	*Interface Requirement*	IN-21
UCB	ISE	WBS-2.1.1	IN.DPU-2	4-Subsystem	Science Telemetry Data Rate	The IDPU DCB shall send telemetry to the C&DH Subsystem via a 38.4 kbaud bi-directional serial interface	*Interface Requirement*	IN-21
UCB	ISE	WBS-2.1.1	IN.DPU-3	4-Subsystem	Command/HK Telemetry Data Rate	The IDPU DCB high speed interface (science data) to the C&DH Subsystem shall be at multiple fixed (commandable) rates from at least 1 kbps to ~2 Mbps (TBR)	*Interface Requirement to Probe. Probe downlink data rates driven by requirement to downlink all science and housekeeping data within 30 minute/day transmitter-on power constraint. Multiple data rates ensures positive link margin for all probes during all parts of orbit.*	IN-10
UCB	ISE	WBS-2.1.1	IN.DPU-4	4-Subsystem	Minimum HK Data Rate	The IDPU DCB shall be able to provide real-time housekeeping data stream at the minimum data rate possible (1kbps)	*Interface Requirement to Probe. Probe minimum downlink data rate driven by TDRSS emergency mode and contingency operations*	M-51
UCB	ISE	WBS-2.1.1	IN.DPU-5	4-Subsystem	Data Compression	The IDPU DCB shall provide loss-less data compression (nominal 2x reduction) for all instrument data	*Power constraint and bandwidth allocations drives on-board data compression.*	M-50
Data Storage								
UCB	ISE	WBS-2.1.1	IN.DPU-6	4-Subsystem	Storage of Instrument Science and HK telemetry	The IDPU DCB shall provide sufficient storage for all instrument science and housekeeping telemetry in SSR when not in ground contact: 750Mbits (if uncompressed) +1 day for contingency	*Allows all instrument data generated to be transmitted to ground.*	IN-12
UCB	ISE	WBS-2.1.1	IN.DPU-7	4-Subsystem	Playback of stored telemetry	The IDPU DCB shall be capable of playing back data upon command during ground contact (pointer from operators)	*Accomodates operations concept to downlink specific data during ground contact*	M-59
UCB	ISE	WBS-2.1.1	IN.DPU-8	4-Subsystem	Stored telemetry re-transmission	The IDPU DCB shall provide the capability to re-transmit the SSR contents	*Accommodates operations concept not to overwrite data on-board until valid data receipt on the ground is confirmed (i.e. transmittal to ground should not erase memory)*	M-59
UCB	ISE	WBS-2.1.1	IN.DPU-9	4-Subsystem	Erasure of stored telemetry	The IDPU DCB shall not erase instrument housekeeping telemetry from memory unless commanded to do so	*Accommodates operations concept not to overwrite data on-board until valid data receipt on the ground is confirmed (i.e. reset should not erase memory)*	M-59
Fault Protection								
UCB	ISE	WBS-2.1.1	IN.DPU-10	4-Subsystem	Command Validation	The IDPU DCB shall validate commands prior to execution	*Precludes the execution of an invalid command.*	P-16
UCB	ISE	WBS-2.1.1	IN.DPU-11	4-Subsystem	Autonomous Fault Protection	The IDPU DCB shall implement autonomous fault protection features to ensure the health and safety of the instruments	*Allows for safe operation of Instruments. Includes instrument over-current protection, high voltage rate shutdown, etc.*	IN-5
UCB	ISE	WBS-2.1.1	IN.DPU-12	4-Subsystem	Autonomous Function Enabling	The IDPU DCB shall enable all autonomous functions to be initiated and disabled by ground command	*Allows flexibility to adjust for on-orbit conditions.*	IN-5
UCB	ISE	WBS-2.1.1	IN.DPU-13	4-Subsystem	Hazardous Commands	The IDPU DCB shall provide separate enable and activation commands for critical instrument functions such as boom deployments	*Safety Requirement*	IN.DPU-49
UCB	ISE	WBS-2.1.1	IN.DPU-14	4-Subsystem	Flight Software Modification	The IDPU DCB shall provide the capability to upload or modify Instrument flight software.	*Ensures fault tolerant system*	P-16
Instrument Accommodation								
UCB	ISE	WBS-2.1.1	IN.DPU-15	4-Subsystem	Science Telemetry	The IDPU DCB shall accommodate continuous instrument data governed by overall system mode (Slow Survey, Fast Survey, Particle Burst, Wave Burst I or II). Modes selected by ATS command or on-board triggering logic.	*Accommodates all instrument data generated. Reflects need to autonomously change instrument data rate as a function of on-orbit environment.*	
UCB	ISE	WBS-2.1.1	IN.DPU-16	4-Subsystem	Instrument Housekeeping Telemetry	The IDPU DCB shall provide housekeeping telemetry sufficient to safely turn-on and operate all instruments (temperatures, currents, voltages, and bi-levels) as defined in Instrument-IDPU ICDs	*Allows instrument operation and performance evaluation, as well as anomaly investigation and resolution*	M-59
UCB	ISE	WBS-2.1.1	IN.DPU-17	4-Subsystem	Instrument Commanding	The IDPU DCB shall provide operational commands and test programs for all instruments as detailed in the Instrument-IDPU ICDs	*Accomodates command and test programs required to operate the instruments (EFI boom deployment, SCM calibration, SST geometric factor control, Solar Wind Attenuator actuator control, etc.)*	IN-20
UCB	ISE	WBS-2.1.1	IN.DPU-18	4-Subsystem	Instrument Initialization Parameters	The IDPU DCB shall provide initialization parameters to the Instruments as detailed in the Instrument-IDPU ICDs	*Provides parameters required to operate the instruments (adjustable moment weighting tables, filter defaults, etc.)*	IN-20
UCB	ISE	WBS-2.1.1	IN.DPU-19	4-Subsystem	Instrument FSW Processing	The IDPU DCB shall provide the on-board FSW processing required and as detailed in the Flight Software Specification	*Provides FSW processing required to operate the instruments (spin fits, moment calculations, spin sectoring, pitch angle computations,*	IN-20
UCB	ISE	WBS-2.1.1	IN.DPU-20	4-Subsystem	Instrument Thermal Control	The IDPU DCB shall provide Instrument thermal control if necessary (PWM)	*Accommodates required instrument thermal environment*	M-28
UCB	ISE	WBS-2.1.1	IN.DPU-21	4-Subsystem	FGM Data	The IDPU DCB shall provide FGM telemetry to the Probe C&DH Subsystem at a sample rate of TBD	*Probe will use sun sensor and FGM data to estimate attitude on the ground. Data passed directly to Probe for possible technology*	PB.ACS-15
Timing								

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
UCB	ISE	WBS-2.1.1	IN.DPU-22	4-Subsystem	Time-based Clock - Fields Instrument	The IDPU DCB shall receive a 8.192MHz (TBR) Master Clock from the Probe C&DH Subsystem.	*Interface Requirement.*	IN-21
UCB	ISE	WBS-2.1.1	IN.DPU-23	4-Subsystem	Time-based Clock - Fields Instrument	The IDPU DCB shall distribute a 2^23 Hz (8.192MHz) Clock to the DFB and FGM	*Interface Requirement. Sufficient for DFB and FGM function.*	IN-21
UCB	ISE	WBS-2.1.1	IN.DPU-24	4-Subsystem	Data Transfer Clock - Fields Instruments	The IDPU DCB shall receive a 1 Pulse Per Second (1PPS) interface (derived from the 8.192 MHz clock) from the Probe C&DH Subsystem	*Provides time synchronization for fields data. Data transfer will be coincident with 1 second pulse*	IN-21
UCB	ISE	WBS-2.1.1	IN.DPU-25	4-Subsystem	Data Transfer Clock - Fields Instruments	The IDPU DCB shall provide a 1 Pulse Per Second (1PPS) to the DFB and the FGM	*Provides time synchronization for fields data. Data transfer will be coincident with 1 second pulse*	IN-20
UCB	ISE	WBS-2.1.1	IN.DPU-26	4-Subsystem	Data Transfer Clock - Particle Instruments	The IDPU DCB shall receive a raw sun pulse signal from the Probe	*Provides spin phase synchronization for particle data. Raw sun crossing data provided by Probe attitude system.*	IN-21
UCB	ISE	WBS-2.1.1	IN.DPU-27	4-Subsystem	Data Transfer Clock - Particle Instruments	The IDPU DCB shall filter the raw sun pulse signal and provide a once-per-spin reference pulse (SRP) to the SST and ESA	*Provides spin phase synchronization for particle data. Data transfer will be coincident with SRP. Filtering details provided in ICD.*	IN.ESA-12
UCB	ISE	WBS-2.1.1	IN.DPU-28	4-Subsystem	Spin-based Clock - Particle Instruments	The IDPU DCB shall distribute a Spin Sector Clock with 2^14 phase pulses per spin to the ESA and SST (synchronized with the SRP)	*SST and ESA formatter requires clock to spin sector data.*	IN.DPU-34
UCB	ISE	WBS-2.1.1	IN.DPU-29	4-Subsystem	Absolute Timing	The IDPU DCB shall receive the Mission Elapsed Time (MET) from the spacecraft and the Universal Time Offset (UTO) as specified in the Spacecraft-IDPU ICD, and will calculate Universal Time (UTC)	*Interface Requirement.*	IN-21
UCB	ISE	WBS-2.1.1	IN.DPU-30	4-Subsystem	Absolute Timing	The IDPU DCB shall use UTC to time stamp instrument telemetry	*Baseline Design.*	IN.DPU-29
UCB	ISE	WBS-2.1.1	IN.DPU-31	4-Subsystem	Time-tag accuracy - Particle Instruments	The IDPU DCB shall time-tag ESA and SST Spin Reference Pulse (SRP) to <5 ms	*0.83 ms = 0.1 degree and 3 second period. Derived from requirement to spin-sector ESA data, synchronize with SST data.*	IN.DPU-34
UCB	ISE	WBS-2.1.1	IN.DPU-32	4-Subsystem	Time-tag accuracy - Fields Instruments	The IDPU DCB shall time-tag DFB and FGM data to <2 ms (max packet rate is 500/sec total)	*Derived from sampling rate of DFB ADC system. Relative timing.*	
UCB	ISE	WBS-2.1.1	IN.DPU-33	4-Subsystem	Relative Sampling Time - Particle	The IDPU DCB subsystem shall obtain time (UTC w/sub seconds) from the Probe C&DH Subsystem to synchronize Bus and Instrument clocks.		IN-21
UCB	ISE	WBS-2.1.1	IN.DPU-34	4-Subsystem	Relative Sampling Time - Particle	The IDPU DCB shall coordinate ESA and SST synchronization by sending spin count to these systems.	*Allows total moments to be calculated on the ground (from partial moments provided by ESA and SST)*	IN.ESA-9
UCB	ISE	WBS-2.1.1	IN.DPU-35	4-Subsystem	Relative Sampling Time - Fields	The relative sampling times of FGM, SCM and EFI channels shall be fixed and well known for all modes of operation.	*Allows for stable inter-calibration between the two magnetic sensors and the EFI*	
DFB Core Functional Requirements								
UCB	ISE	WBS-2.1.1	IN.DPU-36	4-Subsystem	DFB Functional Requirement: On-board Fields FFT Solution	The IDPU DFB shall provide an DFT solution for determining the parallel and perpendicular components of E (and B) in both survey and burst modes and produce spectra for each quantity separately (FPGA-based)		IN.EFI-8
UCB	ISE	WBS-2.1.1	IN.DPU-37	4-Subsystem	DFB Functional Requirement: On-	The IDPU DFB shall integrate FGM digital data and EFI data to produce E·B (FPGA-based)		
BEB Core Functional Requirements								
UCB	ISE	WBS-2.1.1	IN.DPU-38	4-Subsystem	BEB Functional Requirements	The IDPU BEB shall provide sensor biasing circuitry, stub and guard voltage control, and boom deployment for the EFI	*Required to achieve EFI accuracy requirement*	IN.EFI-13
UCB	ISE	WBS-2.1.1	IN.DPU-39	4-Subsystem	EFI Floating Ground Distribution	The IDPU BEB shall distribute a floating ground power supply to the EFI sensors	*Required to achieve EFI accuracy requirement*	IN.EFI-13
UCB	ISE	WBS-2.1.1	IN.DPU-40	4-Subsystem	EFI Floating Voltage Accuracy	The IDPU BEB shall generate six independent BIAS, GUARD and STUB voltages with an accuracy of 0.1% for distribution to the EFI	*Required to achieve EFI accuracy requirement*	IN.EFI-13
LVPS Power Distribution								
UCB	ISE	WBS-2.1.1	IN.DPU-41	4-Subsystem	IDPU-Probe Power Interface	The IDPU LVPS/Probe interface voltage shall be 28+/-6V DC	*Interface Requirement*	IN-21
UCB	ISE	WBS-2.1.1	IN.DPU-42	4-Subsystem	IDPU-Probe Power Interface	The IDPU LVPS shall use a separate 28+/-6V (lock-out) actuator supply from the Probe for all boom deploy mechanisms	*Safety Requirement*	P-18
UCB	ISE	WBS-2.1.1	IN.DPU-43	4-Subsystem	Undervoltage Condition	The IDPU LVPS shall not be damaged by undervoltage conditions	*Provides system fault tolerance*	IN-4
UCB	ISE	WBS-2.1.1	IN.DPU-44	4-Subsystem	Instrument Regulated Voltages	The IDPU LVPS shall provide Instrument regulated, switched and current-limited voltages as detailed in the Instrument-IDPU ICDs	*Interface Requirement. Reflects project decision to provide centralized power conversion, distribution and control for all instruments*	IN-20
UCB	ISE	WBS-2.1.1	IN.DPU-45	4-Subsystem	Transient Power	The IDPU LVPS shall be capable of providing the transient power needs for actuators as detailed in the Instrument-IDPU ICDs	*Interface Requirement. Reflects project decision to provide centralized power conversion, distribution and control for all instruments*	IN-20

