NAVAL RESEARCH LABORATORY

NAVAL CENTER FOR SPACE TECHNOLOGY

Inertial Measurement Unit (IMU) Specification
for the
Full-sky Astrometric Mapping Explorer (FAME)

NCST-S-FM007 **6 June 2001**

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RECORD OF CHANGES

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1.0 SCOPE

1.1 Identification

This specification establishes the top level functional performance, design, manufacture, verification, and acceptance requirements for the Full-sky Astrometric Mapping Explorer (FAME) Inertial Measurement Unit (IMU).

1.1.1 Flight Unit

The IMU Flight Unit shall meet all the requirements of this specification and shall be tested to the performance and acceptance environmental tests of section 4.0.

1.1.2 Qualification Unit

The IMU Qualification Unit shall meet all the requirements of this specification and shall be tested to the performance and qualification environmental tests of 4.0.

1.1.3 Engineering Development Unit

The Engineering Development Unit (EDU) shall meet the form, fit, and function of the Flight Unit. The EDU will be used to verify mechanical and electrical compatibility with FAME's mechanical and electrical systems. The EDU shall not be required to meet the environmental requirements called out in this specification.

1.2 Purpose

This specification establishes the performance, design, manufacture, verification, and acceptance requirements for the FAME IMU.

1.3 Document Overview

This document is organized as follows:

a. Section 1.0, *Scope:* Purpose and contents of this document.

b. Section 2.0, *Referenced Documents:* A list of documents referenced in or required for use with this document.

c. Section 3.0, *Requirements:*

   (1) Paragraph 3.1 provides a comprehensive definition of the IMU.

   (2) Paragraph 3.2 specifies the performance and physical characteristics of the IMU.

   (3) Paragraph 3.3 specifies the minimum design and construction requirements for the IMU.

   (4) Paragraph 3.4 describes the documentation that the Contractor must provide with the IMU.

a. Section 4.0, *Quality Assurance Provisions:* Details the tests to be conducted and the methods of test verification that will be employed.

b. Section 5.0, *Preparation for Delivery:* Provides guidance for preparing the IMU for delivery.

c. Section 6.0, *Deliverables and Tasks*, describes the deliverable data that the Contractor must furnish with the IMU.

d. Section 7.0, *Notes:* Provides additional information that is not contractually binding. Included are a glossary and list of acronyms.

The performance requirements herein are applicable during nominal operations, maintenance, or contingency events. Requirements for earlier or other staged events are noted. Each requirement, unless otherwise noted, represents the required performance of the IMU from the time of its activation through end of mission life.

2.0 APPLICABLE DOCUMENTS

2.1 Government Documents

The following documents of the exact issue shown form a part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this document, the contents of this document shall be considered a superseding requirement. Copies of specifications, standards, drawings, and publications required by Contractors in connection with specified procurement functions should be obtained from the contracting agency or as directed by the contracting officer. Documents beginning with the control number “SSD” and “NCST” are program documents controlled by the Naval Research Laboratory (NRL).

2.1.1 Military Specifications

Most active military specifications are available on-line from: http://astimage.daps.dla.mil/quicksearch/

Number	Title	Paragraph Reference
MIL-DTL-31000A	Technical Data Packages	3.4.2
MIL-PRF-38534D	Hybrid Microcircuits, General Specification for	3.3.1.1.2
MIL-PRF-38535E	Integrated Circuits (Microcircuits) Manufacturing, General Specification for	3.3.1.1.2

2.1.2 Military Standards

Most active military standards are available on-line from: http://astimage.daps.dla.mil/quicksearch/

Number	Title	Paragraph Reference
MIL-STD-1522B	Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems	3.3.1.2.2
MIL-STD-1686C	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment	3.3.1.1.4
MIL-STD-461C	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference	3.3.2.1, 3.3.2.2, 3.3.2.3.1
MIL-STD-461D	Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility	3.3.2.4.1
MIL-STD-462	Measurement of Electromagnetic Interference Characteristics	3.3.2.1, 3.3.2.2, 3.3.2.3.1
MIL-STD-883E	Test Methods and Procedures for Microelectronics	3.3.1.1.2
MIL-STD-961D	Specification Practices	3.4.1
MIL-STD-1629A	Procedure for Performing Failure Modes and Effects Criticality Analysis	3.2.3.2

2.1.3 Military Handbooks

Most active military handbooks are available on-line from: http://astimage.daps.dla.mil/quicksearch/

Number	Title	Paragraph Reference
MIL-HDBK-217F	Reliability Prediction of Electronic Equipment	3.2.3.1
MIL-HDBK-1547A	Electronic Parts, Materials, & Processes for Space & Launch Vehicles	3.3.1.1.3

2.1.4 Other Publications

Number	Title	Paragraph Reference
EWRR 127-1	Eastern and Western Range Regulation 127-1, Range Safety Requirements	3.3.1.2.2
GSFC 311-INST-001A	Instructions for EEE Parts Selection, Screening, and Qualification Available from: http://epims.gsfc.nasa.gov/ctre/parts/inst/prd.htm	3.3.1.1.1, 3.3.1.1.2
GSFC-410-MIDEX-001	MIDEX Assurance Guidelines	3.2.6.2.2.3, 3.3.1, 3.3.1.1.2
MSFC-SPEC-522B	Design Criteria for Controlling Stress Corrosion Cracking	3.3.1.2.2, 3.3.1.2.6
NASA-STD-2100-91	NASA Software Documentation Standard Available from: http://satc.gsfc.nasa.gov/assure/docstd.html	3.4.1, 3.4.3
SP-R-0022	Vacuum Stability Requirements of Polymeric Material for Spacecraft Applications, Specifications for	3.3.1.2.1
SSD-D-IM007	ICM Worst Case Analysis	3.2.3.4, 3.3.1.1.3

2.1.5 NASA Technical Standards

NASA Technical Standards are available on-line from: http://www.hq.nasa.gov:80/office/codeq/doctree/qdoc.pdf

Number	Title	Paragraph Reference
NASA-STD-8739.1	Workmanship Standard for Staking and Conformal Coating of Printed Wiring Boards and Electronic Assemblies	3.3.1.3.1
NASA-STD-8739.2	Workmanship Standard for Surface Mount Technology	3.3.1.3.1
NASA-STD-8739.3	Soldered Electrical Connections	3.3.1.3.1
NASA-STD-8739.4	Crimping, Interconnecting Cables, Harnesses, and Wiring	3.3.1, 3.3.1.3.1
NASA-STD-8739.7	Standard for Electrostatic Discharge Control (Excluding Electrically Initiated Explosive Devices)	3.3.1.1.4

2.1.6 FAME Project Documents

Available to registered users at http://team8200.nrl.navy.mil/

Number	Title	Paragraph Reference
NCST-D-FM007	FAME Contamination Control Plan	3.2.6.1.1, 3.2.6.1.2, 3.2.6.1.3, 3.2.6.2.1
NCST-D-FM018	FAME EMI/EMC Control Plan	3.3.2

2.2 Non-Government Documents

The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on the date of the invitation of bids or request for proposal shall apply. In the event of conflict between the documents referenced herein and the contents of this specification, this specification shall take precedence. Copies of specifications, standards, drawings, and publications required by Contractors in connection with specified procurement functions should be obtained from the contracting agency or as directed by the contracting officer.

2.2.1 Specifications

Not applicable.

2.2.2 Standards

Not applicable.

2.2.3 Other Publications

Number	Title	Paragraph Reference
ANSI/J-STD-001	Requirements for Soldered Electrical and Electronic Assemblies	3.3.1.3.1
ANSI/J-STD-002	Solderability Tests for Component Leads, Terminations, Lugs, Terminals and Wires	3.3.1.3.1
ANSI/J-STD-003	Solderability Test Methods for Printed Wiring Boards	3.3.1.3.1
ANSI/J-STD-004	Requirements for Soldering Fluxes	3.3.1.3.1
ANSI/J-STD-005	Requirements for Soldering Pastes	3.3.1.3.1
ANSI/J-STD-006	Requirements for Electronic Grade Solder Alloys and Fluxed and Non-fluxed Solid Solders for Electronic Soldering Applications	3.3.1.3.1
EIA-625	Requirements for Handling Electrostatic Discharge Sensitive Devices	3.3.1.1.4
IEEE/EIA 12207.0	Standard for Information Technology - Software Life Cycle Processes	3.4.1, 3.4.3
IEEE/EIA 12207.1	Standard for Information Technology - Software Life Cycle Processes - Life Cycle Data	3.4.1, 3.4.3
IEEE/EIA 12207.2	Standard for Information Technology - Software Life Cycle Processes - Implementation Considerations	3.4.1, 3.4.3
IPC-A-600D	Acceptability of Printed Wiring Boards Available from: http://www.ipc.org	3.3.1.3.1
IPC-D-275	Standard for PCB Design and Assembly Available from: http://www.ipc.org	3.3.1.3.1
IPC-FC-250	Performance Specification for Single and Double-Sided Flexible Printed Boards Available from: http://www.ipc.org	3.3.1.3.1
IPC-FC-250A-86	Specification for Single and Double-Sided Flexible Wiring Available from: http://www.ipc.org	3.3.1.3.1

2.3 Order of Precedence

In the event of a conflict between the text of this specification and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3.0 REQUIREMENTS

This section specifies the functional, performance, interface, logistic, quality factor, and design requirements for the IMU. The terms used to define the scope and the extent of the system requirements herein are defined in Section 6.0.

3.1 Item Definition

The item specified herein is the Inertial Measurement Unit (IMU), an element of the FAME attitude control system. The equipment described by the requirements of this section shall satisfy the requirements for examination, analysis, and tests as specified in section 4.0. The IMU shall perform the functions of inertial angular rate measurement (or incremental angular measurement) and inertial acceleration (or incremental velocity measurement) in three mutually orthogonal axes. The IMU provides three-axis rate sensing and three-axis acceleration sensing capability and interfaces to the FAME spacecraft controller (FSC). The IMU will be used to determine vehicle attitude between star sensor updates. Any calibration and compensation required to meet performance requirements shall reside in the IMU. The IMU shall include the following components and characteristics. The IMU functional block diagram is shown in Figure 3-1.

a. Gyroscope

b. Accelerometer

c. Output Data Interface(s)

d. Power Conditioning

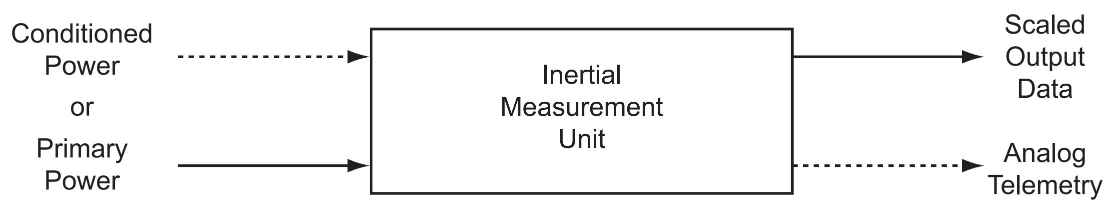


Figure 3-1. IMU Functional Block Diagram

3.1.1 Interface Definition

The IMU will have the interfaces defined in the subsections below. Signal definitions are as follows:

Input and output signals will be active high unless otherwise specified. Active high signals are asserted at the higher (more positive) of two logic voltage levels (high-true). Active low signals are asserted at the lower (less positive) of two logic voltage levels (low-true). Active low signals will be identified by an asterisk (*) after the signal name.

3.2 Characteristics

3.2.1 Performance Requirements

The IMU shall meet the performance requirements and shall provide the capabilities as specified within this document.

3.2.1.1 Gyroscope Performance

3.2.1.1.1 General

The IMU shall provide inertial angular rate indication about three mutually perpendicular axes.

3.2.1.1.2 Maximum Continuous Input Rates

The unit shall be capable of maximum continuous input rates for each axis of 400 degrees/second.

3.2.1.1.3 Output Scale Factors

The output scale factors for each axis shall be as defined below:

3.2.1.1.3.1 Scale Factor Linearity

Scale factor linearity (after compensation) shall be less than 100 ppm (one sigma) per axis.

3.2.1.1.3.2 Scale Factor Stability

Scale factor stability (after compensation) shall be less than 100 ppm (one sigma) per axis.

3.2.1.1.4 Bias Repeatability

Bias repeatability shall not exceed 1 degree/hour (one sigma).

3.2.1.1.5 Angular Random Walk

Angular random walk shall not exceed 0.15 degree/root-hour (one sigma) per axis.

3.2.1.1.6 Bandwidth

The minimum bandwidth for each of the three gyroscope outputs shall be 30 Hz.

3.2.1.1.7 Axis Alignment

The three gyroscope reference axes shall be mutually orthogonal. The physical misalignment of the gyroscope input axes relative to a set of optically derived axes shall not exceed 2 milliradians. The uncertainty in the alignment of the input axes relative to the optical reference axes shall be no greater than 100 microradians.

