THEMIS
Probabilistic Risk Assessment (PRA)

THM-SYS-017a
May 21, 2004

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Document Revision Record

Rev.	Date	Description of Change	Approved By
-	11/12/03	PRA Analysis completed and presented at PDR	-
A	05/21/04	PRA Document developed to clearly state objectives, assumptions and conclusions	ERT

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Identifier	Description

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1. OVERVIEW

THEMIS is a NASA Explorer mission which will launch a constellation of five micro-satellites (probes) in mid-2006. Flying in synchronous orbits within the earth's magnetosphere, the probes will measure the particle processes responsible for eruptions of the aurora.

The Probabilistic Risk Assessment (PRA) is developed to help establish the overall reliability of the THEMIS mission. The mission phases and the minimum/baseline success criteria used in this PRA are described in detail in the THEMIS Fault Tree Analysis (FTA). From the FTA, it should be noted that there are two principle components to the THEMIS mission that must be considered when completing the PRA and assessing the reliability of a single probe:

(1) Constellation redundancy and the use of an on-orbit spare. P3 or P4 probes can replace any other probe during the first year of the mission, resulting in a 4- probe configuration that can accomplish the minimum performance science within 1 year, and near baseline science goals of the mission within 2 years; and

(2) Science resilience. Minimum science can still be accomplished with partial or total sensor failure on one or more of the probes.

Therefore, the Probe flight system is predominantly single-string with some areas of functional redundancy. Nonetheless, this PRA is performed to determine the reliability of a single probe and to identify potential areas where reliability can be effectively increased with little impact.

1.1 SCOPE

The THEMIS approach to Reliability Engineering is provided in *THM-SYS-006 Systems Engineering Management Plan (SEMP)*. The SEMP identifies the type of reliability analyses that will be performed for mission, and the modeling tools and techniques that will be used. To summarize, a Fault Tree Analysis (FTA), Failure Mode and Effects Analysis (FMEA) and Probabilistic Risk Assessment (PRA) are completed during the preliminary and detailed design phases to evaluate the robustness of the system design and the reliability of the overall mission. An Event Tree Analysis (ETA) is then completed in Phase C/D as a tool for operations and contingency planning.

The FTA, as described in *THM-SYS-016 THEMIS Fault Tree Analysis*, was prepared in Phase A. It provides the basis for the system architecture and identifies the areas most critical for further reliability modeling. The FMEA, as described in *THM-SYS-007 THEMIS Failure Modes Effects and Criticality Analysis*, was then developed to determine critical unit failures at interfaces between each unit and identify existing (or add additional) levels of functional redundancy. The PRA, as described here, was then developed using the outline developed for the Probe Bus FMEA. This PRA does not follow an event model. Therefore, it does not address initiating event categories or reliability calculations for pivotal events. This information will be provided in the THEMIS ETA.

1.2 PURPOSE

The purpose of this PRA is to provide a structured, disciplined approach to analyzing system reliability and risk. It is performed in the design phase to trade internal bus architecture and validate reliability related to minimum and baseline mission success criteria. Specifically, the

PRA provides a calculation of reliabilities based on design complexity, operational use, parts count, parts type, and parts failure rates as calculated during the preliminary design stage. As vendors and specific piece parts are selected, the assumptions in this design PRA are revisited and reliability data updated as required.

1.3 OBJECTIVES

The main objectives of this PRA are to:

- Provide a comprehensive and systematic approach to identifying the frequency or likelihood of a subsystem failure;
- Provide an integrated model and quantification for risk estimates from probability calculations and an assessment of uncertainties for all probe bus subsystems; and
- Provide a means of assessing (in conjunction with the ETA) the risk associated with pivotal events.

2. PRA METHODOLOGIES AND APPLICATION

The THEMIS PRA is conducted for all Probe Bus subsystems. The Probe Bus FMEA (provided in *THM-SYS-007*) was used to postulate failure events and the severity of their consequences. Numerical data for failure rates was informally extracted from Swales and Industry EO-1 data. The data is available in the spreadsheet calculations provided in Appendix A.

The following steps describe the PRA process:

1. A Spreadsheet Analysis (provided in Appendix A) is developed with postulated failure events and failure rate numerical estimates.
2. The analysis combines the failure events and estimated rates into Success and Failure Probabilities P(S) and P(F) for each resultant Probe Bus failure.
3. The data are then rolled up into success and failure probabilities for all Probe Components and Probe Subsystems.
4. Probe Component and Probe Subsystem Probabilities are then binned into their assigned Consequence Severity bins.
5. A 5x4 color-coded matrix (provided in Section 3) mapping the failure probabilities at the Subsystem level as a function of their assigned Consequence Severity bins is then developed to clearly show the results of the Spreadsheet Analysis.

