BR-130

The European Astronauts Centre (EAC)

Past and Present Achievements

European Space Agency
Agence spatiale européenne

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January 1998

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Cologne, Germany

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Published by: *ESA Publications Division*
ESTEC, Noordwijk, The Netherlands

Edited by: *B. Kaldeich-Schürmann*

Price: *15 Dutch Guilders*

ISBN: *92-9092-460-8*

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FOREWORD

On 28 June 1989. ESA's Council adopted the Resolution on the European Astronauts Policy, which stipulates the setting up of a single European astronauts corps for ESA activities and programmes.

The ultimate goal of this unified approach is to use all European resources as efficiently as possible, by developing criteria and procedures for the selection, recruitment, training and flight assignment of European astronauts.

In order to implement this policy, the European Astronauts Centre (EAC) was established in May 1990, near Cologne - the second ESA establishment on German soil.

The EAC was given the following main tasks:

- recruitment, assignment and training of ESA astronauts
- ensuring medical support and surveillance
- safeguarding crew safety
- supporting astronauts and their families during preparation for and during flight
- interfacing with other astronaut offices and training organisations worldwide
- management of related agreements
- supporting development programmes and PR activities.

As a result of ESA's internal reorganisation in 1994, all manned space activities are grouped under one directorate, and EAC activities have become an integral part of the Directorate of Manned Spaceflight and Microgravity.

In 1992, a first group of astronauts was recruited. Most of them have now participated in space missions or have served in back-up capacities. Involvement of EAC staff in national missions has also contributed to the experience gained in crew operations.

This publication highlights some results and illustrates how the EAC is preparing to support future Space Station activities.

J. Feustel-Büechl
Director of Manned Spaceflight and Microgravity

INTRODUCTION

In order to prepare for manned missions in the framework of Space Station operations, it is of paramount importance that not only ESA's astronauts are ready to support these activities, but also that ground staff acquire the necessary experience and know-how.

In the absence of its own manned space transportation means, ESA involves its astronauts and their supporting staff as much as possible in missions onboard the US Space Shuttle or Russia's Mir space station. Close interaction with national missions also guarantees an increasing build-up of know-how.

This brochure brings together a number of previous publications which, in a sequential form, give an overview of these activities.

The first article describes the selection process of the new astronaut group in May 1992. The following two articles describe, in more detail, the basic training and an example of mission-related training, respectively.

The major role of an astronaut centre, however, is to support its astronauts during missions. As an example, support was given to the Euromir 95 mission. How this support was perceived by the astronaut himself is the subject of the next article.

Recent developments are giving us the opportunity to look into future tools, including computer-based training and, closely related to this, onboard training tools. The last article describes how the EAC is preparing itself for this new era.

H. Oser
Head of the European Astronaut Centre

A New Generation of Astronauts in Space – The Astronaut Selection Process

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ESA's Council approved the setting-up of a single European Astronauts Corps in June 1989 and as a result the Agency initiated a selection campaign for European Candidate Astronauts. Considerable experience has been gained in the process of this campaign and many lessons have been learnt which will be of great value for future similar selection exercises.

Introduction

The European Astronauts Selection Board (EASB) met for the first time in June 1989. Its main responsibilities and tasks, as laid down in its Terms of Reference, are to advise the ESA Director General on all matters concerning astronaut selection. The EASB supervised the overall planning and procedures for the present selection and recruitment of astronauts, initiating the Announcement of Opportunity, recommending the selection criteria for the Director General's approval, and finally proposing a list of suitable European Candidate Astronaut applicants to him.

An Evaluation and Interviewing Committee (EVINCO) was then set up by the EASB to conduct and assess the professional interviews. The European Astronaut Medical and Psychological Advisory Group (EAMPAG) was to advise ESA on medical and psychological matters related to the selection process. This group is made up of thirteen specialists in medicine and psychology, appointed by the Member-State Delegations.

EVINCO also appointed three working groups – medical, psychological and 'professional' – to develop the selection criteria. The latter were then reviewed, together with the Announcement of Opportunity, by the Ariane and Columbus Programme Boards, and approved by ESA's Director General.

The pre-selection process

The selection process started officially on 1 June 1990 with a letter being sent by ESA's Director General, inviting each of the 13 Member States and Canada to initiate a pre-selection campaign. In the Announcement of Opportunity, ESA strongly recommended to the Member States that they should use the ESA selection criteria (Table 1).

Although ESA was not itself participating in the pre-selection process, EAC was on call to assist the Member States during this phase. Typical requests for assistance involved detailed interpretation of the ESA selection criteria and provision of information on the availability of special medical facilities, such as the centrifuge or the lower-body negative-pressure device, required to perform the space-specific medical tests.

5494 valid applications were received by the 13 Member States (Canada did not participate in this selection process), reflecting the strong interest on the part of young Europeans in ESA's manned space programmes. 12% of these European Candidate Astronaut applicants were women. 23% were pilots, and the remaining 77% were scientists, medical doctors or engineers.

By 30 April 1991, this number had been distilled to the sixty applicants who were presented to ESA. They included five applicants each from Austria, Belgium, France, Germany, Italy, The Netherlands, Norway, Spain, Sweden and Switzerland, four from Ireland and three each from Denmark and the United Kingdom. Shortly thereafter, one of the UK applicants withdrew and so the final number entering the ESA selection process was fifty-nine.

A questionnaire was sent to each Delegation for two purposes: to collect basic statistics on the pre-selection and to gather comments and recommendations in order to improve future selection procedures.

The ESA selection process

The first part of the ESA selection process was divided into two phases:

- A first phase, from 5 June to 20 July, dedicated to psychological assessment and professional evaluation of the applicants. They were called, in three groups, for the psychological tests at DLR in Hamburg (D) and for the professional/psychological interviews at EAC in Cologne.
- A second phase, in September and early October 1991, dedicated to general and to space-specific medical evaluations.

The general medical evaluation was performed by:

- DAMEC, Copenhagen (DK), for the candidates from Denmark, Ireland, Norway, Sweden and the United Kingdom
- DLR, Cologne (D), for the candidates from Austria, Belgium, Germany and The Netherlands
- MEDES, Toulouse, for the candidates from France, Italy, Spain and Switzerland, using the CNEMPN facilities in Paris

This geographical split allowed a good balance to be struck in terms of the number of applicants processed at each location, containment of travel costs, and good harmonisation of results.

For the space-specific medical evaluation, all applicants visited DLR in Cologne. The tests performed there included: centrifuge, lower-body negative-pressure and vestibular system investigations, and altitudechamber exposure. The benefits of the centralised solution in this case included well-established investigation protocols, integrated medical support, and proximity to EAC.

Table 1. Summary of selection criteria

General requirements

Applicants may be male or female. They must be nationals of an ESA Member State or of an ESA Associate State involved in an ESA manned space programme. For the present selection, the preferred age range is 27 to 37. Applicants must be between 153 to 190 cm tall. They should speak and read English. Applicants must possess a University Degree (or equivalent) in the Natural Sciences, Engineering, or Medicine, and preferably have at least three years post-graduate related professional experience (for Laboratory Specialist), or possess a test-, military- or commercial-pilot's licence and have at least three years of professional experience (for Spaceplane Specialist).

Medical requirements

Compliance with medical criteria is mandatory. Applicants should have a satisfactory medical history and be in a sound state of health, have a normal weight, and be of normal psychiatric disposition. A severe history of motion- or air-sickness may result in disqualification.

Abnormally high dosages of any medication may be considered a disqualifying factor.

Applicants must be prepared to provide a full family and personal history and permit the collection of further information if deemed necessary by the examining medical body. They must also be prepared to participate in extensive medical screening, including internal examinations. In addition, certain tests will be performed to evaluate the applicant's bodily system (muscular, cardiovascular and vestibular). These tests will employ such facilties as: centrifuges, rotating chairs, pressure chambers, and aircraft. All information provided will be treated as confidential.

Psychological requirements

The objective of the psychological tests is to ensure that the Candidate Astronaut will be able to cope with the expected occupational demands (which they may not have faced previously in their careers) in an efficient and reliable manner. Their activities, during the extensive training phase and during spaceflight, will have to be conducted under a certain degree of stress and in co-operation with other crew members (male and female).

General characteristics expected of the applicant include good reasoning capability and memory, good concentration, and good aptitude for spatial orientation and manual dexterity. The applicant's personality should be characterised by high motivation, good flexibility, gregariousness, empathy with fellow workers, low level of or disposition towards aggressiveness, and sound emotional stability.

Professional requirements

The applicant's scientific and technical background and ability will be scrutinised by the ESA Evaluation and Interview Committee. The Candidate Astronaut must be well versed in the scientific disciplines and have demonstrated superior capability in applicable fields, preferably including operational skills.

In the second part of the ESA selection process, the EASB drew up a list of twenty-five applicants for the final interviews, which took place in February and April 1992.

The evaluation

The professional evaluation provided the means for ranking all fifty-nine applicants based on the Interview Evaluation Form by scoring the ESA Professional Criteria, applying the weightings according to applicant category (Laboratory or Spaceplane Specialist), and taking into account the expert advice. The psychological assessment provided additional input for assessing an applicant's suitability.

The mandatory compliance with the ESA medical criteria, assessed during the medical evaluation, reduced the original list of fifty-nine applicants to thirty-two: twenty-seven men and five women.

EVINCO was responsible for the final evaluation, integrating the results from the individual evaluations – professional interviews, psychological interviews and tests, and medical tests – and this was completed on 15 November 1991.

From the list of thirty-two applicants meeting the ESA medical criteria, the EASB pre-selected twenty-five for the final interview. Aspects taken into consideration here included professional suitability and trainability, age and career prognosis, and a fair distribution among Member-State nationals.

The results

The end result of this whole process has been the selection of six European Candidate Astronauts, five of whom are currently having an introductory two months of training at EAC. In August, two of them will be joining the First International Cadre of Astronauts for the International Space Station 'Freedom' and will subsequently undergo the requisite Mission Specialist training for Shuttle missions at Johnson Space Center (JSC) in Houston. The other four Candidate Astronauts will follow one year of classical basic training at EAC in 1993. Thereafter, they will be assigned to future missions such as the Columbus Precursor Flights or possible European MIR missions.

The ESA selection campaign has resulted in a 'European Procedure' for selecting Candidate Astronauts. This procedure has turned out to be thorough but somewhat protracted for several reasons, the two most important being that it represents a first attempt to create a European approach, and the complex nature of the environment in which ESA has to operate. ESA had run an earlier selection process in 1977 for the Spacelab Payload Specialists, but that selection was for a unique purpose and was based on NASA selection criteria. At that time ESA had no intention of repeating the procedure on a regular basis. With some improvements here and there, the newly established procedure should be valid for many years to come.

Another important aspect to be considered is that the new selection was not for Payload Specialists only, but for candidates aspiring to be career astronauts. In other words, the previous selection process concentrated on the candidate's scientific background, while the new procedure is much broader since it must take into account scientific, piloting and operations skills. A further complicating factor is that the selection criteria must be acceptable for manned US and CIS space missions, as well as European. The result is a very stringent set of requirements, especially in terms of anthropometric parameters.

As noted earlier, the European Astronauts Policy respects the wish of the Member States to participate in the selection process by performing a pre-selection in each country. Each Member State was free to conduct its pre-selection in accordance with its own criteria, although the Announcement of Opportunity strongly recommended use of the 'ESA Criteria'. In the event, this pre-selection process took one year (June 1990 to May 1991). Four countries – Austria, France, Germany and the UK – decided not to conduct a special pre-selection exercise, but rather to put forward candidates who had been identified in previous national selection processes.