3.2.1.1.8 Sensitivity

Each incremental angle measurement output shall have a maximum threshold of 10 degrees/hour.

3.2.1.1.9 Warm-up Time

The warm-up time for the unit shall not exceed 1 minute.

3.2.1.2 Accelerometer Performance

3.2.1.2.1 General

The IMU shall provide inertial acceleration indication for three mutually perpendicular axes.

3.2.1.2.2 Maximum Continuous Acceleration

The unit shall be capable of maximum continuous acceleration input for each axis of 30 g’s.

3.2.1.2.3 Scale Factor Accuracy

The output scale factor accuracy after compensation shall be less than 400 ppm (one sigma) per axis.

3.2.1.2.4 Bias Accuracy

Bias accuracy shall not exceed 10 mg (one sigma).

3.2.1.2.5 Bandwidth

The minimum bandwidth for each of the three accelerometer outputs shall be 40 Hz.

3.2.1.2.6 Axis Alignment

The three gyroscope reference axes shall be mutually orthogonal. The physical misalignment of the gyroscope input axes relative to a set of optically derived axes shall not exceed 2 milliradians. The uncertainty in the alignment of the input axes relative to the optical reference axes shall be no greater than 500 microradians.

3.2.1.2.7 Least Significant Bit (LSB)

The maximum LSB should be no greater than 0.003 ft/second.

3.2.1.2.8 Warm-up Time

The warm-up time for the unit shall not exceed 1 minute.

3.2.1.3 Output Data Interfaces

3.2.1.3.1 Output Data

The Command, Telemetry, and Data Handling (CT&DH) System interfaces between the IMU and the FSC shall either be compatible with a RS-485 serial digital data bus or be MIL-STD-1553 compatible.

3.2.1.3.2 IMU Output Sampling Period

The sample period of the IMU output shall be ±10 milliseconds. Requirements of paragraph 3.2.1 shall be met using this sample period.

3.2.1.4 Primary Power

The Contractor may choose one of two methods for primary power: a spacecraft-conditioned power source or the spacecraft's primary power. The Contractor shall provide specific power conditioning requirements for inclusion in this specification.

3.2.1.4.1 Conditioned Power (Alternate #1)

The IMU may be powered from the spacecraft using a conditioned power source provided. Conditioned power can supply the following voltages: 5 ±0.25 Vdc, -5 ±0.25 Vdc, +15 ±0.75 Vdc, and -15 ±0.75 Vdc. The combined power input to the IMU from all conditioned sources shall be less than 13 watts. Inrush currents shall be limited to twice the average operating input current.

3.2.1.4.2 Primary Power (Alternate #2)

The IMU may be designed to accept unregulated input power from the FAME spacecraft bus Electrical Power System (EPS) and provide preregulation for use within the subsystem. Switching of input power (i.e., power-on and power-off) shall be accomplished in the EPS, which shall also provide control of inrush current. The equipment shall operate as specified herein when supplied with input power having the characteristics specified below, and shall not impose emissions on the power bus in excess of those specified herein.

3.2.1.4.2.1 Input Voltage

The steady state voltage at the input connector of the equipment will be 24-36 Vdc, excluding noise, ripple and transients.

3.2.1.4.2.2 Source Impedance

The input power will have an equivalent source impedance as depicted in Figure 3-2.

3.2.1.4.2.3 Isolation

The equipment shall be compatible with a single-point ground for primary power with separate positive and return wires brought out to the power input connector. Primary input power and returns to the equipment shall be isolated from the case (chassis) and secondary power circuitry by a minimum dc resistance of one megohm. The case (chassis) or mounting structure shall not be used to conduct power currents.

3.2.1.4.2.4 Power Consumption

The power consumption of the equipment shall not exceed 13 watts.

3.2.1.4.2.5 Inrush Current

The inrush current to the equipment when switching from power-off to power-on in any mode shall not exceed twice the average operating input current, and the input current shall settle to within 10% of the nominal operating value within 200 milliseconds after the application of power. The input power equivalent circuit shall be as shown in Figure 3-2.

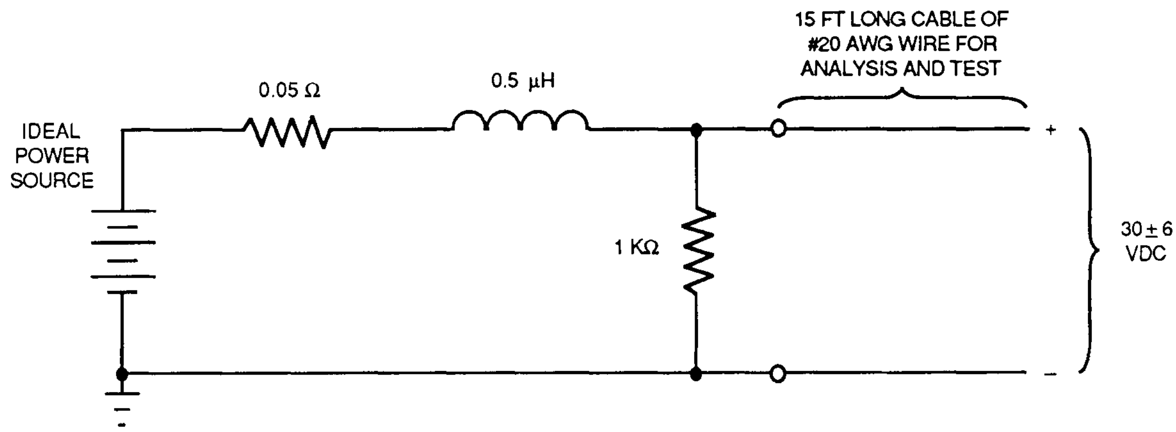


Figure 3-2. Primary Power Input Equivalent Circuit

3.2.2 Physical Characteristics

3.2.2.1 Mass Properties Control and Reporting

The mass properties of the IMU shall be reported and controlled.

3.2.2.1.1 Weight Limits

The weight of the IMU shall not exceed the values listed in Table 3-1 and shall be included in the contractor provided ICD.

Table 3-1. IMU Weight Limits

Unit	Weight	Mass
IMU	8.8 lb	4 kg

3.2.2.2 Dimensions and Envelope

Overall dimensions (including thermal effects and dynamic motion in the launch configuration) shall be reported and controlled in the contractor provided ICD.

3.2.2.3 Coordinate System

Reference axes notation shall use the right-hand rule and be defined in the contractor provided ICD.

3.2.2.4 Minimum Frequency

The stiffness of the IMU shall be such that it produces a fundamental frequencies above 50 Hz in all three axes hard-mounted at its interface.

3.2.2.5 Center of Gravity (CG) Limits

The CG limits shall be defined in the contractor provided ICD.

3.2.3 System Quality Factors

3.2.3.1 Reliability

The contractor shall provide a reliability analysis on the IMU using the parts failure rates of MIL-HDBK-217. As a goal, the IMU design shall be such that a failure in one component does not propagate to other components. As a goal, the IMU shall, when practical, be capable of detecting malfunctions and automatically initiating protective measures to avoid loss of the mission.

3.2.3.2 Failure Modes, Effects, and Criticality Analysis

A failure modes and effects criticality analysis shall be provided in accordance with MIL-STD-1629A.

3.2.3.3 Electrical Stress Analysis

An electrical stress analysis shall be provided in accordance with SSD-D-IM007.

3.2.3.4 Worst Case Analysis

A worst case analysis shall be provided in accordance with SSD-D-IM007.

3.2.3.5 Radiation Analysis

A radiation analysis shall be provided to meet the requirements of paragraph 3.2.6.2.2.3.

3.2.4 Maintainability

No scheduled and preventive maintenance shall be required to meet the performance requirements specified herein.

3.2.5 Fault Detection Capability

As a goal, fault detection, isolation, and checkout capability shall be provided to the subassembly or component level. As a goal, on-orbit fault detection and isolation shall be provided to the component level.

3.2.6 Environmental Conditions

The IMU shall be designed to operate within specification limits during and after exposure, as applicable, to all creditable combinations of operating and non-operating environments. The IMU shall be protected during ground handling and transportation so that the environmental conditions do not exceed flight or orbital conditions. These constraints shall not be interpreted as precluding environmental testing of the IMU. The following subparagraphs describe the general requirements for the environmental conditions that are applicable to the observatory space segment.

3.2.6.1 Non-Operating Environment

The IMU shall meet the requirements of this document without refurbishment or adjustment after exposure to any combination of the environments specified herein for integration and test (I&T) facility (paragraph 3.2.6.1.1), ground handling and transportation (paragraph 3.2.6.1.2), and/or prelaunch (paragraph 3.2.6.1.3).

3.2.6.1.1 Integration and Test Facility Environment

The IMU shall meet the requirements of this document without refurbishment or adjustment after exposure to any combination of the I&T environments listed below:

a. *Ambient Air Temperature:* The ambient air temperature may vary from 7°C to 39°C.

b. *Ambient Pressure*: Naturally occurring at sea level and at 5,000 feet.

c. *Humidity:* The relative humidity may vary between 2% to 98%, non-condensing.

d. *Acceleration, Vibration, Shock, and Loads:* Not applicable.

e. *Cleanliness:* Flight hardware will be maintained in accordance with the requirements of NCST-D-FM007.

3.2.6.1.2 Ground Handling and Transportation

The IMU shall meet the requirements of this document without refurbishment or adjustment after exposure to any combination of the ground handling and transportation environments listed below:

a. *Ambient Air Temperature:* External environment is uncontrolled and will range from -25˚C to +40˚C.

b. *Ambient Pressure*: Naturally occurring at sea level to 50,000 feet.

c. *Humidity:* The relative humidity may vary between 2% to 98%, non-condensing. Internal shipping container environment controlled to prevent condensation of moisture or frost on flight hardware.

d. *Acceleration, Vibration, Shock, and Loads:* The IMU shall not be exposed to environments greater than those experienced during launch and ascent.

e. *Cleanliness:* Protective container or packaging to maintain flight hardware at the cleanliness level specified in NCST-D-FM007.

3.2.6.1.3 Prelaunch

The IMU shall meet the requirements of this document without refurbishment or adjustment after exposure to any combination of prelaunch environments (environments that occur from arrival at the Expendable Launch Vehicle [ELV] launch site to launch) listed below:

a. *Ambient Air Temperature:* Maintained from 7˚C to 39˚C.

b. *Ambient Pressure*: Naturally occurring at sea level and at 5,000 feet.

c. *Humidity:* Maintained between 2% and 98%. Appropriate measures will be implemented to prevent the formation of condensation on the observatory, test equipment, or protective covers.

d. *Acceleration, Vibration, Shock, and Loads:* Observatory shall not be exposed to environments greater than those experienced during launch and ascent.

e. *Cleanliness:* Assembly, test, and preparation area controlled to meet the environment specified in NCST-D-FM007.

3.2.6.2 Operating Environment

The IMU shall be designed to perform as specified for 5 years after exposure to the environments specified herein for launch and ascent (paragraph 3.2.6.2.1) and on-orbit operations (paragraph 3.2.6.2.2).

3.2.6.2.1 Launch and Ascent

The launch and ascent phase covers those environments that occur between terminal countdown and separation from the third stage. The IMU shall meet the requirements of this document without refurbishment or adjustment after exposure to the environments are listed below:

a. *Temperature:* The temperature of the surrounding area and the baseplate will be maintained at any temperature between -20˚C to +55˚C.

b. *Pressure*: The pressure decay curve in the launch vehicle fairing is defined in Figure 3-3. The IMU shall operate at pressures less than 1×10^{-5} torr.

c. *Acceleration and Loads:* For design purposes, component accelerations are provided in Figure 3-4. The design factor of safety requirements for the quasi-static loads and the design limit load factors for the IMU are listed in Table 3-2.

d. *Pyrotechnic Shock:* The IMU shall withstand the pyroshock environment as shown in Figure 3-5. The design factor of safety requirements for the quasi-static loads and the design limit load factors for the IMU are listed in Table 3-2. Pyrotechnique shock testing will be performed at the system level with the spacecraft.

e. *Random Vibration:* The IMU shall withstand the random vibration environment as shown in Figure 3-6 and Figure 3-7.

f. The design factor of safety requirements for the quasi-static loads and the design limit load factors for the IMU are listed in Table 3-2.

g. *Cleanliness:* Assembly, test, and preparation area controlled to meet the environment specified in NCST-D-FM007.

