Notice
These requirements have been generated in partial fulfillment of Task 1.0 of Contract NAS-9-11842. They are being distributed for information purposes and to assist the several ISS vendors who are cooperating with the NASA Manned Spacecraft Center, and its contractor, Intermetrics, Inc., in the Off-the-Shelf Inertial Subsystem Study. These requirements do not reflect any NASA/MSC approval, explicit or implicit.
This document is submitted in partial fulfillment of Task 1.0 and DRL Line Item 002, SE-345T of Contract NAS 9-11842. The Program Manager of this contract at Intermetrics is James H. Flanders. Technical Monitor at MSC is Captain Albert Wetterstroem, EG5.

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LIST OF ACRONYMS -- DEFINITIONS

CDR Critical Design Review is held at the vendors plant and determines eligibility for production.

COFI Checkout and Fault Isolation is the autonomous procedure onboard the vehicle whereby LRU's are tested and, if faulty, isolated.

DRM Design Reference Mission is the standard mission for normal design requirements.

GNC Guidance, Navigation, and Control is the combination of hardware and software items which, in combination, determine the vehicle's state vector, calculate its desired path, and implement the necessary control actions.


HIO High Inclination Orbit is a reference mission launching 25,000 lbs. (11,350 Kg.) into a 270 n. mile (500 Km.)

IAS Integrated Avionics System includes the IMS, the GNC, Communications, Instrumentation, and all avionics gear.

IMU Inertial Measurement Unit is a single assembly of gyros to maintain a three-dimensional reference in space and accelerometers with which to measure specific forces in that frame of reference along with the associated support electronics.

IMS Information Management System. The data collecting and processing system which has no command and control functions.

ISS Inertial Subsystem is a triply redundant array of Inertial Measurement Units (IMU), each of which is an independently replaceable (LRU).

LRU Line Replaceable Unit is that module level of equipment whose failure as a black box can be completely identified and which is regularly replaceable without calibration or adjustment.
MMOS Multi-Mode Optical Sensor is an automatic instrument which mounts opposite each IMU on the navigation base and measures line of sight angles to the horizon, stars, landmarks, beacons, targets, etc.

NB Navigation Base is the rigid common structure connecting each IMU to a MMOS.

SPO South Polar Orbit is a reference mission in which the Orbiter is launched due south from Vandenberg Air Force Base in a polar orbit and lands again at the takeoff point after one revolution.

VAB Vertical Assembly Building is the structure within which the Pre-launch Shuttle sequences are carried out and where the booster and the orbiter are mated.
The objective of this document is to present requirements which must be met by an Inertial Subsystem (ISS) in order that it shall fully support all aspects of Orbiter mission operations. These requirements use the Phase B extension baseline system definition as set forth in late 1971. This means that a dedicated GNC computer is specified for all command control functions instead of a central computer communicating with the ISS through a databus. Forced air cooling is used instead of cold plate cooling. These requirements are expected to be a useful framework on which to build further steps in the process of securing the most cost-effective ISS for NASA's Orbiter vehicle.
1.0 PROGRAM REQUIREMENTS

The Inertial Subsystem (ISS) is the triply-redundant portion of the Guidance, Navigation, and Control (GNC), which acts as the prime navigation sensor and attitude reference for guidance implementation. It consists of three Inertial Measurement Units (IMU). This section addresses itself to broad program requirements which must be met in order that the ISS procurement matches the rest of the Shuttle Program in Reliability and Crew Safety (1.1), Economic Guidelines (1.2) and Schedule Baseline (1.3).

1.1 RELIABILITY AND CREW SAFETY

The ISS design will be derived from an existing design with sufficient operational history to substantiate a relevant performance and reliability history and to insure against residual generic failure modes. Data to substantiate an overall flight MTBF (see Section 4.9.2) of 1500 hours minimum for each IMU will be required. Data to substantiate compatibility with IMU performance requirements (see Sections 4.6 and 4.7) is required. The basic IMU design shall be in production (tail end, mid-point, or beginning) on 31 December of the calendar year 1973 and a substantial, continuing production and/or repair capability shall be indicated.

The ISS shall not contain single point failures which could result in the loss of the crew or of the vehicle. The IMU shall be so designed that no failure in an IMU will cause a failure or overstress any other equipment in the spacecraft.

For design purposes, reliability estimates must be based upon demonstrated component failure rates, "black box" failure rates, or other satisfactorily documented sources. Multiple single string reliability should be emphasized and cross tying of elements within the ISS should be minimized.

Nominal avionics subsystem lifetime shall be in excess of 100 missions. The ISS shall be developed to provide redundant full mission capability and shall avoid degraded performance backup systems concepts, except where redundant functional paths are available as opposed to redundant systems. Multiply-redundant system techniques that minimize or eliminate system transients caused by system component failures shall be used as a baseline.
1.2 ECONOMIC GUIDELINES

To the maximum extent, compatible with the other requirements of this document, the ISS will utilize concepts, configurations, techniques, devices, elements and components that are already proven and in use.

1.3 SCHEDULE BASELINE

The schedule baseline, as shown in Figure 1-1, for the orbiter, defines the avionics schedule. The inertial subsystem schedule requirements are tied directly to the subsystem development schedule which is shown in the bottom half of the figure.
Figure 1-1. OVERALL SPACE SHUTTLE SCHEDULE
2.0 MISSION REQUIREMENTS

2.1 GENERAL

(See Table 2-1 for Summary by Mission Phases.)

2.1.1 Mission Guidelines

The ISS must perform reliably under a variety of environmental conditions over the useful life of the system. A typical mission will last a maximum of seven days in orbit with a system-on time of 75 hours, not including additional standby hours.

Turn around time may be as short as ten days. The last opportunity for full-duration ISS calibration will end at T-96 hours. ISS calibration will end at T-96 hours. ISS operational checkout and platform erection and verification will conclude at T-8 hours. The ISS will support a launch-from-standby requirement of 2 hours. The ISS will support a launch readiness requirement to wait for next earth alignment with a desired orbital plane (approximately 12 hours). The ISS from a fully off and cold condition will support a launch requirement of six hours, complete retesting of GN&C avionics included.

2.1.2 Prime Mission and Design Reference Mission (DRM)

A 100 nautical mile (185 km.) circular orbit launched due east from the Kennedy Space Center, delivering a payload of 65,000 pounds (29,500 kg.) minimum into orbit with up to 7 days stay in orbit. Upon return, the orbiter vehicle shall possess a cross range maneuver capability, normal to either side of the orbital ground track, of up to 1100 nautical miles.

2.1.3 Alternate Mission(s)

2.1.3.1 High Inclination Orbit (HIO)

A 270 nautical mile (500 km.) circular orbit launched at 55 degrees inclination from the Kennedy Space Center, delivering a payload of 25,000 lbs. (11,350 kg.) minimum.
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2.1.3.2 South Polar Orbit (SPO)

A 100 nautical mile (185 km.) circular polar orbit launched due south from Vandenburg Air Force Base, delivering a payload of 40,000 lbs. (18,200 kg.) minimum.

2.1.4 Astronaut Interface

The astronaut interface shall consist of monitoring, commands, and responses through the following interface elements of the orbiter avionics:

- IMU control
- Computer keyboard
- Power/redundancy control panel
- Caution/warning panel

2.2 INTER-MISSION OPERATIONS

Note: The following description of Inter-Mission Operations is representative only. Actual test details will vary with IMU design.

2.2.1 Timeline

The cooldown facility and the refurbishment facility are located at the launch site and at specified alternate sites. The quick turnaround timeline shown in Figures 2-1, 2, 3, 4, and 5 represents the most stringent schedule to which the ISS will be subjected.

2.2.1.1 Post Landing Operations (Figure 2-2)

A defective IMU may be removed. All IMU's that remain onboard must be protected from heat damage during cooldown. The 300°F outside heat on the skin will move inward by conduction as well as outward by radiation. Continuous coolant flow and standby moding will be maintained if necessary.

2.2.1.2 Maintenance Operations (Figure 2-3)

Three different objectives are served by Maintenance Operations of the ISS onboard the orbiter. First, newly installed
Fig. 2-1 - End to End Ground Operations

Fig. 2-2 - Post Landing Operations

Fig. 2-3 - Maintenance Operations
Fig. 2-4 - Prelaunch Operations

Fig. 2-5 - Launch Operations
IMU's are qualified onboard by the Operational Test (see Section 2.2.4). Second, IMU's onboard are re-qualified to proceed into the Prelaunch Operations by the same Operational Test. Finally, the ISS may be called upon to support testing of the Integrated Avionics System (IAS) and the entire Space Shuttle Vehicle (SSV). An IMU is never removed from the SSV for scheduled maintenance.

2.2.1.3 Prelaunch Operations (Figure 2-4)

The ISS is given the Operational Test and the Performance Test (see Section 2.2.4). The balance of ISS ontime as indicated under Integrated Avionics Checkout is devoted to supporting IAS testing.

2.2.1.4 Launch Operations (Figure 2-5)

The ISS is turned on at T-9 1/2 hours and given the Operational Test. Following the successful completion of this test it is ready to support the countdown, launch, and entire mission.

2.2.2 Ground Onboard Checkout (Gimbal Systems)

There are only two main test sequences for ground checkout in the GNC computer memory. These are the Operational Test and the Performance Test. The Operational Test is frequently performed. The Performance Test is performed only in the Pre-launch Operations and in the test stand.

2.2.2.1 The Operational Test

This test is always performed for ground checkout in the following situations:

a) Maintenance Operations (in the vehicle and in the test stand)
b) Prelaunch Operations
c) Launch Operations

The test has three parts: functional checkout, short calibration, and alignment. The short calibration may be dispensed with at the option of the crew or test personnel.