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
UCB	ISE	WBS-2.1.1	IN.DPU-46	4-Subsystem	Power in-rush, ripple, stability	The IDPU LVPS power line characteristics (i.e. transients, in-rush, ripple, stability, etc) shall be as agreed upon and documented in the Instrument-IDPU ICDs	*Interface Requirement. Reflects project decision to provide centralized power conversion, distribution and control for all instruments*	IN-20
UCB	ISE	WBS-2.1.1	IN.DPU-47	4-Subsystem	Switching Frequencies	All IDPU LVPS switching supplies shall run at frequencies greater than 100 kHz (Requested, not required)	*Avoids potential interference with highest sampling rate EFI data*	IN.EFI-6
UCB	ISE	WBS-2.1.1	IN.DPU-48	4-Subsystem	Switching Frequencies	The switching frequencies of all power converters shall be known and analyzed for possible interference with SCM measurements (frequency up to 4kHz)	*Avoids AC magnetic interference*	IN-16
Safety								
UCB	ISE	WBS-2.1.1	IN.DPU-49	4-Subsystem	High Voltage Safety Lock-out	The IDPU shall include sufficient hardware and software safety latches to prevent accidental high voltage turn on to the ESA	*Safety Requirement*	P-18
UCB	ISE	WBS-2.1.1	IN.DPU-50	4-Subsystem	Boom Deploy Safety Lock-out	The IDPU shall include sufficient hardware and software safety latches to prevent accidental deployment of the booms	*Safety Requirement*	P-18
Mechanical								
UCB	ISE	WBS-2.1.1	IN.DPU-51	4-Subsystem	Standard Card Accommodation	The IDPU box shall accommodate at least five 6U VME cards (DFB, BEB, ESA/SST/FGM Interface, LVPS, DCB) and provide as much radiation protection as possible within mass constraints	*Accommodates all IDPU functions including: power distribution and control; data processing and storage; and instrument specific boards*	IN-20
UCB	ISE	WBS-2.1.1	IN.DPU-52	4-Subsystem	FGM Calibration Data	The IDPU box shall be designed in conjunction with board level thermal analysis (part dissipation, heat-sinking, thermal wedge-locks) and	*Required for instrument operation in predicted thermal environment*	M-28

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Probe Bus - General (PB-#)								
Mission Derived Requirements and Flow-down								
Swales	TA	WBS-2.2.2	PB-1	3-Element	Mission Lifetime	The Probe Bus shall be designed for at least a two-year lifetime.	*Flow-down*	M-1
Swales	TA	WBS-2.2.2	PB-2	3-Element	Total Dose Radiation	The Probe Bus shall be designed for a total dose environment of 33 krad/year (66 krad total) (TBR)	*Flow-down*	M-3
Swales	TA	WBS-2.2.2	PB-3	3-Element	SEE Radiation	The Probe Bus shall be Single Event Effect (SEE) tolerant and immune to destructive latch-up.	*Flow-down*	M-4
Swales	TA	WBS-2.2.2	PB-4	3-Element	Probe Safe-Hold Power	The Probe Bus shall have an autonomous safe state after carrier separation.	*Flow-down*	M-7
Swales	TA	WBS-2.2.2	PB-5	3-Element	Failure Detection and	The Probe Bus shall implement Failure Detection and Correction (FDC)	*Flow-down*	M-8
Swales	TA	WBS-2.2.2	PB-6	3-Element	Unique ID	Each Probe Bus shall have a unique ID that is non-volitable on-orbit.	*Flow-down*	M-10
Swales	TA	WBS-2.2.2	PB-7	3-Element	Eclipse Constraint	The Probe Bus shall be designed for a shadow time less than 180 minutes	*Flow-down*	M-25
Swales	TA	WBS-2.2.2	PB-8	3-Element	Minimal Fuel	The Probe Bus shall require the minimal fuel possible to place probes in desired orbits	*Flow-down*	M-18
Swales	TA	WBS-2.2.2	PB-9	3-Element	System Mass Budget	The Probe Bus shall not exceed a dry mass of 47.2 kg (instrument payload not included)	*Ensures limiting mass constraint (deltaV to place probes in required orbits) is met with system margin. Not-to-exceed is CBE of 41kg plus*	M-21
Swales	TA	WBS-2.2.2	PB-10	3-Element	Allocated Mass Budget	No Probe Bus subsystem shall exceed the allocated mass budget in Table M1	*Reflects estimated mass plus contingency based on level of design fidelity.*	PB-9
Swales	TA	WBS-2.2.2	PB-11	3-Element	System Power Budget	The Probe Bus shall require less than 14.5 W average power (instrument payload not included)	*Ensures limiting power constraint (probe power generation and storage capability at mission end-of-life) is met with system margin. Not-to-*	M-23
Swales	TA	WBS-2.2.2	PB-12	3-Element	Allocated Power Budget	No Probe Bus subsystem shall exceed the allocated power budget in Table P1	*Reflects estimated power plus contingency based on level of design fidelity.*	PB-11
Swales	TA	WBS-2.2.2	PB-13	3-Element	Probe Operational Power	Each Probe shall be designed to achieve electrical energy balance over an orbit assuming a 30 minute transmitter power on time and a 180	*Flow-down*	M-25
Swales	TA	WBS-2.2.2	PB-14	3-Element	Allocated Data Budget	The Probe Bus shall not exceed the allocated data budget of 87 Mbits/orbit	*Accommodates 1kbps probe data rate for P3,P4,P5 (one-day orbits). Drives requirement to have multiple data rates for P1 and P2 (multiple-day orbits). Must be sufficient to support minimum probe housekeeping.*	M-26
Swales	TA	WBS-2.2.2	PB-15	3-Element	Data Storage	The Probe Bus shall be capable of storing 1 orbit + 1 days worth of Probe Bus housekeeping data.	*Flow-down*	M-27
Swales	TA	WBS-2.2.2	PB-16	3-Element	Survival Temperature	The Probe Bus subsystems shall survive the temperature ranges provided in Table XX in the ICD	*Provides component limits for Probe thermal design*	M-28
Swales	TA	WBS-2.2.2	PB-17	3-Element	Operating Temperature	The Probe Bus subsystems shall perform as designed within the temperature ranges provided in Table XX in the ICD	*Provides component limits for Probe thermal design*	M-28
Swales	TA	WBS-2.2.2	PB-18	3-Element	Cold Start	The Probe Bus subsystems shall be able to cold start at TBD	*Provides component limits for Probe thermal design*	M-28
Swales	TA	WBS-2.2.2	PB-19	3-Element	Magnetics Cleanliness	All Probe Bus shall comply with the Magnetics Cleanliness standard described in the THEMIS Magnetics Cleanliness Plan.	*Flow-down*	M-32
Swales	TA	WBS-2.2.2	PB-20	3-Element	Switching frequencies	The switching frequencies of all power converters shall be known and analyzed for possible interference with SCM measurements (frequency up to 4kHz)		PB-19
Swales	TA	WBS-2.2.2	PB-21	3-Element	Electrostatic Cleanliness	The Probe Bus shall comply with the THEMIS Electrostatic Cleanliness (ESC) Plan	*Flow-down*	M-34
Swales	TA	WBS-2.2.2	PB-22	3-Element	Contamination Control Plan	The Probe Bus shall comply with the THEMIS Contamination Control Plan	*Flow-down*	M-37
Swales	TA	WBS-2.2.2	PB-23	3-Element	Electrical System Specification	All Probe Bus subsystems shall meet the general electrical system requirements documented in the THEMIS Electrical System	*Flow-down*	M-38
Swales	TA	WBS-2.2.2	PB-24	3-Element	ICD	The Probe Bus shall be compatible per Instrument-Probe Bus and Probe Bus Subsystem ICDs	*Flow-down. Defines where interfaces are documented.*	M-39
Swales	TA	WBS-2.2.2	PB-25	3-Element	ICD	The Probe Bus shall be compatible per IDPU-Probe Bus ICD	*Flow-down. Defines where interfaces are documented.*	M-39
Swales	TA	WBS-2.2.2	PB-26	3-Element	ICD	The Probe Bus shall be compatible per Flight-to-Ground ICD	*Flow-down. Defines where interfaces are documented.*	M-39
Swales	TA	WBS-2.2.2	PB-27	3-Element	ICD	The Probe Bus shall be compatible per Probe-Probe Carrier ICD	*Flow-down. Defines where interfaces are documented.*	M-39
Swales	TA	WBS-2.2.2	PB-28	3-Element	ICD	The Probe Bus shall be compatible per Boeing Mission Specification (Launch ICD)	*Flow-down. Defines where interfaces are documented.*	M-39
Swales	TA	WBS-2.2.2	PB-29	3-Element	Performance Verification	The Probe Bus shall verify performance requirements are met per the Verification Plan and Environmental Specification.	*Flow-down*	M-40
Swales	TA	WBS-2.2.2	PB-30	3-Element	Environments	The Probe Bus shall survive and function prior, during and after exposure to the environments described in the Verification Plan and Environmental Specification.	*Flow-down*	M-41