2.1 WORKSHEET DEFINITIONS

The PRA Spreadsheet Analysis uses the Failure Severity (Consequence) Categories as defined below:

- Level 5: Death/Injury or One or More Personnel; Loss/Damage to Launch Vehicle
- Level 4: Complete Loss of One Probe
- Level 3: Major Compromise of Probe Mission Usefulness (Retention of minimum mission but major degradation of mission performance)
- Level 2: Some Compromise of Probe Mission Usefulness (Minor loss of some mission performance)
- Level 1: No effect upon Probe Mission Usefulness

The PRA Spreadsheet Analysis uses the Failure Probably Categories for a 2-year (17,520 hours) mission as defined below:

Log Scale	Probability of Success P(S) Probability of Failure F(S)
4	P(S) < 0.9000 P(F) > 0.1000
3	0.9000 < P(S) < 0.9900 0.1000 > P(F) > 0.0100
2	0.9900 < P(S) < 0.9990 0.0100 > P(F) > 0.0010
1	0.9990 < P(S) < 0.9999 0.0010 > P(F) > 0.0001

3. PRA RESULTS

Risk Matrices are provided as a graphical representation of the THEMIS PRA Results. Risk is represented as a product of P(F) and Severity as defined in Section 2 above. By convention, increasing risk is upward and to the right. Maximum risk items are in the upper right corner. Figure 1 provides the P(F) and P(S) for elements of each Probe Subsystem. Figure 2 represents the same data, but shows how the matrix is delineated into the specific severity categories.

