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Feasibility Study of the Superconducting Gravity Gradiometer (SGG) Flight Test on the European Retrievable Carrier (EURECA)

Final Report
January 1991

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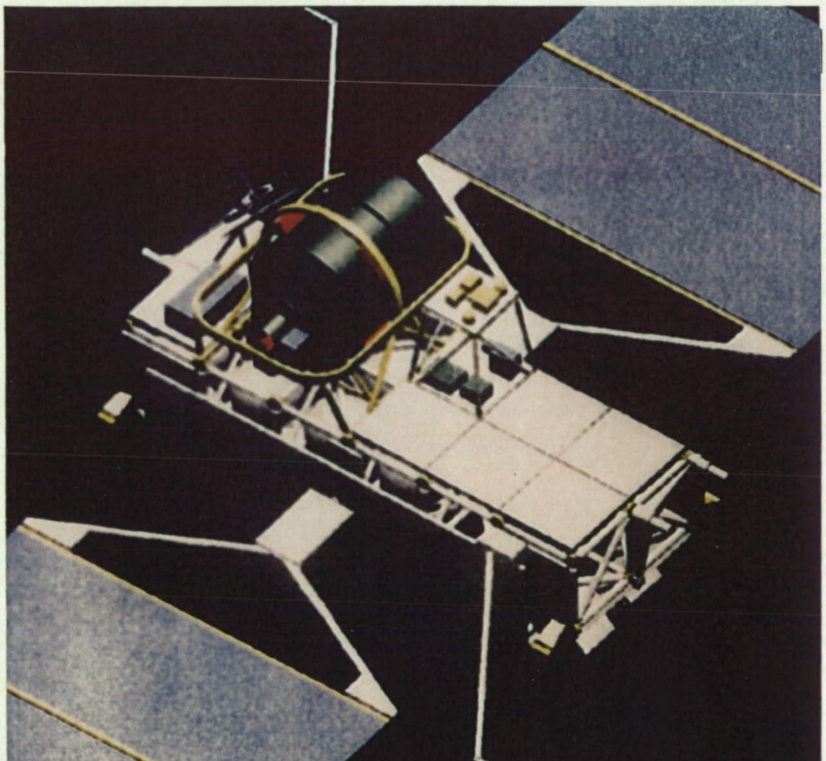

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FEASIBILITY STUDY OF THE SUPERCONDUCTING GRAVITY GRADIOMETER (SGG) FLIGHT TEST ON THE EUROPEAN RETRIEVABLE CARRIER (EURECA)

FINAL REPORT

CONTRACT NO. NAS 8-38138

Prepared for
George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, AL 35812

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Prepared by
GENERAL ELECTRIC COMPANY
Astro-Space Division

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SECTION 1
SUMMARY AND INTRODUCTION

1.1 SUMMARY

A study was performed to determine the feasibility of conducting a flight test of the Superconducting Gravity Gradiometer (SGG) Experiment Module on one of the reflights of the European Retrievable Carrier (EURECA).

The SGG, which is under development by the University of Maryland through NASA, Air Force and Army sponsorship, is an advanced gradiometer based on superconductor technology. The SGG is designed to provide dense, precise, and direct global measurements of gravity that are required to meet future scientific requirements. There are no other feasible alternatives to provide the required resolution and accuracy.

The SGG is an extremely sensitive instrument that will place great demands upon the performance of its spacecraft carrier. To verify the flight performance of such an instrument in an Earth laboratory before committing to a dedicated mission appears to be very difficult, if not impossible. The gravitational acceleration and ambient disturbances on the ground might be far greater than the signals that are to be measured. In addition, there are many unknowns concerning the effects of the orbital and spacecraft environments on the instrument performance. It may be desirable that a space flight test of the instrument be conducted prior to commitment to a dedicated mission.

This study was performed to determine the suitability of using the EURECA spacecraft to accomplish the objectives of an SGG flight test. Under ESA sponsorship, EURECA has been developed expressly to accommodate space science experimentation, while providing a high quality microgravity environment. As a retrievable carrier, it offers the ability to recover the science experiments after a nominal six months of operations in orbit. EURECA is designed to fly a total of five missions.

The study concluded that the SGG Experiment Module can be accommodated and operated in a EURECA reflight mission. It has been determined that such a flight test on EURECA will enable the verification of the SGG Instrument flight performance and validate the design and operation of the Experiment Module. It is also concluded that a limited amount of scientific data might also be obtained in this mission. This report presents the results of the considerations that support these conclusions.

Since the study was limited in time and scope, it was not possible to address some of the flight test considerations fully. Also, the study identified some issues that were only addressed briefly. Because the study showed a strong possibility for a viable SGG flight test on EURECA, it is recommended that additional work be sponsored by NASA to establish clear and conclusive justification for the flight.

1.2 INTRODUCTION

Under NASA and DoD sponsorship, the University of Maryland is developing an advanced spaceborne gravity gradiometer employing superconducting technology. The development of this instrument is required to provide accurate gravity field measurements to NASA's Solid Earth Sciences and Ocean Processes Programs. In addition, NASA's Astrophysics Program has requirements for gravity measurements that relate to tests of General Relativity and other fundamental laws of physics. The DoD has interests in gravity field measurements and associated technology for application to positioning, guidance and testing of precision inertial instruments.

The SGG will permit a space mission with a gravity measurement accuracy of a few mgal (1 gal = 1 cm sec^{-2}) and a spatial resolution goal of 50 km for the global gravity map of the Earth, and of achieving a resolution of 10^{-10} for the inverse square law test. The measurement precision of this instrument in a space mission will dictate platform requirements for very low disturbance levels, precise pointing and control, and isolation from internal and external disturbances that are more severe than for most other satellite missions.

The required instrument sensitivity makes it difficult to verify its performance in Earth-based laboratories, under full gravitational acceleration and ambient disturbances. There are also unknowns concerning the effects of the orbital and platform environments on the instrument performance that can only be determined in an orbital test. Therefore, it is prudent that a precursor test flight be considered to demonstrate the operability of the instrument and its ability to meet the science mission objectives. This will ensure that the risk level for the full-duration science mission is acceptable. The decision to proceed with a test flight will depend upon the success of the ground test program as well as risk management decisions.

In 1985, a study team consisting of members from NASA, DoD, universities, and industry, was formed to develop a total system concept for a space qualified three-axis SGG integrated with a six-axis accelerometer. The SGG Mission (SGGM) Study Team evaluated several options for a flight test of the SGG instrument. Shuttle attached and detached options were identified. The attached concepts, in general, were found to be too restrictive for proper validation of instrument performance. The detached concepts, which were found to be more suitable for a flight test of the SGG instrument, involve carriers that are deployed by the Shuttle, to be either a nearly autonomous subsatellite of the Shuttle, or a carrier left in orbit and retrieved during a later Shuttle mission. Included in the latter group was the European Retrievable Carrier (EURECA), a multi-mission spacecraft designed to support science experimentation. Developed under the sponsorship of the European Space Agency (ESA), EURECA is launched and retrieved by the Shuttle. It offers a high quality microgravity environment, and is capable of operating autonomously during nominal six-month missions.

To further assess the suitability of EURECA for flight test of the SGG instrument, a six-month study, sponsored by the NASA Marshall Space Flight Center, was conducted by the GE Astro-Space Division, in conjunction with MBB-ERNO of Germany, the developer of EURECA. Flight test requirements were established, and a payload accommodation evaluation was made to determine the preferred SGG Experiment Module arrangement. Critical interface, operational, and environmental issues were identified and addressed. The study also included preparation of a preliminary plan for the implementation of the flight test, including a schedule and support for NASA's cost estimation of the Flight Test Program. The study program efforts were enhanced greatly by interim critical reviews and comments by members of the SGGM Working Group.

The results of the study are presented in this report, as well as brief discussions of the SGG instrument and the EURECA Spacecraft. Included in the report are initial requirements definition which describes the interfaces and resources required for flight support of the SGG; configuration concepts and analyses leading to a recommended configuration; mission scenarios and associated analyses which determine the recommended mission profile; an implementation plan which describes the schedule activities for reflight refurbishment, payload integration, ground and flight operations, including SGG on-orbit activation and calibration. A preliminary Instrument Interface Proposal (IIP) is also included which is the interface document required of all experiments that fly on the EURECA platform. Special studies were also conducted, including review of disturbances, analyses of calibration techniques and analysis of shielding requirements. Recommendations are also included on further studies needed to establish a fully supported rationale for the Flight Test.

SECTION 2
STUDY OBJECTIVES, SCHEDULE AND TECHNICAL APPROACH SUMMARY

2.1 STUDY OBJECTIVES

The objective of the study is to assess the feasibility of conducting a flight test of the Superconducting Gravity Gradiometer (SGG) Instrument on a reflight of the European Retrievable Carrier (EURECA). Verification of the instrument flight performance and validation of the design and operation of the supporting and interfacing equipment are essential to the successful implementation of the SGG mission. The goals of the SGG flight test are two fold: an engineering test which verifies the full sensitivity of the instrument and collection of useful geophysics data with reduced sensitivity.

2.2 SCHEDULE

The study is subdivided into five tasks as shown on the program schedule, Figure 2-1, and described below.

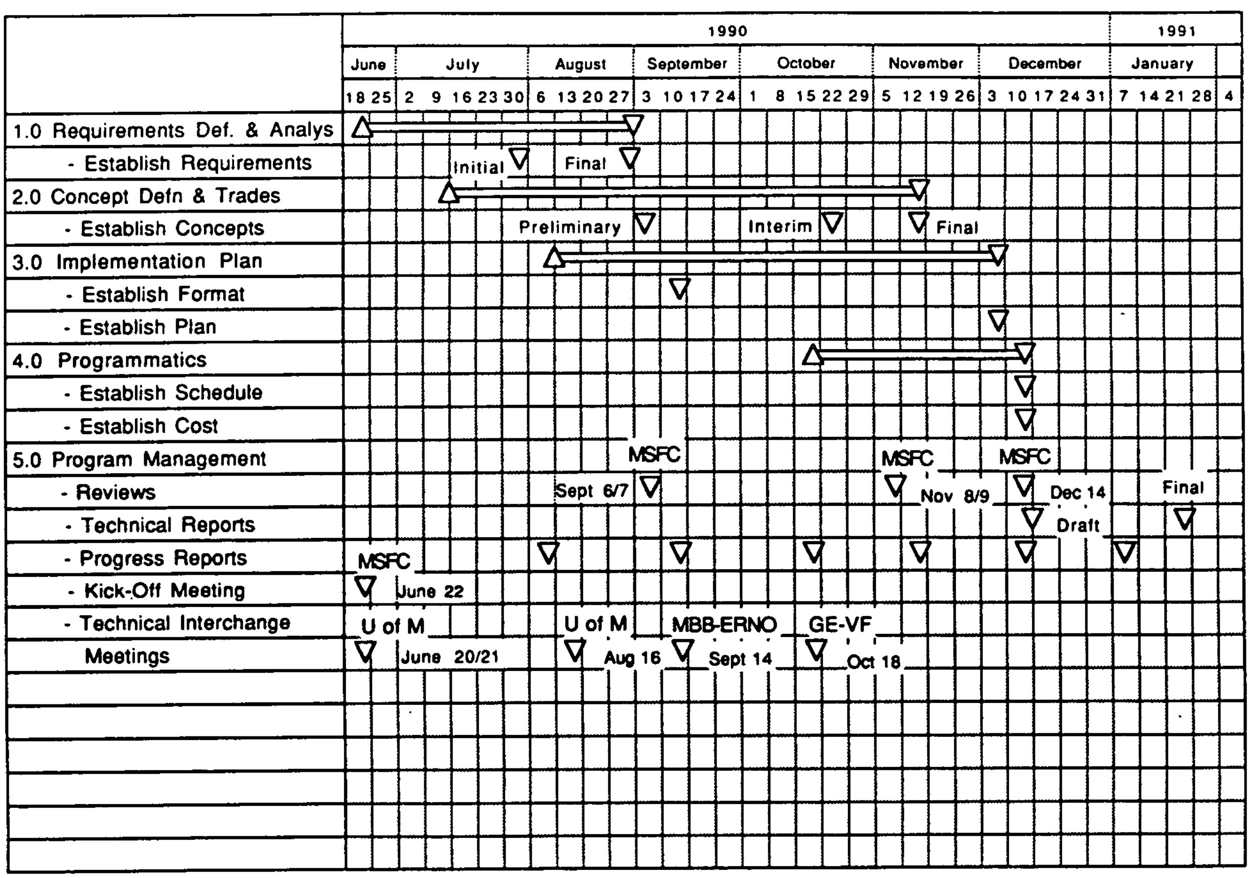


Figure 2-1. Feasibility Study of the SGG Flight Test on EURECA Reflight

2.3 TECHNICAL APPROACH SUMMARY

Task 1.0 Requirements Definition and Analysis. Initially, requirements were defined and analyzed for flight test of the SGG instrument on EURECA. Data sources for the instrument requirements included technical interchanges with the SGGM study team members at the University of Maryland and NASA-MSFC; reference documents, such as NASA Technical Memorandum 4091, "Superconducting Gravity Gradiometer Mission"; and technical interchanges with GE and MBB-ERNO experiment integration engineers. An initial set of requirements was updated at the first working group meeting, and then integrated into the Instrument Interface proposal (IIP) which is included as Appendix A.

Task 2.0 Concept Definition and Trades. Viable concept configurations of the SGG experiment module integrated with the EURECA were generated. These concepts were then evaluated as to accommodation of SGG requirements, accommodation of compatible experiments and adaptability to various operational mission scenarios. The resulting preferred configuration is a product of these trade studies.

Task 3.0 Implementation Plan. Using the EURECA experience as a starting point, an overall EURECA refurbishment, integration, test and flight schedule, with supporting activity timelines, was assembled. Detail activities and schedules were then produced to cover EURECA detailed refurbishment, instrument development, ground operations and flight operations. Finally, activities and timelines describing SGG checkout, deployment, activation, and experiment data acquisition phases were added to complete the SGG Flight Test Program Plan.

Task 4.0 Programmatics. Inputs to the NASA-MSFC schedule and cost estimating tasks were provided as required.

Task 5.0 Program Management. As shown in the program schedule, Figure 2-1, an initial kick-off meeting was held at NASA-MSFC to establish initial definition of the Flight Test requirements. Two working group interim meetings were held at NASA-MSFC for timely critique of the study efforts, resolution of critical issues, and selection of preferred flight test arrangements and conditions. A final meeting was held at NASA-MSFC to present the results of the study program. Other technical interchange meetings were held at the University of Maryland, MBB-ERNO in Bremen, Germany, and at GE in Valley Forge, Pennsylvania. This task also included the technical report, monthly status reports and financial reports.

SECTION 3
SUPERCONDUCTING GRAVITY GRADIOMETER INSTRUMENT*

3.1 THREE-AXIS SUPERCONDUCTING GRAVITY GRADIOMETER

Figure 3-1 schematically shows a single-axis portion of the laboratory model of the SGG (Model III). Two superconducting niobium proof masses, confined by mechanical springs to move along the common axis between them, are levitated against gravity, for ground development and test, by dc magnetic fields produced by the persistent current I_{c2} in a superconducting loop (dotted line). In space, the proof masses are "levitated" in both directions by symmetric persistent currents $I_{c1} \approx I_{c2}$. Persistent currents I_{d1} and I_{d2} are stored in two sensing loops (solid line) constructed with superconducting sensing coils and an input coil to a SQUID. A common acceleration is balanced by adjusting the ratio I_{d1}/I_{d2} so that the SQUID is sensitive only to a differential acceleration. An identical superconducting circuit with the sense of one persistent current reversed is coupled to the proof mass to read the common acceleration (not shown in the figure).

A three-axis gravity gradiometer is an assembly of three sets of single-axis units in three orthogonal directions. Orthogonality and scale factor matching between the three components are assured by careful alignment and calibration. In order to obtain the required sensitivity with a modest-size flight instrument, a superconducting "negative spring," which can compensate the rigidity of mechanical springs by passive means and effectively create a "free-mass" instrument, has been incorporated into the design. Sensitivity to common mode accelerations, due to misalignment of sensitive axes of the accelerometers, is reduced by means of a three-dimensional residual balance, which is achieved by introducing an appropriate amount of coupling to the common mode accelerations at the output of the three-axis gradiometer. Figure 3-2 shows the cross-sectional view of one of the six accelerometers forming the three-axis SGG.

The instrument noise power spectral density is given by:

$$S_r(f) = \frac{8}{m\ell 2}\left[k_B T \frac{2\pi f}{Q(f)} + \frac{(2\pi f_0)^2}{2\beta\eta} E_A(f)\right],$$

where m, f_0, Q(f), and T are the mass, resonance frequency, quality factor, and temperature of the proof masses, respectively; ℓ is the baseline of the gradiometer; β and η are the coupling coefficients of the transducer and the SQUID. Limits from the two noise terms in the above equation are plotted in Figure 3-3 as functions of Q(f) and f_0. For the

*This section was contributed by Dr. Ho Jung Paik, Professor of Physics, and his staff, of the University of Maryland.

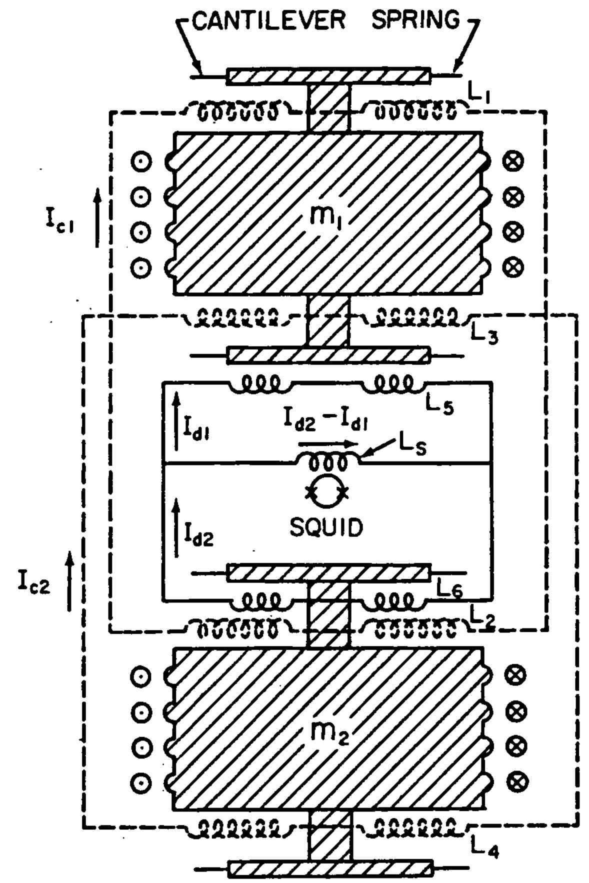


Figure 3-1. Schematic of a Single-Axis Portion of the Engineering Model of the SGG (Model III)

other parameters, design values: $m = 0.8$ kg, $T = 1.5$ K, $\ell = 0.19$ m, $\beta\eta = 0.25$, and $E_A(f) = 3 \times 10^{-30}$ J $Hz^{-1/2}$ (commercial DC SQUID) have been used. The SGG sensitivity goal of 3×10^{-4} E $Hz^{-1/2}$ can be met in the frequency range from 10^{-3} to 10^{-1} Hz, if the effective quality factor Q(f) is 10^5, and the proof mass resonance frequency, f_0, is lowered (by the superconducting negative spring) to 0.1 Hz.

Use of persistent currents for levitation, common mode balance, and sensing assures extreme stability for the transducer. Further, the voltage-to-current conversion factor of the SQUID can be calibrated against the flux quantum, which is a fundamental constant. With these advantages, combined with enhanced mechanical stability of materials at liquid helium temperatures, and the thermal stability of superfluid helium, the goal of instrument drift less than 2×10^{-6} E hr^{-1} should be achievable.

3.2 SIX-AXIS SUPERCONDUCTING ACCELEROMETER

In order to measure the linear and angular accelerations of the platform to the required precision, an SSA (Figure 3-4) is being developed in parallel with the gradiometer. The SSA senses the rigid body motion of all six degrees-of-freedom of a single levitated niobium proof mass. The accelerometer sensing is accomplished by using 24 superconducting "pancake" coils organized as six inductance bridges, coupled to six SQUIDs. The

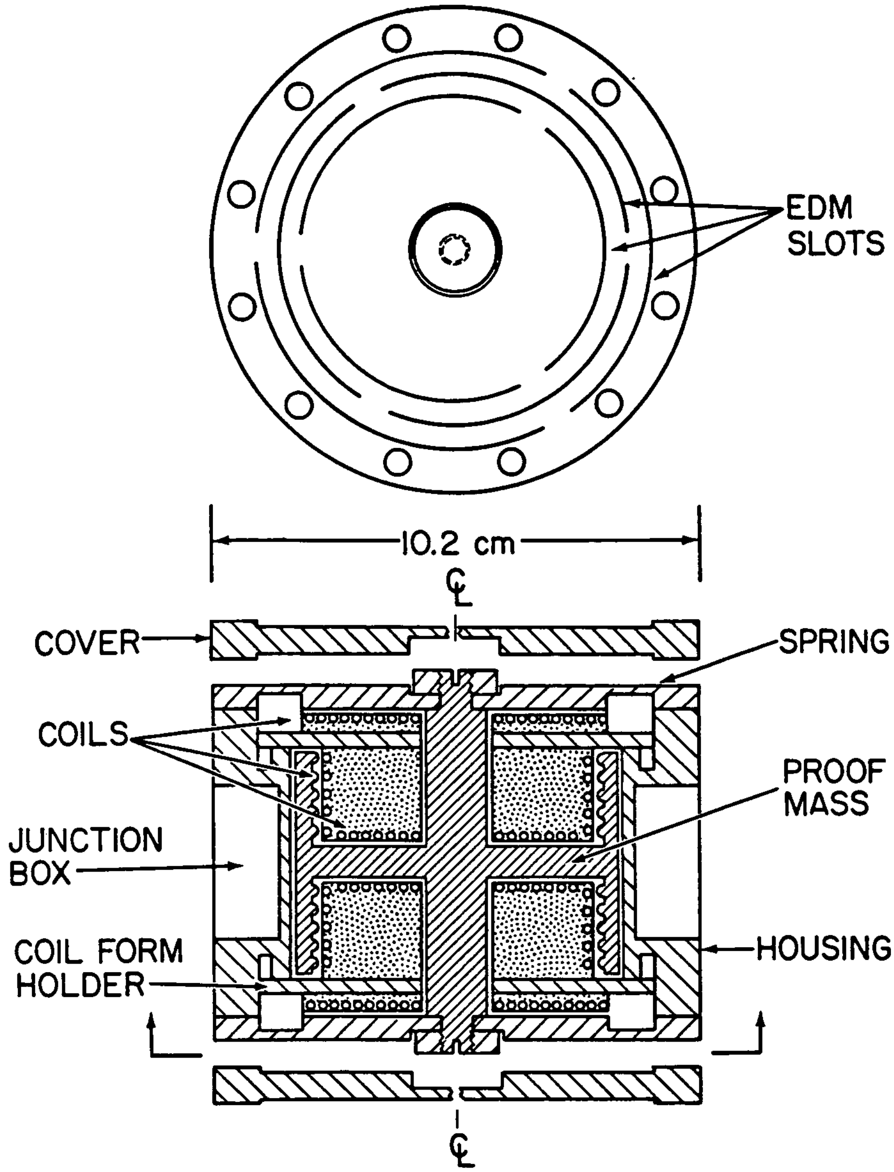


Figure 3-2. Cross-Sectional View of One of the Six Accelerometers Forming the Three-Axis SGG

position of the proof mass in six degrees-of-freedom is proportional to the unbalance of each of the six inductance bridges. Levitation is accomplished by storing persistent current in appropriate combinations of the superconducting coils. The accelerometer is operated in a force rebalance mode. With the proof mass resonance frequency of 1 Hz and $Q = 10^4$, a linear sensitivity of $10^{-13} g_E$ $Hz^{-1/2}$ and an angular sensitivity of 10^{-10} rad sec^{-2} $Hz^{-1/2}$ are expected. The device occupies a 10.2 cm cube.

Figure 3-5 is a photograph of the SGG/SSA instrument package. Six component accelerometers constituting the three-axis gradiometer are mounted on a titanium cube which houses the six-axis accelerometer. The entire assembly fits within a 30-cm diameter sphere and weighs about 40 kg.

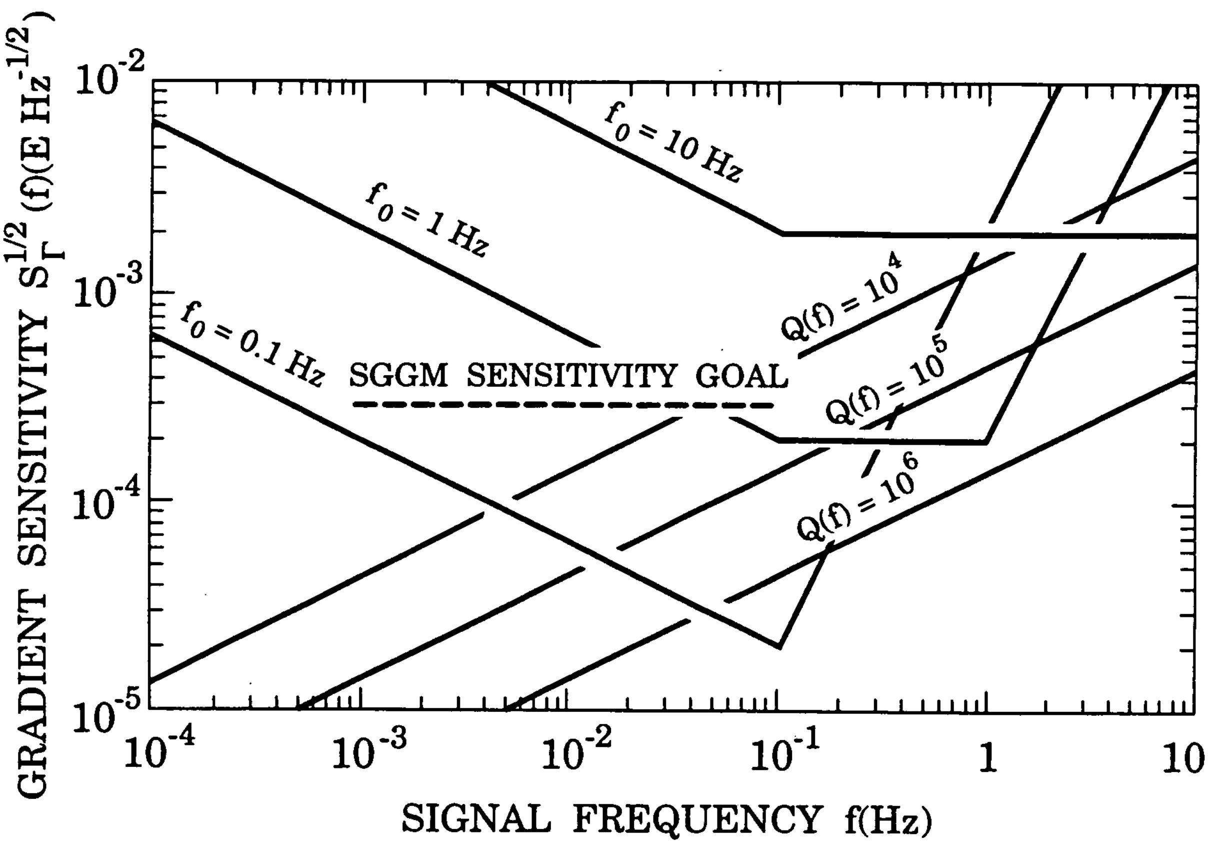


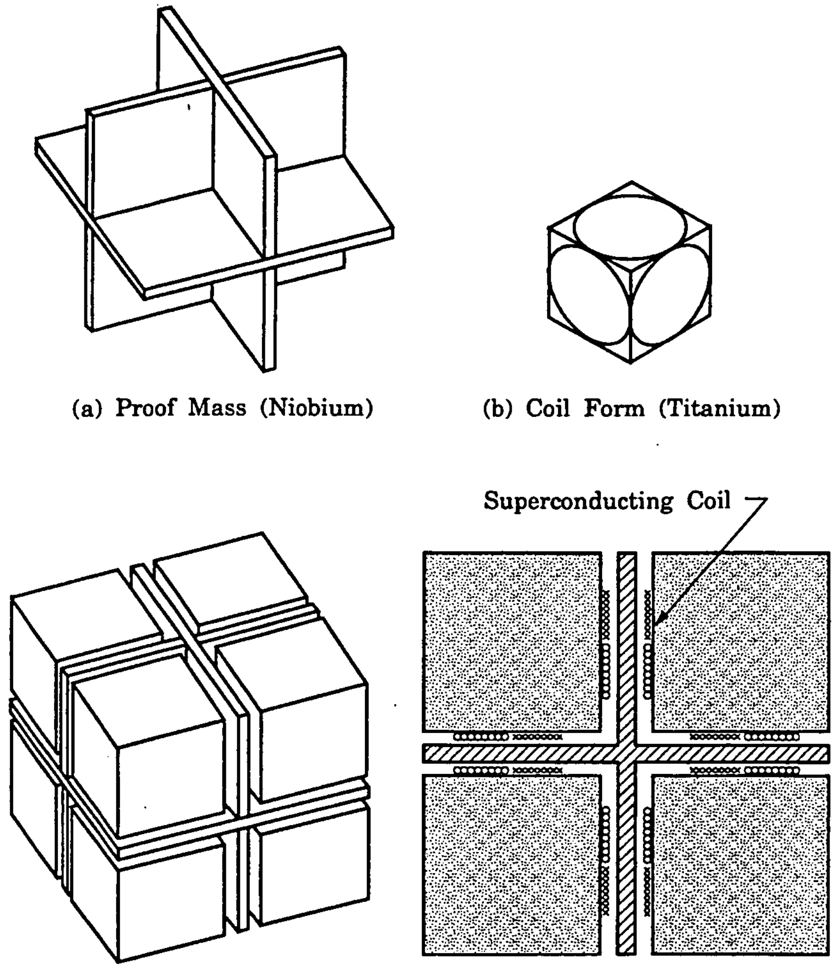
Figure 3-3. SGG Instrument Noise Power Spectral Density

3.3 STATUS OF INSTRUMENT DEVELOPMENT

An SGG capable of satisfying the instrument requirement of the SGGM has been under development since 1980 at the University of Maryland under NASA support. The development of an SSA began in 1985 with the support of the U.S. Air Force. The instrument research and development has demonstrated that superconducting technology not only can be utilized to lower the intrinsic noise of the instrument, but also can meet many of the practical challenges of operating a sensitive gravity measuring instrument in a noisy environment.

A relatively simple prototype, single-axis SGG Model I, was first constructed in order to investigate the basic physics of such an instrument. A detailed analysis of the instrument dynamics was also carried out, including extensive error modeling. Thorough experimental tests of the instrument have shown that the superconducting device closely follows the analytical model. The performance level of 0.3 to 0.7 E $Hz^{-1/2}$ was achieved with this instrument in the laboratory, without any active control or compensation.

Based on the experience obtained with this first instrument and additional superconducting technologies developed to improve the performance of the superconducting gradiometer, advanced designs of the three-axis SGG (Models II and III) were produced. By incorporating an error compensation scheme called "three-dimensional residual balance,"



(a) Proof Mass (Niobium) (b) Coil Form (Titanium)

(c) Assembly Drawing (d) Cross Section View

Figure 3-4. Six-Axis Superconducting Accelerometer (SSA) Assembly

a performance level of 0.05 E $Hz^{-1/2}$ has been demonstrated with the Model II SGG. The Model III SGG represents a further improvement over Model II, in that it contains the "superconducting negative spring" mentioned above. A single-axis portion of Model III SGG has been assembled and is undergoing tests. This third generation SGG should be able to meet the instrument noise goal for the SGGM, 3 x 10^{-4} E $Hz^{-1/2}$.

Error analysis of the instrument has indicated the need to monitor the attitude of the gradiometer platform, in general, to an accuracy which is orders of magnitude lower than can be determined using conventional gyroscopes. This why the University of Maryland group started development of the SSA. A prototype SSA has successfully been operated and an improved version of the SSA (Model II) is undergoing tests.

The single-axis Model III SGG has been integrated with the Model II SSA. It is expected that the basic laboratory tests of the integrated instrument will be completed by the end of 1992.

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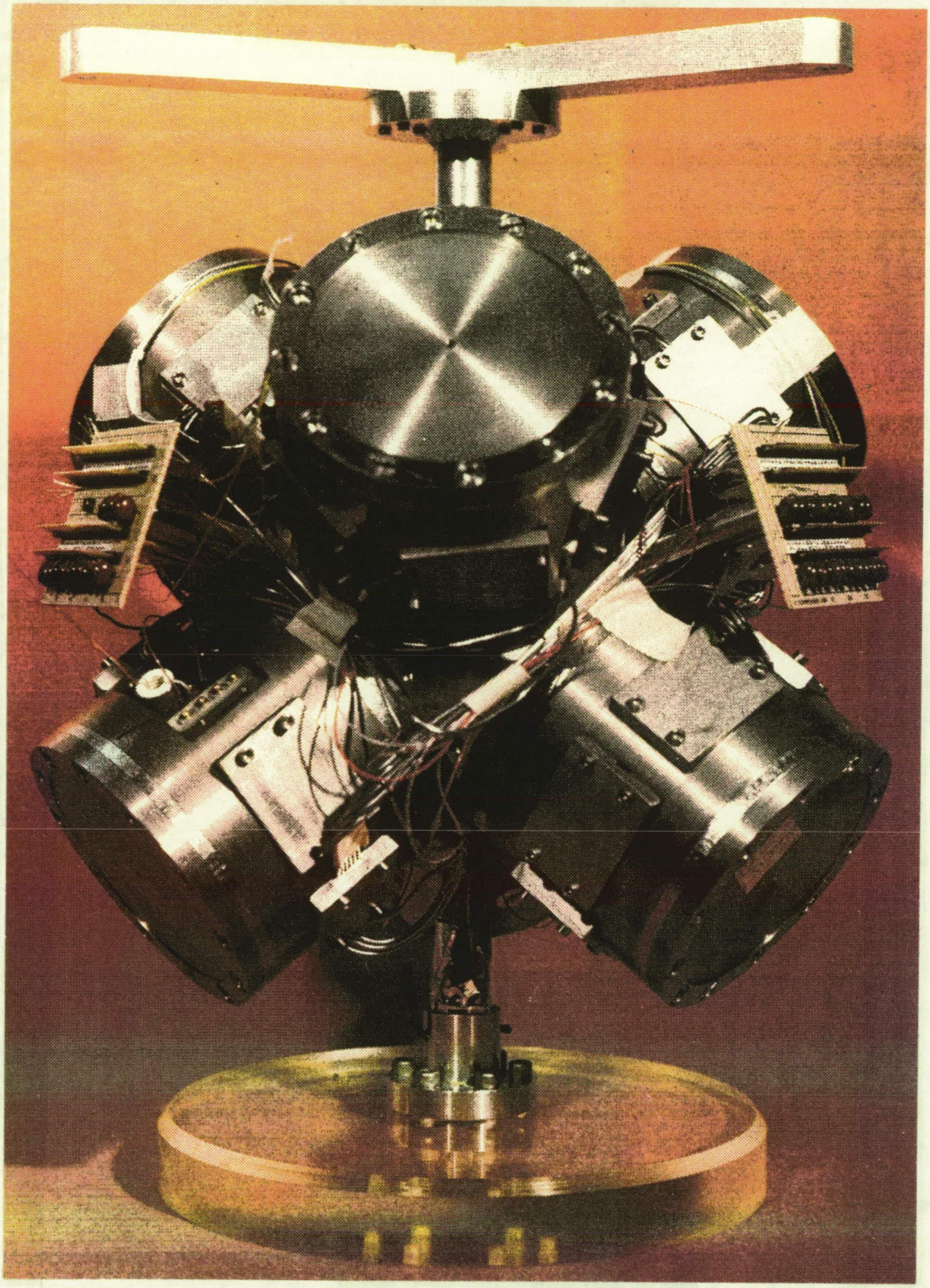

Figure 3-5. SGG/SSA Instrument Package

SECTION 4
EURECA SYSTEM OVERVIEW

The European Retrievable Carrier (EURECA) is a Shuttle-retrievable, free-flying platform. Its first mission will be devoted primarily to material and life sciences which require a micro-gravity environment. The first payload, however, includes a number of other scientific instruments and technology experiments. Formal approval for the first mission was given by ESA at the end of November 1984. Integration and system testing of EURECA is complete and the first launch of EURECA is planned for 1992. The carrier configuration for the first mission is shown on Figure 4-1.

EURECA is designed to accommodate a payload mass of 1000 kg and have a total launch mass of 4400 kg.

Payload Accommodation Resources

The resources available for EURECA's payloads are summarized in Table 4-1 and the envelope available for payloads is shown on Figure 4-2.

EURECA Mission Characteristics

EURECA will be launched and retrieved by the Shuttle at a 300 km nominal/28.5° orbit, where EURECA's on-board propulsion system will transfer it to and from its operational orbit, 500 km nominal/28.5°.

The mission profile shown on Figure 4-3 indicates the orbital maneuvers to be performed by EURECA. The active mission phase (operational phase) lasts 6 months, after which EURECA is ready for retrieval, this taking place within the subsequent 3 months. In the case where retrieval cannot be accomplished within that period, EURECA will ascend to a parking/mission contingency orbit and await a second retrieval attempt. The maximum nominal on-orbit stay time is 9 months. During the retrieval and mission contingency periods EURECA is converted from the operational to the dormant state, where the payload and part of the carrier's subsystems are de-activated.

EURECA's orbital attitude during the operational phase of the mission will be such that its +Z axis is towards the sun (inertially-stabilized mode).

EURECA is fully deactivated while it is in the Shuttle cargo bay except for heating of temperature sensitive equipment and payloads. Heater power is taken from the Shuttle via a retractable umbilical connection.

Deployment and retrieval of EURECA will be accomplished using the Shuttle's Remote Manipulator System (RMS).

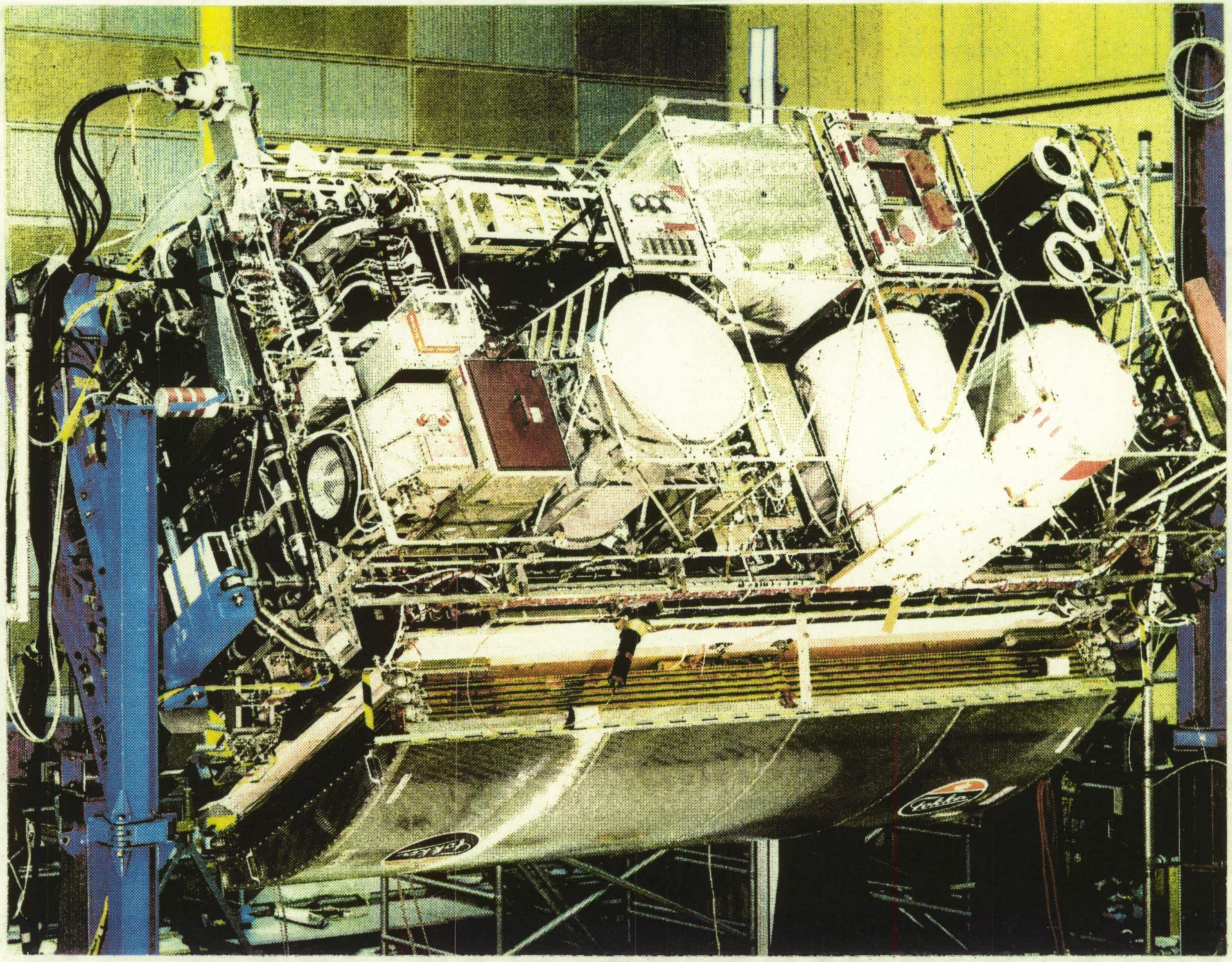

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Figure 4-1. EURECA Mission 1 Configuration

Table 4-1. EURECA Payload Resources

Environment:	Microgravity (Refer to Section 7.2)
Payload mass:	1000 kg
Payload mounting area:	4.2 x 1.4 m
Available payload volume:	14.5 m^3
Payload average main power:	1 kW
Payload peak main power:	1.5 kW limited time
Payload essential power:	100 W
Power interfaces:	14 instrument dedicated 2 high power unprotected
Protection:	Elec. circuit breaker (resettable)
Cooling:	Passive and active by freon cooling loop heat transfer into loop via cold plates or instrument internal ex-changer
Temperature control channels:	6 selectable. Channels can be used as power supply
Scientific data interface:	2 different types *Remote Acquisition Unit*: Max. rate 43 kbps PCM interface *Processor Interface Unit*: Max. rate 21.5 kbps IEEE interface
Average data rate:	1.5 kbps (during non-contact times with the ground)
Burst data rate:	Max. 60 kbps depending on interface
High level command channels:	12
High level monitor channels:	6
Clock interface:	1024 kHz
Clock sync interfaces:	1 (normal/redundant)
Clock sync accuracy:	10 microsec for clock calibration
Pointing:	Sun inertial
Pointing accuracy:	±1° 3 sigma
Attitude measurement accuracy:	0.25° 3 sigma
Software service:	On-board flight software
Fault Detection Isolation and Recovery support software:	Yes, on request

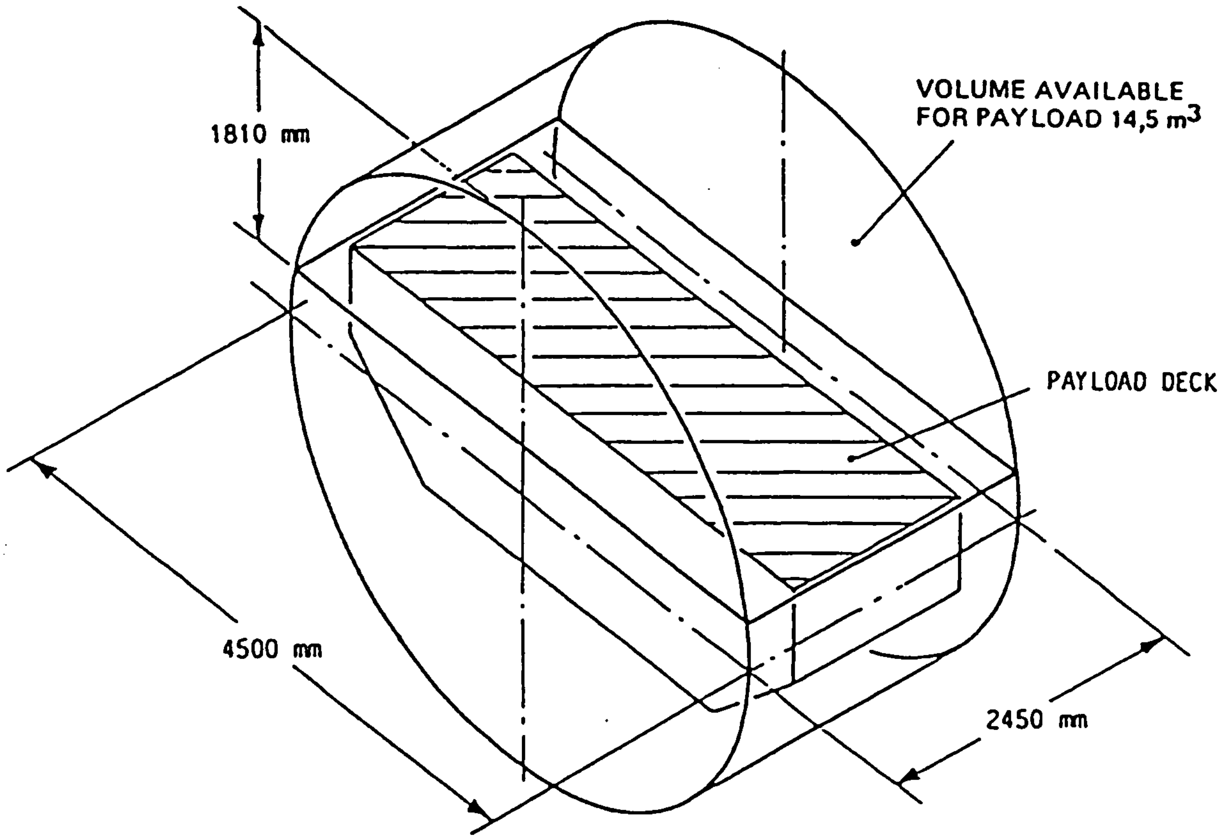
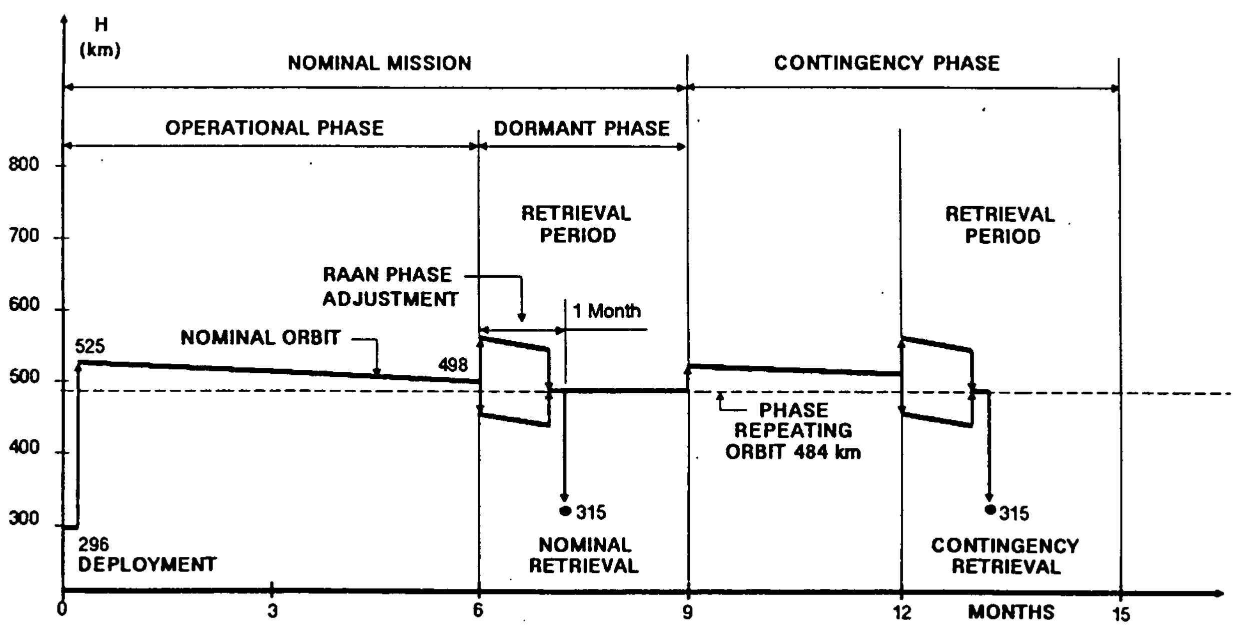


Figure 4-2. Envelope Available for Payloads



RAAN = Right Ascension Ascending Node (EURECA orbit synchronization for Shuttle rendezvous)

Figure 4-3. EURECA Mission Profile

Data Handling Subsystem (DHS)

The DHS is in charge of the data transfer to and from the Operational Control Center (OCC) and the management of the EURECA subsystems and payload. The management task has the following functions:

- Reception of telecommand data for direct commands and packet commands based on the standard ESA TC-frame.
- Decoding and execution of High Level Commands (HLC).
- Acquisition of High Level Monitoring (HLM) data.
- Reception of real-time data packets from the processing unit.
- Generation of the mission elapsed time reference.
- Compilation of the real time telemetry packets, which consist of the processor real-time packet, the mission time, high level monitoring data and the Monitoring/ Reconfiguration Unit (MRU) internal data.
- Transmission of the real-time telemetry packet to ground.
- MRU internal automatic reconfiguration.
- DHS automatic reconfiguration.
- Override capability of automatic reconfiguration activities.
- Control data processing capability.
- Reception and decoding of telecommand packets.
- Processing of the telecommand packet protocol.
- Acquisition of EURECA subsystem and payload monitoring data and generation of telemetry packets.
- Acquisition of telemetry packets from intelligent users.
- Limit sensing capability.
- Exception monitoring capability.
- Self-test capability.
- Fault detection, isolation and recovery capability.
- Transmitting of telemetry packets according to the packet telemetry standard.
- Back-up mission time generation within the processing unit
- Mission elapsed time distribution service.