Table 2 shows some statistics compiled from the responses by the Member States to a questionnaire. The first striking fact is the number of young European professionals interested in space research, with some 23 000 applications being received. This figure includes the Austrian selection in 1988, the German selection in 1986, the selections in France in 1985 and 1990 (not the one in 1980), and the 1989 UK selection. Even the 5494 valid applications after the firt screening is large as compared with the total of 2054 received by NASA for its last selection of 19 astronaut candidates. The distribution between male and female applicants varies

Table 2. Best estimates of applicant preselection

Member State	A	B	CH	D	DK	E	F	F	I	IRL	N	NL	S	UK	
Preselection in	1988			1986			84/85	89/90						1989	Total
Number of Applicants	230	526	447	3800	250	700	1100	297	406	700	180	400	600	13000	22636
Applicable Files	220	323	117	1799	90	658	715	157	330	352	49	240	294	150	5494
Females	20	27	5	350	7	76	79	4	35	56	10		17		686
Pilots	1	65	29	13	40	124	570	157	106	46			107		1258
Remaining after															
Eval. of Prof.+ Med. Files	110	101	39	321	12	150	161	110	242	250	49	90	22	35	1692
Final Interviews	5	7	9	13	3	10	15	18	10	4	5	5	8	4	116
Remaining Applicants	5	7	5	13	3	10	20		10	4	5	5	8	11	106
Females	2	1	0	6	1	0	1		0	1	1	1	1	1	16
Pilots	0	2	1	2	2	4	14		5	2	1	1	3	1	38
Proposed Applicants	5	5	5	5	3	5	5		5	4	5	5	5	3	60
Females	2	1	0	0	1	0	1		0	1	1	1	1	1	10
Pilots	0	1	1	2	2	1	3		1	2	1	1	1	1	17

from country to country, with Swiss females accounting for 4%, and German females 19% (between 10 and 15% in the USA). On average, however, the figure is around 13%.

Table 3 shows the breakdown of the 60 applicants by profession.

Table 3. National applicants grouped by discipline

Country	Pilots	Engin	Phys.	Info/El	Med/Bio	Others	M/F
Austria	0	1	1	2	1	0	3/2
Belgium	1	2	1	0	1	0	4/1
Denmark	2	1	0	0	0	0	2/1
France	3	1	0	0	1	0	4/1
Germany	2	0	2	0	0	1	5/0
Ireland	2	0	0	0	2	0	3/1
Italy	1	2	0	0	2	0	5/0
Netherlands	1	0	2	0	2	0	4/1
Norway	1	1	1	0	2	0	4/1
Spain	2	2	0	0	1	0	5/0
Sweden	1	1	1	2	0	0	4/1
Switzerland	1	1	3	0	0	0	5/0
United Kingdom	1	0	0	0	0	1	1/1
Total	18	12	11	4	12	2	

Total number of applicants, 59 (49 male & 10 female)

Lessons learnt and possible future improvements

In the questionnaire circulated to the Member States, the last two questions were:

- What experience gained during the pre-selection process could be applied in future astronaut selection processes?
- What further suggestions do you have?

The number and variety of responses do not permit a full analysis here, but we can highlight some conclusions drawn from the most relevant ones for future ESA selection procedures, under the three classical headings of medical, psychological and professional:

Medical

There is a general feeling that the anthropometric parameters (mainly imposed for the Hermes seating/environment) are currently too stringent, as they have excluded some professionally good candidates.

Ophthalmology has also been considered very severely by Member States, some of whom have suggested including visual-acuity questions in the medical questionnaire to save time during the pre-selection process.

An important recommendation is that medical tests requiring ionising radiation and/or invasive procedures should not be repeated during the ESA selection if they have already been performed during the Member State's pre-selection processing. To save time and avoid unnecessary tests for candidates, it is suggested also that the selection process start with the most demanding test, namely the 'Coriolis stress test'. Other Member States have suggested starting with an initial medical test such as that for a private pilot's licence.

Psychological

Some Member States have suggested that the standard tests used for the ESA selection process should be made available for their pre-selection process, with the individual countries free to decide on whether or not to use them.

Special psychological tests were used by some Member States which proved to be very effective. As some psychological tests are on the boundaries of psychiatry, it is also recommended that psychiatrists and pschologists be included on the same board.

Professional

In most non-English-mother-tongue countries, the applicant's command of English was tested, but these tests were not highly discriminatory. Some Member States have suggested a clear distribution in the type of candidates sought, in terms of, for example, educational background, experience and, if possible, distribution foreseen in the European Astronaut Corps.

It is strongly suggested that experienced astronauts be included in the selection boards.

Some of the suggestions and recommendations were of a general nature, such as that more time be allowed for the pre-selection and if at all possible the tests should be of a 'go/no go' nature, in order to avoid further questions. A clear distinction between mandatory and optional tests for the pre-selection process was also suggested.

In the original Announcement of Opportunity, the Agency strongly recommended use of the ESA Selection Criteria for the pre-selection process, although each Member State was free to use its own procedures and criteria. The non-adherence to the ESA Criteria by a number of Member States, some of whom made no pre-selection at all, is probably one of the prime reasons for the high percentage of medical rejections (46%) among the fifty-nine 'pre-selected' applicants, reported by the EAMPAG to EVINCO.

The present selection process (preparation, pre-selection by Member States and ESA selection) has also proved too time-consuming, taking in the order of three years from start to finish. By comparison, NASDA's and NASA's last astronaut selection processes each took about eight months.

For future selections, the preparatory process will not be required or can be reduced to a minimum, ie. a few weeks instead of a year, but even two years is a long time to ask applicants to wait for an answer. Improvements to reduce the combined period of pre-selection and selection could focus on combined or overlapping medical pre-selection and selection, with possibly just one psychological assessment and two professional interviews (one national and one by ESA). Success in this respect would depend on greater overall transparency and better coordination in the selection process between the Member States and ESA, as some overlapping of activities would be required. Ideally, the combined pre-selection and selection process should not take longer than one year.

Conclusion

With the selection of six European Candidate Astronauts, the Agency has given credance to the dreams of thousands of young Europeans who are interested in participating in manned space flight. In a joint Europe-wide endeavour, groups of professionals in medicine, psychology, engineering, space sciences and other disciplines have striven to compile a considered set of criteria, tests and questionnaires based upon many years of professional experience, in order to ensure the selection of the best European Candidate Astronauts.

It is now the European Astronauts Centre's responsibility to prepare and train the six European Candidate Astronauts who have been selected for their future careers, working together with the space scientists and engineers to maximise the return from the European space research and development and operations activities of tomorrow.

The Training of the New Astronaut Candidates at EAC

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Introduction

The European Astronauts Centre (EAC), ESA's youngest establishment and the home base for all ESA astronauts, is responsible for all European astronaut matters, and in particular for the selection, medical surveillance and support of astronauts and for their training. EAC has been created in order to develop a centre of expertise for the Agency's manned space activities for the 21st Century.

The first training activities to be undertaken at the European Astronauts Centre have recently been completed, with five new European astronaut candidates receiving an intensive introduction to ESA, the European space programmes, and basic space science and technology. The instructors for these first courses, given in June and July, were a mixture of key ESA personnel and recognised experts from universities and scientific institutes prominent in the space field, as well as experienced astronauts.

Since the Astronauts Centre's foundation in 1990, activities at EAC have focussed initially on the selection of new astronaut candidates and on the development of a training programme to support ESA's manned space activities. The first astronaut selection cycle was completed in May of this year with the choice of six candidate astronauts. Other noteworthy EAC activities in 1992 have been the supporting of the missions by the ESA astronauts Ulf Merbold (IML-1) and Claude Nicollier (Eureca), and by the Belgian astronaut Dirk Frimout (Atlas-1).

We report here on both the Introductory Training that has recently been conducted and on the Basic Training programme that is in preparation for 1993, which together represent the first steps within the overall European astronaut training programme. The complementary training of the European astronaut candidates by NASA and the plans to cooperate with the CIS's Star City activities are also addressed.

First training successfully completed

Four astronaut candidates took up duty and began training at EAC on 1 June this year. Another candidate joined the course later in June, and the sixth is still completing his test-pilot training at the Empire Test Pilot School in the United Kingdom (Fig. 1). Two of the candidates were subsequently enrolled for NASA Mission Specialist training, which started at the beginning of August.

The primary objective of the initial 'Introductory Training' was therefore to provide those candidates who were assigned for NASA training with a solid introduction to ESA, its programmes and other European and cooperative space programmes in order to help them to identify themselves with ESA and to act as its representatives (Table 1). It also provides the candidates with an introduction to, and helps them to integrate into, EAC as the base that will provide them with the requisite support throughout their professional careers as astronauts.

The classroom training includes basic instruction in space technology and operations, an overview of the Agency's major programmes, the history of unmanned and manned space activities, space law and organisational aspects of the Agency. The practical training includes primarily physical training (Fig. 2) at a fitness centre under the guidance and supervision of experienced instructors, who also lecture on the human-physiology aspects of training and the basics of sports medicine.

To prepare the astronaut candidates for their role as prominent ESA representatives in the public eye, a course in media skills is provided by a specialist company. This course is supplemented with a briefing on the Agency's public-relations policy.

Visits to the Spacelab Simulator and the

Microgravity User Support Centre in Cologne complement the theoretical tuition, while visits to the other ESA Establishments give a first impression of the wide variety and scope of ESA's scientific, technological and operational activities.

The team of instructors is made up of staff from the respective programme directorates and administrative services of the Agency, experts from universities and scientific institutes, experienced ESA and national astronauts, contractors and EAC staff. They are able to provide not only first-hand knowledge and expertise in the specific spheres of interest, but also the opportunity for the astronaut candidates to meet and get acquainted with key persons from both ESA and other space organisations. The lectures by experienced astronauts have been particularly appreciated by the candidates, and the ensuing discussions often extend far beyond the formal training time.

A total of 144 h of formal training have been provided by 39 instructors (6 EAC, 19 other ESA and 14 external instructors). Work books have been produced for each lecture on the basis of inputs by the instructors, with the condensed content of each lecture, the presentation handouts, references, a glossary, and recommendations for further reading. The EAC documentation system and the EAC library provide access to additional literature.

As this Introductory Training was the first training conducted by EAC, particular emphasis has been given to strong feedback via questionnaires for instructors and trainees, through the weekly training meeting and informal discussions, and via the final reports. This feedback will provide important input for the further development of the Centre's training activities.

The European training concept

The Introductory Training was the first step in the implementation of the European astronaut training programme that has been under development by EAC since 1990 in support of the Agency's manned space activities, primarily the Columbus and Hermes Programmes, but also the Columbus Precursor Flights (Spacelab; Eureca launch and retrieval).

The programme baselines of Columbus and Hermes contained several types of missions, including combined missions involving both programmes. The interface to NASA and to other partners had to be taken into account

**Figure 1. The European Astronaut Candidates at EAC. From left to right:
Christer Fuglesang (Sweden)
Pedro Duque (Spain)
Marianne Merchez (Belgium)
Maurizio Cheli (Italy)
Jean-François Clervoy (France).**

Thomas Reiter (Germany) will join EAC in December

Table 1. Introductory Training

Content	Hours
Introduction to EAC	10
ESA administration, staff rules, legal aspects	6
Goals of space activities, science and application activities	5
History of space activities, current space programmes worldwide	11
European space programmes	18
ESA's role, European space industry	6
Visits to ESTEC, ESOC and ESRIN	15
Orbital environment	2
Life sciences	5
Materials science	7
Remote-sensing principles and technology	10
Physical training, sports medicine	14
Computer skills, office automation	10
Public-relations briefing, media skills	10
Spacelab systems and operations	4
US professional and social environment	11
Total	144

for the Columbus Attached Laboratory mission and the Precursor Flights. A modular training programme was therefore chosen as the appropriate response to these requirements. This modular concept will also make it easier to meet new requirements resulting from the continuing evolution in the Agency's manned programmes.

The training concept development effort did not start from zero two years ago in that a number of studies had already been conducted in the context of the Columbus and Hermes Programmes and by national agencies. As the definition of the on-board tasks to be conducted by future European astronauts was still in its infancy at the time of these earlier studies, they had to be founded largely on assumptions based on the cooperative missions already undertaken with the United States. In particular, the training experience gained through the Spacelab missions constituted an important input.

All of these inputs had therefore to be consolidated into a formal training programme, subject to review by an international group of experts, including experienced astronauts from Europe, the USA and the CIS. It represents the present astronaut training baseline for the Agency, and it will be continuously updated in the context of changing mission scenarios, more mature definition of on-board tasks, and on the basis of the feedback from its implementation and the evaluation of mission performance.