The test is automatically commanded, monitored and documented by the GNC computer. Crew intervention is always available.
2.2.2.1.1 Functional Checkout. Note: Local latitude, longitude, gravity magnitude, desired azimuth, and vehicle pitch and heading angles are entered into the computer by the crew.

Mode "Off" to "Standby", safe for gyro wheel start. Heaters only. Response to thermal control stimuli, display results to crew. 10 minutes duration.

Mode "Standby" to "Operate". Wheels on. Check all D.C. voltages for level, ripple, and spikes. Check all A.C. voltages. Move platform to triad-up position and check three accelerometer loops for functional operation. Pulse torque each platform axis plus and minus five degrees for proper fine align capability. Display results to crew. 20 minutes duration, temperature stabilized.

2.2.2.1.2 Short Calibration. Place platform in the triad-up position (see end of functional checkout). Hold this configuration for 15 minutes. Computer will report average accelerometer combined scale factor and bias error and average gyro drift to the crew. 15 minutes duration.

2.2.2.1.3 Alignment. Rotate platform to desired gimbal angles based on commanded launch azimuth and known vehicle orientation. Initiate local vertical leveling and gyro-compassing. GNC computer reports on alignment progress to crew based on observed gimbal angles, level accelerometer pulses, and azimuth gyro torquing pulses. MMOS check of alignment may be performed at any time, but the ISS is not involved. Duration may be open ended, or it may terminate when the computer observes that a given criteria has been met. Time to meet alignment specifications of Paragraph 3.2.1: 30 minutes.

2.2.2.2 The Performance Test

The platform is commanded to six different orientations of the inertial sensor input axes (up and down). It is then placed in an inertially-stabilized fine align configuration at each orientation. The vertical accelerometer count gives scale factor and bias data which is separated out when the same axis is oriented down. The output of the horizontal accelerometers produces gyro drift data. Each orientation lasts approximately 20 minutes. 20 x 6 = 2 hours.
The performance test then checks the integrity of the gimbal angle transducers at all points by torquing each platform axis completely through 360° if allowable and monitoring the value and quality of the angle transducer signals. Each rotation takes the following time:

\[ t = \frac{3600 \text{ arc-secs/deg} \times 360 \text{ degrees}}{\text{arc-secs/pulse}} \times (\text{command bit rate})^{-1} \]

Upon conclusion of the test, the GNC computer calculates the accelerometer and gyro performance numbers and displays them to the crew.

2.2.3 Ground Replacement and Retesting Policy

Following determination that an IMU has failed it is removed and a spare IMU is mounted in its place. This spare will have been given its own Operational Test and Performance Test in the test stand coincidental with the beginning of the Prelaunch Test Operations. Consequently, it will not be necessary to re-run the Performance Test on the entire ISS if the replacement occurred after the Performance Test in Prelaunch Operations. See Paragraph 2.2.1.3 and Figure 2-4.

To requalify the ISS at any point during Prelaunch or Launch Operations it is necessary, and sufficient, to re-run the entire Operational Test successfully on the ISS with the new IMU.

2.3 LAUNCH, BOOST AND ORBITAL INSERTION

2.3.1 Update

The navigation data supplied by the ISS may be augmented by the use of other aids, such as radio distance measuring equipment during boost and insertion. However, the ISS performance requirements in this document are based on the non-availability of navigation aids during boost and orbital insertion.
2.3.2 Primary Guidance, Navigation and Control (Orbiter Mated with Re-usable Booster)

During this phase, the ISS shall:

a) provide specific force and angle data to the GNC computer for initialization of powered flight navigation, launch control and lift-off checklist;

b) provide specific force and angle data to the GNC computer for computation of position, velocity, and altitude, for controlling the boost phase.

2.3.3 Failure Detection and Isolation

Each IMU supports failure detection, isolation, and reconfiguration by 1) supplying the data on the basis of which decisions are made and 2) responding by appropriate mode changes, as defined in Section 4.6.6 and 4.7.4, to mode discretes from the GNC computer.

The data for decision-making consists of 1) the normal operational outputs as defined in Section 4.8 and 2) the individual BITE discretes generated in the IMU and transmitted to the GNC computer.

2.4 ABORT

2.4.1 Flyback Abort from Launch

For aborts initiated between +20 and +175 seconds the ISS shall support the GNC computer with attitude and specific force sufficient to effect a normal approach and landing at the launch facility.

2.4.2 Suborbital Abort from Boost

For aborts initiated between +175 and +215 seconds the ISS shall support the GNC computer with attitude and specific force data sufficient to effect a normal approach and landing at TBD Air Force Base.

2.4.2.1 Separation

Support the GNC computer in effecting a safe separation by providing incremental velocity and attitude data.
2.4.2.2 Entry and Transition

Support the GNC computer by providing incremental velocity and attitude data.

2.4.2.3 Approach and Landing.

Support the GNC computer by providing incremental velocity and attitude data.

2.4.3 Once-Around Aborts

Aborts initiated after +215 seconds shall be once-around aborts.

2.4.3.1 Alignment and Calibration

Immediately upon notification that a once-around abort condition exists, the accelerometer loops are closed for an in-orbit bias calibration. If conditions permit, the MMOS automatically makes a measurement of the alignment of the stable member in inertial space and sets a time flag for a second measurement at ten minutes before entry commences. The difference between these two measurements is used to display to the crew a measurement of gyro drifts. Displayed in addition, are the accelerometer bias measurements and for comparison, present compensation values stored in the GNC computer. Update may be automatic or at crew option.

2.4.3.2 Deboost

Support the GNC computer in orienting the orbiter and applying the de-orbit velocity change by supplying angle and incremental velocity data.

2.4.3.3 Entry and Transition

Support the GNC computer in orienting the orbiter in its high angle of attack entry attitude and navigating through entry and transition by supplying angle and specific force data.

2.4.3.4 Approach and Landing

Support the GNC computer by providing specific force and attitude data.
2.5 ORBITAL COAST, ORBITAL TRANSFER, RENDEZVOUS AND DOCKING

2.5.1 Role of External Navigation Sensors

The inertial navigation during these operations for the DRM will be aided by range measurements from a cooperative rendezvous target. These range measurements will be available starting at a minimum distance of 864 nautical miles (1600 kilometers). The MMOS will provide angular data on the vector direction to the cooperative rendezvous target from a minimum range of 54 nautical miles (100 kilometers).

2.5.2 Timeline

During these orbital operations, the longest period that the ISS will go without an update is when the earth orbital transfer and phasing maneuvers to a rendezvous target are initiated directly out of the first insertion orbit. Otherwise, given extra initial insertion orbits, the ISS will be realigned 30 minutes (maximum) prior to initiating orbital transfer and phasing maneuvers.

2.5.3 Functions

The ISS will support the GNC computer in orbital operations by providing angle data for attitude control of the vehicle, incremental velocity for orbital changes, and an inertial reference for control of other sensors.

2.5.4 Failure Detection and Isolation

Same as Section 2.3.3.

2.6 ORBITAL POWER-UP AND CHECKOUT

Note: The following description of Orbital Power-up and Checkout is representative only. Actual test details will vary with IMU design.
2.6.1 Orbital Operational Test

While docked to the Space Station, the ISS will normally be in the Standby Mode. Upon preparation for undocking, the Orbital Operation Test will be performed. The test consists of three parts:

a) Functional Checkout
b) Performance Measurement
c) Alignment

The Functional Checkout is identical to the sequence set forth in Paragraph 2.2.2.1.1 except for initial condition computer entry. The Performance Test must be made in conjunction with the MMOS. The IMU is placed in "Operate" and the MMOS is used to determine its orientation in inertial space. Simultaneously, accelerometer loops are closed and a free-fall bias count is started. The duration of these two free-fall measurements is primarily a function of the available timeline. The measurements are concluded by a second determination of platform orientation with the MMOS. The GNC computer will use the accumulated accelerometer counts and the drift angle to calculate accelerometer bias and gyro gravity-insensitive bias.

If the desired alignment for the next mission phase is known, the Performance Test can be performed at or close to that orientation. Elapsed time between IRU alignment with the MMOS and the De-Orbit Burn shall not exceed 1 hour.

When emergency circumstances require it, the ISS shall support a countdown timeline from the start of the Orbit Operational Test to the De-Orbit Burn which shall not exceed the following:

a) Functional Checkout - 30 mins. (20 minutes if already in standby)
b) Performance Measurement (deleted)
c) Automatic Alignment - 15 mins.

TOTAL BUDGET 45 mins. max.

2.6.2 Failure Detection and Isolation

Identical to Paragraph 2.3.3.
2.7 DE-ORBIT BURN

2.7.1 Countdown

Support the GNC computer by providing angle data with which to orient the orbiter to required de-orbit burn attitude. Provide necessary velocity increment data to accomplish the ullage maneuver correctly.

2.7.2 Burn

Support the GNC computer by providing velocity increment and angle data to the DMS, such that the de-orbit burn is executed.

2.7.3 Tail-Off

Support the GNC computer by measuring the orbiter engine tail-off velocity increment after the engine-off signal has been sent.

2.8 ENTRY AND TRANSITION

2.8.1 Update

The ISS will be the only source of navigation data until the entry and transition phase have been completed.

2.8.2 Attitude Control

The ISS will support the GNC computer by providing angle data with which to control and maintain orbiter attitude.

2.8.3 Navigation

The ISS will support the GNC computer by providing integrated specific force data with which to maintain knowledge of position and velocity.