- Mass memory capability to store processing unit programs and data tables, EURECA subsystem relevant monitoring data, payload data, payload programs and scientific data.
- Context saving capability for subsystems and intelligent instruments.
- EURECA subsystem and payload control and command capability.
- Mission time dependent commanding capability.
- Patch and dump.

The EURECA DHS comprises:

- Two telecommand (TC) links via TTC receivers. The two TC channels are hot redundant. The TC link operates with a data rate of 2 kbps.
- Two telemetry channels with low data rates. The data rate is 2 kbps. These two Low Speed Links (LSL) are dedicated to the high level monitoring data and to the real-time data transmission.
- Two telemetry channels with high data rates. The data rate is 256 kbps. These two High Speed Links (HSL) are dedicated to high level monitoring data, real-time data and deferred data transmission.
- Redundant equipment and facility to command and monitor the EURECA system and payloads.
- A user interface facility to/from intelligent and non-intelligent users.
- Mass data storage facility.

Telemetry and Telecommand Subsystem (TTC)

The TTC subsystem performs telemetry and telecommand communication between EURECA and the Shuttle/ground stations and supports doppler tracking of the spacecraft by the ground segment.

1. Telemetry Data Transmission

   The TTC subsystem supports telemetry data transmission to the Shuttle and to ground stations by two RF power levels (high RF power and low RF power) and by two different modulators (a linear phase modulator to establish a low speed link (LSL) for 2 kbps and a B-Phase Shift Keying (BPSK) modulator to establish a high speed link (HSL) for 256 kbps). RF power levels and modulation schemes are selectable.

   Only one transmitter is active at a time, the other being in cold stand-by. Two telemetry video signals are received from the Data Handling Subsystem (DHS), one sinusoidal 1024 kHz subcarrier Phase Shift Keying (PSK) modulated with 2 kbps PCM-SPL telemetry data and one Non-Return to Zero (NRZ) coded data stream with a symbol rate of 512 kbps (256 kbps data convolutionally encoded to 512 kbps). Only one of the two data streams is downlinked.

2. Telecommand Data Reception

   The TTC subsystem supports reception and demodulation of telecommand signals which are transmitted either by the Orbiter or by ground stations.

   The two transponder receivers are hot redundant so that—regardless of whether antenna element 1 or antenna element 2 faces the Shuttle/ground station—a sufficiently strong RF telecommand signal is received.

   The demodulated telecommand video signals are delivered to the DHS in form of a sinusoidal 16 kHz subcarrier PSK modulated with the 2 kbps PCM-NRZ command data.

   In addition to the S-Band receiver telecommand video signals, the TTC subsystem handles the telecommand video signal delivered by the Inter-Orbit Communications (IOC) link antenna.

Electrical Power Subsystem (EPS)

The electrical power subsystem generates, stores, conditions and distributes power to all subsystem equipment and the payload.

The EURECA EPS has been designed to provide 1000 W continuous power to the payload during the sunlight and eclipse periods of the operational phase.

Energy storage is provided by four Nickel Cadmium batteries. Each battery has a capacity of 40 Ah. All DC power required to supply the other subsystems, assemblies and payloads is routed via and controlled by the Power Distribution Unit (PDU). Essential power is directly derived from the Power Conditioning Unit (PCU) and generated by the essential section of the Battery Discharge Regulators (BDR). Essential power cannot be switched.

Power generation is provided by the Solar Array Assembly (SAA). The SAA consists of two identical wings, each containing five rigid panels, which are divided into a charge array, to charge the batteries, and a load array for direct power supply.

Attitude and Orbital Control Subsystem (AOCS)

The AOCS has features which allow it to perform attitude measurement and control, orbit control, and monitoring and housekeeping activities related to these functions. The AOCS design also allows easy adaptation to other missions' requirements by virtue of its:

- Bus-oriented architecture which allows the addition of extra AOCS equipment via standard interfaces.
- Digital, computerized control systems that allow adaptation and/or addition of functions by software modifications only.

The AOCS stabilizes EURECA during all mission phases, except when EURECA is in physical contact with the Shuttle. In particular, the following tasks are fulfilled:

- Stabilization of EURECA during proximity operations (deployment and retrieval).
- Boost-up and boost-down to and from the operational orbit.
- Sun pointing during operational phase.
- Earth pointing during orbit transfer.
- Slewing for earth and sun acquisition.

EURECA is a three-axis stabilized spacecraft which may, in principle, be orbited in any attitude required to satisfy mission needs. EURECA Mission 1 will be flown with the Z-axis sun-pointing, i.e. in an inertially-stabilized attitude. The spacecraft's attitude is determined by means of sun and infrared earth sensors and an inertial reference unit, and control in a micro–gravity environment is achieved primarily by means of magnetic torquers, which are supplemented by cold gas thrusters. In a non-microgravity environment, additional control may be provided by the Hydrazine thrusters of the Orbit Transfer Assembly.

The EURECA AOCS requirements are summarized in Table 4-2. In addition, EURECA may perform slewing maneuvers, the durations of which, when using the Hydrazine thrusters, are 90° slew around X-axis, 34 sec; 90° slew around Y-axis, 42 sec. The maximum slew rate is approximately 3 deg/sec and is limited by the inertial reference unit gyros.

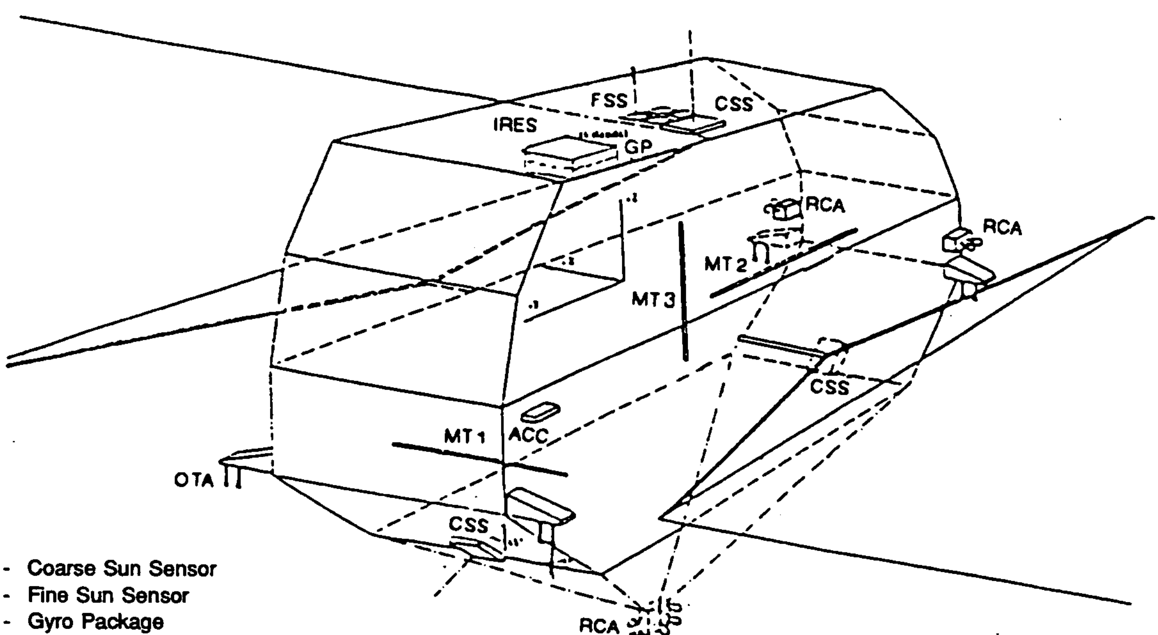
The locations of the carrier's sensors, magnetic torquers and cold gas thrusters are shown on Figure 4-4.

Reaction Control and Orbit Transfer Assemblies (RCA and OTA)

EURECA's Reaction Control Assembly, a nitrogen cold gas thruster system, provides attitude control during the operational phase and during the deployment and retrieval phases in the proximity of the Shuttle. It is used primarily for compensating attitude and rate errors which exceed the momentary compensation capabilities of the magnetic torquers, i.e. the cold gas system is a secondary but important attitude control mode. The RCA is not operated during ascent/descent, dormant and contingency modes.

Table 4-2. EURECA AOCS Characteristics (Operational Mode)

Attitude control by cold gas system and magnetic torquers				
Applied sensors				
• Fine sun sensor	–	for X-axis pointing		
• Infrared earth sensor	–	in Y-axis, for gyro drift		
	–	update once per orbit		
• Gyros (4 of 6)	–	Attitude reference		
• Coarse sun sensor	–	Eclipse detection		
Momentary attitude is calculated by a state observer (Kalman—Filter)				
Required Attitude Accuracy				
• Overall attitude accuracy (all 3 axes):		±0.8°		
• Accuracy of Attitude Prediction (all 3 axes):		±0.2°		
Attitude prediction				
		X-Axis	*Y-Axis*	*Z-Axis*
With Fine Sun Sensor and Earth Sensor		±0.14°	±0.14°	±0.15°



CSS - Coarse Sun Sensor
FSS - Fine Sun Sensor
GP - Gyro Package
IRES - Infra-Red Earth Sensor
MT - Magnetic Torquer
OTA - Orbital Transfer Assembly
RCA - Reaction Control Assembly

Figure 4-4. Location of AOCS Components

The Orbit Transfer Assembly (OTA), EURECA's main propulsion system, uses the monopropellant, Hydrazine, and is designed for orbital transfer maneuvers. It will also be used for attitude and orbital control during EURECA's dormant mode.

Micro-Gravity Measurement Subsystem (MMS)

The MMS is provided principally for micro-gravity missions and is used for verification of the payload environment in the operational phase.

Thermal Control Subsystem (TCS)

The thermal subsystem is subdivided into:

- Active Thermal Control System (ATCS)
- Passive Thermal Control System (PTCS)

Both sections in cooperation are able to control thermally all elements of EURECA's subsystems and payload during the operational and non-operational mission phases, i.e. maintaining the equipment within their temperature limits in order to ensure their proper functioning.

The ATCS provides the thermal heat sink for the directly-cooled instruments and those instruments and subsystem equipment items which are mounted to cold plates. It is activated during the operational phase only to provide cooling of those instruments and subsystem equipment with high heat dissipation. The heat transport to the radiators is performed by a Freon cooling loop driven by a redundantly-designed Freon pump package.

The PTCS uses insulation blankets, coatings and other passive means as required in order to maintain EURECA within its thermal design requirements. The PTCS is supported by an extensive heater system to be applied especially to temperature sensitive instruments and equipment.

The TCS is able to reject the maximum heat load of EURECA of about 2300 W in the operational phase. In order to cover also the non-operational phases, up to 1490 W of electrical power is available to heat temperature sensitive equipment and to operate the Thermal Control Unit which activates and controls the cooling loop and heater system. During the pre-deployment and post-retrieval phase EURECA will get 500 W via the umbilical from the Orbiter, however, this includes heater power dedicated to the payload. During the short deployment and retrieval phase heater power is limited to 120 W by the Shuttle Remote Manipulator System.

EURECA can control the environment for the payloads within the temperature ranges between 0 °C and +40 °C for the operational phase and –10 °C and +40 °C for all non-operational phases.

The passive thermal control hardware used on EURECA is primarily multi-layer insulation, heater foils and paint. Almost the entire carrier will be insulated with only the radiators and trunnions presenting an uninsulated surface to the space environment. The heater system is considered to be a passive element, since it acts to augment the insulation, the definition of both being complementary.

Multilayer insulation (MLI) blankets will be used to protect the instruments and subsystem equipment from external heat fluxes (solar, albedo, earth radiation) and to avoid unwanted heat losses.

Equipment and instruments which will exceed the lower temperature limits, even if partly or completely insulated, need electrical heating. The heater system consists of flat Kapton foil strip heaters located on the instruments and subsystem equipment.

Structure

The primary structure is built from carbon fiber reinforced plastic struts and titanium nodes which form a truss-type framework. This is supported within the Shuttle cargo bay by two longeron trunnions and one keel fitting; additional support structures or cradles are not required. Payloads and subsystem components are attached directly or indirectly via appropriate secondary support structures to the node points of the framework.

A grapple fixture is provided for the deployment and retrieval of EURECA by means of the Shuttle Remote Manipulator System.

SECTION 5
FLIGHT TEST REQUIREMENTS

This chapter summarizes the current status of the key SGG Flight Test Requirements. The requirements are detailed in the Instrument Interface Proposal (Appendix A). These reflect the status achieved during the study. It has to be noted that, when an actual Flight Test Program is undertaken, the requirements will be updated to reflect the current status.

The scientific goals of the SGG Flight Test are:

Goal 1: an engineering test, which verifies the full sensitivity of the instrument, i.e.

10^{-4} E $Hz^{-1/2}$ (Note 1)

over the bandwidth of 0.001 to 0.1 Hz during several intervals of 90 minutes each throughout the mission and

Goal 2: collection of useful geophysics data at a reduced sensitivity of

10^{-2} E $Hz^{-1/2}$

over the bandwidth of 0.001 to 0.1 Hz.

Unless otherwise noted, the following requirements are applicable to both mission goals.

Power

Peak Power:	270 W
Average:	190 W
Standby:	100 W
Stay Alive:	0 W
Voltage level:	28 +0.5/–4.0 VDC

Thermal Dissipation

The thermal dissipation is directly related to the electrical power consumption. The dewar interior is kept to 1.5 K by non-propulsive helium boil-off vented in to space and in the Shuttle cargo bay. The heat dissipated through the helium boil-off, for the proposed dewar design, is approximately 50 mW.

---

1. *Gravity gradient has units of sec^{-2}. However, this unit is too large for real gradients. A more useful unit, the Eötvös (1 Eötvös = 1 E = 10^{-9} sec^{-2}) has been defined.*

Data

Data generation rate during SGG/SSA calibration:	24.128 kbps
Data generation rate during science data acquisition:	6.848 kbps
Continuous instrument housekeeping:	0.8 kbps

The SGG does not require a real time user interface, but rather a time delayed interface and control.

Structures

Soft mounting of the dewar to the spacecraft structure depends on the spacecraft vibration environment. A cut-off frequency of approximately 10 Hz may be required, which in turn may require, the instrument to be locked down to the carrier during Shuttle launch and landing phases.

The mass breakdown of the SGG instrument are given in Table 5-1.

The overall envelope dimensions are:

- dewar and attached items: 1100 mm diameter x 1760 mm length
- electronics box: 200 x 300 x 600 mm.

Disturbances

Pointing Accuracy: ±1 degree

Low-frequency (10^{-3} to 10^{-1} Hz) Acceleration Spectrum:

	Goal 1	*Goal 2*	*Unit*
Linear Acceleration:	2×10^{-8}	2×10^{-7}	g $Hz^{-1/2}$
Angular Acceleration:	10^{-7}	10^{-5}	rad s^{-2} $Hz^{-1/2}$

Contamination by sharp peak modes is permissible as long as they can be identified.

The duration of the required disturbance-free time intervals is 90 minutes.

High-frequency (10 to 1000 Hz) Acceleration Spectrum:

A high frequency attitude rate spectrum is down-converted to produce centrifugal acceleration noise in the sensitive frequency range 10^{-3} to 10^{-1} Hz.

Assuming a relaxation time of 1 sec, the amplitude of the dominant angular mode should not produce an angular rate larger than 0.008 arcsec s^{-1} for goal 1 and 0.08 arcsec s^{-1} for goal 2.

Table 5-1. Mass Breakdown of the SGG Instrument

Item No.	*	Instrument Element	Mass (kg)	COG X mm	COG Y mm	COG Z mm
1	a	Dewar	150	–	center	–
2	a	Helium	30	–	dewar center	–
3	a	SGG/SSA	50	–	dewar center	–
4	a	Mu-Metal Shield	10	–	dewar center	–
7	b	Alignment Sensor	6.8	–	center	–
8	b	Rate Gyros	2 x 4.3	–	center	–
9	de	Dewar Mounting Structure	est. 50	–	center	–
10	de	Calibration Actuators	est. 20 max	–	TBD	–
11	cd	Electronics Unit (TBD)	est. 46 max	–	TBD	–
12		Harness	11	–	TBD	–
13		Development Risk Margin	50	–	TBD	–
		TOTAL	432			

*Notes:

a. Items 2, 3, 4 are contained within item 1.

b. Items 7 and 8 are mounted on dewar "cover" plate.

c. Item 11 is not mounted on the dewar, but elsewhere on the spacecraft.

d. Mass figures of items 9, 10, 11 are rom estimates.

e. Option for calibration actuators considered here: linear motion transducers attached to the external container of the dewar.

Assuming a radius of gyration of 1 m, the linear acceleration amplitude is required to be less than:

	Goal 1	*Goal 2*	*Unit*
at 100 Hz	2.5×10^{-5}	2.5×10^{-4}	g
at 1000 Hz	2.5×10^{-4}	2.5×10^{-3}	g

Ground Operations

Final calibration and test shall be performed after integration with the platform.

Replenishment of dewar with liquid helium shall be as late as possible before launch.

Shuttle Interfaces

The instrument has no direct Shuttle interfaces except for helium venting into the cargo bay.

Mission Profile

Orbit inclination:	28.5 deg	–	Flight Test mission
	(polar	–	science mission)
Altitude:	525/310 km	–	Flight Test mission
	(200 km	–	science mission)
Attitude:	sun inertial & earth pointing – FT		
	(earth pointing - science mission)		

On-Orbit Operations

Calibration is required once every month. Known linear and angular accelerations must be applied at low frequencies (0.1 to 1.0 Hz), see Section 7.1 and Appendix B.

Science data shall be acquired as often as possible during time intervals of 90 minutes.

Capture, Return and Deintegration

Lockdown during Shuttle re-entry and landing may be necessary, if soft mounting of the SGG instrument is provided for on-orbit operations.

Safing, calibration and test are not required after landing.

SECTION 6
ACCOMMODATION STUDIES: CONCEPTS AND TRADE-OFFS

6.1 CONFIGURATION ANALYSIS

SGG Instrument Configuration

The instrument key physical characteristics are summarized in Table 6-1.

Figure 6-1 shows the SGG configuration which, at the beginning of the study, formed the starting point for the configuration analyses.

In the course of the study, however, two modifications were incorporated, which had a major influence on the configuration:

1. Deletion of the SGG instrument Star Trackers because it was considered that the attitude fluctuations—as an error source to the SGG measurements—can be calculated from the SGG instrument internal Six-Axis Accelerometer (SSA).
2. Addition of Linear Motion Transducers to the outer dewar shell for on-orbit calibration purposes (see Section 7.1).

The instrument configuration which was finally derived is shown on Figure 6-2.

SGG Accommodation Options and Trade-Off

From the beginning, it was obvious, that due to its relatively large dimensions, the SGG instrument could only be accommodated close to the center region of the EURECA payload accommodation area ("payload deck").

The three instrument orientations indicated on Figure 6-3 were investigated for their relative merits with respect to:

- Compliance with Shuttle and EURECA envelopes (mandatory)
- SGG distance from EURECA center of gravity (to be minimized)
- Offset of SGG CG relative to EURECA payload deck (to be minimized)
- Location of EURECA Attitude and Orbit Control System tower and sensors (goal: same location as for EURECA baseline configuration to be maintained)
- Protrusion of instrument into EURECA sensor field-of-view (goal: to be avoided)
- Use of payload accommodation area (to be minimized)

This comparison, given in Table 6-2, favors the SGG instrument accommodation with the dewar length axis oriented parallel to the EURECA X-axis (option "A").

Table 6-1. SGG Physical Characteristics

Mass		432 kg
Dimensions	Dewar + Align. System	1060 (dia) x 1760 mm
	Electronics	300 x 200 x 600 mm
Power	Peak	270 W
	Average	190 W
Data Rates	Science	6.9 kbps
	Calibration Mode	24.2 kbps
	House Keeping	0.8 kbps
Cooling	Dewar	Passive (non-propulsive Helium boil off)
	Electronics	Passive/Active

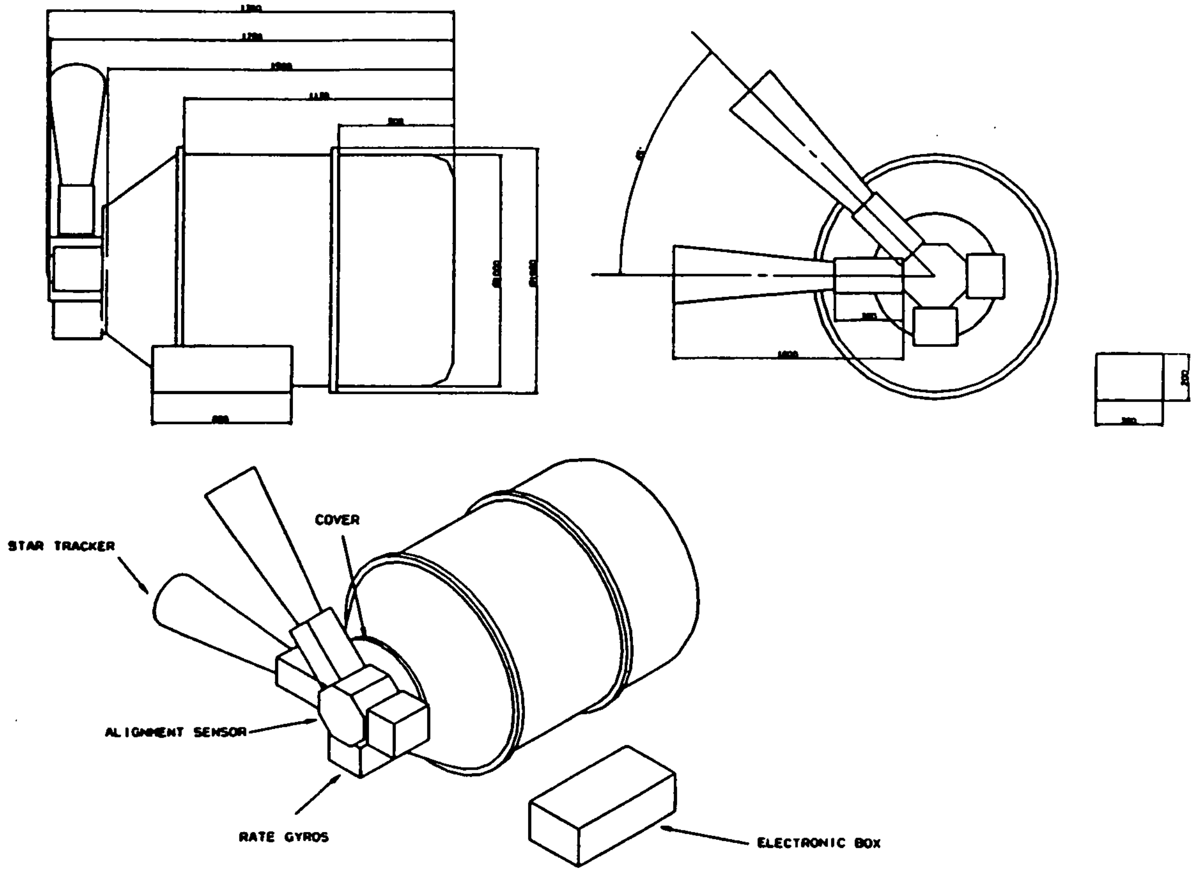


Figure 6-1. SGG Instrument Configuration—Preliminary

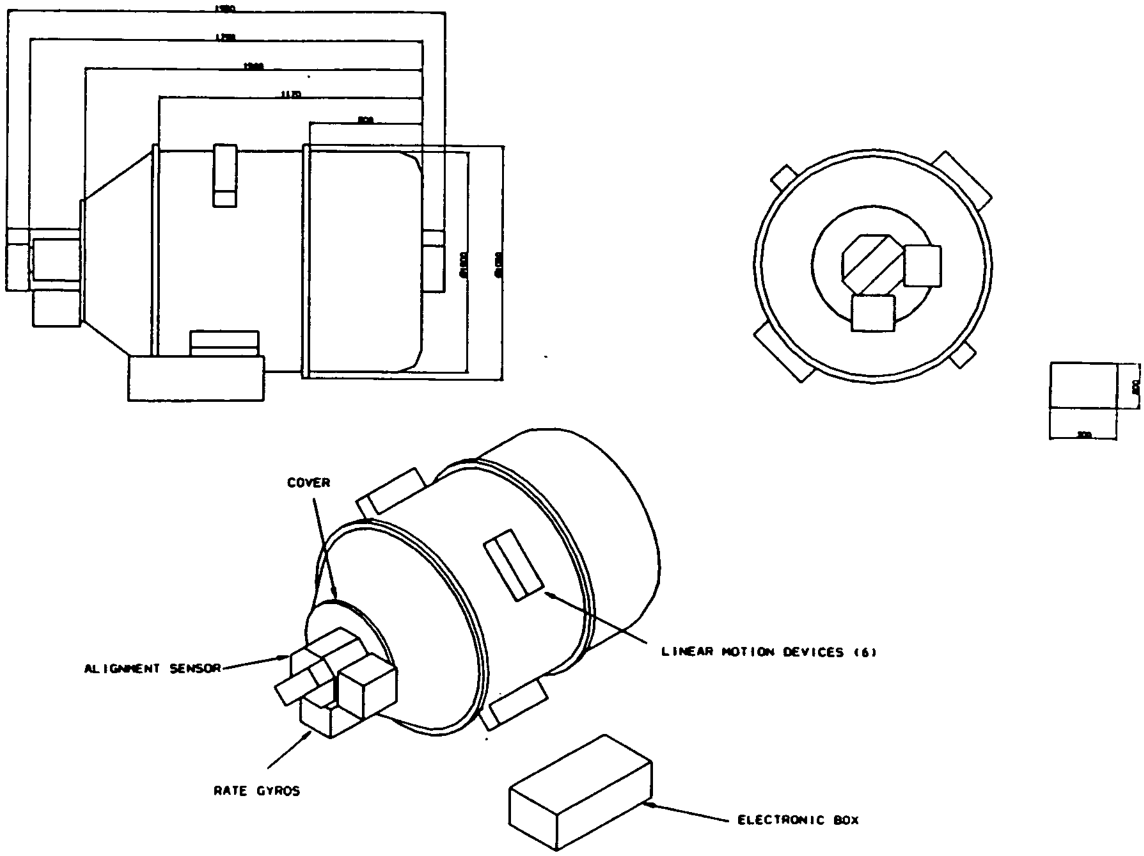


Figure 6-2. SGG Instrument Configuration—Final

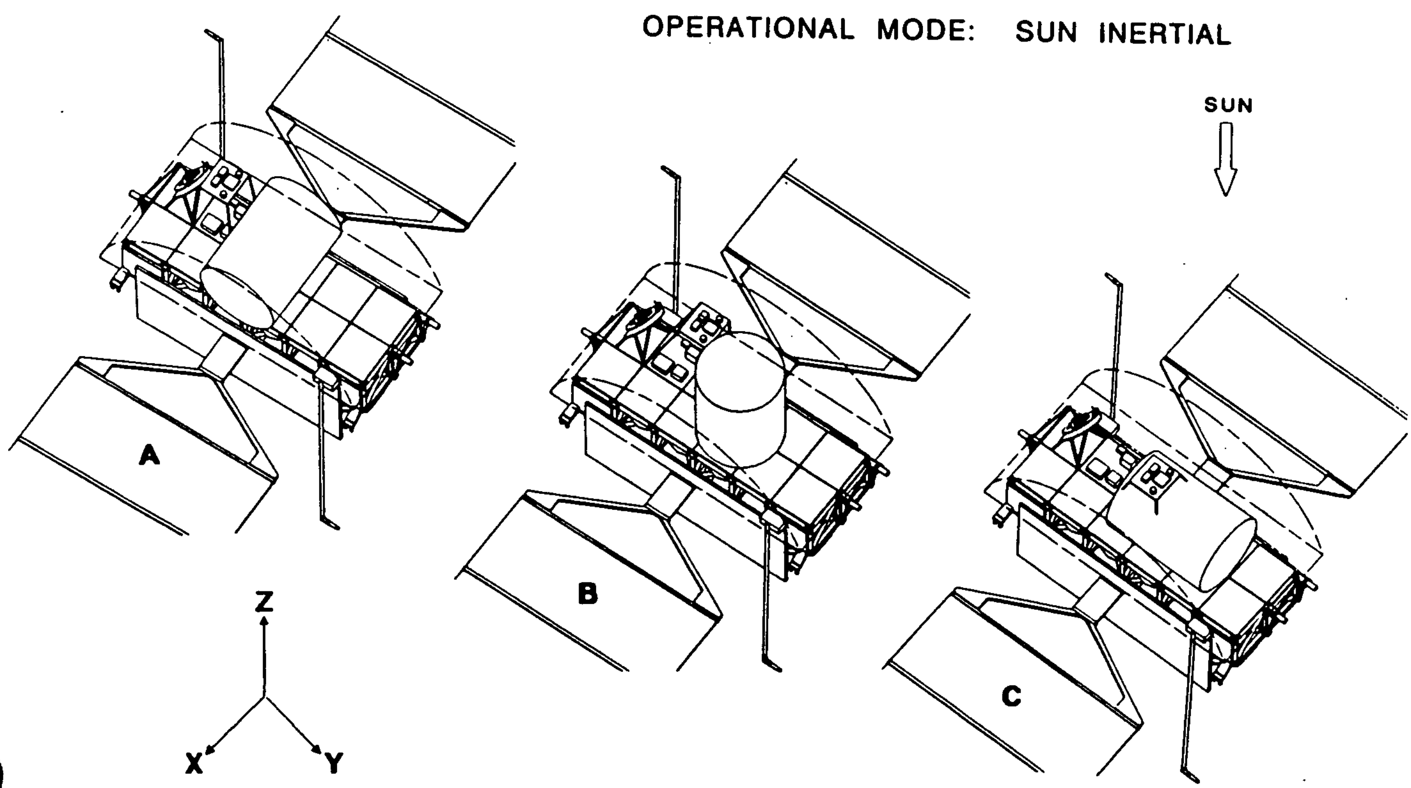


Figure 6-3. SGG Accommodation Options

Table 6-2. Configuration Options—Trade-Off

ACCOMMODATION GOAL	OPTIONS A	B	C
SGG inside Shuttle Transport Envelope	Yes	No	Yes
Close proximity SGG / ERC CG	< 1 m	< 1 m	< 1 m
Min. offset of SGG CG relative to EURECA Payload Deck	Approx. 500 mm	Approx. 880 mm	Approx. 500 mm
Maintain AOCS Sensor location	Yes	No	No
Min. obscuration of AOCS Sensor FOV by SGG	Yes (only CSS affected)	Achievable only by AOCS Tower redesign	Achievable only by AOCS Tower redesign
Optimum use of Payload Deck	4.5 Segments	4.5 Segments	4.5 Segments
	SELECTED OPTION		

With this configuration, all major criteria, except protrusions into the free field-of-view of the AOCS sensors, can be met (see Figure 6-4).

Preferred SGG Instrument Accommodation on EURECA

For calibration purposes, and in order to realize a degree of decoupling from EURECA higher frequency g-jitter, the SGG instrument is mounted, via six Linear Motion Transducers, to a frame, which itself interfaces with the SGG/EURECA mounting bracket.

This configuration is shown on Figure 6-5 and is the preferred SGG Instrument/EURECA configuration.

During Shuttle operations, however, the SGG instrument must be rigidly attached to the EURECA structure in order to comply with the frequency requirement of $f_1 > 30$ Hz (see Section 6.2). The corresponding locking/release mechanism has not yet been defined.

6.2 MECHANICAL INTERFACE

The basic support structure dimensions are selected in order to match the EURECA structure node pattern (see Figure 6-6).

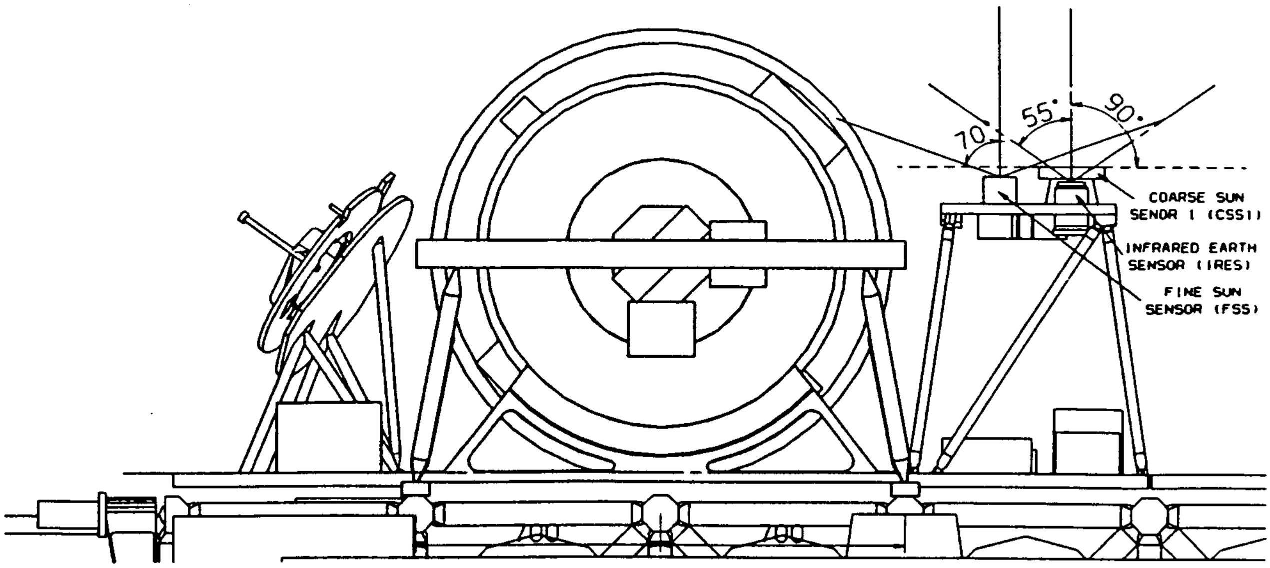


Figure 6-4. EURECA Sensor Field-of-View Analysis

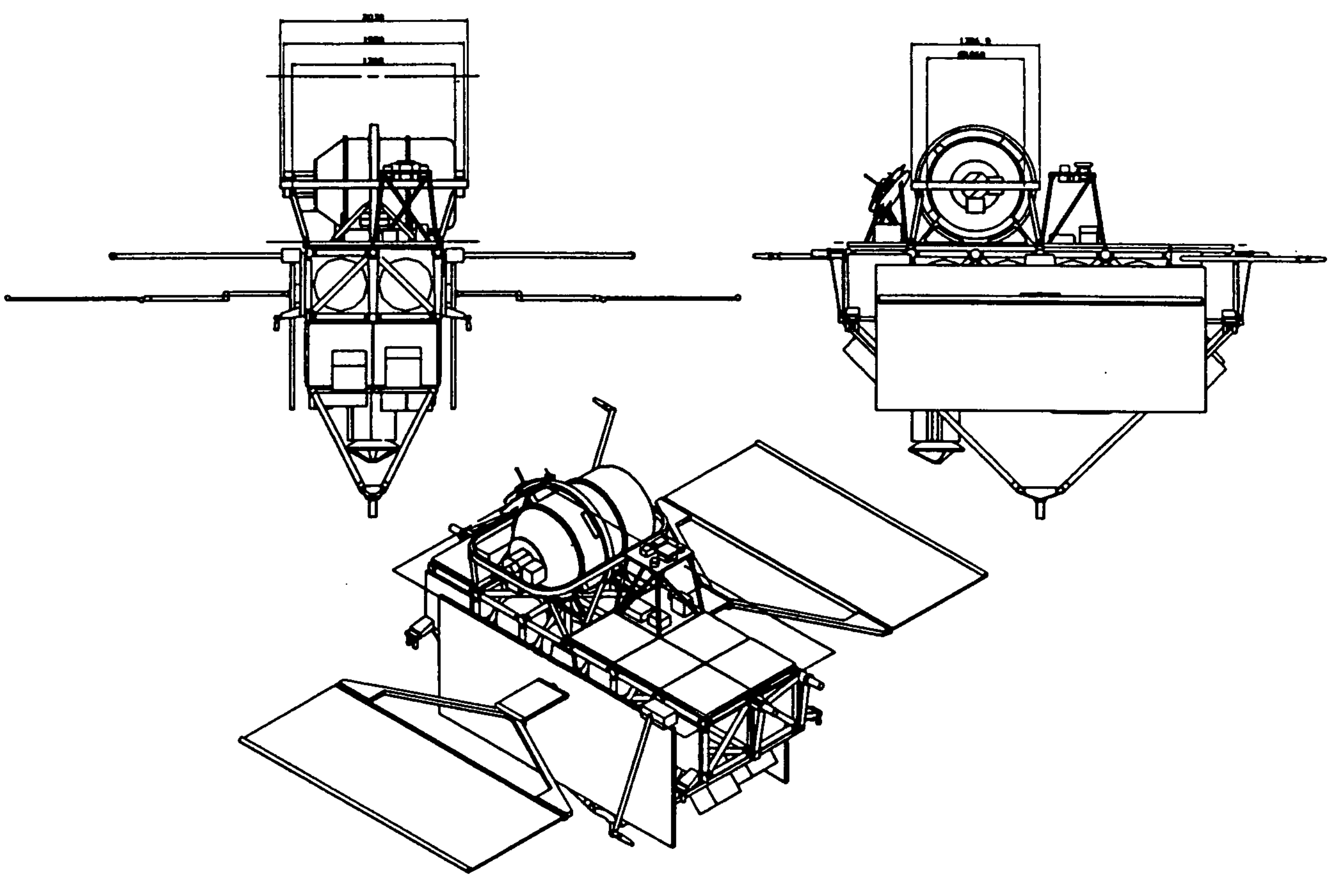


Figure 6-5. SGG Accommodation—Preferred Option

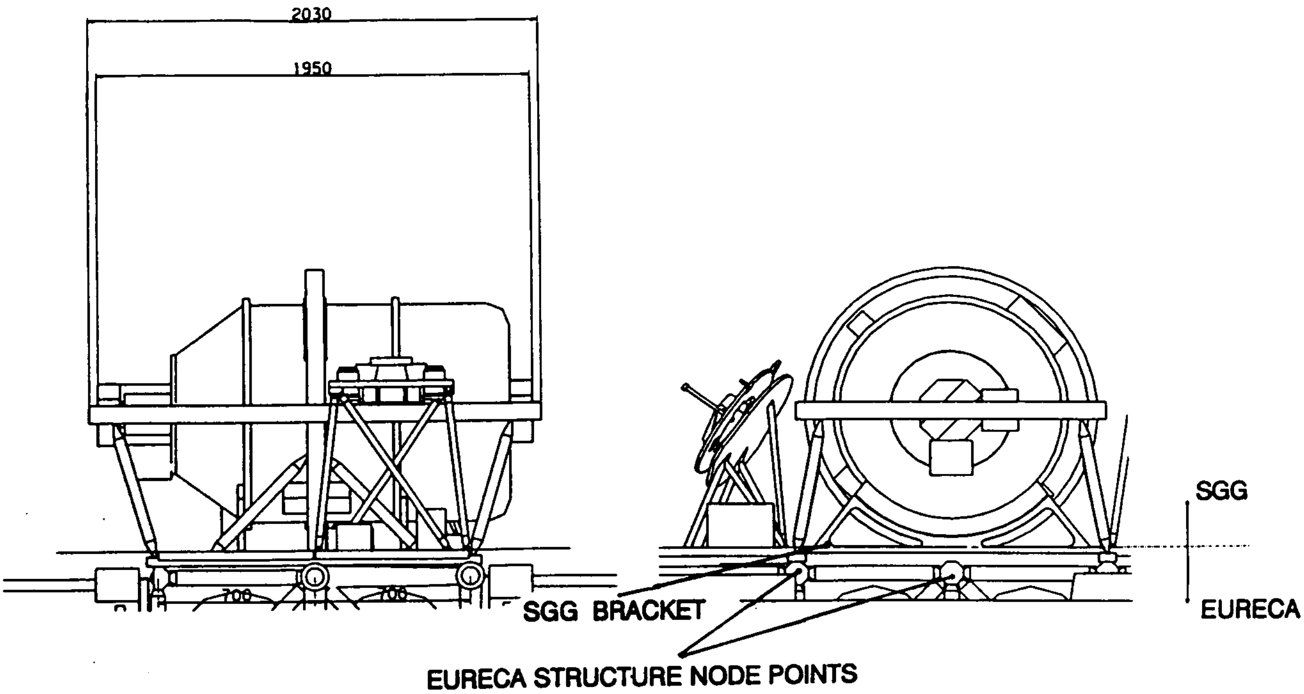


Figure 6-6. SGG Mechanical Interface—Support Structure

It is assumed, that the SGG instrument support bracket will be attached to EURECA at four structural node points with a load distribution as shown on Figure 6-7.

Limit Load Factor:

The stiffness requirement applies for launch and landing configurations. Figures 6-8 through 6-12 are based on the EURECA Environmental Test Specification, Document Number 1200608, and the EURECA Fracture Control Plan 12124-PL-ER-018.

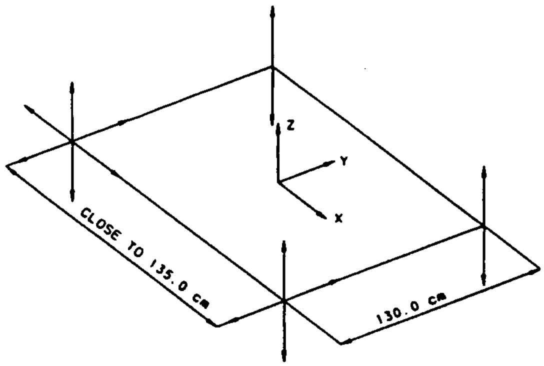
- n_l = 10 (g) to 13 (g), depending on final stiffness of the SGG instrument
- Acting at CG of SGG in worst spatial direction w.r.t. stresses and reactions
- For EURECA equipments/assemblies, within the stiffness requirements (see below), the L.L.F. are as on Figure 6-8

Safety Factors

Design of EURECA assemblies / equipment shall comply with the following safety factors:

Type of Verfication	*Yield*	*Ultimate*
by analysis and static test	1.1	1.4
by analysis only	1.25	2.0

POSITION OF THE SEVEN REACTIONS AT THE SGG/EURECA INTERFACE



LIMIT LOAD FACTORS:

N_i = 10 G TO 13 G, PENDING STIFFNESS OF SGG

ACTING AT SGG CoM IN WORST SPATIAL DIRECTION W.R.T. STRESSES AND REACTIONS

SAFETY FACTORS:

TYPE OF VERIFICATION	YIELD	ULTIMATE
ANALYSIS & STATIC TEST	1.1	1.4
ANALYSIS ONLY	1.25	2.0

STIFFNESS REQUIREMENTS:

FOR SGG ASSEMBLY OF APPROX. 400 KG:	>30 Hz
FOR SGG COMPONENTS:	>50 Hz

Figure 6-7. SGG Mechanical Interface—Interface Reactions

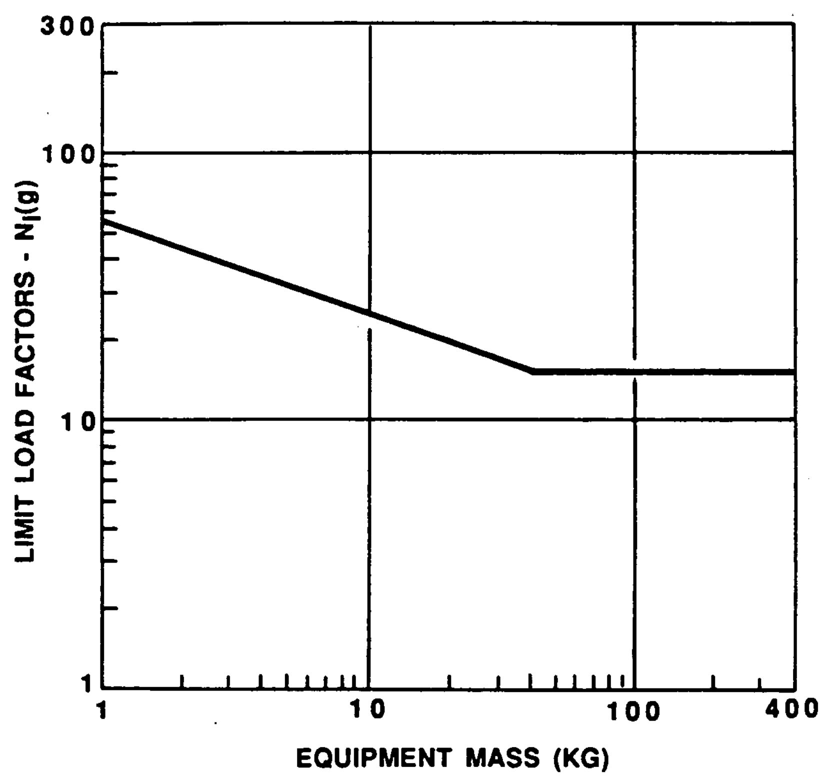


Figure 6-8. Limit Load Factors for Equipment / Bracket Design

Stiffness Requirements

For decoupling SGG from EURECA major modes, and considering a hard-mounted instrument configuration as previously described, the following requirements have to be met:

- For assemblies mounted on EURECA

  Mass 1.0 to 200 kg: f_1 greater than or equal to 35 Hz

  SGG = 432 kg: f_1 greater than or equal to 30 Hz

- For SGG components (active mass above 2 kg): f_1 greater than or equal to 50 Hz

- For SGG electronics (recommended for functional integrity): f_1 greater than or equal to 100 Hz

Design Life Safety/Damage Tolerance

In accordance with NASA NHB 1700.7B "Safety Policy and Requirements for Payloads using the Space Shuttle".

Qualification Tests

1. Sine Vibration (Qualification)

   a. Input into SGG Assembly as on Figure 6-9

   b. Notching of sine input at fundamental may become necessary in order to not exceed the limit load factor.