The overall training programme is composed of three phases (Fig. 3):

- *Basic Training* is the first training phase after recruitment and is designed to give candidates the fundamental notions and skills required for their careers as professional astronauts. It starts with a general introduction to the European Space Agency, its programmes and other European and worldwide space activities. It brings the candidates to an appropriate level of knowledge in basic scientific disciplines and in space technology and operations. In addition, it develops the practical skills needed for flying (pilot qualifications), maintaining one's physical fitness, and making public appearances. Basic Training is effectively regarded as a probationary period, satisfactory conclusion of which after one year leads to certification as a European Astronaut.

Figure 2. Physical-fitness training

- *Specialised Training* is the next step, which provides deeper knowledge of specific space systems, such as the Columbus Attached Laboratory, its subsystems and payloads. It is not geared, however, to a specific mission or its operational procedures, but is more directed towards providing an in-depth knowledge of basic space systems and payload operations. Practical skills in such areas as laboratory work will be further developed in this phase, as well as

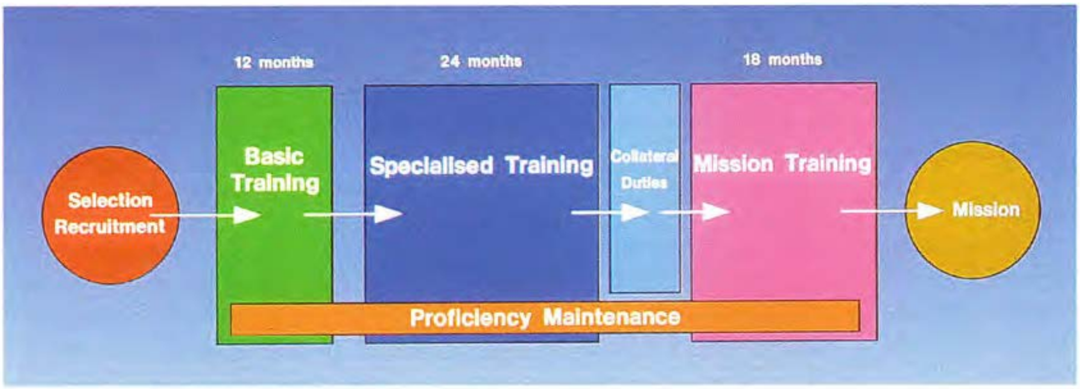

Figure 3. Training programme sequencing

greater proficiency in such disciplines as flying and diving. Specialised Training can be conducted either for a class, or for small groups, as necessary.

The Specialised Training for Space Station 'Freedom' activities will be carried out for an international class which includes US, Canadian, Japanese and European astronauts. This class will be trained at the training facilities of all of the partners, i.e. in Europe for Attached Laboratory systems and European payloads, etc. After two years of successful Specialised Training, astronauts will be eligible for selection for a specific mission, to Space Station 'Freedom' for example.

- *Mission Training* will commence following the selection of the crew for a specific mission. The period between the completion of Specialised Training and mission assignment will be used for associated duties, such as participation in payload development, procedures validation, and ground operations.

  The Mission Training will be undertaken by the crew as a whole. Flight-procedures training will be conducted on simulators that will be highly representative of the flight hardware. Emphasis will be placed on appropriate coordination and interaction between the onboard and ground crews. Important mission sequences will be rehearsed by the crew via 'integrated simulations' using a representative simulator of the full space element linked to the appropriate Control Centres.

  The Mission Training phase will last 18 months. For the Space Station 'Freedom' Programme it will be partly conducted in Europe also, primarily in the context of European payload training.

The first Basic Training course

The first full Basic Training course at EAC will be conducted in 1993. It will consist of the four blocks of activities shown in Table 2, involving a total of around 1000 h of formal training. The 'Introduction' block will complement and reinforce the Introductory Training that the astronaut candidates have already received.

The 'Integration & Refresher' training block covers fundamentals in science and engineering from mathematics and chemistry, through biology and medicine, to astrophysics, electrical and aerospace engineering. The primary objective here will be to bring all of the candidates to a similar level of knowledge, as a prerequisite for the other courses that will follow. This block of about 140 h will therefore be tailored to the specific educational backgrounds of the trainees.

The 'Instruction' training block goes straight into space technology and covers space systems and operations (200 h) and science disciplines (200 h) like life sciences, materials science, fluid science, space science and Earth observation.

The 'Astronauts Capabilities Training' block (320 h) covers a variety of theoretical and practical abilities likely to be needed by the professional astronauts during their careers, including medical and survival training. The medical/psychological training will include the basics of human physiology and medicine, space physiology, group coordination and stress management. Formal physical training will need to be complemented by sports activities outside duty hours. Parabolic flights will provide familiarisation with a microgravity environment, and survival and rescue training will equip candidates to cope with demanding in-orbit situations and to develop team spirit.

Table 2. Basic Training overview

Block	Tasks
Introduction	Introduction to Space Activities
Integration & Refresher	Fundamentals of Sciences and Engineering
Instruction	Space Systems Space Operations and Procedures Life Sciences Material and Fluid Sciences Earth Observation and Space Science
Astronauts Capabilities Training	Medical and Psychological Training Physical Training Flight Training Scuba Diving Space Adaptation Training Behaviour under Extraordinary Conditions Laboratory Skills Training Computer Training Language Workshop Media Skills Training

Figure 4. New EAC accommodation: the Crew Training Complex

The hours currrently allocated to the various training units are target figures which still need some fine tuning in the course of curriculum development. The total of 1000 h of formal training will be divided over 40 weeks, with 5 h of training per day. This is intended to allow some hours per day for private study and for the support of other activities making use of the candidates' specialist expertise.

The detailed curriculum for Basic Training in 1993 is being developed by the EAC Support and Training Division, supported by technical-assistance contracts, and in close collaboration with ESA, industry and scientific experts, and with strong involvement on the part of experienced astronauts.

International cooperation

The training activities at the European Astronauts Centre are aimed at building up European expertise, but they will also form part of an international cooperative endeavour. In the framework of the International Space Station 'Freedom' Programme, a common training concept to which all of the partners are expected to contribute is under development. Each partner will conduct their own Basic Training for their own astronaut candidates, but there will be an agreed 'common core' to this training.

As noted above, two European candidate astronauts have already started Shuttle-oriented Mission-Specialist training at NASA's Johnson Space Center in Houston (USA). The experience gained by these two candidate astronauts, and by an EAC training engineer who is currently also stationed at JSC, will provide a further contribution to the ongoing development of the European training concept.

Close relations have also been established between EAC and Star City. CIS experts participated in the review of the EAC training concept and negotiations on closer cooperation are under way. The planned cooperation will include a four-week training period for three European astronaut candidates at Star City in the last quarter of 1992, participation by Russian instructors in EAC Basic Training in 1993, and the conducting of important parts of this training at Star City in the second half of 1993. This will be an invaluable experience for the candidates and the accompanying training engineer, which will hopefully lead to the eventual participation of European astronauts in Mir missions.

Conclusion

Two years after the creation of the European Astronauts Centre in Cologne, the first six astronaut candidates have been selected and the first training activities have already been completed. Preparation for the Basic Training programme to be conducted in 1993 is the current challenge facing the EAC training team, pending the outcome of the ESA Council Meeting at Ministerial Level in Granada (E) on 9/10 November 1992.

ESA Astronauts Prepare for EuroMir

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In anticipation of a European involvement in a future Manned In-orbit Infrastructure, flight opportunities for the members of the European Astronauts Corps had to be found in the context of cooperative missions with other parties. With this approach in mind, the profile and selection criteria for the new group of European astronauts, recruited in 1992, was tailored both to short-duration Space-Shuttle missions and to long-duration missions onboard the Mir station.

After introductory training at EAC, two of the Candidate Astronauts recruited by the Agency in 1992 joined that year's US Class for Mission Specialists, while the others continued with Basic Training at EAC. Also in 1992, a contract was signed between EAC and the Russian training centre for cosmonauts, ZPK, also known as 'Star City'.

In the meantime, cooperation with the Commonwealth of Independent States (CIS) has been strengthened still further and two flights aboard Mir for European Astronauts have been arranged in the context of the Columbus Precursor Flights programme. The contract with NPO Energia for these two Mir flights, known as EuroMir 94 and EuroMir 95, was signed in July 1993.

The technical objectives of these EuroMir missions were described in detail in a previous article in ESA Bulletin No. 75*. This article focusses on the astronaut-related aspects of these flights.

Astronauts assignments/tasks in the Russian concept

Until now, ESA and its astronauts have been more familiar with the American approach to manned spaceflight, involving frequent missions of short duration. Each of the crew aboard a Space Shuttle flight has certain pre-assigned tasks, for which they train specifically in a typically procedural way. Maintenance and refurbishments – of the Spacelab Module, for example – are executed on the ground after the Shuttle's return.

This is not the case with the Russian concept. With their approach, a relatively small crew is carried to and from the orbiting Mir space station in Soyuz-TM capsules. Supplies are transported separately, using the well-proven Progress system. The operations are thus kept simpler, but are more time-constrained, with longer gaps between missions.

Another important factor is that maintenance and repairs to Mir have to be done onboard – in stark contrast to the Shuttle/Spacelab concept – by a crew of just three:

- a Commander
- an Engineer, and
- a Research Cosmonaut.

Besides being involved in the important piloting phase during transfer, the Commander and Engineer must also undertake a large number of system activities once on board the Mir station. The Research Cosmonaut is also expected to participate in these tasks, contrary to his American counterparts.

The combination of smaller crews and longer mission durations adds another dimension to the Russian concept in that interpersonal skills, group dynamics, and psychological compatibility in general, play a paramount role. Having learned from past experience, the Russian concept places a strong emphasis on overall crew performance rather than individual achievements.

As a consequence, two crews are formed and fully trained in parallel in the run up to a Mir mission. These primary and back-up crews are nominated just three or four weeks before the actual flight is to take place.

These differences are, of course, reflected in the training programme. The Russian training is less procedurally oriented than the American and is based upon a broader background knowledge (multi-functionality). In addition, greater emphasis is placed on (fixed) crew training.

The roles of the ESA Astronauts (Figs. 1 & 2) will differ on the two EuroMir flights. During the first, EuroMir 94, the ESA Astronaut will stay onboard, as a Research Cosmonaut, for a longer period than in the American scenario. The second flight, EuroMir 95, will be unique, however, in that it will be the first time that a non-

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* Titled 'Cooperation with Russia in the Framework of the Columbus Precursor Flights', by W. Nellessen & H. Arend

Figure 1. The two ESA Astronauts selected for EuroMir 94: Ulf Merbold (left) and Pedro Duque

Russian citizen trained as an Engineer will be involved in onboard systems-related functions. In addition, the European Astronaut is scheduled to participate in Extra-Vehicular Activities (EVA) during this second flight.

All of these factors have been taken into account in the formulation of the training programme described below.

The EuroMir training programme

The training programme for the EuroMir missions has been established after a learning process that started as soon as the possibility of cooperation with Russia was envisaged. At that time, the EAC had just completed the Training Concept for the European Astronauts for the Hermes and Columbus Projects, including also the training for the flight opportunities with NASA. In essence, this Training Concept is based on three phases of training that the astronauts should follow consecutively: Basic Training, Specialised Training and Mission Training.

In the early contract with ZPK, the following training objectives were established:

- learning how the Russians train their cosmonauts
- implementation of part of the Basic Training defined in the European Astronauts Training Concept at ZPK
- definition of a preliminary training programme for the Mir missions.

To realise the first objective, bearing in mind that the best way to learn is a 'hands-on' approach, a four-week training period was arranged at ZPK in October/November 1992 for three astronaut candidates and one training engineer*. This session provided good spin-off not only from the training point of view, but also regarding logistics and personnel aspects.

Figure 2. The two ESA Astronauts selected for EuroMir 95: Thomas Reiter (left) and Christer Fuglesang

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* See article titled 'European Astronaut Candidates in Training in the CIS', in ESA Bulletin No. 73 (pp. 61–67).

