EURECA MISSION CONTROL EXPERIENCE AND MESSAGES FOR THE FUTURE

H.Hübner, P.Ferri and W.Wimmer
European Space Operations Centre,
Robert-Bosch Straße 5, 64293 Darmstadt, Germany

ABSTRACT

EURECA is a retrievable space platform which can perform multi-disciplinary scientific and technological experiments in a Low Earth Orbit for a typical mission duration of six to twelve months. It is deployed and retrieved by the NASA Space Shuttle and is designed to support up to five flights. The first mission started at the end of July 1992 and was successfully completed with the retrieval in June 1993.
The operations concept and the ground segment for the first EURECA mission are briefly introduced. The experiences in the preparation and the conduction of the mission from the flight control team point of view are described.

Key Words: EURECA, Spacecraft Operations, Fault Management, On-Board Autonomy, Rendezvous Operations.

1. INTRODUCTION

The EURECA mission represented in many aspects a completely new challenge from the mission control point of view. The main features were the extremely limited ground contact, about 5% of the total mission time during the science phase, which demanded a high level of on-board autonomy (Ferri and Wimmer, 1994; Hübner and Wimmer, 1994), the deployment and retrieval by the Shuttle, including the safety aspects related to the manned spaceflight, the rendezvous activities and the complex inter-agency operations involving the Orbiter, two control centres, ground stations and data relay satellites, the concept of packetised telemetry and telecommands, for the first time fully implemented on a European spacecraft, and the large number of possible payload configurations.

After launch and deployment by the Shuttle into a 424 km circular orbit, EURECA was manoeuvred to the operational orbit of 508 km altitude, where the microgravity environment was established. This was followed by a ten month science phase in which the experiments, in the area of microgravity science, space science and space technology were performed under low acceleration conditions. About one month before the predicted time of launch of the retrieval Shuttle a series of orbital manoeuvres to lower the orbit and to match the retrieval orbital requirements commenced. Shortly before the launch of the retrieval Shuttle EURECA concluded all orbital manoeuvres, and the Orbiter reached it after a three days flight, capturing the spacecraft, safely storing it in the cargo-bay and returning it to Earth after 11 months of flight and more than 5000 revolutions around our planet. For a detailed summary of the EURECA mission, see Wimmer and Ferri (1994).

The EURECA ground segment was designed around the main mission characteristics (Ferri and Kellock, 1992). During the science mission phase contact with the spacecraft was achieved via two ESA ground stations at Maspalomas and Kourou, and a control centre located in Darmstadt, which could also make use of a third station in Perth as a back-up. These ground stations provided in total a daily sequence of about eight contact periods of 5 to 10 minutes, spaced by 90 minutes. A long non-coverage period of about 9 hours occurred between two consecutive sequences of station passes.
During the critical mission phases i.e. during deployment, orbit manoeuvres and retrieval operations, the third ground station at Perth was added, to increase the contact time.
In the phases when EURECA was attached to or in proximity of the Shuttle, contact with the spacecraft was established via the NASA Communications Network (NASCOM), the

NASA Tracking and Data Relay Satellite (TDRS) system and the Orbiter, which guaranteed a practically continuous coverage.

2. MISSION CONTROL CONCEPT AND EXPERIENCES

The manifold characteristics of EURECA's mission profile and the high degree of autonomy and new techniques integrated on-board, required a ground control system and a control concept (Van Casteren and Ferri, 1989) capable of supporting both, a traditional on-line and an advanced off-line operations approach. The traditional approach was characterised by manual uplink of individual telecommands, housekeeping telemetry monitoring and alarm processing. The advanced approach involved typically the activation of on-board application programs for implementing the required operations. The corresponding commands were prepared while the spacecraft was not in contact with the control centre. During ground coverage periods the accumulated spacecraft telemetry was dumped to ground via a high speed link and the prepared series of time tagged commands were uplinked. The execution verification of the on-board activities was based on event messages from the application programs and took place when the spacecraft was not visible anymore to the groundstation.

In this section the characteristics of the operation concept related to the different mission phases are briefly described, followed by a discussion on the most important experiences and lessons learned.

Mission Preparation

The main purpose of the mission preparation activities of the Flight Control Team was to specify the requirements for all the EURECA dedicated ground segment facilities, to customise the mission control software via the preparation of an operational database driving the telemetry processing and the telecommand generation functions, and finally to prepare and validate, based on the spacecraft users manual and other design documentation, the Flight Operation Plan (FOP). This document contains the detailed timelines of all phases of the mission and all the nominal and contingency procedures foreseen for the conduction of the spacecraft and payload operations.