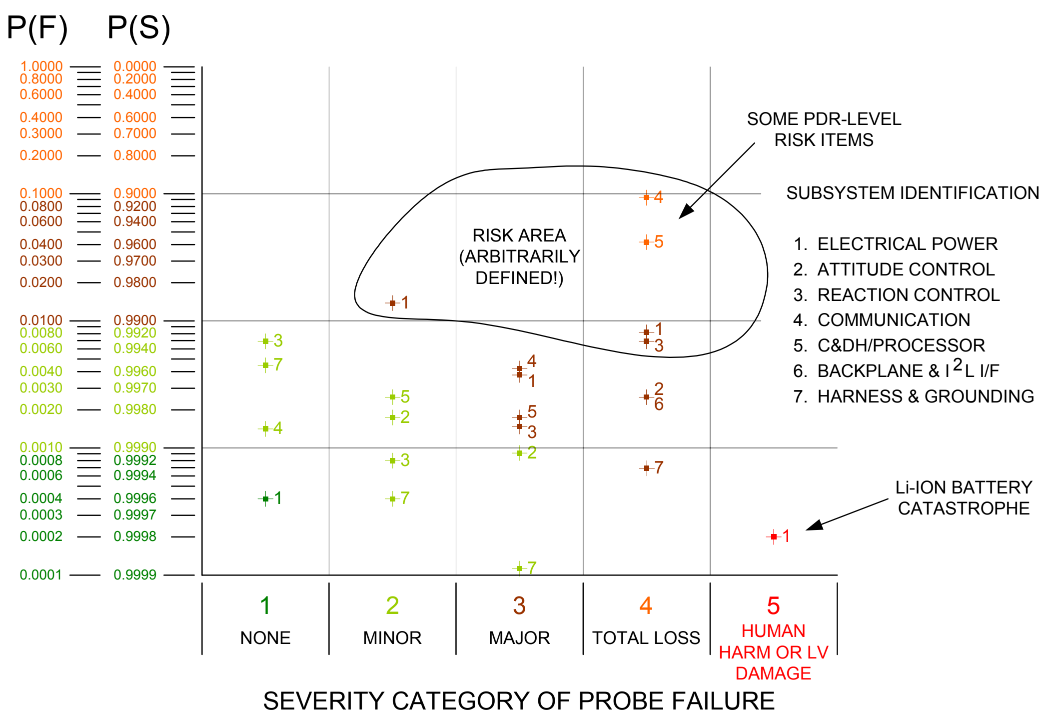

Figure 1: Probe Subsystem P(S) & P(F) for 2 year mission

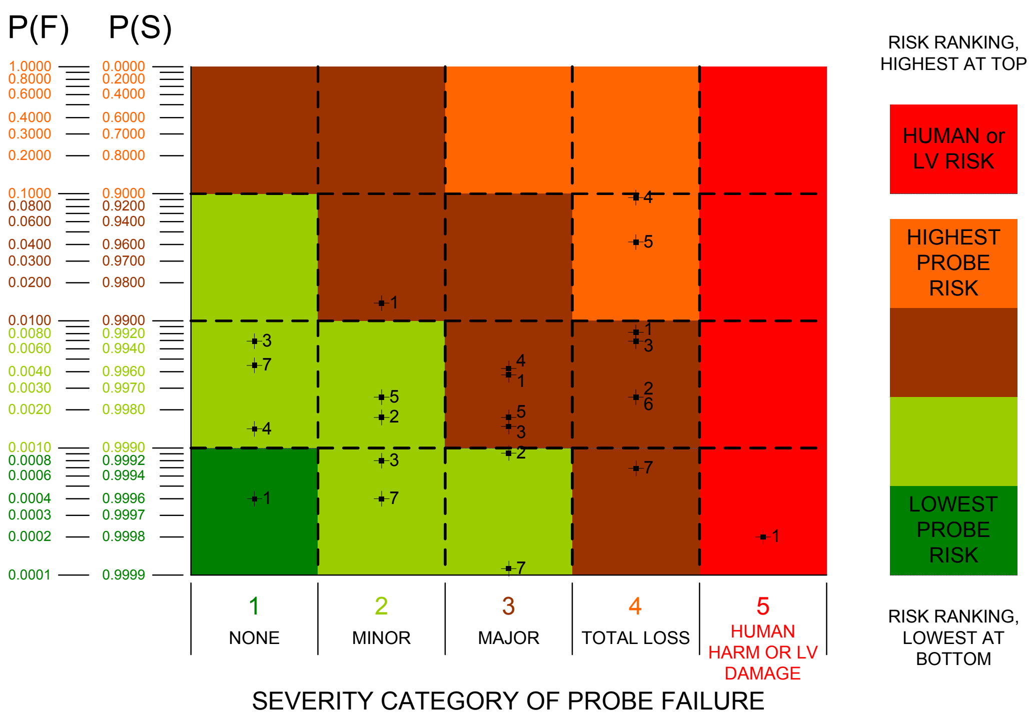

Figure 2: Probe Subsystem PRA Matrix Risk Bins

The P(F) and P(S) "Y" Axis Scale is presented as a Log_{10} scale because the mission time length is only 2 years, all the P(S) values are above .9000 and all but 3 are above .9900. Since by definition P(F) + P(S) = 1, these two scales are equivalent ways of presenting data.

3.1 IDENTIFICATION OF PROBLEM AREAS

From the PRA Spreadsheet Analysis and the Matrix representation above, severity classifications are easily identified. There is a single item in the Severity Category 5. In addition, five failure events stand out as primary Probe functional risks.

3.1.1 RED Failure

A single item, the THEMIS Li-Ion battery, was identified as Severity Category 5. Li-Ion batteries have a well-known catastrophic failure mode. This is an obvious safety issue that will be properly treated.

3.1.2 ORANGE Failures

Two ORANGE items (Severity Category 4) are distinct risks:

1. Communication Subsystems
2. C&DH/Processor Subsystem

3.1.3 BROWN Failures

Three BROWN items (Severity Category 2 and 4) have failure probabilities a decade or more less than the ORANGE items:

1. Electrical Power Subsystem (2 items)
2. Reaction Control Subsystem

3.2 *INVESTIGATION INTO PROBLEM AREAS*

The RED failure identified has been passed on to Safety as a risk that must be further evaluated and properly tracked. The ORANGE and BROWN failures were back-tracked through the Failure Analysis Spreadsheet to their major component-level contributors. This audit process is color-coded in the Spreadsheet Analysis provided in Appendix A. As a summary, the contributors are provided below:

1. Communication Subsystem “Orange” Risk
   a. Severity Category 4: Transponder
2. C&DH/Processor Subsystem “Orange” Risk
   a. Severity Category 4: ColdFire® Processor and Bulk Memory share equally
3. Electrical Power Subsystem “Brown” Risk (2 Items)
   a. Severity Category 4: Switched Shunt Control Circuitry
   b. Severity Category 2: Each of the four Side Panel Solar Arrays share equally
4. Reaction Control Subsystem “Brown” Risk
   a. Severity Category 4: Thruster Valves, 4 pairs share equally

3.3 *CONCLUSION*

Figure 3 provides a summary of the PRA analysis (also provided in Appendix A) and calculated reliability of the THEMIS Probes, **0.82**. The summary also provides the calculated reliability of the two top Probe risks, the Communication and C&DH Subsystems, **0.86**.

	SUBSYSTEMS	COMPONENT P(S)'S GROUPED BY SEVERITY CATEGORY:					SUBSYSTEM P(S)'S GROUPED BY SEVERITY CATEGORY:					
		P(S) for Sev Cat 5	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1	P(S) for Sev Cat 5	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1	Totals All Cat
1	ELECTRICAL POWER SUBSYSTEM						**0.9998**	0.9919	0.9962	0.9876	0.9996	0.975343
All 1.1	Solar Arrays				0.9913							
1.2	Battery Explosion - Safety issue!	**0.9998**										
1.2	Battery		0.9984									
1.3	Battery Relay (BERB)		0.9996									
All 1.4	Shunt Regulation		0.9965	0.9965	0.9963							
All 1.5	Power Distribution		0.9974	0.9996		0.9996						
2	ATTITUDE CONTROL SUBSYSTEM							0.9974	0.9991	0.9982		0.994757
2.1	Sun Sensor			0.9991								
All 2.2	Solid State Gyros (Quan 2)			1.0000	0.9982							
2.3	3-Axis Magnetometer (FGM Instrument)		0.9982									
2.4	Software Functions		0.9991									
3	REACTION CONTROL SUBSYSTEM							0.9931	0.9984	0.9992	0.9931	0.983924
3.1	Software Functions		0.9991									
All 3.2	Tanks (Quan 2)		0.9991									
3.3	Flight Pressure Transducer					0.9997						
3.4	Thermistors					0.9997						
3.5	PRTs					0.9997						
3.6	Pressure/Vent Valve (Quan 1, Manual)					0.9999						
3.7	Fill/Drain Valve (Quan 1 per Tank, Manual)					0.9999						
All 3.8	Filter (Quan 2)		0.9997	0.9995	0.9997							
All 3.9	Latch Valve (Quan 2)		0.9995	0.9989	0.9995							
3.10	Orifice - No Credible Failure Mode											
3.11	Lines		0.9991									
All 3.12	Line Heater Series Strings		1.0000			0.9995						
All 3.13	Tank Heaters		1.0000			0.9995						
All 3.14	Thruster Heaters		1.0000			0.9979						
All 3.15	Thruster Valves		0.9965									
All 3.16	CatBed Heater		1.0000			0.9972						
All 4.	COMMUNICATION SUBSYSTEM		0.9073	0.9958		0.9986		0.9073	0.9958		0.9986	0.902269
All 5.	C&DH/PROCESSOR SUBSYSTEM		0.9588	0.9982	0.9974			0.9588	0.9982	0.9974		0.954633
All 6.	BACKPLANE		0.9974					0.9974				0.997375
All 7.	HARNESS AND GROUNDING		0.9993	1.0000	0.9996	0.9956		0.9993	1.0000	0.9996	0.9956	0.994583
	Total All											**0.815658**
	Total Comm + Processor											**0.861336**