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Swales	TA	WBS-2.2.2	PB-31	3-Element	Integration and Testing	The Probe Bus shall be testable during all levels of integration and test	*Flow-down*	M-42
Swales	TA	WBS-2.2.2	PB-32	3-Element	Component Stiffness	All Probe Bus structural components shall be designed to have a minimum fundamental frequency of 75 Hz (goal) in the stowed configuration.	*Design goal. Avoid coupling between component and Probe / Probe Carrier dynamics. Mass model if below.*	M-46
Swales	TA	WBS-2.2.2	PB-33	3-Element	Ground Station Compatibility	The Probe Bus shall be compatible with BGS, USN, TDRSS, and NASA/GN	*Flow-down*	M-48
Swales	TA	WBS-2.2.2	PB-34	3-Element	Frequency and Data Format	The Probe Bus shall be S-Band, CCSDS-compatible and COP-1 compatible	*Flow-down*	M-49
Swales	TA	WBS-2.2.2	PB-35	3-Element	Transmitter on time	The Probe Bus shall be capable of downlinking all data within 30 minutes per day per probe (maximum transmitter on time).	*Flow-down*	M-52
Swales	TA	WBS-2.2.2	PB-36	3-Element	Uplink data rate	The Probe Bus shall be capable of receiving commands at an uplink data rate of 1 kbps	*Flow-down*	M-55
Swales	TA	WBS-2.2.2	PB-37	3-Element	Link Margin	The Probe Bus shall be designed to accommodate a S-Band uplink and downlink link margin of ≥ 3dB at all points in orbit through all mission phases	*Flow-down*	M-56
Swales	TA	WBS-2.2.2	PB-38	3-Element	Orbital Knowledge	The Probe Bus allow an absolute orbital knowledge accuracy of 10km at Perigee and 100km at Apogee to be determined by the Ground System.	*Flow-down*	M-58
Instrument Derived Requirements								
Swales	TA	WBS-2.2.2	PB-39	3-Element	Probe Stabilization	The Probe shall be spin stabilized, with a spin rate between 6-25 rpm during science operations	*ESA and SST sensors require that the probe spins at 10-30RPM in order to obtain full azimuth coverage.*	IN.ESA-10
Swales	TA	WBS-2.2.2	PB-40	3-Element	Probe Spin Axis Orientation	The Probe spin axis shall be within 10 +/- 5 degrees of the ecliptic during science operations.	*Required by EFI.*	IN.EFI-13
Swales	TA	WBS-2.2.2	PB-41	3-Element	Spin Axis	The Probe spin axis shall be 10 degrees toward the sun on February 21, 2007	*See Phase A Concept Study Report, Section E3, Subsection a4*	PB-40
Swales	TA	WBS-2.2.2	PB-42	3-Element	Absolute Inertial Knowledge	The absolute post-processed inertial attitude (spin-axis) of the Probe shall be known to within 1 degree (3-axis), 3 sigma	*Required by FGM and SCM. Inertial attitude will be calculated on the ground using sun sensor data from probe and FGM data.*	S-8
Swales	TA	WBS-2.2.2	PB-43	3-Element	FGM Pointing Stability Over 12 hours	Angle between FGM instrument axis (transformation TBD) and the ecliptic plane normal shall not vary more than 0.16 (TBR) degrees over any 12 hour period during normal science observation (required outside	*Required by FGM. Measurement of cross tail current in the planar approximation using probes P5 and P4 in the second year.*	S-8
Swales	TA	WBS-2.2.2	PB-44	3-Element	FGM Pointing Stability Over 3 Days	Angles between FGM instrument axis (transformation TBD) and the ecliptic plane normal shall not vary more than 1 (TBR) degree over any 3 day period during normal science observation.	*Required by FGM - limits calibration of individual magnetometers to less frequent than once per few days (adding up 0.16 degrees/12hrs for 3 days gives ~1 degree total)*	S-8
Swales	TA	WBS-2.2.2	PB-45	3-Element	Principle Axis Misalignment and Knowledge	The Probe Bus Principle Axis of Inertia shall be aligned within 5.6 degrees, 3 sigma of the Probe Z axis. The probe principle axis of inertia to Z-axis misalignment shall be estimated to within 0.1 degree, 3 sigma using ground-based processing.	*Required by ESA, SST. ESA FOV is 11.25 degrees/anode:5.6 degrees PA misalignemnt + 5 degrees spin axis pointing < ESA FOV 11.2 degrees so ESA Anode sees pole?* *PA misalignment is a large component of FGM to EFI relative orientation. EFI data is transformed to FGM frame for science.* *FGM and Sun sensor calibration data will be used to estimate PA misalignment.*	IN.ESA-10
Swales	TA	WBS-2.2.2	PB-46	3-Element	FGM, SCM, EFI Axial boom deployment	The spin rate of the Probe Bus shall limit stress on deployment mechanism during rigid boom deployments	*Required for FGM, SCM and Axial EFI Boom Deploy*	PB-48
Swales	TA	WBS-2.2.2	PB-47	3-Element	Radial EFI Boom deployment	The spin rate of the Probe Bus shall keep wire booms from tangling during boom deployments	*Required for EFI Radial Boom Deploy*	PB-48
Swales	TA	WBS-2.2.2	PB-48	3-Element	Dynamic Stability	The Probe Bus shall maintain passive spin stability during all boom deployments.	*Passive spin stabilized system reduces complexity and avoids need for nutation control system*	PB-39
Swales	TA	WBS-2.2.2	PB-49	3-Element	Worst-Case Boom Deployment	One boom deployment failure shall not jeopardize the subsequent deployments and operation of that Probe	*Allows for fault tolerant system*	M-5
Swales	TA	WBS-2.2.2	PB-50	3-Element	Probe Spin Axis Direction	The Probe Bus positive spin vector shall be aligned with the Probe positive Z axis.	*Supports FGM and SCM boom deployment*	PB-48

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
PB Communications (PB.Com-#)								
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-1	4-Subsystem	Ground Station Compatibility	The Communications Subsystem shall be compatible with BGS, USN, TDRSS, and NASA/GN	*flow down*	PB-33
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-2	4-Subsystem	Uplink data rate	The Communications Subsystem shall support an uplink data rate of 1 kbps	*flow down*	PB-36
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-3	4-Subsystem	Receiver Powered at all times	The Receiver shall remain powered at all times	*Hard Critical commanding circuitry must be capable of being commanded at all times. Essential function required for Safe-Hold mode.*	PB.CDH-4
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-4	4-Subsystem	Multiple Downlink Rates	The Communication Subsystem shall support multiple downlink data rates ranging from a minimum of 1 kbps to a maximum of 1024 kbps (TBR - 2048 kbps)	*Baselined downlink capability based upon downlinking all data within <20min per contact. Lower data rate required for P1 and P2.*	PB-35
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-5	4-Subsystem	Link Encoding	The Communications Subsystem shall provide Reed-Solomon & Convolutional encoding on the downlink. (Rate 1/2 K=7)	*Maximize link margin by encoding. Industry Standard*	PB-37
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-6	4-Subsystem	Convolutional Encoding On/Off	The Communications Subsystem shall provide the capability to turn off Convolutional encoding on the downlink.	*Enables increase in data volume if on-orbit link performance is better than expected.*	PB-37
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-7	4-Subsystem	Downlink Power	The Downlink EIRP shall be a minimum of 3.5 dBW within the primary antenna coverage area, defined as the ±45° band about the spacecraft x-y plane	*Baseline UCB station. Envelopes other stations (matches or exceeds).*	PB-37
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-8	4-Subsystem	Uplink Power	The Uplink EIRP shall be TBD dBW	*Baseline meeting link margin requirement*	PB-37
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-9	4-Subsystem	Downlink G/T	The Downlink G/T shall be greater than TBD dB/K	*Baseline meeting link margin requirement*	PB-37
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-10	4-Subsystem	Uplink G/T	The Uplink G/T shall be greater than TBD dB/K	*Baseline meeting link margin requirement*	PB-37
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-11	4-Subsystem	Polarization	The Probe antenna shall have circular polarization	*Baseline meeting link margin requirement, and maintaining compatability with the Ground System*	PB-37
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-12	4-Subsystem	Ranging	The Communications Subsystem shall support two-way coherent doppler ranging	*Supports orbit knowledge requirement*	PB-38
Swales	Kraeuter	WBS-2.2.2.2.6	PB.Com-13	4-Subsystem	Hardline Interface	The Communications Subsystem shall provide "hard line" command and telemetry to accommodate probe testing without using the RF link to the transponder.	*Fundamental to support I&T activities*	PB-31

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
PB Attitude Control System (PB.ACS-#)								
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-1	4-Subsystem	Spin Stabilization	The Bus shall be "passive" spin stabilized	*Support spin rate without complexity and propulsion for nutation control. Keeps wire booms from tangling*	PB-39
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-2	4-Subsystem	Spin Rate Control	The Bus spin rate shall be between 6 and 25 RPM during nominal science operations	*Flow-down from Instruments*	PB-39
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-3	4-Subsystem	Spin Rate Control Accuracy	The Bus shall be capable of increasing or decreasing its spin rate by 1 RPM.	*Spin based on instrument sample rate. Desire to control.*	
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-4	4-Subsystem	On-Board Spin Rate Measurement Resolution	The Bus shall be able to measure its spin rate to 0.1 RPM resolution on-board [TBR].	*Fault Detection*	
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-5	4-Subsystem	On-Board Spin Phase Knowledge	The Bus shall be able to maintain on-board inertial spin phase knowledge to 0.1 degree [TBR] during side thrusting maneuvers.	*Phase tangential thrust to enable thrusting orthogonal to the spin vector. (sun-synchronous pulse triggering).*	
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-6	4-Subsystem	Probe Inertial Pointing	The ACS shall point the probe bus spin axis within 5 degrees (3 sigma) of an inertially fixed observation reference during normal science observation (when the probe is farther than 5 Earth radii from the Earth Center and TBD hours after slew or eclipse exit or entry)	*Enhance B-field measurement accuracy by increasing Z-axis component. The inertially fixed observation plane is rotated 10 degrees from the February 21, 2007 ecliptic plane about an axis in the ecliptic plane perpendicular to a line from the Sun to the Earth.*	PB-40
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-7	4-Subsystem	Principle Axis Misalignment Stability Over 12 Hours	The angle between the probe principle axis inertia and the probe Z-axis shall not vary more than 0.1 degrees (3 sigma) over any 12 hour period during normal science observation (when the probe is farther than 5 Re from the Earth center and TBD hours after slew or eclipse exit or entry).	*Measurement of cross tail current in the planar approximation using probes P5 and P4 in the second year.*	PB-43
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-8	4-Subsystem	Principle Axis Misalignment Stability Over 3 Days	The angle between the probe principle axis inertia and the probe Z-axis shall not vary more than 0.6 degrees (3 sigma) over any 3 day period during normal science observation (when the probe is farther than 5 Re from the Earth center and TBD hours after slew or eclipse exit or entry).	*Limits calibration of individual magnetometers to less frequent than once per few days (adding up 0.1 degrees/12hrs for 3 days gives 0.6 degree total)*	PB-44
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-9	4-Subsystem	Initial spin rate for FGM and SCM boom deployment	The Bus initial spin rate during FGM and SCM boom deployment shall be between 0 and 15 RPM	*Limit stress on deployment mechanism*	PB-46
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-10	4-Subsystem	Spin rate during Radial EFI Boom deployment	The Bus spin rate during radial EFI boom deployment shall be between 2 and 25 RPM	*Limit stress on deployment mechanism* *Keep wire booms from tangling*	PB-47
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-11	4-Subsystem	Spin rate during Axial EFI Boom deployment	The Bus spin rate during axial EFI boom deployment shall be between 0 and 25 RPM	*Limit stress on deployment mechanism* *Keep wire booms from tangling*	PB-46
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-12	4-Subsystem	Positive Stability	The Bus shall maintain positive stability in all nominal on-orbit deployment configurations and all off-nominal configurations in which only one boom deployment fails.	*"Passive" spin stabilized to avoid need for nutation control system* *One boom deployment failure shall not jeopardize the minimum science mission*	PB-48
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-13	4-Subsystem	Sun Sensor Data for Ground-Based Absolute Inertial Pointing Knowledge	The Bus shall produce sun sensor data with suffient accuracy to enable ground-based absolute inertial attitude estimation of the bus spin phase during normal science observations to within 1 degree (3 sigma), over one orbit, using TBD hours of sun sensor measurements.	*Contingency attitude determination without augmentation*	PB.ACS-19
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-14	4-Subsystem	Spin Axis Stability	The angle between the probe spin axis and the observation reference shall not vary more than 0.1 degrees (3 sigma) over any 12 hour period, or 0.6 degrees (3 sigma) over any 3 day period, during normal science observation (when the probe is farther than 5 Re from the Earth center and TBD hours after slew or eclipse exit or entry)	*Measurement of cross tail current in the planar approximation using probes P5 and P4 in the second year. Measurement of current sheet with 2 Probes requires relative probe stability.* *Limits simultaneous calibration of magnetometer to less frequent than once per few days (adding up 0.1 degrees/12hrs for 3 days gives 0.6 degree total)*	
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-15	4-Subsystem	Attitude Sensor Information	The Bus shall provide all raw attitude sensor information in its housekeeping telemetry.	*Ground-based attitude determination will process attitude sensor data*	M-60
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-16	4-Subsystem	Sun Sensor Information to IDPU	The Bus shall provide raw sun sensor information to the C&DH subsystem for transfer to the instrument	*The IDPU shall provide pitch angle computations for the ESA. The DCB shall provide a Spin Phase Clock to the SST and ESA (accurate to +/- TBD). The DCB shall read Sun sensor data from the spacecraft status packet. The DCB shall time-tag Sun sensor data to spin-sector SST and ESA data. The DCB shall calculate the spin period. The DCB shall control the Spin Sectoring Circuit to produce spin pulses at the*	IN.ESA-12
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-17	4-Subsystem	Sun Sensor Data	The Bus shall produce sun sensor data with sufficient (TBD) accuracy to enable ground-based estimation of the spin-phase to within 1 degree, 3 sigma (TBR).	*Spin phase combined with spin axis attitude and principle axis to Z-axis knowledge provides bus Z-axis inertial pointing knowledge*	PB.ACS-19