The two major verification activities before the start of the mission were the System Validation Tests (SVT), to verify all functions of the mission control system and the operational database via a direct link with the real spacecraft, and the simulation campaign, which started about six months before launch and was resumed during the last weeks of the mission to test the new timelines of the retrieval phase. The main purpose of the simulations was to validate the FOP and to train the mission control team in all activities of the mission. The simulation programme for EURECA culminated in the joint simulations with the participation of ESOC, the NASA MCC and the Shuttle crew.

The major problem encountered in this phase was the lack of proper documentation on spacecraft design and functionality. Although this tends to be a common problem of many space projects, in the case of EURECA it was particularly serious due to the complexity of the spacecraft and the large amount of software functions implemented which were not sufficiently described and kept changing during the spacecraft integration process until very late in the programme. This had a severe impact on the workload required for the preparation of the operational database. Frequent changes and corrections were necessary to adapt the database to the new documentation or to the changes in the software. In addition, the lack of previous experience with the packet telemetry concept caused a significant underestimation of the work required for the preparation of the telemetry database.

Another underestimation of the mission preparation effort, also caused by the lack of previous experience, occurred in the area of the interface with NASA. The activities related to the NASA interface involved operational discussion, participation to meetings and telecons, formal review of NASA documentation, preparation and execution of joint integrated simulations. This work had to be carried out by the flight control team in parallel to the other normal mission preparation activities. This problem became evident and highly dangerous during the mission, when similar activities had to be carried out in preparation of the retrieval mission, while the demanding mission control activities of the science phase had to be conducted in parallel by the same people.

The System Validation Tests for the EURECA mission were also anomalous, in comparison to previous projects. The incomplete status of the spacecraft at the time of the first test slot, combined with the frequent announcements of launch delays due to the unstable situation of the Shuttle programme after the Challenger accident extended the test phase to a period of two and a half years, during which more than ten weeks of actual test time with the spacecraft were utilised by ESOC. Although a large part of this time was spent re-testing spacecraft subsystems and functions which did not properly work the first time, the extended test time available for ESOC (for a typical project four to five weeks of test time are reserved for SVT in the last year before launch) allowed the flight control team to integrate the knowledge of spacecraft design and functionality which could not be satisfactorily built on the documentation. The disadvantage of this approach was that a large amount of unforeseen manpower had to be invested in this phase, reducing the quality of the other mission preparation activities.

The preparation of the science operations phase suffered, as a consequence of the above mentioned problems, from the little time dedicated to the definition of nominal procedures for planning and conduction of the routine activities. The software developed for the mission planning tasks was too rigid and restrictive to cope with changing planning requirements and revised payload control concepts. This did not help reducing the overload of the flight control team in the execution of the daily activities, it even required additional manpower for extending the mission planning software and integrating it into the working environment. Other software tools available to the team also created some problems, due to unfriendly user interfaces or insufficient support functions. The characteristics of the EURECA flight control team also caused an uneven distribution of work among the different team members. This situation evolved as a consequence of the fact that the team was based on a small group of engineers who worked on the mission preparation for many years, until only a few months before launch a number of new engineers was added. The result was that the experienced engineers were overloaded and had little time, in the last critical months before launch and during the mission itself, to gradually pass responsibilities to the new team members. In addition the short duration of the mission, the number of spacecraft failures during the science phase, and the intense activities in preparation of the retrieval, which started only a few months after launch, resulted in never reaching a stable, routine phase of the mission operations, in which procedures and responsibilities could have been effectively consolidated.

The experience of the EURECA mission preparation showed that an earlier team build up is absolutely required for a mission of this level of complexity. A kernel of at least five operations engineers should work on the project, in conjunction with the spacecraft and ground segment developers, for several years before launch. The interface with NASA has to be given more emphasis within and outside the flight control team at ESOC. This implies that the nomination of a Flight Director for a mission involving joint operations with the NASA Shuttle environment should occur at least two years before launch, to allow him to familiarise himself with the mission and to supervise the discussions on operational interfaces. The problems encountered with the database generation and lack of information on the spacecraft design could be solved by allowing a deeper and earlier involvement of the ESOC operations personnel in the spacecraft development and particularly in the related integration and testing activities.