Figure 3: PRA Numerical Results

An evaluation was done to assess the impacts of trying to increase this reliability. Note that very high reliability parts are used throughout the design. The calculated reliability is more a reflection of the fact that the THEMIS Probes are predominantly single-string. Therefore, the only way to increase the reliability number significantly is to add redundancy. The impact of adding a redundant transponder was considered (addressing the number one “orange” risk). It was decided that this option was not feasible on such a small spacecraft due to the additional mass and volume required for implementation. However, some piece-part redundancy was added to the system as identified and described in the THEMIS FMEA.

The calculated reliability number for a single probe is considered appropriate for the THEMIS mission given the overall system architecture. As mentioned in the overview, a key aspect of the THEMIS mission is the constellation redundancy and the use of an on-orbit spare. As described further in the FTA, the only real single fault in the THEMIS mission is the launch vehicle and separation event. After this event, more than one Probe must be lost before minimum success is threatened, which greatly increases the overall mission reliability and probability of success.

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6-Nov-03
Rev Orig

THEMIS RELIABILITY CALCULATIONS FOR PRA
INITIATING EVENT FAILURES AND SOME FAILURE EFFECTS
(SOME NUMERICAL CALCULATIONS USING THE "MINI" FMEA OUTLINE)

Mission Time, Years = 2
Computed Mission Time, Hours = 17520

RANKED BY LOSS SEVERITY CATEGORY

				LOSS SEVERITY CATEGORY	FAILURE RATE, (Estimated from EO-1 Analysis) (x 10^{-9}/hour)		Over Entire Mission Life (Individual) P(S)	P(F)	Over Entire Mission Life (Redun Areas) P(S)	LOW-LEVEL ELEMENT P(S)'S GROUPED BY SEVERITY CATEGORY: **P(S) for Sev Cat 5**	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1	COMPONENT P(S)'S GROUPED BY SEVERITY CATEGORY: P(S) for Sev Cat 5	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1
1	ELECTRICAL POWER SUBSYSTEM																		
1.1	Solar Arrays																		
1.1.1	Top Panel (2 strings)		Some Compromise	2	50		0.9991	0.0009					0.9991						
1.1.2	Bottom Panel (2 strings)		Some Compromise	2	50		0.9991	0.0009					0.9991						
1.1.3	4 Side Panels (4 strings per panel)																		
	Side Panel #1		Some Compromise	2	100		0.9982	0.0018					0.9982						
	Side Panel #2		Some Compromise	2	100		0.9982	0.0018					0.9982						
	Side Panel #3		Some Compromise	2	100		0.9982	0.0018					0.9982						
	Side Panel #4		Some Compromise	2	100		0.9982	0.0018					0.9982						
All 1.1	**Solar Arrays**																	0.9913	
1.2	**Battery**	**Battery Explosion - Safety issue!**		**5**	10	EWAG!	0.9998	0.0002		**0.9998**					**0.9998**				
1.2	**Battery**	**A Cell Opens:**	Loss of Probe	4	90		0.9984	0.0016			0.9984					0.9984			
1.3	**Battery Relay (BERB]**		Loss of Probe	4	25	From MIL-217F	0.9996	0.0004			0.9996					0.9996			
1.4	Shunt Regulation																		
1.4.2	Switched Shunt Control Circuits		Loss of Probe	4	200		0.9965	0.0035			0.9965								
1.4.3	Linear Shunt Circuit (Quan 1)		Major Compromise	3	200		0.9965	0.0035				0.9965							
1.4.1	Switched Shunts (Quan 3)																		
	Switched Shunt #1		Some Compromise	2	70		0.9988	0.0012					0.9988						
	Switched Shunt #2		Some Compromise	2	70		0.9988	0.0012					0.9988						
	Switched Shunt #3		Some Compromise	2	70		0.9988	0.0012					0.9988						
All 1.4	**Shunt Regulation**															0.9965	0.9965	0.9963	
1.5	Power Distribution																		
1.5.1	+28V Unswitched to Transponder		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.2	+28V to IDPU		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.3	+28V to Heaters		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.5	+28V to Instruments		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.6	+28V to S/C Heaters		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.7	+28V to Instrument Heaters		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.8	+28V to RCS Heaters		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.10	+28V Pulses to RCS Latch Valves		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.11	+28V Pulses to RCS Thruster Valves		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.12	+28V Pulses to Pyro Arm		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.13	+28V Pulses to Pyro Fire		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.14	Power Distribution and LVPS +5V		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.15	Power Distribution and LVPS +3.3V		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.16	Power Distribution and LVPS +3.3V(2.5)		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.17	Power Distribution and LVPS +/-15V		Loss of Probe	4	10		0.9998	0.0002			0.9998								
1.5.18	Power Distribution and LVPS +/-5V to Gyros		Major Compromise	3	10		0.9998	0.0002				0.9998							
1.5.19	Power Distribution and LVPS +5V to Sun Sensor		Major Compromise	3	10		0.9998	0.0002				0.9998							
1.5.4	+28V to RCS Pressure Transducer		None	1	10		0.9998	0.0002						0.9998					
1.5.9	+28V Pulses to BERB		None	1	10		0.9998	0.0002						0.9998					
All 1.5	**Power Distribution**															0.9974	0.9996		0.9996