2.8.4 Failure Detection and Isolation

Same as Paragraph 2.3.3.
2.9 APPROACH AND LANDING

2.9.1 Update

Following transition, and during approach and landing, the inertial navigation data will be supplemented by external navigation aids including radio distance measuring equipment, and barometric altimetry.

2.9.2 Navigation

The ISS will support the GNC computer by providing integrated specific force data.

2.9.3 Attitude Control

The ISS will support the GNC computer by providing angle data for the purpose of flight path control in response to guidance commands.

2.9.4 Failure Detection, Isolation, and Reconfiguration

Identical to Paragraph 2.3.3.

2.10 INTER-AIRPORT FERRY

2.10.1 Role of External Navigation Sensors

During ferry operations, the inertial navigation data will be supplemented by external navigation aids to permit safe, efficient operation within the CONUS air traffic control system and for occasional intercontinental recovery operations.

2.10.2 Checkout

For ferry operations, the Operational Test will be performed without the short performance test. The Operational Test will conclude with an alignment (in the case of gimbaled IMU's) with a gimbal orientation chosen by the GNC computer for local vertical navigation. This alignment will be calculated by the computer upon receipt of departure and arrival latitude and longitude. No optical alignment information will be used.
2.10.3 **Navigation**

The ISS shall support the GNC computer in atmospheric cruising flight by providing specific force outputs and a stable platform in the local vertical which can be torqued.

2.10.4 **Attitude Control**

The ISS will support the GNC computer by providing angle data for the purpose of flight path control in response to autopilot guidance commands.

2.11 **REFURBISHMENT OPERATIONS**

2.11.1 **Guidelines**

As shown in Figures 2-2 and 2-3, of the two weeks scheduled for the turn-around operation, the time allocated for maintenance and refurbishment is only about three days, plus a fourth day for a post-maintenance checkout. It is essential, therefore, that the number of removals and replacements of LRUs be minimized by employing onboard checkout.

Turn-around time from landing to launch readiness may be less than two weeks total (ten working days). During this time, the orbiter vehicle must go through the series of procedures starting with cool-down and passenger unloading through return to the launch site, cargo unloading, repair refurbishment and resupply, cargo loading, erection and mating, transfer to the launch pad, and finally prelaunch procedures.

IMU's that have remained discrepancy-free on the prior mission remain onboard and support refurbishment of the avionics subsystems and the vehicle as required. Passing the Operational Test (see Section 2.2.4) re-qualifies each IMU in the ISS to proceed into Prelaunch Operations. Refurbishment of individual IMU's means the removal of the IMU to the test stand in the refurbishment facility, and occurs when the unit has incurred a discrepancy report from the previous mission or moves into a discrepant condition during ground operations.
3.0 INERTIAL SUBSYSTEM (ISS) FUNCTIONAL AND DESIGN REQUIREMENTS

3.1 GENERAL DESCRIPTION OF THE INERTIAL SUBSYSTEM

The inertial subsystem shall consist of three Inertial Measurement Units (IMU's). Each IMU is to be functionally independent of the other IMU's and shall consist of gyroscopes, accelerometers, and supporting equipment capable of maintaining a three axis inertial attitude reference and of sensing specific force on the vehicle to the required accuracies.

3.1.1 Symmetrical System

Each IMU shall be symmetrical in the sense that each of the principal instrumented inertial axes shall be equipped with inertial components and electronics having similar performance, reliability, error characteristics, and external interfaces.

3.1.2 Data Interface

The data interface between each IMU and the rest of the guidance, navigation, and control system shall be via the GNC computer. The electrical characteristics of this dedicated, hardwired interface are given in Section 4.4.

All data necessary for the operation, command, control, status monitoring, prelaunch and inflight checkout, operational calibration, and failure monitoring of the ISS must pass through this interface.

3.1.2.1 Output Data

Output data available to the computer shall include at least:

a) delta velocity
b) vehicle attitude (gimballed IMU) or attitude change (strapdown IMU)
c) mode and status
d) fault discretes
e) all data necessary for checkout, calibration, and fault isolation to the LRU level.
3.1.2.2 Input Data

Input data to be received from the computer shall include at least:

a) mode commands
b) alignment information (gimballed IMU only)
c) output data requests
d) gyro torquing commands (gimballed IMU only)

3.1.3 Redundancy Management

The ISS shall provide a fail operational/fail safe capability (FO/FS). It will meet this requirement with triply-redundant IMU's. Onboard checkout and failure isolation (COFI) will be implemented to isolate failures to a LRU level. Each IMU is a separate LRU. Performance monitoring will be used continuously during critical mission phases to permit quick reaction to LRU failure.

All ISS COFI will normally be automatic. Manual COFI by the astronauts through the GNC computer will be always available as an alternative. All ISS reconfiguration will normally be automatic. Manual reconfiguration by the astronauts through the computer will be always available as an alternative.

3.2 ISS PERFORMANCE REQUIREMENTS

3.2.1 Ground Alignment

3.2.1.1 Gimballed Systems

After 30 minutes time of local vertical levelling and gyro compassing, the levelling errors shall not exceed 10 seconds of arc, 1 sigma, and the azimuth errors shall not exceed 100 seconds of arc, 1 sigma.
3.2.1.2 Strapdown Systems

After 30 minutes of time of tracking the local vertical, the levelling errors shall not exceed 10 seconds of arc, 1 sigma. After three azimuth sightings on external targets by the MMOS, the azimuth errors shall not exceed 100 seconds of arc, 1 sigma.

3.2.2 Boost and Orbital Insertion

The navigation performance of the IMU and its associated GNC computer during boost and orbital insertion shall be such that the maximum accumulated errors do not result in a perigee altitude below 95 nautical miles or out-of-plane errors that affect orbital rendezvous fuel reserves by a delta V penalty of more than 35 ft/second.

3.2.3 Abort

3.2.3.1 Flyback Abort from Launch

The IMU and its associated GNC computer shall support a flyback abort to the launch and recovery facility initiated between +20 and +175 seconds, such that the probability of a normal approach and landing exceeds a value of T.B.D.

3.2.3.2 Suborbital Abort from Boost

The IMU and its associated GNC computer shall support a suborbital abort to TBD Air Force Base initiated between +175 and +215 seconds, such that the probability of a normal approach and landing exceeds a value of T.B.D.

3.2.3.3 Once-Around Abort

The IMU and its associated GNC computer shall support a once-around abort to the launch and recovery facility, initiated at any time between +215 seconds and orbital insertion, such that the probability of a normal approach and landing exceeds a value of T.B.D.
3.2.4 In-Space Alignment

The IMU together with the Navbase (NB), the Multimode Optical Sensor (MMOS), and the GNC computer, shall be able to establish the alignment of the IMU accelerometer input axes in the celestial sphere to within 111 seconds of arc, 1 sigma RSS. The IMU contribution to this value from the IMU base to the accelerometer input axes shall not exceed 71 seconds of arc, 1 sigma RSS. Refer to Figure 3-1 and Table 3-1.

3.2.5 Entry Performance

The navigation performance of the IMU and its associated GNC computer during entry shall attain downrange and crossrange position uncertainties at 100,000 feet less than 7.0 nautical miles, 1 sigma.

3.2.6 Inter-Airport Ferry Operations

The IMU in combination with the GNC computer shall demonstrate terminal flight navigation errors not in excess of 1.4 nautical miles per hour, 1 sigma, when operating as an airborne navigation system.

3.3 DESIGN AND CONSTRUCTION

3.3.1 General Safety Guidelines

3.3.1.1 Components

All components associated with enabling the crew to recognize and correct critical system malfunctions should be functionally independent of ground support and external interfaces.

3.3.1.2 Markings

Precautionary safety markings shall be provided as necessary to warn personnel of conditions to be observed to insure safety of equipment.
ITEM | UNCERTAINTY FROM: | TO: | SYMBOL
--- | --- | --- | ---
MMOS | TRUE LINE-OF-SIGHT | MMOS BASE REFERENCE | $U_O$
NB | MMOS BASE REFERENCE | IMU BASE REFERENCE | $U_N$
IMU | IMU BASE REFERENCE | OUTER GIMBAL | $U_G$
IMU | OUTER GIMBAL | ORTHOGONAL GIMBAL | $U_I$
IMU | GIMBAL | STABLE MEMBER | $U_R$
IMU | STABLE MEMBER | ACCELEROMETER INPUT AXIS | $U_A$

Figure 3-1  GEOMETRY FOR ALIGNING GIMBALED SYSTEMS IN ORBIT
<table>
<thead>
<tr>
<th>ITEM</th>
<th>SYMBOL</th>
<th>PARAGRAPH*</th>
<th>UNCERTAINTY (seconds of arc, 1 sigma)</th>
<th>VARIANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-mode Optical Sensor (MMOS)</td>
<td>U₀</td>
<td></td>
<td>60&quot;</td>
<td>3600</td>
</tr>
<tr>
<td>Navigation Base (NB) Mounting</td>
<td>Uₙ</td>
<td>[4.6.7.1]</td>
<td>MMOS 42.5&quot;</td>
<td>1800</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IMU 42.5&quot;</td>
<td>1800</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RSS 60&quot;</td>
<td>3600</td>
</tr>
<tr>
<td>Inertial Measurement Unit (IMU)</td>
<td>U₉</td>
<td>[4.6.7.2]</td>
<td>34&quot;</td>
<td>1150</td>
</tr>
<tr>
<td></td>
<td>U₁</td>
<td>[4.6.7.3]</td>
<td>40&quot;</td>
<td>1600</td>
</tr>
<tr>
<td></td>
<td>U₉</td>
<td>[4.6.5.3]</td>
<td>45&quot;</td>
<td>2025</td>
</tr>
<tr>
<td></td>
<td>Uₐ</td>
<td>[4.6.7.4]</td>
<td>15&quot;</td>
<td>225</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IMU RSS 71&quot;</td>
<td>5000</td>
</tr>
<tr>
<td>End-to-End RSS</td>
<td></td>
<td>[3.2.4]</td>
<td>111&quot;</td>
<td>12,200</td>
</tr>
</tbody>
</table>

* Paragraphs in SE-345T: INERTIAL SUBSYSTEM FUNCTIONAL AND DESIGN REQUIREMENTS FOR THE ORBITER (PHASE B EXTENSION BASELINE)

Table 3-1 Calculation of RSS Alignment in Space Uncertainty (Gimballed IMU) (See Figure 3-1)
3.3.1.3 Separation

Redundant safety-of-flight functions shall be in separate packages and physically isolated, where practical.