Critical Mission Phases

A detailed description and analysis of the critical deployment and retrieval operations can be found in Ferri *et al.* (1993); this section presents a general overview and the most important experiences.

Twelve hours after launch in the cargo-bay of the Space Shuttle Atlantis on the mission STS-46, the EURECA internal power was initially activated by the Shuttle astronauts via switches located in the crew compartment. The commanding activities started immediately after reception of the first telemetry via the NASCOM network. The spacecraft was lifted by the Shuttle robotic arm out of the cargo-bay, while the spacecraft activation continued, including the deployment of the RF antennae and the solar array wings. After release from the Shuttle, the three-axes stabilised attitude was acquired, and the preparation for the first orbit manoeuvre continued. Due to a number of unforeseen fine-tuning activities in the software tables driving the attitude control subsystem on-board and a problem in the ground control computers the orbit manoeuvre was delayed by four days.

The orbit manoeuvre phases were critical phases of the mission to be handled only via the ESA ground stations. The deployment manoeuvres were executed nominally after the correction of an interface problem between two ground computers, causing wrong software parameters to be uplinked to the spacecraft, which delayed the start of the phase. The retrieval manoeuvres, however, uncovered deficiencies in the design of the attitude and orbit control subsystems. First of all, the non-negligible orbital effects of the attitude control in some control modes using hydrazine was underestimated in the design and caused significant changes and higher risks in the conduction of the entire retrieval campaign. The effect of attitude mode changes had to be measured and taken into account in the orbit manoeuvre strategies, but this with a low confidence since many of the mode changes were executed autonomously by the spacecraft and were to a certain extent unpredictable. The loss of two gyroscopes during the nominal mission left the spacecraft with no redundancy for the final phases, but also uncovered a problem in the attitude control software which had to be worked around via complicated and dangerous operational procedures. Finally a problem in the on-board software in charge of compensating the gyro drift was detected by chance before the start of the first descent orbit manoeuvre. The manoeuvre strategy and procedures had to be changed, and a number of unsuccessful attempts had to be executed before a stable work-around approach was defined and the retrieval orbit was reached.

After three days of approach, the Shuttle orbiter reached the proximity of EURECA, which in the meantime had stopped all orbit manoeuvres. In the last revolution around the Earth ESOC configured the spacecraft for retrieval in the Shuttle bay, slewing in a predefined attitude, retracting solar array and antennae, and deactivating and safing all the hazardous subsystems like the hydrazine reaction control system. The final approach of the Shuttle proceeded nominally and the spacecraft was first captured with the robotic arm, and later stowed into the cargo-bay and deactivated. A problem in the final latching of the RF antennae to the body of the spacecraft forced an EVA (Extra-Vehicular Activity) to manually press the antenna booms while ESOC was commanding the latches. This was successfully executed the next day and EURECA returned safely to Earth at the end of the Shuttle mission, a few days later.

The retrieval phase scenario was simpler than the deployment one, and the decision to execute all the time-critical deactivation operations automatically on-board via a time-tagged sequence of commands removed most of the criticality and in particular the dependence from the ground contact which, due to the communications problems experienced in the deployment phase, was not fully trusted. As an additional back-up, NASA offered to add a number of NASA and RTS ground stations for the duration of the critical retrieval phases. The need for an operational contact with EURECA via the additional station did not materialise, but their presence helped in increasing the confidence in the success of the mission. The criticality of the retrieval operations mainly derived from the degradation of the spacecraft performance, in particular in the area of power and in the number of gyroscopes available for attitude control. Fortunately no additional major failures occurred during the final phase of the mission, and every major subsystem performed nominally.

The nature of the deployment and retrieval phases dictated a typical real-time approach to the operational documentation: detailed timelines were produced for the nominal and main contingency cases, which would merge in time order all the activities of all the parties involved. For the Shuttle proximity phases the three timelines of the Orbiter crew (Flight Plan), of the Houston MCC (Ops Support Timeline) and of ESOC (Flight Ops Plan) had to be synchronised. Details of the activities like commands and monitoring parameters were contained in flight control procedures called by the timelines.