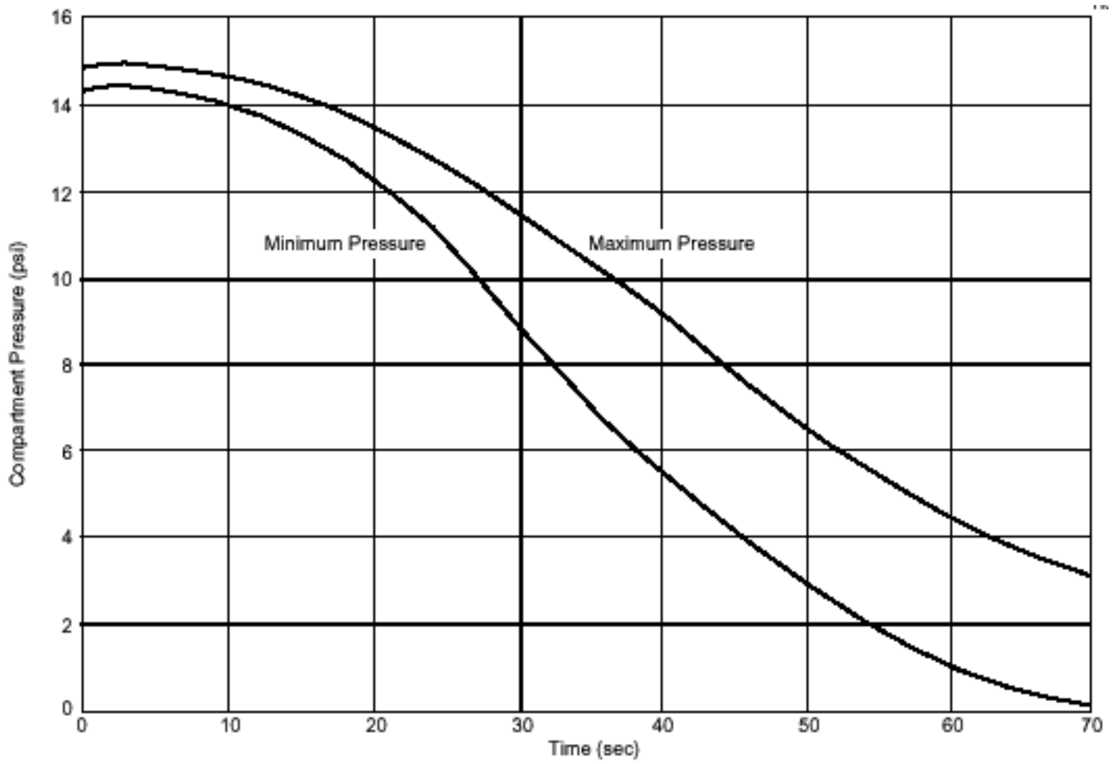
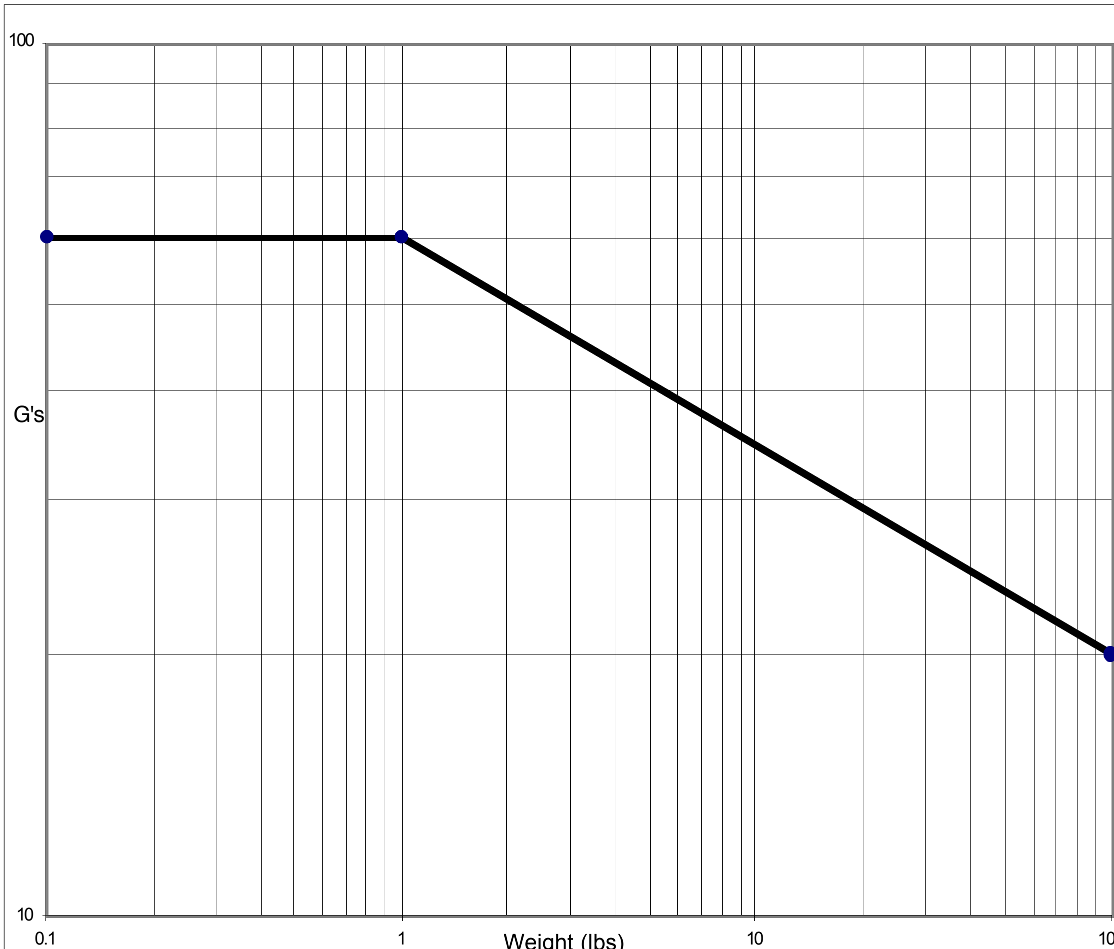


Figure 3-3. Pressure Decay Curve



FAME Flight Level Acceleration Environment for Components
All Three Axes

Design Accelerations

Component Wt. (Lbs)	G's
0.1	60
1	60
100	20

Design Acceleration Philosophy

* These accelerations are to be used for component testing by sine burst or centrifuge,

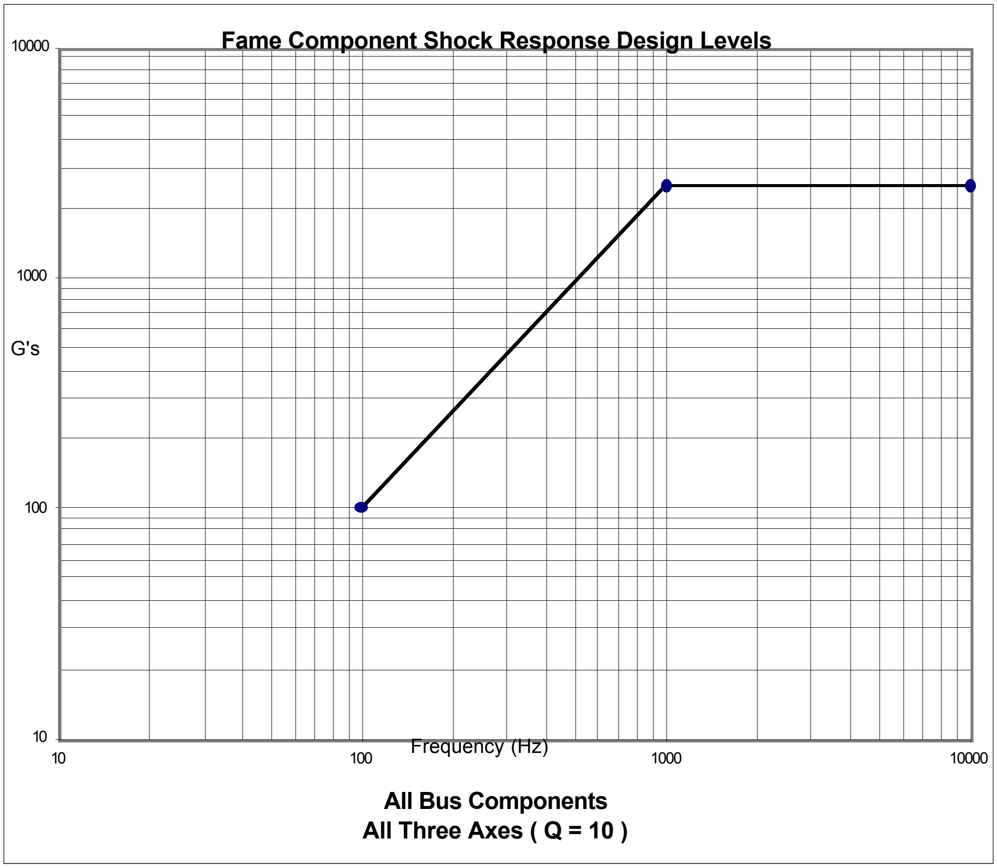
- Appropriate factors of safety shall be applied to these accelerations

- For designated components, the acceleration level from this curve may also be used for vibration test tailoring

Figure 3-4. Component Accelerations

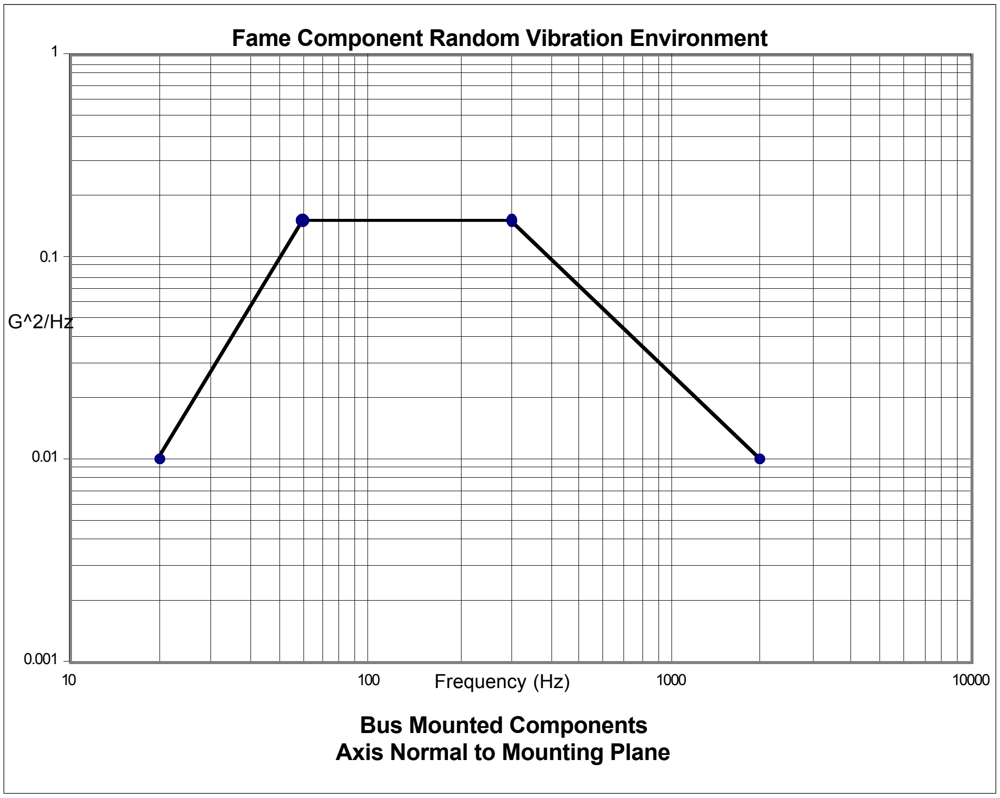
Table 3-2. Quasi-Static Loads and Design Limit Load Factors

	With Test
Yield	1.10
Ultimate	1.40
Fatigue	4.00



Design Environment Shock Response Spectrum Levels		Test Levels	
Frequency (Hz)	G's	Flight	1 Shock per Axis
100	100	Protoflight	2 Shocks per Axis
1000	2500		
10000	2500	Qualification	3 Shocks per Axis

