

EURECA 11 MONTHS IN ORBIT
INITIAL POST FLIGHT INVESTIGATION RESULTS

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SUMMARY

This paper gives a brief overview of the European free flying spacecraft 'EURECA' and the initial post flight investigations following its retrieval in June 1993. EURECA was in low earth orbit for 11 months commencing in August 1992, and is the first spacecraft to be retrieved and returned to earth since the recovery of LDEF.

The primary mission objective of EURECA was the investigation of materials and fluids in a very low micro-gravity environment. In addition other experiments were conducted in space science, technology and space environment disciplines. The European Space Agency (ESA) has taken the initiative in conducting a detailed post-flight investigation to ensure the full exploitation of this unique opportunity.

INTRODUCTION

Ten years ago the ESA identified the need for a retrievable free flying carrier system which would provide flight durations well beyond the 7 to 10 days possible with Spacelab and SPAS. The development of the European RETrievable CARrier (EURECA) was initiated in 1984 with a design and qualification requirement to give a capability for 5 missions of approximately 6 to 9 month's duration. It is Europe's largest and first reusable spacecraft. The second mission is now planned, subject to budget approval, for 1997.

The EURECA programme represents a unique opportunity to undertake a post flight inspection and to compare with the LDEF findings. While this was never a planned goal for the EURECA mission every attempt is being made by the ESA to exploit this opportunity.

EURECA CONFIGURATION

The EURECA flight configuration, often called EURECA-1, consists of the spacecraft and the payload. Figure 1 shows EURECA in its retrieval/launch configuration, with the solar array stowed.

The spacecraft consists of a platform providing accommodation and resources to the payload. The external surface is almost entirely covered by thermal blankets. Exceptions are the radiators and some boxes mounted on the bottom of the spacecraft, which are painted, and the solar array wings. The area of the exposed external surface is about 145 m², including 99 m² of solar array's front and rear surfaces.

The overall configuration of the spacecraft was primarily determined for a maximum payload volume, while minimising Shuttle launch costs. This resulted in an optimum spacecraft length to mass ratio. The spacecraft dimensions are 2.3 m (90.55") deep with the solar arrays retracted, and 4.5m (177.16") diameter to fit within the static envelope of the orbiter. With the solar arrays deployed the wing span is 20 m (785.67"). The mass at launch was slightly less than 4500 kg including 660 kg of hydrazine.

A brief description of the EURECA subsystems and payloads is given in the following.

SPACECRAFT

Structure

The structure consists of a framework of high strength carbon fibre struts, joined together at titanium nodal points. The nodal points are designed either to carry directly the loads of heavy equipment or to allow the mounting of secondary structure aluminium plates, called Equipment Support Panels (ESP) where the lighter boxes and instruments are fastened. In the launch configuration three trunnions (two sill and one keel) provide the load carrying interface to the Shuttle.

To assist deployment and retrieval the spacecraft was fitted with a NASA supplied grapple fixture. At the end of the mission there was evidence of a few micro meteoroid impacts.

Thermal Control

The Thermal Control Subsystem (TCS) task is to ensure that the spacecraft equipment and payload instrument interface temperatures are maintained within the allowable limits in all mission phases. This task is performed by using passive and active thermal control means.

Passive thermal control is principally by the use of Multi Layer Insulation (MLI) blankets (see Fig. 2) and finishing materials. The MLI blankets were found after the mission to have provided an ideal medium for the containment of micro meteoroid particles which may be largely unmodified by hitting the spacecraft. Many impacts have been identified and recorded photographically. Analysis of the impacted material within the blankets will commence later this year when the spacecraft has returned to Europe. The EURECA Project has placed all the blankets at the disposal of the micro meteoroid investigation team.

The active thermal control is by a freon cooled loop, principally for the high energy consuming instruments. The cooling loop collects the heat from the most dissipative items and brings it to two space radiators on the $\pm X$ sides of the spacecraft. These radiators are both 3.5 m by 1.59 m in size. They form part of the solar array assembly and inspection for micro meteoroid impacts will be part of the solar array inspection in Europe. Heaters are used to compensate the heat leak through the insulation and adjust the temperature of the radiator freon temperature. The heater control is performed by a microprocessor based unit upon the readings of about 250 thermistor.

Electrical Subsystem

The Electrical Power Subsystem (EPS) generates, stores, conditions and distributes the power to the system. The power distribution capability is about 2.5/2.8 kW, where 1000 Watts are dedicated to the payloads. The solar generators are two solar array wings, composed by five panels each generating 2500 watts from solar cells on two identical wings of five panels each. The panels are of a rigid honeycomb structure 3.4 metres by 1.4 metres. The glass covering of the solar cells gives very clear indications where micro meteoroids have impacted. The solar arrays are stowed during lift-off and landing and have the capability to deploy and retract on orbit. During the sunlight phases the charge arrays provide power to the Nickel Cadmium batteries, which in turn release power to the system during the eclipse phases. In the deployed configuration the solar arrays are rigidly attached to the main EURECA body and have no rotational degree of freedom so as to avoid drive mechanisms and any associated μ gravity disturbance to the experiments. It was not possible in the USA to deploy the solar arrays after landing for a full inspection. This awaits a detailed investigation, starting in late October, at the manufacture premises near Amsterdam.