The mission control team at ESOC was established according to the standard approach adopted for other projects, with three main groups of controllers responsible for spacecraft operations, ground segment operations and flight dynamics, under the central authority of the Flight Operations Director. Consultancy on all aspects of spacecraft design and functionality was provided by the project support team, formed by experts of the spacecraft manufacturers and the ESA project team. For both deployment and retrieval phases one of the main critical aspects was the crew safety constraints on the EURECA operations. Due to the very limited visibility of the EURECA status available to the Shuttle crew and to the NASA flight controllers, this was fully delegated to ESOC. When EURECA was in the Shuttle cargo bay or in its proximity the safety status of the spacecraft was continuously monitored at ESOC and reported to the NASA mission controllers. Multiple failure tolerance was implemented in the mission control software to avoid inadvertent uplinking of hazardous commands to the spacecraft at the wrong time. One of the difficult tasks was to continuously derive the safety status of the spacecraft from the available telemetry, which in some cases was not complete and explicit enough for a real-time judgment, in particular in the activation and deactivation phases, when the spacecraft configuration was continuously changing. One of the improvements successfully implemented in the flight control team at ESOC for the retrieval mission was the assignment of a dedicated operations engineer to the safety monitoring, assessment and reporting to the Flight Director.

Concerning the experience gained in the EURECA critical phases it should be stressed that in particular the deployment phase suffered a large number of major anomalies, many of which occurring in parallel, which were kept under control without any impact on the crew safety nor on the mission success, and with only minor delays. From the errors discovered in the on-board attitude control parameters and in the communications between the thermal control and the data handling subsystem important lessons could be learned in the way autonomous functions have to be implemented and operated.
An important experience resulting from the retrieval phase was the preparation and execution of the EVA procedure to latch the antenna booms. The frenetic preparation of a completely new procedure in the night before the EVA became necessary due to a double failure situation, the antenna latching problem and the failure of the power interface via the robotic arm to the EURECA thermal control, which forced the ground controllers to berth the spacecraft with unlatched antennae, to avoid thermal problems. This starting position for the EVA was not foreseen, and the final success of the activity was a major achievement in the overall NASA-ESA cooperation for this mission.

The traditional approach to the critical mission phase operations proved to be successful in this extremely dramatic scenario; the deficiencies in the timely monitoring of safety items was successfully corrected in the retrieval phase by the introduction of a dedicated controller position.

Science Operations Phase

Eighteen days after launch the spacecraft was successfully configured for the science operations phase, including the activation of the freon cooling loop, the micro-gravity measurement system, and the low-thrust attitude control system. In addition each payload instrument was at least activated once and checked out. The ground segment configuration was characterised by an off-line operations scheme and a close interface with the Project Scientist, who coordinated the input of the more than 30 scientists, representing them in the EURECA Weekly Operations Review Meeting at ESOC. The science community could receive telemetry data electronically in their home institutes via an active Data Disposition System; Principal Investigators were able to request changes to the configuration of their instrument via a Telecommand Request interface (via FAX or E-Mail) in response to their evaluation of spacecraft and payload telemetry.

The mission operations scheme applied during the science operations phase consisted of three main tasks: mission planning, real-time pass operations and spacecraft performance monitoring.

The mission planning task was performed daily in order to prepare all inputs required for both the pass operations and the spacecraft performance monitoring. Based mainly on a version of the Mission Baseline Plan updated every two weeks, on decisions taken in the last Weekly Operations Review Meeting, on the most recent Telecommand Requests, and on the potential feedback from the monitoring task, a file was prepared which contained the commands to be uplinked to the on-board Master Schedule during the next ground contact periods. In addition, detailed instructions for non-standard operations to be carried out by the spacecraft controllers during the next ground station passes were prepared on paper.

Spacecraft Controllers were in charge of preparing and conducting the pass operations. Flight Control Procedures (FCP) detailed the required standard activities such as uplink of telecommands, Master Schedule, monitoring of telemetry, dump of on-board memory and transfer of dumped data from the ground station to the control centre. A short list of basic health checks were part of the standard activities to be performed in every pass. The results of these, together with the alarms raised automatically by the control software in case of out-of-limit conditions in the telemetry, were used to detect severe anomalies of the spacecraft in real-time. Only in very few cases, requiring easy and well defined recovery actions, on-line Contingency Recovery Procedures could be used during the short passes. For all other anomalies, off-line recovery strategies were applied, either by an on-call system engineering support or as part of the performance monitoring task.

Spacecraft Performance Monitoring normally started when all the telemetry generated during the day, downlinked from the spacecraft and temporarily stored in the ground stations, was received and pre-processed at ESOC, and all the post-pass activities were completed. Based on the results of telemetry and telecommand verification checks, automatically performed by the control system, findings during the manual screening of report and exception messages and results from the special checks eventually indicated in the instructions from the mission planner, the overall spacecraft performance could be assessed, and in particular the successful execution of operations verified. If recovery actions were required, these were turned into internal Telecommand Requests and handed over to the engineer in charge of the next planning session. Once per week the activities were reported to and discussed in the Weekly Operations Review Meeting.