Figure 3-5. Pyroshock Environment



Flight Level Environment

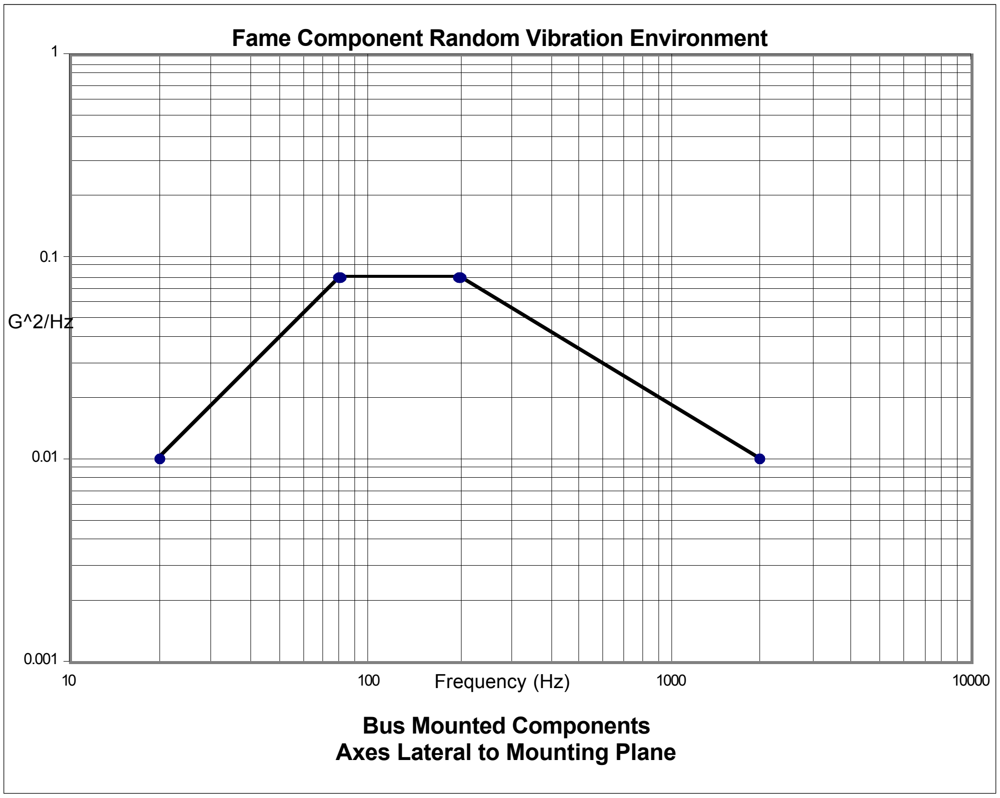
Frequency (Hz)	G^2/Hz
20	0.01
60	0.15
300	0.15
2000	0.01

9.9 Grms

Test Levels

	Margin Above Flight Level (dB)	Duration (Minutes)
Non-Flight Prototypes (Design & Qualification Level)	6	2
Flight Units (Protoflight Acceptance Test)	3	2

Figure 3-6. Random Vibration Environment, Axes Normal To Mounting Plane



Flight Level Environment

Frequency (Hz)	G^2/Hz
20	0.01
80	0.08
200	0.08
2000	0.01

7.4 Grms

Test Levels

	Margin Above Flight Level (dB)	Duration (Minutes)
Non-Flight Prototypes (Design & Qualification Level)	6	2
Flight Units (Protoflight Acceptance Test)	3	2

Figure 3-7. Random Vibration Environment, Axes Lateral To Mounting Plane

3.2.6.2.2 Orbital Operations

The orbital operations phase covers those environments that occur when the observatory reaches geosynchronous altitudes. The IMU shall meet the requirements of this document without refurbishment or adjustment during exposure to any combination of the following environments:

3.2.6.2.2.1 Temperature

The IMU baseplate temperature will be maintained to -20˚C to +55˚C.

3.2.6.2.2.2 Pressure

The IMU shall meet the requirements of this document while operating in a hard vacuum of less than 1 x 10^{-5} torr.

3.2.6.2.2.3 Particle Radiation

The FAME observatory will be subjected to galactic cosmic radiation, geomagnetically trapped particle radiation, and solar particle event (SPE) radiation (Table 3-3). It is imperative that mission critical electronics continue to operate within specifications until the end of the 5 year extended mission and during the worst case solar activity. Therefore, design requirements shall address Total Ionizing Dose (TID) and Single Event Effects (SEE) as required by paragraph 5.8 of GSFC-410-MIDEX-001. The anticipated 5 year observatory radiation environment is shown in Figure 3-8.

Table 3-3. FAME Radiation Dose Estimates and Requirements for 5-Year Mission Duration Beginning in November 2004

Hemisphere Aluminum Shielding Thickness	Total Dose +0% Margin for 5 Year Mission
mils(Al)	**rads(Si)**
0.5	4.68E+08
5.0	1.15E+08
10.0	5.25E+07
25.0	1.14E+07
50.0	2.47E+06
75.0	8.37E+05
100.0	3.36E+05
125.0	1.46E+05
150.0	6.66E+04
175.0	3.27E+04
200.0	1.82E+04
225.0	1.14E+04
250.0	7.79E+03
275.0	5.65E+03
300.0	4.35E+03
350.0	3.06E+03
400.0	2.56E+03
Note 1. The 2-π hemispherical shielding assumes that substantial satellite structures attenuate the radiation environment in the other hemisphere (e.g. boxes near a surface). 4-π geometry may be a more appropriate where structures are deep within the satellite. Note 2. Spherical shielding is usually a conservative assumption, and refined dose estimates based on ray tracing sector analyses will lead to lower doses for box geometries of equal thickness.	

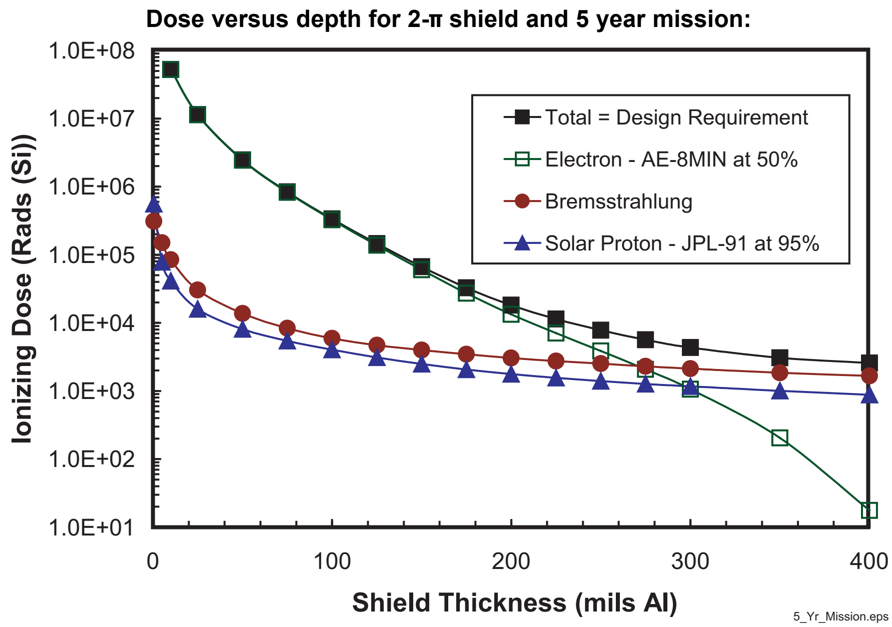


Figure 3-8. Observatory Radiation Environment

3.2.6.2.2.3.1 Total Ionizing Dose

a. Any part used in the observatory shall meet the requirements of this document at a minimum TID failure level of 18.2 krad(Si). This level is arrived at using the depth-dose relation of Figure 3-8 with an assumed hemispherical shield thickness of 200 mils Al. The minimum hardness level of 18.2 krad(Si) also includes a factor of 2 that is recommended for uncertainty in the environment.

b. Any part that does not meet this minimum requirement of 18.2 krad(Si) shall be identified in the Preliminary Design Review (PDR).

3.2.6.2.2.3.2 Single Event Effects

SEE shall be considered for the galactic cosmic ray environment and for the worst expected SPE.

a. The galactic cosmic ray design environment for the nominal case of 200 mils Al shielding during solar minimum conditions is a Linear Energy Transfer of 35 MeV cm^2/mg.

b. The observatory will be subjected to occasional SPE producing high fluxes (>10^5 p/cm^2/s) for short periods and with elevated levels for periods of up to several days. While the science mission may be interrupted during SPE, the events must not compromise the survival of the observatory or the completion of the science mission objectives.

3.2.6.2.2.3.2.1 Single Event Induced Destructive Failure

a. The IMU shall not be susceptible to single event induced failure (including latchup, burnout, gate rupture, and secondary breakdown) unless the Single Event Latchup (SEL) effects can be mitigated by design.

b. Where single event failure cannot be ruled out the part shall be identified at PDR and its use, along with mitigation approach, justified.

3.2.6.2.2.3.2.2 Single Event Induced Non-Destructive Failures

a. The use of parts with these non-destructive failure modes may be allowed if analyses can show that they do not cause uncorrectable errors or affect system performance. Such parts shall be identified at PDR, along with failure effect and mitigation strategy (e.g., watchdog timer with autonomous power cycle or reset command).

3.2.6.2.2.3.2.3 Single Event Induced Soft Errors

a. Nondestructive SEE (including Single Event Upsets [SEU] or transients in linear devices) shall not cause IMU failure, compromise IMU health, or affect IMU performance.

b. The use of parts with soft error modes may be allowed if analyses show that uncorrectable errors or effects to system performance do not occur. Such parts shall be identified at PDR/CDR, along with failure effect and mitigation strategy (e.g., Error Detection and Correction [EDAC] on memories or filters on linears).

3.2.6.2.2.4 Acceleration

The accelerations experienced by the IMU during orbital operations will not exceed launch loads in any direction.

3.2.6.2.2.5 Pyrotechnic Shock

The pyrotechnic shock environment experienced by the IMU during orbital operations will not exceed the launch and ascent environment.

3.2.6.2.2.6 Random Vibration

The random vibration environment experienced by the IMU during orbital operations will not exceed the launch and ascent environment.

3.2.7 Transportability

3.2.7.1 Packaging and Transporation

Packaging shall be sufficient to ensure that the IMU is received in working condition and is free of damage or defects caused by transportation. If required, a packaging and transportation plan or procedure shall be developed. The plan shall address special handling requirements as applicable to the unit being delivered. Transportation of any explosive devices (i.e., ordnance) shall be in accordance with the requirements of the applicable carrier.

3.2.7.2 Marking

Marking for shipment shall be appropriate for the mode of shipment.

3.3 Design and Construction

The following paragraphs describe the general requirements for design and construction that are applicable to the IMU.

3.3.1 Parts, Materials, and Processes

The Contractor shall implement a Parts, Materials, and Processes (PMP) in accordance with the guidelines contained in GSFC-410-MIDEX-001, paragraph 5.1, *Parts*, and paragraph 5.2, *Materials and Processes*.

a. The radiation hardness characteristics of all EEE parts shall be established, implemented, and maintained. Resultant data shall be presented for review at the PDR and the Final Design Review (FDR).

b. Interconnecting cables, harnesses, and wiring shall be selected in accordance with the guidelines of NASA-STD-8739.4.

c. Electronic parts and materials that have been permanently installed in an assembly and which are then removed from an assembly for any reason shall not be used in any item of spaceflight hardware.

3.3.1.1 Parts

3.3.1.1.1 EEE Standard Parts Selection Criteria

The goal of the EEE parts program is to provide the highest reliability level available within the program and schedule limitations.

a. The Contractor shall select standard EEE parts in accordance with GSFC 311-INST-001A with a quality level no lower than Level 2.

b. All other parts selection shall be considered nonstandard and shall be presented for review at the PDR and FDR.

3.3.1.1.2 EEE Parts Procurement, Processing, and Screening

The Contractor shall use the following guidelines for establishment of their parts program:

a. EEE parts shall be procured and screened as specified herein, except that rescreening of JANTXV devices is not required, and requirements for a coordinated parts procurement do not apply. A parts control board is optional.

b. Specific FAME program parts screening requirements are as follows:

   (1) The parts program shall provide for a review of Government-Industry Data Exchange Program (GIDEP) alerts, notices, and advisories and provide notification to NRL on affected parts and assemblies.

   (2) Microcircuits and semiconductors shall be subjected to radiographic (X-ray) inspection and Particle Impact Noise Detection (PIND) as appropriate to their construction.

   (3) Parts screening guidelines shall be required for all nonstandard parts.

   (4) Microcircuits per MIL-PRF-38534 or MIL-PRF-38535 are preferred. However, microcircuits that are fully compliant with paragraph 1.2.1 of MIL-STD-883 may be used with approval from the FAME Project Management Office (PMO). If a microcircuit is not a Qualified Parts List (QPL) class B part or purchased from a Qualified Manufacturer List (QML) vendor, then it shall be considered as nonstandard and subject to review at the PDR and FDR.

   (5) The decision criteria to perform Destructive Physical Analysis (DPA) will be in accordance with the guidelines provided in GSFC 311-INST-001A for a quality level no lower than Level 2. Except as otherwise specified in paragraph 5.2 of GSFC-410-MIDEX-001, a DPA should not be required unless it is deemed necessary as indicated by failure history, GIDEP alert, or a parts control board.

   (6) The parts program shall ensure that the results of receiving inspection, parts tests, material review boards, and parts problems reported from system testing are documented and periodically reviewed.

3.3.1.1.3 EEE Parts Stress Derating

As part of the design process, the Contractor shall derate all EEE parts such that the applied stresses do not exceed the derating criteria guidelines of SSD-D-IM007 (as tailored for the FAME program) and MIL-HDBK-1547.

3.3.1.1.4 Electrostatic Discharge Sensitive EEE Parts

a. All electrical components using ESD parts shall provide adequate protection to preclude part failure resulting from handling, shipment, or storage situation.

b. ESD protection shall be in accordance with approved processes and procedures that implement NASA-STD-8739.7, MIL-STD-1686, or EIA-625 guidelines.