To achieve the second objective, a common Basic Training Plan was established and three months of this programme were contracted to be implemented at ZPK.

With respect to the third objective, a first draft training programme was defined for the Mir missions, harmonised with the Basic Training.

In summary, a Training Programme was derived by seeking answers to the following questions:

- What do the astronauts need to know in order to safely go to and return from the Mir Space Station aboard Soyuz?
- What do they need to know to live and work aboard Mir?
- What physical, psychological and physiological condition must they be in (involving psychological, biomedical and physical training)?
- What work/experiments need to be done onboard the orbiting complex?.

The three phases of the overall training programme are shown in Figure 3.

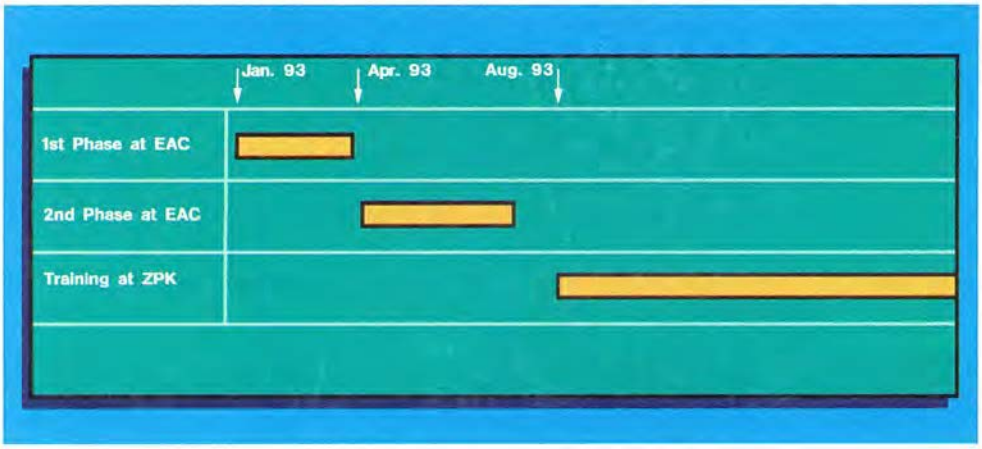

Figure 3. The overall EuroMir Training Plan

First phase of Basic Training at EAC

This phase lasted from January until March 1993 and the training focussed mainly on the fundamentals of several disciplines, a first Russian language course with a native Russian instructor, and other activities from the Basic Training curriculum, such as physical training and flight piloting training.

The following courses were followed:

Russian language:	100 h
Fundamentals, aerospace engineering:	20 h
Fundamentals, electrical engineering:	12 h
Fundamentals, space sciences:	16 h
Physical training:	25 h
Flight training*:	45 h

Second phase of Basic Training at EAC

The astronauts' training continued at EAC from April to July 1993, this period being dedicated primarily to an intensive Russian language course provided by the ZPK instructor, some fundamentals of life-sciences needed for a better understanding of the experiments (the majority of them dealing with life-sciences) to be performed aboard Mir, several courses on Soviet manned programmes provided by ZPK instructors, and a scuba-diving course.

Both the physical training and the flight-proficiency maintenance training were continued during this period, the time allocations being roughly as follows:

Intensive Russian language course:	200 h
Fundamentals of life sciences (biomedical training):	11 h
Soviet manned programmes, ground safety and flight safety:	11 h
Scuba diving:	approx. 40 h
Physical training and flight-proficiency maintenance:	approx. 35 h
Media skills, space law, space organisations:	11 h.

Training at ZPK

Thanks to the three months of Basic Training included in the EAC/ZPK contract, the European Astronauts' training for Mir missions could start in Star City by 9 August 1993. From this date onwards, the Astronauts have been following their training at ZPK on a continuous basis, except for some periods spent in Western Europe in between for the flight-proficiency maintenance and experiment training (Fig. 4).

The times allotted for the major subjects for EuroMir 94 and EuroMir 95 training are shown in Table 1.

Logically, the training at ZPK started with those courses that are least affected by knowledge of the Russian language, such as the vestibular, psychological and physical training, or with subjects that are not critical to mission success. In this way, the Astronauts have more time to become proficient in Russian before proceeding to the more essential training.

A standard week of training at ZPK in this first stage might be composed of:
- approximately 6 to 8 h of Russian-language training
- two sessions per week of physical training, totalling 4 h
- two sessions per week of vestibular training, totalling 2 h

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* Two astronaut candidates with no previous flight experience obtained their Private Pilot's Licences (PPL)

Table 1

Training subject	EuroMir94 (hours)	EuroMir95 (hours)
Theory of manned space vehicles	30	30
Manned space-vehicle control systems	20	20
Fundamentals of space navigation	30	30
Transport spacecraft Soyuz-TM	75	75
Research onboard Mir	20	20
Biomedical training (including physical and psychological training)	325	630
Technical training	315	685
Russian language	160	280
Crew training (including experiment training)	630	870
EVA training	—	100

- two sessions per week of psychological training, totalling 2 h
- lectures and practical sessions on other subjects, totalling around 20 h
- private study and examinations, around 4 h in total.

Experiment training

We will focus here on the EuroMir-94 mission, during which some thirty experiments are to be performed. Not all of these experiments need training, some of them being pre and post-flight experiments which only require Baseline Data Collection.

The experiment training has been structured as follows:

1. Experiment Introduction at EAC: From 18 to 22 October 1993, the Principal Investigators briefed the Astronauts on the scientific background behind each experiment.
2. Hardware and experiment familiarisation, which started in January 1994 at EAC.
3. Nominal Procedures training.
4. Non-Nominal Procedures training.
5. Refresher training, if needed.

This training takes place in Western Europe as well as at ZPK, and is harmonised with the Baseline Data Collection activities.

Operational aspects of the astronaut activities

At present, historical changes are taking place in the CIS. As a consequence, the country is in a transient stage whereby the old systems of working have lost much of their efficiency, but the new systems that must replace them are not yet fully in place. This demands a constant awareness of the changes taking place and a high degree of flexibility.

As far as communication is concerned, the public network is having great difficulty in coping with the exponentially increasing demand for communications lines and is heavily overloaded. With the assistance of ESA's European Space Operations Centre (ESOC) in Darmstadt (D), fax and PROFS connections are in place to ZPK using an X.25 interface. At present, this system is being extended to allow Internet access and data base connections. Audio connections are still a concern and this is being remedied with satellite-based connections (inter alia by using an Inmarsat portable station).

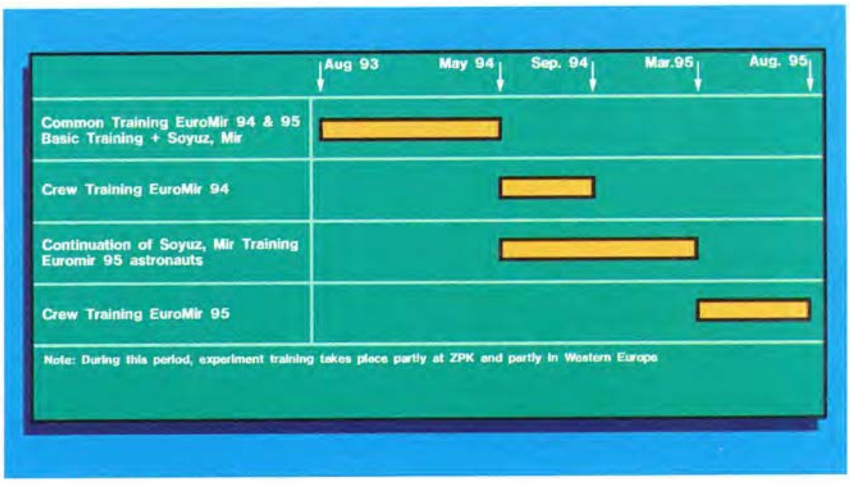

Figure 4. The ZPK Training Plan

A point-to-point audio/video communication system, using DICE, connects ZPK to the other centres concerned and allows satellite-supported links independent of the public networks.

Local logistics are also strongly influenced by the internal changes. It was, therefore, of paramount importance to have a permanently manned ESA office at ZPK for the EuroMir Project. This office houses the above-mentioned communications devices and services the many other office functions that are still difficult to provide in a flexible manner at the current time. Dr. S. Jähn who runs this office has previous Soviet flight experience (Salyut-6/Soyuz-31) and his knowledge of the

Figure 5. One of the ESA Astronauts training at ZPK in a Russian EVA suit

Russian language and customs is proving an indispensable asset.

EAC has established a dedicated team to support its Astronauts for the EuroMir missions, but here too tasks can be very demanding in the present constantly changing environment. The on-site support to the training is provided with a two-fold objective in mind: besides the support aspect, one should not forget the 'precursor nature' of these missions, allowing ESA to acquire both training and operational experience for future mission scenarios.

Because the long-duration EuroMir missions are specifically of interest for life-sciences, the medical-support aspect has been carefully examined. Baseline Data Collection will become a considerable but demanding task, strongly influencing the Astronauts' activities. The important role of Crew Surgeon has therefore been awarded to European doctors with specific experience in this field. A consortium of medical specialists from DLR in Germany and MEDES in France, supported by DAMEC of Denmark, is providing these crew surgeons, who have had previous experience with operational space medicine, in the framework of bilateral cooperative missions using Mir.

Conclusion

The political changes of recent years have offered ESA considerably enlarged scope for international cooperation in the provision and exploitation of space flight opportunities. This not only provides the scientific user community with an increased number of possibilities for experimentation in space, but also enlarges the scope thereof due to the longer durations of the new flight opportunities offered.

From the point of view of astronaut activities, the EuroMir missions will allow ESA to acquire in-depth knowledge of a different training approach and operational concept to that with which it has so far been familiar. In the context of further international cooperation in manned spaceflight, this could become an important asset. Expanded joint activities in the future will require joint training in a well-structured and 'standardised' manner. By being involved in an unbiased way in both training concepts, ESA could play a catalytic role at the time when it becomes necessary to decide upon a common concept acceptable to all parties involved in the cooperative space missions of the future.

Medical and Ground Crew Support during Euromir 95

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The longest manned mission previously supported by ESA was Euromir 94, which lasted just 30 days. The quantum leap to the originally planned 135 days of the Euromir 95 mission meant that a number of concepts needed to be rethought and adapted. One of the more obvious consequences was that the astronaut would be separated for a much longer period from his home environment, which meant that some of the ground-related support also had to be re-evaluated. Additional support associated with the 'psychological climate' onboard the station as a result of the longer mission duration was also necessary. Post-flight analysis has shown that all support elements functioned satisfactorily, but a number of potential improvements have also been identified.

Introduction

The Euromir 95 flight represented an important increment in ESA's experience with long-term manned spaceflights. Whereas the 30 days of the earlier Euromir 94 flight were not considered critical in terms of the isolation involved, a number of lessons were learnt which were important enough to be carefully considered for Euromir 95. Debriefings and feedback from other long-duration flights involving the presence of foreign astronauts on-board Mir also received attention.

The ground support provided during the Euromir 95 flight fell into two distinct categories:

- Medical support
  Differences in medical philosophy have led to the principle that the progress of all ESA astronauts throughout such missions should be followed by ESA-assigned medical staff, reporting to a Medical Board independent of the mission management structure. For long-duration missions, there is then the additional benefit of a long-standing relationship between the astronaut and the crew surgeons, providing the astronauts with the necessary degree of confidence in their medical support team that can be so important during such long and isolated stays.
- Ground support
  For long-duration missions like Euromir 95, proper support for the astronaut's family also has to be ensured, an important aspect here being regular contact between the astronaut in space and his/her family and other close friends back on the ground, in so far as the mission's technical constraints and short communications slots allow.

Medical operations support

The ESA/EAC Medical Operations team is responsible for the health and well-being of the the ESA astronauts during all phases of a space mission. The length of the Euromir 95 mission provided a unique opportunity to accumulate new experience, but also called for modifications to the medical support programme devised for earlier much shorter missions such as the Euromir 94 mission and Shuttle trips.