Data Handling

The Data Handling Subsystem (DHS) performs the management, control and monitoring of the EURECA on-board operations, except those relevant to the attitude and thermal control which are performed autonomously. In short, the DHS stores and executes instructions received by telecommand from the EURECA Operations Control Centre (OCC) at ESOC (European Space Operation Centre), Darmstadt, Germany. It also controls the spacecraft and the payload during the non-contact time, and stores the spacecraft housekeeping as well as the payload science data for later transmission to the OCC. To avoid any μ gravity to the experiments by the use of a data tape recorder a magnetic bubble memory with a capability of 128 Mbs was installed.

Attitude Control

The Attitude and Orbit Control Subsystem (AOCS) measures and controls the EURECA attitude and orbit during both orbit transfer manoeuvres and nominal flight operations. The attitude sensors available on-board are optical (three coarse sun sensors (CSS), two fine sun sensors (FSS) and two low altitude conical earth sensors (LACES)) and inertial (three gyro packages containing two gyros each, one accelerometer package). The actuators are three magnetic torque rods, one hydrazine pressurised monopropellant propulsion system, equipped with eight 20 N thrusters and one nitrogen cold gas propulsion system equipped with twelve 20 mN thrusters. The AOCS can operate in several modes. After release from the RMS and before retrieval the spacecraft is in Proximity Operation Mode (POM). The control is performed using gyros as sensors and cold gas thrusters. This mode cannot be maintained for very long because of the gyro drift. The Sun Acquisition Mode (SAM) is used to bring EURECA to the +Z axis sun pointing attitude, with the Y axis in the orbit plane and +X axis towards the northern hemisphere. Sensors used are the six gyros, CSS, FSS and LACES, while the actuators are the hydrazine thrusters. The Earth Acquisition Mode (EAM) is used as preparatory to the orbit transfer manoeuvres. While the +Y axis is always pointing to the centre of the earth, four orientations are possible for the X and Z axes in order to allow in-plane and out-of-plane down manoeuvres. The actuators used are the hydrazine thrusters and the sensors are the gyros, CSS, FSS and LACES. The Orbit Transfer Mode (OTM) is used after the EAM in order to boost the spacecraft in the new orbit. The attitude and sensors of EAM are maintained, while the hydrazine thrusters are used in an off modulation mode during the burn.

During the Operational Mode (OM) the spacecraft +Z axis is sunpointing and the payload is operating under micro gravity conditions. The sensors used are four gyros, FSS and LACES, while the actuators are the magnetic torquers together with the cold gas thrusters. When the micro gravity and attitude pointing requirements are not mandatory, the spacecraft can be operated in Dormant Mode (DM). The attitude is basically the same with reduced accuracy in sun pointing. The sensors are the same as in OM, while the actuators are magnetic torquers, hydrazine thrusters to control rotations around X and Y axes and cold gas around Z axis. If an error occurs in the AOCS which cannot be autonomously recovered, the AOCS configures to Safe Emergency Mode (SEM). Only the CSS and three gyros are used as sensors and hydrazine thrusters in the submode SEM2 and cold gas in the submode SEM1 as actuators.

Microgravity Measurement Subsystem

The Microgravity Measurement Subsystem (MMS) monitors the on-board residual acceleration during the EURECA flight operations in the frequency bandwidth from 0 Hz to 5 Hz and stores the measurement data for later on-ground analysis.

Telemetry

The Telemetry Tracking and Command (TTC) subsystem transfers telemetry data from EURECA to the ground stations and telecommands from the ground stations to EURECA in two ways: via direct RF S-band link during nominal operations and via the Orbiter during deployment and retrieval operations.

INSTRUMENTS

The EURECA-1 payload complement consists of 15 instruments. Except one, mounted on the bottom of the spacecraft, all other instruments are accommodated on the platform top side. Half of the payload complement is dedicated to the microgravity research, including material and life science. The remaining instruments are dedicated to astronomical observation and technology research.