3.3.1.2 Materials

3.3.1.2.1 Outgassing

a. Materials exhibiting total mass loss (TML) of 1.0% or less and collected volatile condensable material (CVCM) values of 0.1% or less shall be used in accordance with SP-R-0022.

b. Any materials that fail to meet these criteria shall be identified to the FAME PMO.

3.3.1.2.2 Structural and Metallic Materials

MSFC-SPEC-522 Table I materials are strongly preferred. MSFC-SPEC-522 Table II and Table III materials should receive careful consideration and shall be identified at the PDR and FDR.

a. Metallic materials shall be corrosion resistant by nature or shall be corrosion inhibited by means of protective coatings.

b. Base metals intended for intermetallic contact that form galvanic couples shall be plated with those metals that reduce the potential difference or shall be suitably insulated by a nonconducting finish.

c. Electrical bonding methods shall include provisions for corrosion protection of mating surfaces. Use of dissimilar metals shall be avoided.

d. Pressurized systems shall meet the requirements of MIL-STD-1522 and EWRR 127-1.

3.3.1.2.3 Magnetic Materials

The residual dipole of the FAME space segment must be minimized and the use of magnetic materials should be avoided whenever possible. When magnetic materials must be used they shall be identified, along with the field intensity caused by the material, at the PDR and FDR.

3.3.1.2.4 Finishes

a. Cadmium and zinc coatings shall not be used.

b. Pure tin coated components shall not be used within electronic boxes.

3.3.1.2.5 Toxic Products and Formulations

Toxic products and formulations shall meet the applicable OSHA and launch site safety requirements.

3.3.1.2.6 Stress Corrosion

Materials shall be selected to control stress corrosion cracking in accordance with MSFC-SPEC-522.

3.3.1.2.7 Polymer Materials

Uralane 5750 (B/A) shall be used for conformal coating applications.

3.3.1.3 Processes

3.3.1.3.1 Soldering and Other Processes

Soldering and other processes shall be specified in NRL-approved process specifications. NRL reserves the right to inspect and approve all process specifications.

a. Special processes (e.g., adhesive bonding, plating, etc.) shall be in accordance with NRL-approved process specifications.

b. Soldering of electrical connections shall be in accordance with ANSI/J-STD-001 (High Reliability Class) and the applicable associated standards ANSI/J-STD-002 through -006 or to process specifications that implement NASA-STD-8739.3 and NASA-STD-8739.4 guidelines.

c. Crimping of electrical connections shall be in accordance with process specifications that implement NASA-STD-8739.4 guidelines.

d. Conformal coating and staking of printed wiring boards and electronic assemblies shall be in accordance with process specifications that implement NASA-STD-8739.1 guidelines.

e. Printed Circuit Boards (PCBs) used in the fabrication of the equipment shall conform to the requirements of IPC-D-275, IPC-FC-250, IPC-FC-250A-86, and IPC-A-600D (or their NRL-approved equivalents) or NASA-STD-8739.2.

3.3.1.3.2 Traceability Process

The Contractor shall maintain a system for categorizing PMP and EEE parts into sets of homogeneous groups and tracing those parts through the fabrication, assembly, test, and delivery cycles.

a. The IMU PMP shall be traceable from the initial vendor of part, material, or component through the completed hardware item.

b. EEE parts shall be traced by part number, serial number (when available), and lot number.

(1) The Contractor shall maintain fabrication records (i.e., travelers) that provide two-way traceability from the first stages of assembly through final acceptance testing.

(2) Specific entries shall be made on the fabrication record as parts are installed.

(3) Traceability records shall be as shown in Table 3-4.

Table 3-4. Traceability and Lot Control

Part	Relevant Information
Electronic Piece Parts	Mfg/Date/Lot Code
Printed Circuit Boards	Serial Number
Potting/Adhesives/Coatings	Batch Number
Plating of Electronic Housings	Production/Manufacturer Lot Number
Modules and Assemblies	Serial Number
Connectors	Manufacturer Lot Number and Date Code
Chassis Case and Structures	Lot or Heat Treat Number

c. All electronics piece parts installed shall be identified and documented in order to be traceable to a specific manufacturer, lot number, or date/lot code.

d. The Contractor shall maintain coupons for all Printed Wiring Boards (PWBs) used in each final assembly. The coupons shall have traceability as defined in paragraph 3.3.1.3.2.c.

3.3.1.3.3 Failure Reporting and Corrective Action System

a. The Contractor shall establish and maintain a closed loop failure reporting and corrective action system (FRACAS) for reporting, analysis, and corrective action of failures occurring during the acceptance testing phases and continuing until integration with the ELV.

b. The FRACAS shall determine whether failures are caused by design deficiencies, human error, defective parts, infant mortality, test equipment, environmental exposure, or software.

3.3.2 Electromagnetic Environment

The IMU shall be designed and constructed such that each item is compatible with itself and with its known environments.

3.3.2.1 Conducted Emission

The IMU shall meet the conducted emissions levels defined in Figure 3-9 and Figure 3-10 for FAME. The requirements are modifications of the MIL-STD-461C limits. MIL-STD-462 test methods shall be used.

3.3.2.2 Conducted Susceptibility

The IMU shall not exhibit malfunctions, degradation of performance, or deviation from specification when subjected to the levels defined in Figure 3-11 for CS01 or 0.18 Vrms (0.5 Vp-p) from a 50 Ohm source for CS02 frequency range of 50 kHz to 400 MHz. The requirements are modifications of the MIL-STD-461C limits. MIL-STD-462 test methods shall be used.

3.3.2.3 Radiated Emissions.

The subsystem shall be designed to limit radiated emissions to the levels specified herein.

3.3.2.3.1 Narrowband Emissions

The apparent field strength of narrowband emissions at one meter from the IMU shall be limited to the values shown in Figure 3-12. The requirement is a modification of MIL-STD-461C Part 3, Curve #1. A notch was included for the frequency range of 2015 - 2130 MHz. MIL-STD-462 test methods shall be used.

3.3.2.3.2 Broadband Emissions

Not applicable.

3.3.2.4 Radiated Susceptibility

The IMU shall be designed to operate without malfunction, undesirable response, or deviation from specified performance tolerances when subjected to the radiated emissions specified herein.

3.3.2.4.1 Narrowband Susceptibility

The IMU shall withstand a modified MIL-STD-461D RS103 level of 20 V/m, 1 kHz pulse modulation for frequencies from 10 kHz to 18 GHz, with a 40 V/m notch at 2200 to 2300 MHz. MIL-STD-462 test methods shall be used.

3.3.2.4.2 Broadband Susceptibility

Not applicable.

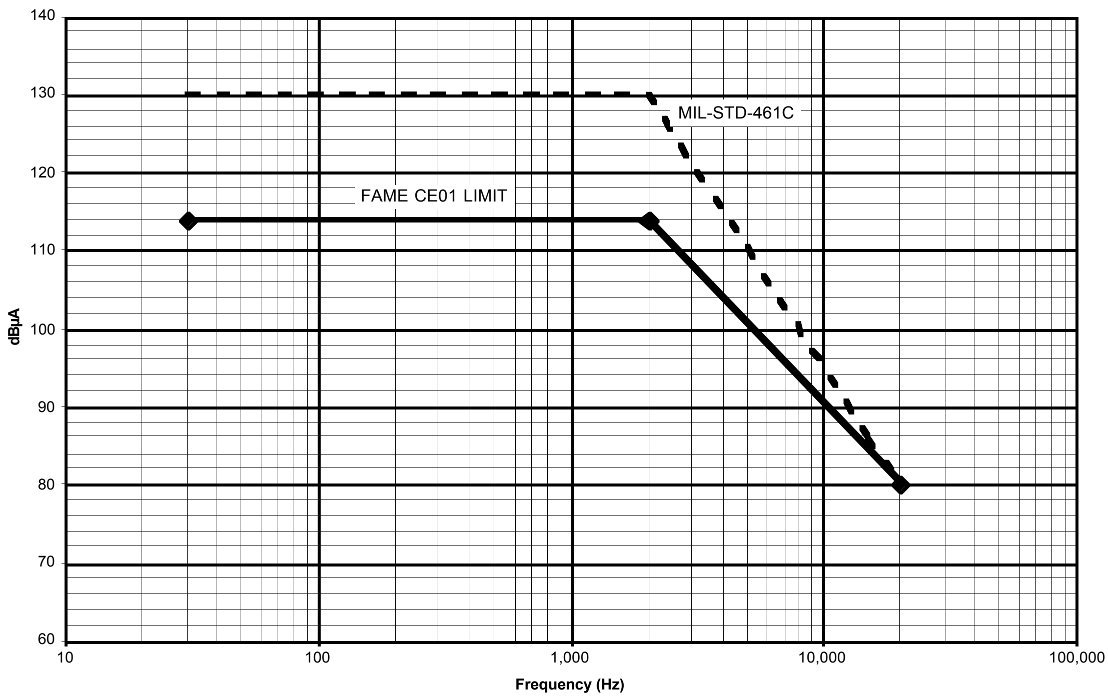


Figure 3-9. Limit for CE01 Narrowband Emissions

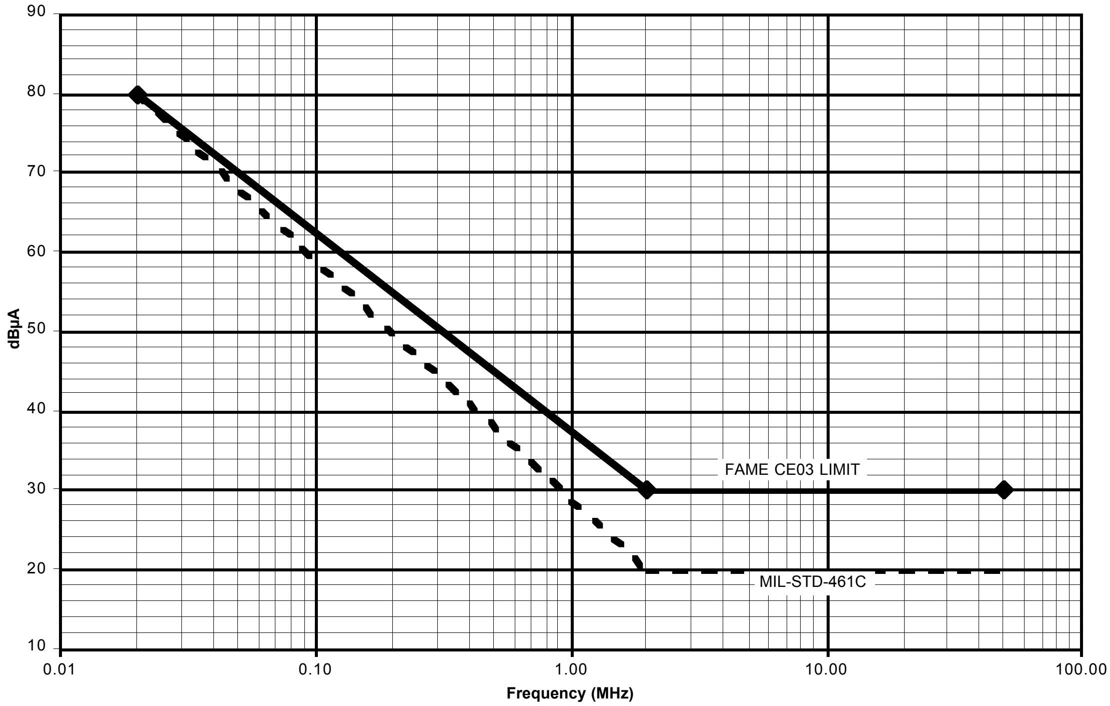


Figure 3-10. Limit for CE03 Narrowband Emissions

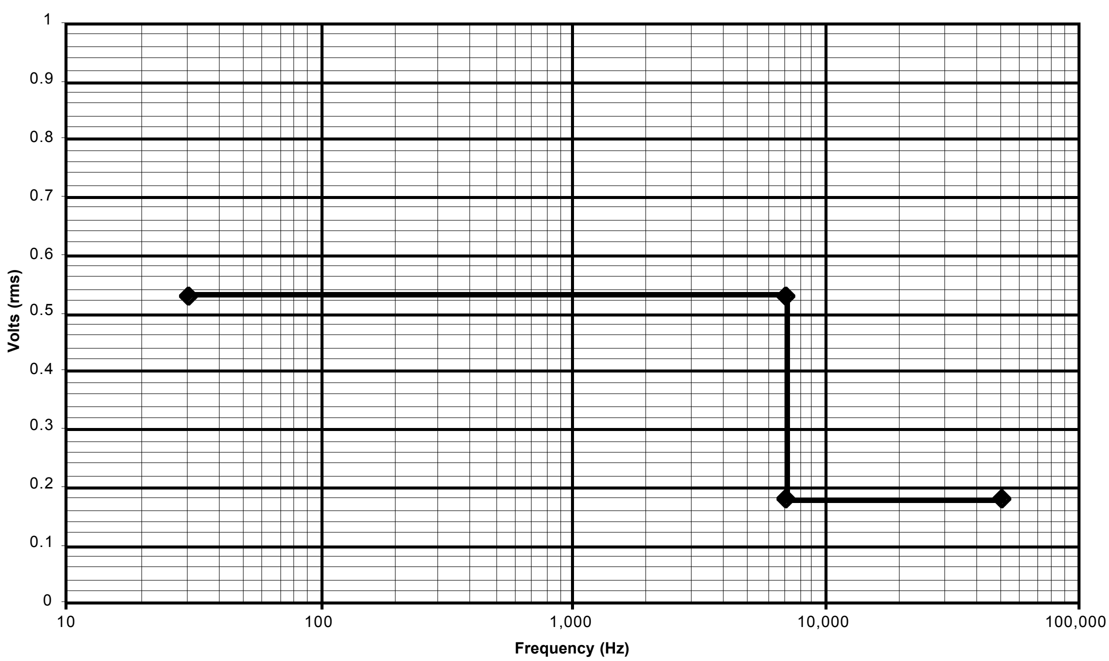


Figure 3-11. CS01 Voltage Injection Levels (30 Hz to 50 kHz)