RANKED BY LOSS SEVERITY CATEGORY

			LOSS SEVERITY CATEGORY	FAILURE RATE, (Estimated from EO-1 Analysis) (x 10^{-9}/hour)	Over Entire Mission Life (Individual) P(S)	Over Entire Mission Life (Individual) P(F)	Over Entire Mission Life (Redun Areas) P(S)	LOW-LEVEL ELEMENT P(S)'S GROUPED BY SEVERITY CATEGORY: **P(S) for Sev Cat 5**	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1	COMPONENT P(S)'S GROUPED BY SEVERITY CATEGORY: P(S) for Sev Cat 5	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1
2	ATTITUDE CONTROL SUBSYSTEM																
2.1	**Sun Sensor**	Major Compromise	3	50	0.9991	0.0009				0.9991					0.9991		
2.2	Solid State Gyros (Quan 2)																
	Solid State Gyro #1			50	0.9991	0.0009											
	Solid State Gyro #2			50	0.9991	0.0009											
	Both Fail to Operate:	Major Compromise	3				1.0000			1.0000							
	One Fails to Operate:	Some Compromise	2				0.9982				0.9982						
All 2.2	**Solid State Gyros (Quan 2)**														1.0000	0.9982	
2.3	**3-Axis Magnetometer (FGM Instrument)**	Loss of Probe	4	100	0.9982	0.0018			0.9982					0.9982			
2.4	**Software Functions**	Loss of Probe	4	50	0.9991	0.0009			0.9991					0.9991			