Of direct interest to the study of exposure to the space environment are the following experiments:

TICCE. The Timeband Capture Cell Experiment (TICCE) is designed to study the microparticle population in near-Earth space, typically Earth debris, meteoroids, and cometary dust. TICCE captures micro particles in excess of 3 km/s and stores the debris for retrieval and post mission analysis. Particles detected by the instrument pass through a front foil and into a debris collection substrate positioned 100 nm behind the foil. Each perforation in the foil will have a corresponding debris site on the substrate. Lately it was recognised that additional debris collection techniques were more suitable to the particle sampling. Therefore two additional arrays were added to the four containing the described capture cells. The additional arrays employ new techniques for impact debris collection, like silica aerogel materials and extremely thin aluminium foils, which have been developed by the lesson learnt from the NASA LDEF experience.

EXO BIOLOGY & RADIATION ASSEMBLY (ERA). To study the interaction of cosmic ray particles with biological matter, the synergism of space vacuum and solar UV, and the spectral effectiveness of solar UV on viability should be improved as a result of this instrument. ERA consists of deployable and fixed experiment trays, and a number of cylindrical stacks, known as Biostacks, containing biological objects such as spores, seeds or eggs alternated with radiation and track detectors.

ATOMIC OXYGEN SAMPLE TRAY (AOST). Two rectangular trays alongside the AOCS sensors and fitted to the +Z sun facing upper surface of the spacecraft. Numerous samples were attached to investigate the effects of UV radiation, AO, and thermal cycling on materials used for thermal control (films, paints and anodisation). Two contamination sensors were also fitted.

DOSIMETER (see later paper)

IN-ORBIT CURING EXPERIMENT (ICE). This is a sample of an Inflatable Space Rigitised Structure (ISRS) material which is a colamination of Kapton and Kelvar with epoxy prepregnated and sewn together. When exposed to radiation the foils cure in a few orbits. The dimensions are 300 mm x 120 mm.

MISSION PROFILE

Launch and Deployment

The EURECA mission started with the STS-46 Atlantis lift-off on July 31st 1992 at 13:56 GMT. The orbit achieved was very close to nominal. The first Orbiter state vector indicated an orbit at an inclination of 28.45 and 425 X 424 km altitude. EURECA was released from the Orbiter on August 2nd, at 7:07 GMT.

Operational Orbit

Immediately after release preparation for the orbit transfer manoeuvres commenced. After two transfer manoeuvres EURECA commenced its operations at an orbit of 508 km. From this point until the descent orbit transfer manoeuvre for retrieval, no orbit maintenance was performed. Therefore the orbit of EURECA was solely determined by the Earth gravity potential, atmospheric drag and the other natural orbit perturbations. The decay of the average altitude axis is plotted in Figure 3 versus the Mission Elapsed Time (MET) in days. The operational mode attitude of EURECA is inertial with the +Z axis pointing to the sun and the Y axis in the orbit plane. The +Y surfaces fly parallel to the velocity vector every orbit at midnight, while the -Y surfaces do it at orbital noon. The above considerations are important to judge the predictions of the meteoroid and debris "frontal" impacts.

Retrieval

The descent orbit transfer manoeuvre preceded by about three weeks the retrieval Shuttle lift-off STS-57 of Endeavour on the 21st June 1993. The orbit eccentricity had been corrected and the spacecraft was placed in a phase repeating parking orbit of 474 km. The rendezvous phase took place at the end of the third flight day. The final approach was manually executed by the Orbiter crew, who took care to minimise any contamination and/or disturbance to the attitude of EURECA by the Orbiter jet plume impingement. After retraction of the appendages, EURECA was grappled and stowed in the cargo bay. The Orbiter extended its mission, due to weather constraints at KSC, landing there on the 1st July 1993.

MISSION FLUX PREDICTIONS

The atomic oxygen prediction analysis was run over the mission duration of 324 days using the three dimensional tool ESABASE . The MSIS-86 reference atmosphere model was used in conjunction with the mean monthly value of the solar F10.7 cm radiation. The value of this parameter is linearly extrapolated between the months in order to obtain a daily figure. A plot of the variation of solar 10.7 cm radiation can be seen in Figure 4.

The mission accumulated AO fluence was calculated for the front and rear of the solar arrays, and to all six faces of the main spacecraft body. It should be noted that the present version of the analysis tool does not take into account the thermal motion effects of the atomic oxygen and also does not include any reflection of scattering. The results are shown in Figure 5. The accumulated fluence for the solar arrays and the ram direction are as follows:

Solar array front:	1.025×10^{20}	atoms / cm ²
Solar array rear:	1.821×10^{20}	atoms / cm ²
Ram:	4.911×10^{20}	atoms / cm ²

POST FLIGHT ACTIVITIES

Following the landing immediate checks were made to confirm that there were no hydrazine leaks from EURECA propulsion system. These checks indicated a completely sealed system. In addition a ground cable was connected to the Orbiter and charging of the EURECA instrument 'PCF's 'battery was conducted for a period of 4 hours to ensure continued adequate cooling of its samples. The Orbiter was then moved into the Orbiter Processing Facility 7 hours after landing. The cargo bay doors were opened on the 6th July and a full inspection of the upper surface of EURECA was made and a comprehensive photographic survey was taken. On the 7th July access was provided, via a suspended bucket, for the Project to remove the PCF samples. These samples were packed and flown to Europe and handed over to the respective investigators. The spacecraft, along with the Spacehab module and the SHOOT experiment, were removed in one operation from the Orbiter and placed in the Inter Facility Transport Canister. This canister was moved to the Vertical Processing Facility at KSC on the 9th July.