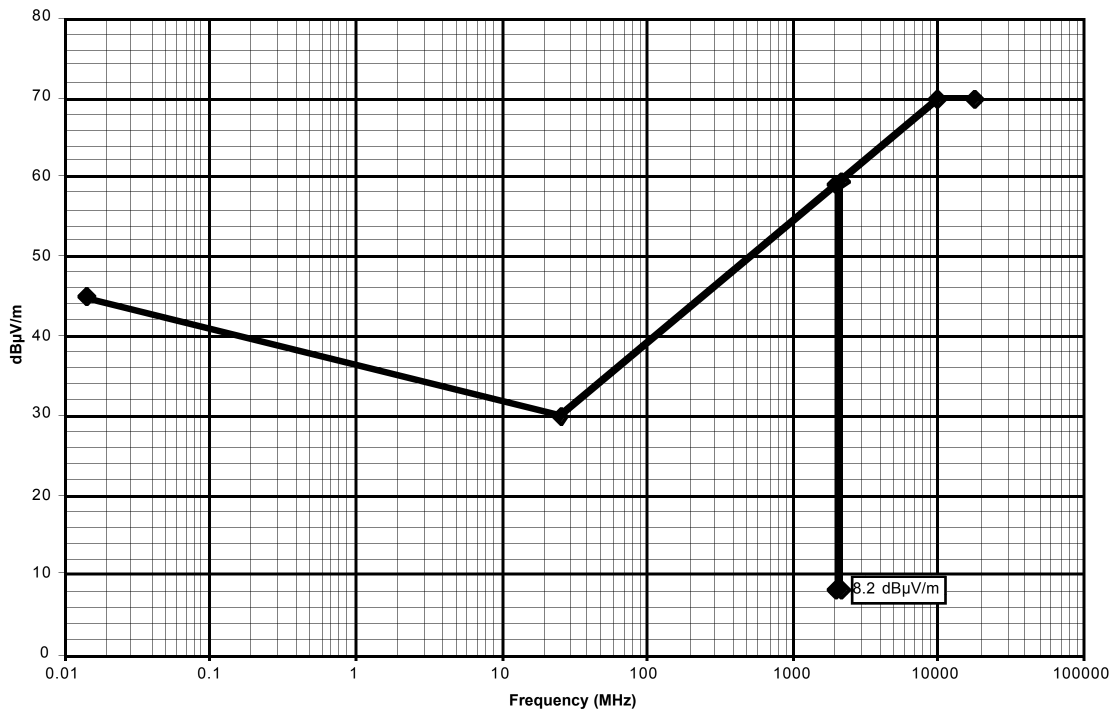


Figure 3-12. Limit for RE02 Narrowband Emissions (14 kHz to 18 GHz)

3.3.3 Corona Suppression

The IMU shall be designed to minimize the occurrence of corona discharge in all normal operating environments.

3.3.4 Nameplate and Product Marking

IMU components that are interchangeable shall be identified by part number and serial number or lot number.

3.3.5 Workmanship

a. All parts and assemblies shall be designed and manufactured in accordance with NRL-approved process specifications or drawings.

b. All parts and assemblies shall be free of defects that would interfere with operational use, such as excessive scratches, nicks, burrs, loose material, contamination, and corrosion.

c. Equipment shall be manufactured, processed, tested, and handled such that finished items are of sufficient quality to ensure reliable operation, safety, and service life in the operational environments.

3.3.6 Interchangeability

Assemblies, components, and parts having identical part numbers shall, where practicable, meet the requirements for an interchangeable item as defined in paragraph 6.1.3.

3.3.7 Safety

The IMU shall not present non-controllable health hazards associated with electrical discharge, ionizing or non-ionizing radiation, noise, or other emissions. The IMU shall be designed such that no single failure or single operator error can result in a critical hazard. The Contractor shall document any hazards to provide a basis for reducing risk to an acceptable level, along with any necessary personnel protection procedures. No health hazards shall exist when the IMU is removed, maintained, installed, or in storage. The IMU and its associated ground support equipment (GSE) shall be capable of being safely stored, handled, transported, installed, and checked out at all times prior to launch, in accordance with procedures agreed to between NRL and the Contractor.

3.4 Documentation

Documentation shall be prepared according to the Contractor's established practices for spaceflight equipment. The documents shall meet the intent of NRL's internal methods and practices for control of spaceflight hardware. The results of trades studies, analyses, and development efforts shall be documented to support critical design decisions and milestone technical reviews during the course of the system development.

3.4.1 Specifications

a. Specifications shall be prepared in accordance with MIL-STD-961 and the appropriate Data Item Descriptions (DIDs) or their NRL-approved equivalents.

b. Software specifications shall be prepared in accordance with NASA-STD-2100-91, IEEE/EIA 12207.0, IEEE/EIA 12207.1, IEEE/EIA 12207.2, or their NRL-approved equivalents.

c. These documents shall be subject to change control procedures and every proposed engineering change shall consider the effect of that change on these documents so that compatibility is maintained.

3.4.2 Drawings

a. Specifications and hardware shall be supported by drawings in accordance with MIL-DTL-31000 or NRL-approved equivalent.

b. The final system documentation shall be such that subsequent production items can be produced or procured that are essentially equivalent in all respects to those initially tested or delivered.

c. This final documentation shall also be adequate to allow the rapid incorporation of changes and modifications that have been approved by the procuring activity.

d. Documentation describing space segment operational procedures shall include contingency procedures to minimize the effect of possible on-orbit anomalies.

3.4.3 Test Plans and Procedures

a. All test plans and procedures shall be documented so that testing can be accomplished on site by skilled engineering personnel.

b. Software test plans, descriptions, and procedures shall be prepared in accordance with NASA-STD-2100-91, IEEE/EIA 12207.0, IEEE/EIA 12207.1, and IEEE/EIA 12207.2.

3.4.4 Precedence

The order of precedence of the requirements specified herein is:

a. Safety;

b. Mission;

c. Design to cost;

d. Performance;

e. Quality factors; and

f. All other requirements are considered equal in order of precedence.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General

This section describes the analyses, tests, and inspections required for the IMU verification process. Verification of IMU design, construction, and performance will assure that the hardware and software conform to the requirements stated herein. The preferred method is test, where practical, to obtain empirical data to support verification. However, to meet program technical, schedule, and cost objectives, reuse of previously qualified flight equipment may dictate use of other verification methods (e.g., inspection, analysis, and review of design documentation). The analyses, tests, and inspections specified in Table 4-1 (included at the end of this section) will be conducted to verify that all requirements specified in Section 3.0 have been achieved.

4.1.1 Responsibility for Tests

The Contractor will perform all or any of the verification requirements of this specification. Except as otherwise specified, the Contractor may use its own or any other facilities suitable for performance of the inspection and test requirements specified herein, unless disapproved by the government. The FAME PMO reserves the right to perform any tests or inspections set forth herein when deemed necessary to ensure that supplies and services conform to prescribed requirements. Ultimate responsibility for proper operation of each component or subsystem remains with the NRL subsystem manager.

4.2 Quality Assurance Program Requirements

The Contractor's quality assurance program shall provide control of the following areas:

a. Reliability (paragraph 3.2.2.1);

b. Parts, materials, and processes (paragraph 3.3.1);

c. Workmanship (paragraph 3.3.5);

d. Nonconforming material (paragraph 4.2.1); and

e. Verification of design requirements (paragraph 4.3).

4.2.1 Control and Use of Nonconforming Material

Non-conforming material shall not be used without NRL approval. All nonconforming material used in the final product shall be adequately documented. Nonconforming material shall be stored in a controlled area until disposition can be made.

4.3 Verification and Verification Documentation

The requirements of Section 3.0 shall be verified by one or more of the methods detailed in the Verification Requirements Checklist (Table 4-1).

a. Similarity;

b. Analysis;

c. Inspection;

d. Validation of Records;

e. Demonstration and Measurement;

f. Simulation;

g. Review of Design Documentation; and

h. Test.

Verification will be documented using the Verification Matrix. The matrix will include a separate record for each paragraph. Each record will include the requirement, verification description, compliance data, and approval block. All verification documentation will be made available to inspection, test, and assessment personnel. Applicable verification drawings, specifications, and procedures will be physically located at the verification site at the time of the verification event.

4.3.1 Verification by Similarity

Verification by similarity is a method of verification that verifies a requirement based on existing results from components and assemblies of like kind and includes a review of prior relevant hardware configurations and applications. Hardware of similar design and manufacturing process that have been qualified to equivalent or more stringent specifications may be verified by similarity.

4.3.2 Verification by Analysis

A method of verification, taking the form of the processing and accumulated results and conclusions, intended to provide proof that verification of a requirement(s) has been accomplished. The analytical results may be based on engineering study, compilation or interpretation of existing information, similarity to previously verified requirements, or derived from lower level examinations, tests, demonstrations, or analyses. Analyses will be performed as specified in Table 4-1 to verify applicable requirements of Section 3.0. The analytical methods that may be used include engineering analyses in the specified technical discipline, similarity to a previously verified requirement, review of drawings and data, use of experience, or prior testing. When an analysis is specified in Table 4-1, a detailed engineering study to verify compliance with Section 3.0 of this document will be performed and documented.

4.3.3 Verification by Inspection

An element of verification consisting of investigation, without the use of special laboratory appliances or procedures, to determine compliance with requirements. Examination is nondestructive and includes (but is not limited to) visual inspection, simple physical manipulation, gauging and measurement. Inspections will be performed as specified in Table 4-1 to verify applicable requirements of Section 3.0. These inspections are to be performed before unit qualification or acceptance testing as part of the normal quality control inspection process.

4.3.4 Validation of Records

Validation of records is a method of verification that consists of a systematic review of all relevant records to demonstrate compliance with a requirement. This method occurs as part of the hardware and software buy-off process. For requirements verified by this method, the approved buy-off package will serve to certify verification.

4.3.5 Demonstration or Measurement

A method of verification that is limited to readily observable functional operation to determine compliance with requirements. This method will not require the use of special equipment or sophisticated instrumentation.

4.3.6 Simulation

Verification by simulation is a process of verifying a requirement through the use of a representative device or system that emulates the behavior of a device or system to be verified. This method is often used when direct measurements is not possible.

4.3.7 Review of Design Documentation

Verification by the review of design documentation is a method of verification that consists of a systematic review of design documentation to determine compliance with a requirement.

4.3.8 Verification by Test

A method of verification that employs technical means, including (but not limited to) the evaluation of functional operation by use of special equipment or instrumentation, simulation techniques and the application of established principles and procedures, to determine compliance with requirements. The analysis of data derived from test is an integral part of this verification method.

Verification performed by test will be conducted in accordance with NRL-approved test procedures. Criteria and procedures for critical parameters monitoring during test will be developed and include, as appropriate, test chamber temperature, test article temperature, pressure, test voltages and currents, test acoustic spectrum and level, test vibration spectrum and level, illumination, particle or radiation flux, instrument response and telemetry, and contamination. The FAME program will use the four types of tests specified below:

a. Functional tests to verify in an abbreviated fashion that the unit or system is functioning;

b. Performance tests to demonstrate and quantify the specified optical, electrical and/or mechanical performance parameters of the unit or system;

c. Qualification tests to verify inherent functional performance capabilities in excess of the design requirements over the specified environment, including special interface qualification tests performed at Kennedy Space Center (KSC) or NRL using flight equivalent units; and

d. Acceptance tests to gain confidence that each unit has achieved the inherent design capability verified on a sample basis.

4.3.8.1 Functional/Performance Tests

Functional or performance tests will be performed before, during, and after environmental exposures as part of the acceptance and qualification test sequences. This performance check will be made in accordance with approved test procedures. A record will be made of all data necessary to determine complete operational and performance characteristics.