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-18	4-Subsystem	Principle Axis Misalignment Knowledge	The Bus principle axis to Z-axis misalignment shall be estimated to within 0.1 degree, (3 sigma) during FGM calibration using ground-based processing.	*PA misalignment is a large component of FGM to EFI relative orientation -- FGM to inertial. EFI data is transformed to FGM frame for science. FGM and Sun sensor calibration data will be used to estimate PA*	PB-44
Swales	LeBoeuf	WBS-2.2.2.2.1	PB.ACS-19	4-Subsystem	Probe spin axis inertial pointing knowledge	The probe spin axis inertial orientation shall be estimated in ground-based processing to within 1 degree, 3 sigma once per orbit during normal science operation (when the probe is farther than 5 Re from the Earth center and TBD hours after slew or eclipse exit or entry)	*Baseline attitude determination will use sun sensor and FGM data to estimate attitude near perigee. Spin axis attitude will be propagated around the rest of the orbit.*	PB-42
PB Reaction Control System (PB.RCS-#)								
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-1	4-Subsystem	Maximum Probe Dry Mass	Each THEMIS Probe shall be designed to accommodate a 82kg (TBR) dry mass	*Includes Project margin for dry mass*	M-22
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-2	4-Subsystem	Delta V capability	The Reaction Control System shall provide the required delta-V of 650m/s (566m/s + 15% contingency) plus TBD propellant margin (on launch) (TBR)	*Required to meet orbital placement and phasing. 15% contingency required to account fo errors in the delta-V calculations. TBD margin on launch required to account for operator errors, etc. on-orbit.*	M-22
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-3	4-Subsystem	ACS maneuvers capability	The Reaction Control System shall provide 1.6kg + 15% (TBR) of Hydrazine propellant for probe attitude control maneuvers for the maximum expected probe dry mass.	*Spin Axis precession, spin rate control. 15% contingency required to account for errors in the attitude control calculations*	PB.ACS-3
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-4	4-Subsystem	Delta V impulse, maximum	The Bus shall be capable of providing a delta-V impulse less than 80cm/s (Orbit control)	*Mission maneuver design decision, sets maximum thruster size From DRM, spin plane booms???*	
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-5	4-Subsystem	Delta V Impulse, minimum	Maneuvers shall be completed within planned mission time constraints (TBD Value)	*Mission maneuver design decision, sets minimum thruster size*	PB.ACS-3
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-6	4-Subsystem	Propulsion plume contamination	The propulsion plume thrust vector shall point away from the ESA and SST apertures.	*ESA and SST sensors are contamination sensitive*	PB-22
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-7	4-Subsystem	Δ-V Orientation	The Reaction Control System shall Provide Δ-V capability along the positive spin axis	*Large orbit adjust burns, to be accomplished with steady state burns will make use of axial thrusters oriented along the spin axis.*	PB-8
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-8	4-Subsystem	Δ-V Orientation	The Reaction Control System shall Provide Δ-V in the spin plane	*Minor Delta-V adjustments normal to the spin axis must not require re-orienting the spacecraft spin axis*	PB-8
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-9	4-Subsystem	Spin Rate Control	The Reaction Control System shall Provide Spin Rate Control	*Deployment of booms and other perturbations will cause deviations from the required spin rate. The RCS must be capable of compensating for these variations.*	PB.ACS-3
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-10	4-Subsystem	Spin Axis Precession Control	The Reaction Control System shall Provide Spin Axis Precession control	*Initial separation from the launch vehicle as well as performance of orbit adjust maneuvers will require control of spin axis orientation*	PB.ACS-6
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-11	4-Subsystem	Δ-V and Δ-ω Budgets	The Reaction Control System shall maintain probe spin balance from launch phase though deorbit	*Derived Requirement,*	PB.ACS-12
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-12	4-Subsystem	Δ-V and Δ-ω Budgets	The Reaction Control System shall have a minimum impulse bit of TBD for $\Delta-\omega$	*Spin rate trim burns*	PB.ACS-3
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-13	4-Subsystem	Monitoring	The Reaction Control System shall provide pressure telemetry.	*Pressure telemetry (along with Temperature telemetry from the thermal subsystem) will be used to assess the health of the propulsion system and assist in propellant use bookkeeping.*	PB.CDH-20
Swales	McCullough	WBS-2.2.2.1.2	PB.RCS-14	4-Subsystem	Monitoring	The Reaction Control System shall provide positive indication of latch valve position	*Prelaunch activities require operation and monitoring of latch valve positions*	P-18

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
PB Electrical Power System (PB.EPS-#)								
Swales	Kraeuter	WBS-2.2.2.2.4	PB.EPS-1	4-Subsystem	Power Distribution	The EPS shall control and distribute electrical power to the Probe Bus and the IDPU.	*The Probe Bus distributes power to the Subsystems and IDPU. IDPU distributes power to the instruments.*	PB-24
Swales	Kraeuter	WBS-2.2.2.2.4	PB.EPS-2	4-Subsystem	Probe Bus Voltage Range	The EPS shall provide 28+/-6 V to the Instrument IDPU	*Interface Requirement*	PB-25
Swales	Kraeuter	WBS-2.2.2.2.4	PB.EPS-3	4-Subsystem	Actuator Power Interface	The EPS shall provide a separate 28+/-6V (lock-out) actuator supply	*Safety Requirement for Instrument deployment devices*	P-18
Swales	Kraeuter	WBS-2.2.2.2.4	PB.EPS-4	4-Subsystem	Maintain Power Positive	The EPS shall be designed so that the battery is charged during normal science mode	*Derived by requirement to be achieve energy balance during all modes of operation (nominal mode)*	PB-13
Swales	Kraeuter	WBS-2.2.2.2.4	PB.EPS-5	4-Subsystem	Maintain Bus Power Through Launch	The Battery capacity shall be sufficient to provide power for the Bus through the worst-case launch scenario of less that TBD hours, until positive power balance is achieved.	*Derived by requirement to achieve energy balance during all modes of operation (post-launch mode)*	PB-13
Swales	Kraeuter	WBS-2.2.2.2.4	PB.EPS-6	4-Subsystem	On-orbit Average Power	The EPS shall be provide at least 41.5 W on-orbit average power EOL.	*Flow-down*	M-24
Swales	Kraeuter	WBS-2.2.2.2.4	PB.EPS-7	4-Subsystem	Peak Power Load	The EPS shall provide peak power of 65W (TBC) during downlink operations for a duration of 30 minutes	*Derived by requirement to achieve energy balance during all modes of operation (downlink mode). Based on required transmitter on time per orbit.*	PB-13
Swales	Kraeuter	WBS-2.2.2.2.4	PB.EPS-8	4-Subsystem	Operation During Maximum Eclipse Length	The EPS shall provide an average power of 49W (TBC) during the maximum eclipse duration of 180 minutes	*Derived by requirement to be achieve energy balance during all modes of operation (eclipse mode). Based on maximum eclipse assumption.*	PB-13
Swales	Kraeuter	WBS-2.2.2.2.4	PB.EPS-9	4-Subsystem	Solar Array Sizing	The Solar Array shall be sized to meet worst case power requirements at EOL.	*Derived by requirement to be achieve energy balance during all modes of operation (EOL).*	PB.EPS-6
Swales	Kraeuter	WBS-2.2.2.2.4	PB.EPS-10	4-Subsystem	Battery On/Off Control for test	The EPS shall provide the means of switching the battery on/off the Bus.	*Battery must be able to be switched on and off during I&T*	PB-31
Swales	Kraeuter	WBS-2.2.2.2.4	PB.EPS-11	4-Subsystem	Battery On/Off Control On-orbit	It shall not be possible to switch the battery off the bus during flight.	*Battery must not be able to be switched off during flight.*	PB-4
Swales	Kraeuter	WBS-2.2.2.2.4	PB.EPS-12	4-Subsystem	Solar Array Interconnects	The Solar Array manufacturing shall be compliant with the Electrostatic Cleanliness (ESC) Plan	*Required to mitigate Electro Static Cleanliness Concerns*	PB-21