   Number of sweeps:

   Assuming 1 through 10 flights: 1 sweep up and down for each axis

2. Random Vibration (Qualification)

   a. Input into SGG Assembly as given on Figure 6-10

   b. Notching of random input at fundamental may become necessary in order to not exceed the limit load factor

   Relevant for:
   - mounted on nodal points
   - all axes
   - mass greater than 100 (kg)

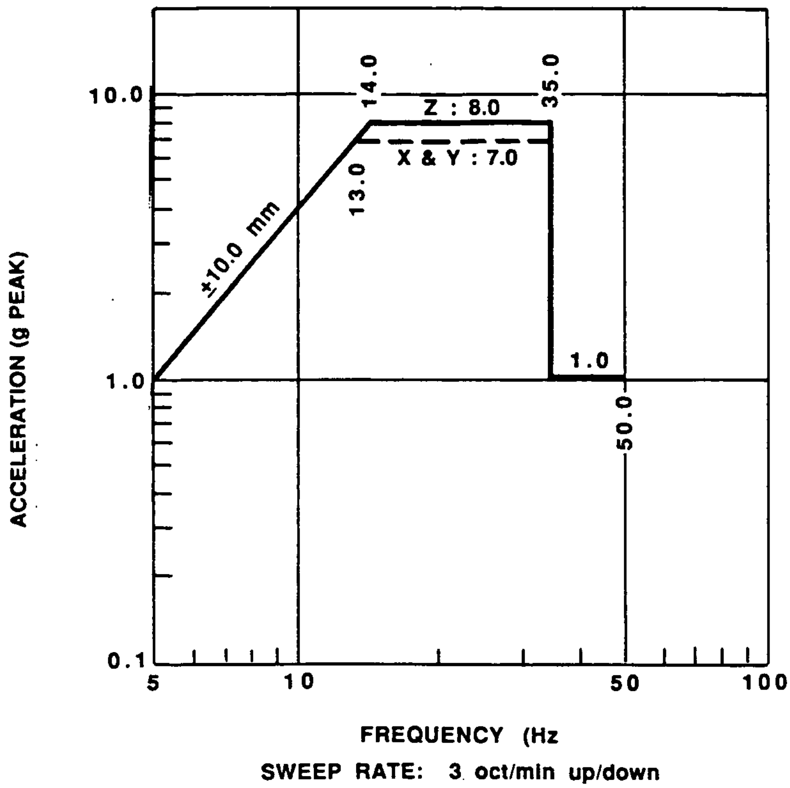
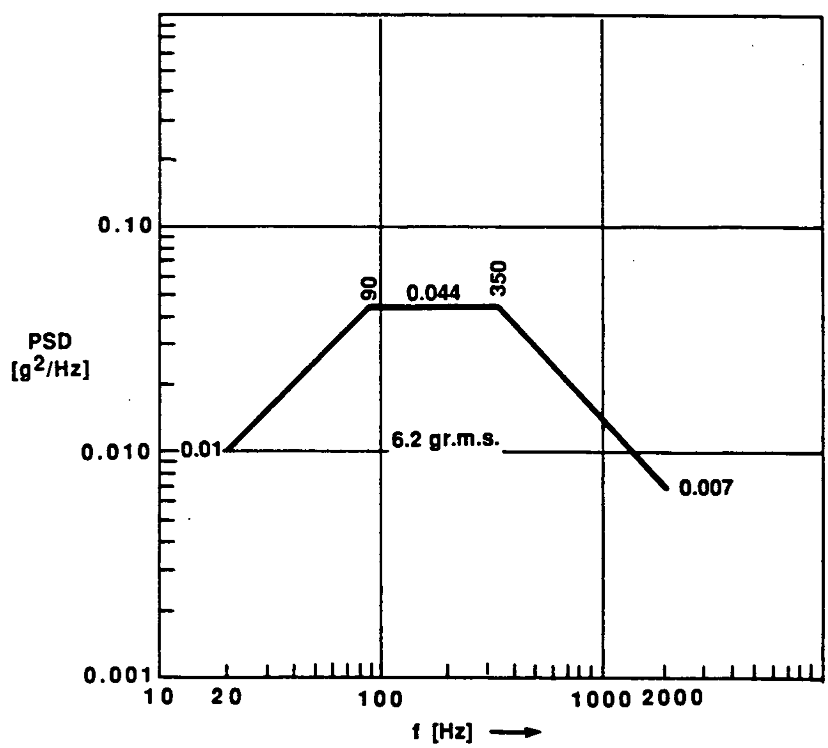


Figure 6-9. Sinusoidal Test Levels



Note: The above levels are, however, from 1984. With a potential update for EURECA 2 (1990/1991), lower levels (about 0.02 g2/Hz between 90 and 350 Hz) are expected.

Figure 6-10. Random Vibration Test Level / EURECA Environment for Protoflight Models

3. Acoustic Noise (Qualification)
   a. Input level as on Table 6-3.
   b. An acoustic test shall be performed on the SGG assembly when responses due to acoustics are expected to be dictating the random vibration environment for SGG components.
   c. Acoustic noise levels (Qual) shall also be used when defining random vibration, qualification test levels for SGG components.

Vibration Inputs for SGG Components

1. The definition of appropriate levels is the responsibility of the SGG design authority.
2. The qualification levels for sinusoidal and random vibrations shall not be below the above defined assembly levels.
3. The acceptance random vibration level shall not be below the levels given on Figure 6-11.

Shock

1. No shocks are expected during any flight condition.
2. Bench handling shock test is required for all component qualification models.

6.3 ELECTRICAL POWER

The SGG power requirements in the various mission phases can be met by the EURECA standard provisions (see Table 6-4).

6.4 DATA HANDLING

The SGG Instrument Requirements

The SGG Instrument requirements are summarized in Table 6-5.

The EURECA Capabilities

The software system for EURECA consists of the software packages that are needed by the various subsystem processors to control and monitor the operation of EURECA's subsystems and payload.

Table 6-3. Acoustic Noise Qualification Test Levels

1/3 OCTAVE BAND CENTER FREQUENCY [Hz]	ACOUSTIC NOISE TEST LEVEL [dB] Ref. $2x10^{-5}$ [N/m²]	TEST DURATION TIME QUALIFICATION MODEL	PROTOFLIGHT MODEL
31.5	122.0		
40.0	124.0		
50.0	125.5		
63.0	127.0		
80.0	128.0		
100.0	128.5		
125.0	129.0		
160.0	129.0		
200.0	128.5		
250.0*	127.0		
315.0*	126.0	100 sec + (50 sec per mission)	70 sec
400.0*	125.0		
500.0	123.0		
630.0	121.5		
800.0	120.0		
1000.0	117.5		
1250.0	116.0		
1600.0	114.0		
2000.0	112.0		
2500.0	110.0		
Overall:	138.0		

Note: Starred (*) frequencies may have higher sound power levels associated with shuttle orbiter vents.

Note: Noise levels due to Shuttle vent door: the levels depend on the distance between the item and the vent door.

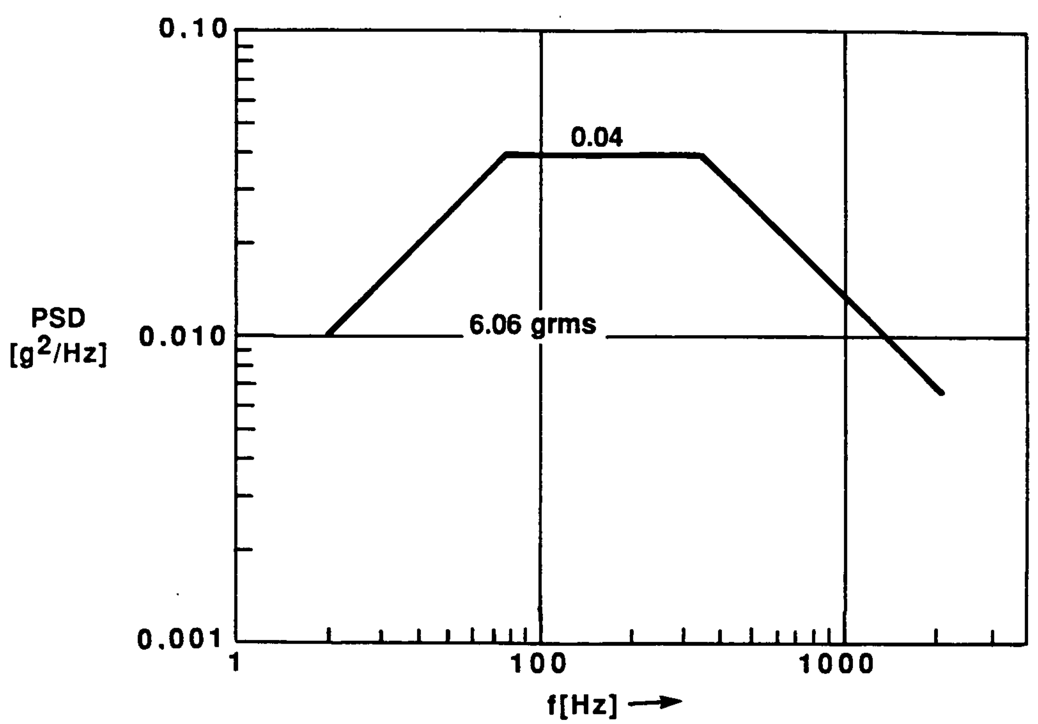


Figure 6-11. Random Vibration Acceptance Level

Table 6-4. Electrical Power

SGG POWER REQUIREMENT

EURECA MISSION PHASE	SGG POWER DEMAND	SGG ACTIVITY/TASK	DURATION
DEPLOYMENT	190	GO/NOGO TEST	90 MINUTES
ORBIT TRANSFER	0	---	2 DAYS
PAYLOAD OPERATIONAL	270	CALIBRATION	90 MINUTES REPEATEDLY
	190	PERFORMANCE VERIFICATION AND SCIENCE DATA GENERATION	
	100	STAND BY	MONTHS

ACCOMMODATION

THE SGG REQUIREMENT CAN BE SATISFIED BY A STANDARD EURECA POWER OUTLET, WITH THE FOLLOWING FEATURES:

VOLTAGE LEVEL:	24 TO 28.5 V
RATING	16 AMPS
INDIVIDUALLY SWITCHABLE AND PROTECTED	

Table 6-5. Data Handling Requirements

SGG REQUIREMENT:

SGG TASK/ACTIVITY	SGG DATA GENERATION RATE (kbps)	DURATION	TOTAL NET DATA PER EVENT (Mbits)
GO/NOGO TEST	0.8 + TBD	90 MINUTES	TBD
CALIBRATION CYCLE	24.128	90 MIN. PERIODS, REPEATED	130.3
MEASUREMENT CYCLE	6.848	90 MIN. PERIODS, REPEATED	37.0
HOUSE KEEPING (HK)	0.8	CONTINUOUS ALSO DURING STAND-BY PERIODS	---

The software system provides interfaces to the Space Transportation System, to the EURECA ground segment and to each instrument.

In the flight configuration of EURECA, the onboard software performs all monitoring, control and sequencing necessary to fly the spacecraft and operate the instruments. Due to the limited ground contact with the operation center the onboard software has the capability to operate the subsystems and payload autonomously and to recover from basic failures within the constraints of the EURECA software system capabilities.

The nominal ground station during the EURECA operational phase is Maspalomas (Canary Islands). For extended tracking and commanding capabilities during the EURECA ascent and descent maneuvers, additional ground stations at Perth (Australia), Malindi (Kenya) and Kourou (French Guiana) are employed.

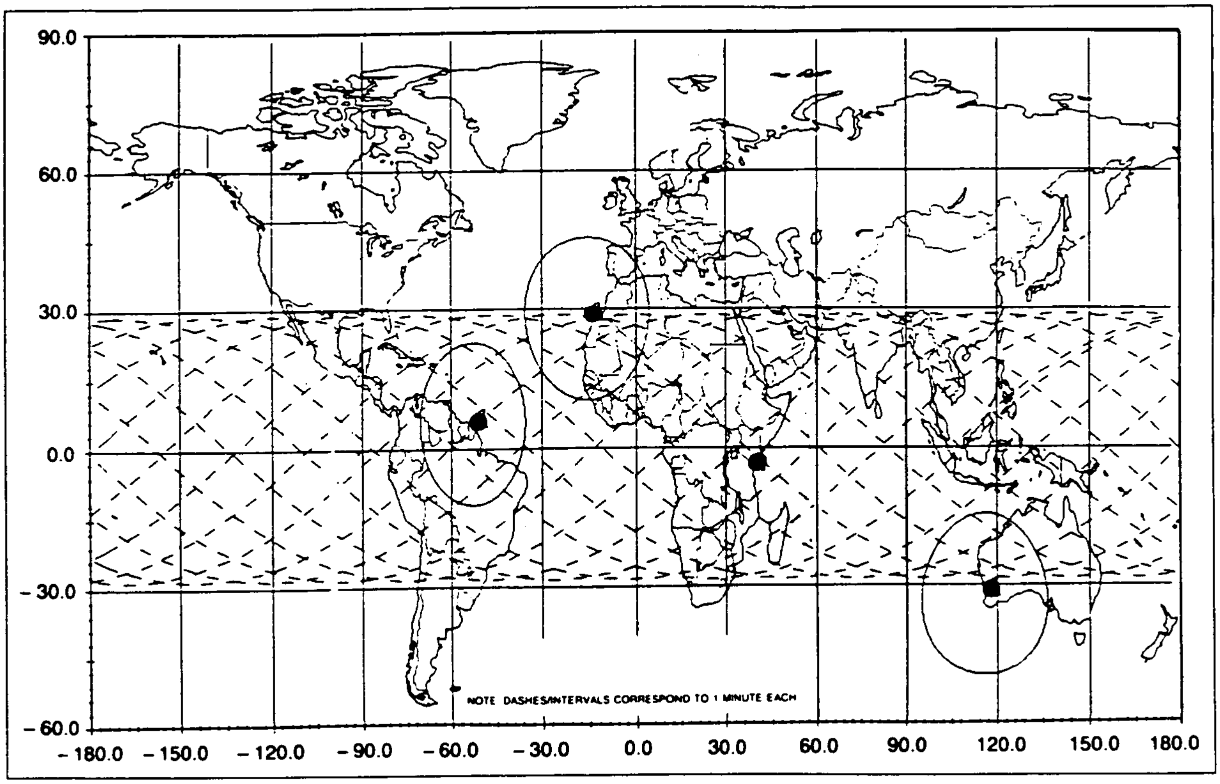
During ground contact all data stored during non contact time from payload and subsystems as well as real-time telemetry data will be sent to the ground station. The operation control center can command the carrier by immediate or time tagged commands. EURECA on-board software provides the capability for maintenance/update via the Telemetry/Telecommand command interfaces.

During EURECA deployment and retrieval operations, a continuous contact with the operation control center is foreseen to allow intimate EURECA monitoring and quick reaction control. This is the period when EURECA is in range of the Shuttle PI link. The data collection/distribution on-board and communication to ground is performed by using packet telemetry/telecommand mechanisms.

A schematic of this system and the related capabilities for on- board and space-to-ground communication is given in Figure 6-13.

In addition to the amount of "net" telemetry data generated within the instrument, the packet concept requires, that headers and trailers be added to each packet. For the accommodation considerations below, the following percentages of packet overheads were assumed:

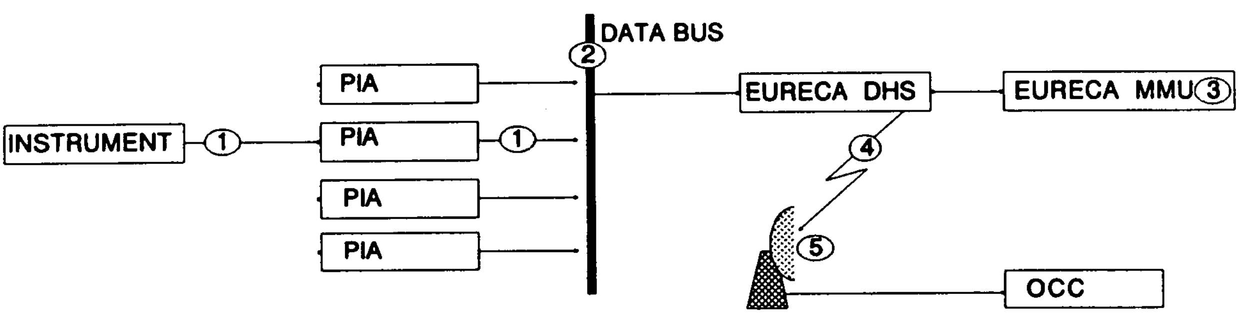
1. For an optimum (i.e. maximum) SGG packet length, the overhead for the link between the instrument and the PIA is approximately 3 %.
2. For intermediate storage of data on the EURECA Mass Memory Unit (MMU), it is approximately 5 %.
3. For the downlink of data to a ground station, the overhead is approximately 10 %.



Three stations monitor EURECA's signals during the retrieval phase: Perth in Australia (right below), Maspalomas in the Canary Islands and Kourou (French Guiana).

Figure 6-12. EURECA Ground Stations

EURECA CAPABILITIES FOR INSTRUMENT TELEMETRY DATA HANDLING



1. MAX. 20 kbps PER CHANNEL
2. MAX. 80 kbps BURST RATE FOR MULTI-USER OPERATION
3. MASS MEMORY UNIT CAPACITY: 104 Mbits FOR INSTRUMENT DATA (STORAGE OF 1.5 Kbps OVER 17 HRS NON GROUND-CONTACT TIME)
4. HIGH SPEED LINK: 250 Kbps PAYLOAD AND SYSTEM DATA
5. ONE GROUND STATION: TYPICALLY 5 PASSES PER DAY
   MAX. NON GROUND CONTACT TIME 17 HOURS
   TYPICAL CONTACT TIME PER PATH: 8 MINUTES

Figure 6-13. EURECA Data Handling Capabilities

Discussion of Issues

1. Data Transfer: Instrument-to-PIA Channel Capacity Shortage

   a. Measurement:

      The data rate of 6.9 kbps is well within PIA limits.

   b. Calibration:

      The data rate is 24.1 kbps calibration data
      + 0.8 kbps housekeeping data

      24.9 kbps "net" SGG data

      * 1.03 = 25.7 kbps on instrument/PIA channel

   Viable design solutions are identified in Figure 6-14.

2. Data Storage: Mass Memory Unit (MMU) Capacity Limitations

   The amount of SGG data to be stored on the MMU will exceed the capacity of the MMU for intermediate payload data storage, which is limited to 104 Mb:

SGG Task	*Amount of MMU Data*
calibration	130.3 + overheads = 140.9 Mb
measurements	37.0 + overheads = 40.0 Mb
housekeeping/hr	2.9 + overheads = 3.1 Mb/hr

   a. SGG Measurement Task

      As can be seen from the above Table, the 40.0 Mb SGG data per measurement cycle can be stored on the MMU together with the continuously-generated SGG housekeeping data, which amount to 52.9 Mb for a 17 hour EURECA non-ground-coverage period.

   b. SGG Calibration Task

      Here, the above Table indicates, that the MMU capacity does not comply with the 193.8 Mb storage requirement (140.9 Mb from calibration plus 52.9 Mb from housekeeping)

      Viable design and operational solutions are identified in Figures 6-15 and 6-16.

6.5 ENVIRONMENTAL ANALYSIS

Thermal Environment

The thermal environment offered by EURECA for payload instruments accommodated within the system Multi-Layer Insulation (MLI) tent is maintained in the temperature range –10°C to +40°C over the mission.

PRESENT SITUATION:

THE SGG DATA GENERATION RATE DURING CALIBRATION (25.7 + 0.8 Kbps) IS CONSIDERABLY HIGHER THAN THE CAPACITY OF A PIA CHANNEL

SOLUTIONS:

- INTERMEDIATE STORAGE OF DATA WITHIN SGG AND LATER TRANSFER TO THE EURECA DHS AT A REDUCED RATE
- MULTIPLEXING OF SGG DATA USING 2 PIA CHANNELS TO ACHIEVE THE REQUIRED 26.5 Kbps CAPABILITY
- REDUCTION/COMPRESSION OF DATA WITHIN SGG TO CORRESPOND WITH A TELEMETRY DATA RATE OF LESS THAN 20 kbps

Figure 6-14. PIA Channel Capacity

PRESENT SITUATION:

THE EURECA MASS MEMORY UNIT (MMU) CAPACITY FOR INSTRUMENT TELEMETRY (104 Mbits) IS SMALLER THAN THE AMOUNT OF DATA GENERATED BY AN SGG CALIBRATION CYCLE CYCLE (MORE THAN 140.9 Mbits)

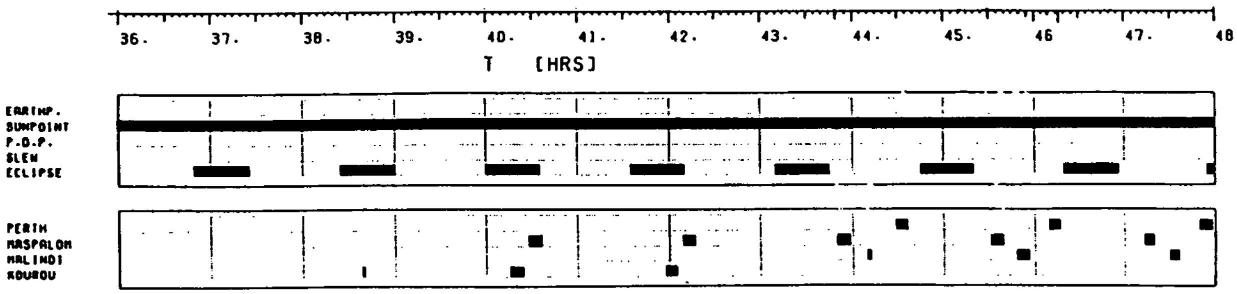
SOLUTION:

- THE EURECA MMU CAPACITY CAN BE DOUBLED BY ADDITIONAL MEMORY PAGES TO A TOTAL OF 256 Mbits, I.E. APPROX. 232 Mbits AVAILABLE FOR PAYLOAD DATA
- REDUCTION/COMPRESSION OF DATA WITHIN SGG TO REDUCE THE AMOUNT OF DATA TO BE STORED IN THE MMU
- USE OF ADDITIONAL GROUND STATIONS AND EXECUTION OF SGG CALIBRATION CYCLES DURING ORBIT PERIODS WITH MAXIMUM DOWNLINK TIMES

Figure 6-15. On-board Data Storage

ENHANCED EURECA DOWNLINK CAPABILITIES BY ADDITIONAL GROUND STATIONS

- → NOMINAL EURECA GROUND STATION: MASPALOMAS
- → POTENTIAL ADDITIONAL GROUND STATIONS: KOUROU, MALINDI, PERTH
- → STRATEGY: PERFORM SGG CALIBRATION CYCLES DURING ORBIT PERIODS WITH MAX. DOWNLINK TIMES



TYPICAL OPTIMIZED WINDOW FOR SGG CALIBRATION

ON-BOARD STORAGE W.O. DATA DUMP: 97 Mbits CALIBRATION+ HK DATA (1 H)

DUMP OF UP TO 87.4 Mbits INSTRUMENT NET DATA PER GROUND SEGMENT PASS

Figure 6-16. EURECA Ground Station Contact Periods

From the accommodation standpoint, it is favorable to decouple the SGG dewar thermally from the EURECA environment specified above, i.e., the SGG design should include passive cooling techniques. SGG equipment mounted separately to the dewar should have its own thermal control, which could be provided by EURECA. SGG internal high stability circuits may require a very stable thermal environment which must be provided by the SGG internal controls.

The starting point for establishing a thermal control concept is a SGG Thermal Mathematical Model (TMM) nodal distribution as defined on Figure 6-17.

The related thermal properties are given in Table 6-6.

The SGG TMM may be used to identify critical items which will have to be investigated by a detailed thermal analysis.

Microgravity Environment

Refer to Section 7.2.

Electromagnetic Environment

Refer to section 7.5.

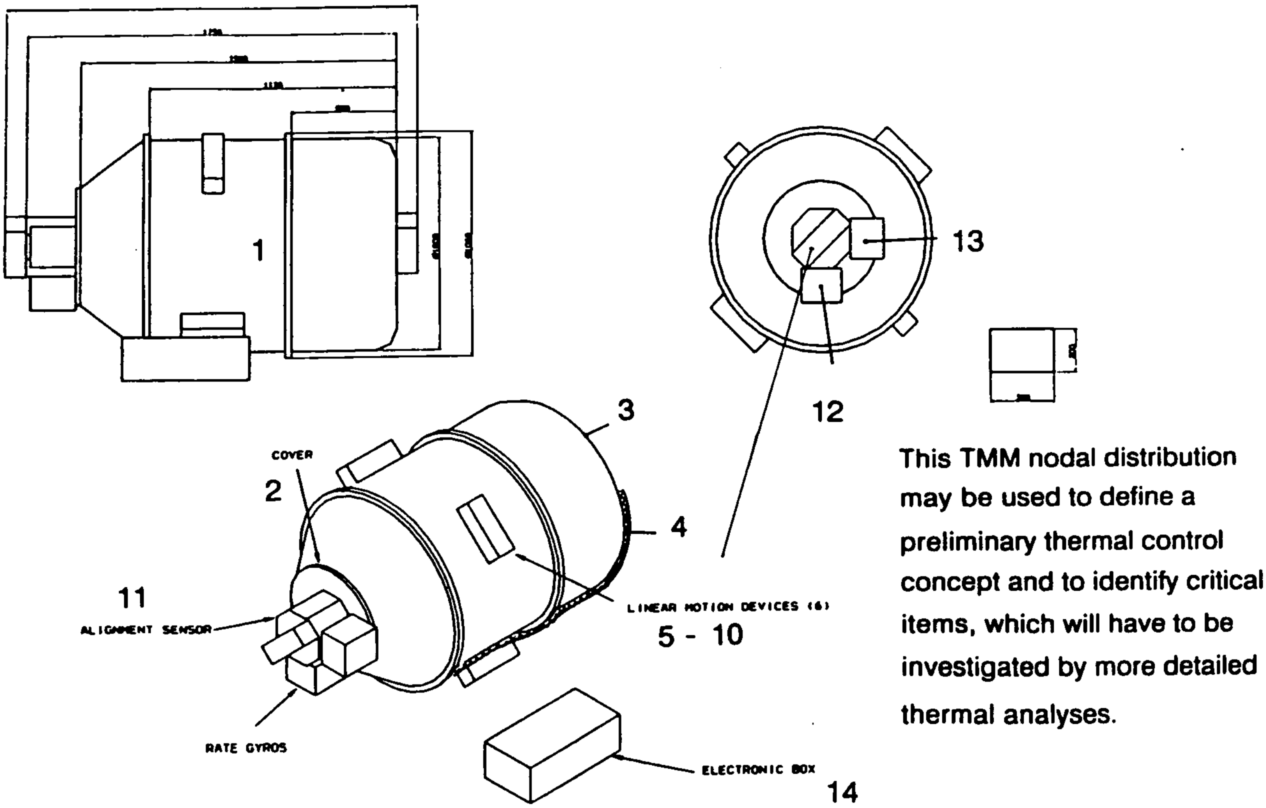


Figure 6-17. SGG Thermal Node Model (Proposal)

6.6 OPERATIONAL ANALYSES, MISSION PROFILE

One of the SGG Flight Test Objectives is to obtain scientific data during periods of least disturbance to the instrument caused by the carrier and its environment, and at altitudes down to 250 km. This objective can be met by operating EURECA in a "quiet" mode, i.e. by operating it with the disturbing subsystems switched off, and by making use of EURECA's orbit transfer capability.

The feasibility of achieving this objective is dependent on:

- EURECA's orbit transfer propellant capacity and
- EURECA's onboard battery capacity and performance.

The minimum instrument disturbance mode is achieved by orbiting EURECA with quiescent subsystems and in an earth pointing mode in which the platform's Z-axis is aligned with the velocity vector. EURECA's normal attitude is sun inertial. Consequently, and because the carrier has fixed solar arrays, the platform can only be operated in an earth pointing mode for about three orbits (approx. 4 1/2 h) before the batteries must be recharged by re-aligning the carrier with the sun. This mode may be repeated several times. The individual earth pointing periods are considered to be adequately long for obtaining useful scientific data and also for calibrating the instrument.

Node No.	Item	Dimensions (mm)	Weight (kg)	Specific Heat (J/kgK)	Power Dissipation (W)	Solar Absorp. alpha (-)	Infrared Emissivity epsilon(-)	Interface Conductance (W/K)	MLI Cond. (W/m K)	Operat. Temperature Limits min/max (°C)
1	SGG/SSA Assy Dewar Int.(1)		80.0	900.0 (2)	<1.0				epsilon_{eff} = 0.0022(7)	<-271
2	SGG Cover	d=500	50	900.0 (2)	N/A	0.20 (6)	0.05(5)/0.85(6)	0.01(8)		
3	SGG Cyl.	d=1000, l=1500	110	900.0 (2)	N/A	0.20 (6)	0.85(6)	0.20(3)		
4	SGG Ext. MLI		3.0	900.0 (2)	N/A	0.36	0.80		9×10^{-4}	
5	Lin. Mot. Tr. 1	200x100x100	3.5	900.0 (2)	5.0 (2)	0.20 (4)	0.85(4)	2.00		-25/+50(2)
6	Lin. Mot. Tr. 2	200x100x100	3.5	900.0 (2)	5.0 (2)	0.20 (4)	0.85(4)	2.00		-25/+50(2)
7	Lin. Mot. Tr. 3	200x100x100	3.5	900.0 (2)	5.0 (2)	0.20 (4)	0.85(4)	2.00		-25/+50(2)
8	Lin. Mot. Tr. 4	200x100x100	3.5	900.0 (2)	5.0 (2)	0.20 (4)	0.85(4)	2.00		-25/+50(2)
9	Lin. Mot. Tr. 5	200x100x100	3.5	900.0 (2)	5.0 (2)	0.20 (4)	0.85(4)	2.00		-25/+50(2)
10	Lin. Mot. Tr. 6	200x100x100	3.5	900.0 (2)	5.0 (2)	0.20 (4)	0.85(4)	2.00		-25/+50(2)
11	Aligmm. Sensor	d=250, l=250	6.8	900.0 (2)	7.0(4)	0.20 (4)	0.85(4)	0.60(4)		-25/+50(4)
12	Rate Gyros1	200x150x150	4.3	900.0 (2)	4.0	0.20	0.10	0.40		-10/+50
13	Rate Gyros2	200x150x150	4.3	900.0 (2)	4.0	0.20	0.10	0.40		-10/+50
14	Electr. Box	600x300x200	46.0	900.0 (2)	50.0(4)	0.20 (4)	0.85(4)	2.00		-25/+50(4)

Notes:
(1) incl. Helium
(2) assumption, based on similar components
(3) decoupled from structure, basing on interface conductance for MAUS containers
(4) assumption, based on similar experiment components (GAUSS-Camera, MOMS-02 etc.)
(5) internal
(6) external
(7) the Dewar MLI conductance is reflected by the above mentioned effective epsilon value
(8) estimated for I/F conductance to SGG/SSA

Table 6-6. SGG Thermal Properties

Disturbances to the carrier arising from its environment can also be minimized by orbiting EURECA at higher than its nominal mission altitude (500 km). Carrier operation at higher altitudes (800 km), however, does not satisfy the scientific objective requirement, even though, at this altitude, with quiescent subsystems and with the carrier oriented in earth pointing mode, the conditions for instrument calibration can be met.

Variations in EURECA's mission profile have been investigated with respect to the propellant mass required to conduct the SGG Flight Test Mission. The mission profile, which sizes EURECA's basic propellant quantity is shown on Figure 6-18; the variations to the mission are shown on Figures 6-19 through 6-21 and the results of the investigation are summarized in Table 6-7. As can be seen, mission options 2 and 3 are not feasible because the quantity of propellant required for these combinations of orbits cannot be accommodated onboard EURECA. Mission option 1 is feasible but it will require 4 extra tanks (three Hydrazine and one pressurant) to be accommodated on the payload deck alongside the SGG instrument. In this case, EURECA will be dedicated to the SGG Flight Test Mission, since the instrument and extra propellant and subsystem mass is approx. 1000 kg (EURECA's maximum payload mass). The mission profile shown on Figure 6-22 is, therefore, recommended. In this case, EURECA is operated at its nominal altitude and the scientific measurements are made during the retrieval period at an altitude of about 300 km prior to EURECA's rendezvous with the Shuttle (see also Section 8.4).

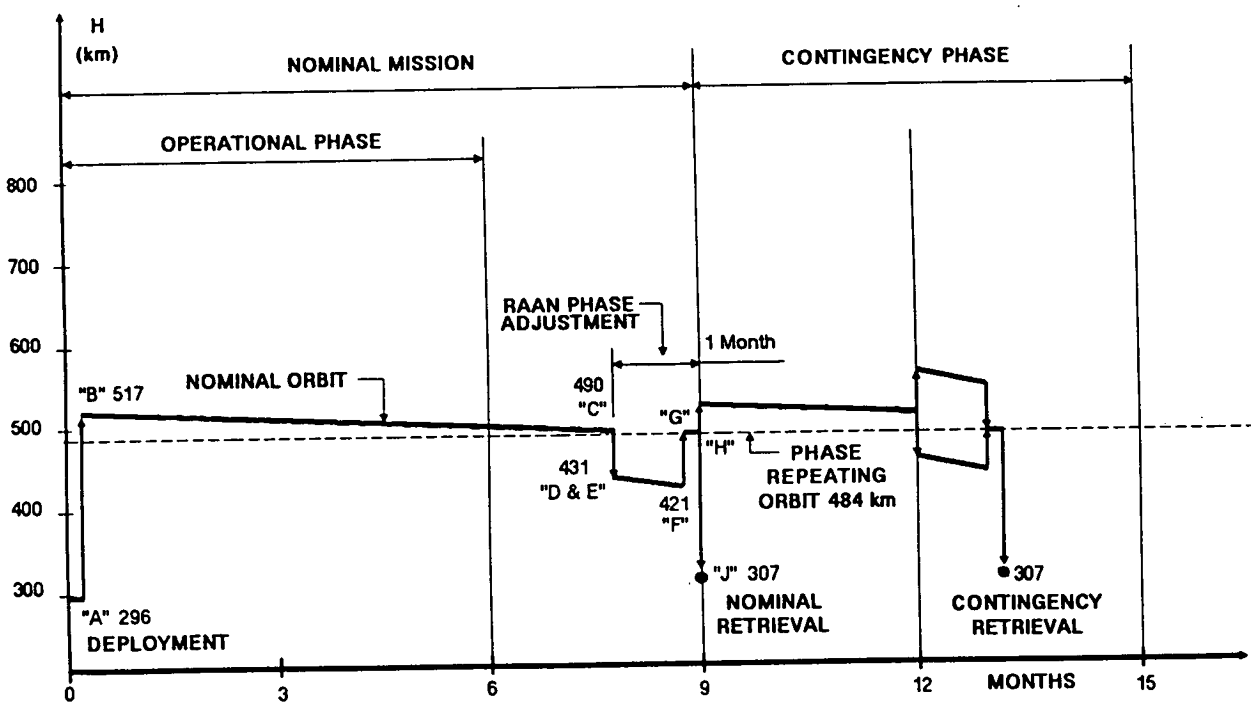


Figure 6-18. EURECA Mission 1—Propellant Budget Design Case

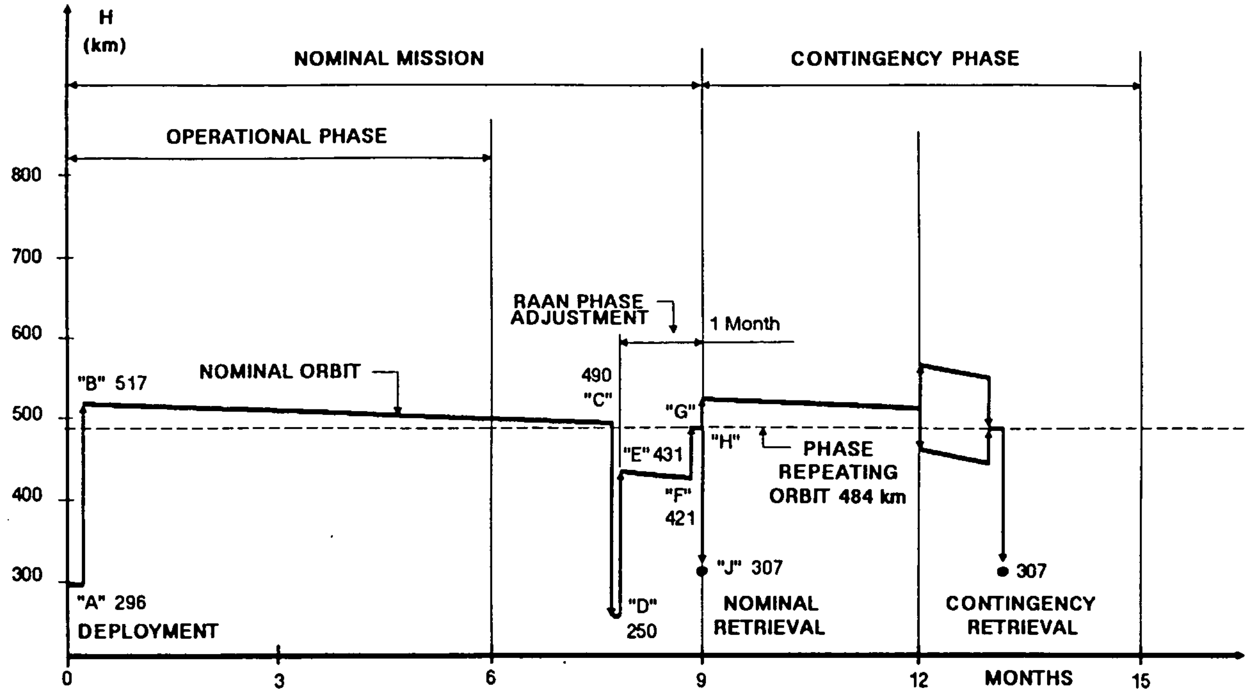


Figure 6-19. SGG Flight Test Mission Profile—Option 1

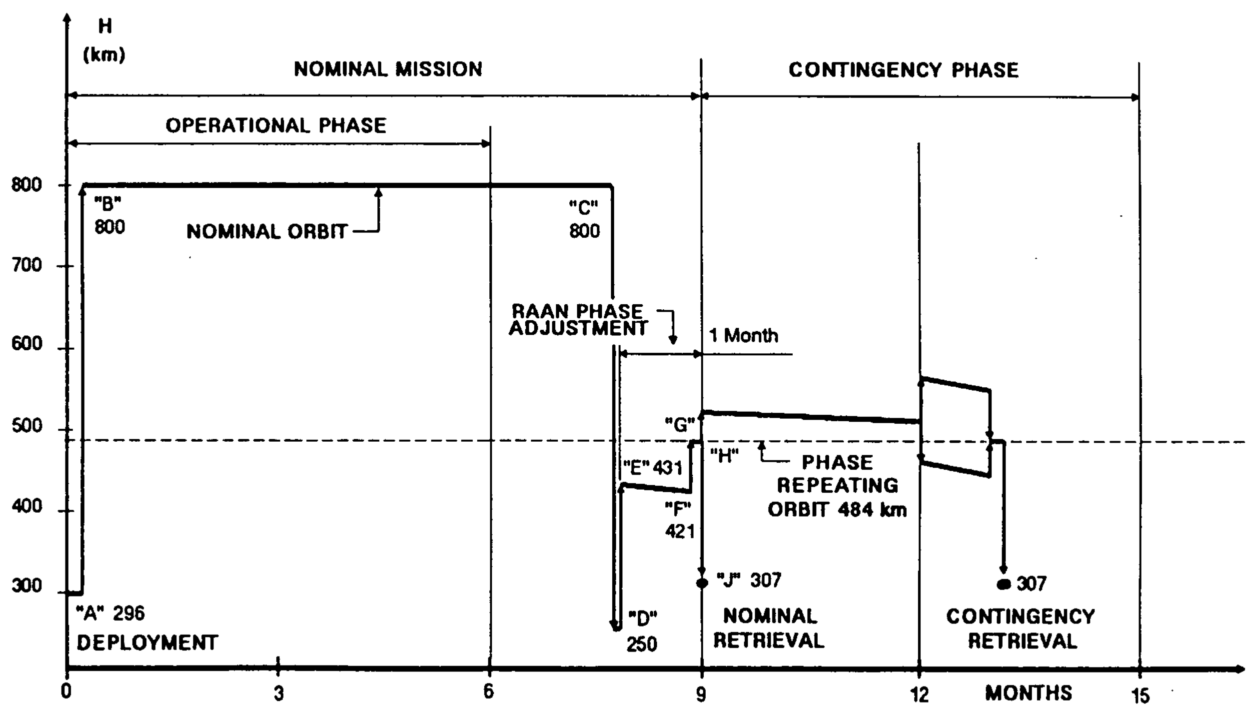


Figure 6-20. SGG Flight Test Mission Profile—Option 2

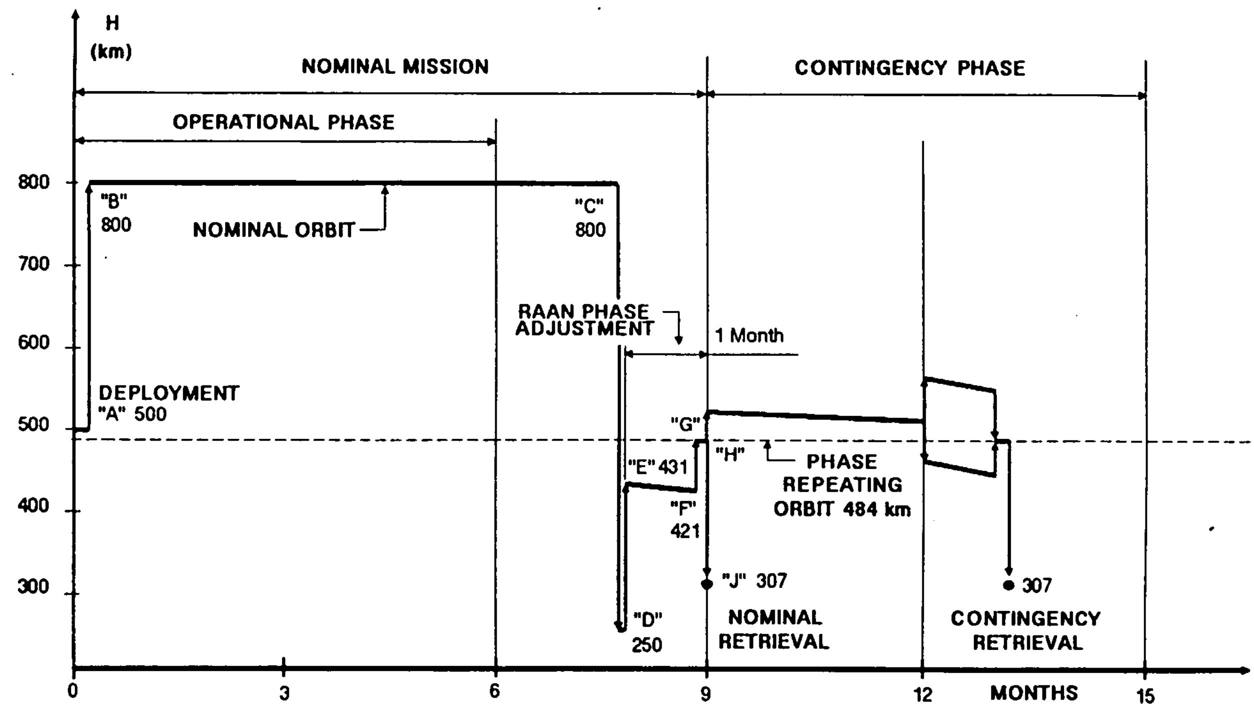
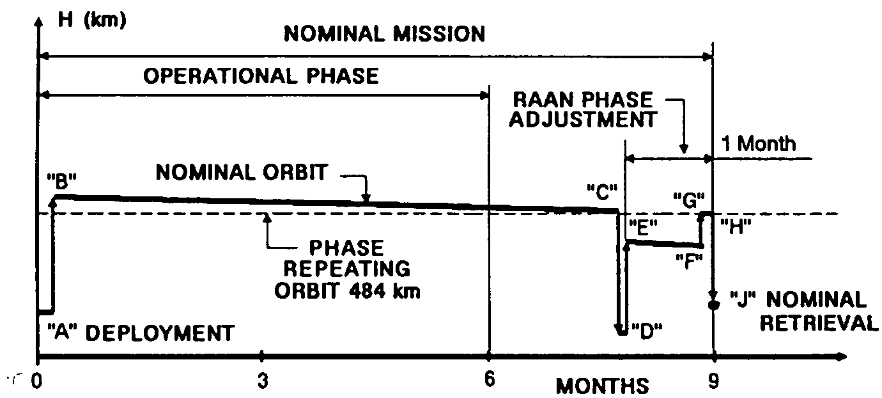


Figure 6-21. SGG Flight Test Mission Profile—Option 3

Table 6-7. SGG Flight Test Mission Profiles—Propellant Budgets



INITIAL MASS	4400 kg
SPECIFIC IMPULSE	223 sec
PROPELLANT	HYDRAZINE

m = OTM PROPELLANT MASS

REGION	B/L		1		2		3	
	H	m	H	m	H	m	H	m
A - B	296 - 517	244	296 - 517	244	296 - 800	522	500 - 800	312
B - C	517 - 490	0	517 - 490	0	800 - 800	0	800 - 800	0
C - D	490 - 431	61	490 - 250	252	800 - 250	501	800 - 250	501
D - E	431 - 431	0	250 - 431	181	250 - 431	157	250 - 431	157
E - F	431 - 421	0	431 - 421	0	431 - 421	0	431 - 421	0
F - G	421 - 484	65	421 - 484	65	421 - 484	65	421 - 484	65
G - H	484 - 484	0	484 - 484	0	484 - 484	0	484 - 484	0
H - J	484 - 307	177	484 - 307	177	484 - 307	177	484 - 307	177
Total kg		547		919		1422		1212

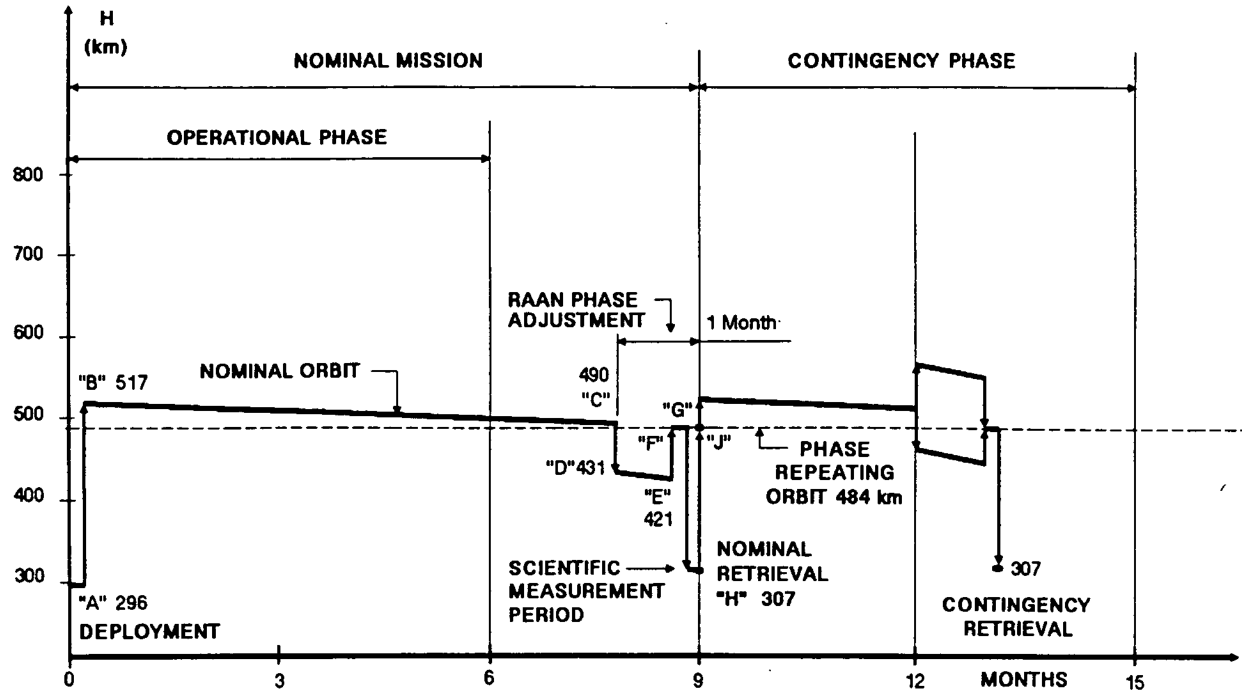


Figure 6-22. Recommended SGG Flight Test Mission Profile

SECTION 7
SPECIAL STUDIES

During the course of the flight test study, several issues were identified which necessitated complementary studies to resolve them. These special studies are presented in this section.

7.1 ON-ORBIT CALIBRATION TECHNIQUES

The Superconducting Gravity Gradiometer (SGG) is calibrated in five steps. These are listed in Table 7-1 and shown in more detail in Appendix B. The first two steps (Six-Axis Superconducting Accelerometer (SSA) Bridge Balance and SGG Accelerometer Balance) do not require any input excitation. The final three steps all require background noise levels below 2.0 X 10^{-8} g/Hz$^{1/2}$ and 0.2 arcsec/sec^{2}Hz$^{1/2}$. The expected noise levels will be discussed in Section 7.2. Each of the final three steps also requires input linear and/or angular accelerations that are well known.

The SGG Gradiometer Balance requires a sinusoidal input signal of 10^{-6} g with a frequency of 0.1 Hz. The required signal duration of 10.0 seconds is equivalent to only one cycle, so it is recommended that 50.0 seconds of data be acquired to avoid contamination by startup transients. This acceleration should be applied along the "umbrella" axis of the gradiometer. This is the axis which is parallel with the vector sum of the three sensitive axes of the gradiometer.

The SSA/SGG Accelerometer Calibration requires a sinusoidal input signal of 10^{-5} g at 1.0 Hz. This input is applied parallel to one of the sensitive gradiometer axes for a period of 3.0 minutes. The signal is then repeated along each of the two remaining sensitive axes. This step also requires angular acceleration inputs with a magnitude of 100 arcsec/sec^2 at 1.0 Hz with a duration of 3.0 minutes which are applied in a manner similar to the linear inputs except that they are applied about the sensitive axes of the gradiometer rather than along them.

Finally, the SGG Gradiometer Calibration requires a sinusoidal input signal of 10^{-6} g at 0.1 Hz. This input is applied in a manner identical to the linear inputs for the SSA/SGG Accelerometer Calibration except that the duration is 14.0 minutes per axis. This step also requires angular acceleration inputs. These have a magnitude of 10 arcsec/sec^2 at 1.0 Hz with a duration of 14.0 minutes per axis and are applied as were the angular inputs for the SSA/SGG Accelerometer Calibration.

The tentative procedure for calibration is to perform steps one through four during one quiet period and step five during a subsequent quiet period. Preliminary analyses indicate that calibration data can be measured for approximately 15.0 minutes between attitude control adjustments to null the platform angular rates.