3.3.1.4 Interlocks

To avoid both personnel hazards and equipment damage during maintenance, safety interlocks which remove at least input power are mandatory on all assemblies.

3.3.1.5 Single Point Failures

There shall be no single point failures which will result in loss of the vehicle or crew.

3.3.1.6 Reliability Estimates

For design purposes, reliability estimates must be based on demonstrated component or "black box" failure rates or other satisfactorily documented sources.

3.3.2 Materials, Processes and Parts

Materials, processes and parts are required to be selected from lists which prevent the use of exotic materials, costly processes and unqualified parts to the extent compatible with cost effectiveness. Careful attention will be given to selection in accordance with reliability and life span requirements of end items.

3.3.3 Commercial Designs

The IMU design may make use of commercially produced designs, the individual components of which may not meet the detailed documentation and qualification requirements specified in this document provided:

a) The design has been used sufficiently that its suitability, reliability, cost of maintenance, and other characteristics are such that they will meet the requirements for the space shuttle vehicle IMU.

b) The basic commercial version of the IMU design shall be in production (tail end, mid point, or beginning) on 31 December of the calendar year 1973, and a substantial, continuing production and/or repair capability shall be indicated.
c) Any changes, modifications or additions to the basic commercial design shall conform to the detailed requirements given in this document.

3.3.4 Standard, Commercial and Qualified Non-Electrical/Electronic Parts

The selection of parts shall be made in accordance with the requirements of the Government design specification applicable to that equipment. Parts which are in current production, available as indicated by being on qualified parts lists, and available throughout the operational phase shall be used to the maximum extent possible. Those parts which are to be obtained from only certain of the many suppliers listed in the QPL shall be considered non-standard (selected) parts. When no general specification exists, the selection procedure for parts shall follow the order of precedence established in MIL-STD-143. Unless otherwise specified, air vehicle commercial parts covered by ANA Bulletin 147 shall be considered as being within Group I standards as defined by MIL-STD-143.

3.3.5 Moisture and Fungus Resistance

Materials that are nutrients for fungi should not be used when their use can be avoided. When used and not hermetically sealed, they shall be treated with a fungicidal agent which will render the resulting exposed surface fungus-resistant. If they are used in a hermetically sealed enclosure or if they are used and stored in a continuously controlled environment, fungicidal treatment will not be necessary.

3.3.6 Corrosion of Metal Parts

3.3.6.1 Corrosive Metals

Metals shall be of the corrosion-resistant type or suitably treated to resist corrosive conditions likely to be met in storage or normal service.

3.3.6.2 Dissimilar Metals

Unless suitably protected against electrolytic corrosion, dissimilar metals, as defined in standard MS-33586, shall not be used in contact with each other.
3.3.7 Contamination Control

With the exception of fabrication and repair of the gyroscopes and accelerometers, the fabrication, assembly, test, maintenance, and repair of the IMU shall not require cleanliness standards beyond those used in standard airline instrumentation factory and depot areas.

3.3.8 Storage

Shuttle IAS, not immediately required for mission preparation, will be placed in a protected environment for temporary storage.

While in storage, the equipment shall be packaged to withstand the environment specified in Section 4.3.1.

3.3.8.1 Preservation, Packaging and Packing

Preservation, packaging and packing methods shall be as specified in NHB 5300.4 (1B)/NHB 6000.1 (1A). Components and spare parts shall be packaged in accordance with TBD. Packing shall be designed to TBD. Protection shall be provided against damage from repeated handling. Containers such as cleated panel boxes, open slat crates, and cartons shall be used as applicable.

3.3.8.2 Package Construction

Packages shall be constructed with provisions for unpacking for periodic inspection and repacking of the inspected items in the original container. Packages shall also be constructed to immobilize and cushion the items against damage during shipping and handling.

3.3.9 Transportability

The IMU shall be air transportable in general accordance with the provisions of MIL-A-421, Air Transportability Requirements. Units of the avionics equipment shall have appropriate shipping containers where necessary to meet these requirements and during shipment the natural and induced environmental requirements for these units, as specified in Section 4.3.1 shall not be exceeded.
3.3.10 Identification and Marking

The identification and marking of the GN&C equipment shall be in accordance with MIL-STD-129. The designation of electronic equipment shall conform to the requirements of (TBD). Serialization markings of new equipment shall conform to the requirements of (TBD). Markings associated with synthetic rubber goods shall conform to the requirements of MSC-STD-105. Packaging markings requirements shall conform to the requirements of MIL-STD-129.

The contractor shall request appropriate deviations where these standards are excessively restrictive and not consistent with cost objectives.

3.3.11 Interchangeability and Replaceability

Total space shuttle turn-around time from landing to launch readiness should be less than two weeks. The removal and replacement time of components shall be minimized with onboard checkout and module accessibility.

All shuttle avionics hardware shall be designed to the greatest extent possible to permit commonality of systems, subsystems, components and parts for common use and interchangeability between the booster, orbiter, and other program elements.

Interchangeability and replaceability items shall be categorized within the definition established by MIL-STD-447. Drawings shall be marked to show interchangeability or replaceability status. As an objective, no "in position" electrical adjustments shall be required when a part of the equipment categorized as interchangeable is replaced with an identical part.

Support equipment items shall be interchangeable functionally in accordance with the requirements of MIL-S-8512. Electronic test equipment shall be interchangeable functionally to the extent specified in MIL-T-21200. The contractor shall request appropriate deviations where these standards are considered to be excessively restrictive and not consistent with cost objectives.

3.3.12 Inflight Maintenance

There shall be no requirement for inflight maintenance.
3.3.13 **Human Performance/Human Engineering**

Design of the LRU and GSE and arrangement of components shall be in conformance with established human engineering design criteria. Displays and controls shall be provided as necessary for acceptable and accurate operation of the equipment.

MIL-STD-1472 shall be used as a guide for the application of human engineering principles to the design of the equipment elements. The contractor shall request appropriate deviation to assure that the standards are not excessively restrictive and inconsistent with cost objectives.

3.3.14 **Skill Levels**

Shuttle support equipment will be designed for use by personnel at a skill and knowledge level consistent with those required for operational high performance land-based aircraft equipment.

3.3.15 **Workmanship**

All flight equipment facilities, support equipment, and training equipment workmanship shall be of the highest quality which is commensurate with the use of the item and cost effective design.

3.3.16 **Electromagnetic Interference Control**

The inertial subsystem and support equipment shall not radiate, conduct, or be susceptible to radiated or conducted interference signals in excess of the limits of MIL-STD-461A, MIL-STD-462, and MIL-STD-463.

3.3.17 **Sealing**

The IMU shall be adequately sealed to prevent contamination of the unit and the SSV atmosphere during its anticipated lifetime.
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4.0 INERTIAL MEASUREMENT UNIT (IMU) SPECIFICATIONS

4.1 FUNCTIONAL CHARACTERISTICS

The IMU, working in conjunction with an external, dedicated Guidance, Navigation, and Control (GNC) digital computer, shall provide an inertial reference for the space shuttle orbiter both within and outside the atmosphere.

4.1.1 Type

The IMU may be either a strapdown system or a four gimbal platform system.

4.1.1.1 Gimbal Functions

If the IMU is a four gimbal platform, it shall provide outputs of digitized gimbal angles and integrated specific force referenced to a selected inertially stabilized coordinate system, when provided with proper timing, control, and torquing signals from the GNC computer.

4.1.1.2 Strapdown Functions

If the IMU is a strapdown system, it shall provide outputs of digitized angular change of the vehicle with respect to inertial space and integrated specific force referenced to vehicle coordinates, when provided with proper timing and control signals from the GNC computer.

4.1.2 Size and Configuration

4.1.2.1 Packaging

The IMU shall consist of a single unit. This unit shall contain all of the inertial components, supporting structure, and electronics required to operate the IMU to obtain the performance specified in this document.
4.1.2.2 Weight

The IMU shall not exceed forty (40) lbs. in weight as installed.

4.1.2.3 Volume

The IMU shall not exceed two thousand (2000) cubic inches in volume as installed.

4.1.2.4 Mounting

The IMU will be secured to the pressurized side of a bulkhead which it shares with the Multi-Mode Optical Sensor (MMOS) on the unpressurized side of the bulkhead. This common structure shall serve as a Navigation Base (NB). The IMU alignment to the NB on the pressurized side shall be obtained by a precision fit between three or more pairs of fittings. One side of each set shall be mounted to, and be a permanent part of, the IMU. The other side shall be mounted to and be a permanent part of the NB.

The NB-mounted parts shall be supplied to the vehicle contractor to be permanently mounted on the NB to an Interface Control Document negotiated between NASA, the vehicle contractor, and the ISS vendor. The mechanical interface of the IMU is at the parting line of the above fitting pairs.