RANKED BY LOSS SEVERITY CATEGORY

3	REACTION CONTROL SUBSYSTEM			LOSS SEVERITY CATEGORY	FAILURE RATE, (Estimated from EO-1 Analysis) (x 10^{-9}/hour)	Over Entire Mission Life (Individual) P(S)	P(F)	Over Entire Mission Life (Redun Areas) P(S)	LOW-LEVEL ELEMENT P(S)'S GROUPED BY SEVERITY CATEGORY: **P(S) for Sev Cat 5**	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1	COMPONENT P(S)'S GROUPED BY SEVERITY CATEGORY: P(S) for Sev Cat 5	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1
3.1	**Software Functions**		Loss of Probe	4	50	0.9991	0.0009			0.9991					0.9991			
3.2	Tanks (Quan 2)																	
	Tank #1	**Either Leak, Rupture:**	Loss of Probe	4	25	0.9996	0.0004			0.9996								
	Tank #2	**Either Leak, Rupture:**	Loss of Probe	4	25	0.9996	0.0004			0.9996								
All 3.2	**Tanks (Quan 2)**														0.9991			
3.3	**Flight Pressure Transducer**		None	1	15	0.9997	0.0003						0.9997					0.9997
3.4	**Thermistors**		None	1	15	0.9997	0.0003						0.9997					0.9997
3.5	**PRTs**		None	1	15	0.9997	0.0003						0.9997					0.9997
3.6	**Pressure/Vent Valve (Quan 1, Manual)**		None	1	5	0.9999	0.0001						0.9999					0.9999
3.7	**Fill/Drain Valve (Quan 1 per Tank, Manual)**		None	1	5	0.9999	0.0001						0.9999					0.9999
3.8	Filter (Quan 2)	**Either Filter Clogged:**																
	Filter #1																	
	Filter #2																	
		Probes 1 or 2: Late in life	Loss of Probe	4	15	0.9997	0.0003			0.9997								
		Probes 1 or 2: Early in life	Major Compromise	3	15	0.9997	0.0003				0.9997							
		Probes 3,4, or 5: Late in life	Major Compromise	3	15	0.9997	0.0003				0.9997							
		Probes 3,4, or 5: Early in life	Some Compromise	2	15	0.9997	0.0003					0.9997						
All 3.8	**Filter (Quan 2)**														0.9997	0.9995	0.9997	
3.9	Latch Valve (Quan 2)	**Valve Stuck Closed:**																
	Latch Valve #1																	
	Latch Valve #2																	
		Probes 1 or 2: Late in life	Loss of Probe	4	30	0.9995	0.0005			0.9995								
		Probes 1 or 2: Early in life	Major Compromise	3	30	0.9995	0.0005				0.9995							
		Probes 3,4, or 5: Late in life	Major Compromise	3	30	0.9995	0.0005				0.9995							
		Probes 3,4, or 5: Early in life	Some Compromise	2	30	0.9995	0.0005					0.9995						
All 3.9	**Latch Valve (Quan 2)**														0.9995	0.9989	0.9995	
3.10	Orifice (Quan 2)	**Orifice - No Credible Failure Mode**																
3.11	**Lines**		Loss of Probe	4	50 total	0.9991	0.0009			0.9991					0.9991			
3.12	Line Heater Series Strings (Two series strings powered redundantly)																	
	Heater #1				15	0.9997	0.0003											
	Heater #2				15	0.9997	0.0003											
		Loss of Both Heater Strings	Loss of Probe	4				1.0000		1.0000								
		Loss of One Heater String	None	1				0.9995					0.9995					
All 3.12	**Line Heater Series Strings**														1.0000			0.9995
3.13	Tank Heaters (These are redundant)																	
	Heater #1				15	0.9997	0.0003											
	Heater #2				15	0.9997	0.0003											
		Loss of Both Heater Strings	Loss of Probe	4				1.0000		1.0000								
		Loss of One Heater String	None	1				0.9995					0.9995					
All 3.13	**Tank Heaters**														1.0000			0.9995
3.14	Thruster Heaters (These are redundant, 2 per Thruster)																	
	Thruster T1, Heater #1				15	0.9997	0.0003											
	Thruster T1, Heater #2				15	0.9997	0.0003											
	Thruster T2, Heater #1				15	0.9997	0.0003											
	Thruster T2, Heater #2				15	0.9997	0.0003											
	Thruster A1, Heater #1				15	0.9997	0.0003											
	Thruster A1, Heater #2				15	0.9997	0.0003											
	Thruster A2, Heater #1				15	0.9997	0.0003											
	Thruster A2, Heater #2				15	0.9997	0.0003											
		Loss of Both Heaters	Loss of Probe	4				1.0000		1.0000								
		Loss of One Heater	None	1				0.9979					0.9979					
All 3.14	**Thruster Heaters**														1.0000			0.9979
3.15	Thruster Valve (Quan 2 in series per Thruster)																	
	Thruster T1, Valve #1				25	0.9996	0.0004											
	Thruster T1, Valve #2				25	0.9996	0.0004											
	Thruster T2, Valve #1				25	0.9996	0.0004											
	Thruster T2, Valve #2				25	0.9996	0.0004											
	Thruster A1, Valve #1				25	0.9996	0.0004											
	Thruster A1, Valve #2				25	0.9996	0.0004											
	Thruster A2, Valve #1				25	0.9996	0.0004											

	Thruster A2, Valve #2				25	0.9996	0.0004					
All 3.15	**Thruster Valves**	**Either or Both Valves "Non-Fire"**	Loss of Probe	4				0.9965	0.9965		0.9965	
3.16	CatBed Heater (These are redundant, 2 per CatBed)											
	Thruster T1, Heater #1				20	0.9996	0.0004					
	Thruster T1, Heater #2				20	0.9996	0.0004					
	Thruster T2, Heater #1				20	0.9996	0.0004					
	Thruster T2, Heater #2				20	0.9996	0.0004					
	Thruster A1, Heater #1				20	0.9996	0.0004					
	Thruster A1, Heater #2				20	0.9996	0.0004					
	Thruster A2, Heater #1				20	0.9996	0.0004					
	Thruster A2, Heater #2				20	0.9996	0.0004					
		Loss of Both CatBed Heaters	Loss of Probe	4				1.0000	1.0000			
		Loss of One CatBed Heater	None	1				0.9972		0.9972		
All 3.16	**CatBed Heater**										1.0000	0.9972

RANKED BY LOSS SEVERITY CATEGORY

			LOSS SEVERITY CATEGORY	FAILURE RATE, (Estimated from EO-1 Analysis) (x 10^{-9}/hour)	Over Entire Mission Life (Individual) P(S)	P(F)	Over Entire Mission Life (Redun Areas) P(S)	LOW-LEVEL ELEMENT P(S)'S GROUPED BY SEVERITY CATEGORY: **P(S) for Sev Cat 5**	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1	COMPONENT P(S)'S GROUPED BY SEVERITY CATEGORY: P(S) for Sev Cat 5	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1
4	COMMUNICATION SUBSYSTEM																
4.1	Antenna	Loss of Probe	4	20	0.9996	0.0004			0.9996								
4.2	Transponder	Loss of Probe	4	5000	0.9161	0.0839			0.9161								
4.3	Uplink FPGA on Communications Board	Loss of Probe	4	80	0.9986	0.0014			0.9986								
4.4	Command FIFO (One Integrated Circuit Device)	Loss of Probe	4	80	0.9986	0.0014			0.9986								
4.5	Discrete Cmd Gen (Part of Power Board FPGA)	Loss of Probe	4	80	0.9986	0.0014			0.9986								
4.10	Telemetry FIFO (One Integrated Circuit Device)	Loss of Probe	4	80	0.9986	0.0014			0.9986								
4.11	RS Encoder (One Integrated Circuit Device)	Loss of Probe	4	80	0.9986	0.0014			0.9986								
4.12	Downlink FPGA on Communications Board	Loss of Probe	4	80	0.9986	0.0014			0.9986								
4.13	Software Functions	Loss of Probe	4	50	0.9991	0.0009			0.9991								
4.7	Analog Telemetry Current Source	Major Compromise	3	80	0.9986	0.0014				0.9986							
4.8	Analog Telemetry Multiplexer	Major Compromise	3	80	0.9986	0.0014				0.9986							
4.9	Telemetry Processor (Part of Power Board FPGA)	Major Compromise	3	80	0.9986	0.0014				0.9986							
4.6	Separation Interface (Telemetry function only)	None	1	80	0.9986	0.0014						0.9986					
All 4.	**COMMUNICATION SUBSYSTEM**													0.9073	0.9958		0.9986