Table 7-1. SGG Calibration Requirements

1) **SSA BRIDGE BALANCE - NO INPUT REQUIRED**

2) **SGG ACCELEROMETER BALANCE - NO INPUT REQUIRED**

3) **SGG GRADIOMETER BALANCE - 10^{-6}g AT 0.1 Hz (10 SECOND DURATION)**
BACKGROUND < 2 x 10^{-8} g/Hz$^{1/2}$ AND 0.2 arc sec/S^2 Hz$^{1/2}$

4) **SSA/SGG ACCELEROMETER CALIBRATION - 10^{-5}g AT 1.0 Hz (THREE MINUTES PER AXIS)**
100 arc sec/S^2 at 1.0 Hz (THREE MINUTES PER AXIS)
BACKGROUND < 2 x 10^{-8} g/Hz$^{1/2}$ AND 0.2 arc sec/S^2 Hz$^{1/2}$

5) **SGG GRADIOMETER CALIBRATION - 10^{-6}g at 0.1 Hz (14 MINUTES PER AXIS)**
10 arc sec/S^2 AT 0.1 Hz (14 MINUTES PER AXIS)
BACKGROUND < 2 x 10^{-8} g/Hz$^{1/2}$ AND 0.2 arc sec/S^2 Hz$^{1/2}$

Also note that reducing the acceleration input frequencies from 0.1 and 1.0 Hz to 0.05 and 0.5 Hz was considered. This will be further discussed in Section 7.3.

A number of different techniques were considered for generating the required calibration acceleration environments. One technique would be to employ the EURECA platform's thrusters. The platform has two classes of thrusters.

The Orbital Transfer Assembly (OTA) thrusters are Hydrazine thrusters that are normally employed for changing the EURECA platform's orbit. Each OTA thruster has a nominal steady state thrust level of 22 N ±10%. The minimum on (0.025 seconds) and off (0.50 seconds) times are such that 0.1 and 1.0 Hz signals could be developed. However, due to the rapid rise time to nominal thrust and the fact that the thrusters cannot be throttled, the input signal would be nearly a square wave. This could result in a significant amount of higher frequency structural response. Also, the thrust level would result in larger acceleration levels than desired (approximately 500 μg).

The Reaction Control Assembly (RCA) thrusters are cold gas thrusters that are normally used to adjust the EURECA platform's attitude. Each RCA thruster supplies a nominal steady state thrust level of 0.02 N ±10%. The minimum on-time is 1.0 seconds and there is no minimum off time. While the resulting acceleration is closer to desired levels (approximately 0.5 μg), this signal would also be more of a square wave than a sinusoid.

Figure 7-1 presents the locations of the OTA and RCA thrusters on the EURECA platform. As can be seen, uncoupled excitation in all three linear and all three angular directions is not feasible. Only the OTA thrusters can supply uncoupled linear acceleration and then only in the EURECA +Z direction. They can also supply angular rates only about the X and Y axes (about 900 arcsec/sec^2 which is too large).

The RCA thrusters can supply relatively uncoupled excitation in all three angular directions (about 0.8 arcsec/sec^2 which is too small) but cannot yield uncoupled linear motion. Note from Table 7-2 that none of the eight OTA thrusters are aligned directly along the EURECA coordinate system axes and only two of the twelve RCA thrusters are.

Due to the fact that the required uncoupled sinusoidal accelerations of appropriate magnitude cannot be generated by the EURECA platform thrusters, it is not recommended that the thrusters be employed as the source of the calibration acceleration signals.

Note that the same conclusion can be reached for the magnetic torquers since they also supply square wave signals rather than sinusoids and have torque magnitudes, and therefore angular accelerations, even smaller than those due to the RCA thrusters. Additionally, the magnetic torquers cannot generate linear acceleration inputs.

Since the EURECA platform cannot supply the accelerations needed to calibrate the SGG, the experiment must supply actuators to perform this task. Three different actuator concepts were considered. These could be grouped into two classes. The first class acts by accelerating the entire SGG/EURECA vehicle by moving small masses while the second class accelerates the SGG relative to the EURECA platform. With both classes of actuator it is possible to either hard or soft mount the SGG dewar to the EURECA platform payload deck. A soft mount with a frequency of about 5.0 Hz will significantly reduce the transmission of any high frequency structural response to the instrument while not adversely effecting the applied low frequency acceleration signal.

Rotary actuators are comprised of an unbalanced mass rotating in a plane. Both linear rotation along an axis and angular rotation about a perpendicular axis may be generated by employing two rotary actuators acting in the same plane. If the two unbalanced masses are in phase and rotating in opposite directions, a linear acceleration results. If the masses are 180 degrees out of phase and rotating in opposite directions, an angular acceleration results. This is sketched in Figure 7-2.

Since the mass unbalance is fixed, the resulting accelerations are proportional to the square of the signal frequency. Thus, increasing the signal frequency from 0.1 to 1.0 Hz results in the applied acceleration increasing by a factor of 100. For the EURECA/SGG flight test mission, it was found that a pair of unbalanced 0.73 kg masses with a 7.6 cm offset resulted in linear accelerations of 10^{-6} g at 0.1 Hz and 10^{-4} g at 1.0 Hz.

EUREKA THRUSTER CONFIGURATION

OTA HYDRAZINE THRUSTERS

RCA COLD GAS THRUSTERS

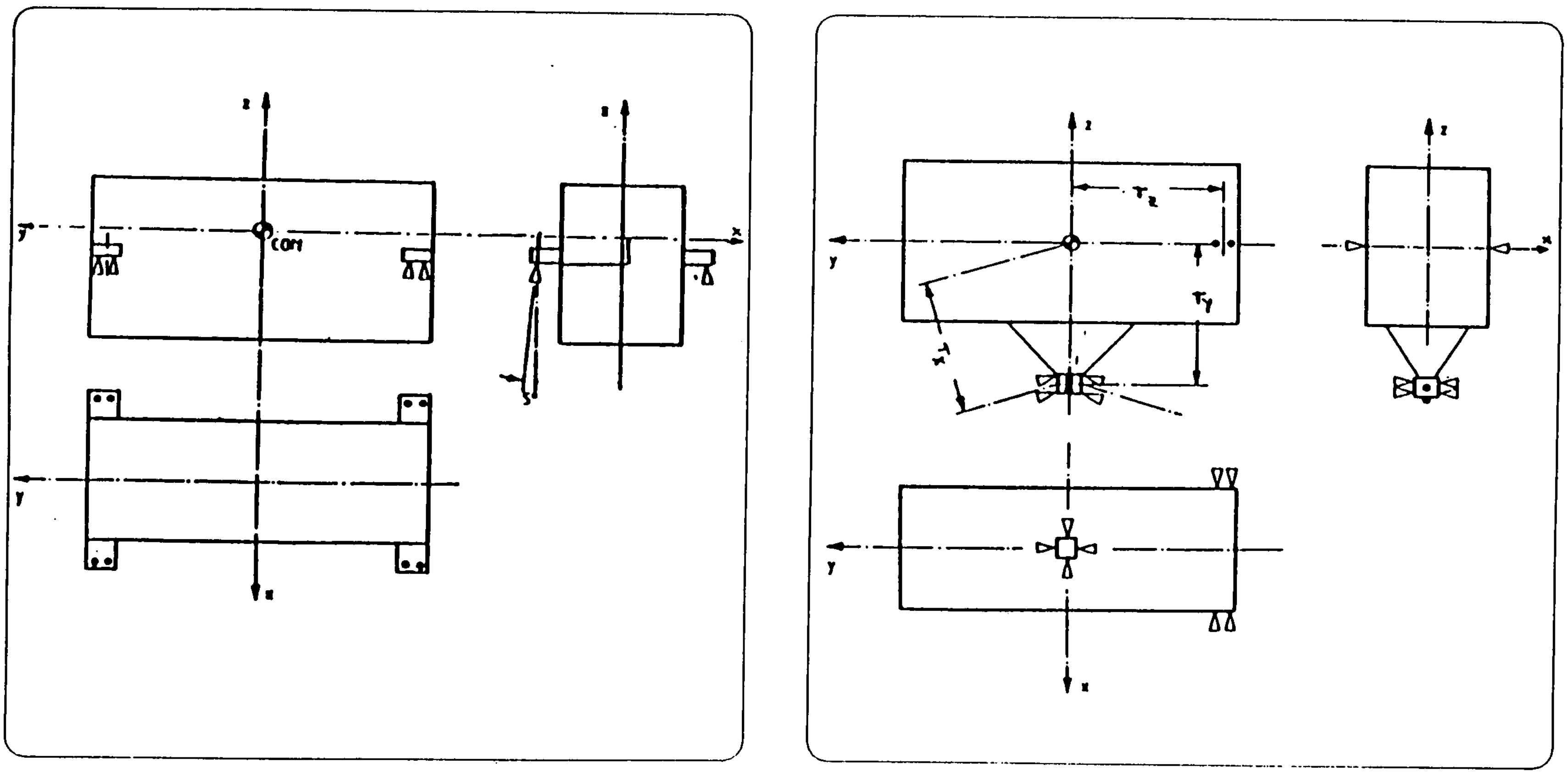
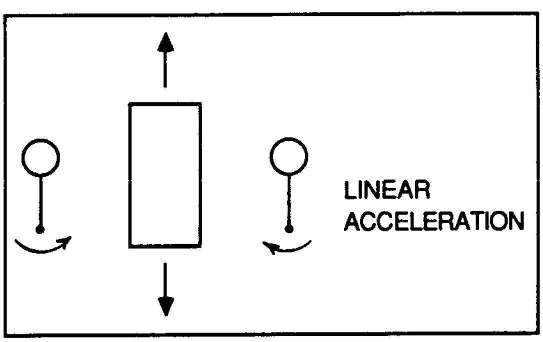


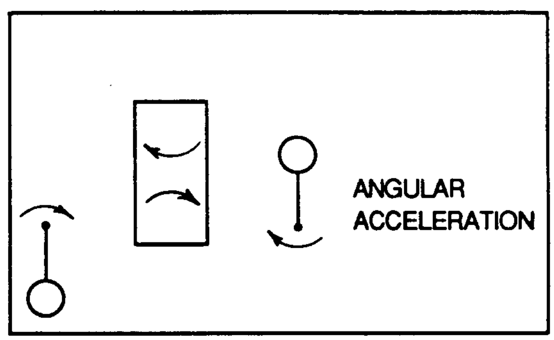
Figure 7-1. SGG Instrument Calibration

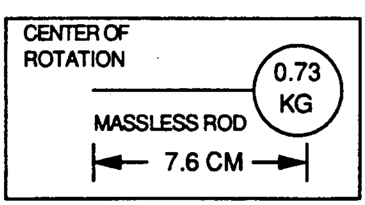
Table 7-2. SGG Instrument Calibration

OTA AND RCA THRUST VECTORS

Thruster Nr.		Location (mm) x	y	z	Thrust Vector (nominal) x	y	z
OTA	1	1036.1	2106	-842.5	-sin 5°	0	cos 5°
	2	1036.1	2006	-842.5	-sin 5°	0	cos 5°
	3	1036.1	-2106	-842.5	-sin 5°	0	cos 5°
	4	1036.1	-2006	-842.5	-sin 5°	0	cos 5°
	5	-1036.1	2106	-842.5	sin 5°	0	cos 5°
	6	-1036.1	2006	-842.5	sin 5°	0	cos 5°
	7	-1036.1	-2106	-842.5	sin 5°	0	cos 5°
	8	-1036.1	-2006	-842.5	sin 5°	0	cos 5°
Thruster		**x**	**y**	**z**	**x**	**y**	**z**
RCA	1	0	300	-2519.5	0	-cos 18°	sin 18°
	2	0	285.5	-2559.4	0	-cos 20°	sin 20°
	3	0	-300	-2519.5	0	+cos 18°	sin 18°
	4	0	-285.3	-2559.4	0	+cos 20°	sin 20°
	5	193	0	-2538	-cos 9°	0	sin 9°
	6	201	0	-2575	-cos12°	0	sin 12°
	7	-193	0	-2538	+cos 9°	0	sin 9°
	8	-201	0	-2575	+cos12°	0	sin 12°
	9	925	-2075	- 480	- 1	0	0
	10	925	-2025	- 480	-cos 6°	-sin 6°	0
	11	-925	-2075	- 480	1	0	0
	12	-925	-2025	- 480	cos 6°	-sin 6°	0







ACTUATOR CAPABILITIES

10^{-6}g @ 0.1 Hz
10^{-4}g @ 1.0 Hz

Figure 7-2. SGG Calibration—Rotary Actuators

Linear actuators act in a manner similar to the rotary actuators. A typical linear actuator is a linear DC motor (See Figure 7-3). For this study, it was found that a moving mass of 2.3 Kg was adequate in most cases. As with the rotary actuators, both linear acceleration along an axis and angular acceleration about a perpendicular axis can be achieved by using two actuators in the same plane with their axes of motion parallel. If the motion of the masses are in phase, a linear acceleration results. If they are 180 degrees out of phase, an angular acceleration results. Note that the linear actuator allows more flexibility in operations because both frequency and the resulting acceleration can be adjusted as desired. However, this can lead to unacceptable actuator displacement levels for low frequencies or high accelerations.

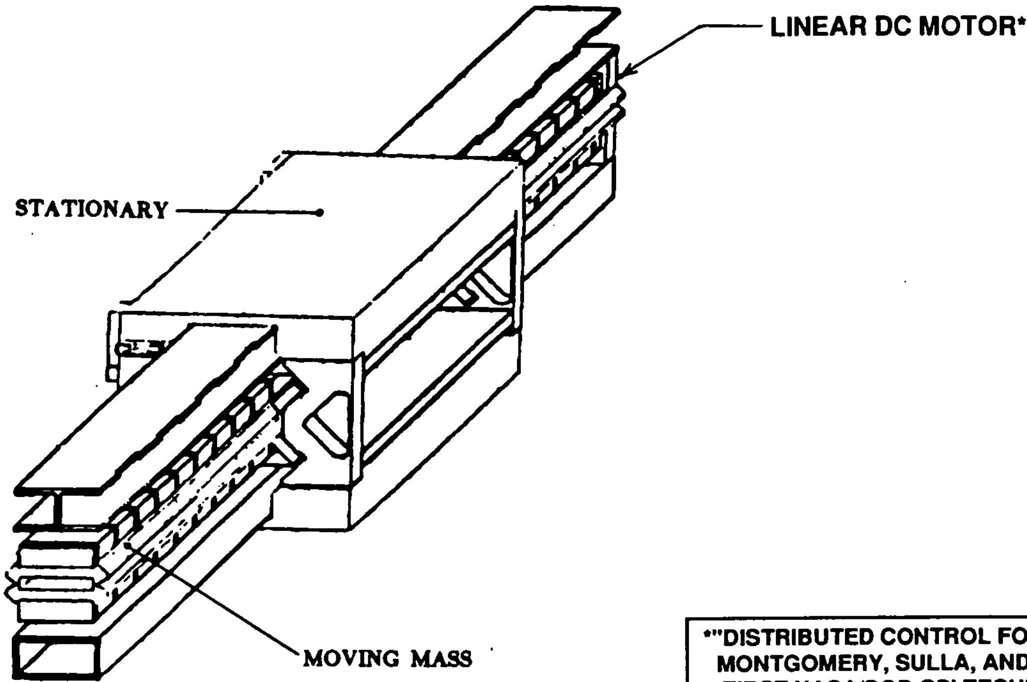
The final actuator concept considered actually combines a single axis actuator with a three axis isolator. In this concept, once again, a pair of these actuators acting parallel to each other supply both linear acceleration along one axis and angular acceleration along a perpendicular axis. The actuator is a pair of ring shaped electromagnetic coils and three axis isolation is supplied by a bellows spring device. This is displayed in Figure 7-4. The SGG is accelerated relative to the EURECA platform in this concept. Since the platform is approximately ten times as massive as the SGG, this has the effect of decoupling the SGG from the EURECA platform.

Note that this concept, as well as all soft mount concepts, will require mechanisms to lock the SGG to the platform and carry the loads that result during launch and landing. These isolator locks must be capable of being latched and unlatched remotely while the platform is on orbit.

In order for this concept to work, the active actuators must be able to overcome the stiffness of the isolator springs of all six actuators present while supplying the required acceleration environment to the experiment. These force levels are significantly larger than those required to supply the acceleration environment. If an active feedback loop is required to control the input environment, this concept could require the development of a complex control system.

Both linear and rotary actuators can be located a number of different ways upon the EURECA/SGG flight test mission in an effort to achieve the desired acceleration environment for calibration. Three different configurations were considered.

In the first, the actuators were mounted directly to the dewar (see Figure 7-5). The sensitive axes of the gradiometer (X_0, Y_0, and Z_0) were aligned such that the "umbrella axis" of the gradiometer was parallel with the EURECA platform Z axis. The projection of the X_0 axis onto the EURECA platform payload deck was parallel with the EURECA platform X axis. The location and orientation of the six actuators upon the surface of dewar are shown in the figure.



*"DISTRIBUTED CONTROL FOR COFS I," MONTGOMERY, SULLA, AND LINDER, FIRST NASA/DOD CSI TECHNOLOGY CONFERENCE, NOCV. 18 - 21, 1986

Figure 7-3. SGG Calibration—Linear Actuator

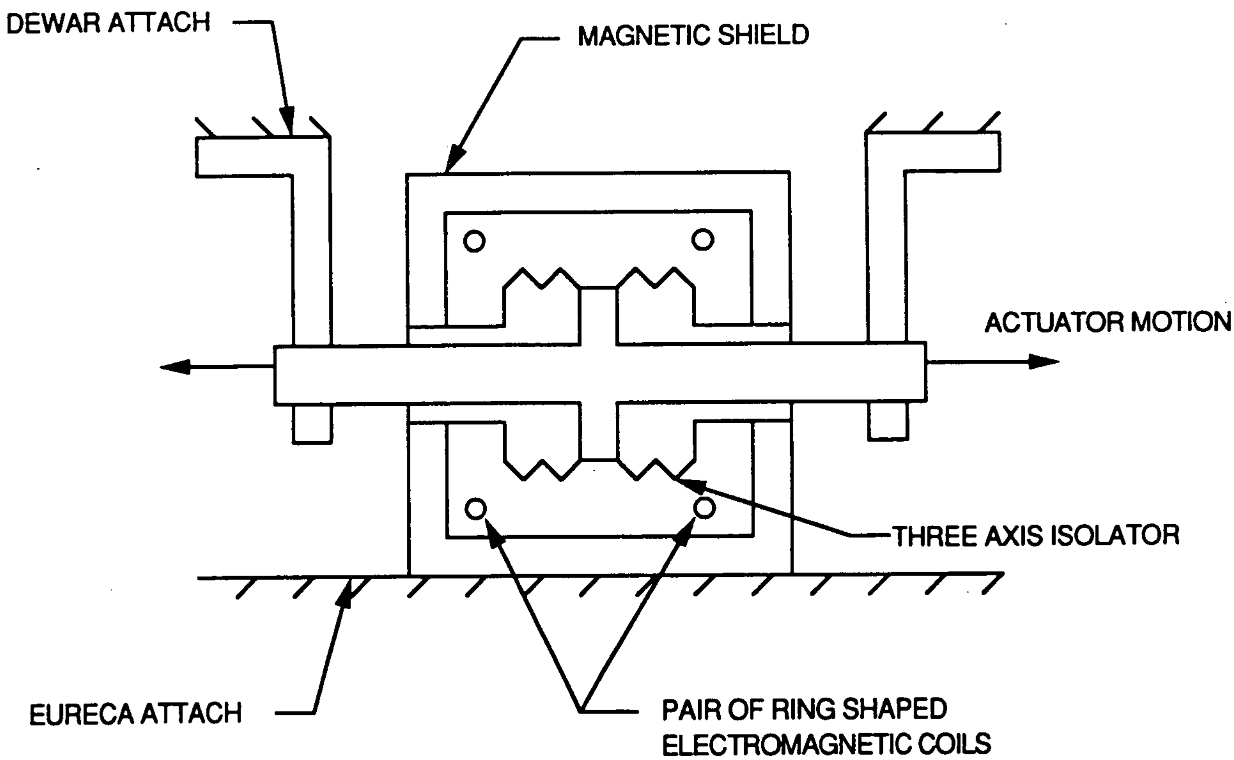


Figure 7-4. SGG Calibration—SGG/EURECA Relative Motion

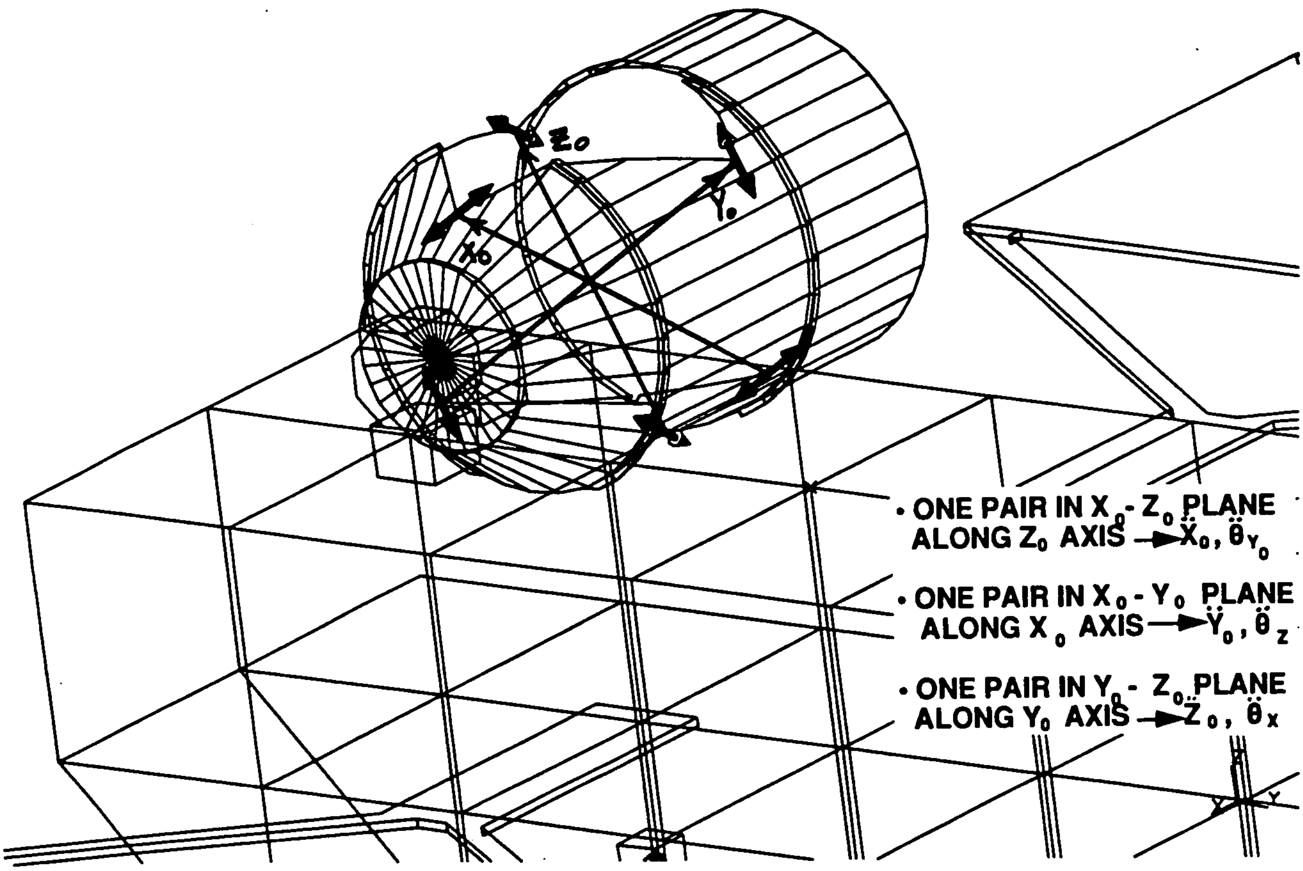


Figure 7-5. SGG Calibration—Actuators Mounted on Dewar

This configuration has the advantage of using the least amount of room on the payload deck. This is of importance since the SGG/EURECA flight test mission is considered a shared mission and other payloads will be present. It also simplifies the alignment of the actuators with the dewar since they are mounted directly on the dewar.

Alternatively, the actuators could be integrated with the EURECA platform. In this configuration, which is shown in Figure 7-6, five of the six actuators are located upon the payload deck. The sixth actuator is located near the keel trunnion fitting. The goal of this arrangement is to arrange the actuators about the vehicle center of mass while keeping as many actuators as possible on the payload deck to simplify integration. This will tend to reduce cross axis coupling. If linear actuators are employed, the force levels can be adjusted to correct for the different moment arms between two active actuators and the center of mass. However, this configuration requires more room on the payload deck and adds complexity to the alignment of the actuators with the SGG. This is particularly true for the actuator located near the keel fitting since this structure is removed for transportation. Integration of this actuator with the EURECA platform will also be complicated by the fact that this is not a standard location for accommodating payload hardware.

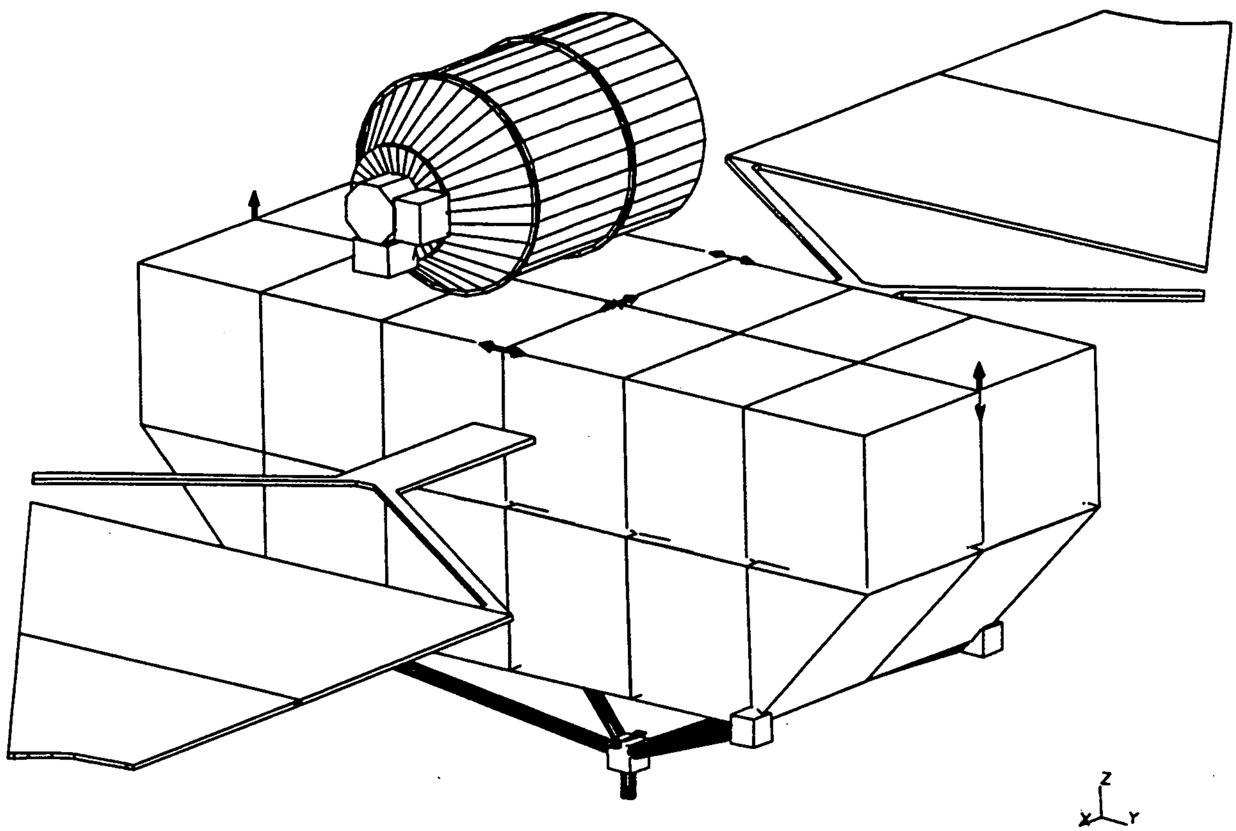


Figure 7-6. SGG Calibration—Actuators on Payload Deck

In an effort to further reduce the cross axis coupling, the two actuators acting in the Y direction can be moved down closer to the vehicle center of mass (see Figure 7-7). This reduces the coupling between Y axis inputs and rotations about the X axis, but will greatly complicate integration. First, the EURECA platform has no provisions in its design to accommodate payloads anywhere other than on the payload deck. Also, if the actuators really were mounted on the solar array yokes as is shown, alignment of the actuators to the instrument would have to be achieved after deployment of the arrays. Additionally, this location would be likely to increase the dynamic response of the arrays to the input forcing function.

Figure 7-8 presents the configuration where the actuators move the dewar relative to the EURECA platform. Only half of the actuators are visible in this view. There is an actuator parallel to each of those visible located on the opposite side of the dewar. The placement of the actuators is somewhat arbitrary, but the actuators around the circumference of the dewar are rotated 45 degrees from the EURECA Y and Z axes in order to minimize the amount of room the instrument occupies on the payload deck.

This configuration has advantages similar to that of the first case discussed. In addition, the coupling between axes is greatly reduced due to the high ratio between the EURECA mass and SGG mass.

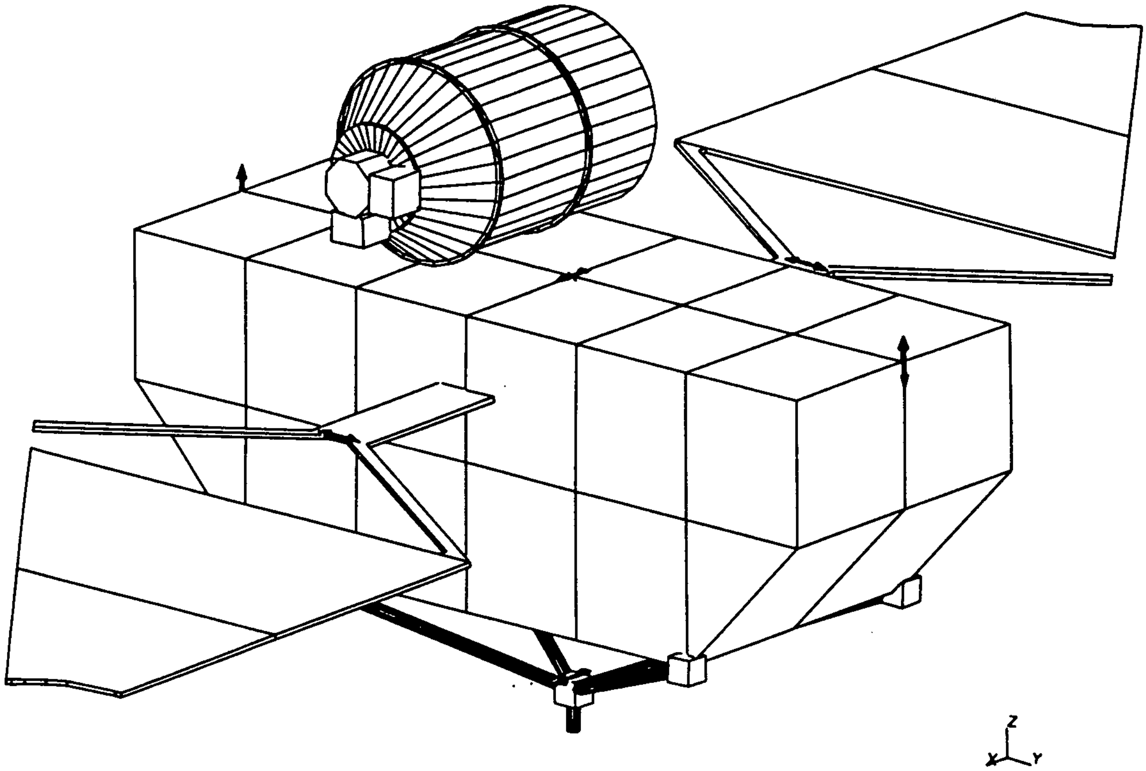


Figure 7-7. SGG Calibration—Actuators Mounted About CG

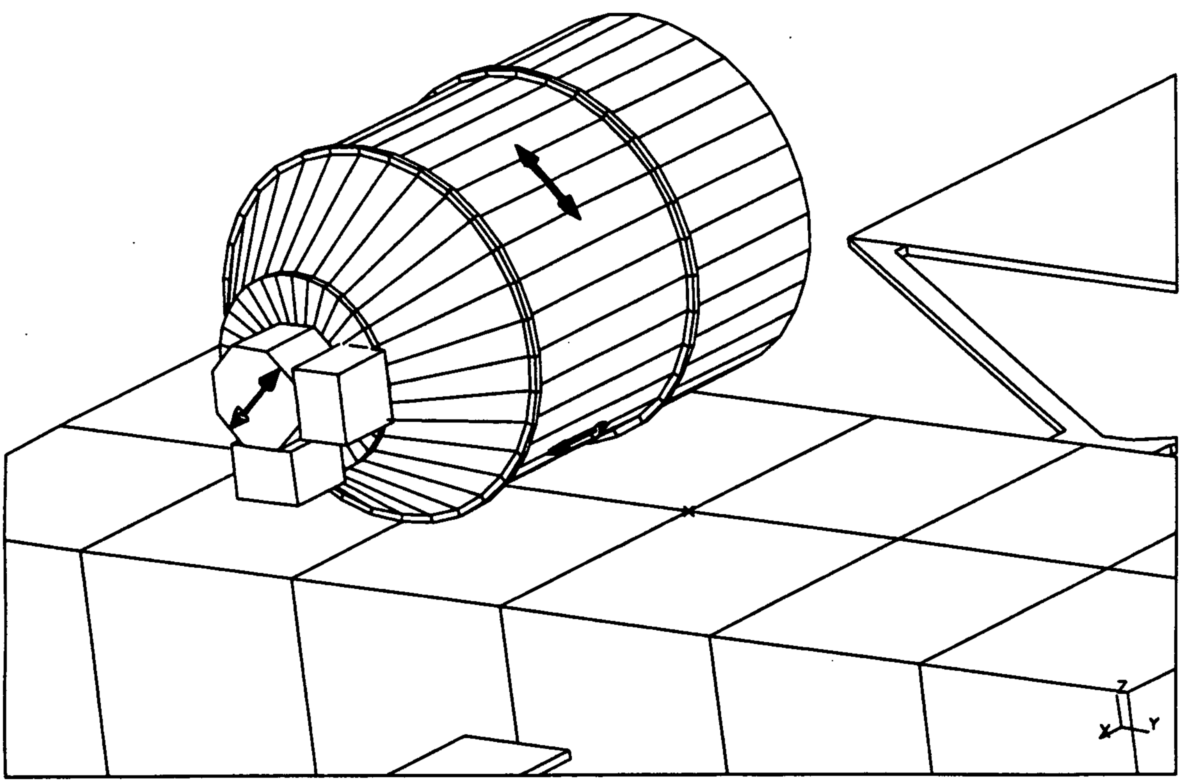


Figure 7-8. SGG Calibration—SGG/EURECA Relative Motion

A preliminary analysis of these configurations was performed. The assumptions are as shown in the Table 7-3. The weight, inertia, and position properties are based upon the baseline configuration developed in this study. Both the SGG and the EURECA platform were assumed to be rigid. Actually, the platform has solar array modes starting at 0.15 Hz which will interact with the applied calibration disturbance and may significantly alter the results. Everything is assumed to be linear, with all inputs and outputs aligned precisely as desired and of exactly the magnitude desired.

Table 7-3. SGG Calibration, Preliminary Results—Assumptions

- **SGG AND EURECA ARE RIGID**
- **SGG PROPERTIES**
  - **CM AT X = - 31.0 cm, Y = 70.0 cm, Z = 62.0 cm**
  - **WEIGHT = 425 kg**
  - **I_{xx} = 53.3 kg -m^2 , I_{yy} = I_{zz} = 107.0 kg -m^2**
- **EURECA PROPERTIES**
  - **SYSTEM CM AT X = Y = 2.0 cm, Z = - 47.0 cm**
  - **WEIGHT = 3975 kg**
  - **I_{xx} = 6480 kg -m^2, I_{yy} = 9770 kg -m^2, I_{zz} = 12100 kg -m^2**
- **ACTUATOR AXES, SGG AXES ALIGNED PRECISELY AS DESIRED**
- **ACTUATORS PERFECTLY IN PHASE AND BALANCED, SUPPLY CORRECT FREQUENCY AND FORCE INPUT**

Even with these assumptions, there is significant cross coupling evident for the various configurations. The configurations considered in this analysis are as follows; rotary actuators on dewar, linear actuators on the dewar, linear actuators on the payload deck, and SGG/EURECA relative motion. Additional cases with rotary actuators and the configuration with actuators mounted upon the solar array yokes were not considered for reasons which will be discussed in the following pages.

The performance of these configurations was examined for the following steps; gradiometer balance, SSA/SGG calibration for linear inputs and angular inputs, and SGG gradiometer calibration for linear inputs and angular inputs. The results of this analysis will now be addressed in some detail.

First, the format of Table 7-4 will be discussed. The first column denotes the configuration being considered. The second column defines the amount of mass that is in motion. For instance, for the rotary actuators mounted on the dewar during gravity gradiometer balance, six 0.73 kg masses are in motion. The mass listed in the last row of this column is that of the dewar. Actually, the platform is also moving out of phase with the dewar and at smaller displacements.

Table 7-4. SGG Calibration, Preliminary Results—Gradiometer Balance

CASE	MOVING MASS (kg)	PEAK FORCE/ ACTUATOR (N)	MAX ACTUATOR MOTION (P-P) (mm)	RESULTING ACCELERATION (μg)	MISALIGNMENT (DEG)	PEAK INDUCED LINEAR ACCELERATION (μg)	PEAK INDUCED ANGULAR ACCELERATION (arcsec/S2)
ROTARY ACTUATORS ON DEWAR	0.73 x 6	0.0216	150.	1.96	27.9	.873	1.62
LINEAR ACTUATORS ON DEWAR	2.3 x 6	0.0216	48.	1.96	27.9	.873	1.62
LINEAR ACTUATORS ON PAYLOAD DECK	2.3 x 6	0.0329	74.	2.08	5.64	0.348	0.646
SGG/EURECA RELATIVE MOTION	425.	0.00209	0.060	1.80	1.30	0.0717	0.206

- **DESIRED CALIBRATION ACCELERATION 1.73 μg ALONG SGG UMBRELLA AXIS AT 0.1 Hz**

The third column shows the highest force any actuator has to deliver to generate the desired input acceleration while the fourth column is the maximum displacement any actuator has to achieve. Note that the peak displacement is fixed for rotary actuators.

The magnitude of the resulting acceleration is presented in the fifth column. This can be compared to the desired magnitude shown in large print at the bottom of the table.

Shown in the sixth column is the angle between the desired direction of the acceleration and the calculated direction. The seventh column is the peak component of linear acceleration induced by any input while the eighth column displays the peak induced angular acceleration.

From Table 7-4 it is evident that none of the configurations are required to develop a large force to generate the acceleration environment required for gradiometer balance. Note that while the SGG/EURECA relative motion force is shown as being roughly an order of magnitude lower than the other cases, this is misleading. The force shown is only that required to accelerate the mass of the dewar and does not include the force necessary to achieve the peak deformation of the isolator springs (which is roughly four orders of magnitude larger).

The table also shows that the SGG/EURECA relative motion case requires the capability of controlling deflections accurately to thousandths of a millimeter. Sensing and controlling deflections accurately at this level may present a significant challenge.

All four configurations generated accelerations which were of approximately the correct magnitude, but only the last two configurations had the vector oriented in approximately the correct direction. This is due to the large induced accelerations resulting in the cases with the actuators mounted upon the dewar. These induced accelerations occurred because of the offset between the line of action of the vector sum of the applied forces and the vehicle center of mass. While it is possible to realign the actuators on the dewar to minimize the coupling in this step, the problem would reappear in subsequent steps as it is not possible to have all three axes pass near the center of mass. This is the major disadvantage of mounting the unbalanced mass actuators on the dewar.

Table 7-5 presents similar information for the linear acceleration input portion of the SSA/SGG calibration step. In general, the peak actuator force is higher while the actuator motion is smaller than was the case for the gradiometer balance. This is a consequence of the higher acceleration level and the higher frequency required for this step.

Table 7-5. SGG Calibration, Preliminary Results—SSA/SGG Calibration, Linear Inputs

CASE	MOVING MASS (kg)	PEAK FORCE/ ACTUATOR (N)	MAX ACTUATOR MOTION (P-P) (mm)	RESULTING ACCELERATION (μg)	MISALIGNMENT (DEG)	PEAK INDUCED LINEAR ACCELERATION (μg)	PEAK INDUCED ANGULAR ACCELERATION (arcsec/S2)
ROTARY ACTUATORS ON DEWAR*	0.73 x 2	2.16	150.0	160.	50.	120.	180.
LINEAR ACTUATORS ON DEWAR*	2.3 x 2	.216	4.83	16.	50.	12.	18.
LINEAR ACTUATORS ON PAYLOAD DECK	2.3 x 2	.329	7.37	13.65	9.14	3.48	6.46
SGG/EURECA RELATIVE MOTION	425.	.0209	.00602	10.02	3.22	0.560	1.67

*WORST CASE ORIENTATION - FORCE NORMAL TO RADIUS VECTOR AND TORQUE ABOUT LOW INERTIA AXIS

- **DESIRED CALIBRATION ACCELERATION 10 μg ALONG EACH AXIS AT 1.0 Hz**

The resulting acceleration of the rotary actuator acceleration is more than ten times higher than the desired levels. This is due to the fact that the actuator was set up to give the desired force level at 0.1 Hz. Since the mass unbalance arm is fixed, the force levels cannot be adjusted to desired levels at other frequencies.

As was true for the previous step, only the configurations with the linear actuators on the deck and the case with SGG/EURECA relative motion have the resulting acceleration fairly well aligned with the desired direction.

During the SSA/SGG calibration angular inputs, it was found that the rotary actuators were unable to supply sufficient angular acceleration at 0.1 Hz (see Table 7-6). Once again, this is a consequence of the actuators being optimized to the 0.1 Hz linear input force requirements.

Table 7-6. SGG Calibration, Preliminary Results—SSA/SGG Calibration, Angular Inputs

CASE	MOVING MASS (kg)	PEAK FORCE/ ACTUATOR (N)	MAX ACTUATOR MOTION (P-P) (mm)	RESULTING ACCELERATION (arcsec/S2)	MISALIGNMENT (DEG)	PEAK INDUCED LINEAR ACCELERATION (μg)	PEAK INDUCED ANGULAR ACCELERATION (arcsec/S2)
ROTARY ACTUATORS ON DEWAR*	0.73 x 2	2.16	150.	63.	-	41.	-
LINEAR ACTUATORS ON DEWAR*	2.3 x 2	3.42	76.	100.	-	66.	-
LINEAR ACTUATORS ON PAYLOAD DECK	2.3 x 2	5.07	110.	100.	-	53.9	-
SGG/EURECA RELATIVE MOTION	425.	.0516	.018	100.	-	0.624	-

*FORCE NORMAL TO RADIUS VECTOR, TORQUE ABOUT MAXIMUM INERTIA AXIS

• **DESIRED CALIBRATION ACCELERATION 100 ARCSEC/S^2 ABOUT EACH AXIS AT 1.0 Hz**

In general, while the peak force and displacement values were significantly larger than those required for the linear inputs, none of the actuator requirements appear infeasible. However, for all three cases employing unbalanced moving mass actuators there was significant linear acceleration induced by the angular inputs. Indeed, these acceleration levels were higher than the signals required for the linear acceleration SSA/SGG calibration and appear to be large enough to contaminate the angular calibration. The linear accelerations result from the fact that the dewar is mounted well away from the vehicle center of mass. Thus when the vehicle experiences an angular acceleration the dewar is accelerated linearly tangential to the vehicle. The only way to reduce this effect for actuators which work by moving the entire vehicle is to move the dewar closer to the center of mass. Unfortunately, a significant reduction in the distance between the vehicle center of mass and the dewar is not feasible for the EURECA design.

It should be noted that the SGG/EURECA relative motion case had very little induced linear acceleration. This makes this actuator concept the most likely to allow successful calibration and therefore the preferred candidate.

The results of the linear and angular SGG gradiometer calibration steps are qualitatively similar to those discussed so far. They are displayed in Tables 7-7 and 7-8 respectively. Only one additional strong limiter occurs. The linear actuators are required to undergo extremely large peak to peak deflections (as high as 1100 mm) in order to apply the forces

Table 7-7. SGG Calibration, Preliminary Results—SGG Gradiometer Calibration, Linear Inputs

CASE	MOVING MASS (kg)	PEAK FORCE/ ACTUATOR (N)	MAX ACTUATOR MOTION (P-P) (mm)	RESULTING ACCELERATION (μg)	MISALIGNMENT (DEG)	PEAK INDUCED LINEAR ACCELERATION (μg)	PEAK INDUCED ANGULAR ACCELERATION (arcsec/S2)
ROTARY ACTUATORS ON DEWAR*	0.72 x 2	.0216	150.	1.60	50.	1.2	1.8
LINEAR ACTUATORS ON DEWAR*	2.3 x 2	.0216	48.	1.60	50.	1.2	1.8
LINEAR ACTUATORS ON PAYLOAD DECK	2.3 x 2	.0329	74.	1.37	9.14	0.348	0.646
SGG/EURECA RELATIVE MOTION	425.	.00209	0.060	1.002	3.22	0.0560	0.167

*WORST CASE ORIENTATION - FORCE NORMAL TO RADIUS VECTOR AND TORQUE ABOUT LOW INERTIA AXIS

• **DESIRED CALIBRATION ACCELERATION 1.0 μg ALONG EACH AXIS AT 0.1 Hz**

Table 7-8. SGG Calibration, Preliminary Results—SGG Gradiometer Calibration, Angular Inputs

CASE	MOVING MASS (kg)	PEAK FORCE/ ACTUATOR (N)	MAX ACTUATOR MOTION (P-P) (mm)	RESULTING ACCELERATION (arcsec/S2)	MISALIGNMENT (DEG)	PEAK INDUCED LINEAR ACCELERATION (μg)	PEAK INDUCED ANGULAR ACCELERATION (arcsec/S2)
ROTARY ACTUATORS ON DEWAR*	0.72 x 2	0.0216	150.	0.63	-	.41	-
LINEAR ACTUATORS ON DEWAR*	2.3 x 2	0.342	760.	10.0	-	6.6	-
LINEAR ACTUATORS ON PAYLOAD DECK	2.3 x 2	0.507	1100.	10.0	-	5.39	-
SGG/EURECA RELATIVE MOTION	425.	0.00516	0.18	10.0	-	0.0624	-

*FORCE NORMAL TO RADIUS VECTOR, TORQUE ABOUT MAXIMUM INERTIA AXIS

• **DESIRED CALIBRATION ACCELERATION 10 ARCSEC/S^2 ABOUT EACH AXIS AT 0.1 Hz**

necessary to perform the angular calibration. Motions this large are not likely to be feasible. The required motion could be reduced by making the moving mass larger or by placing actuators further from the center of mass of the vehicle. Both of these solutions have negative aspects.

This only further enforces the idea that the relative motion actuators are best suited for supplying the required environments for calibration of the instrument on this mission. This is not to say that design of the actuators will be trivial. Small deflections will have to be controlled very precisely with as many as six actuators acting in phase simultaneously. The actuators must be capable of deforming the isolation spring system which requires forces as high as 35.0 N from two actuators to deform six 63.0 N/mm springs 0.092 mm. The development of the required control system could require a significant amount of effort.

7.2 EURECA ATTITUDE CONTROL AND MICROGRAVITY ENVIRONMENT

The SGG microgravity environment requirements are shown in the Table 7-9. As can be seen, these requirements are quite demanding. They are broken into two categories corresponding to the two goals of the mission. The first goal is to demonstrate full sensitivity of the instrument for periods of 1.5 hours. The second goal is to perform continuous data measurement with degraded performance.