4.1.2.5 Installation Requirements

The IMU, in combination with its mechanical fittings, shall be so designed and configured that it can be installed and removed when the orbiter vehicle attitude with respect to the ground is either Z axis down (in the hangar) or X axis up (on the stack).* Such installation and removal shall not degrade the alignment integrity of the interface hardware. The elapsed time for physically removing an IMU and installing a replacement shall not exceed fifteen minutes. Removable hoisting slings and handles may be used to achieve the above requirements.

* Axis references are to standard NACA/NASA practice in designation of aircraft axis systems.
4.1.2.6 Alignment Repeatability

The mechanical fittings shall maintain the alignment of the IMU to the NB to the accuracy specified in Section 4.6.7.1 or Section 4.7.5.1, whichever is applicable. This alignment is to be repeatable over the projected useful life of the vehicle and IMU. In particular, the mounting attachment points should preserve their tolerances after one hundred (100) IMU installation cycles, of which 75 are with the orbiter Z axis down, and 25 are with the orbiter X axis up.

4.1.2.7 Thermal Interface

The design of the IMU shall provide for thermal control by forced air circulation as specified in Section 4.9.7.

4.1.2.8 Electrical Connectors

The mechanical design of the IMU shall provide the necessary electrical connectors for operation of the IMU. Details of the location, orientation, types of connectors, and signal assignment to connector pins shall be the subject of an Interface Control Document to be negotiated between NASA, the vehicle contractor, and the IMU vendor.

4.2 APPLICABLE DOCUMENTS

4.2.1 NASA Documents
- To be determined -

4.2.2 Military Documents
- To be determined -

4.2.3 Precedence

Where the requirements of this document and those of any applicable government specification differ, the requirements of this document shall govern. In all other instances, publications shall be used in order of precedence established by MIL-STD-143A.
4.3 ENVIRONMENTAL SPECIFICATIONS

4.3.1 Transportation, Handling and Storage

The following represent the environmental extremes which may be encountered by the equipment in a non-operating condition during transportation, handling, and storage. The equipment may be protected by suitable packaging for transportation and storage if these environments exceed the design operating requirements. The equipment shall be capable of meeting the operating performance requirements of its performance specification after exposure to these environments while protected by its normal packaging.

4.2.1.1 Temperature (air)

<table>
<thead>
<tr>
<th>Type</th>
<th>Range</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air transportation</td>
<td>-45 to +140 F</td>
<td>8 hours</td>
</tr>
<tr>
<td>Ground transport</td>
<td>-20 to +145 F</td>
<td>2 weeks</td>
</tr>
<tr>
<td>Storage</td>
<td>+25 to +105 F</td>
<td>3 years</td>
</tr>
</tbody>
</table>

4.3.1.2 Pressure

<table>
<thead>
<tr>
<th>Type</th>
<th>Range</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air transportation</td>
<td>Minimum of 3.47 psia</td>
<td>8 hours (35,000 ft. altitude)</td>
</tr>
<tr>
<td>Ground transport</td>
<td>Minimum of 11.78 psia</td>
<td>3 years (6,000 ft. altitude)</td>
</tr>
</tbody>
</table>

4.3.1.3 Humidity

0 to 100% relative humidity, including conditions wherein condensation takes place in the form of water or frost, for at least 30 days.

4.3.1.4 Sunshine

Solar radiation of 360 BTU per sq. ft/hr for 6 hours/day for 2 weeks.

4.3.1.5 Rain

Up to 0.6 inches/hr for 12 hours; 2.5 inches/hr for 1 hour.
4.3.1.6 Sand and Dust

As encountered in desert and ocean beach areas; equivalent to 140-mesh silica flour with particle velocity up to 500 ft/min. and a particle density of 0.25 grams per cubic foot.

4.3.1.7 Fungus

As experienced in Florida climate. Materials will not be used which will support or be damaged by fungi.

4.3.1.8 Salt Spray

Salt atmosphere as encountered in coastal areas, the effect of which is simulated by exposure to a 5% salt solution by weight for 48 hours.

4.3.1.9 Ozone

Three years exposure, including 72 hrs. at 0.5 ppm; three months at 0.25 ppm; and the remainder at 0.05 ppm concentration.

4.3.1.10 Vibration

Sinusoidal in any direction with frequency and amplitude as specified in Table 4-1.

4.3.1.11 Shock

As would result from a free fall drop from the height specified in Table 4-2. The packaging container shall attenuate the shock such that the packaged equipment shall not be exposed to a shock level exceeding its design capabilities.

4.3.2 Non-Operating Period - Installed or Out of Shipping Container

4.3.2.1 Temperature

0 to 160° F.
### Table 4-1 Vibration

<table>
<thead>
<tr>
<th>Weight*</th>
<th>5.0 to 26.5</th>
<th>26.5 to 52.0 Hz</th>
<th>52.0 to 500.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>+1.56g pk.</td>
<td>0.043 (double</td>
<td>+6.0g pk.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>amplitude)</td>
<td></td>
</tr>
<tr>
<td>50-300</td>
<td>+1.30g pk.</td>
<td>0.036 &quot;</td>
<td>+5.0g pk.</td>
</tr>
</tbody>
</table>

*Weight of equipment and package or containers

### Table 4-2 Packaging Shock

<table>
<thead>
<tr>
<th>Weight*1 (lbs)</th>
<th>Dimensions*2 (in. max)</th>
<th>Free-Fall</th>
<th>Drop Height Edgewise</th>
<th>Drop Height Cornerwise</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>36</td>
<td>30</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>50-100</td>
<td>48</td>
<td>21</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>100-150</td>
<td>60</td>
<td>18</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>150-200</td>
<td>60</td>
<td>16</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>200-600</td>
<td>72</td>
<td>-</td>
<td>36</td>
<td>36</td>
</tr>
</tbody>
</table>

*1 Weight of equipment and package or containers  
*2 Dimension along any edge or diameter
4.3.2.2 Pressure
2 psia below ambient to 15 psia.

4.3.2.3 Shock
20 g for 11 msec.

4.3.2.4 Vibration
Less severe than Launch, Section 4.3.4.

4.3.2.5 Humidity
0-95% at 0° to 150°F with condensation in the form of water or frost for 30 days.

4.3.2.6 Salt Spray
Salt encountered in coastal areas, the effect of which is simulated by exposure to a 5% (by weight) salt solution for 48 hours.

4.3.3 Ground Operations (Installed) - Prelaunch and Post Flight

4.3.3.1 Ambient Air Temperature
Low: 60°F
Nominal: 74°F
High: 120°F

4.3.3.2 Forced Cooling Air
Low: 60°F
Nominal: 74°F
High: 120°F for 30 minutes only
T.B.D. lbs/min.

4.3.3.3 Humidity
0-95% at 0°-150°F with condensation in the form of water or frost for 30 days.
4.3.3.4 Salt Spray
Salt encountered in coastal areas, the effect of which is simulated by exposure to a 5\% (by weight) salt solution for 48 hours.

4.3.3.5 Vibration
Less severe than Launch, Section 4.3.4.

4.3.3.6 Pressure
2 psia below ambient to 15 psia.

4.3.4 Flight Operations

4.3.4.1 Air Temperature (Ambient)
Low: 60°F
Nominal: 74°F
High: 120°F

4.3.4.2 Forced Cooling Air
Low: 60°F
Nominal: 74°F
High: 120°F for 30 minutes only
T.B.D. lbs./min.

4.3.4.3 Pressure
10-17 psia.

4.3.4.4 Sinusoidal Vibration
As specified in MIL-E-5400, Figure 2, Curve IVA.

4.3.4.5 Random Vibration-Launch
.00125 \(g^2/Hz\) at 20 Hz with linear increase to .002 \(g^2/Hz\) from 40 to 2000 Hz.
4.3.4.6 Random Vibration - Flight

.001 g²/Hz at 20 Hz with linear increase to .005 g²/Hz from 100 to 2000 Hz.

4.3.4.7 Load Factor - Boost and Abort

10g longitudinal
5g transverse

4.3.4.8 Load Factor - All Other Phases

+3 g any direction.

4.3.4.9 Humidity

0-95% at 0° to 150°F with condensation in the form of water or frost for 30 days.

4.3.4.10 Shock

20g, 11 milliseconds, basic
40g, 11 milliseconds, crash safety
4.4 ELECTRICAL CHARACTERISTICS OF SIGNAL INTERFACES

4.4.1 Serial Digital Output from the IMU

Word Length
TBD

Voltage Input Levels: The voltage levels will be as follows:

   a) Binary "1"   +5.4 to +6.6 volts
   b) Binary "0"   0.0 to +0.5 volts

Bit Rate: 256000 bits per second maximum

Input Impedance of Computer: 10,000 ohms minimum

Source Impedance of IMU: shall not exceed 100 ohms

Rise and Fall Times: Less than 0.2 microseconds
as measured between the 10 and 90% amplitude points

Synchronization: The computer shall provide both
a bit sync and word gate signals to synchronize the IMU serial output

Parity Provisions: TBD

4.4.2 Serial Digital Input to the IMU

The GNC computer can output TBD bit serial words to the following specification:

Voltage Levels: The following levels shall be as follows:

   a) Binary "1"   +3.0 to +10.0 volts
   b) Binary "0"   -0.5 to +1.5 volts

Bit Rate: 256,000 bits per second maximum

Output Impedance: The output impedance of the computer shall be 5000 ohms maximum

Load Impedance: The load seen by the signal source shall be 50,000 ohms minimum
Rise and Fall Times: The Rise and Fall times of the pulses shall be less than 0.3 microseconds as measured between the 10 and 90% amplitude points.

Synchronization: The computer shall provide both bit sync and word gate signals to synchronize the IMU serial input.

Parity Provisions: T.B.D.