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
PB Command and Data Handling (PB.CDH-#)								
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-1	4-Subsystem	CCSDS Compatibility	All Bus command and telemetry shall be compatible with CCSDS recommendations	*NASA standard.*	PB-34
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-2	4-Subsystem	COP-1 Protocol	The C&DH subsystem shall use the COP-1 protocol	*NASA standard.*	PB-34
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-3	4-Subsystem	Receive & Process Commands	The C&DH subsystem shall receive and process commands destined for the Bus electronics	*Core function of C&DH, derived from need to get data, also needed for responding to FDC*	PB-5
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-4	4-Subsystem	Receive Ground Commands at all times	The C&DH subsystem shall be capable of receiving ground commands at all times	*Minimum amount of autonomous operation requires continuous commanding capability.*	PB-4
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-5	4-Subsystem	Hardline Interface	The C&DH subsystem shall provide "hard line" command and telemetry to accommodate probe testing without a transponder.	*Fundamental to support I&T*	PB-31
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-6	4-Subsystem	Command processing rate	The C&DH subsystem shall be capable of processing commands at a rate of 1kbps	*Supports baseline uplink rate*	PB-36
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-7	4-Subsystem	Special Commands	The C&DH subsystem shall execute Special commands (hardware-decoded) immediately with no involvement from the Flight Computer	*Capability to remotely reset Flight Computer due to an upset.*	PB-4
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-8	4-Subsystem	Flight Computer Commands	The C&DH subsystem shall forward all other commands (software-decoded) to it's Flight Computer for processing.	*Most commands will be processed by the Flight Computer.*	PB.CDH-3
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-9	4-Subsystem	Maintain command order	The C&DH subsystem shall maintain the order of commands	*Core function.*	PB.CDH-3
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-10	4-Subsystem	Instrument Commands	The C&DH subsystem shall forward all Instrument commands to the IDPU within TBD seconds of receipt	*Architecture Decision. The IDPU receives commands via the Flight Computer*	PB.CDH-3
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-11	4-Subsystem	Real-time & Stored Commands	The C&DH subsystem shall provide real-time and stored command capability	*The Flight Computer will be capable of executing commands in real-time, or at the time specified in the command*	PB.CDH-3
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-12	4-Subsystem	Absolute Time Commands	The C&DH subsystem shall provide Absolute Time Sequence (ATS) commands expressed in UTC times with resolution of 1 second	*The Flight Computer will be capable of executing commands using absolute time*	PB.CDH-3
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-13	4-Subsystem	Relative Time Commands	The C&DH subsystem shall provide Relative Time Sequence (RTS) commands	*The Flight Computer will be capable of executing commands using relative time*	PB.CDH-3
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-14	4-Subsystem	Instrument Command Storage	The C&DH subsystem shall provide a sufficient amount of command storage.	*Command storage will be sized during design process.*	PB.CDH-3
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-15	4-Subsystem	Load and Execute Commands	The C&DH subsystem shall be able to load and execute commands simultaneously	*Capability to execute commands during command loads.*	PB.CDH-3
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-16	4-Subsystem	Separation Detection	The C&DH subsystem shall detect the Launch Vehicle separation signal and autonomously begin a pre-programmed command sequence to separate from the Probe Carrier	*Design Decision to reduce cost of the Probe Carrier. The C&DH subsystem will contain functionality to autonomously issue commands to separate the Probe from the Carrier*	P.C.Mec-2
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-17	4-Subsystem	Autonomous Fault Protection	The C&DH subsystem shall implement autonomous fault protection features to ensure the health and safety of the probe	*The C&DH subsystem will contain functionality to autonomously issue commands to safe the Probe*	PB-5
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-18	4-Subsystem	Autonomous Function Enabling	The C&DH subsystem shall be capable of enabling or disabling each autonomous function via ground command	*Design Decision for safety. Autonomous functions should be able to be disabled*	PB.CDH-17
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-19	4-Subsystem	Flight Software Modification	The C&DH subsystem shall provide the capability to upload or modify Probe Bus flight software.	*Flight software should be able to be modified without requiring physical contact with the hardware.*	P-16
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-20	4-Subsystem	Provide Engineering Telemetry	The C&DH subsystem shall provide Bus housekeeping telemetry sufficient to safely operate the probe (temps, currents, voltages, and bi-levels).	*Telemetering engineering data is the responsibility of the C&DH subsystem*	M-59
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-21	4-Subsystem	ACS Sensors and Actuators	The C&DH subsystem shall receive telemetry from the ACS sensors and actuators, and include it in housekeeping telemetry	*The C&DH subsystem telemeters data from the sun sensor*	PB.ACS-15
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-22	4-Subsystem	Generation of housekeeping telemetry	The C&DH subsystem shall generate real-time housekeeping telemetry at all times	*The C&DH subsystem continuously generates housekeeping telemetry*	PB.CDH-20
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-23	4-Subsystem	Transmission of housekeeping telemetry	The C&DH subsystem shall transmit real-time housekeeping telemetry when in ground contact	*Housekeeping telemetry is transmitted real-time when in ground contact*	M-59
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-24	4-Subsystem	Storage of housekeeping telemetry	The C&DH subsystem shall store housekeeping telemetry when not in ground contact	*Housekeeping telemetry is always buffered by the C&DH subsystem*	PB-15
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-25	4-Subsystem	Housekeeping telemetry storage capacity	The C&DH subsystem shall be capable of storing one orbits + 1 days worth of minimum housekeeping telemetry	*Storage for one orbit + 1 day of HK TLM is nominally sized at 11 Mbytes*	PB-15
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-26	4-Subsystem	Playback of stored telemetry	The C&DH subsystem shall play back stored telemetry when commanded	*Stored telemetry is not automatically deleted after playback*	M-59

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-27	4-Subsystem	Erasure of stored telemetry	The C&DH subsystem shall erase stored telemetry after playback only when commanded to do so.	*Stored telemetry is maintained after playback*	M-59
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-28	4-Subsystem	Telemetry over-write	The C&DH subsystem shall be capable of altering the housekeeping telemetry acquisition rate based on ground command	*Maximizes utilization of on-board telemetry storage capability*	M-59
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-29	4-Subsystem	Interleaving of telemetry streams	The C&DH subsystem shall be capable of playing back stored telemetry interleaved with real-time housekeeping telemetry	*Playback of storned telemetry will not affect transmission of real-time telemetry*	M-59
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-30	4-Subsystem	N/A	Deleted	*N/A*	N/A
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-31	4-Subsystem	Multiple Downlink Rates	The C&DH subsystem shall be capable of downlinking at multiple selectable rates ranging from 1 kbps to 1024 kbps (TBR - 2048 kbps)	*Multiple downlink rates. NTIA bandwidth could be a problem for >1Mbps*	PB-14
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-32	4-Subsystem	Housekeeping Telemetry Storage Rate	The C&DH subsystem housekeeping telemetry storage rate shall be programmable from 250 bps to 4000 bps.	*Lowest telemetry storage rate for housekeeping is 250 bps to allow for flexibility in the case of missed passes*	PB.CDH-25
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-33	4-Subsystem	Time-tagging of Telemetry Data	C&DH subsystem telemetry data shall be time-tagged with acquisition time accurate to within +/- (TBD) ms	*Time tagging telemetry data*	
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-34	4-Subsystem	Time-tagging of ACS Telemetry Data	C&DH subsystem ACS telemetry data shall be time-tagged with acquisition time accurate to within +/- (TBD) ms	*Time tagging telemetry for the ground ACS system has tighter time tagging requirements than other data. ACS data includes sun sensor, gyros, thruster information.*	PB.ACS-15
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-35	4-Subsystem	Virtual Channel IDs	The telemetry format shall provide the means of distinguishing between data streams by the use of virtual channel IDs	*Use virtual IDs to distinguish between different data streams*	M-60
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-36	4-Subsystem	Master Clock	The C&DH subsystem shall provide a 8.192 MHz (TBR) master clock to the IDPU. Clock tolerance and stability is TBD.	*Master Clock distributed*	PB-25
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-37	4-Subsystem	1 Pulse Per Second interface	The C&DH subsystem shall provide a 1 Pulse Per Second (1PPS) interface (derived from the 8.192 MHz clock) to all Subsystems and the Instrument	*Use 1PPS interface to synchronize subsystems.*	PB-25
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-38	4-Subsystem	IDPU Synchronization	The C&DH subsystem shall distribute time (UTC w/sub seconds) to the IDPU to synchronize Bus and Instrument clocks.	*Distribute time between Bus and Instrument electronics*	PB-25
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-39	4-Subsystem	IDPU Commands & Telemetry	The C&DH subsystem shall send commands to and receive housekeeping telemetry from the IDPU via a bi-directional serial interface	*Instrument requirement*	PB-25
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-40	4-Subsystem	Command/Telemetry Interface Rate	The bi-directional serial interface to the IDPU shall have a transfer rate of 38.4 (TBR) kbps	*Design decision*	PB-25
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-41	4-Subsystem	Instrument Telemetry	The C&DH subsystem shall receive FGM telemetry from the IDPU	*Instrument utilizes Bus downlink to send engineering data to the ground*	PB.ACS-15
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-42	4-Subsystem	Instrument Telemetry	Instrument HSK & FGM telemetry shall be included in real time HKS	*Attitude Control software on the ground requires engineering data from the Instrument*	PB.ACS-15
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-43	4-Subsystem	C&DH to IDPU Telemetry	Sun Sensor telemetry shall be sent to the IDPU to within +/- TBD timing accuracy	*The IDPU provides a Spin Phase Clock to the SST and ESA. Spin Pulse from the Probe would be simplest implementation.*	PB.ACS-16
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-44	4-Subsystem	Maintain UTC Time	The C&DH subsystem shall maintain Coordinated Universal Time (UTC) with an accuracy of +/- TBD.	*1 second per day goal. May drive operational requirements.*	
Swales	Kraeuter	WBS-2.2.2.2.1	PB.CDH-45	4-Subsystem	Maintain MET Time	The C&DH subsystem shall maintain Mission Elapsed Time (MET)	*Core function*	PB-25

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
PB Flight Software (PB.FSW-#)								
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-1	4-Subsystem	On-board Flight Software	The C&DH subsystem shall contain Flight Software in order to perform the specified C&DH functions	*Design Decision: The Bus Avionics will contain a single board computer that will require flight software*	
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-2	4-Subsystem	Flight Software Storage	The Flight Code shall be stored in Electrically Erasable Programmable Read-Only Memory (EEPROM) residing within the Bus Avionics	*Design Decision: Flight software must be stored in EEPROM*	
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-3	4-Subsystem	Code Image	The Code Image (Build Number) loaded onto each of the 5 THEMIS Probes shall be identical.	*Probes must be identical*	PB-6
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-4	4-Subsystem	Data Image	Probe Specific Data Images (Tables) shall be loaded onto each of the 5 THEMIS Probes.	*Required for each probe to have a unique ID*	PB-6
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-5	4-Subsystem	Software Load Integrity	Upon a load of code or data image to the C&DH processor, it shall be possible to verify the integrity of the image.	*Required for Flight Software Assurance*	P-16
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-6	4-Subsystem	Software Version	The Flight Software Code image version loaded and executing on a Probe shall be reported in real-time telemetry.	*Required for Flight Software Assurance*	P-16
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-7	4-Subsystem	Probe ID	The Probe Specific Data Image shall contain the probe's unique ID, which will be available in real-time telemetry.	*Required for each probe to have a unique ID*	PB-6
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-8	4-Subsystem	Flight Software Maintenance	The Flight Software shall provide commands and telemetry required to perform dumps, loads, and telemetering of memory and tables.	*Core Software Function*	
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-9	4-Subsystem	Cold Restart	The Flight Software shall perform a Cold Restart upon any of the following conditions: Power-On of the Bus Avionics, Ground Command, or 5 (TBC) ground selectable consecutive Warm Restarts	*Number of Warm Resets is a default variable.*	
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-10	4-Subsystem	Cold Restart	The Flight Software shall be capable of processing ground commands within 40 seconds (TBC) after a Cold Restart	*System must be able to start up from Cold Restart*	PB-18
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-11	4-Subsystem	Initialization	The Flight Software shall initialize the processor and its on-board devices and peripherals as needed for its own operation without operator intervention		
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-12	4-Subsystem	Warm Restart	Upon a warm restart, the system startup software shall reload the code area but preserve RAM data areas.		
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-13	4-Subsystem	Warm Restart	The flight software shall be able to perform a warm restart in an attempt to recover from a detected software anomaly with minimal impact on normal processing activity.	*Possibly want to change thruster state on warm restart*	
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-14	4-Subsystem	Watchdog Timer	Upon any kind of Restart, the Flight Software shall begin servicing the Watchdog hardware within 40 seconds (TBC)		
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-15	4-Subsystem	Command Validation	The Flight Software shall validate commands prior to execution	*Required for Flight Software Assurance*	P-16
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-16	4-Subsystem	Command Rejection	The Flight Software shall reject any command that cannot be validated	*Required for Flight Software Assurance*	P-16
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-17	4-Subsystem	Command Execution Verification	All commands executed by the processor shall be verifiable on the ground. Where end point telemetry verification is not possible, separate counters in software shall increment to indicate whether the command was processed or rejected by the Flight Software	*Required for Flight Software Assurance*	P-16
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-18	4-Subsystem	Memory Integrity	The Flight Software shall verify program and data code area integrity	*Required for Flight Software Assurance*	P-16
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-19	4-Subsystem	CPU Utilization	Maximum CPU utilization shall be less than 50% during the PDR phase, and shall be less than 75% at CDR	*Design Goals*	
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-20	4-Subsystem	EEPROM Utilization	Maximum EEPROM utilization shall be less than 50% during the PDR phase, and shall be less than 75% at CDR	*Design Goals*	
Swales	Hammers	WBS-2.2.2.2.3	PB.FSW-21	4-Subsystem	Processor RAM Utilization	Maximum Processor RAM utilization shall be less than 50% during the PDR phase, and shall be less than 75% at CDR	*Design Goals*	