RANKED BY LOSS SEVERITY CATEGORY

			LOSS SEVERITY CATEGORY	FAILURE RATE, (Estimated from EO-1 Analysis) (x 10^{-9}/hour)	Over Entire Mission Life (Individual) P(S)	P(F)	Over Entire Mission Life (Redun Areas) P(S)	LOW-LEVEL ELEMENT P(S)'S GROUPED BY SEVERITY CATEGORY: **P(S) for Sev Cat 5**	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1	COMPONENT P(S)'S GROUPED BY SEVERITY CATEGORY: P(S) for Sev Cat 5	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1
5	C&DH/PROCESSOR SUBSYSTEM																
5.1	Clock Oscillator	Loss of Probe	4	100	0.9982	0.0018			0.9982								
5.2	ColdFire Processor	Loss of Probe	4	600	0.9895	0.0105			0.9895								
5.3	Processor FPGA	Loss of Probe	4	300	0.9948	0.0052			0.9948								
5.4	RAM	Loss of Probe	4	100	0.9982	0.0018			0.9982								
5.5	Boot PROM	Loss of Probe	4	50	0.9991	0.0009			0.9991								
5.6	Program Storage EEPROM	Loss of Probe	4	100	0.9982	0.0018			0.9982								
5.7	RS-422 Command Driver to IDPU	Loss of Probe	4	50	0.9991	0.0009			0.9991								
5.9	RS-422 2Mbps Data Receiver from IDPU	Loss of Probe	4	50	0.9991	0.0009			0.9991								
5.10	RS-422 Clock Interfaces to IDPU	Loss of Probe	4	50	0.9991	0.0009			0.9991								
5.14	Bulk Memory	Loss of Probe	4	600	0.9895	0.0105			0.9895								
5.15	Bulk Memory FPGA	Loss of Probe	4	300	0.9948	0.0052			0.9948								
5.16	Software Functions	Loss of Probe	4	100	0.9982	0.0018			0.9982								
5.11	RS-422 One PPS Interfaces to IDPU	Major Compromise	3	50	0.9991	0.0009				0.9991							
5.12	Sun Pulse Interface to IDPU	Major Compromise	3	50	0.9991	0.0009				0.9991							
5.8	RS-422 Status Receiver from IDPU	Some Compromise	2	50	0.9991	0.0009					0.9991						
5.13	3.3V Power Switch to EEPROMs	Some Compromise	2	100	0.9982	0.0018					0.9982						
All 5.	**C&DH/PROCESSOR SUBSYSTEM**													0.9588	0.9982	0.9974	