4.4.3 Parallel Digital Output from the IMU

Word length: TBD

Voltage input levels: The voltage levels will be as follows:

a. Binary "1" +5.4 to +6.6 volts
b. Binary "0" 0.0 to +0.5 volts

Sampling Rate: The sampling rate capability of each word shall be any rate up to 16,000 samples per second.

Input Impedance of Computer: Each input channel shall exhibit the following impedances to ground when all channels are actively connected into the system:

a. During sampling: 10,000 ohms, minimum
b. During non-sampling: 50,000 ohms, minimum
c. Equipment Off: 10,000 ohms, minimum

Source Impedance of IMU: Shall not exceed 100 ohms

Rise and Fall Times: Less than 0.2 microseconds as measured between the 10 and 90% amplitude points.

Data Accepted Pulse: The Computer shall provide a data accepted pulse for each digital parallel word.
4.4.4 Parallel Digital Inputs to the IMU

The GNC computer can output T.B.D. bit parallel words to the following specifications.

Voltage Levels:

a) Binary "1" +3.0 to +10.0 volts
b) Binary "0" -0.5 to +1.5 volts

Date Rate: The maximum rate at which the signal may switch logic levels is 16,000 times per second.

Load (IMU) Impedance: The load seen by the signal source shall be 50,000 ohms minimum.

Output Impedance: The output impedance of each signal is 5,000 ohms maximum.

Rise and Fall Times: Rise and fall times of the outputs are less than 0.3 microseconds as measured between the 10- and 90-percent amplitude points.

Data Input Command Pulse: The computer shall provide a Data Input Command Pulse for each digital parallel word. The occurrences of this pulse shall cause the IMU to read the state of the input word into an appropriate holding register.

4.4.5 IMU/GMC Computer Analog Interface

If an analog interface capability of the GNC computer exists, it may be used wherever appropriate in terms of ease of mechanization, range, and accuracy. Each analog output of the IMU shall have its own signal conditioner and output lead. There should be no time-sharing of leads or conditioners under control of the digital interface. Each analog input channel shall be used for only one function. There should be no time-sharing of interface leads as a function of mission phase, system (IMU) mode, or digital input command.
4.4.6 Analog Outputs from the IMU

Voltage Range: 0 to +5 VDC

Input Impedance of GNC Computer:

a) During sampling: 50,000 ohms, minimum
b) During non-sampling: 2 megohms, minimum
c) System 'off': 50,000 ohms minimum

Output Impedance of IMU: 100 ohms maximum

Sampling Rate: Up to 16,000 samples per second

Signal Returns: There shall be one signal ground lead for each 8 signals

Signal Grounding: T.B.D.

4.4.7 Analog Inputs to the IMU

Voltage Range: 0 to +5 VDC

Quantization: Voltage is derived from an 8 bit digital word at 20 mv per step

Source Impedance: Signal source impedance shall be 5,000 ohms maximum.

Load Impedance: The input impedance of the IMU shall be greater than 1 megohm

Back Current: At a +5V output, the IMU shall draw no more than the following currents:

a. During sampling: 50 nanoamps, maximum
b. During non-sampling: 20 nanoamps, maximum
4.4.8 IMU Timing Signal Input from the GNC Computer

T.B.D.

4.4.9 Protection of Signal Interfaces

Over/under voltage protection: all IMU input and output signal lines shall be protected against abnormal signal levels in that the presence of either high or low abnormal voltages will neither cause permanent failure of the effected channel nor cause degradation of other IMU characteristics. Protection shall be provided for voltages from -2 volts DC to the maximum positive excursion of the +28 volt DC power bus.

Short protection: in the event that any signal output should become terminated in an abnormal impedance, only that output shall be degraded. Normal operation of the affected output shall be realized without replacement of components when the abnormal load is removed.

4.5 ELECTRICAL POWER

4.5.1 DC Power

4.5.1.1 AC/DC Option

The IMU shall operate from DC power of the characteristics specified in Section 4.5.1.2, except that the 400 Hz power described in Section 4.5.2 may be used to operate fans and angle transducers.

4.5.1.2 DC Power Characteristics

The main DC power distribution system will have the following characteristics at the load interface:
Nominal Voltage: 28 VDC
Voltage range: 24 to 34 VDC
Transients: $\pm 50\text{V}$, of the form $E = e^{t/J}$ volts referenced to the nominal voltage, where $J = -4.35 \times 10^{-6}$ seconds.
Ripple: 3V peak to peak

4.5.2 AC Power

4.5.2.1 Scope

The orbiter will have an inverter-driven AC power distribution system of limited capability. A small amount of this power may be drawn by the IMU for fan and angle transducers. Heater power shall not be drawn from this interface.

4.5.2.2 AC Power Characteristics

The inverter AC power bus will have the following characteristics at the load interface:

- **Voltage:** 115 $\pm$ 1% VAC RMS
- **Number of phases available:** 3
- **Phase Angles:** 120 $\pm$ 4 degrees
- **Transients:** Peak voltage not less than 90 volts or more than 200 volts, recovery within 100 milliseconds.
- **Frequency:** 400 $\pm$ 0.5 Hz
- **Waveshape:** Per MIL-I-27273A

4.5.2.3 Loss of AC Power

The IMU must be able to continue operating within specification in the event of the loss of any one of the three phases of AC power in the vehicle.

4.5.3 Grounding Philosophy

The vehicle AC and DC power systems are to be multiple-point grounded to the vehicle structure. The basic ground point will be the cryogenic tanks, and all other points will be connected back to those tanks with heavy copper straps.
4.5.4 **Undervoltage Protection**

Voltages less than the minimum specified in Sections 4.5.1 and 4.5.2 shall not cause damage to any part of the IMU if applied. Following a transient undervoltage event, the IMU shall, to the maximum extent possible, return to normal operation.

4.5.5 **BITE on IMU Power**

A BITE discrete shall be set by occurrence of voltage levels outside the range specified in Sections 4.5.1 and 4.5.2.

4.5.6 **No Battery Backup**

The IMU shall not include any provision for a battery backup for continued operation in the face of transient loss of power.
4.6 PERFORMANCE REQUIREMENTS FOR GIMBALLED SYSTEMS

4.6.1 General

The requirements for this section shall apply for all phases of a mission from initial power up preceding checkout, through boost, insertion, rendezvous, deorbit burn, entry, transition, approach, and landing, and also during all phases of inter-airport ferry operations.

4.6.2 Accelerometers

4.6.2.1 Scale Factor

The scale factor of the accelerometer output shall not exceed 5 cm/second/pulse. At a specific force of 10 g's the accelerometer loop shall not be saturated. (The following values are residual bias plus random uncertainties after compensating bias values have been applied. These values shall be valid for 225 flight hours*, including nine (9) turn-ons.)

4.6.2.2 Bias

The bias error shall not exceed 50 micro-g's, 1 sigma.

4.6.2.3 Scale Factor

The scale factor error shall not exceed 100 parts per million, 1 sigma.

4.6.3 Gyros

4.6.3.1 Gimbal Rate Under Gyro Digital Pulse Torquing

The gyro digital pulse torquing loops shall be capable of rotating the platform at 360°/hr. (with respect to inertial space) about each of the three gyro input axes.

(The following values are residual bias plus random uncertainties after compensating bias values have been applied. These values shall be valid for 225 flight hours*, including nine (9) turn-ons.)

* See Paragraph 4.9.2.3 for a definition of flight hours.
4.6.3.2 Non-Acceleration Sensitive Bias

This bias shall not exceed .030 degrees per hour, 1 sigma. In addition, it shall be demonstrated that hour-to-hour random variation does not exceed .005 degrees per hour.

4.6.3.3 Acceleration Sensitive Bias

This bias shall not exceed 0.100 degrees per hour per g, 1 sigma.

4.6.3.4 Gyro Pulse Torquing Scale Factor Uncertainty

This uncertainty shall not exceed 200 ppm, 1 sigma.

4.6.4 Gimbal Servo Loops

4.6.4.1 Overall Performance

The four gimbals shall be controlled by servo amplifiers using the gimbal management scheme which requires that the redundant (next to inner-most) axis be driven towards null at all times. Synchronization of the stabilization loops shall be direct and well-damped starting from any reasonable combination of initial conditions. The stabilization loops shall remain stable and in positive control of the gimbals for any attitude of the IMU stable member.

4.6.4.2 Vehicle Rate Isolation Performance

The gimbal system and its servo loops shall be capable of following any vehicle motion at constant rates up to 50°/second without loss of inertial reference.

4.6.4.3 Redundant Axis Null

The redundant gimbal axis shall remain within thirty (30) seconds of arc of null for all constant angular rate up to 50°/second.
4.6.4.4 Flip Zenith Performance

Dwelling or angular oscillation of the vehicle near the flip zenith of the gimbal set shall not cause the redundant axis to deviate from null by more than 30 seconds of arc and shall not cause loss of inertial reference.

4.6.4.5 Redundant Axis Null Discrete

At all times when the inner redundant axis is not at null to within 30 seconds of arc, an output discrete shall be generated for transmission to the digital computer.

4.6.5 Attitude Angle Measuring System

4.6.5.1 System Definition

This system shall consist of a dual, integral one-speed/eight-speed resolver unit and an associated analog-to-digital converter, one for each gimbal axis except for the redundant axis.

The IMU shall be able to generate a digital output representing the angles of the gimbals other than the redundant gimbal (which is always driven to null). These digital words are to be transmitted to the external digital computer on request from the computer.

4.6.5.2 Quantization

The least significant bit of each angle data word shall have a value of 20 seconds of arc or less.