The decentralised mission support scenario for Euromir 95 required the setting up of reliable communications links and reporting chains. In addition, the European crew surgeons working at the Russian Control Centre at Kaliningrad (TsUP) had to be trained to operate within the Russian flight operations team, on the basis of bilateral agreements between the Russian and the ESA Medical Operations teams.

Medical operations setup for Euromir 95

Two flight surgeons, Dr. A. Putzka and Dr. K. Lohn, were provided by the contractor DLR Medical Operations, and one, Dr B. Comet, by the subcontractor MEDES. Their shift schedule was such that each surgeon was on duty at TsUP for a 2 – 3 week period, covering all onboard activities from the first morning space-to-ground contact until the last communication in the evening.

During Euromir 94, it was found to be important to establish a link between the TsUP

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[*] Space Consultant

flight surgeons and the flight control team at the Payload Operations Centre (SCOPE). A dedicated crew-surgeon console was therefore installed at SCOPE in Oberpfaffenhofen (D) to enable the medical team to communicate via the digital intercom system (DICE). There was one public DICE line and one secure line, which was used to communicate confidential medical information, between the two centres.

The TsUP-based flight surgeons interfaced directly with their Russian counterparts and were responsible for all medical issues arising during the mission. All routine inflight medical checks and the countermeasure program were monitored and, in concurrence with the Russian crew surgeons, the appropriate recommendations were uplinked to the crew. In addition, the surgeons provided support to the timeline planners for all crew-schedule-related activities.

There was a private medical conference between the ESA astronaut and the ESA surgeon(s) approximately two to three times per week, on the understanding with the Russians that any information gathered that could have an impact on the mission's execution would be passed on to them. Information from these conferences was used to brief the Payload Operations Manager (EPOM) and the Mission Management on the ESA astronaut's health and workload, so that the daily activity plan for onboard tasks could be fine-tuned or adapted as necessary.

In addition, the Russian medical team issued an extensive daily medical report, which was translated and sent to the chief crew surgeon at SCOPE.

The SCOPE crew surgeon's role was to collect all medical information from the TsUP surgeons and to provide the SCOPE team and ESA Mission Management with a thorough understanding of the medical situation. A secondary task was to provide the link with the ESA Medical Board for decisions relating to the execution of the human life-sciences experiments. The Russian and the ESA Medical Boards had approved all of the life-sciences experiments, including the operational procedures to be followed, before the flight. Any changes to those agreed protocols had to be re-approved by the ESA Medical Board. The SCOPE surgeon was responsible for informing the Medical Board about any such changes, in addition to filing the nominal reports on the mission's progress. Thirdly, the SCOPE surgeon had to interface with the responsible safety officer in the event of apparently hazardous operations or equipment malfunctions that might affect the crew's health.

Figure 1 shows the links and interactions between the various teams, but does not reflect the hierarchical structures.

Figure 1. In-flight medical-operations setup

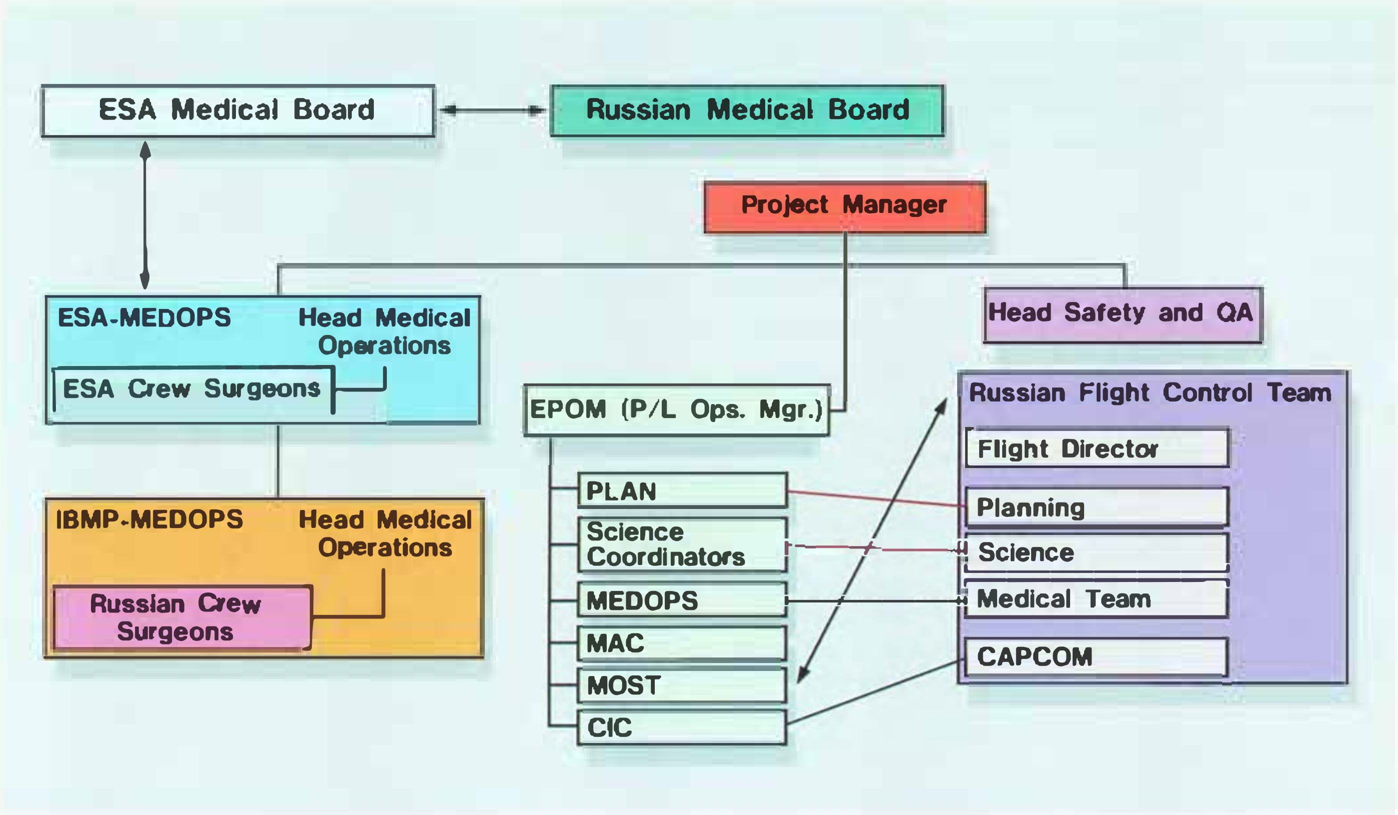

Figure 2. Medical countermeasures taken onboard before landing - the LBNP suit

Medical-operations documentation

In order to define clearly the roles and responsibilities of the medical-operations personnel and to make those roles more transparent to the Euromir 95 mission management, several documents were created.

The first document to be finalised and approved was the 'Euromir 95 Medical Flight Rules'. This document describes in detail all rules governing the daily tasks of the medical team, the rationales behind those rules, and the structure of the decision-making processes during nominal inflight operations and in contingency situations.

The second document, on 'Medical Data Protection Policy', defines the rules for protecting the astronaut's private medical data from public release, and the underlying criteria for medical data exchange with, for example, the scientific community. Further documents, such as the 'Medical Checklist', were published to give other non-medical flight controllers a more detailed insight into possible medical situations that might be encountered during a long-duration mission like Euromir 95.

A 'Medical Console Handbook' was used by all flight surgeons as the main reference for their work at the medical consoles, either in TsUP or SCOPE. It covers the operation of all equipment, contains basic space-medicine chapters, and lists all contact personnel needed to cope with contingency or emergency situations.

A 'Handbook on the Russian Medical Programme' compiles all available information about the routine inflight medical examinations and the countermeasures programme. This handbook was also made available to the life-sciences team, for whom detailed knowledge of these medical routines was especially important in the setting up of their experiment programme.

As the TsUP-based ESA surgeons were to be integrated into the Russian medical system, a 'Joint Medical Support Requirements' agreement was established with their Russian counterparts. This document describes the training needed by a foreign flight surgeon in order to be certified to work in the Control Centre. Fortunately, the ESA flight surgeons selected for EuroMir 95 had previously provided mission support in Russia and therefore required no further training. More importantly, it spells out the interactions and responsibilities of both medical teams, includes western-European medical data-protection guidelines, and formalises the Russian agreement to the routinely scheduled private medical conferences.

Lessons learnt

The Euromir 95 mission as a whole was a great success from the medical and ground-support points of view especially, in that it served to prove that the current medical-operations structure is well able to support long-duration missions. It also demonstrated that an open and transparent mode of working, whilst still protecting the astronaut's medical privacy to the greatest degree possible, enhances the relationship between the medical operations, the mission management and the other ground personnel to the benefit of all concerned.

Nevertheless, there are still some elements that can be improved for future missions, particularly in the context of the broadening of multinational cooperation in the International Space Station era:

(i) Although there was a dedicated secure voice link between SCOPE and TsUP, it could not always be used as expected because there was only one DICE console available at TsUP, which was shared by all personnel. It is mandatory to have a dedicated crew-surgeon console in each control centre in future.

(ii) As one might expect, engineering knowledge is limited in the true medical community. To improve the interfacing between the medical staff and the engineers (e.g. safety officers) and in order to incorporate new technologies such as telemedicine, a biomedical engineer should become a permanent part of the European medical team, as is already the case in the American and Russian systems.

(iii) The chief crew surgeon at SCOPE for Euromir 95 served in parallel as the executive secretary of the ESA Medical Board. This double function sometimes led to misunderstandings within the ground team. In the future, those functions should either be separated during a mission or both tasks should be made more transparent to the other ground controllers.

(iv) Negotiations with the Russian side were sometimes somewhat cumbersome, despite the excellent translational support. It is advisable for the future to have available a native Russian translator intimately familiar with medical terminology. This becomes even more important in the framework of ever wider international co-operation.

Family and ground support

For such long-duration missions, one can only expect an astronaut to concentrate fully on his/her tasks if he/she knows that their family is being well taken care of, and that they can have regular contact. Such support should not be over-institutionalised, but needs to be sufficient to instil a feeling of mutual confidence between the astronaut and his/her family and the crew surgeon and EAC support staff.

As far as the contact aspect is concerned, one really needs more location-independent communication possibilities. The Russian system provides a videolink from TsUP once every two weeks, as well as allowing regular short phone calls from private locations (via the installation of a specific system). This, however, requires that the astronaut's family be present in Russia. A video link provided via the DICE system proved to be a valuable addition, especially when the families were on the move or further afield. Audio contact could also be made by linking the space-to-ground loop to the public telephone network, which not only provided a good backup system but also provided contact with other more remote family members from time to time.

As a result of conflicting feedback from earlier flights, various aspects of the Euromir 94 flight were analysed with the help of a psychologist trainee at EAC. As a result, a number of recommendations for improvement were implemented for Euromir 95. A typical example was the news summaries, which were collected and condensed at EAC, and then transmitted in the astronaut's mother tongue to the station at regular intervals.

In fact, the cultural isolation problems cited after earlier Russian cooperative missions were not reported at all during Euromir 95. The well-balanced composition of the crew certainly played a very important role in this respect, but a number of small support activities undoubtly contributed also (e.g. presents and video tapes sent up at Christmas).

The two Euromir 95 Crew Interface Coordinators (CICs) were based, together with the two Experiment Coordinators, at the main Control Centre (TsUP) in Kaliningrad, near Moscow. They worked in two shifts, from one afternoon to the next, with a one-hour overlap for handover purposes. From the fourth week of the mission onwards, one of the four persons was always free for relaxation.

There were several systems available for communications between TsUP and SCOPE, serving complementary as well as back-up functions. These included the DICE system and a dedicated audiosystem, called VIS, in addition to the classical communication tools of telephone, fax and e-mail. An Internet link that became available near the end of the flight also proved to be very useful.

When communicating with the Mir station, there are typically 10 passes per day/night,

Figure 3. A rare social event – visitors in space

each affording only between 10 and 20 mins of link time (because only ground stations on Russian territory are used). Given the predominant system-related communications needs, this strongly limits the ground contact time available for the ESA astronaut. A good understanding prior to the flight of the activities to be performed onboard is therefore a must, as well as a good command of Russian as the station's working language.