EURECA was lifted out of the canister and placed into its own integration and transportation kit. This provided an opportunity for a full visual and photographic survey of the complete spacecraft. The general conclusion was that a significant change of colour had occurred most pronounced where out-gassing had deposited onto the MLI on the +z surfaces (normal sun facing axis). Areas of paint delamination and many micro meteoroid impacts were clearly visible. All photographs taken are on CD-ROM for detailed examination by the specialists. Numerous specialists participated in this initial inspection at KSC.

On the 14th July, EURECA was moved to Astrotech, Titusville. The first task was to depressurise the propulsion and the cold gas attitude control system and to remove the remaining hydrazine. Tests confirmed that all hydrazine valves were in the closed position. Concerns had been raised, following an in flight anomaly, that the valves might inadvertently open on landing. The pressure was reduced from the helium and nitrogen gas tanks and then the hydrazine was removed. An amount of 323 kg of hydrazine was removed. At launch the tanks had been filled with 660 kg. EURECA was moved into the High Bay on the 6th August for deintegration and preparation for transportation to Europe which took place on the 29 September 1993.

RESULTS OF INITIAL POST FLIGHT ANOMALY INVESTIGATION

Battery capacity measurements were made. The results compared very closely with pre-flight values. Initial calculations show only a 2% reduction in charge capacity at the end of the mission. The uncertainties expressed prior to the launch as to the life capabilities of batteries manufactured in 1985 and removed from cold storage in January 1992 for installation have been answered.

Samples of the freon system have been taken for analysis and the system has been drained for removal of the instruments and the freon pump package. The residual freon accumulator pressure on the spacecraft was 6.1 bars and the loss of freon from the accumulator, since filling 18 months previously, is calculated as being approximately 1.2 litres. This is significantly less than worst case pre-flight estimates. The freon pump operated for just over 4000 hours on orbit and it can be seen that the pumps could have supported a very long mission (qualified for 10000 hours). NASA MSFC plans to perform all post flight inspection activities on the freon pump package, prior to clearance for re flight on a Spacelab mission.

The in-flight anomalies, of progressive loss of power, await to be investigated at Fokker in November. However, based on the limited visibility that exists behind the panels some damage caused by arcing is visible on a number of Wiring Connect Panels (short silver busbars). Inspection of the antennas revealed that on both antennas 1 & 2 the MLI was found to be trapped between the antennae's head and the spacecraft support structure. It is concluded that this trapping was most likely there prior to launch. In addition along the boom of antennae 2 there was interference from the MLI at two positions. The MLI at these two positions could be easily moved but would have put some load on the boom that might have prevented full retraction.

POST FLIGHT INITIAL MATERIAL ASSESSMENT

The ESA material team performed a comprehensive inspection at ASTROTECH, while the carrier was prepared for shipment to Europe and storage. The investigation consisted of four types of survey:

- Visual inspection
- Photographic documentation of the carrier and payload (more than 1000 photos taken)
- Organic contamination (70 wipes taken)
- Thermo-optical properties (100 a/E measurements taken)

In general terms, the most conspicuous visual effects on the EURECA hardware exposed to space are various outgassing deposits present next to venting holes or gaps between blankets in the top and bottom parts of the spacecraft. An example of this was the contamination of some samples on the Atomic Oxygen Sample Tray due to outgassing from the spacecraft at an adjacent thermal blanket joint. In its interiors EURECA is visually clean as in the pre-launch state.

The β -cloth exposed to space in the top deck of EURECA (+Z face) has turned light brown as a result of possible contamination by Ultra Violet radiation. Organic contamination tests results are not yet available. This change in colour has resulted in an increase of the Solar Absorptance of 0.06 on most of the blankets and up to 0.15 in very contaminated areas. No appreciable change was found in the Normal Emittance values. The FEP tape on the AOCS tower is heavily contaminated; peculiar shadowing effects are visible.

The +X and -X thermal hardware surfaces of the spacecraft are less degraded than the top, as it can be expected from the smaller solar input: the Solar Absorptance has an increase of 0.02 on most of the blankets and up to 0.04 in very contaminated areas closed to blanket gaps. The performance degradation of the β -cloth on the +Y and -Y surface is similar to the one observed in the top deck. The paint of SCUFF Plate is powdering and peeling, showing signs of Atomic Oxygen degradation.