4.6.5.3 Accuracy

Each digital angle data word produced by the angle measuring system shall be accurate to 45 seconds of arc, 1 sigma for angular rates of up to TBD degrees/second and linear accelerations up to 3 g's. Under the same conditions of acceleration, but at a vehicle angular velocity of up to 50 degrees/seconds, the digital angle data word shall be accurate to 3 minutes of arc, 1 sigma. The above accuracy requirements shall be met with the vehicle in any attitude.
4.6.6 Modes of Operation

The IMU shall have at least the following modes:

a) Off: in this mode, all power to the IMU has been shut off by external means.

b) Standby: Wheels are off, platform heat and thermal control are active. Only the electronics required for these functions are to be on. Cage to zero gimbal angles within one second.

c) Operate: Wheels are on and in this mode the system is completely operational. The gyroscopes, accelerometers, gimbal servo system, and angle readout are all functioning, subject to the requirement that the external digital computer shall supply the necessary timing signals, torquing signal, and data requests.

Two submodes of this mode are specified. In the first of these, the IMU is operating as an inertial reference. It may receive gyro torquing pulses from the external digital computer, and is capable of outputting attitude and change in velocity data to the digital computer. In the second submode, which is used during initial alignment of the platform, the platform can be coarse aligned to specified gimbal angles or gyro slewed to a desired inertial orientation under control of the external digital computer. In this submode, the IMU platform must be capable of being driven through 180° about any axis in less than 2 minutes to within 2 degrees max. of the desired angles.

4.6.7 Alignments

Note: The following specifications are to be met with the IMU completely assembled and operating. They are described in sequence from the outside to the inside. Reference may be made to Figure 3-1 and Table 3-1.

4.6.7.1 Navbase to IMU Base

When the IMU attachment to the Navbase has been completed with electrical and cooling air connections intact, and the IMU is in an operating condition, the misalignment between the NB reference axis system and the IMU base reference system shall not exceed the following about any axis:

42.5 arc seconds, 1 sigma.
These limits shall be held whether the IMU has been installed with the orbiter Z axis down (in the hangar) or X axis up (on the stack)*.

4.6.7.2 IMU Base to Outer Gimbal Axis

The outer gimbal axis shall be parallel to the IMU base reference system to within 34 seconds of arc (1 sigma).

4.6.7.3 Intergimbal Axis Orthogonality

The departure of successive gimbal axes from ideal orthogonality shall not exceed 40 seconds of arc (1 sigma).

Note: A platform or stable member axis system shall be defined by the innermost gimbal axis rotation vector and the zero of its angle transducer.

4.6.7.4 Accelerometer Input Axis Misalignment

The misalignment of each accelerometer input axis with respect to the stable member axis system shall not exceed 15 seconds of arc, 1 sigma.

4.6.7.5 Gyro Input Axis Misalignment

The misalignment of each gyro input axis with respect to the stable member axis system shall not exceed one (1) minute of arc, 1 sigma.

4.7 PERFORMANCE REQUIREMENTS FOR STRAPDOWN SYSTEMS

4.7.1 General

The requirements for this section shall apply for all phases of a mission from initial power up preceding checkout through boost, insertion, rendezvous, deorbit burn, entry, transition, approach, and landing, and also during all phases of inter-airport ferry operations.

* Axis references are to standard NACA/NASA practise in designation of aircraft axis systems.
4.7.2 Accelerometers

4.7.2.1 Scale Factor

The scale factor of the accelerometer output shall not exceed 5 cm/second/pulse. At a specific force of 10 g's the accelerometer loop shall not be saturated. (The following values are residual bias plus random uncertainties after compensating bias values have been applied. These values shall be valid for 225 flight hours*, including nine (9) turn-ons.)

4.7.2.2 Bias

The bias error shall not exceed 50 micro-g's, 1 sigma.

4.7.2.3 Scale Factor

The scale factor error shall not exceed 100 parts per million, 1 sigma.

4.7.2.4 Case Rotation Sensitivity

The performance specified above shall be maintained while the accelerometer case is rotating at 50 degrees per second about any case axis.

4.7.2.5 Case Rotation Induced Damage

No damage to the accelerometers shall result from the application of 90 degrees per second about any case axis with the accelerometer loops closed.

4.7.3 Gyros

(The following values are a residual bias plus random uncertainties after compensating bias values have been applied. These values shall be valid for 225 flight hours*, including nine (9) turn-ons.)

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* See Paragraph 4.9.2.3 for a definition of flight hours.
4.7.3.1 Non-Acceleration Sensitive Bias

This bias shall not exceed .030 degrees per hour, 1 sigma. In addition, it shall be demonstrated that hour-to-hour random vibration does not exceed .015 degrees per hour.

4.7.3.2 Acceleration Sensitive Bias

This bias shall not exceed 0.100 degrees per hour 1 sigma.

4.7.3.3 Gyro Scale Factor

At vehicle angular rates below TBD degrees per second, the gyro scale factor shall not exceed 20 seconds of arc per pulse. The gyro torquing loops shall not be saturated at 50 degrees per second. Gyro scale factor stability shall be 50 parts per million.

4.7.3.4 Case Rotation Sensitivity

The performances specified above shall be maintained while the gyro case is rotating at 50 degrees per second about any case axis.

4.7.3.5 Case Rotation Induced Damage

No damage to the gyros shall result from the application of 90 degrees per second about any case axis with the gyro loops closed.

4.7.4 Modes of Operation

The strapdown IMU shall have the following modes:

a) Off: in this mode, all power to the IMU has been shut off by external means.

b) Standby: inertial sensor heat and thermal control are active. Only the electronics required for these functions are to be on.

c) Operate: the unit is completely operational provided that the external GNC computer supplies the necessary timing and moding signals.
4.7.5 Alignments

Note: The following specifications are to be met with the strapdown IMU completely assembled and operating. They are described in sequence from the outside to the inside.

4.7.5.1 Navbase to IMU Base

When the IMU attachment to the Navbase has been completed with electrical and cooling air connectors intact, and the IMU is in an operating condition, the misalignment between the NB reference axis system and the IMU base reference system shall not exceed the following about any axis:

42.5 arc seconds, 1 sigma

These limits shall be held whether the IMU has been installed with the orbiter Z axis down (in the hangar) or X axis up (on the stack).

4.7.5.2 IMU Base to Inertial Sensor Mount

The misalignment of the inertial sensor mounting element with respect to the IMU base shall be less than 50 seconds of arc, 1 sigma, in any direction.

4.7.5.3 Inertial Sensor Mount to Accelerometer Input Axis

The alignment of each accelerometer input axis with respect to the inertial sensor mount shall not exceed 15 seconds of arc, 1 sigma.

4.7.5.4 Inertial Sensor Mount to Gyro

The alignment of each gyro axis with respect to the inertial sensor mount shall not exceed fifteen (15) seconds of arc, 1 sigma.
4.8 DATA INTERFACES

4.8.1 Data Interfaces Common to Strapdown and Gimbaled Systems

4.8.1.1 Accelerometer Pulses

The IMU shall be capable of transmitting accelerometer pulses serially to the dedicated GNC computer.

4.8.1.2 Check Out and Failure Isolation (COFI)

The IMU shall be capable of transmitting a sixteen bit word to the GNC computer on demand which contains a complete set of BITE and status discretes.

4.8.1.3 Mode Control

The IMU shall be capable of receiving from the GNC computer mode control discretes.

4.8.1.4 Timing

The IMU shall be capable of receiving from the GNC computer serial timing pulses which are the primary control of logic timing and frequency in the IMU.

4.8.2 Data Interfaces for Gimbaled Systems

4.8.2.1 Gimbal Angle

The IMU shall be capable of transmitting three sixteen bit words to the GNC computer on demand which contain the three gimbal angle converter outputs.

4.8.2.2 Coarse Alignment

The IMU shall be capable of receiving from the GNC computer three eight bit words corresponding to coarse gimbal angles to be commanded as part of IMU initialization. As an alternative, those IMU's which have a capability for analog gyro-controlled slewing shall be capable of receiving a slew-on and a slew direction discrete.
4.8.2.3 Fine Alignment

The IMU shall be capable of accepting serial, digital gyro torquing pulses of a positive and negative sense applied to each of the three orthogonal platform axes.

4.8.3 Data Interfaces for Strapdown Systems

4.8.3.1 Gyro Pulses

The IMU shall be capable of transmitting gyro pulses serially to the dedicated GNC computer.

4.9 GENERAL DESIGN REQUIREMENTS

4.9.1 General Specification

The requirements of MIL-E-5400 shall apply as requirements for this equipment except where specifically modified or superceded by this document.

4.9.2 Reliability and Quality Assurance

4.9.2.1 Definitions

The definitions given in MIL-E-721B shall apply in this document.

4.9.2.2 Unverified Failure

A transient failure which cannot be made to repeat and whose cause cannot be identified.

4.9.2.3 Flight Hours

Flight hours associated with an orbiter mission begin when the IMU is powered up beyond a heat only condition in the prelaunch phase. Thereafter, all hours are counted in which the system is in an operating mode (i.e., above standby heat only), until the orbiter returns to the cooldown facility after a mission.
4.9.2.4 MTBF Value

The MTBF of the IMU shall exceed 1500 hours when determined by one of the two methods specified below. If the MTBF of the IMU thus obtained is less than 1500 hours, the vendor shall prepare and submit a plan for improving MTBF of the system to 1500 hours minimum.

4.9.2.5 Experienced MTBF

Each IMU shall achieve 1500 hours or more calculated on the basis of failures experienced during flight hours. This number shall be independent of the number of turn-ons and the number of legitimate moding changes. False positive failure indications (such as false BITE alarms) will be counted as failures in this calculation.