The amount of written information that could be sent up was also rather limited, relying on so-called 'radiograms'. In practice, sending small 'electronic packages' to the onboard laptop computer proved more effective.

The use of Russian as the principal language of communication allowed the Russian crew members to feel more involved in the ESA scientific programme, and it also allowed the ground controllers to give advice as they were able to listen in. This was a 'lesson learnt' from Euromir 94, where the ESA astronaut communicated with the ground mainly in English.

Conclusion

The Euromir 95 support concept proved to be a viable setup that worked very satisfactorily. The more harmonious cooperation with the Russian medical infrastructure was clearly beneficial and merits further development and follow up.

A major conclusion, however, is that in the International Space Station scenario ESA needs to provide its astronauts, and their families, with carefully structured support before, during and after their flights. This support needs to address not only the technical demands of the particular mission, but also the cultural factors that begin to play an ever-increasing role as the durations of our astronauts' stays in space become ever longer.

Regular communication with the crew is considered a must for long-duration missions, not least for psychological reasons. Internet connections to TsUP and electronic-mail possibilities need to be further investigated and improved.

Crew Support Tools for Euromir 95

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The Euromir 95 long-duration mission raised many new crew-support issues for ESA. Previous mission experience indicated the need for increased emphasis on generic tools for astronaut Thomas Reiter. In addition, some possible solutions could be demonstrated to combat Mir's onboard stowage problem.

Overall, the mission considerably increased ESA's operational experience, while the experimental introduction of certain items generated a vast number of 'lessons learned' in the crew-support domain. Further experience in this area would enhance Europe's role in the International Space Station's operational phase.

Introduction

Euromir 95's planned duration of 135 days far exceeded the experience of any ESA Astronaut. The 30-day Euromir 94 mission had already indicated the need for new tools, unavailable in the Russian system, to help run the onboard programme. Further important feedback from the Euromir 94 debriefings highlighted the problems with stowage aboard the station.

Based on these requirements, we can categorise the support tools provided for Euromir 95 as:

a. Generic off-the-shelf tools
These were taken up by the astronaut, independently of the experiment programme, to make life on board more comfortable at the same time as assisting him with his work.

b. Specific operational support tools
Based upon feedback from earlier missions regarding stowage and handling constraints, a number of items were flown on an experimental basis. These were aimed primarily at supporting operational activities, whilst at the same time contributing to 'lessons learnt' for future missions.

c. A Payload and Crew Support Computer (PCSC)
A commercial laptop has been selected as a standard tool for the International Space Station era and flew as part of Euromir 95. It was specifically equipped to meet the experiment data-handling needs and to provide the astronaut with a suitable support tool.

Generic off-the-shelf tools

On the basis of lessons learnt from Euromir 94 and the inputs from both Euromir 95 astronauts, a number of off-the-shelf items were purchased for operational onboard support. The following table lists the items, describes their operational usage and suggests improvements where necessary:

Item	A	B	Cn	D
Stopwatch	x		C1	
Sunglasses (standard NASA issue)	x		C2	
Swiss Army Knife	x	x		
0.9 Mechanical pencils + refills and tip eraser	x	x		
Waterproof marker	x	x		
Space Pen				x
Ear plugs (disposable foam type)	x	x		
Eye mask		x		x
Mini Maglite (AAA batt.)	x	x		
Portable MD Player-Recorder + power adapter + folding headphone (lightweight)	x			
NASA grey duct tape	x	x		
Dictaphone		x		x
Sailing rope (diam. 3 mm)	x			

A = used frequently during the flight
B = design excellent, no improvements necessary
C = design good, room for operational optimisation
  C1 = have the display show simultaneously the actual time (in large digits) and stopwatch time
  C2 = use denser sunglasses, for greater protection against UV radiation
D = rarely or not used during the flight

Specific operational support tools

A fundamental problem faced by any astronaut on Mir is the absence of a proper stowage system. After more than a decade in orbit, Mir's interior could be described as organised chaos. Combined with the usual difficulties of working in microgravity (everything silently floats away if not properly fixed or stored), this constitutes a major operational problem for the astronaut (Fig. 1). This subject was specifically addressed at the Euromir 94 debriefings, with the main drawbacks being identified as:

- difficulty in setting up experiments
- difficulty in temporarily stowing products
- risk of losing smaller items such as the important data carriers (PCMCIA cards, floppy disks, etc.)
- loss of valuable time during operations.

Two new operational support tools were designed and developed to help remedy this operational problem: the Mission Stowage Bag and the Crew Vest.

Figure 1. Some of Thomas Reiter's personal items 'tied down' aboard Mir

Mission Stowage Bag

The Mission Stowage Bag (MSB) was developed with two main objectives in mind:

- provision of a central, readily accessible storage place for most of the science data carriers and some other regularly used items
- allowing the astronaut to gather up the science data carriers quickly in the event of an emergency evacuation.

More than 40 experiments were conducted during Euromir 95, filling a whole series of data carriers. Several of them were not planned to be placed in the MSB, either because they were constantly in use within the station or were to be used only once.

Only a portion of the items present in relatively large quantities (60 dictaphone cassettes, 20 35 mm films, 30 Betacam cassettes) were placed in the MSB at any given time:

- 12 PCMCIA cards
- 15 Betacam cassettes
- 8 Hi8 cassettes
- 32 dictaphone cassettes
- DI8 bag (DAT tapes, memory cards, floppy disks)
- 6 memory cards
- 2 audio tapes
- 10 35 mm films
- Flight Data File (FDF)
- laptop + power cable
- one string of batteries.

Specific MSB features included (Fig. 2):

- All pockets containing mission data carriers were white and attached with velcro to baseplates. The astronaut could thus rip off the pockets quickly and collect them in the emergency bag (a large bag used as MSB upload packaging).
- Materials used: Nomex fabric (90 g and 180 g), Nomex Velcro, FR4-plates (fibreglass-reinforced material, type Hgw 2372.1 DIN 7735), Nomex cord and four metal rings.
- Foldable design, allowing compact upload dimensions ($385 \times 225 \times 115$ mm^3); installed dimensions in Mir were 840×740 mm^2. The FR4-plates, sewn permanently into the MSB baseplate, gave it the requisite stiffness in orbit.
- Rear of the MSB had four large pouches for general stowage (personal items, temporary stowage, etc).

Figure 2. The Mission Stowage Bag (MSB)

The MSB was anchored in Mir's Spektr module and used on a daily basis by Thomas Reiter to store his private possessions, photographic and computer equipment, consumables such as earplugs and batteries, most of the Betacam cassettes and a few PCMCIA cards. Most of the data carriers were stowed next to their corresponding hardware for operational convenience. Reiter had decided to rescue only the magnetic-optical disk (the central backup medium) in the event of an emergency evacuation. The emergency bag was used as a temporary store for Betacam cassettes and T2 samples.

Figure 3. Cosmonauts Sergei Avdeev and Yuri Gidzenko and ESA Astronaut Thomas Reiter wearing their Crew Vests

MSB lessons learnt

- The MSB concept is extremely useful.
- The MSB should allow the stowage of:
  - most of the astronaut's personal items
  - photo and computer equipment, multi-purpose tools
  - consumables (earplugs, batteries, bolts, velcro, duct tape, ziplock bags, etc.)
  - non-specific experiment data carriers such as tapes, cassettes and films
  - experiment-specific data carriers such as PCMCIA cards and floppies (astronaut decides on orbit if it is operationally useful to store them there)
  - general stowage for items unforeseen by ground planners.
- Introduce an Emergency Bag with a mission-dependent design for carrying the central backup medium (magneto-optical disk during Euromir 95) and those items planned for return aboard Soyuz.
- Standardise the packaging of up/download items, and have someone co-ordinate this and their operational use onboard.
- Provide a few simple General Stowage Bags for the astronaut to stow items and data carriers no longer needed.
- The foldable design is very practical; there is no need to switch to stowage lockers. Retain the FR4-plates for stiffness and keep the simple cords for attachment.

Crew Vest

This multi-purpose vest was developed to allow its wearer to carry around a wide range of items and to provide temporary storage during experiment work and onboard engineering.

Two lists of requirements were compiled for it in consultation with ESA Astronauts Thomas Reiter and Christer Fuglesang. List 1 specified items with permanent and dedicated positions, whilst list 2 covered all the other items the vest should be able to accommodate.

List 1	List 2
– Pocket calculator	– PCMCIA cards
– Dictaphone	– Sunglasses
– Swiss army knife	– Floppy disks
– Maglite	– Betacam cassette
– Yellow stickers	– Hi8 cassette
– Blood/salva/urine sample holders	– Flight Data File
– Pen & pencil	– Small items, such as bolts

Specific features of the Vest included (Fig. 3):

- Material used: jeans fabric as basis, Nomex (90 g & 180 g) for the pockets, synthetic zip fastener, Nomex velcro and two synthetic whalebones for stiffness.
- The vest was sleeveless, body-hugging and had three large ventilation holes at shoulder blade height.
- A large pocket on the lower back, accessible from the left, provided a place for the Flight Data File. A second pocket on top, accessed from the right, held large items such as the duct tape and Betacam cassettes.

The three Crew Vests were not delivered to Mir until 20 December 1995 aboard Progress-M 30, by which time Thomas Reiter had been working in space for more than three months. This was a great pity as the astronauts organise themselves and their experiments during the first two weeks of a mission, and it is during this phase, and subsequent periods of Progress unloading, that the Crew Vest would be of greatest use.

Astronaut feedback was notable on the apparently extremely impractical nature of the standard onboard overall: pockets were small and few, with no pockets suitable for items such as pencils and screwdrivers; the short sleeves made them too cold when in the Spektr module, whilst they were too warm when in Mir's core module.

Crew Vest lessons learnt

- In general, standard daily clothing should be a practical, light overall with long sleeves and dedicated pockets for at least a pen/pencil, Swiss army knife, Maglite, screwdriver, dictaphone, small notebook, sunglasses and tissues.
- There should also be a supplementary belt/harness to help move equipment around, providing temporary storage for several items, both large and small.

Payload and Crew Support Computer (PCSC)

Along with other similar equipment already aboard Mir, the PCSC laptop computer and accessories (including four hard disks with two configurations) were used by the ESA Astronaut under an ESA/NASA agreement covering the sharing of technology resources for research purposes. By exchanging the main hard disk, the PCSC could be configured either to supporting the experiment programme or to serve as a personal computer for the crew. It could also be attached to NASA's Mir Interface to Payload Systems (MIPS), whereby the MIPS MO disk could be used to make an additional copy of the collected experiment data, which could then be sent back to the ground via Mir's telemetry system.

The PCSC was essentially a commercial IBM 750C ThinkPad laptop, with an 80486 SL Intel processor running at 33 MHz, 12 Mbytes of Random Access Memory (RAM), an exchangeable 340 Mbyte hard disk, a 1.44/2.88 Mbyte disk drive, a 26.7 cm active-matrix display, a Type-III PCMCIA slot, and an integrated TrackPoint pointing device.

Figure 4. The Payload and Crew Support Computer (PSCS), accessories and peripherals with the onboard stowage bag

The main modifications to the off-the-shelf laptop were the addition of a DC/DC converter, so that it could be powered by Mir's standard 28 VDC supply, and the coating of the various internal boards with a non-conductive film to trap escaping gases and protect the various components against short circuiting by any metallic particles floating in weightlessness.

The basic computer was complemented with several accessories: four exchangeable hard disks, two PCMCIA 260 Mbyte hard disks, four floppy disks, five MO disks of 1.2 Gbyte capacity each, power cable, serial and parallel loopback connectors (for testing the computer) and other small spare parts.

Everything was labelled and each item was packed into labelled Nomex pouches, which had exterior Velcro strips. The pouches were then placed in an aluminium/Nomex stowage container, providing easy access to the computer and the accessories which would remain fixed inside even when the lid was open. The stowage container with all the PCSC items weighed 7 kg and was delivered by Progress-M 28, launched on 20 July 1995.

A pre-mission agreement with NASA allowed the three additional MIPS laptops (also IBM ThinkPad 750C's) already onboard Mir to be configured as part of the PCSC facility. At least two PCSC-configured computers were thus available at all times.