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
PB Mechanical Systems (PB.Mec-#)								
Swales	Lashley	WBS-2.2.2	P.B.Mec-1	4-Subsystem	Instrument Accomodation	The Probe structure shall accommodate the location, alignment, co-alignment, envelope, interface, mass, stability, harnesses, and FOV of the instruments as defined in Instrument-Probe ICDs. The structure shall provide access to the instruments during I&T.	*Interface Requirement*	PB-24
Swales	Lashley	WBS-2.2.2	P.B.Mec-2	4-Subsystem	Tank Accommodation	The Probe structure shall accommodate the propulsion system tanks, lines, valves and thrusters as defined in TBD.	*Interface Requirement*	PB-24
Swales	Lashley	WBS-2.2.2	P.B.Mec-3	4-Subsystem	Accommodation	The Probe shall provide access to the RCS vent and drain valves and tubes with the Probe integrated to the PC on the launch vehicle (TBR).	*Interface Requirement*	PB-27
Swales	Lashley	WBS-2.2.2	P.B.Mec-4	4-Subsystem	Accommodation	The Probe structure shall accommodate the interfaces and envelopes of the Probe spacecraft avionic components and harnesses as defined in TBD. The structure shall provide access to the components during I&T.	*Interface Requirement*	PB-24
Swales	Lashley	WBS-2.2.2	P.B.Mec-5	4-Subsystem	Mass properties	The Probe shall have a ratio of spin axis of inertia to transverse axis of inertia > 1.04 for all nominal and off-nominal on-orbit configurations.	*Ensure that Probe is passively spin-stable under all conditions*	PB.ACS-1
Swales	Lashley	WBS-2.2.2	P.B.Mec-6	4-Subsystem	Mass properties	The Probe Principle Axis of Inertia shall be aligned within 5.6 degrees, 3 sigma, (TBR) of the Probe Z axis.	*5.6 degrees PA misalignemnt + 5 degrees spin axis pointing < ESA FOV 11.2 degrees so ESA Anode sees pole?*	PB.ACS-6
Swales	Lashley	WBS-2.2.2	P.B.Mec-7	4-Subsystem	Mass properties	The Probe c.g. shall be offset from the Probe Bus Z axis by less than TBD in.	*Probe balance requirement*	PB.ACS-6
Swales	Lashley	WBS-2.2.2	P.B.Mec-8	4-Subsystem	Mass properties	The probe structure shall be designed for a max Probe wet mass of 134 kg (TBR)	*Ensure that Probe structural design can support the heaviest possible probe.*	M-45
Swales	Lashley	WBS-2.2.2	P.B.Mec-9	4-Subsystem	Mass properties	The structural mass of any Probe shall be less than the mass in Table XX (TBR)	*Mass allocation*	PB-10
Swales	Lashley	WBS-2.2.2	P.B.Mec-10	4-Subsystem	Mass properties	The deviation in launch mass from Probe to Probe shall be less than 5% (TBR)	*Simplify spin balancing of Probe Carrier assembly and minimize needed balance mass. Ensures symetrical release dynamics.*	M-47
Swales	Lashley	WBS-2.2.2	P.B.Mec-11	4-Subsystem	Stiffness	The probe shall be designed to have a fixed base minimum lateral fundamental frequency of 35 Hz (TBR).	*Avoid coupling between Probe and Probe Carrier structuraldynamics*	M-46
PB Thermal (PB.Thm-#)								
Swales	Zara	WBS-2.2.2	PB.Thm-1	4-Subsystem	Thermal Operating Limits	The spacecraft TCS shall keep all bus components within operating temperatures (provided in Table T1) when powered on.	*Components need to be at a certain temperature to operate within specification.*	PB-17
Swales	Zara	WBS-2.2.2	PB.Thm-2	4-Subsystem	Thermal Survival Limits	The spacecraft TCS shall keep all bus components within survival temperatures (provided in Table T1) when powered off.	*Components need to be at a certain temperature to prevent any damage to that component.*	PB-16
Swales	Zara	WBS-2.2.2	PB.Thm-3	4-Subsystem	Worst-case cold condition	The Probe Bus TCS shall maintain temperature limits worst case eclipse time of 180 minutes	*Analysis shows that the current system design is power limited while in eclipse, causing temperatures to drop to an unacceptable level after the time specified.*	PB-7
Swales	Zara	WBS-2.2.2	PB.Thm-4	4-Subsystem	Transmitter on time	The Probe thermal design shall allow for a minimum of 30 minutes transmitter on time per 24 hours.	*Thermal has to design for at least 30 min. of heat from the transponder, but can set limits on operations on how frequently each pass can take place.*	PB-35
Swales	Zara	WBS-2.2.2	PB.Thm-5	4-Subsystem	Operational Heaters Duty Cycle	The spacecraft heaters shall operate at less than 50% duty cycle for operational cases.	*Provides heater power margin for operational cases*	PB-17
Swales	Zara	WBS-2.2.2	PB.Thm-6	4-Subsystem	Survival Heaters Duty Cycle	The spacecraft heaters shall operate at less than 70% duty cycle for survival cases.	*Provides heater power margin for survival cases*	PB-16
Swales	Zara	WBS-2.2.2	PB.Thm-7	4-Subsystem	Heater Thermostats	There shall be redundant thermostats wired in series to control each heater circuit.	*When a thermostat fails, it usually fails closed. The redundant thermostat will maintain control of the heater circuit.*	M-5
Swales	Zara	WBS-2.2.2	PB.Thm-8	4-Subsystem	Temperature Monitoring	The spacecraft TCS shall have sufficient temperature sensors (50 per probe TBR) for temperature monitoring and control.	*Need to monitor key bus temperatures and instruments to verify the status of the TCS.*	PB.CDH-20
Swales	Zara	WBS-2.2.2	PB.Thm-9	4-Subsystem	MLI Venting	MLI blankets shall have venting designed for the LV pressure profile.	*Delta II Requirement (adequate venting)*	PB-28
Swales	Zara	WBS-2.2.2	PB.Thm-10	4-Subsystem	MLI Vent path	The MLI vent path shall conform to the Contamination Control Plan.	*Control contamination paths.*	PB-22
Swales	Zara	WBS-2.2.2	PB.Thm-11	4-Subsystem	MLI Grounding	MLI blankets shall have electrical grounding with a maximum value of 10 ohms (TBR)	*Protects components from Electro Static Discharge*	PB-21
Swales	Zara	WBS-2.2.2	PB.Thm-12	4-Subsystem	MLI ESD Coating	Exterior MLI blanket outer layers shall be coated to prevent surface charging per the Electrostatic Cleanliness Plan	*Protects Electro Magnetic Interference concerns*	PB-21
Swales	Zara	WBS-2.2.2	PB.Thm-13	4-Subsystem	Instrument Heat Transfer	The heat transfer by conduction between instrument components and spacecraft shall be less than .05 W/°C (TBR)	*Isolating the instruments from the spacecraft bus will simplify sub-system level testing, reduce bus heater power, and simplifies integrated thermal analysis.*	PB-24

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Swales	Zara	WBS-2.2.2	PB.Thm-14	4-Subsystem	Thermal model deliverables	Each instrument shall deliver a reduced thermal model to the spacecraft prior to PDR, CDR, PER, and PSR.	*Temperature predictions rely on an accurate thermal model that includes all the instruments.*	PB-24
Swales	Zara	WBS-2.2.2	PB.Thm-15	4-Subsystem	Minimum Turn on Temperature	No Probe Bus component shall be powered on when its temperature is below the minimum turn-on temperature.	*Components have a minimum temperature when it can be turned on.*	PB-18
PB.Harness (PB.Hrn-#)								
Swales	Kraeuter	WBS-2.2.2.2.5	PB.Hrn-1	4-Subsystem	Power & Data Harnesses	The Probe Bus harness shall provide power and data connections between the Probe Bus subsystems and the IDPU	*Generic, Many parents.*	N/A