4.9.2.6 Predicted MTBF

In the early phases of this program, before sufficient flight hours have been accumulated on the IMU to demonstrate the MTBF as specified above, the MTBF shall be calculated using data derived from the experience with similar systems where such data is available. Where such data is not available, calculations employing component counts and component failure rates may be used. Where appropriate, suitable derating factors reflecting the environment and component stress levels should be applied. The detailed explanation of the calculations shall be presented for NASA approval.

4.9.3 Maintainability

4.9.3.1 General

The IMU shall be designed for a minimum of maintenance with ease of removal and replacement. Maximum use will be made of aircraft design practice. The IMU design shall minimize the number of personnel, special tools, handling equipment, and procedures required for all levels of maintenance. Identification markings and instructions shall be provided on the equipment to assure the safe and efficient performance of maintenance. All replacement units shall be keyed to eliminate erroneous insertions. Physical removal of replaceable modules with high failure rates will not require the prior removal of nonfailed components.
The IMU is a single line replaceable unit (LRU). It shall be designed to include the capability for isolating faults as specified in Section 4.9.8 at any time the IMU is operating. IMUs are not field repairable. Repair is accomplished at a maintenance depot or in the manufacturer's facilities.

4.9.3.2 Elapsed Time To Repair

The mean time to repair a failed IMU, including all diagnosis, retesting, and requalification for flight required as a part of the repair, shall not exceed T.B.D. hours. The above calculation does not include transportation time to and from the maintenance depot or manufacturer's facilities.

4.9.3.3 Demonstration

Compliance with the requirement of Section 4.9.3.2 shall be demonstrated by a calculation of the time to repair or replace each component in the IMU, weighted by the appropriate probability of failure as derived in the reliability calculation described in Section 4.9.2. If the mean time to repair the IMU exceeds the value specified in Section 4.9.3.3 the IMU vendor shall prepare a plan meeting the requirement.

4.9.3.4 Mean Cost of Maintenance

The mean cost of maintenance of the IMU shall be calculated using the cost of repair or replacement of each component in the IMU, weighted by the probabilities of failure derived in the reliability calculation described in Section 4.9.3.2. The cost of maintenance labor, and any retesting or requalification that is required, shall be included in this calculation.

If the maintenance cost per flight hour, as calculated above, exceeds TBD dollars, the IMU vendor shall prepare a plan for reducing this cost.

4.9.4 Modularity

The IMU shall make use of a modular design to facilitate maintenance and repair. The design shall be such that it is possible to replace electronic modules other than those physically located on the inertial platform or inertial component mounting base, without removing any of the inertial components or disturbing the mechanical fittings upon which the alignment accuracy of the system depends.
The inertial components shall be modular in design so that the replacement of a gyro unit or an accelerometer unit, or alternately the replacement of a prealigned inertial instrument cluster (if the design of the system is such that the instrument cluster is removable as a unit), shall result in the attainment of the alignment accuracies specified in Sections 4.6.7 and 4.7.5 through the use of normal instrument technician skills. Optical alignment for replacement of the inertial components or cluster shall not be a requirement.

4.9.5 Totalizing Time Meter

Two elapsed time meters, in accordance with MIL-M-7793, which indicate "on time" shall be furnished as a part of the IMU. These meters shall be located so that they may be conveniently read with the IMU mounted on its Navbase without removing a cover or any other part of the unit. One of these meters shall record the total time that the IMU is in the operate mode and the other shall record the total time that it is in the standby or operate mode.

4.9.6 Design Lifetime

The IMU shall be designed to have a lifetime, with normal maintenance, in excess of 100 nominal space shuttle vehicle missions or alternate missions, plus anticipated qualification, acceptance and maintenance operation, spread over a period of 10 years.

4.9.7 Thermal Requirements

The IMU shall be forced air cooled using conditioned air supplied by the vehicle thermal control system per Section 4.3.4.2.

4.9.7.1 Temperature Control Requirements - Operating Mode

With the exception of the conditions specified in Section 4.9.7.4 during all test and flight operations in which the IMU is in the operate mode, the temperature control shall hold the platform temperature to within 0.1 of the deviation which shifts the gyro or accelerometer performance by its 1 sigma value.
4.9.7.2 Temperature Control Requirements - Standby Mode

With the exceptions of the conditions specified in Section 4.9.7.4, during all test and flight operations in which the IMU is in the standby mode, the temperature control shall hold the platform temperature to within 0.1 of the deviation which shifts the gyro or accelerometer performance by its 1 sigma value.

4.9.7.3 Temperature Control Requirements - Cooldown

During cooldown, when the IMU may be near structure whose exterior surfaces are cooling down from 300°F, the temperature control shall hold the platform temperature within the deviation which shifts gyro or accelerometer performance by its 1 sigma value. During the cooldown period, cooling air will be supplied to the IMU.

4.9.7.4 Operation Without Cooling Air

In the event that the vehicle cooling air system fails, the IMU shall be able to continue operation for a period of TBD minutes in an environment equivalent to that specified as MIL-E-5400 Class TBD. A performance degradation of TBD % in gyro and accelerometer performance will be allowed during these conditions.

4.9.7.5 Overheat Protection

The IMU design shall incorporate sensors which will turn the system off in order to prevent damage to the equipment due to excessively high temperature.

4.9.7.6 Ground Operation

The system shall be able to operate up to TBD minutes in a compartment ambient of TBD °F maximum without external cooling. The atmospheric pressure will correspond to an altitude of TBD feet above sea level maximum. A temporary performance degradation of TBD % in gyro and accelerometer performance will be allowed during operation under these conditions.
4.9.8 Built In Test Equipment (BITE)

4.9.8.1 General

The IMU shall have BITE for fault detection purposes. As a minimum, the BITE system internal to the IMU shall be capable of detecting improper operation in such of the following parameters as are applicable to the particular design:

a. stable member temperature
b. DC power supplies
c. angle transducer excitation
d. accelerometer rebalance loops and outputs
e. stabilization loops
f. gyro motor power supply
g. gyro motor spin synchronization
h. redundant gimbal loop null
i. angle transducer digitized readout
j. gyro rebalance loops and outputs

These and other discretes shall be combined in the most appropriate manner for the individual IMU design to make one or more IMU malfunction discretes, which shall be available at the IMU electrical interface. Additional discretes, appropriate for fault isolation including the separation of permanent from transient faults shall also be available at the interface.

The IMU shall also have a mechanical BITE indicator located so that it may be observed without removing a cover or any other part from the unit. This indicator shall be set in the event of the occurrence of any malfunction condition in the IMU, and may only be reset manually.

4.9.8.2 Probability of Detection

The combination of BITE discretes shall give a probability of 90% that an IMU failure will be detected. This requirement shall be demonstrated with a calculation using the probability-of-failure rates determined in Section 4.9.3. If the above 90% detection rate is not met, the IMU vendor shall prepare a plan for improving the capabilities of the BITE system.
4.9.8.3 Probability of Failure Identification

The IMU BITE system and other signals that are available at the IMU interface shall be designed to assist in the maintenance and fault isolation of the system. In particular, the BITE interface, other interface signals, and specified procedures shall be able to verify with TBD% confidence that an observed failure was indeed within the IMU and that the IMU should be replaced. This determination shall require not more than TBD minutes to accomplish. The satisfaction of this requirement shall be demonstrated.

4.10 MAINTENANCE AND TEST FACILITIES

The IMU shall be designed to conform to a maintenance and test philosophy under which the IMU is not removed from the vehicle unless an indication of a failure or an observed out-of-specification operation has occurred.

A test facility shall be provided at the launch site which shall have 1) the capability of performing tests on the fully assembled IMU to verify that a failure indication or other improper operating condition exists, and 2) the capability of performing requalification, recalibration, and reacceptance tests on the IMU. No further maintenance capabilities will be provided. IMU's which exhibit a definite failure indication, or which are unable to pass the requalification or reacceptance test, will be returned to the vendor or depot for further corrective action.

4.10.1 Test Facility

4.10.1.1 Test Stand

The test stand shall provide the identical mechanical interface to that found on the Navigation Base. The test stand shall provide continuous angle settings about a trunnion axis from level to 90° of tilt. The trunnion readout total included error shall not exceed ± 5 arc seconds at any point. The trunnion shall support a continuous rotary degree of freedom of 360° under the IMU fixture with a total included readout error not to exceed ± 5 arc seconds at any point.
4.10.1.2 Electrical Interface

The electrical interface to the IMU from the test facility shall be identical in both signal characteristics and power level, to that defined for the on-board installation. In addition, supplemental connections may be made to the IMU through test points and test connectors which are not accessible when the IMU is installed in the vehicle. Breakout boxes will be allowed.

4.10.1.3 Cooling

The test stand shall provide a cooling interface identical to that of the space shuttle vehicle, and a capability of varying the conditions at this interface over the full range of specified thermal interface conditions.

4.10.1.4 Computer

The test stand will include a computer capable of simulating the dedicated GNC computer in the vehicle and also of operating such automatic features of the test stand as are provided.

4.10.2 Tests

4.10.2.1 Operational and Performance Test

The test stand will be able to run the operational test and performance test in order to requalify the IMU for manned space flight.

4.10.2.2 Alignment Test

The test stand will be able to run a series of alignment tests to recalibrate or verify the mechanical alignments of the gimbals and inertial sensors.

4.10.2.3 Fault Detection and Isolation

The test stand will be able to perform a series of trouble shooting tests to detect and isolate faults within the IMU. To accomplish this, the test stand will be able to exercise all of the electrical interfaces to the IMU over the specified range of operation.
4.10.2.4 Reacceptance Test

The test stand will be capable of running a limited reacceptance test for reacceptance of an IMU following a maintenance action.