The EURECA solar arrays will be deployed at the manufacturer premises in mid November. At that point a team led by ESA will execute a detail inspection of the hardware. From the inspections carried out in Astrotech the solar arrays appear to be in general good condition. Several impact features up to 500 μm are visible on the outer panel. The epoxy adhesive used for glass fibre cloth bonding is darkened. The colour of RTV S-691 used for ATOX protection changed from red to brown.

POST FLIGHT IMPACT ANALYSIS

A global optical survey of the outer surfaces of the EURECA main body has been completed. There have been 75 confirmed impact holes in the MLI ($>200 \mu\text{m}$). 11 impacts were identified in the scuff plates. More details on the impact analysis will be given in separate reports.

FUTURE PLAN FOR INVESTIGATION OF MATERIALS AND MICRO METEOROID AND DEBRIS IMPACTS

From mid November the ESA post flight investigation teams will concentrate their efforts on the solar arrays. ESA plan is to study Atomic Oxygen effects, and changes in material properties in general on all solar arrays components (insulation foil, KAPTON ITO, flex prints, etc.).

Samples of the MLI blankets will be subjected to impact tests to enable the relation of particle size to damage to be determined. The micro-meteoroid team will conduct a global survey on the arrays (front and back), recording features larger than $200 \mu\text{m}$. A more detailed survey will be executed in selected areas. By mid 1994, ESA expects to complete a catalogue with the results of the impact survey and material investigations. It is planned to recover part of the meteoroid or debris trapped in some of the MLI blankets for analysis.