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Probe Carrier (PC-#)								
Swales	TA	WBS-2.2.4	PC-1	3-Element	System Mass Budget	The Probe Carrier Mass with no Probes Installed shall not exceed 103kg (includes harness)	*Based on Delta II throw weight to orbit*	M-45
Swales	TA	WBS-2.2.4	PC-2	3-Element	Allocated Mass Budget	No Probe Carrier subsystem shall exceed the allocated mass budget in Table M1.	*Reflects estimated mass plus contingency based on level of design fidelity.*	PC-1
Swales	TA	WBS-2.2.4	PC-3	3-Element	Contamination Control Plan	The Probe Carrier shall comply with the THEMIS Contamination Control Plan	*Flow-down*	M-37
Swales	TA	WBS-2.2.4	PC-4	3-Element	ICD	The Probe Carrier shall be compatible per the Probe-Probe Carrier ICD	*Adherence to ICDs ensures interface requirements are met*	M-39
Swales	TA	WBS-2.2.4	PC-5	3-Element	ICD	The Probe Carrier shall be compatible per the Probe Carrier-Launch Vechicle ICD	*Adherence to ICDs ensures interface requirements are met*	M-39
Swales	TA	WBS-2.2.4	PC-6	3-Element	Environments	The Probe Carrier shall survive and function prior, during and after exposure to the environments described in the Verification Plan and Environmental Specification.	*Flow-down*	M-41
Swales	TA	WBS-2.2.4	PC-7	3-Element	PCA Fundamental Frequency	The fundamental frequency of the Probe Carrier Assembly (Probe Carrier + 5 Fueled Probes) in launch configuration shall be greater than 15 Hz in lateral and 35 Hz in axial.	*Flow-down*	M-46
Swales	TA	WBS-2.2.4	PC-8	3-Element	PCA CG Location	The CG location of the Probe Carrier Assembly (Probe Carrier + 5 Fueled Probes) shall be within TBD of the PCA centerline.	*Flow-down*	M-47
Swales	TA	WBS-2.2.4	PC-9	3-Element	PCA/Probe Deployments	The Probe Carrier shall be designed to prevent collisions (probe-to-probe, probe-to-carrier).	*Collision are bad.*	M-43
PC Mechanical (PC.Mec-#)								
Swales	Lashley	2.2.2.3	P.C.Mec-1	4-Subsystem	Accommodations	The Probe / Carrier shall accommodate 5 probes of the maximum mass allocation, with a minimum static clearance of 4 inches (TBR) between adjacent Probes	*Derived based on clearance required to reduce collision risk on deployment*	PC-9
Swales	Lashley	2.2.2.3	P.C.Mec-2	4-Subsystem	Deployment	The Probe Carrier shall reliably release all 5 probes with a minimum clearance between Probes (at any time after release) of TBD in. Release shall be accomplished with the Probe Carrier spin rate uncertainty of +/-5 rpm.	*Ensure that PC spin rate is accommodated and there is no collision after release.*	PB-39
Swales	Lashley	2.2.2.3	P.C.Mec-3	4-Subsystem	Deployment Fault Tolerance	The Probe Carrier shall successfully deploy any four Probes if one Probe fails to deploy.	*Avoid single point mission failure*	M-5
Swales	Lashley	2.2.2.3	P.C.Mec-4	4-Subsystem	Deployment Synchronization	The timing error for simultaneous deployments shall be less than 1 sec.	*Analysis shows that simultaneous deployment is necessary to reduce collision risk*	PC-9
Swales	Lashley	2.2.2.3	P.C.Mec-5	4-Subsystem	Deployment Time	The Probes shall be released from the Probe Carrier within TBD seconds of receiving the deployment signal from the launch vehicle	*Release before 3rd stage begins to tumble - reduce collision risk*	PC-9
Swales	Lashley	2.2.2.3	P.C.Mec-6	4-Subsystem	LV Interface	The Probe Carrier Assembly (Probe Carrier, with all 5 Probes installed), shall interface with the Delta 2 third stage and fit within the shroud envelope.	*Delta requirement*	M-43
Swales	Lashley	2.2.2.3	P.C.Mec-7	4-Subsystem	LV Spin Rate	The Probe Carrier Assembly (Probe Carrier, with all 5 Probes installed) in the launch configuration shall survive a maximum Launch Vehicle spin rate of 65 rpm.	*Delta requirement*	M-43
Swales	Lashley	2.2.2.3	P.C.Mec-9	4-Subsystem	Mass properties	The Probe Carrier Assembly (Probe Carrier, with all 5 Probes installed) shall be balanced to produce a 3 sigma maximum CG within 1.3 mm (0.05 in) of the centerline.	*Delta requirement*	M-47
Swales	Lashley	2.2.2.3	P.C.Mec-10	4-Subsystem	Mass properties	The Probe Carrier Assembly (Probe Carrier, with all 5 Probes installed) shall be balanced to produce a 3-sigma maximum principal axis misalignment less than 0.25 deg with respect to the PCA Z axis.	*Delta requirement*	M-47
Swales	Lashley	2.2.2.3	P.C.Mec-11	4-Subsystem	Mass properties	The Probe Carrier Assembly (Probe Carrier, with all 5 Probes installed) shall have a roll MOI > 515 kg-m^2 (TBR)	*Delta requirement*	M-47
Swales	Lashley	2.2.2.3	P.C.Mec-12	4-Subsystem	Servicing	It shall be possible to remove any Probe from the PC while the PC is on the launch vehicle (TBR)	*Allows servicing of component failures during final integration*	
PC Thermal (PC.Thm-#)								
Swales	Zara	WBS-2.2.4	PC.Thm-1	4-Subsystem	Thermal Control System	The Probe Carrier shall have a passive Thermal Control System (TCS).		
Swales	Zara	WBS-2.2.4	PC.Thm-2	4-Subsystem	Worst Case Conditions	The Probe Carrier TCS shall be designed for worst case hot and cold thermal environments.		
Swales	Zara	WBS-2.2.4	PC.Thm-3	4-Subsystem	Aerodynamic Heating	The Probe Carrier TCS shall be designed for worst case aerodynamic heating environments.		

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Swales	Zara	WBS-2.2.4	PC.Thm-4	4-Subsystem	Interface Temperature Limits	The Probe Carrier TCS with 5 Probes installed shall maintain Probe Carrier to Probe interface temperatures within Probe survival limits during ground/launch/ascent and Probe pre-release from Probe Carrier.		
PC Harness (PC.Hrn-#)								
Swales	Ajluni	WBS-2.2.4	PC.Hrn-1	4-Subsystem	Routing	The Probe Carrier harness shall connect the Launch Vehicle to each Probe.	*The Probe Carrier does not contain any electronics, and only serves to hold and connect each probe to the LV.*	
PC ACS (PC.ACS-#)								
Swales	Ajluni	WBS-2.2.4	PC.ACS-1	4-Subsystem	Spin Stability	TBD		

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Ground Station (GS.STN-#)								
UCB	MB	WBS 3.1	GS.STN-1	4-Subsystem	Compatibility	The THEMIS ground stations shall be RF and data compatible with the space segment on both the telemetry and the command link.	*Ensures telemetry can be recovered and probes can be commanded.*	
UCB	MB	WBS 3.1	GS.STN-2	4-Subsystem	Decoding	The THEMIS ground stations shall perform Viterbi decoding and Reed-Solomon error correction on the telemetry stream.	*With the appropriate link margin, error detection and correction will ensure a telemetry bit error rate of 10-6.*	
UCB	MB	WBS 3.1	GS.STN-3	4-Subsystem	Telemetry Link	The THEMIS ground stations shall be able to close the telemetry link at various data rates commensurate with probe range with a link margin of at least 3 dB.	*Maximize probe bus and instrument data recovery as function of probe range out to 31.6 Re. Allow for telemetry reception at low data rate to support maneuvers and contingency operations.*	
UCB	MB	WBS 3.1	GS.STN-4	4-Subsystem	Data Volume	The THEMIS ground stations shall recover a telemetry data volume of 591 Mbits / orbit / probe.	*Ensures that sufficient telemetry bandwidth is available to recover both science and engineering data.*	
UCB	MB	WBS 3.1	GS.STN-5	4-Subsystem	Virtual Channel IDs	The THEMIS ground stations shall split received telemetry data by Virtual Channel ID, record all data locally and route real-time data to command and control workstations via network connections.	*Data stream is split for probe bus and science data processing as well as real-time command and control.*	
UCB	MB	WBS 3.1	GS.STN-6	4-Subsystem	Data Buffer	The THEMIS ground stations shall buffer recovered telemetry data for at least 10 days.	*Temporary backup storage in case network links are down.*	
UCB	MB	WBS 3.1	GS.STN-7	4-Subsystem	Command Link	The THEMIS ground stations shall provide command capabilities to allow closure of the command link out to 31.6 Re with a link margin of at least 3 dB.	*Ensures that sufficient effective radiated power is available to close the command link at a data rate of 1 kbps with a bit error rate of 10-7.*	
UCB	MB	WBS 3.1	GS.STN-8	4-Subsystem	Acquisition Sweep	The THEMIS ground stations shall acquire the command link using a STDN compatible acquisition sweep procedure.	*Driven by probe transponder and common ground station characteristics.*	
UCB	MB	WBS 3.1	GS.STN-9	4-Subsystem	COP-1 Protocol	The THEMIS ground stations shall support the COP-1 protocol for command verification.	*Ground stations receive telecommands from ITOS in form of CLTUs and forward these to the probes. Likewise, real-time telemetry transfer frames are forwarded from the probes to ITOS to close the command verification loop.*	
UCB	MB	WBS 3.1	GS.STN-10	4-Subsystem	Doppler Format	All THEMIS ground stations shall provide two-way Doppler tracking data in Universal Tracking Data Format (UTDF).	*Two-way Doppler tracking data are required for orbit determination.*	
UCB	MB	WBS 3.1	GS.STN-11	4-Subsystem	Data Transfer	The THEMIS ground stations shall transfer all tracking data to the THEMIS Mission Operations Center post-pass for orbit determination.	*Primary orbit determination will be performed at the MOC using GTDS.*	
UCB	MB	WBS 3.1	GS.STN-12	4-Subsystem	Ranging	The Berkeley Ground Station shall be the primary ground station for THEMIS and shall be equipped with additional hardware and software systems to provide two-way digital range tracking data.	*Technology demonstration of enhanced orbit determination capabilities for future constellation missions. SatTrack Orbit Determination Tool will be used to process two-way Doppler and two-way ranging data simultaneously.*	
Mission Operations Center (GS.MOC-#)								
UCB	MB	WBS 3.1	GS.MOC-1	4-Subsystem	Integrated MOC	All aspects of THEMIS Mission Operations shall be performed at the Mission Operations Center, located at UCB / SSL.	*Integrated Mission Operations Center reduces overall ground systems complexity.*	
UCB	MB	WBS 3.1	GS.MOC-2	4-Subsystem	MOC Infrastructure	The Mission Operations Center shall provide hardware, software and IT networking systems to support all mission operations functions.	*Provides infrastructure to perform all tasks required to operate the five probes and to recover all science and engineering data via primary and secondary ground stations.*	
UCB	MB	WBS 3.1	GS.MOC-3	4-Subsystem	Data Flow	The Mission Operations Center shall interface with other THEMIS ground system elements such as the ground stations, the TDRSS Ground Terminal and the Science Operations Center.	*Ensures seamless data flow from the probes to all required ground system elements and vice versa, and exchange of all required data products.*	
UCB	MB	WBS 3.1	GS.MOC-4	4-Subsystem	End-to-End Testing	The Mission Operations Center shall provide secure data interfaces to allow for remote probe operation and end-to-end data flow testing during mission integration.	*Allow for end-to-end data compatibility testing, telemetry page development, simulations and operator training.*	
UCB	MB	WBS 3.1	GS.MOC-5	4-Subsystem	Voice Loops	The Mission Operations Center shall provide two SCAMA voice loops to allow for communications with other facilities supporting the mission.	*Provide voice loops for end-to-end data flow test coordination, pre-launch simulations, launch and ground station support.*	
UCB	MB	WBS 3.1	GS.MOC-6	4-Subsystem	Security	The Mission Operations Center shall adhere to NASA IT Network Security standards.	*Ensures that space and ground systems are protected against unauthorized physical and network access (applies to THEMIS and other supported missions).*	
Mission Operations (GS.OPS-#)								
UCB	MB	WBS 3.1	GS.OPS-1	4-Subsystem	Mission Support	THEMIS Mission Operations shall support all phases of the mission.	*Mission operations include pre-launch, launch and early orbit, normal, contingency and end-of-life operations.*	
UCB	MB	WBS 3.1	GS.OPS-1	4-Subsystem	Mission Support	A complete set of ephemeris and mission planning products shall be generated to support all mission planning functions, ground contact scheduling and generation of command loads for all probes.	*Generate all products based on latest state vector for each probe.*	