Three PCMCIA hard disks carrying upgrade software and three PCMCIA SRAM cards containing MIPS software were delivered in September 1995 by Soyuz-TM 22. Two more PCMCIA SRAM cards were delivered by Space Shuttle mission STS-74 in November 1995. An additional PCMCIA hard disk with upgrade software and three fresh PCMCIA SRAM cards were uploaded with the Progress flight in December 1995.

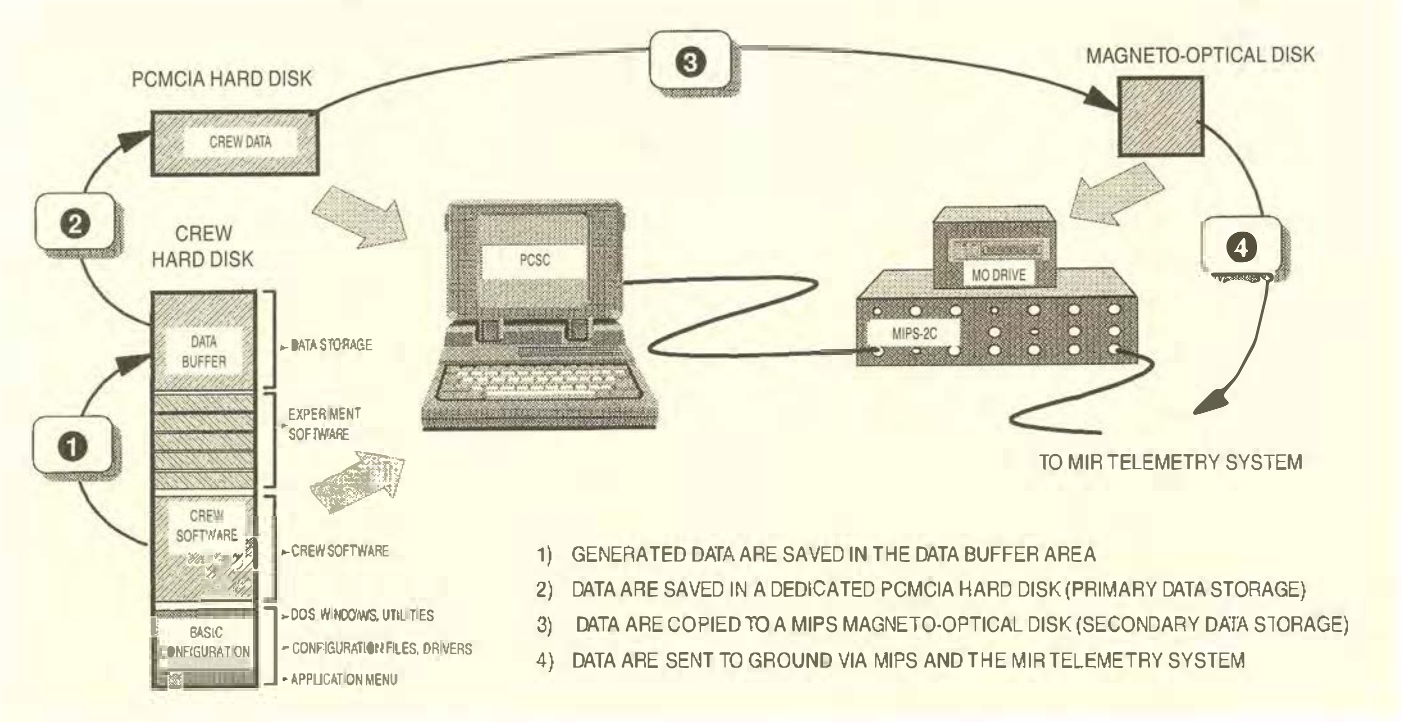
STS-74 returned with an MO disk containing all the experiment data collected thus far. A second MO disk and a PCMCIA hard disk were brought back by the crew aboard Soyuz in February 1996. All other exchangeable hard disks and PCMCIA hard disks were returned by STS-76 in March 1996, the ESA laptop remaining behind on Mir for future use.

Software configuration and data handling
The 'payload hard disk' was installed in the PCSC, carrying mostly software for supporting the experiments programme. Twelve Life Sciences and Technology experiments used the computer for experiment hardware command and control, data acquisition and data handling. The 'crew hard disk' was installed in a MIPS computer, making it the 'PCSC crew computer', typically used in standalone mode as a personal computer, but it could also be interfaced to MIPS for data downloading and telemetry. This hard disk was notionally divided into three areas: basic configuration; crew software; data buffer.

The basic configuration area essentially contained the Operating System (DOS, Windows), configuration files, software drivers and software utilities. It also contained a simple shell DOS program, provided by NASA, that ran at the end of the booting sequence. This program provided a selectable menu to start Windows 3.1 or to access NASA's software for handling MIPS. While the basic utilities contained tools and batch programs that automated all the tedious and repetitive operations, extreme care was taken to ensure that the astronaut was always aware of the work being performed in background mode by the computer so that he could intervene and correct any problem manually.

The crew software area contained all the software used exclusively by the crew. This was mostly commercial software that could be run under Windows 3.1. In parallel, some experimental software was also run from the

Figure 5. Computer hardware and software configuration, with a schematic indication of the data flow



crew computer, notably experiment T8, which would record and notify the operator of possible system anomalies due to radiation hits corrupting RAM data.

The data buffer area contained both experiment-generated and personal data. These were also copied into a specific PCMCIA hard disk that was considered to be the Primary Data Storage medium. At the end of the mission, the data buffer area was copied onto a MIPS MO disk as the Secondary Data Storage medium. Both were returned to Earth.

Software packages

The software instaled in the crew hard disk was selected by the crew and basically contained the same software tools used by the astronauts in their offices or at home: word processor, electronic spreadsheet, database and drawing package. They were used mainly for taking notes, writing reports or letters, reviewing online documentation and making lists for tracking equipment. Several of these documents (normally containing up to four or five pages of text) were exchanged between Mir and the control centre in Kaliningrad. In addition, an orbital tracking program provided the crew with real-time information on the ground areas visible from Mir's observation windows. This was used mainly for photographic purposes and for supporting public-relations activities.

A simple time-line program called the Crew Activity Organiser System was also provided. This tool, built by the European Astronaut Centre and normally used for displaying training time-lines, was tested in orbit for receiving and displaying the daily activity time-line.

Finally, a graphics package that displayed digitised images allowed the crew members to select their favourites from the 'Ars ad Astra' art collection of original drawings expressly created by artists from all over the world. This package was also used to view family photographs provided by the wives for inclusion on the hard disk without the crew's prior knowledge.

Data telemetry

Despite several glitches, a high proportion of the experiment data was successfully dispatched to the ground via MIPS and Mir's telemetry system. This allowed the experimenters to view their data relatively soon after its generation (typically 2 – 3 days) and, when necessary, to take corrective actions. While the majority of the two-way traffic concerned the experiments, the ESA Astronaut regularly sent and received text files (typically in ASCII format). In fact, he regularly generated reports and messages complementing the information transferred during the normally short audio and video connections with Mir. Once received on the ground, the Crew Interface Co-ordinator would forward the relevant items to the interested parties and collect and compile the replies to be sent to Mir. This worked very well and was invaluable in expediting operations.

Figure 6. Laptop connected to the Mir Interface Payloads System (MIPS) during telemetry transmission

Computer lessons learnt

The use of the laptop by the ESA Astronaut as a personal and mission-management support tool contributed to the mission's success. For this tool to be effective, however, an informatics environment must be built up for each astronaut as early as possible during mission preparation. This environment has to contain all of the software necessary for satisfying astronaut and mission requirements, plus all available experiment support documentation with ready access.

Conclusion

Euromir 95 served as a demonstration testbed for several elements that will be required for future International Space Station missions. From this point of view, it fully deserved its designation as a 'precursor mission'. Some of the innovations were immediately successful and can be further employed with only minor improvements. In a few cases, the initial designs proved to be less robust than expected under operational conditions and major redesigns will result from the 'lessons learnt'. Overall, however, a great deal of experience was gained that will be invaluable to the Agency in its preparations for future long-duration space missions.

Euromir 95: ESA Astronaut Thomas Reiter carrying out maintenance work onboard Mir

Working Aboard the Mir Space Station

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For more than ten years, the Mir station has been the World's only permanently manned laboratory in low earth orbit. With an orbital inclination of 51.6°, its ground track covers more than 85% of the Earth's surface, where approximately 95% of the population lives.

For the transfer of up to three crew members per trip to and from Mir, the 6.9 t Soyuz spacecraft is used. In general, the station's crew is changed every six months, with an overlap during the exchange of between one and two weeks. A Progress spacecraft (an unmanned derivative of the Soyuz vehicle) visits the station every three months to resupply it, with up to 2.1 t of payload, and to reboost it to maintain its nominal orbital altitude.

The station's core module, injected into orbit in February 1986, contains the central control post for most onboard systems, the computer for attitude control, and the telemetry and communications system. It also contains the station's largest work space, which is 7.0 m long and varies in width between 1.5 and 2.5 m.

The station elements

The layout of the station during the Euromir 95 mission is shown in Figures 1 and 2. The Kvant module, which contains many astrophysical sensors and experiments, has been attached to the station (along the +X-axis) since April 1987. Three more modules have been docked to the central node of the station since then:

- Kvant-2 in December 1989 (along the +Y-axis), containing systems for earthobservation and the airlock for EVA operations
- Kristall in June 1990 (along the −Z-axis), containing furnaces for materials-science experiments and astrophysical sensors, and
- Spektr in June 1995 (along the −Y-axis), containing cameras and systems for earth-observation.

During Space Shuttle flight STS-74 in November 1995, an Interface Module was permanently attached to Kristall's APDS-port (Androgynous Peripheral Docking System) to facilitate future Shuttle dockings. In March 1996, the station achieved its final configuration when the fifth module, Priroda, was attached along the +Z-axis. Two docking ports on the central node (−X) and the Kvant module (+X) are available for the Soyuz and Progress spacecraft. There are two more APDS-ports on the rear end of Kristall and on the Interface Module.

With Priroda's arrival, the total mass of the Mir complex reached 120 t and it now contains a hermetic volume of approximately 350 m^3. A maximum of 35 kW of electrical power is provided by the station's solar arrays and the power supply to all modules is based on a 27 V direct-current bus.

The station's attitude is generally controlled with the help of 12 gyrodynes, located on the Kvant and Kvant-2 modules. Its reaction-control system is activated only briefly when the gyrodynes need to be desaturated.

Mir's Environmental Control and Life-Support Systems (ECLSS)

The station has five generic ECLS systems on board:

- oxygen-production and air-filtering systems
- an air-conditioning system
- a ventilation system
- water-regeneration systems
- a thermal-control system.

Oxygen is produced by two electrolysis units – one in Kvant and one in Kvant-2 – which use water distilled from the urine-collection system. Nominally, these units are operated sequentially. A contingency system, also located in Kvant, uses pyrotechnic cartridges for oxygen production.