RANKED BY LOSS SEVERITY CATEGORY

No.	Item	Condition	Effect	LOSS SEVERITY CATEGORY	FAILURE RATE, (Estimated from EO-1 Analysis) (x 10^{-9}/hour)	Over Entire Mission Life (Individual) P(S)	P(F)	Over Entire Mission Life (Redun Areas) P(S)	LOW-LEVEL ELEMENT P(S)'S GROUPED BY SEVERITY CATEGORY: **P(S) for Sev Cat 5**	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1	COMPONENT P(S)'S GROUPED BY SEVERITY CATEGORY: P(S) for Sev Cat 5	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1
6	BACKPLANE																	
6.1	I^{2}C Interfaces (Quan 3)	**Any Fails to Operate:**																
	I^{2}C Interface #1		Loss of Probe	4	50	0.9991	0.0009			0.9991								
	I^{2}C Interface #2		Loss of Probe	4	50	0.9991	0.0009			0.9991								
	I^{2}C Interface #3		Loss of Probe	4	50	0.9991	0.0009			0.9991								
All 6.	**BACKPLANE**														0.9974			
7	HARNESS AND GROUNDING																	
7.1	Pyro Arm Plug	**No Credible Failure Mode**																
7.2	RCS Arm Plug	**No Credible Failure Mode**																
7.3	Fusing (Steered Redundant) - for non-critical loads only																	
7.3.1	Gyro +/-5V power (Quan 2 fuses)																	
	Fuse #1				25	0.9996	0.0004											
	Fuse #2				25	0.9996	0.0004											
		Both Fuses Fail Open:	Major Compromise	3				1.0000			1.0000							
		One Fuse Fails Open:	None	1				0.9991					0.9991					
7.3.2	Bus heaters (Quan 2 fuses)																	
	Fuse #1				25	0.9996	0.0004											
	Fuse #2				25	0.9996	0.0004											
		Both Fuses Fail Open:	Loss of Probe	4				1.0000		1.0000								
		One Fuse Fails Open:	None	1				0.9991					0.9991					
7.3.3	RCS heaters (Quan 2 fuses)																	
	Fuse #1				25	0.9996	0.0004											
	Fuse #2				25	0.9996	0.0004											
		Both Fuses Fail Open:	Loss of Probe	4				1.0000		1.0000								
		One Fuse Fails Open:	None	1				0.9991					0.9991					
7.3.4	Instrument heaters (Quan 2 fuses)																	
	Fuse #1				25	0.9996	0.0004											
	Fuse #2				25	0.9996	0.0004											
		Both Fuses Fail Open:	Loss of Probe	4				1.0000		1.0000								
		One Fuse Fails Open:	None	1				0.9991					0.9991					
7.3.5	Pressure Transducer (Quan 2 fuses)																	
	Fuse #1				25	0.9996	0.0004											
	Fuse #2				25	0.9996	0.0004											
		Both Fuses Fail Open:	None	1				1.0000					1.0000					
		One Fuse Fails Open:	None	1				0.9991					0.9991					
7.4	Primary Return wires		Loss of Probe	4	20 total	0.9996	0.0004			0.9996								
7.5	Secondary/Signal Return wires		Loss of Probe	4	20 total	0.9996	0.0004			0.9996								
7.6	Chassis Return wires		Some Compromise	2	20 total	0.9996	0.0004					0.9996						
All 7.	**HARNESS AND GROUNDING**														0.9993	1.0000	0.9996	0.9956

6-Nov-03
Rev Orig

THEMIS RELIABILITY CALCULATIONS ROLL-UP FOR PRA
INITIATING EVENT FAILURES
("ROLL-UP" OF NUMERICAL CALCULATIONS USING THE "MINI" FMEA OUTLINE)

	SUBSYSTEMS	COMPONENT P(S)'S GROUPED BY SEVERITY CATEGORY:					SUBSYSTEM P(S)'S GROUPED BY SEVERITY CATEGORY:					
		P(S) for Sev Cat 5	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1	P(S) for Sev Cat 5	P(S) for Sev Cat 4	P(S) for Sev Cat 3	P(S) for Sev Cat 2	P(S) for Sev Cat 1	Totals All Cat
1	**ELECTRICAL POWER SUBSYSTEM**						**0.9998**	0.9919	0.9962	0.9876	0.9996	0.975343
All 1.1	**Solar Arrays**				0.9913							
1.2	**Battery Explosion - Safety issue!**	**0.9998**										
1.2	**Battery**		0.9984									
1.3	**Battery Relay (BERB)**		0.9996									
All 1.4	**Shunt Regulation**		0.9965	0.9965	0.9963							
All 1.5	**Power Distribution**		0.9974	0.9996		0.9996						
2	**ATTITUDE CONTROL SUBSYSTEM**							0.9974	0.9991	0.9982		0.994757
2.1	**Sun Sensor**			0.9991								
All 2.2	**Solid State Gyros (Quan 2)**			1.0000	0.9982							
2.3	**3-Axis Magnetometer (FGM Instrument)**		0.9982									
2.4	**Software Functions**		0.9991									
3	**REACTION CONTROL SUBSYSTEM**							0.9931	0.9984	0.9992	0.9931	0.983924
3.1	**Software Functions**		0.9991									
All 3.2	**Tanks (Quan 2)**		0.9991									
3.3	**Flight Pressure Transducer**					0.9997						
3.4	**Thermistors**					0.9997						
3.5	**PRTs**					0.9997						
3.6	**Pressure/Vent Valve (Quan 1, Manual)**					0.9999						
3.7	**Fill/Drain Valve (Quan 1 per Tank, Manual)**					0.9999						
All 3.8	**Filter (Quan 2)**		0.9997	0.9995	0.9997							
All 3.9	**Latch Valve (Quan 2)**		0.9995	0.9989	0.9995							
3.10	**Orifice - No Credible Failure Mode**											
3.11	**Lines**		0.9991									
All 3.12	**Line Heater Series Strings**		1.0000			0.9995						
All 3.13	**Tank Heaters**		1.0000			0.9995						
All 3.14	**Thruster Heaters**		1.0000			0.9979						
All 3.15	**Thruster Valves**		0.9965									
All 3.16	**CatBed Heater**		1.0000			0.9972						
All 4.	**COMMUNICATION SUBSYSTEM**		0.9073	0.9958		0.9986		0.9073	0.9958		0.9986	0.902269
All 5.	**C&DH/PROCESSOR SUBSYSTEM**		0.9588	0.9982	0.9974			0.9588	0.9982	0.9974		0.954633
All 6.	**BACKPLANE**		0.9974					0.9974				0.997375
All 7.	**HARNESS AND GROUNDING**		0.9993	1.0000	0.9996	0.9956		0.9993	1.0000	0.9996	0.9956	0.994583
	Total All											**0.815658**
	Total Comm + Processor											**0.861336**