Table 7-9. Microgravity Assessment—Introduction

- **THE SUPERCONDUCTING GRAVITY GRADIOMETER HAS DEMANDING MICROGRAVITY ENVIRONMENT REQUIREMENTS**
  - **GOAL 1: FULL SENSITIVITY, 1.5 HOUR DURATION**

    10^{-3}Hz TO 10^{-1}Hz, PSD = $4 \times 10^{-16} g^2$/Hz

    2.5×10^{-5}g at 100 Hz

    2.5×10^{-4}g at 1000 Hz

  - **GOAL 2: DEGRADED PERFORMANCE, CONTINUOUS OPERATION**

    10^{-3}Hz TO 10^{-1}Hz, PSD = $4 \times 10^{-14} g^2$/Hz

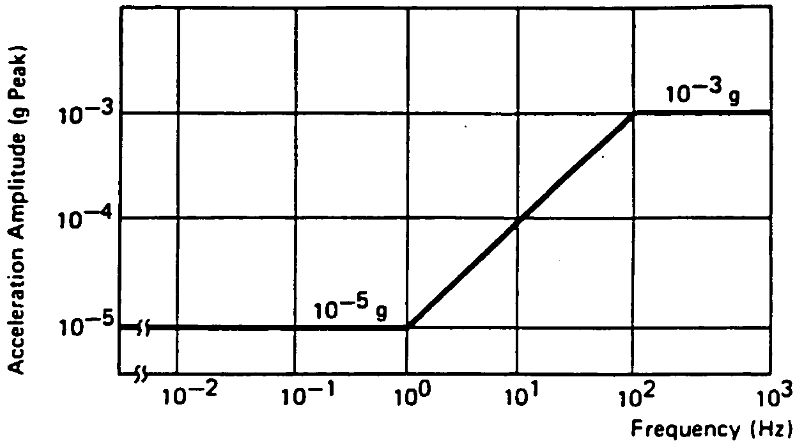
    2.5×10^{-4}g at 100 Hz

    2.5×10^{-3}g at 1000 Hz

- **THE ENVIRONMENT UPON THE EURECA PLATFORM MUST BE COMPARED TO THESE REQUIREMENTS**

The requirements are stated in terms of Power Spectral Density (PSD) for low frequencies (0.001 through 0.1 Hz) and in terms of acceleration for high frequencies (100–1000 Hz). It is necessary to determine if the EURECA platform can meet these requirements.

The first step taken to assess the ability of the EURECA platform to meet the required microgravity environment was to compare the requirements to the EURECA microgravity specification. This is stated as a function of peak acceleration verses frequency and is shown in the Figure 7-9. It is necessary to determine the appropriate technique for comparing this specification with the SGG requirements.



- EURECA ENVIRONMENT IS STATED IN TERMS OF PEAK SINE. RELATIONSHIP BETWEEN THIS DATA AND SGG REQUIREMENTS MUST BE DEFINED.

Figure 7-9. Microgravity Assessment—EURECA Microgravity Specification

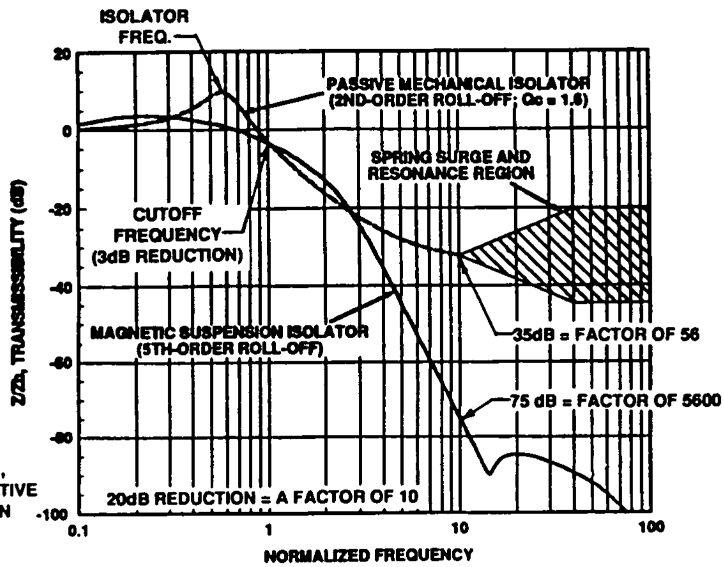
For high frequencies, the SGG requirements and the EURECA specification are directly comparable. The goal one requirement is not met by a factor of 40 at 100 Hz and by a factor of 4 at 1000 Hz. Similarly, the goal 2 requirement is not met by a factor of 4 at 100 Hz and is met at 1000 Hz.

There is a relatively simple way to significantly improve this performance. By mounting the dewar on a five Hz passive mechanical isolator system, a response reduction of about a factor of 60 at 100 Hz is feasible while a reduction of about a factor of 20 is feasible at 1000 Hz. This can be seen in Figure 7-10. Thus, with the addition of a mechanical isolator system to the instrument, it appears that the EURECA platform's specification will meet the required levels.

It should also be noted that during quiet operations it is expected that the platform's cooling pump and attitude control systems will be inactive. The EURECA microgravity specification assumes that these subsystems are active. Therefore, the actual environment experienced during quiet periods should be significantly lower than the specification. Simulations investigating the amount of this reduction will be discussed later in this section.

At low frequencies the EURECA platform specification is in terms of peak sine while the SGG requirement is in terms of PSD. In order to make a comparison of these to environments, it was necessary to convert them to a common form.

It was decided to convert both environments to 3σ random peak accelerations. The equations shown in Table 7-10 were employed. This was straight forward for the SGG requirement, but for the EURECA specification an amplification factor had to be chosen. Amplification is difficult to estimate accurately so two values were chosen to bound the problem.



REFERENCE

FROM HONEYWELL PRESENTATION, "ADVANCED TECHNOLOGY FOR ACTIVE AND PASSIVE VIBRATION ISOLATION OF SPACEBORNE PAYLOADS"

- MECHANICAL ISOLATOR APPEARS TO ACHIEVE HIGH FREQUENCY REQUIREMENTS

Figure 7-10. Microgravity Assessment—High Frequency

Table 7-10. Microgravity Assessment—Low Frequency

- EURECA PLATFORM ENVIRONMENT IN TERMS OF PEAK SINE
- UNIVERSITY OF MARYLAND SUPERCONDUCTING GRAVITY GRADIOMETER REQUIREMENT IN TERMS OF PSD
- IN ORDER TO COMPARE ENVIRONMENT TO REQUIREMENT

    1) CONVERT SGG REQUIREMENT TO ESTIMATED 3σ RANDOM PEAK ACCELERATION

    $$3\sigma = 3\sqrt{(PSD)\,(\Delta f)}$$

    2) CONVERT EURECA ENVIRONMENT (AT 0.1 Hz) TO ESTIMATED PSD

    $$PSD = \frac{Q\ddot{x}^2}{4.5\pi f_n}$$

    3) CONVERT EURECA ESTIMATED PSD TO ESTIMATED 3σ RANDOM PEAK ACCELERATION

    $$3\sigma = 3\sqrt{(PSD)\,(\Delta f)}$$

The two values of Q chosen were 250 and 4.5π. These values are based upon empirical data from the damping of deployed solar arrays on a number of previously launched satellites. 250 is a worst case value and Q should be less than this while 4.5π corresponds to an optimistically high level of damping so Q is likely to be higher than this value.

It was found that even with the lower value of Q, the EURECA specification exceeded the SGG requirements by a large amount (A factor of 1580 for goal 1 and a factor of 158 for goal 2). Since this occurs at low frequency (0.1 Hz), it is not practical to improve this performance with a simple isolator. Additionally, the results will be worse for data measured at lower frequencies. It is necessary to analyze the EURECA platform in more detail to see if better performance can be achieved.

By a fortunate coincidence, the microgravity environment of the EURECA platform was measured in a test which occurred during the current flight test study. Measurements of the environment on the payload deck were made at the MBB/ERNO facilities located in Bremen, Germany. For this test, the EURECA vehicle was mounted on a 5 Hz air bag suspension system. The solar arrays remained stowed. Two plots of the resulting data are presented in Figures 7-11 and 7-12.

In Figure 7-11, the response of the vehicle due to the ambient background noise at the facility was measured. Because of the suspension system, no useful data under about 10 Hz was measured. Also shown in this chart is the high frequency full science requirement. From this it can be seen that the ambient environment was generally well below the requirement.

This means that a reasonable measurement of the environment with all subsystems operational may be made. This is presented in Figure 7-12. Except for a fairly narrow band near 100 Hz, the measured environment is below the SGG requirements. This performance is significantly better than the EURECA specification between 100 and 1000 Hz. Note that there are some significant responses between 10 and 100 Hz due to the response of structural modes. The microgravity environment on orbit during the SGG flight test mission should be much lower than that achieved in the ground test since the thermal pump and the ACS systems will be off during quiet periods.

One of the special studies performed early in this flight test study was to determine the controllability of the EURECA platform in a low earth orbit (250 km altitude). The goal was to be able to obtain useful scientific data at low altitude during a platform quiet mode (see Table 7-11). There are a number of disturbances that act upon the platform at this altitude. Detailed plots of the disturbances are included in Appendix C. The disturbances considered include gravity gradient torques, torques due to atmospheric drag, and magnetic torquer characteristics.

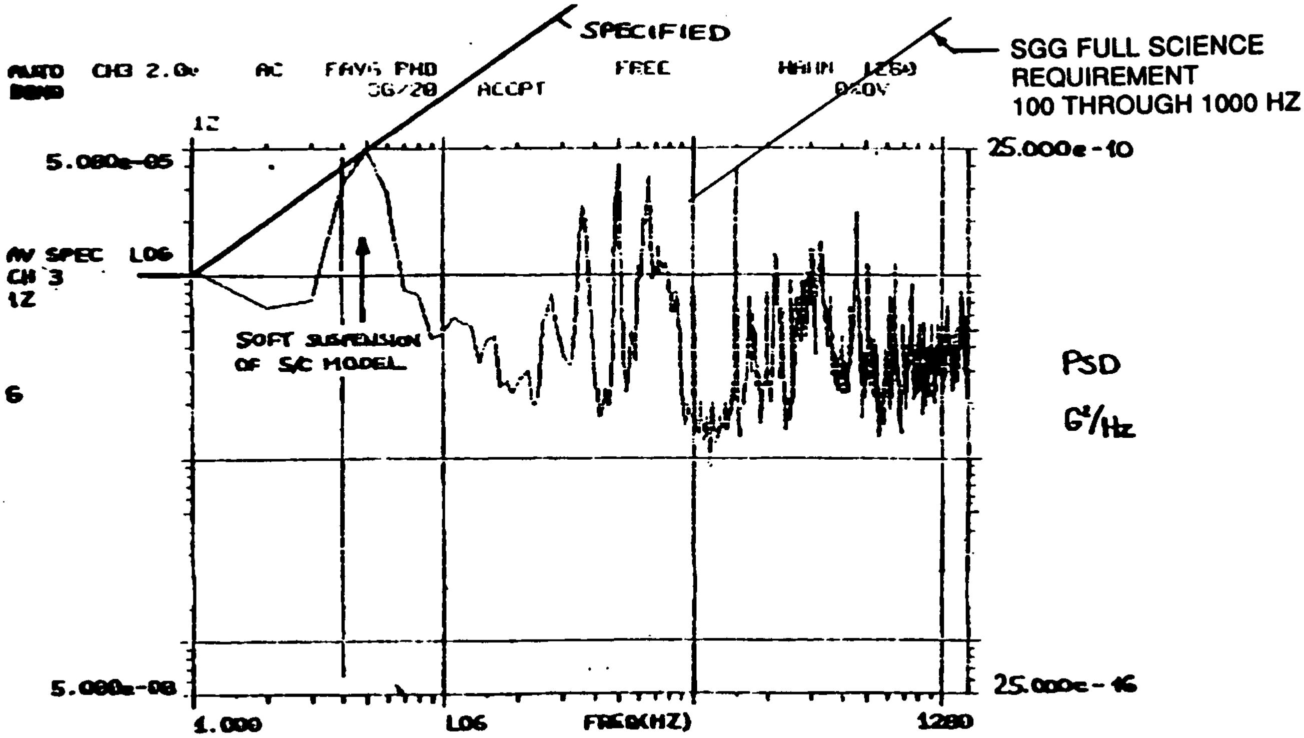


Figure 7-11. EURECA Vibration Environment—Ground Test Data, Background Environment

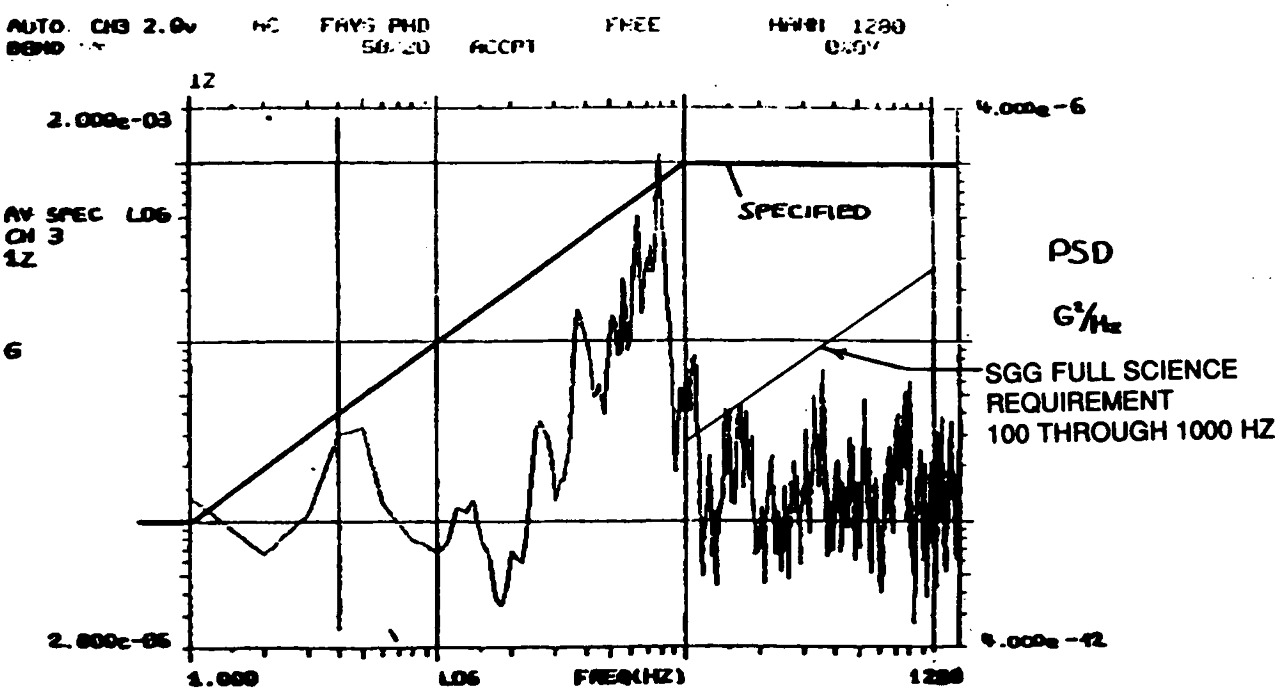


Figure 7-12. EURECA Vibration Environment—Ground Test Data, All Subsystems On

Table 7-11. EUREKA Attitude Control

REQUIREMENT

- SGG flight test requirement: obtain useful scientific data at low altitude during platform "quiet" mode.

OBJECTS OF ANALYSIS

- To determine contollability of EURECA at, for example, H = 250 km in earth pointing mode.
- To determine degree of drift / rotation of carrier
- Show whether or not magnetic torquers can compensate atmospheric drag and gravity gradient disturbances.

ASSUMPTIONS

- EURECA orbited with carrier's axis of symmetry (Z – axis) along velocity vector, i.e. Y – axis earth pointing.
- Solar arrays symmetrically deployed and mutually perpendicular to spacecraft's axes.
- Relatively high value of sun activity: F10.7 = 225.

The results of this special study showed that the platform was controllable in an earth pointing mode at an altitude of 250 km using only the magnetic torquers for control. During one orbit the drift from the velocity vector was less than 0.4 degrees. Note that this is not a quiet period since the magnetic torquers will impart a significant amount of noise to the structure which will impact the SGG measurements. Also note that battery charge/ discharge cycles and failure modes of the control system were not considered in this special study.

A number of simulations have been run at the nominal altitude of 500 km. The cases included nominal attitude control operations, control by attitude jets only, and attitude control inactive. The PSD response between 0.001 and 0.1 Hz for each of these simulations was estimated and compared to the SGG requirement.

Figure 7-13 shows a typical input control torque profile for the nominal control system simulation. As can be seen, the attitude control system is active nearly continuously during the orbit. The PSD response between 0.001 and 0.1 Hz for this simulation was estimated to be 8×10^{-13} g^2/Hz. This is 20 times the desired level for continuous operation with degraded performance.

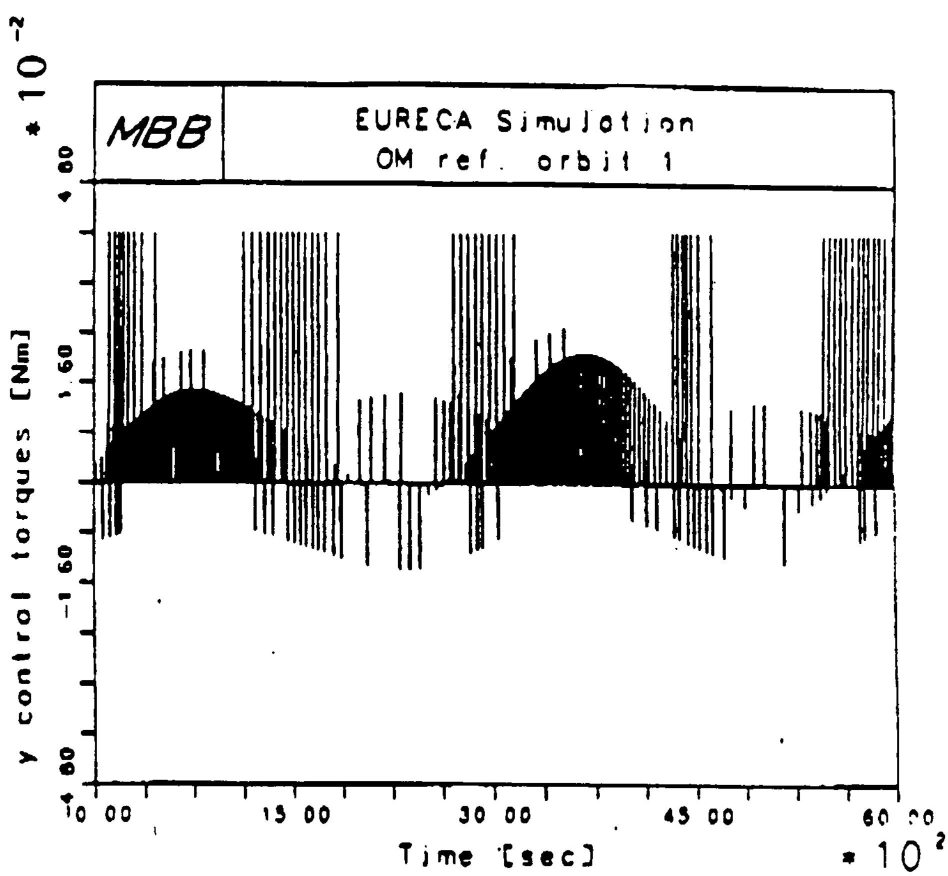


Figure 7-13. EURECA Vibration Environment—ACS Active Simulation

Therefore, another simulation was performed which employed only the attitude control jets for control. The acceleration response is presented in Figure 7-14. From this data the overall PSD level between 0.001 and 0.1 Hz was estimated to be 2 X $10^{-14} g^2/Hz$. This is one half of the required environment for continuous operations with degraded performance. Thus it appears that this mode of operation will meet the requirements for continuous operations with degraded performance. It is not adequate for demonstration of full sensitivity.

A potential technique for achieving full sensitivity for 90 minutes is to turn the attitude control system off for an orbit. Figure 7-15 presents the results of such a simulation. The spacecraft rotates 475 degrees during the one orbit simulation when the attitude control system is turned off. Since the code that was being employed for this simulation is only valid for relatively small angles, the only real conclusion that can be reached from this analysis is that it is likely that angular rates build up too rapidly to allow the control system to be turned off for an entire orbit. A possible solution to this problem is to allow the vehicle to drift for a period of time (approximately 15 minutes) while data is being measured, then perform a burn to null the angular rates and repeat the cycle. Transients from the attitude burns should decay quite rapidly (approximately 13 seconds for fluid slosh to decay to 0.1% of the initial value). This will allow data to be measured during quiet periods while

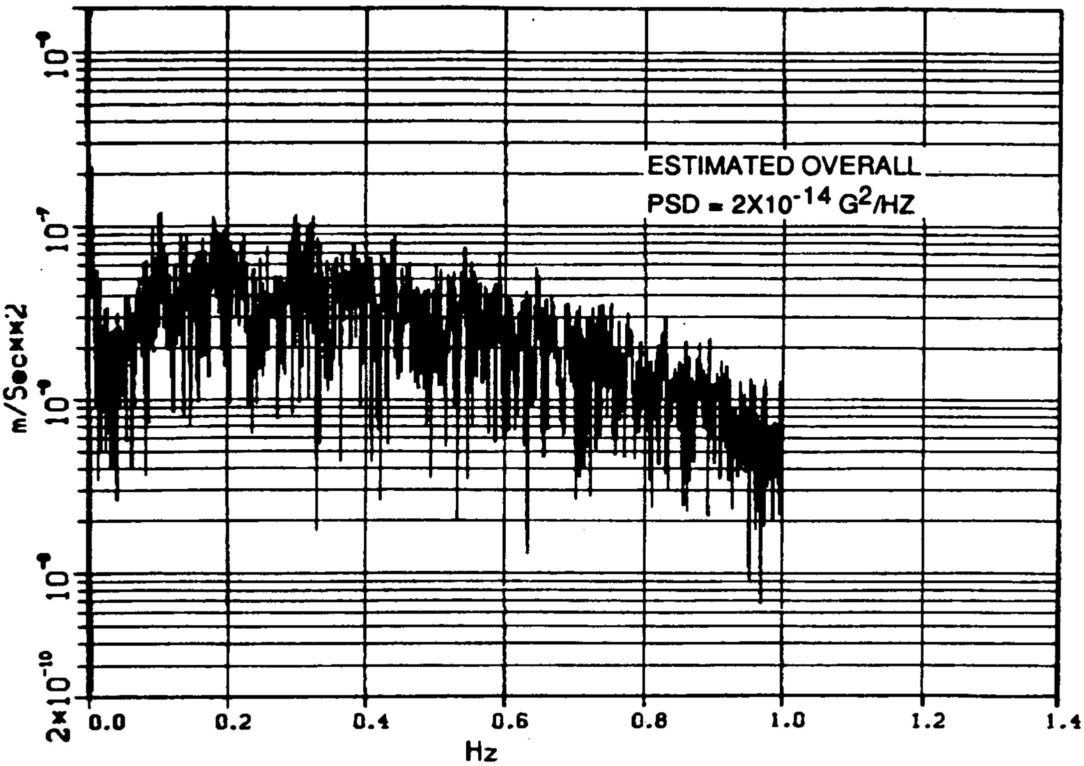
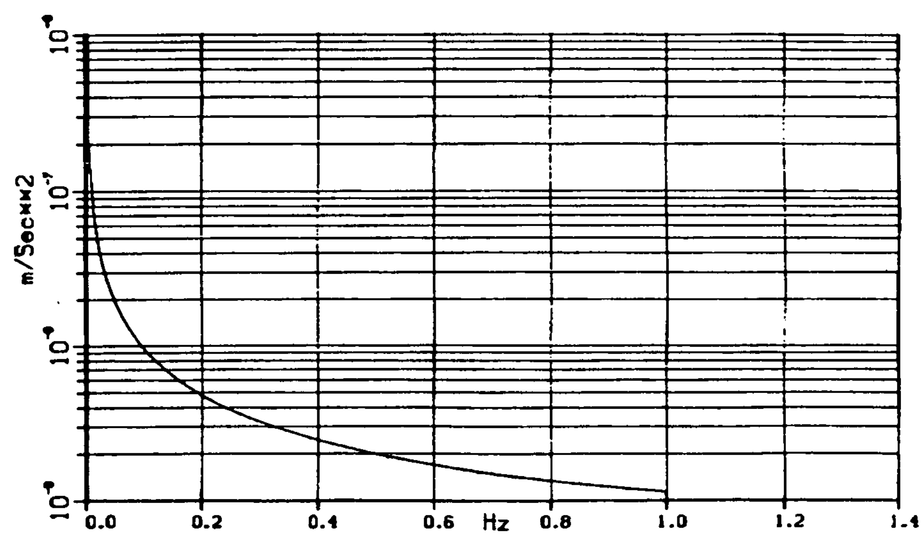


Figure 7-14. EURECA Vibration Environment—ACS–Only Jets Active Simulation



- SIMULATION SHOWS SPACECRAFT TUMBLING (475° IN ONE ORBIT)
- HOWEVER, SIMULATION ONLY ACCURATE FOR SMALL ANGLES

- POSSIBLE SCENARIO
  - SGG TAKES DATA (14 MINUTE PEAK DURATION FOR CALIBRATION)
  - EURECA ACS FIRES JETS, NULLS RATE
  - WAIT FOR TRANSIENTS TO DECAY
  - SGG TAKES NEXT DATA SAMPLE

- FOR THIS SIMULATION:
  ANGULAR RATES ≃ 500 ARC SEC/SEC
  RESULTING CENTRIPITAL ACC ≃ 0.9 μg

Figure 7-15. EURECA Vibration Environment—ACS Inactive Simulation avoiding having the spacecraft tumbling. This mode of operation should be investigated in more detail during follow on studies to ensure that the environment is quiet enough, that a high enough percentage of time is available for taking measurements, and to confirm that the EURECA control system can operate in this manner.

7.3 FUEL TANKS AND SLOSHING

There is a concern the motion of fuel in the hydrazine propellant tanks will disturb the SGG measurements. The fundamental mode of fuel slosh has been estimated with a test at the MBB/ERNO facilities in Bremen, Germany. It was found that the fundamental mode had a frequency of 1.21 Hz and that approximately 7.2 kg of fuel participated per tank for tank loadings similar to that expected for the SGG/EURECA flight test mission. There is an uncertainty of plus or minus 50% associated with both of these values. The damping of the fuel motion was also measured and was found to be 7%.

Due to the uncertainty in measurement of the sloshing frequency, it is possible that the mode could be highly coupled with the input forcing function for accelerometer calibration which occurs at 1.0 Hz. Since fuel slosh tends to be a highly non-linear phenomenon, it is recommended that this potential problem be investigated in more detail in future studies. For this study, a preliminary linear approximation has been employed to assess the potential impacts of fuel slosh coupling to the calibration forcing function.

The ratio of the fuel motion to the motion of the platform can be estimated employing the relation shown in Figure 7-16. This relation assumes that the fuel motion will not significantly affect the motion of the platform and that the system is linear and lightly damped.

FUEL COUPLING TO FORCING FUNCTION ESTIMATED USING THE RELATION

$$\frac{X}{X_o} = \frac{1}{\left(1 - \omega^2/\omega_n^2\right)^2 + \left(2\zeta\,\omega/\omega_n\right)^2}$$

ω **IS FORCING FUNCTION FREQUENCY**

ω_n **IS FLUID NATURAL FREQUENCY**

ζ **IS PERCENT DAMPING**

X_o **IS MOTION OF EURECA IN THIS CASE**

Figure 7-16. EURECA—Fluid Motion/Calibration Disturbance Coupling

As the frequency of the forcing function approaches the natural frequency of the system, the response to input ratio rapidly increases. Due to this relationship, it was initially recommended that the forcing function frequencies be reduced from 0.1 and 1.0 Hz to 0.05 and 0.5 Hz to minimize coupling between the fuel motion and the calibration forcing functions.

In order to adequately assess the impact of fuel slosh, it is necessary to have allowable signal levels. Table 7-12 displays the relations employed to define the size of the gravity gradient signal being measured by the SGG in units of Eötvös during calibration, quiet operations, and earth pointing operations. It is desired that unwanted signals be a relatively small percentage of these signals so that they do not contaminate the results. Alternatively, if the unwanted signal can be adequately predicted, it can then be removed from the data.

The symbols employed in the table are defined as follows:

PSD = required power spectral density,
g = acceleration of gravity,
R_R = rejection ratio,
Δf = bandwidth
B_L = gradiometer baseline,
ζ = percent damping,
f_n = natural frequency,
A = applied acceleration, and
α = angular acceleration.

Table 7-13 compares the gravity gradient signals generated by fuel slosh and by platform to dewar relative motion to the desired signal levels. Note that the disturbance gravity gradient signals were calculated along the most severe axis. In all cases it is found that the fuel slosh signal is significantly less than the required signal level. This is true even when the forcing function has the same frequency as the fuel slosh. Indeed, the 1.0 Hz forcing function is employed in calibrating the SSA/SGG accelerometer which is very insensitive to gravity gradient disturbances.

However, in some cases the signal due to the platform to dewar relative motion is significantly larger than the requirement. This is particularly true during SGG gradiometer calibration. Since the unwanted signal is inversely proportional to the square of the excitation frequency this result is worse at lower frequencies and it is recommended that the calibration be performed at 0.1 and 1.0 Hz.

Table 7-12. EURECA—Fluid Motion, Gravity Gradient Requirements

QUIET OPERATIONS $\frac{(PSD)(g)(R_R)(\Delta f)^{1/2}}{B_L} = \frac{(PSD)(g)(R_R)(2\zeta f_n)^{1/2}}{B_L} = 4.0 \times 10^{-5} E$

EARTH POINTING - SAME RELATION, REQUIREMENT = 4.0×10^{-4} E

GRADIOMETER BALANCE - $\frac{(A)(R_R)(g)}{B_L} = 4.9 \times 10^{-2} E$

ACCELEROMETER CALIBRATION LINEAR INPUTS - $\frac{(A)(g)}{B_L} = 4.9 \times 10^{5} E$

ACCELEROMETER CALIBRATION - ANGULAR INPUTS - $\left(\frac{\alpha}{2\pi f_n}\right)^2 = 2.4 \times 10^{1} E @ f_n = 0.5$ Hz

GRADIOMETER CALIBRATION - LINEAR INPUTS - $\frac{(A)(R_R)(g)}{B_L} = 4.9 \times 10^{-3} E$

ACCELEROMETER CALIBRATION - ANGULAR INPUTS - $\left(\frac{\alpha}{2\pi f_n}\right)^2 = 2.4 \times 10^{1} E @ f_n = 0.05$ Hz

Table 7-13. EURECA—Fluid Motion, Response vs. Requirement

CASE DESCRIPTION	EXCITATION FREQUENCY (Hz)	SLOSH FREQUENCY (Hz)	$\frac{X}{X_O}$	FUEL SIGNAL (E)	VEHICLE SIGNAL (E)	REQUIREMENT (E)
SGG GRADIOMETER BALANCE	.1	1.21	1.014	2.6×10^{-4}	2.8×10^{-2}	4.9×10^{-2}
SGG GRADIOMETER BALANCE	.05	1.21	1.0034	1.0×10^{-3}	$\boxed{1.1 \times 10^{-1}}$	4.9×10^{-2}
SSA/SGG ACC. CAL - LINEAR	1.0	1.21	8.78	4.8×10^{-5}	2.8×10^{-3}	4.9×10^{5}
SSA/SGG ACC. CAL - LINEAR	0.5	1.21	1.45	1.1×10^{-4}	1.1×10^{-2}	4.9×10^{5}
SSA/SGG ACC. CAL - LINEAR	1.0	1.0	51.0	1.7×10^{-4}	2.8×10^{-3}	4.9×10^{5}
SSA/SGG ACC. CAL - LINEAR	0.5	.605	8.78	1.9×10^{-4}	1.1×10^{-2}	4.9×10^{5}
SGG GRAD CAL - LINEAR	.1	1.21	1.014	2.6×10^{-4}	$\boxed{2.8 \times 10^{-2}}$	4.9×10^{-3}
SGG GRAD CAL - LINEAR	.05	1.21	1.0034	1.0×10^{-3}	$\boxed{1.1 \times 10^{-1}}$	4.9×10^{-3}
SSA/SGG ACC. CAL - ANG.	.5	1.21	1.45	-	9.5×10^{-3}	2.4×10^{1}
SGG GRAD CAL - ANG.	.05	1.21	1.45	-	9.5×10^{-2}	2.4×10^{1}
QUIET	1.0	1.21	8.78	9.3×10^{-6}	-	4.0×10^{-5}
EARTH POINTING	1.0	1.21	8.78	9.3×10^{-6}	-	4.0×10^{-4}

RECOMMEND 0.1 AND 1.0 Hz BE RETAINED AS CALIBRATION FORCING FUNCTION FREQUENCIES. FLUID SLOSH SHOULD BE CONSIDERED IN MORE DETAIL IN FUTURE STUDIES.

When this is done, the unwanted signal during SGG gradiometer linear axis calibration is approximately six times the desired signal. This implies that this signal will have to be predictable to within 1% to 10% in order to adequately eliminate it from the data. While this is possible, it will prove challenging. At 0.05 Hz the problem would be even worse. The effects of dewar to vehicle relative motion should be studied in more detail in future work. It is recommended that a finite element model of the SGG/EURECA flight test configuration be developed and that a transient response analysis be performed to better characterize the amount of motion occurring. It is also recommended that the required levels be reviewed and relaxed if found to be overly conservative.

7.4 MAGNETIC TORQUER ASSEMBLIES

The magnetic field at the instrument due to the magnetic torquer bars was calculated. Each torquer bar was assumed to have a 500,000 pole cm dipole field along the axis of the bar (see Table 7-14). Two bars were assumed to be located 2.5 meters from the instrument while the remaining bar was 2.3 meters from the instrument. With these assumptions, it was found the magnetic field at the instrument due to the torquer bars was less then 40% of that due to the earth's magnetic field. Therefore the field produced by the torquer bars should not be a problem.

Figure 7-17 shows the position of the magnetic torquer bars on the EURECA platform. The three torquer bars have been darkened for the sake of clarity. During the SGG/EURECA flight test mission, the SGG dewar would be located approximately where the payload labeled 11A AMF is shown in this figure.

7.5 MAGNETIC SHIELDING

The current shield design works well at room temperature. It is recommended that the flight shield be similar but operate at cryogenic temperatures (see Table 7-15). This will require the replacement of Mumetal with Cryoperm 10. It is estimated that this material will give the same performance at cryogenic temperatures as the Mumetal shield does at room temperature.

There is an induced dipole in the magnetic shield due to both the earth's magnetic field and the magnetic field of torquer bars (see Table 7-16). However, these dipoles are significantly less (less than 5%) than the dipole capabilities of each torquer and should have negligible impact upon the control system. There is also a 0.04 N force maximum induced on the shield. This is reacted by an equal and opposite force acting upon the torquer bar and again should have minimal impact upon the control of the system.

The magnetic shield also provides adequate AC shielding at 0.1 to 1.0 Hz. The AC shielding ratio is approximately equal to the DC shielding ratio. The dewar will supply additional AC shielding.

Table 7-14. Torquer Bar Field at Experiment

<u>ASSUMPTIONS</u>

DIPOLE 500,000 POLE CM, EACH BAR (500 AMPERE TURN METER²)
FIELD ALONG AXIS OF BAR
DISTANCE TO EXPERIMENT 2.3 M, 2.5 M, 2.5 M

BAR	DISTANCE (METERS)	FIELD (OERSTED)
1	2.3	.084
2	2.5	.061
3	2.5	.061
TOTAL	-	.119
EARTH'S FIELD		.3 EQUATOR .6 POLES

$$H = \frac{2M}{r^3}$$

H = OERSTEDS
M = DIPOLE
r = DISTANCE, CM

$$H_T = [H_1^{\,2} + H_2^{\,2} + H_3^{\,2}]^{1/2}$$

<u>CONCLUSION</u>: FIELD PRODUCED BY TORQUER BARS IS LESS THAN EARTH'S FIELD AND SHOULD NOT BE A PROBLEM

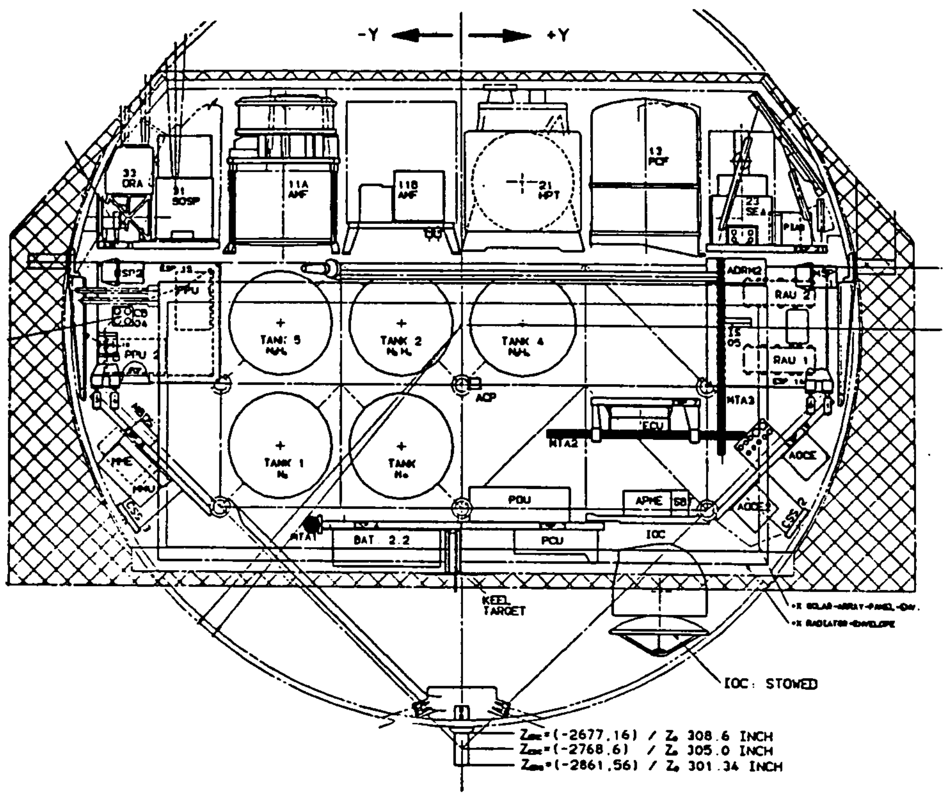


Figure 7-17. Magnetic Torquer Locations

Table 7-15. Shielding

PRESENT DESIGN	DOUBLE SHIELD	1.5 mm THICK EACH MUMETAL
	ROOM TEMPERATURE OPERATION	
	SHIELDING RATIO	4500 (CALC)
RECOMMENDATION	MATERIAL	CRYOPERM 10 (80% Ni, 20% Fe) VACUUM SCHMELZE ISELIN, NJ
		CRYOPERM 10 IS SIMILAR TO MUMETAL BUT HAS SPECIAL ANNEAL
		PROPERTIES AT 4°K SAME AS ROOM TEMPERATURE
	SHIELDING RATIO	4500 ROOM TEMP 4500 4°K

Table 7-16. Effects of Shield

• FORCE ON SHIELD DUE TO TORQUER BARS FULLY EXCITED AT 500,000 POLE CM		< 0.04 N
• INDUCED DIPOLE		
EARTH'S FIELD	POLES (H = .6)	18,000 POLE CM
	EQUATOR (H = .3)	9,000 POLE CM
TORQUER BARS	(H = .12)	3,600 POLE CM

EFFECTS OF EARTH'S FIELD AND TORQUER BAR FIELD ON SHIELD ARE NEGLIGIBLE.

SECTION 8
IMPLEMENTATION PLAN

8.1 EURECA GROUND TURNAROUND

Integration of the SGG instrument into the overall EURECA mission planning and implementation process has to be reconciled with the overall EURECA ground-turnaround scenario. (See Figure 8-1.)

The ground-turnaround is here defined as the elapsed time between the Shuttle/EURECA landing after a mission and the launch for the subsequent mission. The ground-turnaround activities are grouped into the following seven main sequences:

1. Post-Mission Phase (Return from EURECA Mission)
2. De-integration Phase
3. Refurbishment and Modification Phase
4. External Refurbishment of Subsystems
5. External Refurbishment of Payload Instruments
6. System Test Phase (for next Mission)
7. Pre-Mission Preparation Phase

The EURECA ground-turnaround scenario and its implications for the SGG Flight Test implementation are described for two alternate processing scenarios:

1. EURECA and SGG processing in Europe
2. EURECA and SGG processing in USA (at Astrotech, Florida)

Processing in EUROPE (Figure 8-2)

The total processing time in this scenario is 27 months. The post-mission phase includes a comprehensive confidence test of the carrier and the payload instruments. This provides, at an early date, the capability to perform trouble shooting and to initiate the detailed planning of all refurbishment activities for the carrier subsystems and the payload instruments which might be reflown on the subsequent mission. De-integration to the extent necessary for refurbishment is performed at EURECA's home base in Bremen, Germany. External refurbishment of the subsystems at the contractor's and of the reflight payloads at their home institutes has to be performed within a 6 to 8 month window. After reinstallation of the refurbished items and performance of the system tests, EURECA is shipped to the launch site in the USA for final pre-mission processing.

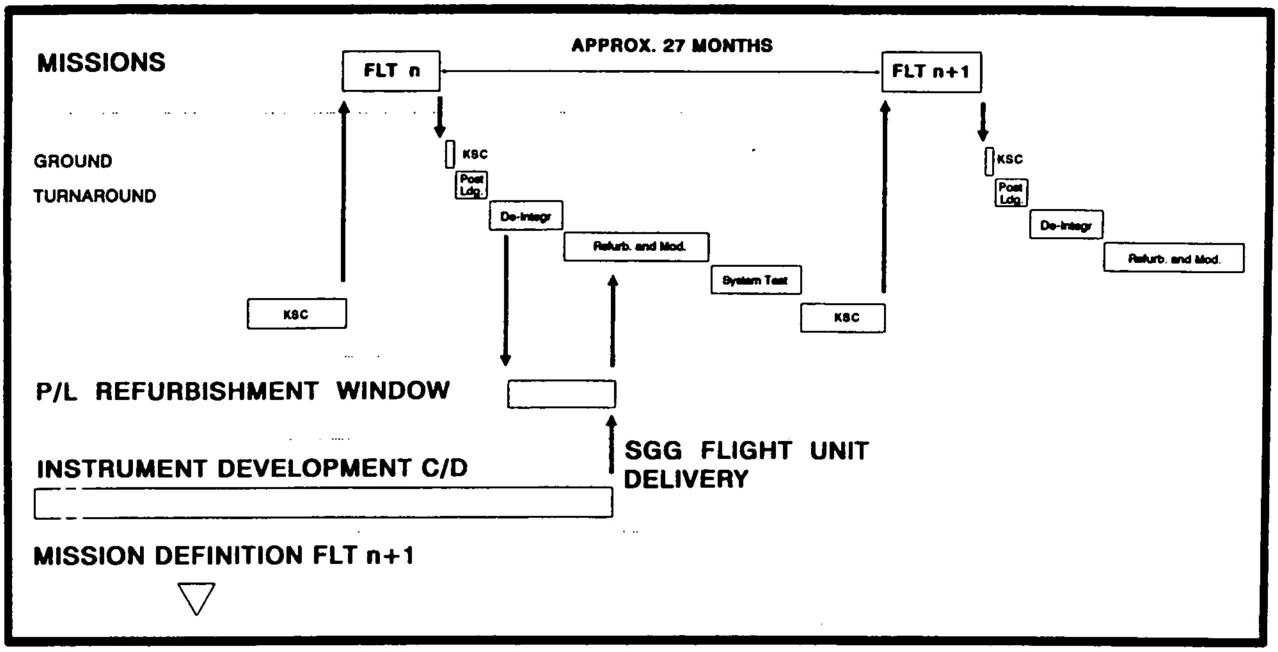


Figure 8-1. EURECA Turnaround Schedule

Processing in USA (Figure 8-3)

In comparison with processing in Europe, the ground-turnaround time is reduced by 3 months. This option constitutes a higher risk for subsystem and payload refurbishment, owing to the numerous overseas transports between the contractor and the payload home sites and the EURECA processing facility in the USA. On the other hand, the clear advantage of this scenario for SGG integration is, that the EURECA test equipment can easily be accessed for instrument development tests on breadboard or Engineering Model level.

It has to be noted that both scenarios require integration of the SGG Flight Model to EURECA 16 months before launch.

8.2 PAYLOAD INTEGRATION

A EURECA mission has to be defined 42 months before launch and the payload instrument Flight Units (FU) have to be delivered for integration to EURECA 16 months before launch. It is assumed here, that the mission under consideration comprises a multi-instrument payload complement. The two milestones defined above form the boundary conditions for the lower level detail analytical and physical integration steps. (See Figure 8-4.)