4.3.8.2 Environmental Tests

4.3.8.2.1 Acceptance Tests

Acceptance tests will be conducted to demonstrate acceptability of an item for movement to the next stage of testing or buy-off. Acceptance tests are intended to act as a quality screening and process control tool to detect deficiencies of workmanship, material, and quality. The following acceptance tests shall be performed as detailed in Table 4-1.

4.3.8.2.1.1 Physical Test

The values and parameters specified in this specification for weight, center of gravity, moment of inertia, and envelope shall be verified.

4.3.8.2.1.2 Random Vibration

Random vibration levels shall be at flight levels plus 3 dB, 1 minute duration in each of three axes. Testing shall be accomplished in each of three mutually perpendicular axes. Verification shall be conducted to assure compliance with paragraph 3.2.6.2.1.

4.3.8.2.1.3 Thermal Cycling

The thermal cycling test demonstrates the ability of IMU components to operate under the anticipated temperature extremes plus a 5^{o}C design margin and may reveal latent workmanship defects or marginal EEE parts. Components shall exhibit normal turn-on characteristics at the specified high and low temperatures. This shall be demonstrated during the last high and low temperature dwell after the IMU has been in an unpowered state for at least 0.5 hour. Additionally, functional tests shall be performed at the hot and cold dwells during the first and last cycle and after return of the IMU to ambient temperature. Thermal cycling requirements are shown in Figure 4-1.

Procedure	No. of Cycles	T_{High}	T_{Low}
Qualification	13	65°C	-30°C
Acceptance	7	60°C	-25°C

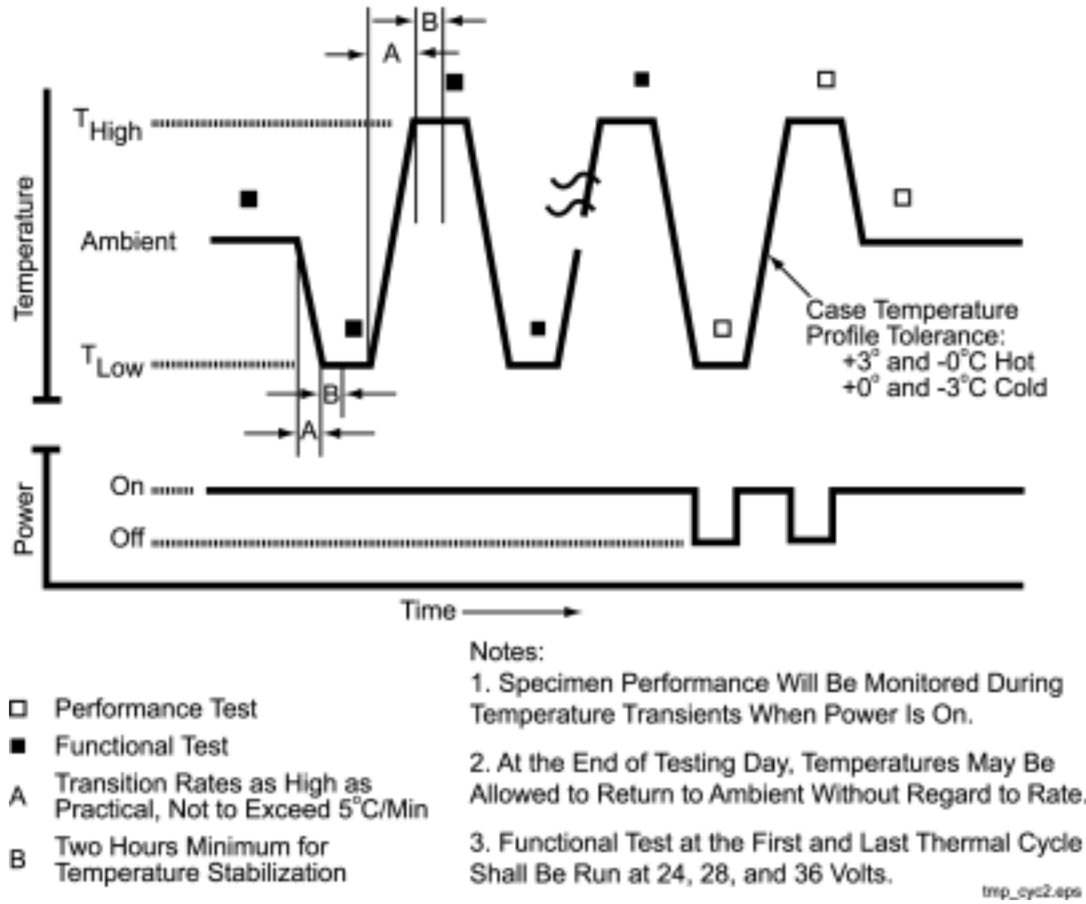


Figure 4-1. Thermal Cycling Profile

4.3.8.2.1.4 Thermal Vacuum

Tests shall be conducted to verify compliance with this specification. Baseplate temperature limits shall be 5°C above and 5°C below flight temperature extremes. The pressure shall be 1 x 10^{-5} torr or less. The number of cycles shall be at least one and the dwell time at high and low temperature extremes shall not be less than 6 hours or the time required to verify subsystem performance. Critical parameter monitoring shall be accomplished during temperature transients. Thermal vacuum requirements are shown in Figure 4-2.

Procedure	No. of Cycles	T_{High}	T_{Low}
Qualification	3	+65°C	-30°C
Acceptance	1	+60°C	-25°C

☐ Performance Test (Acceptance)

A Maintain System Temperature Until Interior Temperature Stabilizes

B Operate Over Flight Period

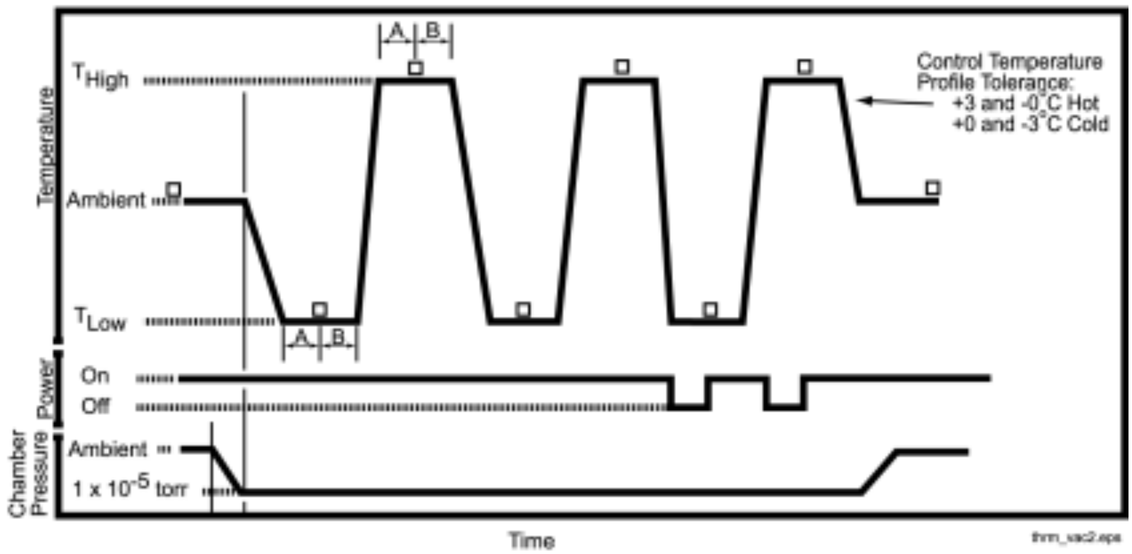


Figure 4-2. Thermal Vacuum Profile

4.3.8.2.1.5 Burn-In Tests

The burn-in test shall be performed to reveal material or workmanship defects that may occur early in the life of the component. Burn-in testing shall only be required on EEE components containing active parts. The total operating time for component burn-in shall be 200 hours including the operating time during thermal and thermal-vacuum cycling. Additional test time beyond that required for thermal cycling shall be conducted at ambient temperatures. The final 50 hours of the component burn-in test shall be failure-free.

4.3.8.2.2 Qualification Tests

Qualification tests will be conducted to demonstrate that the design and manufacturing methods used in the construction of the IMU have resulted in an item that meets the specified requirements and has suitable margins when exposed to the expected operating environments. The following qualification tests shall be performed as detailed in the Verification Requirements Checklist (Table 4-1).

4.3.8.2.2.1 Random Vibration

Random vibration levels shall be at flight levels plus 6dB, 2 minute duration in each of three axes. Testing shall be accomplished in each of three mutually perpendicular axes. Verification shall be conducted to assure compliance with paragraph 3.2.6.2.1.

4.3.8.2.2.2 Pyrotechnic Shock

The pyroshock test shall demonstrate the capability of the component to withstand the expected pyrotechnic shock environment. The test may be conducted at the IMU or after integration at the spacecraft (system) level by actuating devices that produce shock external to the IMU. Verification shall be conducted to assure compliance with paragraph 3.2.6.2.1.

4.3.8.2.2.3 Thermal Stability

Tests shall be conducted to verify that the IMU alignments remain within the stated requirement during expected thermal states.

4.3.8.2.2.4 Thermal Cycling

The thermal cycling test demonstrates the ability of IMU components to operate under the anticipated temperature extremes plus an 10^{o}C design margin and may reveal latent workmanship defects or marginal EEE parts. Components shall exhibit normal turn-on characteristics at the specified high and low temperatures. This shall be demonstrated during the last high and low temperature dwell after the IMU has been in an unpowered state for at least 0.5 hour. Additionally, functional tests shall be performed at the hot and cold dwells during the first and last cycle and after return of the IMU to ambient temperature. Thermal cycling requirements are shown in Figure 4-1.

4.3.8.2.2.5 Thermal Vacuum

The thermal vacuum test demonstrates the capability of the IMU to perform in a thermal vacuum environment that simulates the design environment extremes plus a 10^{o}C design margin. Tests shall be conducted to verify compliance with paragraph 3.2.6.2.2.1. Critical parameter monitoring shall be accomplished during temperature transients. Thermal vacuum requirements are shown in Figure 4-2.

4.3.8.2.2.6 Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC)

The EMI/EMC test demonstrates that the electromagnetic interference characteristics (emission and susceptibility) of the component under normal operating conditions does not result in malfunction or the IMU, and that the component does not emit, radiate, or conduct interference that results in malfunction of other system components. Tests shall be conducted to verify compliance with paragraph 3.3.2.

4.3.9 Verification of Safety Requirements

Safety related requirements will be verified as part of the range safety process.

Table 4-1. Verification Requirements Checklist

Requirement		Verification Method									
Paragraph No.	**Title**	**Not Applicable**	**Similarity**	**Analysis**	**Inspection**	**Validation of Records**	**Demonstration or Measurement**	**Simulation**	**Review of Design Documentation**	**Acceptance Test**	**Qualification Test**
3.0	REQUIREMENTS	X									
3.1	Item Definition	X									
3.1.1	Interface Definition								X		
3.2	Characteristics	X									
3.2.1	Performance Requirements	X									
3.2.1.1	Gyroscope Performance	X									
3.2.1.1.1	General								X		
3.2.1.1.2	Maximum Continuous Input Rates									X	
3.2.1.1.3	Output Scale Factors									X	
3.2.1.1.3.1	Scale Factor Linearity									X	
3.2.1.1.3.2	Scale Factor Stability									X	
3.2.1.1.4	Bias Repeatability									X	
3.2.1.1.5	Angular Random Walk									X	
3.2.1.1.6	Bandwidth									X	
3.2.1.1.7	Axis Alignment									X	
3.2.1.1.8	Sensitivity									X	
3.2.1.1.9	Warm-up Time									X	
3.2.1.2	Accelerometer Performance	X									
3.2.1.2.1	General	X									
3.2.1.2.2	Maximum Continuous Acceleration									X	
3.2.1.2.3	Scale Factor Accuracy									X	
3.2.1.2.4	Bias Accuracy									X	
3.2.1.2.5	Bandwidth									X	
3.2.1.2.6	Axis Alignment									X	
3.2.1.2.7	Least Significant Bit (LSB)									X	
3.2.1.2.8	Warm-up Time									X	
3.2.1.3	Output Data Interfaces								X		
3.2.1.3.1	Output Data								X		
3.2.1.3.2	IMU Output Sampling Period								X		
3.2.1.4	Primary Power	X									
3.2.1.4.1	Conditioned Power (Alternate #1)									X	
3.2.1.4.2	Primary Power (Alternate #2)									X	
3.2.1.4.2.1	Input Voltage									X	
3.2.1.4.2.2	Source Impedance									X	
3.2.1.4.2.3	Isolation									X	
3.2.1.4.2.4	Power Consumption									X	