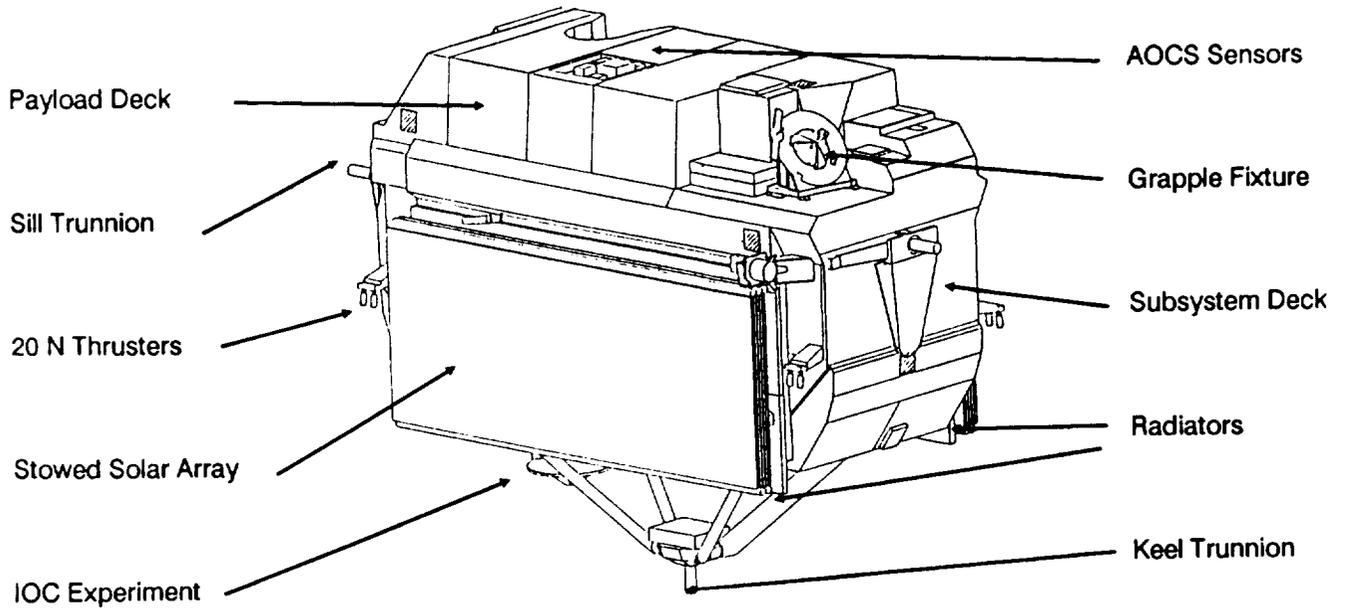


Figure 1. EURECA Configuration

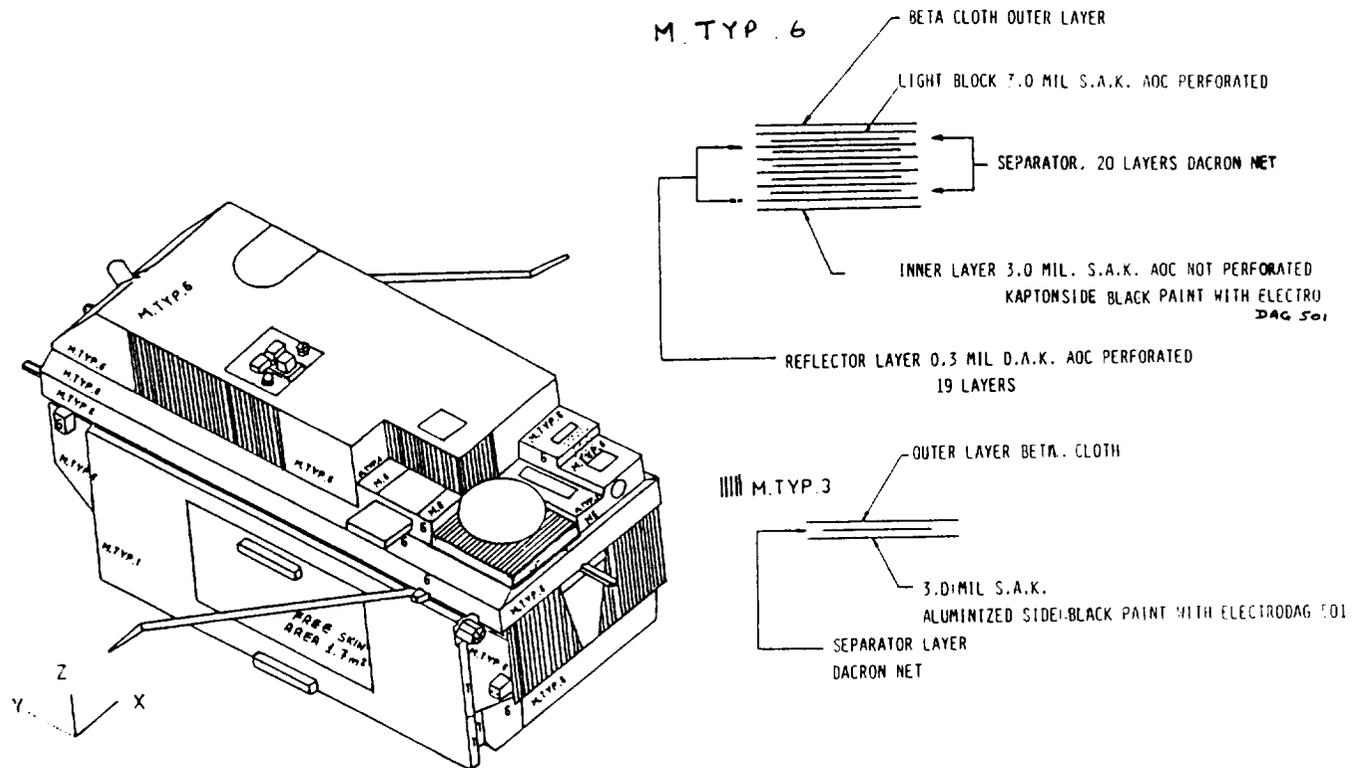


Figure 2. Thermal Blankets