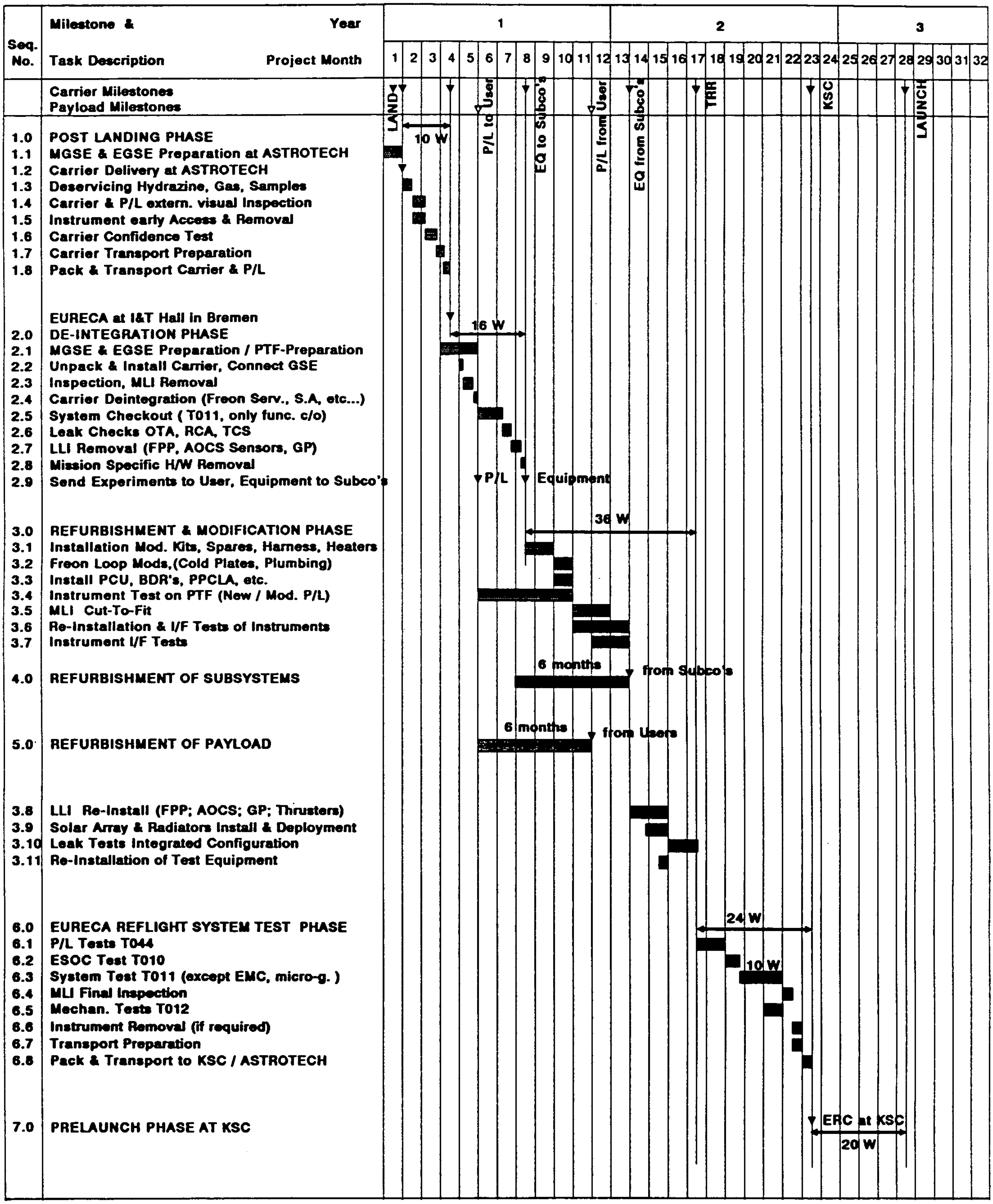


Figure 8-2. Carrier Processing in Europe

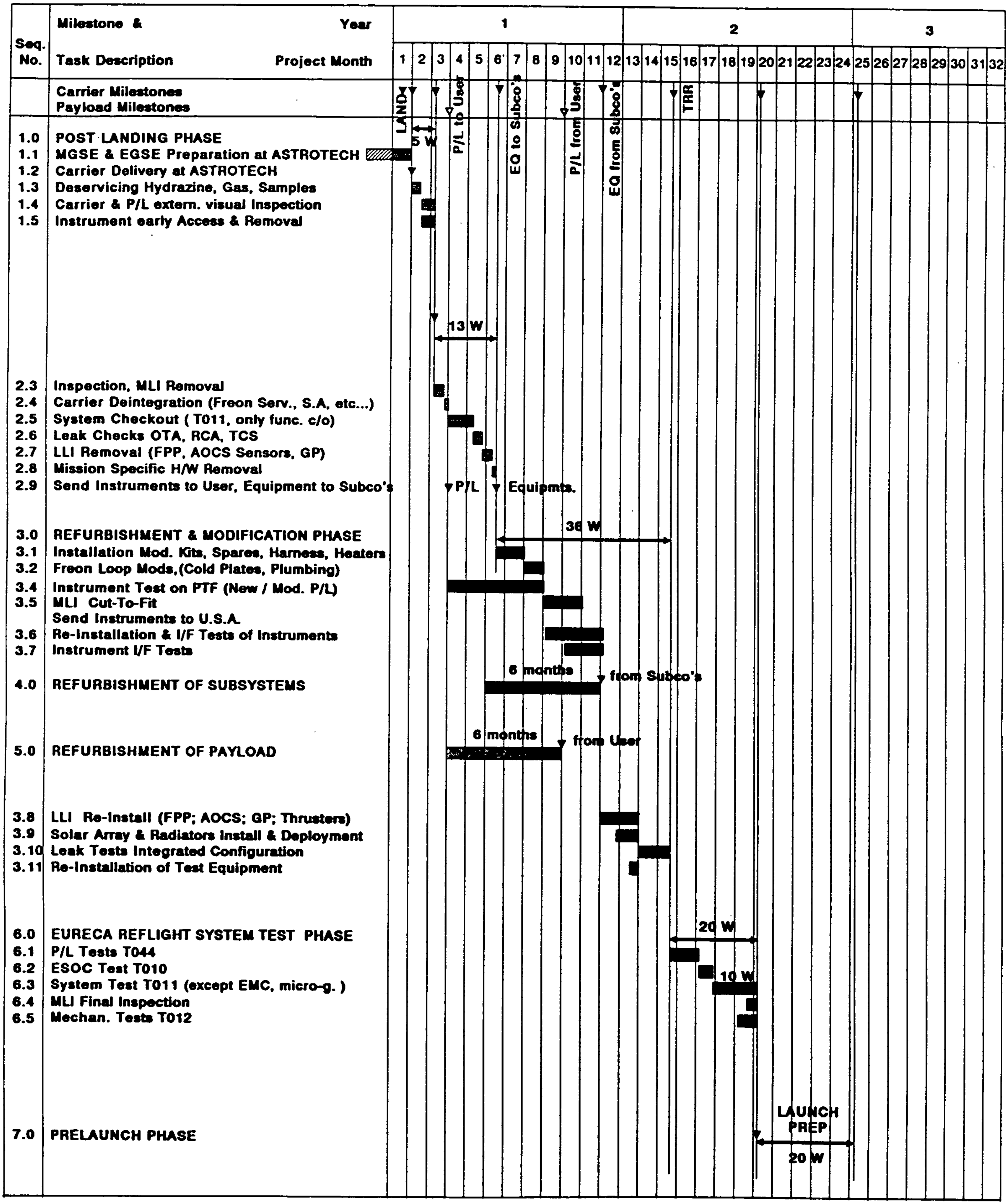


Figure 8-3. Carrier Processing in USA

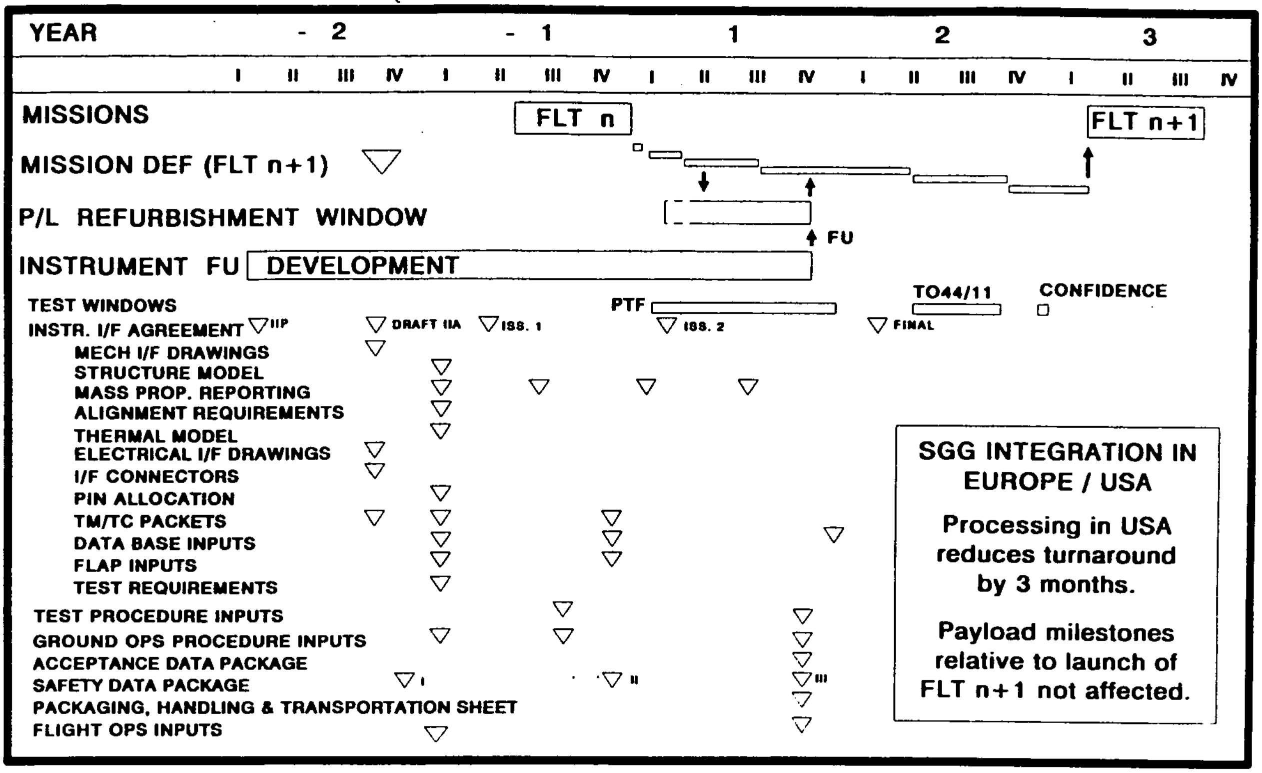


Figure 8-4. Payload Integration Schedule

Interface Documentation

IIP: The instrument requirements and the proposed method of interfacing with EURECA are laid down in the Instrument Interface Proposal (IIP) data sheets. Requirement and resource conflicts between the platform and the payload instrument have to be resolved and trade-offs have to be performed so as to arrive at the most appropriate instrument accommodation on EURECA.

IIA: When the mission is formally agreed (42 months before launch), the IIP will be upgraded to the Instrument Interface Agreement (IIA), which from then on forms the key document controlling the physical and functional interfaces.

User Deliveries: User documentation has to be available in time for system level analyses, such as:

- Structural Model: for Shuttle/EURECA coupled load analysis
- Thermal Model: for system thermal analysis
- Safety Data Package: for safety analyses

Instrument Testing

Definition of instrument test requirements and the related test procedures have to be timed in accordance with the allocated test windows given on Figure 8-4.

PTF: Prior to integration of the Flight Unit (FU) to EURECA, the instrument will be tested on the Payload Test Facility (PTF). These tests in general comprise:

- verification of Instrument Test Equipment interfaces to the EURECA EGSE
- initial activation
- communication protocol compatibility between the instrument and the EURECA Data Handling System
- initial instrument functional tests

The PTF tests may be performed well in advance of the FU tests so that preliminary information on the instrument-to-platform compatibility can be gained.

T 044/011

After integration to EURECA, initial tests will be performed with the individual instrument Flight Units (T 044). These tests will include the full instrument test program as planned to be performed in the later acceptance test phase (T 011).

T 011 will cover:

- System Functions
- Electromagnetic Compatibility
- Mission Sequence
- Leak
- Mass Properties
- Alignment

Unique operator training requirements identified for the SGG instrument may be accomplished during functional testing. This would include familiarization with normal functions as well as planning for contingency operation.

Confidence Test

This is the last system check before the launch.

Model Philosophy

The EURECA payload test approach is nominally based on the availability of two payload models, namely the Engineering Model (EM) and the Flight Unit (FU). For the SGG, a one-model approach is taken. Nevertheless, preliminary testing of the SGG before its integration should be performed using, e.g.:

- Breadboard equipment in order to checkout the data communication protocol.
- Simulators in order to perform initial functional verification.

The overall breakdown of the activities at integrated system level is shown on Figure 8-5.

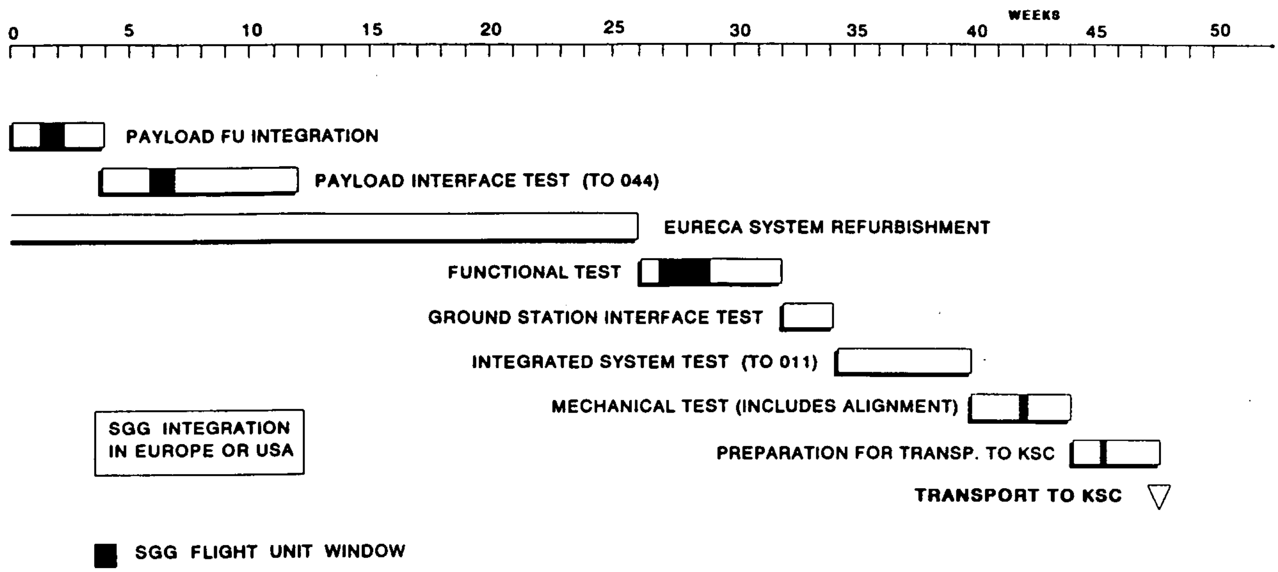


Figure 8-5. Overall System Integration and Test Schedule

8.3 GROUND OPERATIONS

Pre-Mission

EURECA processing will take place at the Astrotech and at the Kennedy Space Center (KSC) at the following locations:

- Payload Processing Facility – PPF (Astrotech)
- Vertical Processing Facility – VPF
- Launch Pad
- Orbiter Processing Facility – OPF

On arrival at KSC, EURECA with its integrated instruments will be installed in the PPF. Here all spacecraft and payload equipment which had to be disconnected for transport due to the envelope constraints of the ferry aircraft (Boeing 747F) will be installed.

After assembly, a confidence test will be performed to verify newly mated interfaces and the overall performance of the subsystems and the instruments. The overall test time for EURECA and its payload is limited to approximately 12 days and payload check-out will be limited to approximately 2 hours for each instrument to verify that no damage has occurred during transport.

Payload check-out will cover the following activities:

- Activation/control/monitoring via the Master Test Processor
- Instrument housekeeping via the Master Test Processor

Scientific data is not required to verify the health of the instruments and are therefore not required for check-out. If for other reasons, such as alignment and calibration, scientific data are required, they will be recorded (either on disk or tape). These data will be packetized and supplied to the instrument user for off-line evaluation on his payload test equipment.

During the confidence test, an ESOC Link Test (PI Link Test) will be performed to verify the monitoring and control functions from ESOC via the Mission Control Center (MCC) to the spacecraft and payload.

The confidence test is the last payload check-out activity prior to launch. EURECA will then be transported to the Hazardous Processing Facility, where propellant loading will be performed. During this activity, EURECA will not be powered and no payload tasks are performed. EURECA will then be transported to the Vertical Processing Facility, where it will be installed in the Vertical Processing Handling Device (VPHD). After assembly of the total Shuttle payload in the VPHD, the Shuttle/payload interface test will be performed. During this test, the PI Link Test will be repeated to verify the monitoring and control functions from ESOC via MCC to EURECA. Afterwards, the whole Shuttle payload will be transported in the vertical canister to the launch pad, where it will be installed into the Rotatable Service Structure (RSS) for loading on the Shuttle. Late access to instruments is possible at this stage of operations. Instruments which require sample or battery installation or other services, e.g. SGG helium replenishment, must provide access facing out of the Shuttle cargo bay.

Service must be kept to a minimum, because Shuttle and payload processing time at the time of a EURECA flight will be extremely limited. EURECA will not be powered up for payload processing at the pad, which means that newly mated interfaces will not be verified by the on-board system.

Servicing may be performed at the PPF, HPF, VPF, RSS and Shuttle. STS on-line servicing activity (activities in VPF, RSS and Shuttle) shall be avoided and necessity must be proven by analysis to be assessed by NASA within the framework of the Payload Integration Plan (PIP).

Servicing of EURECA, when located in the RSS, is limited to 8 hours in total.

Instrument servicing at late access time before L-51 hours is limited to a maximum of 3 hours.

The EURECA instrument interface will be deactivated during servicing operations. For extremely sensitive instrument environmental control, the umbilical may be considered for power distribution.

Instruments which have to be installed at the launch pad with a weight exceeding 20 kg will require a hoisting device. This device which is a NASA service (extra) will require an interface plate for the interface between the hoisting device and the instrument. The installation for one instrument, or sample, must not take longer than 2 hours, this includes the mechanical, electrical and MLI installation. A continuity test after electrical connection must also be performed within the two hours. Test equipment at the launch pad has to be kept to a minimum and only hand-carried equipment can be accepted. All equipment required for servicing must be provided by the instrument user to KSC requirements. Afterwards, the Shuttle cargo bay doors will be closed and no monitoring is available, until EURECA is deployed about 5 to 8 days later.

The schedule for pre-mission operations related to the SGG Flight Test Mission and the windows during which the instrument, or access to it, is required, is shown on Figures 8-6 and 8-7.

Post-Mission

After the mission, the Shuttle normally will land at Edwards AFB. After the ferry flight to KSC, the Shuttle will then be towed to the Shuttle Processing Facility, where safing and deservicing will be performed.

Samples can be removed from only those instruments, where samples are degraded on the ground, approximately 9 days after landing.

EURECA will be transported to the Hazardous Processing Facility for deservicing and afterwards will be prepared in the PPF for air transport. The instruments normally will be removed from EURECA on arrival in Europe and handed over to the instrument user. Under certain circumstances, however, the instrument may be removed in the USA. In the case of the SGG instrument, it will be removed in the USA.

The schedule of activities related to post-mission operations is given on Figure 8-8.

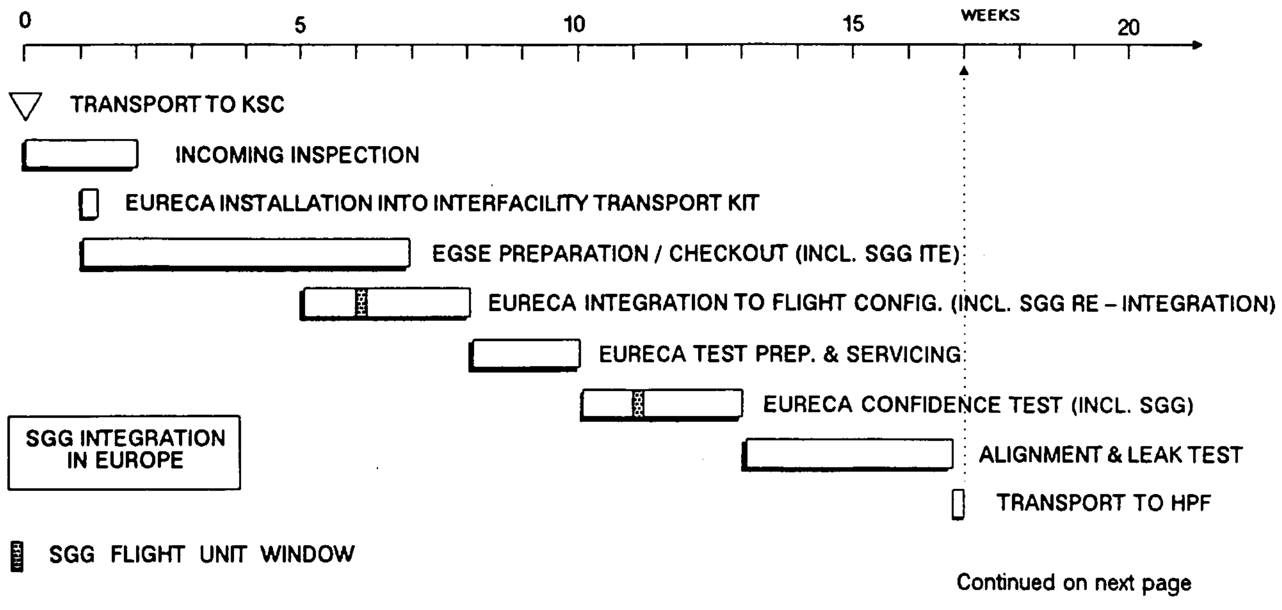


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Figure 8-6. Ground Operations Schedule in USA—Pre-Mission

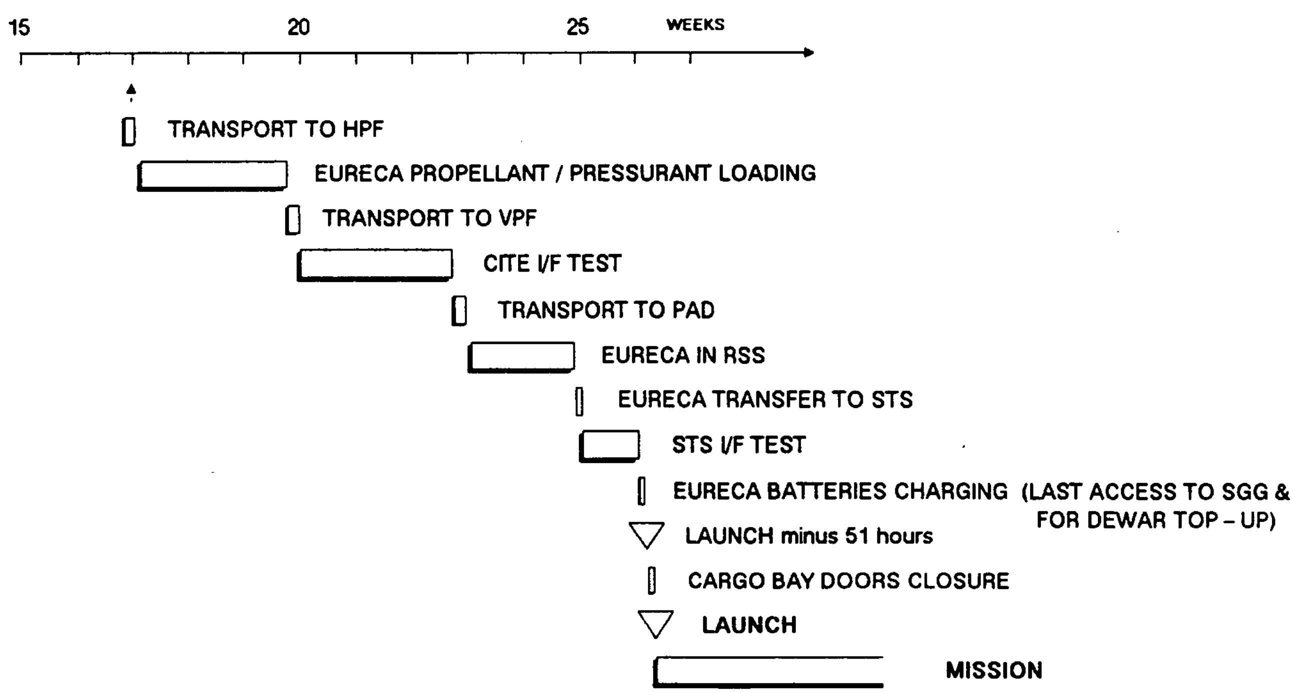


Figure 8-7. Ground Operations Schedule in USA—Pre-Mission

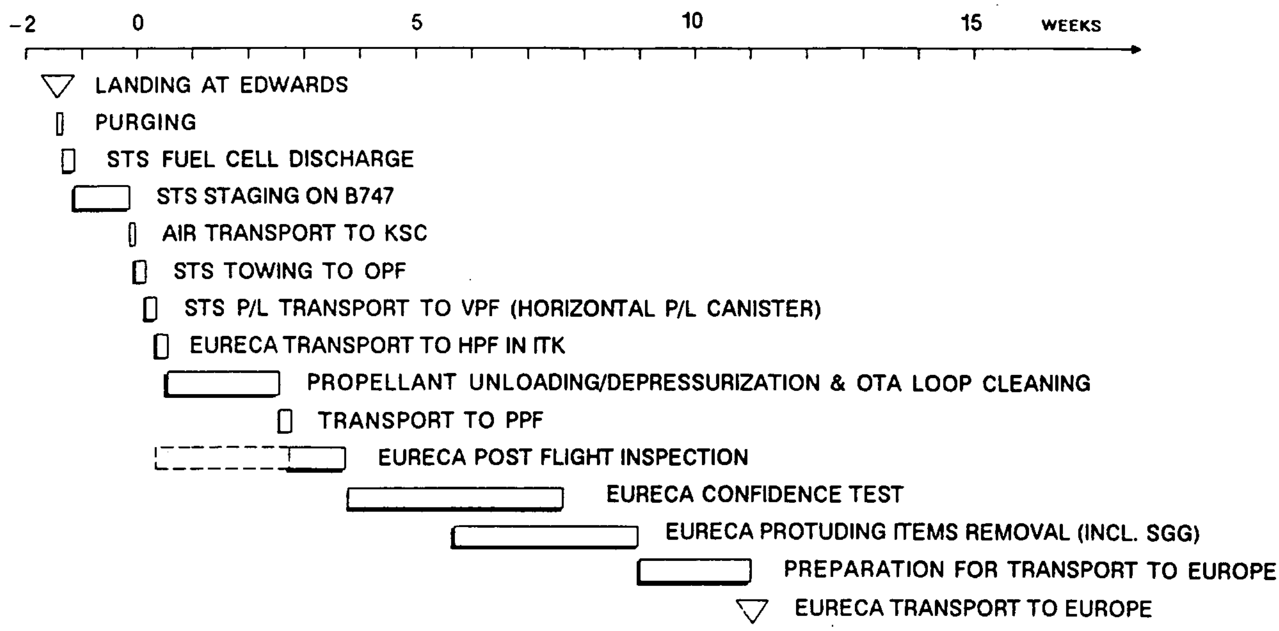


Figure 8-8. Ground Operations Schedule in USA—Post-Mission

8.4 FLIGHT OPERATIONS

The typical EURECA mission phases and the related major aspects are shown in Figures 8-9 and 8-10.

Flight control is the summary term for all control activities undertaken from the ground in order to ensure reliable EURECA mission conduct, proper use of on-board systems and their resources, and safety of spacecraft and instruments. Flight control thus comprises the entire operations planning process, the implementation of planned operations and failure recovery operations as well as the final verification of achievements with regard to mission state, mission products and spacecraft/instrument performance.

During the mission, the operations control center exercises control over EURECA and its payload. Uplinks and downlinks interconnect the two elements and allow the operation of the system as a control loop. In this control loop, the operation control center is the decision-making element. It decides on necessary command interactions and sends them through a TTC station to the EURECA for execution. Subsequently, the system/payload provides, as a feedback to the control center, telemetry data which indicate the reactions to control interactions from ground.

C-2

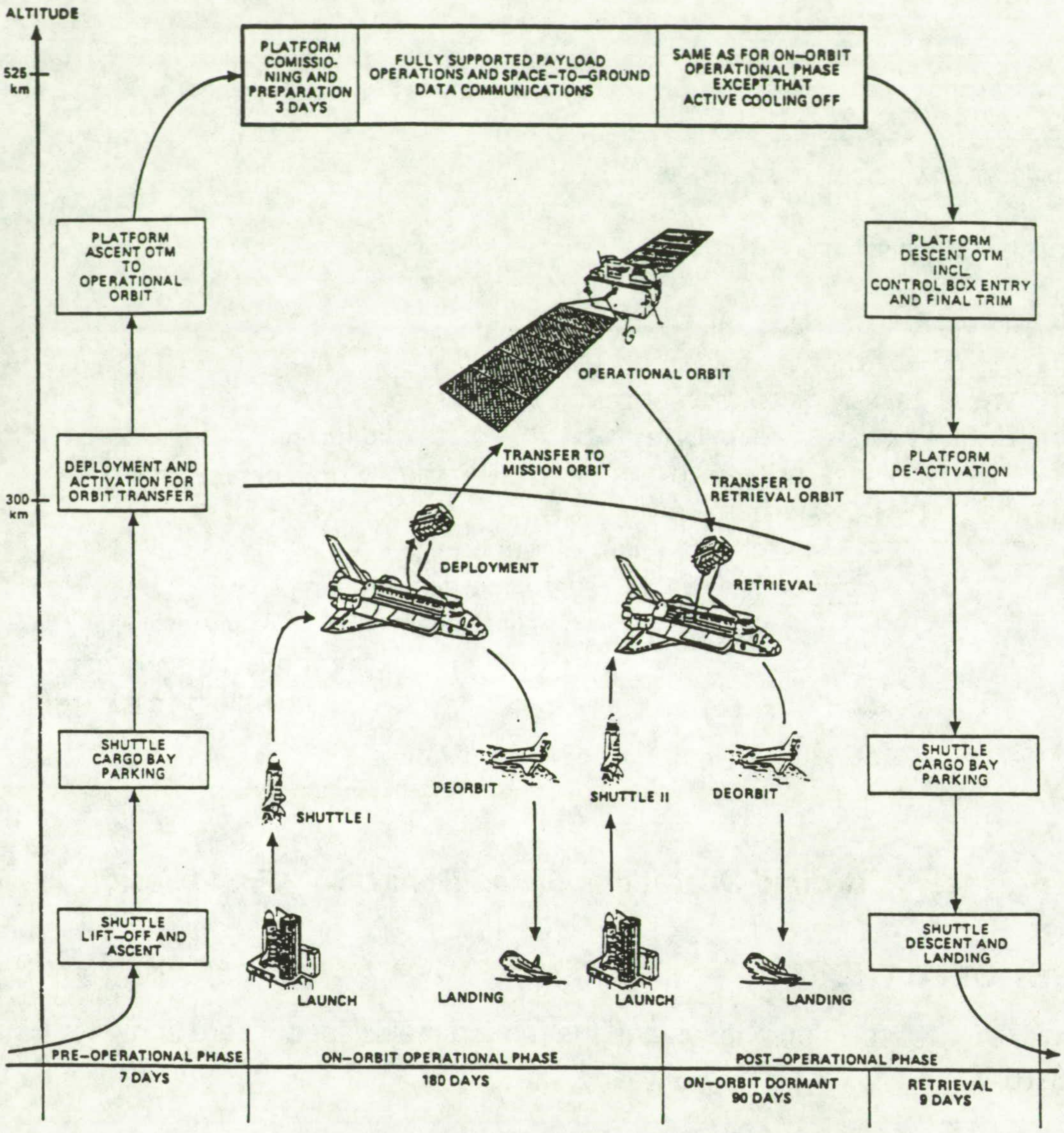


Figure 8-9. EURECA Mission Phase

The control center undertakes real-time and deferred time data analyses and concludes from the results whether the EURECA spacecraft payload is performing correctly or whether it is necessary to initiate failure recovery operations.

The top level functional objectives defined for the SGG Flight Test Mission are:

- Go/No-Go Test
- Calibration
- Experiment Data Acquisition

Their inter-relationship is shown on Figure 8-11.

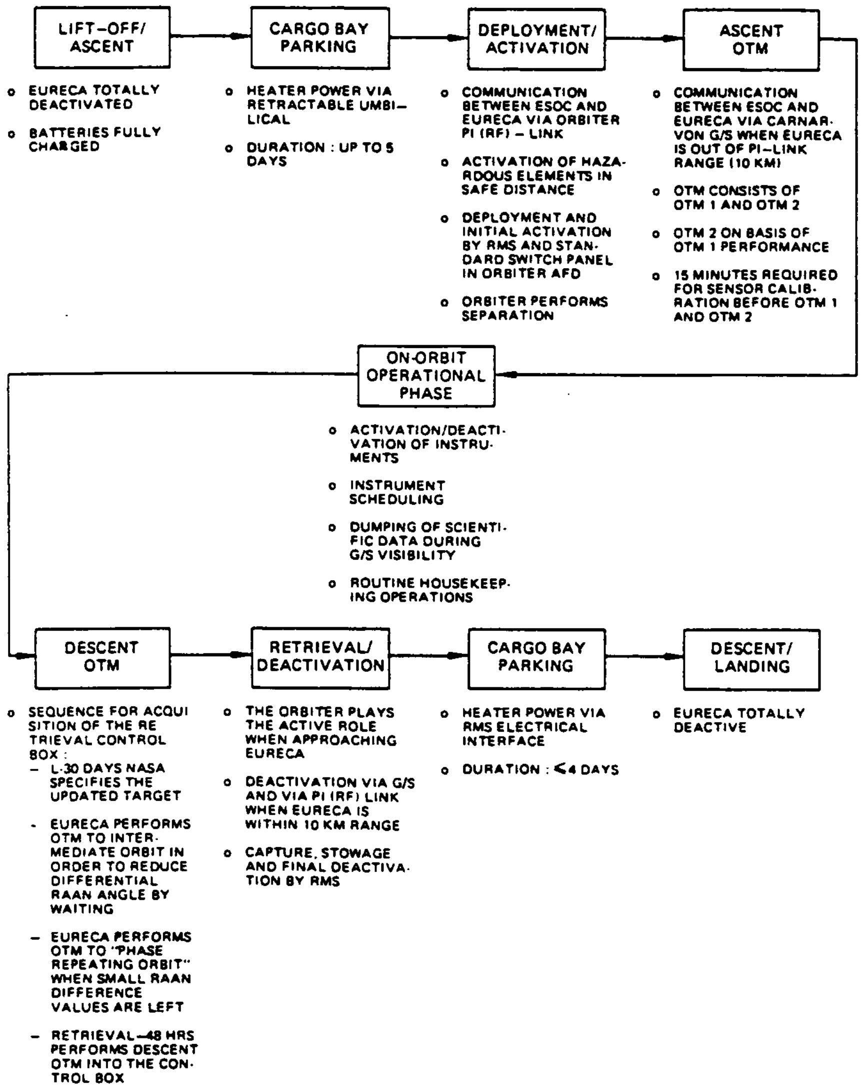


Figure 8-10. EURECA Mission Phases

SGG Go/No-Go Test

The SGG Principal Investigator requires that the SGG instrument be checked out well in advance of the EURECA ascent orbit transfer maneuver, so that he has the choice of aborting the mission, should any major SGG instrument failure be detected.

There are two viable options for implementation of the check-out:

1. ***During the Cargo Bay Parking Phase (Figure 8-12)***

   Depending on the Shuttle mission timeline, this phase may last up to five days. The power and data transmission capabilities, given on Figure 8-12 are not to be understood as absolute technical limitations, rather they reflect the standard resources assigned to EURECA as a Shuttle quarter payload. Allocation of

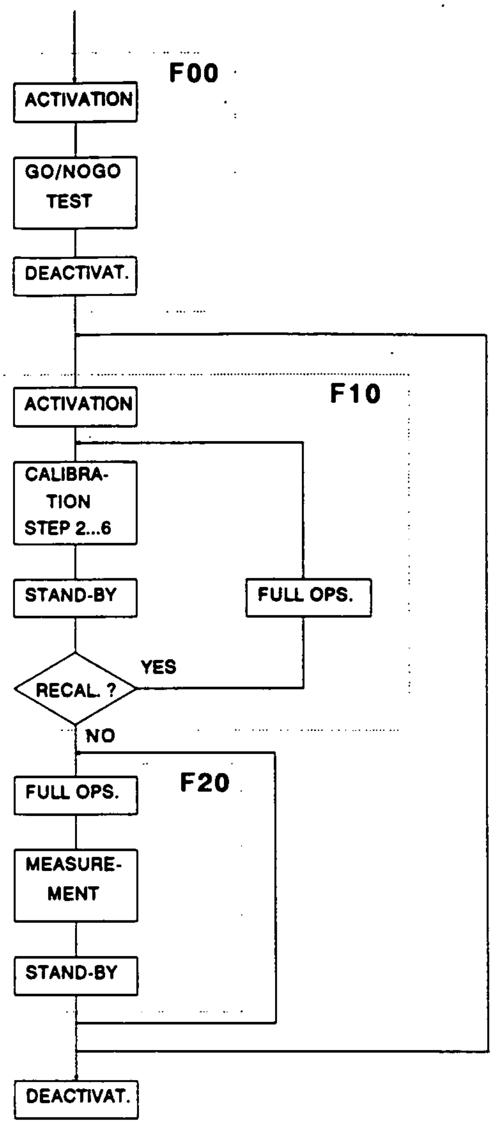


Figure 8-11. SGG Functional Objectives

extended resources, which, depending on the detailed Go/No-Go Test concept, may be required by SGG, will have to be agreed on with the Shuttle operator at a later date.

2. ***During EURECA Deployment and Activation Phase (Figure 8-13)***

   Check-out during this phase offers the advantage that the SGG dewar unlock activity, identified as a critical task for the SGG Flight Test Mission, can be performed before deployment and, therefore, be verified as part of the check-out. The time limitation of approximately 25 minutes, however, is very severe and is a major constraint for defining a Go/No-Go test concept. The data given on Figure 8-13 with regards to the telemetry transmission capability is not a technical limitation of the affected systems but is negotiable with the Shuttle operator.

EURECA CARGO BAY PARKING PHASE (SAME AS EURECA MISSION 1)

STS CARGO BAY DOORS OPENING

[30 MIN.] EURECA THERMAL CONTROL SYSTEM (TCS) ACTIVATION AND CHECK-OUT

[UP TO 5 // DAYS] THERMAL CONDITIONING OF EURECA

[30 MIN.] TCS DEACTIVATION

INITIATION OF ACTIVITIES FOR EURECA GRAPPLING AND UNBERTHING

OPTION 1: SGG CHECK-OUT DURING CARGO-BAY PARKING PHASE

DURATION OF WINDOW:	UP TO 5 DAYS
POWER:	MAX. 200 W
TELEMETRY:	-MAX. 1.35 kbps, TO BE SHARED WITH TELEMERY FROM EURECA SYSTEM; -TM TRANSMISSION TO GROUND VIA DEDICATED (PDI-) INTERFACE, ROEU, SHUTTLE AND TDRSS

Figure 8-12. SGG Check-Out: Shuttle Cargo Bay

EURECA DEPLOYMENT AND ACTIVATION PHASE (SAME AS EURECA MISSION 1)

EURECA GRAPPLING AND UNBERTHING BY RMS

[EPS 130 MIN.] EURECA ACTIVATION AND CHECK-OUT

EURECA ANTENNA & SOLAR ARRAY DEPLOYMENT AT RMS [25 MIN.]

SUN PHASE

EURECA BATTERY CHARGING [30 MIN.]

EURECA RELEASE AND SEPARATION FROM STS [25 MIN.]

INITIATION OF EURECA ASCENT MANOEUVRE

OPTION 2: SGG CHECK-OUT DURING EURECA DEPLOYMENT AND ACTIVATION

DURATION OF WINDOW:	MAX. 25 MINUTES
POWER:	MAX. 1000 W (SUN PHASE ONLY)
TELEMETRY:	- MAX. 2 kbps (VIA SHUTTLE / TDRSS, TO BE SHARED WITH EURECA SYSTEM TM) - PACKET LENGTH LIMITED TO APPR. 350 BYTES

Figure 8-13. SGG Check-Out: EURECA Deployment Phase

Calibration and Data Acquisition

Typical SGG on-orbit task sequences for the Flight Test on EURECA are described on Figure 8-14. The calibration sequence is performed repeatedly so as to achieve reiteratively the required SGG/SSA balancing. Data acquisition is performed while EURECA is operated in a "quiet" mode with respect to the SGG instrument micro-g environment. This means, that the major disturbance sources, such as the fluid loop and the attitude control actuators are switched off. Calibration cycles have to be synchronized with time periods of maximum EURECA ground-station coverage (see Section 6.4).

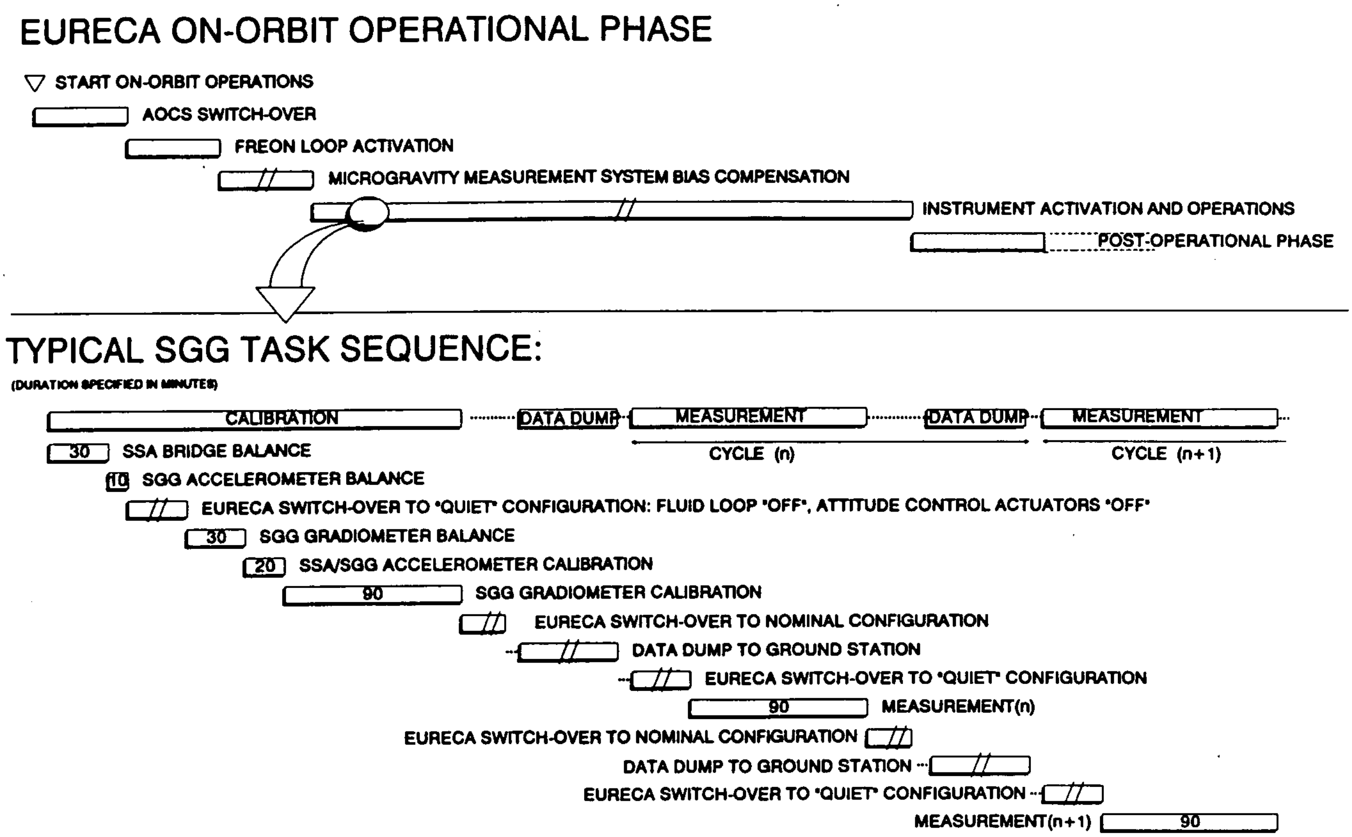
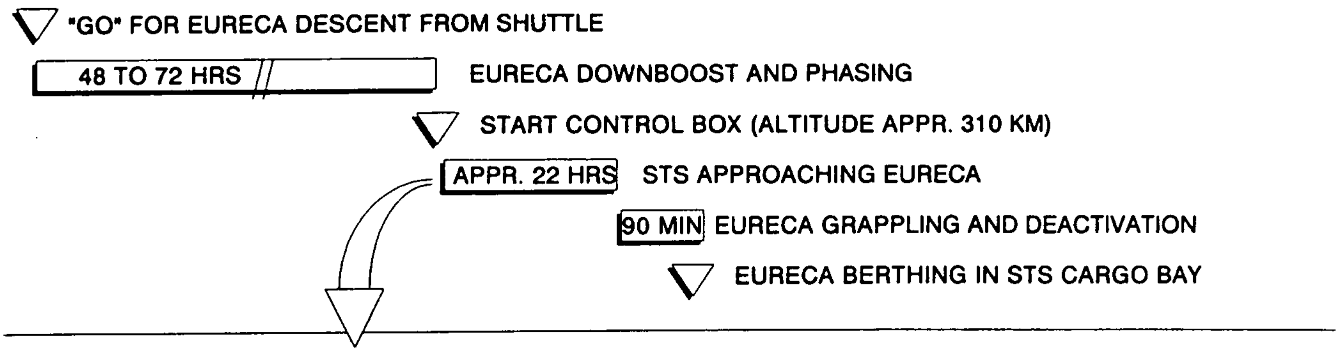


Figure 8-14. SGG Flight Test Mission—Sequences

For SGG data acquisition at an altitude of approximately 310 km, a time window limited to 22 hours is available after EURECA has descended to its retrieval orbit and prior to grappling by the Shuttle (see Figure 8-15). In this case also, the EURECA resources, other than active cooling, are available to the SGG instrument. The duration of this window is dependent on the Shuttle/EURECA retrieval scenario, which may be altered in agreement with the Shuttle operator.

EURECA ORBIT TRANSFER AND STS BERTHING (SAME AS EURECA MISSION 1)



SGG MEASUREMENT CYCLES AT 310 KM ORBIT ALTITUDE:

DURATION OF WINDOW: APPR. 22 HRS FOR STANDARD STS APPROACH, WINDOW PENDING ON SHUTTLE APPROACH SCENARIO

OTHER RESOURCES: SAME AS FOR ON-ORBIT OPERATIONAL PHASE

Figure 8-15. Experiment Data Acquisition

SECTION 9
CONCLUSIONS

The results of this study indicate that the EURECA platform may be a suitable carrier for a flight test of the SGG instrument. The EURECA platform offers a unique capability for microgravity instruments-Shuttle launched and retrieved, designed for low disturbance levels, capable of long duration free flight, versatile and adaptable, and perhaps most important of all, the EURECA is an existing hardware element that will be flight proven well in advance of the SGG flight test need date. EURECA offers an effective approach for the SGG flight test by sharing costs with multiple compatible payloads.

The EURECA was not designed specifically for the SGG flight test mission and the SGG instrument is a very sensitive measuring device. Consequently, over the course of the study, there were areas of mismatch between the capabilities of EURECA and the requirements of the SGG Flight Test. However, the study efforts accomplished reconciliation of most of the differences which resulted in the establishment of mutually agreeable conditions. Several areas identified in the course of this study require additional analyses to verify the tentative conclusions reached.

9.1 ACCOMMODATIONS

9.1.1 Configuration

The selected configuration of the SGG mounting on the platform deck does not drive the SGG design. This location provides space for mounting compatible payloads and does not require relocation of the EURECA AOCS sensor. An optimal location for the SGG would be at the center of gravity of the EURECA in order to eliminate unwanted motion vectors during calibration. However, that location is not feasible as an extensive redesign and requalification effort of EURECA would be necessary.

9.1.2 Mechanical Interface

The SGG/EURECA mechanical interface is at the EURECA payload deck. Reaction positions, limit load factors, safety factors and stiffness requirements are described in this document. No incompatibilities are known to exist.

9.1.3 Electrical Power

The maximum SGG electrical power demand is 270 Watts during the calibration phase. This demand may be satisfied by a standard, individually switched and protected, EURECA power circuit of 16 Amperes, 24 to 28.5 VDC.

9.1.4 Data Handling

Initial requirements were for data generation rates of 62.4/36.5 kbps (calibration/ operation). These rates were considerably greater than the capacity of an EURECA payload interface channel. Subsequent reevaluation of the data rates led to a reduction to 24.1/6.8 kbps which reduces the overload of the single 20 kbps PIA channel. Possible solutions include utilization of more than one PIA channel to achieve the capability required and/or data compression to correspond with a telemetry data rate of less than 20 kbps.

9.1.5 Thermal

A nodal distribution for a thermal math model was defined. Thermal accommodation is not expected to be a critical determinant; however, further thermal analyses should be conducted in a more detailed study.

9.2 MISSION PROFILE

The nominal baseline EURECA orbit is 500 km. For recovery operations by Shuttle, the platform descends to 300 km. Even though the SGG is a very sensitive instrument, a low altitude is desirable to provide the desired measurement accuracy, while minimum disturbances, usually available at the higher altitudes, are desirable for instrument calibration and sensitivity demonstration. Alternative orbits of 800 and 250 km were reviewed. A combination of 800/250 km profile was found to be not feasible as the propellant required exceeded available EURECA resources including additional tankage. A combination of 500/250 km would be feasible only if an entire EURECA mission is dedicated to the SGG. This scenario requires that all available payload mass, exclusive of the SGG, be given over to propellant tankage for orbit adjust maneuvers.

The baseline EURECA orbit of 500 km is recommended for the SGG flight test. Data acquisition at a lower altitude may be accomplished at the retrieval altitude of 300 km without a propellant penalty, if sufficient advance notice of Shuttle arrival is provided. Presently only two days of advance notice are given to EURECA operations. This permits enough time for EURECA to move from the 500 km orbit to the 300 km orbit plus a modest reserve, which permits limited data acquisition at the lower altitude. An additional advance notice of the pending Shuttle launch would provide an opportunity to conduct operations at the lower altitude without a chargeable propellant penalty.

9.3 MICROGRAVITY DISTURBANCES

In order to accommodate the most sensitive data acquisition periods, it will be necessary to turn off the active thermal control system (Freon pump), the magnetic torquer bars and the attitude control system (control jets). The spacecraft will be allowed to drift until a predetermined rate builds up, or for a predetermined time during calibration, at which time the control jets are fired to null the rate. After the transients decay, SGG takes the next data sample. Time marking of the jet firing allows elimination of the affected data from the samples. Present attitude simulations are accurate for small angles only and are not meaningful for the potential large excursions that may accompany these exercises.

9.4 CALIBRATION

The most promising calibration technique is to introduce a known relative motion between EURECA and the SGG instrument. Pairs of electromagnetic actuators would be powered on in turn to provide linear and angular motion about the appropriate SGG axes. After completion of the calibration cycle, the actuators would act as a spring isolator to minimize transmission of disturbances to the SGG.

Any disturbances introduced by sloshing of the hydrazine tanks appear to be damped out, as shown by analyses. However, because the natural frequencies of the fluid motion have such a large error band, additional analyses/tests may be required.

9.5 MAGNETIC SHIELDING

In order to achieve the same shielding ratio on-orbit as experienced in the laboratory on earth, it is recommended that two layers of shielding material be utilized. In order to reduce weight, at least one layer should be within the Dewar, close to the inner wall. That material should be Cryoperm 10 or equivalent so as to preserve the proper characteristics at the SFHe temperatures.

9.6 IMPLEMENTATION PLAN

ESA's current planning, reflected in the "Announcement of Opportunity" [3], is based on further EURECA flights in 1994 and 1996. EURECA processing in Europe for a reflight requires 27 months while a US based processing flow requires 24 months. No impact on SGG experiment processing is anticipated.

SECTION 10
RECOMMENDATIONS

The key factors necessary to determine feasibility of an SGG Flight Test on EURECA were considered in this study. Although it was found that such a test is viable, it is necessary that additional study and analyses be performed on some of these factors. In particular, solutions were proposed for some critical issues which should be studied further to provide confirming substantiation. Presented below are recommendations for additional study.

10.1 INSTRUMENT CALIBRATION

The method of on-orbit calibration is an important consideration as it impacts the EURECA platform as well as the SGG and SSA. Analyses conducted to date show that the SGG/EURECA relative motion technique provides the best capability with the least impact on the SGG and platform. However, the envelope of performance requires a number of factors to be optimized. It is recommended that the next layer of detail be examined for the recommended method and off optimum conditions be explored to determine their impact. A part of this study should include a conceptual design and analyses of the force/isolator device in order to characterize its performance. A transient response analysis incorporating finite element models of the EURECA platform and the SGG experiment module should be performed. This will allow much better estimates of cross-axis coupling to be developed.