Requirement		Verification Method									
Paragraph No.	**Title**	**Not Applicable**	**Similarity**	**Analysis**	**Inspection**	**Validation of Records**	**Demonstration or Measurement**	**Simulation**	**Review of Design Documentation**	**Acceptance Test**	**Qualification Test**
3.2.1.4.2.5	Inrush Current									X	
3.2.2	Physical Characteristics	X									
3.2.2.1	Mass Properties Control and Reporting					X					
3.2.2.1.1	Weight Limits				X						
3.2.2.2	Dimensions and Envelope				X						
3.2.2.3	Coordinate System			X							
3.2.2.4	Minimum Frequency			X							
3.2.2.5	Center of Gravity (CG) Limits			X							
3.2.3	System Quality Factors	X									
3.2.3.1	Reliability			X							
3.2.3.2	Failure Modes, Effects, and Criticality Analysis			X							
3.2.3.3	Electrical Stress Analysis			X							
3.2.3.4	Worst Case Analysis			X							
3.2.3.5	Radiation Analysis			X							
3.2.4	Maintainability	X									
3.2.5	Fault Detection Capability								X		
3.2.6	Environmental Conditions	X									
3.2.6.1	Non-Operating Environment	X									
3.2.6.1.1	Integration and Test Facility Environment			X							
3.2.6.1.2	Ground Handling and Transportation			X							
3.2.6.1.3	Prelaunch			X							
3.2.6.2	Operating Environment	X									
3.2.6.2.1	Launch and Ascent									X	X
3.2.6.2.2	Orbital Operations	X									
3.2.6.2.2.1	Temperature			X							
3.2.6.2.2.2	Pressure			X							
3.2.6.2.2.3	Particle Radiation			X							
3.2.6.2.2.3.1	Total Ionizing Dose			X							
3.2.6.2.2.3.2	Single Event Effects			X							
3.2.6.2.2.3.2.1	Single Event Induced Destructive Failure			X							
3.2.6.2.2.3.2.2	Single Event Induced Non-Destructive Failures			X							
3.2.6.2.2.3.2.3	Single Event Induced Soft Errors			X							
3.2.6.2.2.4	Acceleration	X									
3.2.6.2.2.5	Pyrotechnic Shock	X									
3.2.6.2.2.6	Random Vibration	X									
3.2.7	Transportability	X									

Requirement		Verification Method									
Paragraph No.	Title	Not Applicable	Similarity	Analysis	Inspection	Validation of Records	Demonstration or Measurement	Simulation	Review of Design Documentation	Acceptance Test	Qualification Test
3.2.7.1	Packaging and Transportation			X							
3.2.7.2	Marking	X									
3.3	Design and Construction	X									
3.3.1	Parts, Materials, and Processes			X					X		
3.3.1.1	Parts	X									
3.3.1.1.1	EEE Standard Parts Selection Criteria			X					X		
3.3.1.1.2	EEE Parts Procurement, Processing, and Screening			X					X		
3.3.1.1.3	EEE Parts Stress Derating			X					X		
3.3.1.1.4	Electrostatic Discharge Sensitive EEE Parts				X				X		
3.3.1.2	Materials	X									
3.3.1.2.1	Outgassing			X					X		
3.3.1.2.2	Structural and Metallic Materials				X				X		
3.3.1.2.3	Magnetic Materials			X					X		
3.3.1.2.4	Finishes				X				X		
3.3.1.2.5	Toxic Products and Formulations				X				X		
3.3.1.2.6	Stress Corrosion				X				X		
3.3.1.2.7	Polymer Materials				X				X		
3.3.1.3	Processes	X									
3.3.1.3.1	Soldering and Other Processes				X				X		
3.3.1.3.2	Traceability Process				X				X		
3.3.1.3.3	Failure Reporting and Corrective Action System			X	X						
3.3.2	Electromagnetic Environment	X									
3.3.2.1	Conducted Emission										X
3.3.2.2	Conducted Susceptibility										X
3.3.2.3	Radiated Emissions.	X									
3.3.2.3.1	Narrowband Emissions										X
3.3.2.3.2	Broadband Emissions	X									
3.3.2.4	Radiated Susceptibility	X									
3.3.2.4.1	Narrowband Susceptibility										X
3.3.2.4.2	Broadband Susceptibility	X									
3.3.3	Corona Suppression			X							
3.3.4	Nameplate and Product Marking				X						
3.3.5	Workmanship				X						
3.3.6	Interchangeability			X							
3.3.7	Safety			X							
3.4	Documentation	X									

Requirement		Verification Method									
Paragraph No.	Title	Not Applicable	Similarity	Analysis	Inspection	Validation of Records	Demonstration or Measurement	Simulation	Review of Design Documentation	Acceptance Test	Qualification Test
3.4.1	Specifications				X				X		
3.4.2	Drawings				X				X		
3.4.3	Test Plans and Procedures				X				X		
3.4.4	Precedence	X									

5.0 PREPARATION FOR DELIVERY

This section provides guidance for preparing the IMU for delivery.

5.1 Packaging and Transportation

Packaging and transportation of the IMU for delivery shall be in accordance with paragraph 3.2.7.

5.2 Containers

The Contractor shall use customer approved industry standard containers for aerospace electronics suitable for hand carrying the packaged item.

6.0 Deliverables and Tasks

6.1 Monthly Status Reports

The Contractor shall provide a monthly status report via DD Form 1423, Contract Data Requirements List (CDRL) A001, identifying progress to date, planned efforts for the next reporting period, and program issues and problems.

6.2 Program Support Documentation

The Contractor shall provide the necessary planning and schedule to meet the delivery requirements. The Contractor shall comment on any potential problems in the schedule and provide a detailed plan of attack for solving those problems. A detailed schedule must be prepared, maintained, and provided to the COR, with schedule changes and/or updates provided. The data shall be provided monthly starting 30 days after award of contract (DAC) via DD Form 1423, A001. The Contractor shall inform the COR within seven days of any and all events or delays at the Contractor's facility that may impact schedule, performance, quality, delivery, or cost. If any delays occur or are anticipated to occur, the Contractor shall notify the COR by phone, following up with a written notification to the Contract Negotiator (identified in Section G of the contract). The Contractor shall provide a copy of the written notification to the COR.

6.3 Interface Control Document

The IMU Interface Control Document (ICD), DD From 1423, A009, shall provide all of the electrical and mechanical interfaces for the IMU. This shall include schematics, timing diagrams, pinouts, and command and control requirements. The Contractor shall deliver a complete ICD 45 days after contract.

6.4 Design Packages

6.4.1 Preliminary Design Review Package

A Preliminary Design Review (PDR) package, DD Form 1423, A002, consisting of engineering drawings, schematics, analyses, and schedule in accordance with this specification, shall be furnished to the COR seven days prior to the scheduled PDR. A summary of actions and action items resulting from the PDR shall be furnished to the COR within two weeks after the PDR.

6.4.2 Final Design Review Package

A Final Design Review (FDR) package, DD Form 1423, A003, consisting of engineering drawings, schematics, analyses, and schedule in accordance with this specification, shall be furnished to the COR seven days prior to the FDR. A summary of actions and action items resulting from the FDR shall be furnished to the COR within two weeks after the FDR.

6.4.3 Drawings

6.4.3.1 Assembly

The Contractor shall deliver a complete set of all assembly drawings for the IMU, DD Form 1423, A004, at PDR. If changes to the drawings are required, revised drawings will be sent to the COR.

6.4.3.2 Schematics and Parts List

The Contractor shall deliver a complete parts list for the IMU, DD Form 1423, A005, along with annotated schematics at PDR. If any changes are required, a revised parts list and annotated schematics will be sent to the COR.

6.4.3.3 Engineering Changes

The IMU shall be fabricated and assembled in accordance with drawings, parts lists, processes, and other documents listed on Contractor drawings. These documents shall be submitted to and approved by the COR. Upon establishment of the baseline configuration between the Contractor and the COR, the Contractor shall make no changes to any of these without written approval from the COR via a Change Control Notice (CCN). When changes need to be made they will be provided according to DD Form 1423, A006.

6.5 Testing Packages

6.5.1 Test Procedures

Test procedures, DD Form 1423, A007, shall be prepared by the Contractor and submitted for COR approval 30 days prior to testing.

6.5.2 Test Reports

Test reports, DD Form 1423, A008, shall be generated by the Contractor and submitted upon final delivery of the unit tested. Test reports shall document all test failures and anomalies. Test reports shall include assembly and test log books. A Certificate of Compliance with the specification shall be provided with the test reports and unit tested.

6.6 System Effectiveness

6.6.1 Worst Case Analysis

The Contractor shall deliver a worst case analysis 180 days after contract award, per DD Form 1423, A010.

6.6.2 Electrical Stress Analysis

The Contractor shall deliver a stress analysis 180 days after contract award, per DD Form 1423, A011.

6.6.3 Worst Case Timing Analysis

The Contractor shall deliver a worst case timing analysis 180 days after contract award, per DD Form 1423, A012.

6.6.4 Reliability Analysis

The Contractor shall deliver a reliability analysis 180 days after contract award, per DD Form 1423, A013.

6.6.5 Failure Modes and Effects Criticality Analysis

The Contractor shall deliver a failure modes and effects criticality analysis 180 days after contract award, per DD Form 1423, A014.

6.6.6 Radiation Analysis

The Contractor shall deliver a radiation analysis 180 days after contract award, per DD Form 1423, A015.

6.7 Tasks

6.7.1 Kick-Off Meeting

The Kick-Off Meeting will be held at the Contractor's facility by 14 days after contract award.

6.7.2 Preliminary Design Meeting

The Preliminary Design Review will be held at the Contractor's facility 60 days after contract award.

6.7.3 Final Design Review

The Final Design Review will be held at the Contractor's facility 30 days prior to start of testing.

7.0 NOTES

This section provides additional information that is not contractually binding. Included are a glossary and list of acronyms.

7.1 Definitions

7.1.1 Contractor

A Contractor shall be an organization awarded a contract to supply a product or service.

7.1.2 Production Hardware

Hardware fabricated and inspected to production drawings, identical in performance, configuration, and fabrication to the article to be flown.

7.1.3 Interchangeable Items

When two or more items possess such functional and physical characteristics as to be equivalent in performance and durability and are capable of being exchanged one for the other without alteration of the items themselves or of adjoining items except for adjustment, and without selection for fit or performance, the items are interchangeable.

7.1.4 Replacement Item

An item that is functionally interchangeable with another item, but which differs physically from the original part in that the installation of the replacement part requires operations such as drilling, reaming, cutting, filing, shimming, etc. in addition to the normal applications and methods of attachment.

7.1.5 Part

One piece or two or more pieces joined together that are not normally subject to disassembly without destruction of designed use.

7.1.6 Device

Electromechanical or mechanical items that perform a specific function and are intermediate in complexity between piece parts and components. For example: valves, small motors, relays, gyros, connectors, vidicon tubes, batteries, etc.

7.1.7 Component

A combination of parts, devices, and structures, usually self-contained, that perform a distinctive function in the operation of the overall equipment; i.e., a "black box."

7.1.8 Operating Failure Rate

The operating failure rate represents a mathematical combination of failure rates associated with a part's failure modes that may occur in an operation sequence under laboratory conditions.

7.1.9 Cycle

A cycle (e.g., thermal vacuum testing) shall be defined as the transition from a nominal to a positive or negative extreme, and the transition to the opposite extreme and back to nominal.

7.2 Acronyms and Abbreviations

AKM	Apogee Kick Motor
CCN	Configuration Change Notice
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CG	Center of Gravity
COR	Contracting Officer's Representative

CT&DH	Command, Telemetry, and Data Handling
CVCM	Collected Volatile Condensable Material
DAC	Days After Contract
DID	Data Item Description
DPA	Destructive Physical Analysis
EDAC	Error Detection and Correction
EEE	Electrical, Electronic, and Electromechanical
ELV	Expendable Launch Vehicle
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPS	Electrical Power System
FAME	Full-sky Astrometric Mapping Explorer
FDR	Final Design Review
FMECA	Failure Modes, Effects, and Criticality Analysis
FOV	Field of View
FRACAS	Failure Reporting and Corrective Action System
GIDEP	Government-Industry Data Exchange Program
GSE	Ground Support Equipment
I&T	Integration and Test
ICD	Interface Control Document
IMU	Inertial Measurement Unit
KSC	Kennedy Space Center
LET	Linear Energy Transfer
LSB	Least Significant Bit
MIDEX	Medium Class Explorer
NRL	Naval Research Laboratory
PCB	Printed Circuit Board
PDR	Preliminary Design Review
PIND	Particle Impact Noise Detection
PMO	Project Management Office
PMP	Parts, Materials, and Processes
PWB	Printed Wiring Board
QML	Qualified Materials List
QPL	Qualified Parts List
SEE	Single Event Effects
SEFI	Single Event Functional Interrupt
SEL	Single Event Latchup
SEU	Single Event Upset
SPE	Solar Particle Event
T&C	Telemetry and Command
TID	Total Ionizing Dose
TML	Total Mass Loss