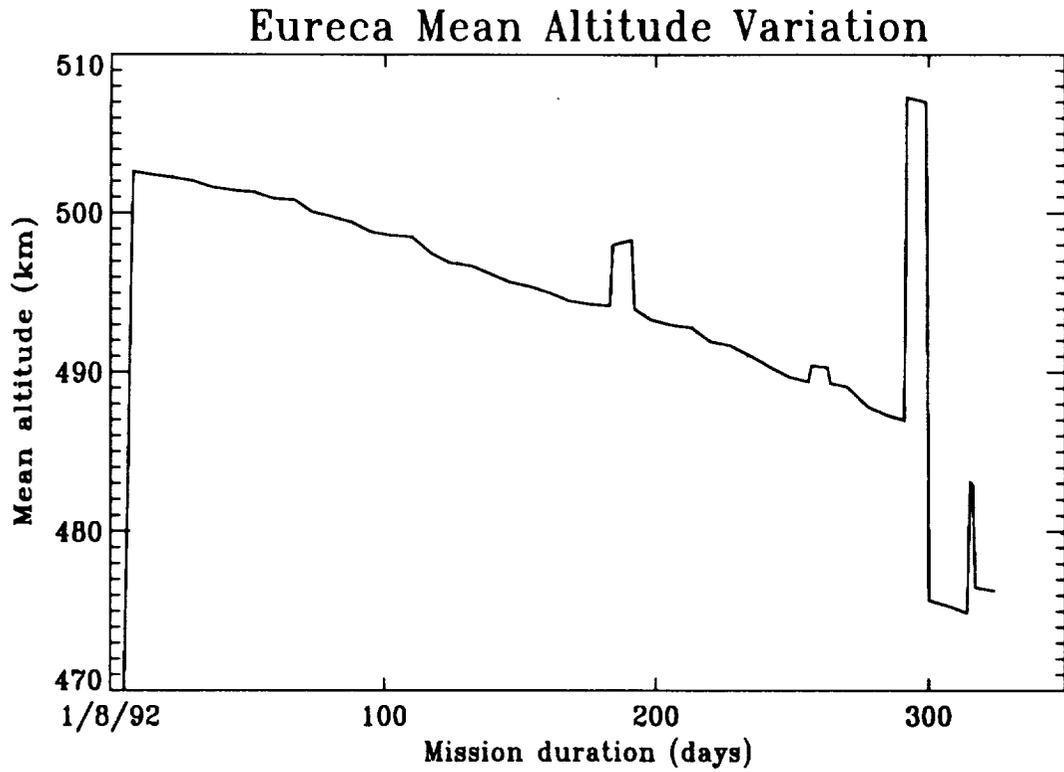


Figure 3. Mean Altitude Variation

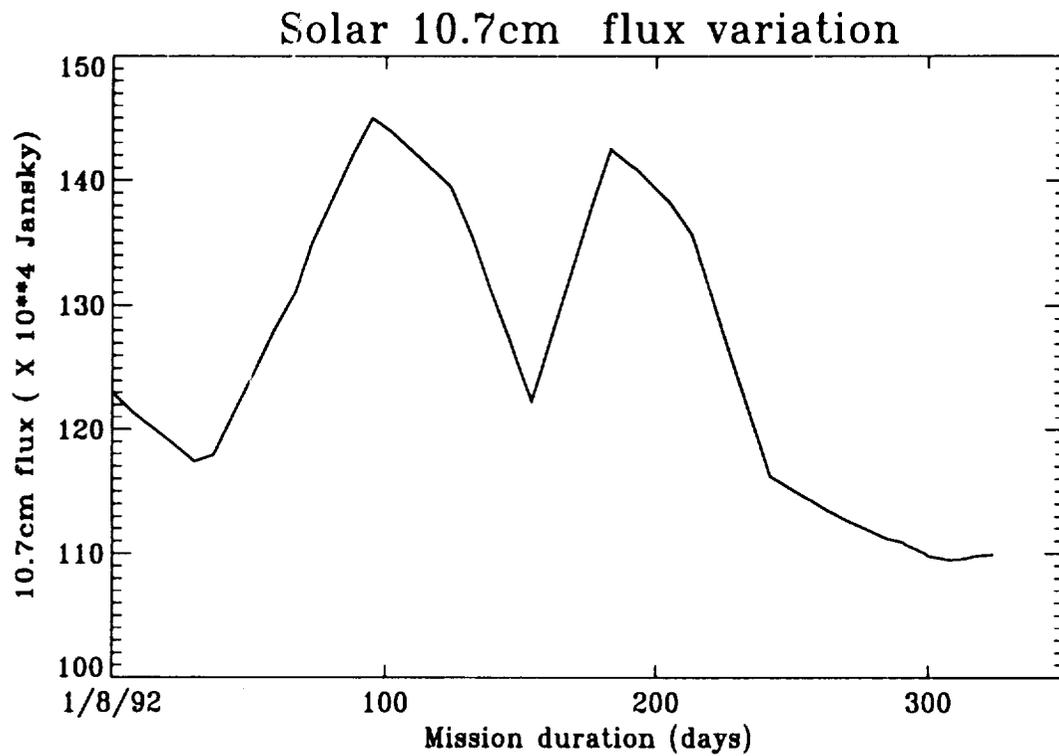


Figure 4. Variation of Solar Radiation During the Mission