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
UCB	MB	WBS 3.1	GS.OPS-1	4-Subsystem	Mission Support	Mission planning functions shall ensure that all probes are configured and operated according to specifications, and yield optimum science data while preserving fuel and maintaining adequate margins and probe health.	*Maintain optimum operational status of all probes and ensure that science requirements are met.*	
UCB	MB	WBS 3.1	GS.OPS-1	4-Subsystem	Mission Support	Probe state-of-health shall be monitored during real-time pass supports. Post-pass telemetry playback shall be used to examine back-orbit data for limit violations.	*Monitor probe state-of-health throughout the entire orbit.*	
UCB	MB	WBS 3.1	GS.OPS-1	4-Subsystem	Mission Support	Mission operations shall include data trending to establish baseline parameters and to uncover any developing anomalous conditions early on.	*Provide operational baseline and prevent risk to flight hardware due to out-of-limit operation.*	
UCB	MB	WBS 3.1	GS.OPS-1	4-Subsystem	Mission Support	Command loads generated on the ground shall be verified prior to upload.	*Ensure correct probe operation and reduce operational risk.*	
UCB	MB	WBS 3.1	GS.OPS-1	4-Subsystem	Mission Support	All critical commands, table loads and flight software patches shall be verified on the probe simulator prior to upload.	*Minimize risk to flight hardware and software.*	
UCB	MB	WBS 3.1	GS.OPS-1	4-Subsystem	Mission Support	The orbit of each probe shall be determined with an accuracy of 10 km at perigee and 100 km at apogee based on two-way Doppler tracking data.	*Adequate accuracy for ground antenna pointing and science requirements.*	
UCB	MB	WBS 3.1	GS.OPS-1	4-Subsystem	Mission Support	All orbit maneuvers shall be carefully planned and validated prior to execution.	*Ensure that critical maneuver commands are correct and yield the desired orbit change at minimum fuel consumption.*	
UCB	MB	WBS 3.1	GS.OPS-1	4-Subsystem	Mission Support	Attitude determination of all probes shall be ground based and shall be based on raw Sun sensor and FGM data. FGM data recorded near perigee shall be used to cross-calibrate the Sun sensor on each probe.	*Ground based attitude determination is part of the Attitude Control System.*	
UCB	MB	WBS 3.1	GS.OPS-1	4-Subsystem	Mission Support	All attitude maneuvers shall be carefully planned and validated prior to execution.	*Ensure that critical maneuver commands are correct and yield the desired attitude change at minimum fuel consumption.*	
UCB	MB	WBS 3.1	GS.OPS-1	4-Subsystem	Mission Support	Probe anomaly resolution shall be conducted in consultation with pertinent subsystem engineers, instrument scientists and project management personnel.	*Recover probe bus and instruments to a safe operating state as quickly and efficiently as possible.*	
Science Operations Center (GS.SOC-#)								
UCB	MB	WBS 3.2	GS.SOC-1	4-Subsystem	Level 0 Data Processing	Downlinked data files shall be stripped of Virtual Channels and filed by Application Identifier (APID)	*Level 0 to Level 1 Data Processing*	S-20
UCB	MB	WBS 3.2	GS.SOC-2	4-Subsystem	Level 1 Data Processing	The SOC shall produce summary plots for viewing and downloading from WWW.	*IDL routines produce GIF and Common Data Format (CDF) files used for summary plots*	S-20
UCB	MB	WBS 3.2	GS.SOC-3	4-Subsystem	Data Archival - Probe Data	All raw and processed data (Level 0 and 1) shall be archived to disk array and DVD: Data Volume ~100 Gbytes/year (all probes)		S-20
UCB	MB	WBS 3.2	GS.SOC-4	4-Subsystem	Data Archival - Ground Data	GBO data sets shall be mirrored from University of Calgary and University of Alberta: Data Volume ~2 Tbytes/year (all sites)		S-20
UCB	MB	WBS 3.2	GS.SOC-5	4-Subsystem	Data Distribution	DVDs shall be distributed to NSSDC and Co-I Institutions		S-20
UCB	MB	WBS 3.2	GS.SOC-6	4-Subsystem	Data Access - Full Data Set	Complete spacecraft data set shall be accessible from local disk array at UCB		S-17
UCB	MB	WBS 3.2	GS.SOC-7	4-Subsystem	GBO Data Access	GBO data shall be accessed from UC and UA mirror site		S-17
UCB	MB	WBS 3.2	GS.SOC-8	4-Subsystem	Data Validation	Data shall be validated on a daily basis by designated operations scientist	*Assures data quality, monitors housekeeping data trends, identifies and tabulates geophysical events of special interest*	S-14
UCB	MB	WBS 3.2	GS.SOC-9	4-Subsystem	Data Analysis Platform	Data shall be portable to variable platforms - PC and UNIX	*Project decision that data should not necessarily have to go through SDT*	S-17
UCB	MB	WBS 3.2	GS.SOC-10	4-Subsystem	Instrument Commanding	The SOC will using modified version of existing FAST system for stored instrument command loads	*Similar heritage system will be used for THEMIS*	
UCB	MB	WBS 3.2	GS.SOC-11	4-Subsystem	Instrument Command Uplink	Instrument command loads shall be transferred to MOC for integration into overall spacecraft load and uplink to spacecraft		

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
Ground Based Observations (GB-#)								
UCB	SH	WBS 3.3	GB-1	3-Element	GBO Science Objective	GBO shall monitor the auroral light and ionospheric currents across North America in order to localize the time, location, and evolution of the auroral manifestation of the substorm.	*Addresses mission requirement to determine substorm onset time and substorm meridian magnetic local time (MLT) using ground ASIs (one per MLT hr) and GMAGs (two per MLT hr) with t_res<30s and dMLT<6 degrees respectively, in an 8hr geographic local time sector including the US.*	S-1
UCB	SH	WBS 3.3	GB-2	3-Element	Local Time Duration	The GBO shall cover 8 hrs of Geographic Local Time over North American segment (allows continuous 12 hr conjunctions with probes)	*Derived Requirement from GBO objective*	GB-1
UCB	SH	WBS 3.3	GB-3	3-Element	Number of ASI	The GBO shall include at least one ASI per MLT hour within this geographic segment	*Derived Requirement from GBO objective*	GB-1
UCB	SH	WBS 3.3	GB-4	3-Element	Number of GMAG	The GBO shall include two auroral GMAG per hour (MLT) (high/low lat.) within this segment.	*Derived Requirement from GBO objective*	GB-1
UCB	SH	WBS 3.3	GB-5	3-Element	Timing Accuracy	Timing accuracy of phenomena observed shall be better than 10s absolute	*Derived Requirement from GBO objective*	GB-1
UCB	SH	WBS 3.3	GB-6	3-Element	ASI Sensitivity	Detectable response for aurora shall be < 10kRayleigh	*Derived Requirement from GBO objective*	GB-1
UCB	SH	WBS 3.3	GB-7	3-Element	GMAG Sensitivity	Sensitivity of GMAG instrument shall be < 1nT	*Derived Requirement from GBO objective*	GB-1
UCB	SH	WBS 3.3	GB-8	3-Element	Site Preparation	Integrate ASI from UCB, GMAG from UCLA with site prep and deployment provided by UCalgary	*Implementation Requirement*	
UCB	SH	WBS 3.3	GB-9	3-Element	Schedule for qual unit	Build, calibrate and qualify first unit within one year after start of Phase B	*Implementation Requirement*	
UCB	SH	WBS 3.3	GB-10	3-Element	Schedule for first flight units	Five sites shall be installed two winters before THEMIS launch	*Implementation Requirement*	
UCB	SH	WBS 3.3	GB-11	3-Element	Number of Sites	Total GBO installed network shall be 20 sites, located across Alaska and Canada.	*Implementation Requirement*	
GBO- All Sky Imager (GB.ASI-#)								
UCB	SH	WBS 3.3	GB.ASI-1	4-Subsystem	FOV	Field of view shall be greater than 170°		GB-3
UCB	SH	WBS 3.3	GB.ASI-2	4-Subsystem	Spectral Bandpass	Spectral passband shall include all visible wavelengths (400 - 700nm)		GB-3
UCB	SH	WBS 3.3	GB.ASI-3	4-Subsystem	Sensitivity	Sensitivity: Detectable response for aurora < 10kRayleigh		GB-6
UCB	SH	WBS 3.3	GB.ASI-4	4-Subsystem	Spatial resolution	Spatial resolution shall be better than TBD pixels per all sky image diameter		GB-3
UCB	SH	WBS 3.3	GB.ASI-5	4-Subsystem	Viewport	Shall have heated dome viewport		GB-11
UCB	SH	WBS 3.3	GB.ASI-6	4-Subsystem	Programmable exposure time	Shall have programmable exposure time		GB-5
UCB	SH	WBS 3.3	GB.ASI-7	4-Subsystem	Maximum exposure time	Maximum exposure time shall be greater than 1s		GB-5
UCB	SH	WBS 3.3	GB.ASI-8	4-Subsystem	Dark Noise	Dark noise resulting from maximum exposure shall be less than TBD		GB-5
UCB	SH	WBS 3.3	GB.ASI-9	4-Subsystem	Programmable repetition interval	Shall have programmable exposure repetition interval		GB-5
UCB	SH	WBS 3.3	GB.ASI-10	4-Subsystem	Minimum repetition interval	Minimum repetition interval shall be less than 5s		GB-5
GBO- Ground Magnetometer (GB.MAG-#)								
UCB	SH	WBS 3.3	GB.MAG-1	4-Subsystem	Sensitivity	Sensitivity shall be < 1nT		GB-7
UCB	SH	WBS 3.3	GB.MAG-2	4-Subsystem	3-axis magnetic sensing	Shall include 3 axes of magnetic sensing		GB-4
UCB	SH	WBS 3.3	GB.MAG-3	4-Subsystem	Dynamic range	Shall provide ±2000nT dynamic range		GB-4
UCB	SH	WBS 3.3	GB.MAG-4	4-Subsystem	Time resolution	Shall provide 1 second time resolution		GB-5
GBO- Observatory (GB.OBS-#)								
UCB	SH	WBS 3.3	GB.OBS-1	4-Subsystem	Unattended Operation	Shall provide unattended operation for up to 4 months per observation season		GB-2

Org.	Owner	WBS	ID	Level	Title	Statement	Rationale	Parent ID
UCB	SH	WBS 3.3	GB.OBS-2	4-Subsystem	Programmable command I/F	As a goal, provide programmable command interface to upload new observation parameters and new operating software		GB-2
UCB	SH	WBS 3.3	GB.OBS-3	4-Subsystem	Digital I/F	Shall provide digital interface and data storage for ASI and GMAG		GB-2
UCB	SH	WBS 3.3	GB.OBS-4	4-Subsystem	Geographic position	Shall provide GPS receiver for geographic position calibration and time stamp		GB-2
UCB	SH	WBS 3.3	GB.OBS-5	4-Subsystem	Daily uplink	Shall provide a means for daily uplink of "stream 1" data		GB-2
UCB	SH	WBS 3.3	GB.OBS-6	4-Subsystem	Link capacity	As a goal, stream 1 link capacity (including all stations) should be greater than 39Mbits per day per station		GB-2
UCB	SH	WBS 3.3	GB.OBS-7	4-Subsystem	Storage	Shall store high resolution, "stream 2", data locally on HD, minimum 63GB/season		GB-2
UCB	SH	WBS 3.3	GB.OBS-8	4-Subsystem	Electrical compatibility	Shall be compatible with locally provided power		GB-2
UCB	SH	WBS 3.3	GB.OBS-9	4-Subsystem	Controlled environment	Shall provide controlled environment enclosure for ASI, GMAG and local electronics		GB-2
UCB	SH	WBS 3.3	GB.OBS-10	4-Subsystem	Mechanical compatibility	Shall be compatible with ASI dome, and provide required level of heated air flow		GB-2
UCB	SH	WBS 3.3	GB.OBS-11	4-Subsystem	Internal temperature limits	Maintain internal ambient temperature at 25° ± 15°C		GB-2
UCB	SH	WBS 3.3	GB.OBS-12	4-Subsystem	External temperature limits	Operate in external ambient temperature range of -60° to +50°C including solar load		GB-2
UCB	SH	WBS 3.3	GB.OBS-13	4-Subsystem	Ruggedized enclosure	Provide suitably rugged enclosure, stable mounting and shock protection		GB-2
UCB	SH	WBS 3.3	GB.OBS-14	4-Subsystem	Power control	Shall provide controlled power-up and power-down automatically		GB-2
GBO- Ground Site (GB-GnS)								
UCB	SH	WBS 3.3	GB.GnS-1	4-Subsystem	Unobstructed viewing	Shall provide a largely unobstructed viewing over 160° hemisphere		GB-11
UCB	SH	WBS 3.3	GB.GnS-2	4-Subsystem	Magnetic interference	Shall provide site that is clear of magnetic interference		GB-11
UCB	SH	WBS 3.3	GB.GnS-3	4-Subsystem	Power service	Shall provide power, 120 V, 60Hz at TBD A service		GB-11
UCB	SH	WBS 3.3	GB.GnS-4	4-Subsystem	Maintenance	Shall provide field operator for periodic maintenance and "stream 2" data retrieval		GB-11