10.2 MAGNETIC TORQUER ASSEMBLY

The desire for longer duration "quiet time" for experiment data acquisition opportunities is the motivating force for non or low disturbance attitude control methods. At least two methods should be examined:

1. The output of the MTA may be reduced to a consistently low level which may be acceptable to the experiment and thereby increase the time of quiet drift before a thruster firing is necessary to bring the platform back to the proper attitude.
2. Study the possibility of modulating the MTA control such that very gradual increases and decreases in torque output are effected rather than total on-off control. The concept is that the work under the force-time curve would be the same as for the on-off control method, but the peak force would be closer to the average force and therefore disturbances would be lessened.

10.3 ATTITUDE CONTROL SIMULATION

The present EURECA attitude control system simulation programs are valid for small angle displacements only, as these were designed for evaluating tight control with the AOCS. In order to simulate the effects of the quiet drift flight in which all active control systems are turned off, the simulation program must be revised and verified to account for potentially large angle displacements.

10.4 INVERSE SQUARE LAW—SHUTTLE AS AN OBJECT

Opportunities for obtaining data that could be used as a check of the inverse square law are presented when the Shuttle deploys the EURECA and retreats and also when the Shuttle approaches the EURECA during retrieval. The feasibility of conducting tests during these periods has not been investigated and is subject to operational considerations of both EURECA and Shuttle as well as safety considerations for Shuttle operations. Timelines and associated separation distances would enable the principal investigator to determine acceptability of the constraints imposed for a test opportunity. It is recommended that the feasibility of these test opportunities be determined.

10.5 HIGH AND LOW EARTH POINTING ORBITS

Data sessions in the earth pointing mode are desired at both high and low orbits. The quiet drift orbit of primary data acquisition is neither sun nor earth oriented. In order for earth pointing opportunities to be viable, the studies recommended under 10.2 above must prove that an active control method is feasible. The second part of the analyses required here is to then extend that active control method to lower altitudes while maintaining a no or low disturbance profile. Finally, a thermal model should be constructed to verify that the dissipation modes are sufficient for all planned modes.

10.6 VERIFICATION OF CALIBRATION TECHNIQUES

SGG calibration techniques, while applied in a microgravity environment, must be proven and verified on the ground. It is not obvious as to how this might be accomplished. The plan for verification method could have a substantial impact on the design of the force/isolator device. It is recommended that a study be accomplished to determine feasible 1-g test approaches to test the microgravity performance of the force/isolator device.

10.7 DATA HANDLING AND TANK SLOSH

Depending upon funding availability, the following recommendations may be considered for study.

1. ***Data Handling.*** The high data rates for the calibration mode drive the overall SGG requirements. Several possible solutions to be studied include utilization of an

expanded on-board memory, of additional ground stations and of more than one PIA channel and/or data compression to correspond with a telemetry data rate of less than 20 kbps. An end-to-end study is recommended to define the requirements and methods for data acquisition through to on ground data usage.

2. ***Tank Slosh***. During calibration, forces inputted to the SGG experiment will be reacted by EURECA. The hydrazine tank model shows the natural frequency of the tank to be within 20 percent of the calibration forcing frequency, with an estimated frequency uncertainty of 50 percent. To avoid coupling, a design requirement should be imposed that the calibration frequency must be sufficiently removed from both the EURECA system and hydrazine tank frequencies. In order to quantify the tank frequency, it is essential that the model be improved.

SECTION 11
ACRONYMS

ADE	Antenna Drive Electronics
ADRM	Antenna Drive/Retraction Mechanism
AOCE	Attitude and Orbit Control Electronics
AOCS	Attitude and Orbit Control Subsystem
ATCS	Active Thermal Control System
BDR	Battery Discharge Regulator
B/L	Baseline
BPSK	B-Phase Shift Keying
CL	Command Loop
C/O	Check-Out
CS	Command Sequencer
CSS	Coarse Sun Sensor
DHS	Data Handling Subsystem
ECU	Electronics Control Unit
EGSE	Electrical Ground Support Equipment
EM	Engineering Model
EMC	Electro-Magnetic Compatibility
EPS	Electrical Power Subsystem
ESOC	European Space Operations Center
ESSIT	EURECA Software Simulator
FDIR	Failure Detection, Isolation and Recovery
FLAP	Flight Application Software
FM	Flight Model
FOV	Field-of-View
FSS	Fine Sun Sensor
FPP	Freon Pump Package
GP	Gyro Package
HLC	High Level Commands
HLM	High Level Monitoring
HSL	High Speed Link
H/W	Hardware

I/F	Interface
IOC	Inter-Orbit Communication
IRES	Infra-Red Earth Sensor
IRU	Inertial Reference Unit
I/S	Interconnecting Station
ITE	Instrument Test Equipment
KSC	Kennedy Space Center
LSL	Low Speed Link
MBM	Magnetic Bubble Memory
MCC	Mission Control Center
MLI	Multi-Layer Insulation
MMS	Microgravity Measurement Subsystem
MMU	Mass Memory Unit
MRU	Monitoring/Reconfiguration Unit
MS	Master Schedule
MT	Magnetic Torquer
MTP	Master Test Processor
NRZ	Non-Return to Zero
OCC	Operational Control Center
OCDE	Orbital Control Drive Electronics
OPF	Orbiter Processing Facility
OTA	Orbital Transfer Assembly
OTM	Orbit Transfer Maneuver
PCM	Phase Change Modulation
PCU	Power Control Unit
PDU	Power Distribution Unit
PFM	Protoflight Model
PI	Principal Investigator
PIA	Processor Interface Adapter
PIP	Payload Implementation Plan
PIU	Processing Interface Unit
P/L	Payload
PPF	Payload Processing Facility
PPU	Payload Processing Unit
PSK	Phase Shift Keying
PTF	Payload Test Facility
PTCS	Passive Thermal Control System

RAU	Remote Acquisition Unit
RCA	Reaction Control Assembly
RCDE	Reaction Control Drive Electronics
RF	Radio Frequency
RMS	Remote Manipulator System
RSS	Rotatable Service Structure
SAA	Solar Array Assembly
SAS	Sun Acquisition Subsystem
SPA	S-Band Power Amplifier
SPL	Standard Programming Language
S/S	Subsystem
STS	Space Transportation System (NASA)
S/W	Software
TC	Telecommand
TCS	Thermal Control Subsystem
TCU	Thermal Control Unit
TM	Telemetry
TTC	Telemetry and Telecommand Subsystem
VPF	Vertical Processing Facility
VPHD	Vertical Processing Handling Device

APPENDICES

APPENDIX A

INSTRUMENT INTERFACE PROPOSAL (IIP)

GE Astro Space

MBB ERNO

SUPERCONDUCTING GRAVITY GRADIOMETER (SGG)

DOC. NO.: IIP/1231602

Prepared by MBB/ERNO as part of the
Feasibility Study:
SGG FLIGHT TEST ON EURECA

Issue: 2	Date: 20. Nov. 1990
Revision: -	Date: -

W. Koehler-Naumann S. Ransom

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

SUPERCONDUCTING GRAVITY GRADIOMETER (SGG)

Instrument Interface Proposal

Data Sheet Package

This is a preliminary version of the IIP for reference purposes only. When an actual Flight Test Program is undertaken, this document would be updated to reflect the then current status.

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

IIP DATA SHEET CONTENT CHANGE RECORD

Reason for Change	Affected Section	Affected Page	Brief Description of Change
Issue 2	All	All	Update of document according to progress achieved through study investigations

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

List of Data Sheets

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Data Sheet No.: 1

KEY PERSONNEL
(IIP Chapter Reference: 1.3)

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College Park, Maryland 20742......................
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Alabama 35812.......................................
U.S.A. ....
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Name: ....
Address: ....
....
....
Phone: .... Telefax: ....

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Data Sheet No.: 2-1

INSTRUMENT DESCRIPTION

(IIP Chapter References: 3.2; 6.3; 8.2; 8.3)

(1) Scientific Objectives:

Primary Mission Objectives:

Geophysics:	High sensitivity /resolution measurement of the earth`s gravity field

Secondary Mission Objectives:

Fundamental Physics:	Null test of the gravitational inverse square law

Note: With a very sensitive instrument like SGG, it is virtually impossible to verify the instrument flight performance unambiguously, under the full gravitational acceleration and ambient disturbances existing in an Earth laboratory: the gradient errors due to ground accelerations are several orders of magnitude greater than the gravity gradient signals that are to be measured.

Therefore, a SGG Flight Test as a precursor to the Science Mission (SGGM) is considered beneficial. The goals of a SGG flight test are to provide for an engineering test, which verifies the full sensitivity of the SGG instrument and to collect useful geophysics data at a reduced sensitivity.

The SGG description, the requirements and I/F definitions in this IIP form the basis for studying the SGG accommodation on the EURECA spacecraft for the SGG Flight Test Mission, envisaged for 1995/96.

(2) Envisaged Scientific Return / Objectives of the <u>SGG Flight Test on EURECA:</u>

The objectives of the <u>Flight Test</u> are listed below in roughly descending order of importance. However, many of the objectives are interrelated and all are considered vital to the program.

1. Validate the flight performance of the SGG instrument.
   (a) Demonstrate the full instrument sensitivity of 3×10^{-4} E x $Hz^{(-0.5)}$ over the bandwidth of 0.1 to 0.001 Hz for brief periods.
   (b) Demonstrate continuous operation of the SGG at the sensitivity level of 10^{-2} E x $Hz^{-0.5}$ over the bandwidth of 0.1 to 0.001 Hz.
   (c) Evaluate the operational characteristics of the instrument, including sensitivity, stability, noise spectrum, and bandwidth in a low-g environment.
   (d) Validate the common mode balance.
   (e) Determine if the noise figure of the accelerometer would permit its use to control the SGGM spacecraft during the Science Mission.
2. Validate the design and operation of the Experiment Module.
   (a) Evaluate the interface method between the Experiment Module and the spacecraft. Evaluate the vibration levels coupled to the instrument and determine the degree to which these can be compensated for or supressed.
   (b) Determine the effect of liquid helium at low-g for this particular design, including thermal isolation and control, and force and torque balancing of the He vents. Validate He boiloff management techniques.
3. Validate alignment and attitude control of the Experiment Module.
   (a) Investigate the alignment of the instrument with the external naviga-

tion base. Determine the performance of the alignment system.

(b) Evaluate the accuracy, with which the instrument may be pointed and controlled.

4. Determine the noise spectrum of the carrier.
   (a) Evaluate orbital aberrations (drag, gravity gradients, thermal).
   (b) Evaluate platform noise: linear and angular accelerations, self-gravity noise, and electromagnetic disturbances.
5. Validate the analytic predictions of the instrument error model.
6. Assess the performance of automated instrument control. Validate algorithms that will be used.
7. Data Handling and Analysis: validate the techniques for processing the data.

(3) Previous Space Application of Instrument:

None

(4) Development Status of Instrument:

Laboratory models of the Superconducting Gravity Gradiometer (SGG) and the Six-Axis Superconducting Accelerometer (SSA) existing at University of Maryland.

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Continuation Sheet For: ...INSTRUMENT DESCRIPTION..............................

Data Sheet No.: 2-4

(5) **Description of Instrument: (Data Sheet DS 2)**
-Checklist-

	Attached	Not yet available	Not applicable
Instrument General Arrangement Drawing(s)	☒ 11	☐ 12	
Perspective/isometric view(s) of Instrument	☒ 21	☐ 22	
Exploded/sectional view(s) of Instrument	☒ 31	☐ 32	
Integration/Interface Drawing(s)	☐ 41	☒ 42	
Functional Block Diagrams:			
- Optical System	☐ 51	☒ 52	☐ 53
- Electrical System	☐ 61	☒ 62	☐ 63
- Data Handling System	☐ 71	☒ 72	☐ 73
- Thermal System	☐ 81	☒ 82	☐ 83
- Other (please specify)			
....	☐ 91	☐ 92	
Instrument Function	☒ 15	☐ 16	
Instrument/Carrier Attachment (Proposal)	☐ 35	☒ 36	
Instrument GSE	☐ 37	☒ 38	

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Continuation Sheet For: ....INSTRUMENT DESCRIPTION.............................

Data Sheet No.: 2-5

(6) Instrument Physical/Environmental Requirements:
-Checklist-

		Attached	Not yet available	Not applicable
- Mechanical/Structural	(DS 3,4,5,6,7)	☒ 42	☐ 43	☐ 44
- Electrical	(DS 12,13)	☒ 45	☐ 46	☐ 47
- Data Handling	(DS 13)	☒ 55	☐ 56	☐ 57
- Thermal Environment	(DS 8,9,10)	☐ 65	☒ 66	☐ 67
- Magnetic/RF Shielding	(DS 11)	☒ 75	☐ 76	☐ 77
- Microgravity Level	(DS 11)	☒ 85	☐ 86	☐ 87

(7) Instrument C/O and Operations Requirements:
-Checklist-

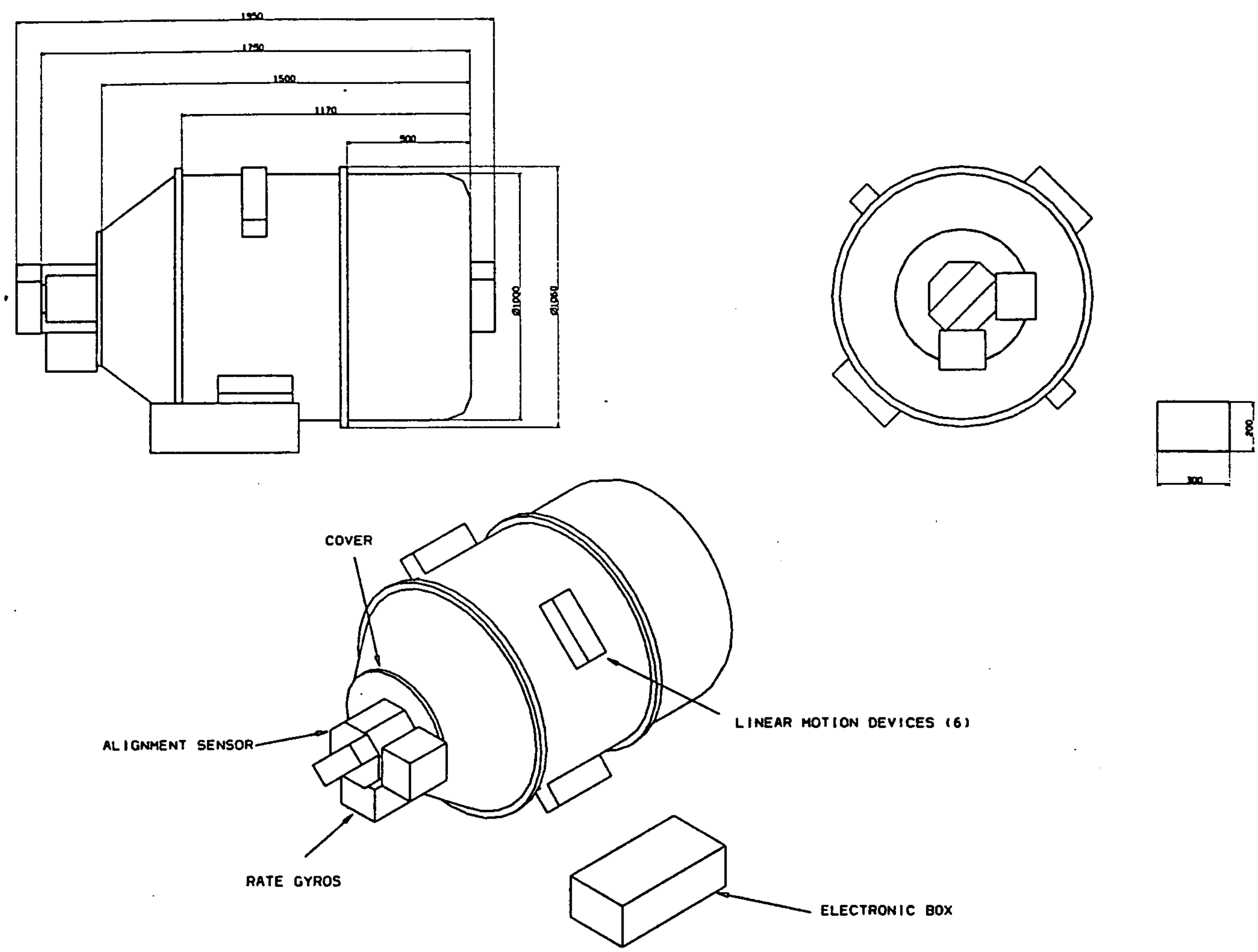
		Attached	Not yet available
- Ground Operations	(DS 16,17)	☒ 95	☐ 96
- In-orbit Operations	(DS 14,15,18)	☒ 105	☐ 106
- Operational Time-line	(DS 18)	☒ 125	☐ 126
- Functional Objectives	(DS 18)	☒ 135	☐ 136

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Continuation Sheet for: .....INSTRUMENT DESCRIPTION............................

Data Sheet No.: 2-6

Instrument General Arrangement



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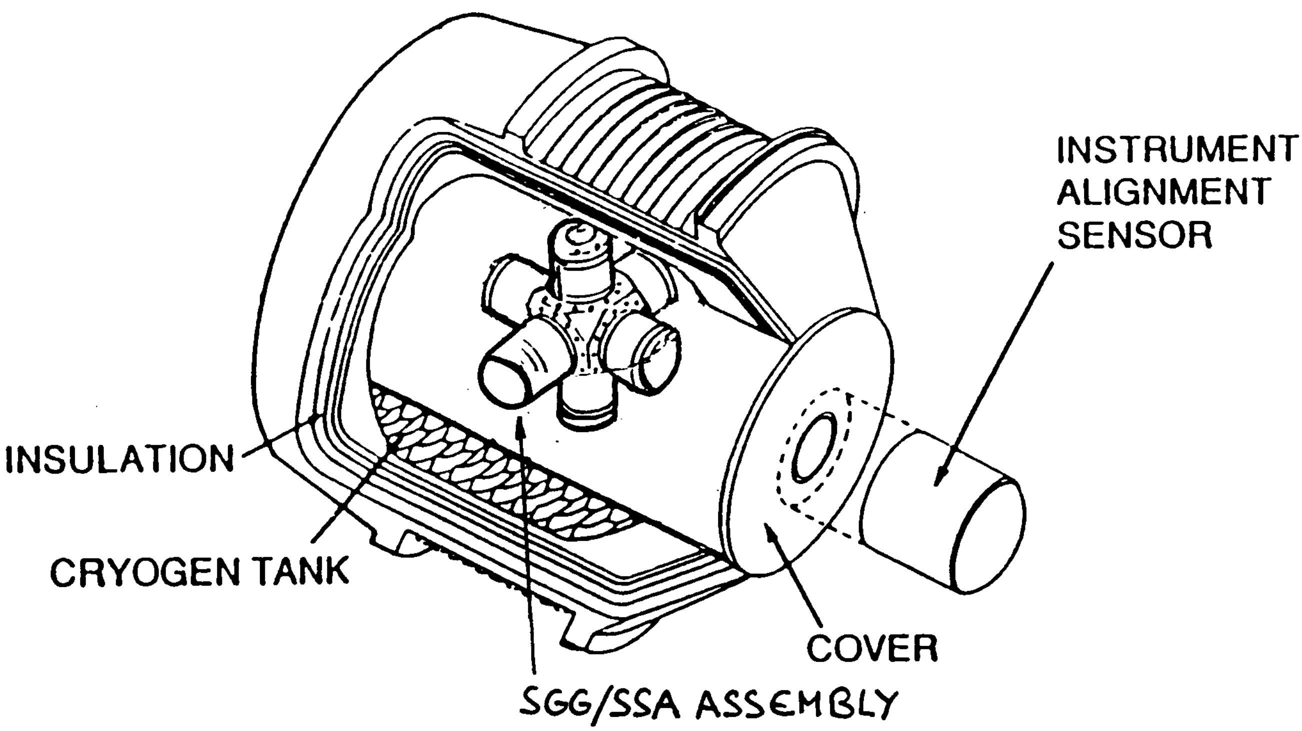
Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

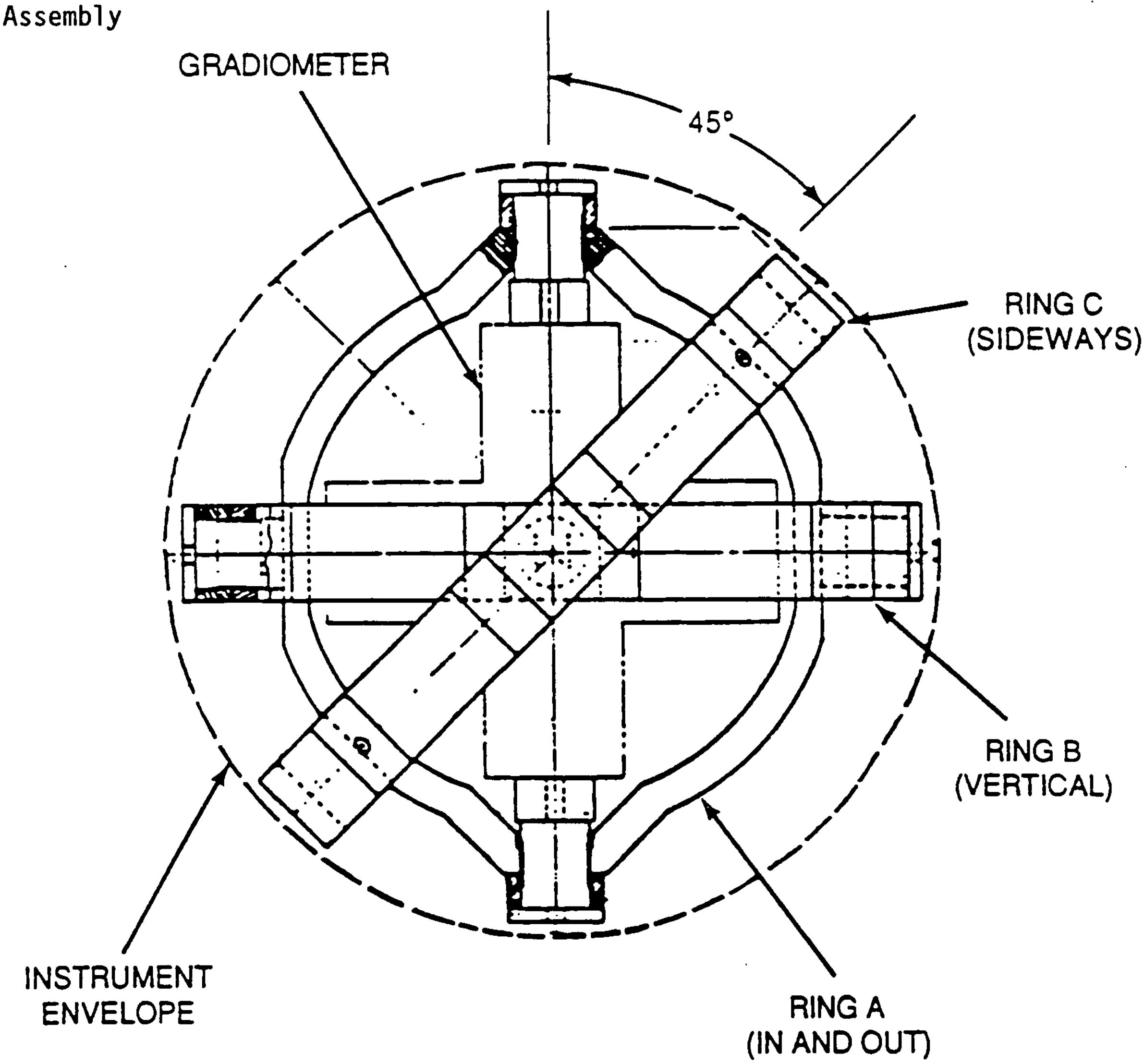
Continuation Sheet for: .....INSTRUMENT DESCRIPTION.............................

Data Sheet No.: 2-7

Instrument Sectional View



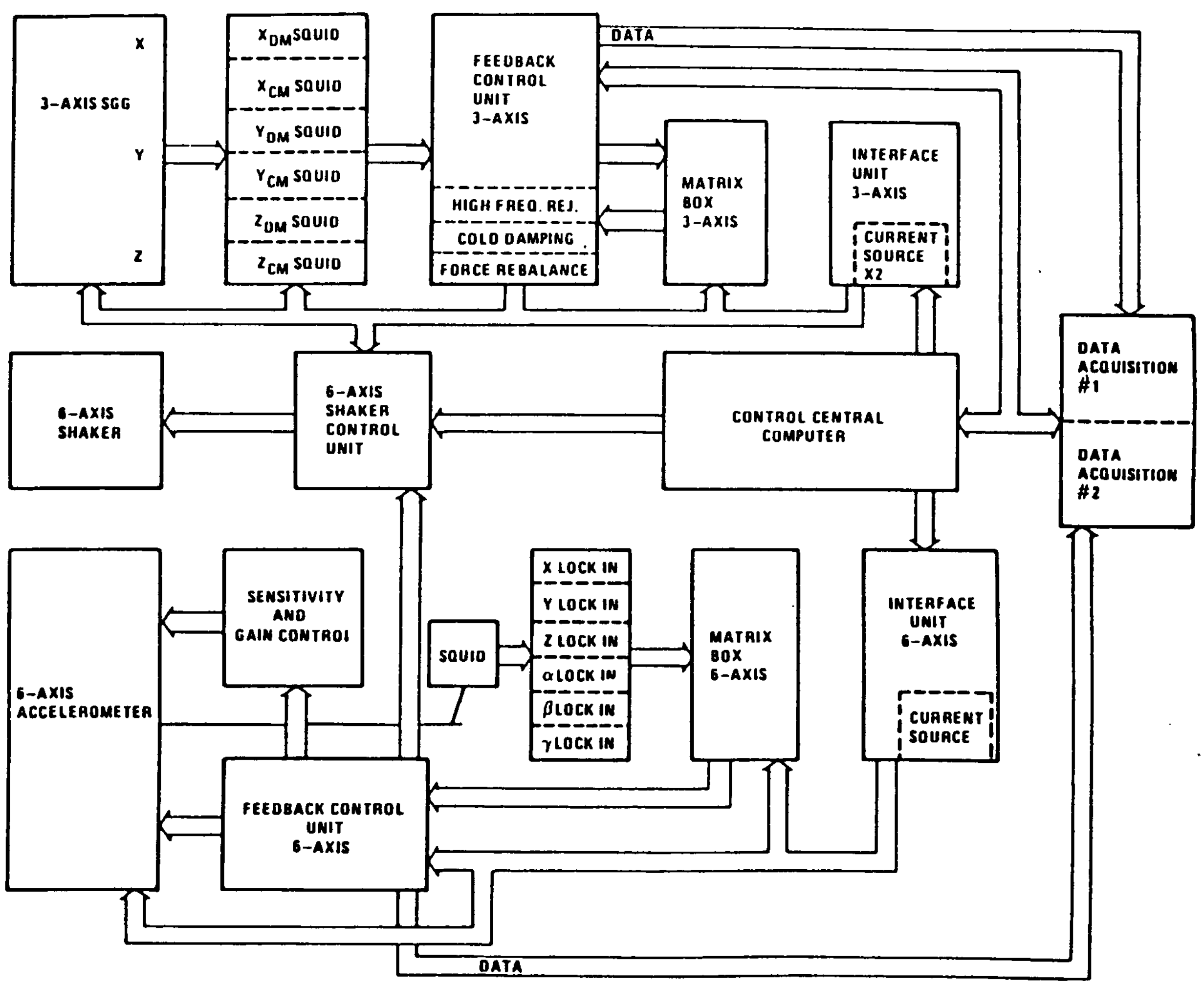
SGG/SSA Assembly



Three-axis SGG and SSA mounted on the six-axis shaker (top view).

Note: For the SGG Flight Test on EURECA, external actuators (Linear Motion Devices) as shown on data sheet 2-6 will be applied. The Six-Axis Shaker shown above may be reintroduced as an integral part of the SGG Science Mission.

SGG/SSA Functions



Three-axis SGG and SSA control block diagram.

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Continuation Sheet for: .....INSTRUMENT DESCRIPTION............................

Data Sheet No.: 2-10

Instrument Thermal Control (1)

It is a key requirement, that a cryogenic environment of $T < 1.8$ K be maintained for the SGG/SSA assembly during the mission.
To this purpose, the passive technology of cooling with a superfluid helium dewar has been employed; waste heat is gotten rid of by helium boiloff. The dewar concept is shown on Data Sheet No. 2-7.
The dewar internal heat load is estimated to be 10 to 12 mW (SQUID plus harness dissipation).
Heat fluxes from the exterior into the dewar consist of:

- IR fluxes from the spacecraft environment
- conduction through dewar support structure
- conduction soak-back from equipment, mounted to the dewar cover plate and shell (Alignment Sensor, Rate Gyros, Linear Motion Devices...).

It is an obvious goal for the accomodation of the SGG instrument on any spacecraft, to minimize these external heat fluxes.

The SGG instrument temperature limits, its thermal properties and the heat generation profile, which are requested to be specified in Data Sheets No. 9 and 10 of this EURECA IIP remain undefined for the time being.

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Data Sheet No.: 3

INSTRUMENT ENVELOPE(S)
(IIP Chapter Reference: 4.2)

Refer to the dimensions, specified on Data Sheet No. 2-6.

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Data Sheet No.: 4

INSTRUMENT FIELD(S) OF VIEW
(IIP Chapter Reference: 4.3)

The instrument does not require a field-of-view.

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Data Sheet No.: 5-1

INSTRUMENT MASS
(IIP Chapter Reference: 4.4, 6.2)

Item No.	*	Instrument Element	Mass (kg)	COG X mm	COG Y mm	COG Z mm	Inertia J_{XX} kgm	Inertia J_{YY} kgm	Inertia J_{ZZ} kgm
1	a	Dewar	150	-	center	-			
2	a	Helium	30	-	dewar center	-			
3	a	SGG/SSA	50	-	dewar center	-			
4	a	Mu-Metal Shield	10	-	dewar center	-			
		(Subtotal)	(240)						
7	b	Alignm. Sensor	6.8	-	center	-			
8	b	Rate Gyros	2 x 4.3	-	center	-			
9	de	Dewar Mounting Structure	est.50	-	center	-			
10	de	Shakers	est.20 max	-	TBD	-			
		(Subtotal)	(85)						
11	cd	Electronics Unit	est.46 max	-	TBD	-			
		(not defined yet, but to be understood as containing the power and data electronics, covering the functions of: Central Micro-processor control of the instrument (C&DH), Temporary Data Storage (Mass Memory), Multiplexer, Spacecraft I/F Unit, Insulation and Thermal Control,...)							
12		Harness	11	-	TBD	-			
		(Subtotal)	(57)						
13		Development Risk Margin	50	-	TBD	-			
Total			432						

*** Notes:**

a) items 2, 3, 4 are contained within item 1;
CoG of total mass of items 1, 2, 3, 4 at center of dewar
b) items 7 and 8 are mounted on dewar "cover" plate
c) item 11 is not mounted on the dewar, but elsewhere on the spacecraft
d) mass figures of items 9, 10, 11 are rom estimates
e) option for shakers considered here: linear motion transducers attached to the external containment of the dewar

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Data Sheet No.: 6

INSTRUMENT METHOD OF ATTACHMENT
(IIP Chapter Reference: 5.1)

-- TBD --

Notes: (a) Since non-gravitational disturbances, exceeding the limits, specified on Data Sheet No. 11-2, must be compensated for, a potentially required decoupling of carrier induced dynamic disturbances from the SGG/SSA assembly during orbital operations could be a major driver for designing an appropriate dewar support structure ("soft mount")

(b) The SGG/SSA assembly eigenfrequencies (dynamic mass less than 1 kg) are:

differential mode:	1 to 7 Hz
common mode:	10 to 50 Hz

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Data Sheet No.: 7

INSTRUMENT ALIGNMENT/POINTING REQUIREMENTS
(IIP Chapter Reference: 5.2)

Alignment

(a) Alignment of SGG with respect to EURECA axes is not required.
(b) Orientation of SGG external base (external SGG experiment structure) with respect to EURECA axes has to be determined by alignment measurement.

S/C Orientation (ref. also to Data Sheet No. 18)

For SGG Flight Test, sun inertial orientation as well as earth-pointing orientation are required.

S/C Pointing Accuracy

1 degree (half-cone) in all three axes required

S/C Attitude Data (ref. also to Data Sheet No. 11)

A constant angular rate is acceptable to SGG. The angular rate jitter, however, has to be minimized.

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Data Sheet No.: 8

INSTRUMENT TEMPERATURE LIMITS
(IIP Chapter Reference: 6.1)

(ref. also to explanatory section, Data Sheets No. 2-10 to 2-16)

Item No. (a)	Instrument Element	Temperature Limits				Temperature Gradient			
		Operational		Non-operat.		Operational		Non-operat.	
		min.	max.	min.	max.	local	rate	local	rate
		°C	°C	°C	°C	°C/cm	°C/hr	°C/cm	°C/hr
1	dewar	- as low as possible -				- as low as possible -			
7	Align. Sens.		- T B D -				- T B D -		
8	Rate Gyros		- T B D -				- T B D -		
10	Shakers		- T B D -				- T B D -		
11	Electronics		- T B D -				- T B D -		

(a) numbering of items identical to mass tables Data Sheet 5-1 and power demand table, Data Sheet No. 12-1.

Temperature Control Requirements:

☒ Passive (MLI + Electrical Heaters): for dewar and attached items

☒ Indirect Active (Cold Plate): electronics (to be reviewed, since the active cooling loop pump package would then be required, producing vibration disturbances acting on the SGG instrument)

☐ Direct Active (Fluid):

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Data Sheet No.: 9-1

INSTRUMENT THERMAL PROPERTIES
(IIP Chapter Reference: 6.1)

Item No.	Instrument Element	Instrument External Surface				Thermal Capacitance
		Area	Surface Finish	Material	Emissivity/ Absorptivity	
		m^2	-	-	α_N ϵ_N	J/K
----------------	----------------	----------------	T B D	----------------	----------------	----------------

Does the Instrument have an independent cooling system?

☒ Yes Type: .He dewar / passive boiloff.............................

☐ No

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Data Sheet No.: 9-2

Continuation Sheet for: ...INSTRUMENT THERMAL PROPERTIES......................

Item No.	Instrument Element	Contact (Mounting) Area			
		Area	Surface Finish	Material	Thermal Conductance
		m	-	-	W/K
----------------	----------------	----------------	T B D	----------------	----------------

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Data Sheet No.: 10-1

INSTRUMENT HEAT GENERATION PROFILE
(IIP Chapter Reference: 6.1)

Note: These data may be submitted in graphical form, i.e. as a chart showing heat dissipation (W) versus time (complete mission)

---------------------------------- T B D ----------------------------------

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Data Sheet No.: 11-1

INSTRUMENT ENVIRONMENTAL CHARACTERISTICS AND REQUIREMENTS
(IIP Chapter Reference: 6.4)

(1) RF fields produced by the Instrument

Item No.	Instrument Element	Strength dB V/m	Frequency MHz
	- - -	T B D	- - -

(2) Magnetic fields produced by the Instrument

Item No.	Instrument Element	AC		DC
		Strength $dBpT_{rms}$	Frequency kHz	Strength mT
	- - -	T B	D	- - -

(3) Instrument sensitive to magnetic fields? ☒ Yes ☐ No

Instrument sensitive to RF fields? ☒ Yes ☐ No

Note: Electromagnetic interferences are not considered a problem, since superconductors permit nearly perfect electromagnetic shielding. Magnetic contamination inside the SGG/SSA RF shields is counteracted by a Mu-metal shield inside the dewar.

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Continuation Sheet For: INSTRUMENT ENVIRONMENTAL CHARACTERISTICS & REQUIREMENTS.

Data Sheet No.: 11-2

(4) Micro-g disturbances produced by the Instrument

It is inherent to the measurement principle of the SGG, that self-induced micro-g disturbances be kept to an absolute minimum. Potential disturbance sources are:

- LHe boiloff momentum
- drives of a potential temporary Data (Mass Memory) Storage Device
- shakers (temporarily used for SGG/SSA calibration only)
- earth magnetic field interaction with the residual magnetic field of the SGG Mu-metal shield

(5) Instrument sensitive to micro-g disturbances? ☐ Yes ☐ No

In order to achieve the scientific goals of the SGG Science Mission, an instrument sensitivity of 3 x 10 exp(-4) E x Hz exp(-0.5) to the gravity gradient signal spectrum in the sensitive signal frequency range of 0.01 to 0.1 Hz must be realized.
This means, in terms of requirements put on the spacecraft, that any translational and angular accelerations, as the pertinent error sources, must be kept close to the following limits:

PARAMETER	ERROR MECHANISM	ORIENTATION	REQUIRED CONTROL/KNOWLEDGE	
LINEAR ACCELERATION	$-\frac{1}{\ell}\,\delta\hat{n}_{\perp}\cdot\vec{a}(t)$		$2\times10^{-7}\,g_E\,Hz^{-1/2}$	$2\times10^{-8}\,g_E\,Hz^{1/2}$
ALTITUDE STABILITY	$(\hat{n}\cdot\vec{\nabla})\hat{n}\cdot\overleftrightarrow{\Gamma}_E\,\delta\vec{h}(t)$		$7\ m\ Hz^{-1/2}$	$7\times10^{-2}\ m\ Hz^{-1/2}$
POINTING STABILITY	$2\,\vec{\theta}(t)\times\hat{n}\cdot\overleftrightarrow{\Gamma}_E\cdot\hat{n}$	INERTIAL EARTH-FIXED	$2\times10^{-6}\ rad\ Hz^{-1/2}$ $3\times10^{-4}\ rad\ Hz^{-1/2}$	$2\times10^{-8}\ rad\ Hz^{-1/2}$ $3\times10^{-6}\ rad\ Hz^{-1/2}$
ATTITUDE RATE	$\vec{\Omega}(t)\cdot\vec{\Omega}(t)-[\hat{n}\cdot\vec{\Omega}(t)]^2$		$3\times10^{-6}\,rad\ s^{-1}\,Hz^{-1/4}$	$3\times10^{-7}\,rad\ s^{-1}\,Hz^{1/4}$
ATTITUDE ACCELERATION	$\delta\hat{n}_{+\ell}\times\hat{n}\cdot\vec{\alpha}(t)$		$10^{-5}\,rad\ s^{-2}\,Hz^{-1/2}$	$10^{-7}\,rad\ s^{-2}\,Hz^{1/2}$

These requirements are understood as variables of quasistatic conditions over time increments of 90 minutes (duration of a single SGG active measurement time slice)

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Continuation Sheet For: INSTRUMENT ENVIRONMENTAL CHARACTERISTICS & REQUIREMENTS.

Data Sheet No.: 11-3

(6) Other environmental disturbances ☒ Yes ☐ No

(a) LHe boiloff

He venting is necessary throughout all ground and flight phases, due to LHe boiloff from the SGG experiment module dewar. The boiloff mass flow is stongly dependent on the dewar temperature environment and the dissipations in the dewar inside. The total amount of LHe required for a six months mission is estimated to be 30 kg.

(b) Mass distribution variations

The dewar with the sensitive SGG/SSA assembly inside should preferrably be located near to the EURECA CoG, but away from the fuel tanks, which introduce variable masses (fuel consumption over the mission) and mass distribution disturbances (fuel sloshing).

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Data Sheet No.: 12-1

INSTRUMENT POWER DEMANDS
(IIP Chapter Reference: 7.1, 8.2 and 8.3)

(1) Instrument Power Demands During Mission

Item No. (a)	Instrument Element	Operation Mode	EURECA Source		Power(W) Average/ Peak	Duration (h)
			TCU	PDU		
3	SGG / SAA	on	-	x	< 1	
7	Alignment Sensors	on	-	x	TBD	
8	Rate Gyros	on	-	x	TBD	
10	Shakers	on	-	x	TBD	
11	Electronics Unit (incl. Data acquisition, ...)	on	-	x	TBD	
	TOTAL/detail (incl. Data Acquisition)	Calibration			peak 270 av. TBD	repeatedly for TBD day
		Normal Operation			peaks TBD av. 190	TBD weeks
		Stand-By			100	TBD
		Stay-Alive			0 (Zero)	TBD
	TOTAL / Summary (incl. Data Acquisition)				270/190	TBD weeks

(a) same item numbering as on mass table (ref. to Data Sheet No. 5-1)

Is essential power required? ☐ Yes .... W ☒ No

Does the Instrument have an independent power source?

☐ Yes Type .... Energy .... ☒ No

(2) Power Demand During Pre-Launch and Post-Landing Ground Phases

Power needed? ☐ Yes ....W ☒ No

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Continuation Sheet For: .....INSTRUMENT POWER DEMANDS.........................

Data Sheet No.: 12-2

(3) Instrument Power Profile

No.[a]	Phase / Activity	Power (W)	Duration
-	pre-launch: EURECA check-out	peak 270 av. 190	TBD
-	pre-launch: Shuttle integrated	0	6 weeks
1	Shuttle ascent	0	3 hours
2	EURECA deployment (SGG Go/Nogo test)	TBD	TBD min
3	EURECA orbit transfer	0	2 days
4	on-orbit calibration	270	TBD days
5,8	on-orbit performance demonstration & verification & "test" science data generation	190	TBD weeks
6	SGG idle phase (SGG switched off)	100	up to several months
7,9	EURECA orbit transfer	0	2 days
-	EURECA parking/retrieval by STS	0	up to several months
10	Shuttle descent	0	3 days
-	post-landing: Shuttle integrated	0	2 weeks
-	post-landing: EURECA check-out	peak 270 av. 190	6 weeks

(a) identical phase numbering as in Data Sheet No. 18

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Data Sheet No.: 13-1

INSTRUMENT DATA HANDLING REQUIREMENTS
(IIP Chapter Reference: 7.2)

(1) Instrument/EURECA DHS Interface

☒ PIA Note: The PIA interface is recommended by EURECA, since it is a close derivative of the IEEE 488 standard, which presently is also applied in the SGG ground laboratory at the University of Maryland

☐ RAU

(2) Type of Data Delivered to DHS

☒ Preprocessed Serial/Parallel

☒ Unprocessed Digital No. of channels .estim. 3.....
Analogue No. of channels .estim. 3.....

☒ Fault/Status Indication Digital No. of channels .estim. 3.....
Analogue No. of channels .estim. 3.....

(3) Data Rates (via EURECA data bus)

Note: The figures given in the summary table below, specify the net amount of data, generated <u>within</u> the SGG instrument during its repeatedly occuring, active measuring phases of:
- initialization
- calibration
- performance demonstration
- science data generation.

The figures do <u>not</u> include any packetizing overheads resulting from the telemetry packet (TM packet) generation.

Mode	Data Rates			
	Peak (kbps)	Peak Duration	Average (kbps)	Minimum (kbps)
Operational:				
- Measurement	-	-	24128/6848*	-
- Housekeeping	-	-	0.8	-
Stand-by	-	-	0.8	-

* Note: First value is for calibration, second for normal operation of the SGG

(4) Instrument DEP (Dedicated Experiment Processor)

Type: ....TBD..................

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Continuation Sheet For: ...INSTRUMENT DATA HANDLING REQUIREMENTS...............

Data Sheet No.: 13-2

(5) Data Storage

☒ by EURECA DHS: - TBD -

☒ by Instrument: - TBD -

(6) Data Buffer

☐ by EURECA DHS

☒ incorporated in Instrument Size ....TBD....... kBytes

(7) Program Storage required by EURECA DHS

☒ Yes Size ......TBD........... kBytes

☐ No

(8) DHS Command and Monitoring Functions

Is health signal from EURECA DHS required? - TBD -

(Note: implementation of this feature is recommended)

Is discrete monitoring required? Yes

If yes, for which purpose(s)?

............- latching status of the SGG locking mechanism ....

....

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Continuation Sheet For: ....INSTRUMENT DATA HANDLING REQUIREMENTS...............

Data Sheet No.: 13-3

(8) continued

Instrument Command Profile:

No. of high-level commands	estim.: 2....	(for potentially safety-critical functions, as e.g. locking of "soft-mount" at the end of the SGG operations)
No. of discrete commands	.......5.....	
No. of packetized commands	......TBD....	
No. of additional commands	......TBD....	

Purpose:

....

....

(9) Data Acquisition Profile

Source of Data:

Signal	Number of channels	Sampling Frequency (sec^{-1})	Resolution (bits/channel)	Source Data Rate (bits/sec)
Measurement				
SGG Diff. Mode Output	3	200*/20**	16	9600*/960**
SGG Comm. Mode Output	3	200*/20**	16	9600*/960**
SSA Outputs	6	20	16	1920
Accelerometer Outp.	3	20	16	960
Gyro Outp.	4	20	16	1280
Housekeeping				
Temperatures	6	4	16	384
Pressures	3	4	16	192
He Quantity	1	4	16	64
He Boiloff	1	4	16	64
He Sloshing	1	4	16	64
Total				24128*/6848**

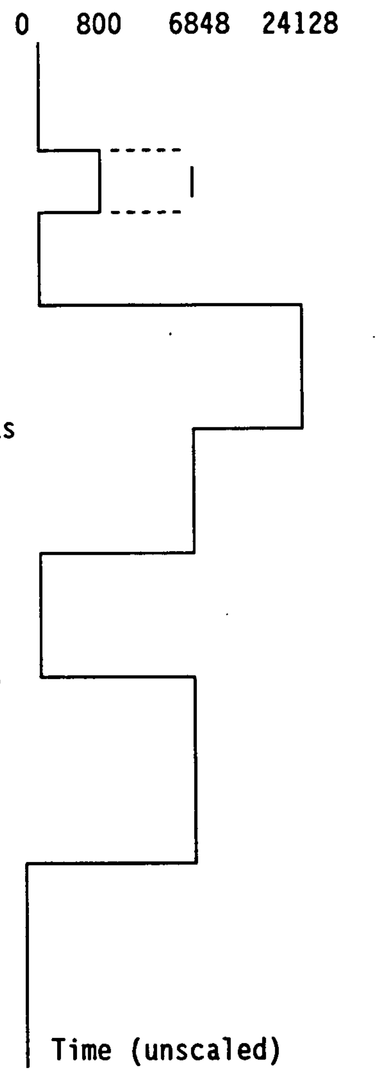
* calibration mode / ** normal measurement mode

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Continuation Sheet For: ....INSTRUMENT DATA HANDLING REQUIREMENTS..............
Data Sheet No.: 13-5

Data Generation Profile:

No (a)	Phase/ Activity	Duration	Net Data Generation Rate (bps)	Remarks
1	Shuttle ascent	-		
2	SGG Go/Nogo test	TBD minutes		
3	EURECA deployment and orbit transfer	-		
4	SGG on-orbit calibration	TBD days repeatedly		repeated "quiet periods" of 90 min. duration each
5	SGG system performance demonstration and verification	TBD weeks		
6	SGG idle state	-		
7	EURECA orbit transfer	-		
8	SGG system performance demonstration and verification; "test" science data	1-2 days		repeated "quiet periods" of 90 min. duration each
9	EURECA transfer to Shuttle rendez-vous / parking orbit	-		
10	Shuttle descent	-		



(a) phase numbering identical to Data Sheet No. 18-2

(10) Instrument Schedule / Timeline

Controlled by: ☒ EURECA DHS

☒ Instrument

Description:
Instrument control and internal task scheduling during the active measurement phases will autonomously be performed by the instrument Central Control Computer (ref. to Data Sheet No. 2-9).
Higher level control functions, such as activation / deactivation, lock / unlock of dewar and initiation of instrument active measurement phases will have to be controlled and scheduled through the EURECA DHS Master Schedule.

(11) Instrument-Specific/Special Requirements

To be identified.

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Data Sheet No.: 14-1

INSTRUMENT TIME REFERENCE REQUIREMENTS
(IIP Chapter Reference: 7.3)

(1) Does instrument require a clock, synchronized with GMT?

☐ Yes ☐ No ☒ TBD

(2) Accuracy ...TBD........

(3) Resolution ...TBD........

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Data Sheet No.: 14-2

INSTRUMENT FLAP SOFTWARE REQUIREMENTS
(IIP Chapter Reference: 7.3)

(1) Instrument FLAP Modules, Nominal Operation:
(provide draft list, e.g. activation, mode transition, deactivation, etc.)

- Unlock of dewar (in case of "soft-mounting")
- Activation
- Initiation of active measurement phase
- Initiate calibration cycle
- ....
- TBD
- ....
- Switch to stand-by mode
- Deactivation
- Lock of dewar

(2) Instrument FLAP modules, Contingency Operation:
(provide draft list, e.g. HV shut-down, emergency off, etc.)

TBD

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Data Sheet No.: 15-1

INSTRUMENT ON-GROUND TELEMETRY & TELECOMMAND REQUIREMENTS
(IIP Chapter Reference: 7.4)

(1) Location of Ground Facility: ....TBD................................

(2) Data Transmission to/from EURECA Operations Center

☐ Public Networks ☐ Hot Line

☐ Tape ☐ Other: ....

☐ TBD

(3) Type of Data required by User at Ground Facility:

Science; housekeeping TM data; ancillary data, as eg. EURECA orbit parameters; time correlations (on-board / GMT)

(4) Are near real-time telemetry data required?

☐ Yes ☐ No (during Go/Nogo test and after each calibration run)

(5) Instrument Telecommand Profile: (see Data Sheet No. 13-3)

No. of high-level commands ....

No. of discrete commands ....