The sequence of the science operations was mainly driven by the limited availability of electric power and external events or constraints. Long term experiments, in particular those which could not be interrupted without endangering their mission product were given precedence in planning. Further resources to be considered during planning were the on-board storage capacity, the amount of application programs allowed to be run in parallel and the available cooling capability.

The science operations could be implemented to a large extent according to the schedule laid down in the baseline plan prepared pre-mission. All science objectives, with few exceptions when severe equipment failures were encountered, could be fulfilled in the first 5 and a half months of the science mission phase. After this time the freon cooling system had to be deactivated, due to power shortages caused by the degradation of the solar panels, excluding operations of actively cooled payloads from that time onwards. However, the rest of the payload could continue operating, resulting in an over-performance of up to 175% w.r.t. the planned science program.

Highlights of the payload operations (for details see Innocenti and Mesland, 1993) were, among others, the first use of an inter-orbit communications link via Olympus satellite for operational purposes (uplink of Master Schedule, Nov. 24, 1993), the direct transmission of payload telemetry to home institutes (Oct.15, 1993), the parallel operations of solar science instruments with their 'sister instruments' on the ATLAS-2 mission flown on a Space Shuttle, the successful EURECA depointing to support additional WATCH observations of different areas of the X-ray sky.

Most of the payload instruments experienced anomalies during the mission. The most severe cases encountered were the loss of the Radiofrequency Ion Thruster Assembly (RITA) quite early in the mission, the problems of the primary cooling system in the Protein Crystallisation Facility, and the Timeband Capture Cell Experiment foil movement failure. Other payload instruments showed relatively minor problems, often in the area of the communication functions with the data handling subsystem, which could be worked-around operationally and did not seriously reduce their science return.

The functionality and the Man-Machine Interface of several tools in the working environment of the operations team were not appropriate to the tasks they were used for. This had to be overcome by many additional manual steps, which were very time consuming and error-prone (e.g. long sequences of commands with many parameters had to be typed in by hand because no interface existed between the computer which received the data electronically as part of Telecommand Requests and the control system computer). Many of these shortcomings arose because functions had to be dropped during the implementation stage due to time or budget limitations.

During its eleven months in orbit EURECA experienced a relatively high number of on-board anomalies, which had to be recovered from ground or counteracted by operational work-around solutions. Development, testing and execution of work-around solutions put a significant additional workload on the operations team. In particular in the beginning of the mission, when frequent communications outages between payload or subsystems and the data handling subsystem had to be recovered manually from ground, the pass-operations were seriously affected. Very often the scheduled pass activities, in particular dumping of telemetry from the on-board storage, had to be delayed or spread over several passes.

For the spacecraft performance monitoring the on-board communications problems caused further difficulties because the observability of the spacecraft temperatures was lost completely until recovery, i.e. either corrupted or old data were downlinked during this time. This data had to be manually filtered out if used for further analysis until a specific filter program was developed. A new on-board software was developed in the first weeks of the mission to recover autonomously from the above problems (Domesle *et al.*, 1994) This reduced the observability outages and simplified the pass operations significantly. Unfortunately the new software could not completely solve the problem due to other software design limitations on-board, therefore recovery was still left to the ground about once very fortnight.

progressive and unpredictable degradation of olar array performance forced the flight l team to take additional power margin into t in science operations planning. nore a special passive retrieval scenario developed, in case the power loss would to support the retrieval as planned. the initial tendency of the solar array did not continue and no mission ad to be sacrificed, nor had an recovery scenario to be applied. However, the impact of this degradation on science operations was limited only due to the fact that a high power consumer instrument, RITA, failed after one month operation, releasing a large amount of power to the rest of the payload.

For many of the anomalies encountered work-around solutions could be found. This process however did not only require to reconfigure on-board items or to uplink new on-board software, but also to update operational documentation like in the User Manual and the FOP. In some cases new software had to be written for special evaluation purposes. Before a decision on a work-around solution could be taken, potential side-effects had to be excluded. This was extremely difficult in those areas where little on-board changes could develop large effects (e.g. in the area of Attitude Control Subsystem fault management software), or complex dependencies between real-time procedures (e.g. power degradation fault management) were not sufficiently documented. In some cases work-around solutions could not be applied since a final assessment of the side effects could not be made with the available simulation tools on ground. In other cases it was found out later that side-effects had been overlooked.