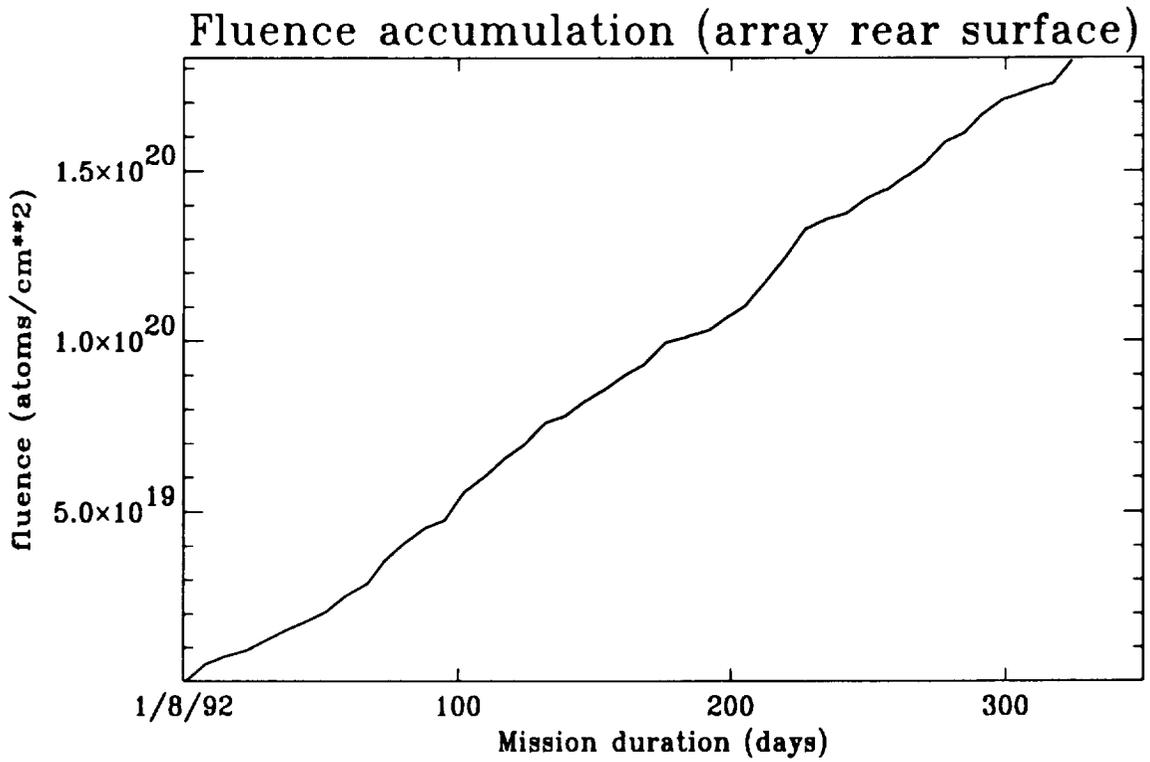
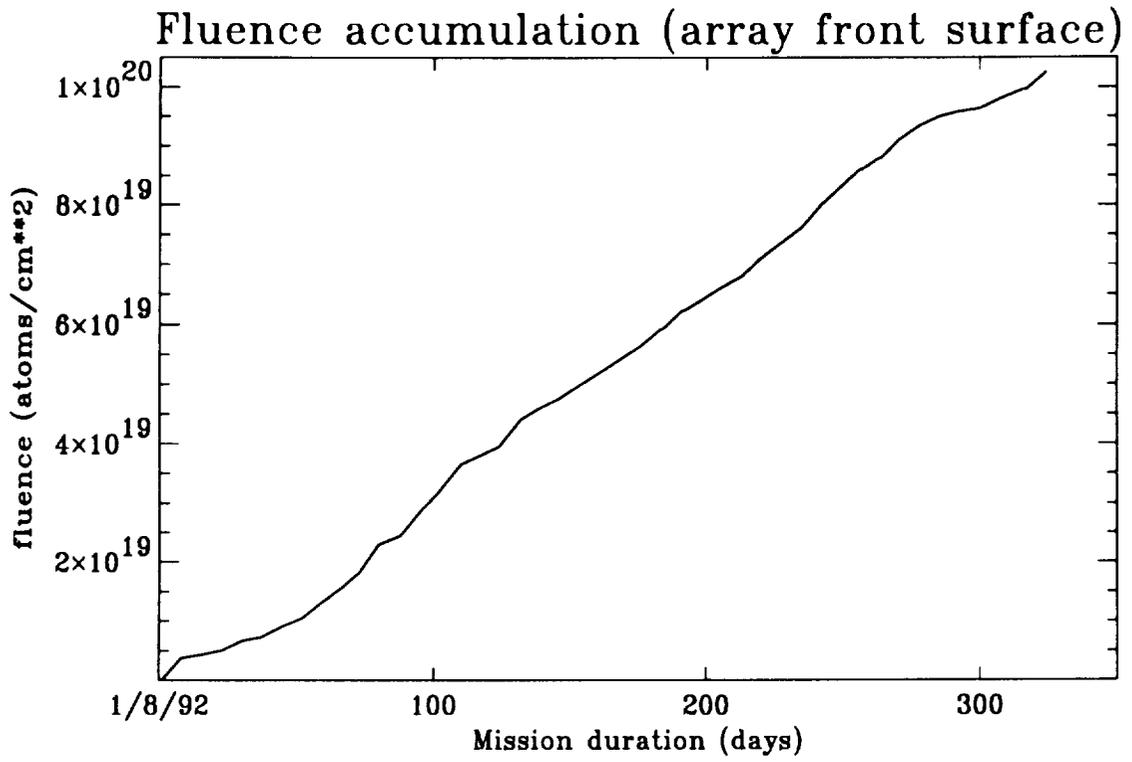


Figure 5. Accumulated Fluence on the Solar Arrays.