No. of packetized commands ....

No. of additional commands ....

Purpose:...

(6) Telecommand Data - TBD -

No. of commands to be transmitted per orbit ....

No. of near-real-time commands ....

Time needed for transmission ....

(7) Command Data Transmission Profile - TBD -

Note: Data may be submitted in graphical form

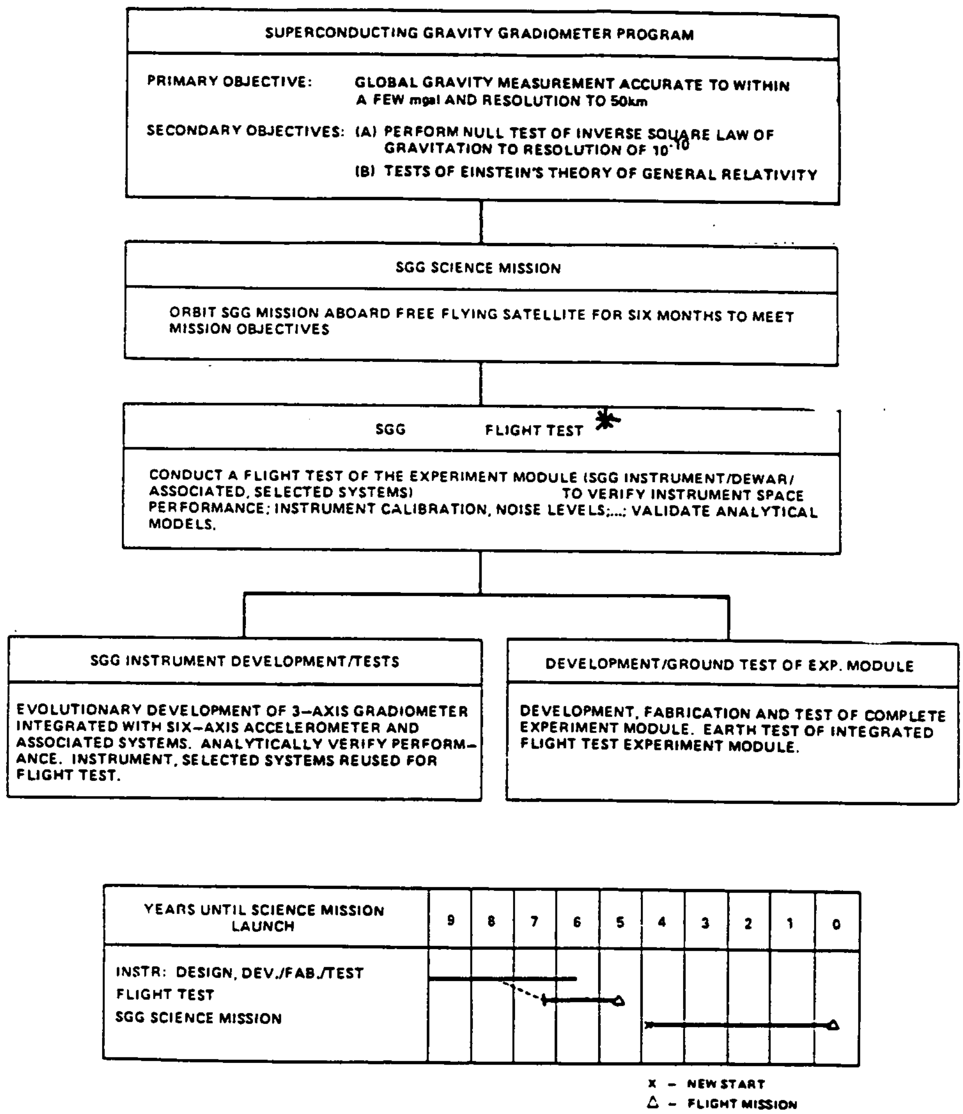
Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Data Sheet No.: 16-1

INSTRUMENT DEVELOPMENT & TEST PHILOSOPHY
(IIP Chapter Reference: 8.1)

<u>The Program</u>
The SGG program elements necessary to accomplish the science mission goals are outlined in below figure.

Note: This IIP serves the purpose, to form a basis for studying the SGG accomodations and the feasibility of performing the **<u>Flight Test on the EURECA carrier</u>**.



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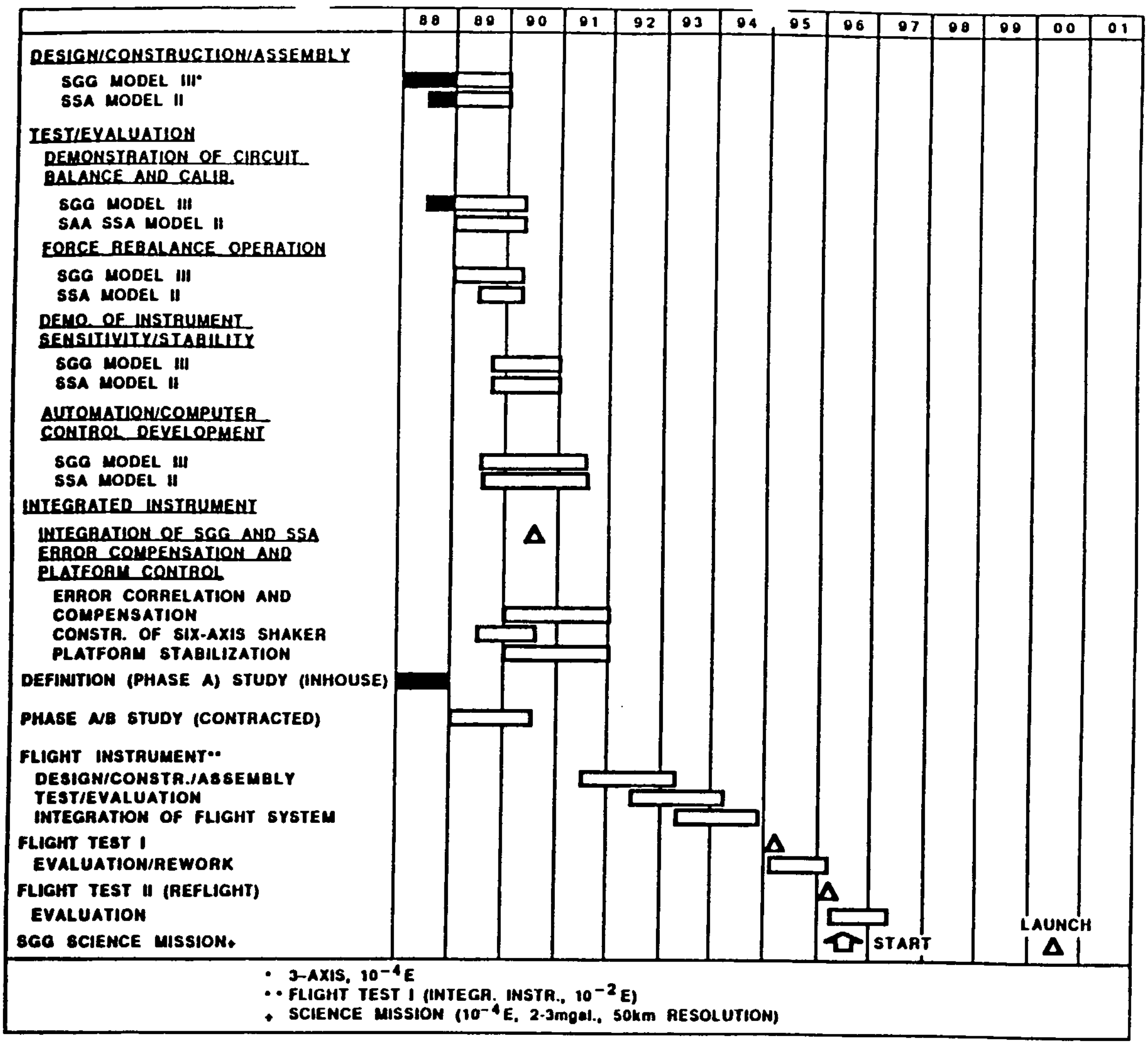
Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Continuation Sheet For: ....INSTRUMENT DEVELOPMENT & TEST PHILOSOPHY...........

Data Sheet No.: 16-2

Instrument Development

The SGG development tasks and the schedule are given below:



Since the low-g times, available in earth-bound laboratories (drop-towers: approx. 4 sec.; parabolic flights: approx. 20 sec.) are deemed to be too short to permit proper initialization and stabilization of the gradiometer and the accelerometer, the orbital Flight Test will be the first opportunity to operate the instrument in a low-g environment.

Model and Test Philosophy

A protoflight approach is taken, ie. the Flight Test hardware is expected to be an upgraded version of the laboratory prototype model III SGG, integrated with the model II SSA.

The approach to flight instrument qualification / acceptance testing is TBD.

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Data Sheet No.: 17-1

PRELAUNCH/POSTLANDING REQUIREMENTS
(IIP Chapter Reference: none)

	Yes/ No	Pre-launch	Post-landing	Required Time in hours (estim.)
(1) Nominal P/L Processing Requirements in Building 1 (Astrotech)				
- Removal/Replacement of items (acc. Transp. Envelope)	Yes	☒	☒	
- Alignment Measurement	Yes	☒	☐	TBD hrs
- Calibration, while integrated on EURECA (appr. Launch-2 months and Landing +2 months)	Yes	☒	☒	TBD days
- Insensitive Sample/Probe Installation: LHe transfer to dewar	Yes*	☒	☐	TBD hrs
- Confidence Test/ Check-Out	Yes	☒	☒	TBD hrs
(2) Hazardous P/L Processing Requirements: LHe filling of dewar	Yes*	☒	☐	TBD hrs

(3) Late Access Requirements (pre-launch): Yes*

Potential LHe replenishment of dewar in the NASA Shuttle Vertical Processing Facility (VPF) necessary, for compensation of He boiloff losses during ground processing phases.

(4) T-0 Power/Control I/F Requirement: None

(5) Early Access Requirement(post-landing): None

* GSE and further provisions as well as procedure outline for LHe transfer and dewar replenishment are TBD.

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Data Sheet No.: 18-1

INSTRUMENT MISSION & OPERATIONS REQUIREMENTS
(IIP chapter reference: none)

(1) Required orbit: (see also Data Sheet No. 7)

Inclination	Optimal for SGG: 90 degrees .... EURECA Capability: 28.5 degrees .... The Principal Investigator has agreed that the requirements of the Flight Test may be fulfilled by the EURECA capability of 28.5 deg.
Altitude	a) Nominal EURECA orbits: 525 km and 310 km.....or b) SGG dedicated orbits: 800 km / 200 km..........
Orientation / Attitude	sun inertial; earth pointing for 200/310 km orbit

-- continued on next page --

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Continuation Sheet for: ...INSTRUMENT MISSION & OPERATIONS REQUIREMENTS.........

Data Sheet No.: 18-2

(2) Required Mission Profile

No	Phase/ Activity	Required Attitude (km)	Required Orientation	Duration	SGG Switching Status	Remarks
1	Shuttle Ascent	-	-	-	off	-
2	SGG Self-Test and C/O	-	-	TBD minutes	on	-
3	EURECA Deploy-ment and Orbit Transfer	to 525 or 800	-	-	off	-
4	SGG on-orbit calibration	525/800	sun inertial and earth pointing acceptable	TBD days	on	Activities no. 4 and 5 require minimized spacecraft induced disturbances (ref. to Data Sheet No. 11). This may potentially be realized during repeated (e.g. once per day) "quiet periods" of 90 min. duration each, by e.g.: - deactivation of active cooling system (freon pump package) - deactivation of reaction control actuators (thrusters, magnetic torquers).
5	SGG system per-formance demon-stration and verification	525/800	sun inertial and earth pointing acceptable	4 weeks	on	
6	SGG idle state	-	-	-	off or stand-by	This phase is potentially available for extended operations of other payloads.
7	EURECA Orbit Transfer	to 200 or 315	-	-	off	-
8	SGG system per-formance demon-stration and verification; "test" science data	315/200	sun inertial and earth pointing acceptable	1-2 days	on	Activity no. 8 requires minimized spacecraft in-duced disturbances (ref. to Data Sheet No. 11). This may potentially be realized during repeated (e.g. once per day) "quiet periods" of 90 min. duration each, by e.g. - deactivation of active cooling system (freon pump package) - deactivation of reaction control actuators (thrusters, magnetic torquers)
9	EURECA Transfer to Shuttle rendez-vous / parking orbit	-	-	-	off	-
10	Shuttle Descent	-	-	-	off	-

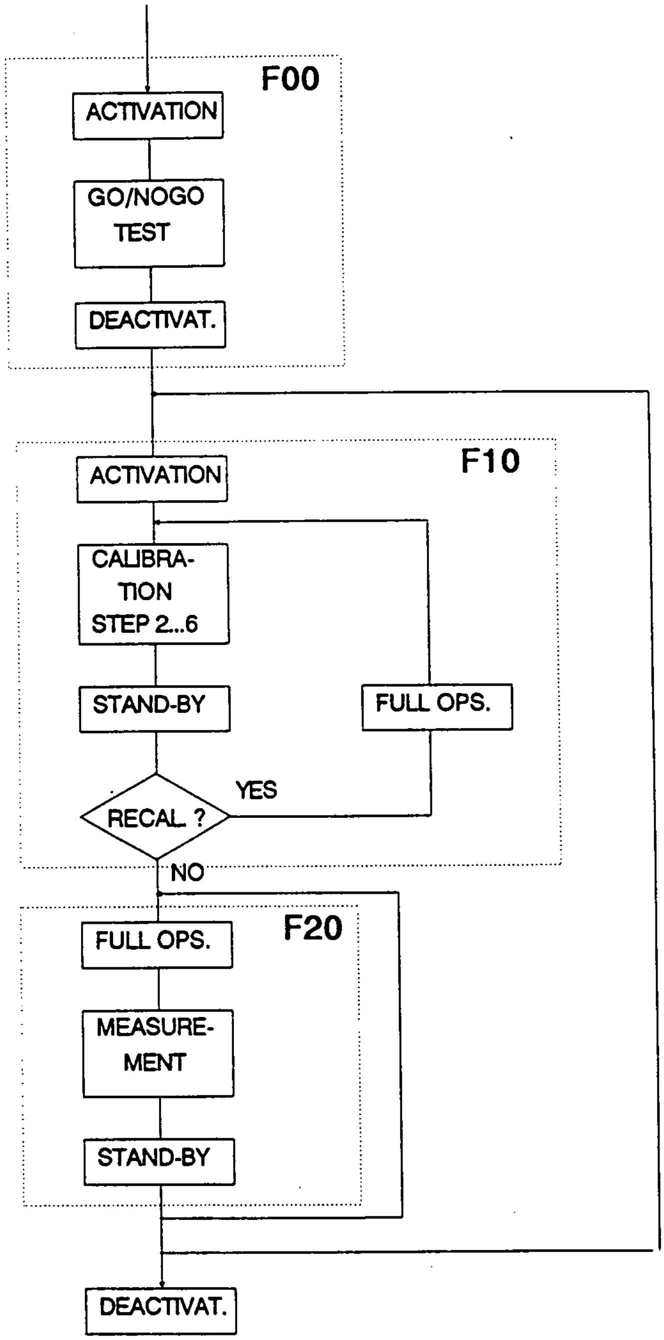
Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Continuation Sheet for: ...INSTRUMENT MISSION & OPERATIONS REQUIREMENTS.........

Data Sheet No.: 18-3

(3) Functional Objectives

SGG Functional Objectives Flow Chart:



Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Continuation Sheet for: ...INSTRUMENT MISSION & OPERATIONS REQUIREMENTS.........

Data Sheet No.: 18-4

(3) continued

SGGF00

FO code

FUNCTIONAL OBJECTIVE

TITLE:	GO/NOGO-TEST
BRIEF DESCRIPTION:	FUNCTIONAL INTEGRITY CHECK
NUMBER OF FO PERFORMANCES:	ONCE
PREFERRED EXECUTION TIME:	PRIOR EURECA ASCENT ORBIT TRANSFER
DEPENDENCE ON OTHER FOs:	NONE

Step Number	1	2	3	4	5	6	7	8	9	10
Duration (~~sec~~),(min),(~~hour~~)	1	(1)	1							
Power (W)	— 270		(2)—							
Cooling (W)	— TBD —									
Data Rate (bps)	800	(3)	800							
CLs / CSs	1	5	1							
Packet Content Tables (max)	0	0	0							
Microgravity sensitive (Y/N)	N	Y	N							
Moving parts (Y/N)	N	N	N							
Real Time (Y/N)	— (4) —									
Comments	n/a	(5)	n/a							

Step No.	Step Description
1	ACTIVATION
2	GO/NOGO TEST
3	DEACTIVATION
4	
5	
6	
7	
8	
9	
10	

No.	Notes and Comments
(1)	ORDER OF 1 ORBIT (90 MINUTES)
(2)	PEAK POWER, SEE ALSO NOTE (5)
(3)	PENDING SELECTED SGG MODE: - CALIBRATION 25 kbps
	- MEASUREMENT 7 kbps
	- HOUSEKEEPING 0,8 kbps
(4)	DATA TO BE EVALUATED, WHILE EURECA WILL STILL BE CLOSE TO
	THE SHUTTLE IN ORDER TO ALLOW FOR MISSION ABORT
(5)	GOAL OF TEST TO BE DEFINED YET

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER......................

Continuation Sheet for: ...INSTRUMENT MISSION & OPERATIONS REQUIREMENTS.........

Data Sheet No.: 18-5

(3) continued

SGGF10 (FO code)

FUNCTIONAL OBJECTIVE

TITLE:	CALIBRATION
BRIEF DESCRIPTION:	CALIBRATION OF SGG AND SSA
NUMBER OF FO PERFORMANCES:	4 to 8 (ONCE PER MONTH)
PREFERRED EXECUTION TIME:	DURING ON-ORBIT OPS PHASE/RETRIEVAL ORBIT
DEPENDENCE ON OTHER FOs:	NONE

Step Number	1	2	3	4	5	6	7	8	9	10
Duration (~~sec~~),(min),(~~hour~~)	1	30	10	30	6x3	6x14	0,5	0,5		
Power (W)	270 (1)	270 (1)	270 (1)	270 (1)	270 (1)	270 (1)	100	270 (1)		
Cooling (W)	TBD									
Data Rate (bps)	800			24128			800	800		
CLs / CSs	1	1	1	1	1	1	1	1		
Packet Content Tables (max)	0	0	0	0	0	0	0	0		
Microgravity sensitive (Y/N)	N	Y	Y	Y	Y	Y	N	N		
Moving parts (Y/N)	N	N	N	Y	Y	Y	N	N		
Real Time (Y/N)	N	N	N	(2)	(2)	(2)	N	N		
Comments	n/a									

Step No.	Step Description
1	ACTIVATION
2	SSA BRIDGE BALANCE
3	SGG ACCELEROMETER BALANCE
4	SGG GRADIOMETER BALANCE
5	SSA/SGG ACCELEROMETER CALIBRATION
6	SGG GRADIOMETER CALIBRATION
7	SWITCH TO SGG STAND-BY MODE
8	SWITCH TO SGG FULL OPERATION MODE
9	
10	

No.	Notes and Comments
(1)	PEAK POWER
(2)	RESULTS OF CALIBRATION STEPS SHOULD BE JUDGED ON
	GROUND BY PI

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

Continuation Sheet for: ...INSTRUMENT MISSION & OPERATIONS REQUIREMENTS.........

Data Sheet No.: 18-6

(3) continued

SGG F20 — FO code

FUNCTIONAL OBJECTIVE

TITLE:	MEASUREMENT
BRIEF DESCRIPTION:	DATA TAKING OF EARTH GRAVITY FIELD
	AND PERFORMANCE DEMONSTRATION
NUMBER OF FO PERFORMANCES:	REPEATEDLY
PREFERRED EXECUTION TIME:	N/A
DEPENDENCE ON OTHER FOs:	NONE

Step Number	1	2	3	4	5	6	7	8	9	10
Duration (~~sec~~),(min),(~~hour~~)	0,5	90(1)	0,5							
Power (W)	140	140	100							
Cooling (W)	TBD	TBD	TBD							
Data Rate (bps)	800	6848	800							
CLs / CSs	1	1	1							
Packet Content Tables (max)	0	0	0							
Microgravity sensitive (Y/N)	N	Y	N							
Moving parts (Y/N)	N	N	N							
Real Time (Y/N)	N	N	N							
Comments	N/A	N/A	N/A							

Step No.	Step Description
1	SWITCH TO SGG FULL OPERATION MODE
2	DATA TAKING
3	SWITCH TO SGG STAND-BY MODE
4	
5	
6	
7	
8	
9	
10	

No.	Notes and Comments
(1)	VARIABLE, MAY BE SPLIT UP INTO TIME SLICES OF APPROX.
	15 MIN. DURATION EACH

(4) Instrument Calibration

As calibration requires excitation of the SGG / SSA assembly at definite frequencies in all six degrees of freedom on a micro-g level, three approaches to on-orbit calibration have been conceived:

(a) excitation of the entire spacecraft
(e.g. through its Attitude Control System actuators)

(b) excitation of the dewar (relative motion between dewar and spacedraft)

(c) shaking of the SGG / SSA assembly inside the dewar

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

ABBREVIATIONS

ADP	Acceptance Data Package
AO	Announcement of Opportunity
AOCS	Attitude and Orbital Control Subsystem
BPSK	B-Phase Shift Keying
CL	Command Loop
C/O	Check-out
CPU	Central Processing Unit
CSS	Coarse Sun Sensor
DHS	Data Handling Subsystem
EM	Engineering Model
ESP	Equipment Support Panel
FLAP	Flight Application Software
FM	Flight Model
FMECA	Failure Mode, Effects and Criticality Analysis
FOV	Field-of-view
FSS	Fine Sun Sensor
GMT	Greenwich Mean Time
HSL	High-Speed Link
H/W	Hardware
ICS	Interconnect Station
ID	Identity
I/F	Interface
IIA	Instrument Interface Agreement
IOC	Inter-orbit Communication
IRES	Infra-red Earth Sensor
KSC	Kennedy Space Centre
LSL	Low-Speed Link
MBM	Magnetic Bubble Memory
MMU	Mass Memory Unit
MRU	Monitoring/Reconfiguration Unit
NRZ	Non-Return to Zero
OTM	Orbital Transfer Maneuver
PFM	Proto-Flight Model
PI	Principal Investigator

Instrument Name: .....SUPERCONDUCTING GRAVITY GRADIOMETER.......................

PIA	Processor Interface Adapter
P/L	Payload
PM	Pulse Modulation
PPU	Powerful Processing Unit
PSK	Phase Shift Keying
QM	Qualification Model
RAU	Remote Acquisition Unit
RMS	Remote Manipulator System
S/C	Spacecraft
SI	System International
STS	Space Transportation System (NASA)
S/W	Software
TBD	To be defined
TC	Telecommand
TM	Telemetry
TTC	Telemetry and Telecommand Subsystem
VCD	Verification Control Document

APPENDIX B

SGG CALIBRATION PROCEDURE

ON-ORBIT SSA/SGG CALIBRATION

Ho Jung Paik (10/5/90)

***Required Instrumentation*:** A six-shaker capable of producing acceleration amplitudes of 10^{-6} g and 10 arcsec s^{-2} at 0.1 Hz and 10^{-5} g and 100 arcsec s^{-2} at 1 Hz with less than 50 percent mixing between the axes. An orthogonal triad of accelerometers with 10^{-7} g $Hz^{-1/2}$ sensitivity and two two-degree-of-freedom gyros with 1 arcsec s^{-2} $Hz^{-1/2}$ sensitivity. The orthogonality between the sensitive axes should be 10^{-3} or better.

1. **SSA Bridge Balance**

   Required Acceleration: None.

   Required Time: 30 minutes.

   Procedure:

   a. Introduce He gas to a pressure of 10^{-3} Torr.

   b. Store nominal values of persistent currents in all levitation coils of SSA.

   c. Apply small AC signals to all six sensing circuits of SSA, close the feedback loops, ramp up the AC signals, and measure the SSA outputs.

   d. Compute from the feedback currents the required correction to the persistent current in each levitation coil.

   e. Adjust the persistent currents in the levitation coils as required.

   f. Repeat steps c) through e) until all the bridges are balanced to 10^{-6} (four iterations).

2. **SGG Accelerometer Balance**

   Required Acceleration: None.

   Required Time: 10 minutes.

   Procedure:

   a. Store nominal values of persistent current in all levitation and sensing coils of SGG.

   b. Decay the currents in the SGG accelerometer sensing coils and measure the inductances of the accelerometer sensing coils.

   c. Compute the correct values for the persistent currents in the accelerometer sensing coils.

   d. Store the required persistent currents in the accelerometer sensing coils.

e. Repeat steps b) through d) for the SGG gradiometer sensing coils.

f. Repeat steps b) through d) for the SGG accelerometer sensing coils.

(This achieves an SGG accelerometer balance against a differential mode acceleration to 10^{-2}.)

3. **SGG Gradiometer Balance**

Required Acceleration: A linear acceleration of 10^{-6} g amplitude at 0.1 Hz. A background acceleration level of 2×10^{-8} g $Hz^{1/2}$ and 0.2 arcsec s^{-2} $Hz^{-1/2}$.

Required Time: 30 minutes.

Procedure:

a. Apply a linear acceleration of 10^{-6} g amplitude at 0.1 Hz (for 10 seconds) along an axis other than one of the sensitive axes of SGG (preferably along the symmetry axis of the umbrella) and measure the gradiometer responses.

b. Compute the required correction to the persistent current in each sensing coil.

c. Adjust the persistent currents in the sensing coils as required.

d. Repeat steps a) through c) until a common-mode balance of 10^{-6} is achieved in all three axes (four iterations).

e. Vent the He gas to space.

4. **SSA/SGG Accelerometer Calibration**

Required Acceleration: Three linear acceleration components of 10^{-5} g amplitude at 1 Hz and three angular acceleration components of 100 arcsec s^{-2} amplitude at 1 Hz. A background acceleration level of 2×10^{-8} g $Hz^{-1/2}$ and 0.2 arcsec s^{-2} $Hz^{-1/2}$.

Required Time: 20 minutes.

Procedure:

a. Apply linear acceleration of 10-5 g amplitude at 1 Hz (for three minutes each) consecutively in three independent directions (preferably along the three sensitive axes of the SSA) and measure the SSA and SGG responses.

b. Measure simultaneously the linear and angular accelerations using the conventional accelerometers and gyros, and compute the linear and angular accelerations at SSA/SGG to a signal-to-noise ratio of 10^3.

c. Apply angular accelerations of 100 arcsec s^{-2} amplitude at 1 Hz (for three minutes each) consecutively about three independent directions (preferably about the three sensitive axes of the SSA) and measure the SSA and SGG responses.

d. Repeat step b).

e. Compute the calibration matrix coefficients for the SSA and SGG accelerometers by comparing the SSA and SGG responses with the computed accelerations, and enter these values into the error compensation circuits.

(The SSA and SGG accelerometers have now been orthogonalized and calibrated 10–3.)

5. **SGG Gradiometer Calibration**

Required Acceleration: Three linear acceleration components of 10^{-6} g amplitude at 0.1 Hz and three angular acceleration components of 10 arcsec s^{-2} amplitude at 0.1 Hz. A background acceleration level of 2 x 10^{-8} g $Hz^{-1/2}$ and 0.2 arcsec s^{-2} $Hz^{-1/2}$.

Required Time: 90 minutes.

Procedure:

a. Apply linear acceleration of 10^{-6} g amplitude at 0.1 Hz (for 14 minutes each) consecutively in three independent directions (preferably along the three sensitive axes of the SGG) and measure the SGG and SSA responses to a signal-to-noise ratio of 10^3.

b. Apply angular accelerations of 10 arcsec s^{-2} amplitude at 0.1 Hz (for 14 minutes each) consecutively about three independent directions (preferably about the three sensitive axes of the SGG) and measure the SGG and SSA responses, as well as the second harmonic responses of SGG, to a signal-to-noise ratio of 10^3.

c. Compute the SGG error coefficients for all six degrees of freedom and enter these values to the error compensation circuit.

d. Compute the centrifugal acceleration components from the SSA angular accelerometer responses and compare them with the second harmonic responses of the SGG gradiometer to determine the SGG gradiometer calibration.

(The accelerations have now been balanced to 10^{-7} and the SGG has been calibrated to 10^{-3}.)

APPENDIX C

ORBITAL DISTURBANCE SIMULATION DATA

APPENDIX C

The microgravity disturbance environment simulating low earth orbit conditions for the SGG/EURECA test flight mission is presented in this appendix in the form of a number of time history plots. Figure C-1 shows the gravity gradient torques acting upon the vehicle. The torques due to atmospheric drag are displayed in Figure C-2. Figure C-3 is the sum of these two disturbances. Presented in Figure C-4 are the magnetic torquer characteristics while the residual disturbance is given in Figure C-5. Finally, the angular drift from the nominal earth pointing mode is shown in Figure C-6.

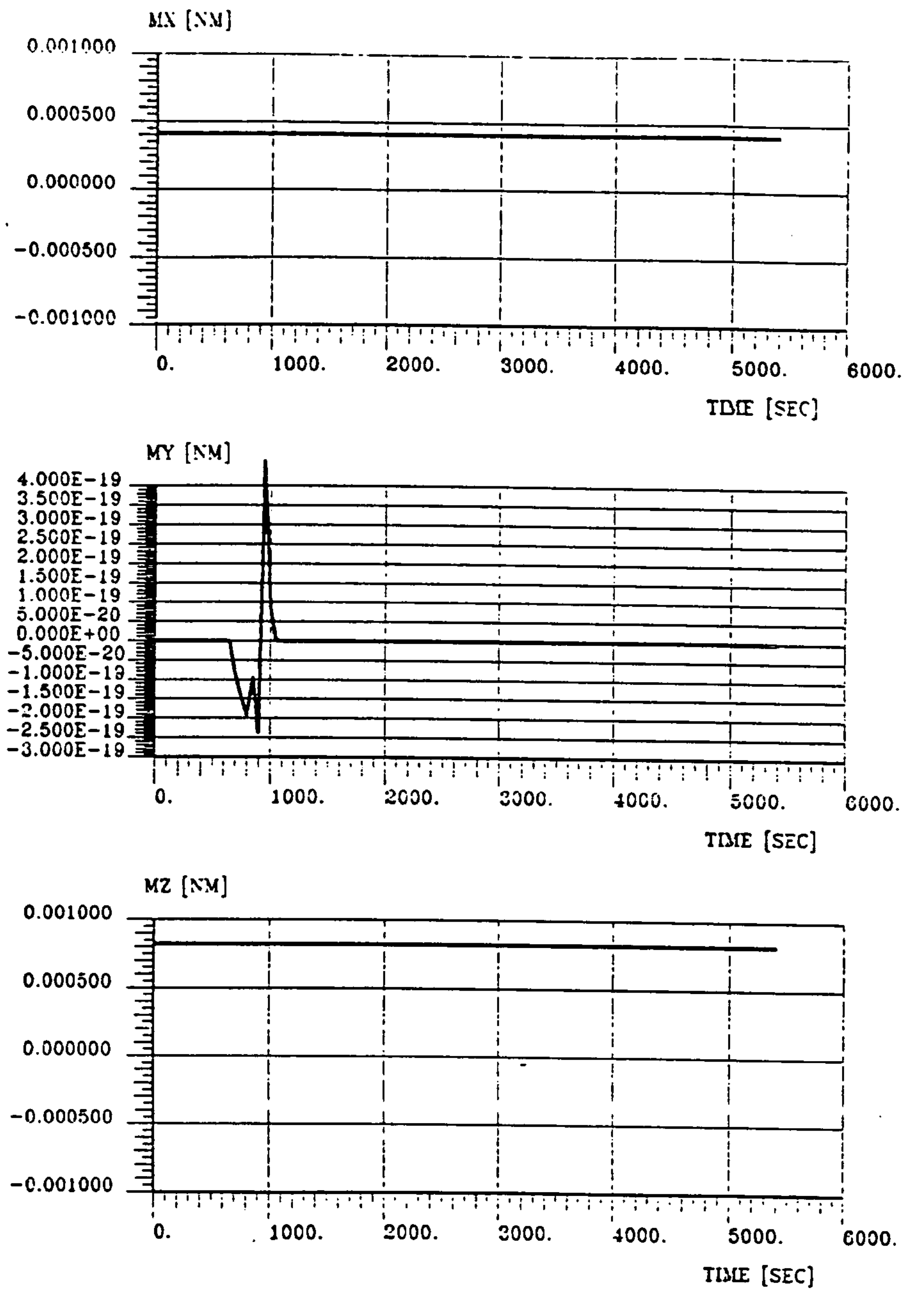


Figure C-1. Gravity Gradient Disturbances H = 250 km

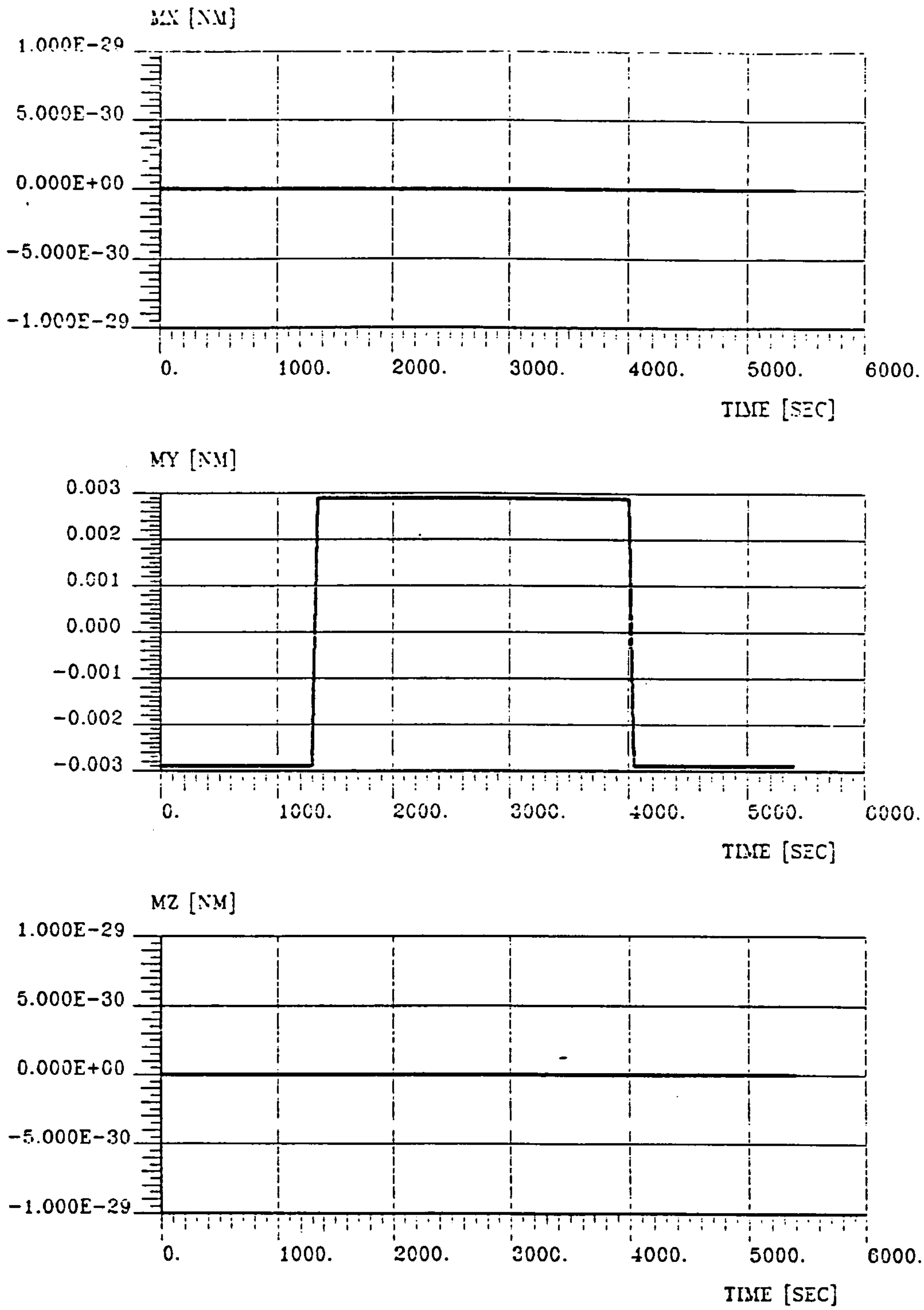


Figure C-2. Atmospheric Disturbances H = 250 km

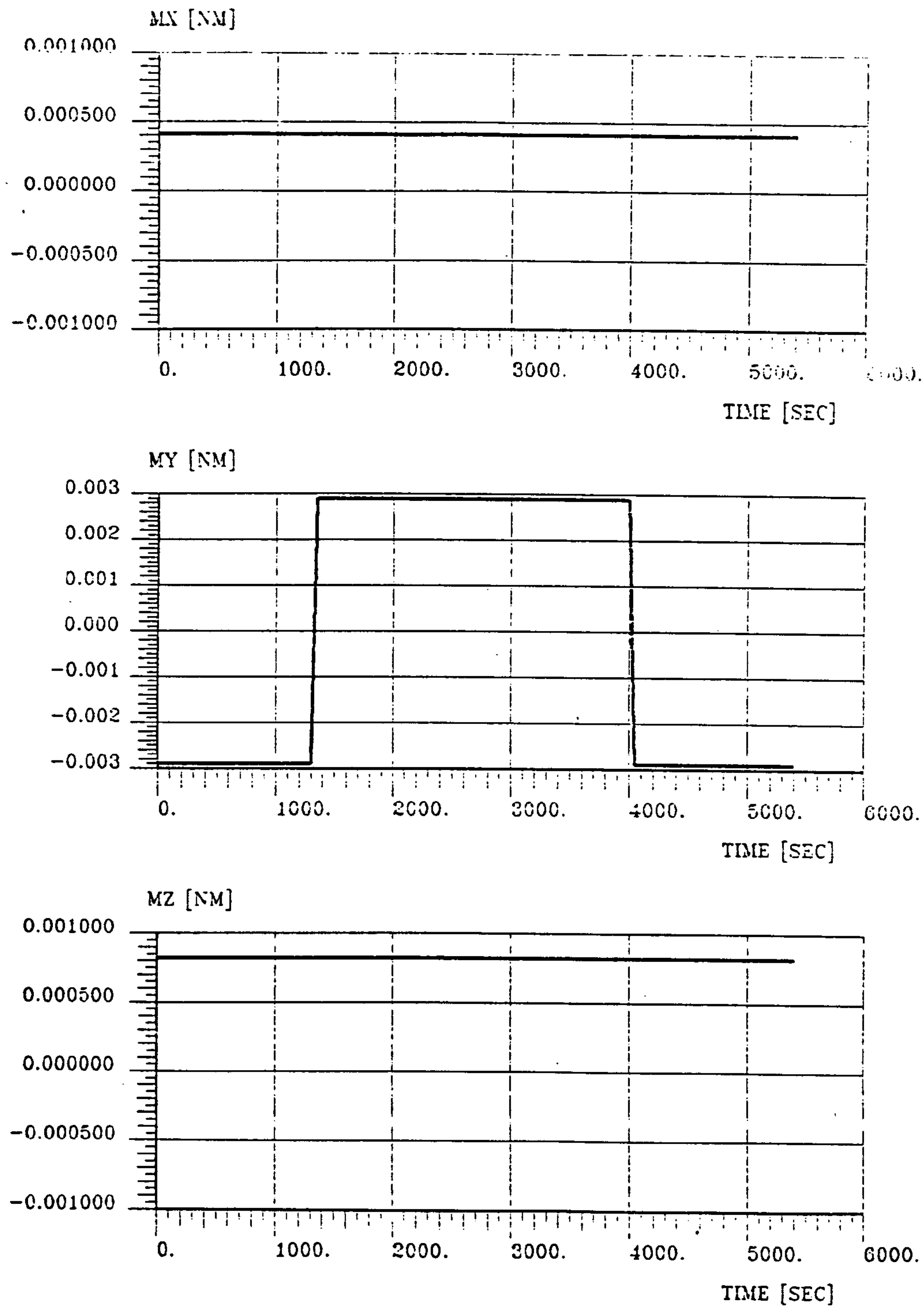


Figure C-3. Total Disturbances H = 250 km

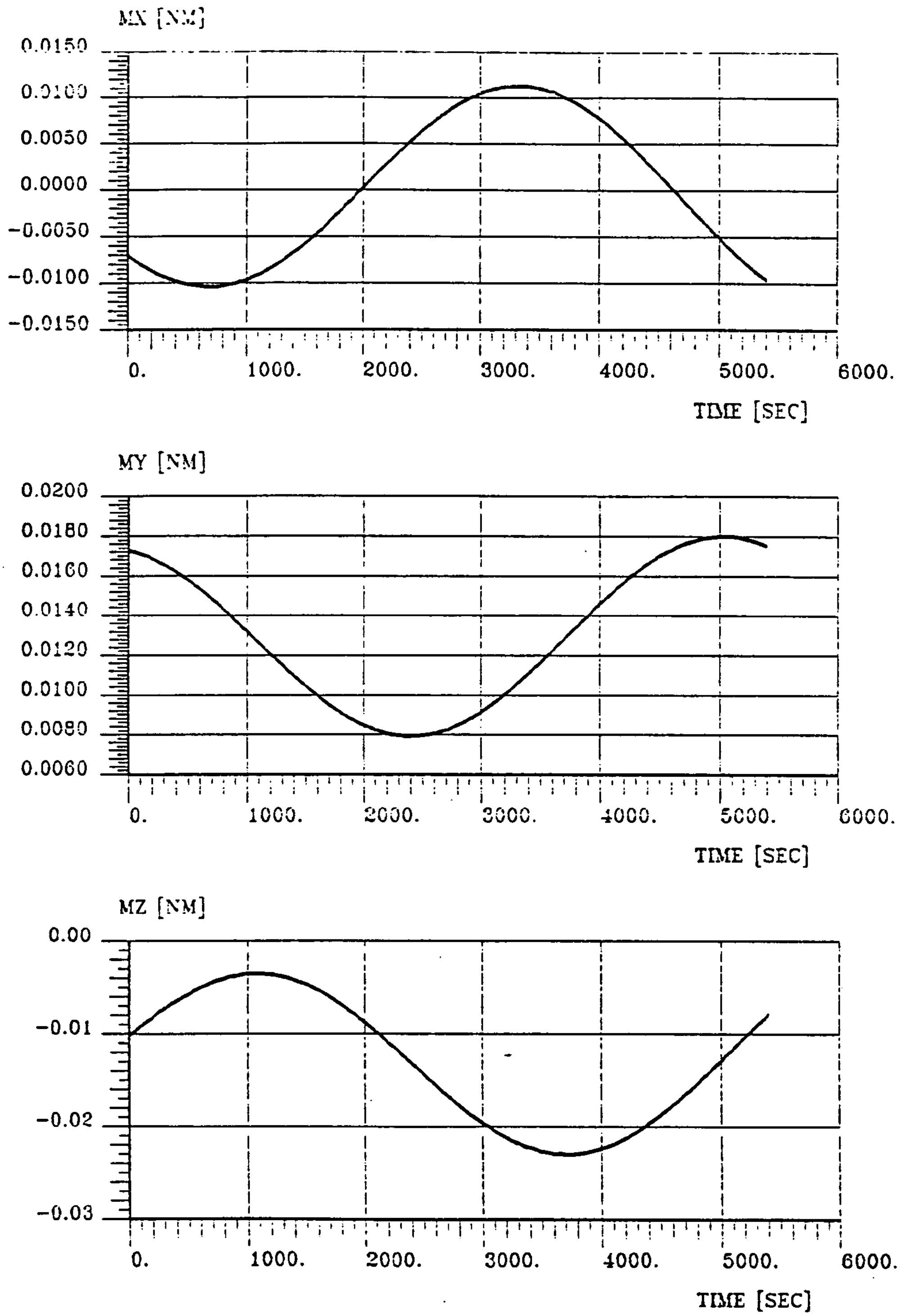


Figure C-4. Magnetic Torquer Characteristics

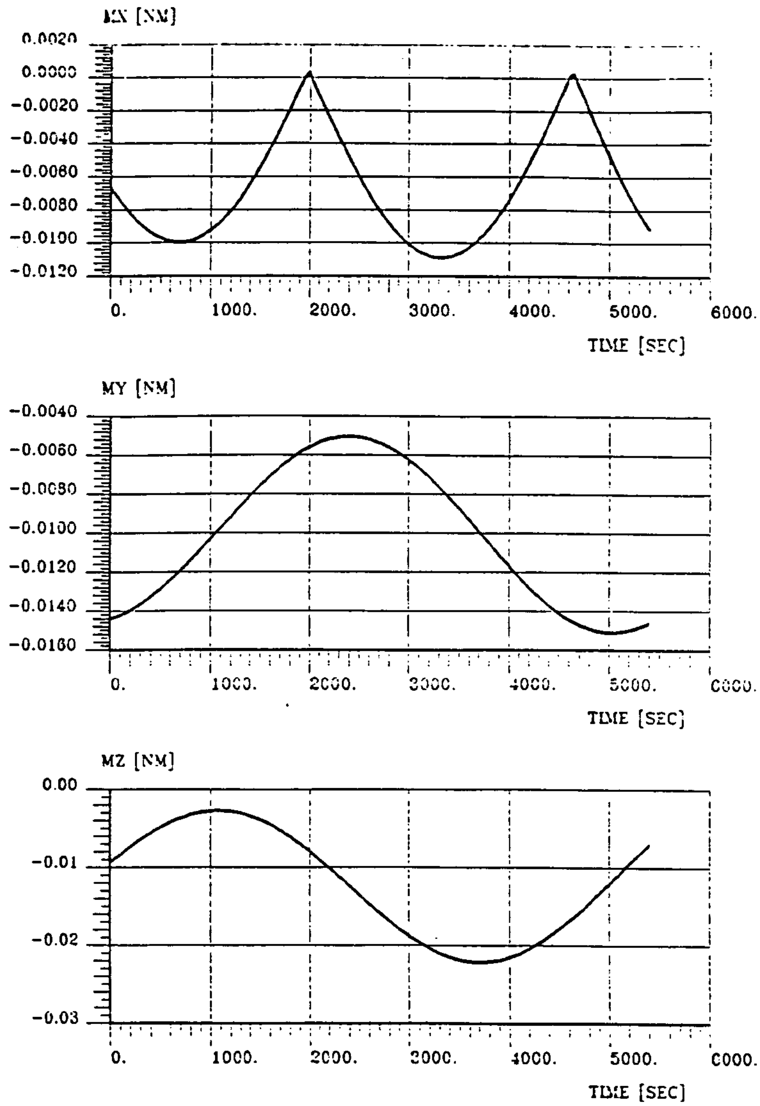


Figure C-5. Residual Disturbances H = 250 km

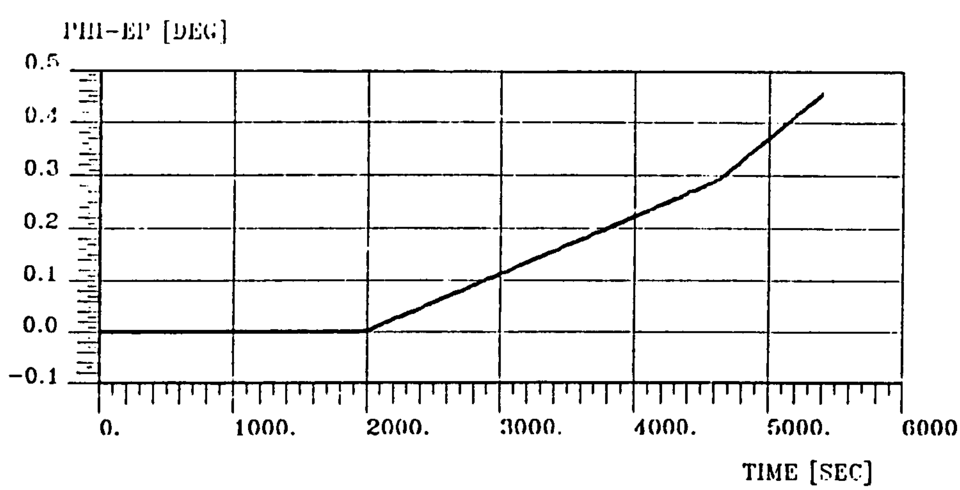


Figure C-6. Drift from Nominal Earth Pointing Mode

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15. Supplementary Notes

16. Abstract

This study examined the feasibility of conducting a flight test of the Superconducting Gravity Gradiomenter (SGG) on the European Retrievable Carrier (EURECA). The SGG is an advanced gradiometer that provides dense, precise and direct global gravity measurements. This extremely sensitive instrument places great demands on the spacecraft carrier. EURECA, a retrievable carrier, was developed expressly to accommodate experiments requiring a high quality microgravity environment. The study concluded that the SGG Experiment Module can be accommodated and operated in a EURECA reflight mission. This flight test permits the verification of the SGG Instrument flight performance, validation of the design and operation of the Experiment Module, as well as, collection of a limited amount of scientific data.

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