Summarising the experiences from this phase it must be said that the operations concept used for this mission phase was in general well suited to the mission characteristics. Its inherent flexibility allowed to implement the planned mission operations, to isolate and recover almost all observed anomalies and to define all required work-around solutions without introducing significant delays to the mission progress. Critical operations, like On-Board Software Maintenance activities, could be integrated in this approach as well. Weak points have been identified in the functions and the man-machine interface of the tools in the operations environment, which could be improved without major efforts. Problems encountered on the spacecraft seem to imply the need for more robust and flexible functionalities, on-board and on-ground, in order to cope with unforeseen anomalies and to support the implementation of work-around solutions. As a multiple work-around solutions situation becomes extremely difficult to manage, an increased effort should be spent during spacecraft development and test.

Lessons Learned

EURECA provided an excellent opportunity to build up a unique operational expertise in Europe in the following areas: manned spaceflight, including commanding and crew safety responsibilities; rendezvous activities; joint operations with NASA involving Shuttle, data-relay satellites, and complex ground segments; multidisciplinary science missions in low Earth orbit; advanced autonomous space-segments.
In running this mission a wide range of experiences was gained by using the spacecraft and the ground segment and by applying the described operations approach. The main lessons learned in the different areas are summarised in the following.

Spacecraft. Design, development and testing should aim to produce highly robust, flexible, and reliable components in order to avoid failures and malfunctions on one hand and to minimise the impact of unforseen anomalies on other components. Critical areas in this respect seem to be the on-board communication and autonomous functions, which caused most of the severe anomalies in the mission with often dangerous side-effects. Completeness, stability, and early availability of a Spacecraft User Manual is very important to avoid overload situations for the flight control team during the final phase of the mission preparation.

Ground Segment. Flexible tools and man-machine-interfaces, well adapted to the often variable needs of mission control, play a very important role in the ability and capability to implement operational work-around solutions. particularly sensitive in this aspect are mission planning tools. For missions of the complexity of EURECA the flight control team should be built up several years before launch, to cope with the workload required for inter-agencies cooperation, database work, FOP preparation and verification activities.

Operations Concept. After extending the flight control team structure for critical phases by a dedicated safety engineer position, the operations scheme used in this missions was well suited to the mission. All encountered anomalies, even those occurring in parallel, could be successfully handled without delaying the mission progress.

3. CONCLUSIONS

The success of the EURECA A1 mission is the proved that the basic operations concept, the ground and space segment design were adequate. Several shortcomings in the system could be identified before and during the mission for which relatively simple solutions can be implemented for a future flight. Since the satellite needs only a relatively small funding in order to be prepared for another flight (about 67.6 MAU for all industrial costs, including launch support), and there are still EURECA slots allocated on NASA's shuttle manifest, a unique opportunity exists to repeat the success of the EURECA A1 mission on a second flight in the near future.

4. REFERENCES

Domesle, R., H.Hübner and J.Leclerc (1994). On-board Software Maintenance Activities During The EURECA A1 Mission. *EURECA Technical Report, ESA WPP-69.* European Space Agency, Paris.

Ferri, P. and S.Kellock (1992). A User View of the EURECA Ground Segment. *Proc. of the 2nd SpaceOps Symposium.* Pasadena (CA).

Ferri, P., H.Hübner, S.Kellock and W.Wimmer (1993). The Joint ESA-NASA Operations for EURECA Deployment and Retrieval. *ESA Bulletin,* **76**, 81-90.

Ferri, P. and W.Wimmer (1994). The Experience with the EURECA On-Board Autonomous Fault Management Functions., *Proc. of the IFAC Symp. on Automatic Control in Aerospace.* Palo Alto (CA).

Hübner, H and W.Wimmer (1994). Experience with EURECA's On-Board Autonom' from an Operations Point of View. *To l published*

Innocenti, L. and D.Mesland (1994). EURF Scientific Results: An Overview. *EU' Technical Report, ESA WF* European Space Agency, Paris.

Van Casteren, J. and P.Ferri (1989). F Flight Operations, *ESA Bulletin,*

Wimmer, W. and P.Ferri (1994). Mission Summary. *EUREC Report, ESA WPP-69.* Eur Agency, Paris.