For the removal of carbon-dioxide and other detrimental pollutants from the station's atmosphere, a total of four systems are available. The two main units, located in Kvant, employ regenerative filters, which are periodically connected to vacuum venting lines. For contingency operations, there are two more systems in the core module which use LiOH catridges for carbon-dioxide filtering and

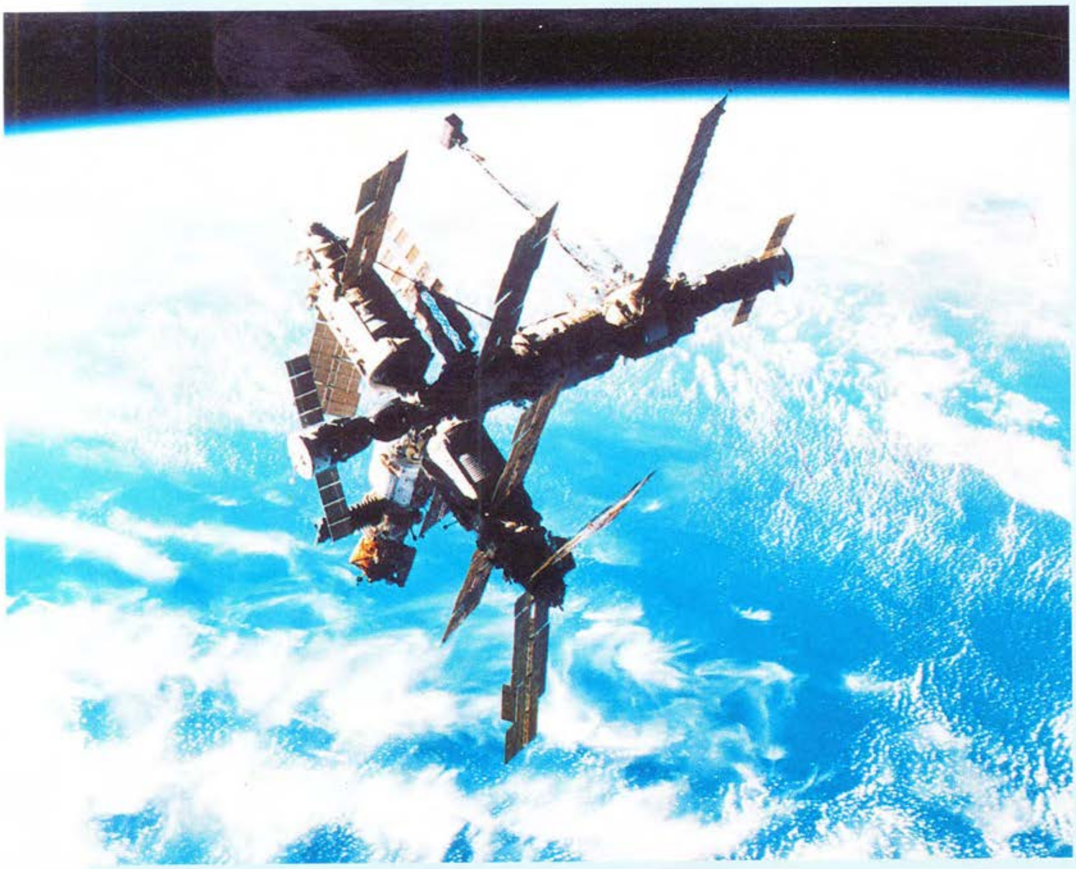
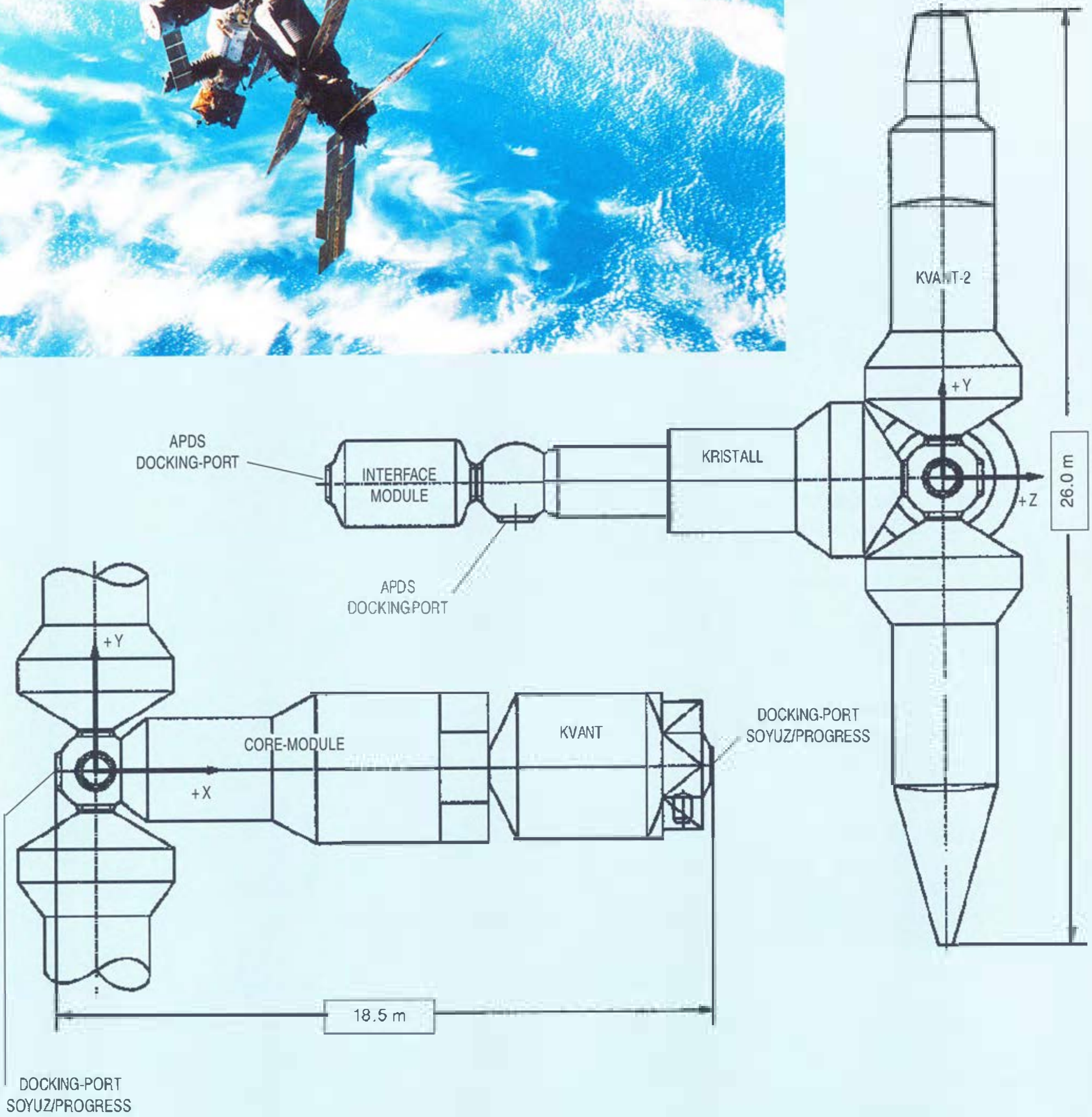


Figure 1. The Mir station, photographed from the Space Shuttle

Figure 2. Schematic of Mir's configuration at the time of the Euromir 95 mission



cartridges containing other materials for the pollutants.

There are two air conditioners in the core module, one connected directly to one of the module's cooling loops and one using a conventional freon loop for efficient cooling and dehumidifying. If necessary, moisture removal from the station's atmosphere can be supported by the air conditioner in the Soyuz capsule.

To ensure a standard flow pattern within each module and air exchange between all modules, numerous ventilators are used (approx. 30 in the core module and 20 in the other modules). In the nominal flow pattern, air is routed from the region beside the front hatch through the free working space. Via lattices in the rear part of the modules, it enters the area behind the panels and moves in the opposite direction towards the front again, passing through air-liquid heat exchangers and dust filters.

Air exchange between the various modules takes place via flexible ventilation ducts (Fig. 3), driven by ventilators, installed at 5 to 7 m intervals.

There is a unit for regenerating distilled water from the urine collection system installed in the Kvant-2 module. As already mentioned above, this water is used for oxygen generation in the two electrolysis units. Another system installed in the core module regenerates drinking water from the condensate produced by the air conditioners. In this unit, the condensate is filtered, sterilized and re-mineralized, mainly for food preparation purposes.

Every module of the Mir station is equipped with its own thermal-control system. In general, internal thermal-control loops are used to maintain the temperatures of the station's atmosphere, internal structure and onboard systems within a given range. Excessive heat is initially transferred to external thermal-control loops via heat exchangers and then radiated into space.

In contrast to the Kvant module, which contains only one internal and one external circuit, all other modules are equipped with redundant internal and external thermal-control loops. The core module even contains two types of redundant internal circuits, namely two low- and two medium-temperature loops.

The Kristall module has a separate loop cooling the furnaces, while in Kvant-2 another separate loop removes heat from the electrolysis unit.

Discrete temperatures for the cooling fluid in the external thermal-control loops can be selected by the crew or by ground control. The selected temperature is then maintained by an electronic unit, regulating the flow of cooling fluid through the radiators. In this way, a constant temperature difference is maintained between the internal and external circuits in the heat exchangers. The radiators either contain coils of the cooling loop or a single cooling line to which heat pipes are connected.

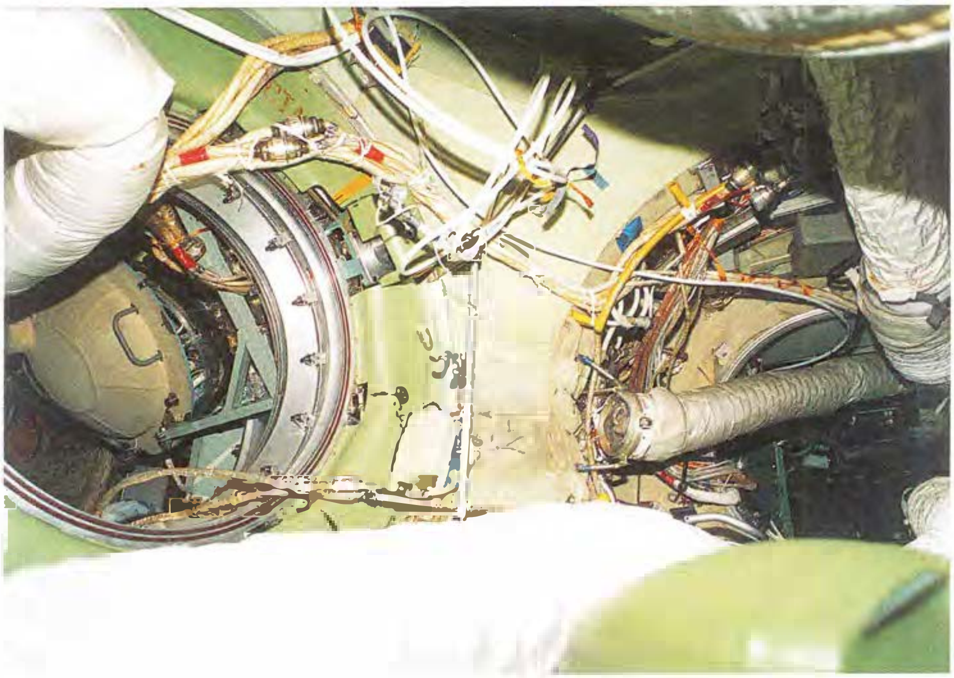


Figure 3. Some of Mir's flexible ventilation ducting

Operating routines

The daily work routine onboard a space station is mainly determined by four factors:

- available resources (such as hardware, consumables, energy, crew time, etc.)
- functionality of onboard systems and experiment equipment
- skills of the various crew members, and
- available ground support.

Daily schedule and crew time

In contrast to short-term missions, where the crew usually works in shifts, where the daily networking time is comparatively high and where experiments are run to a very tight schedule, long-term missions require more balanced planning in order to maintain good crew performance. Consequently, the daily work aboard Mir is planned in a very similar way to that in a 'normal' working environment on the ground.

During nominal operation, a Mir working day consists of 6.5 nett working hours (experimental work and/or system maintenance). In addition, 2 h per day are planned for physical fitness activities to counteract the effects of long-term weightlessness on the human body. One hour each evening is foreseen for debriefing sessions with the ground staff and preparations for the next day's activities.

This schedule is maintained for the 5 working days each week. At weekends, the work schedule is slightly reduced, to 3 – 5 h, including normal 'housekeeping tasks', but the 2 h of physical-fitness training is maintained.

Given that the two main objectives of the Euromir 95 mission were execution of the scientific programme and the acquisition of operational experience in conducting normal maintenance and repair work onboard Mir, approximately 70% of the total working time was allocated to the experiment programme, and the remainder to the onboard engineering tasks.

Experiment hardware and data handling

As there were no spare payload racks available, all of the Euromir 95 experiment equipment had to be self-contained, apart from being connected to the station's power supply. Only in two cases was equipment connected directly to Mir's telemetry system (the TITUS materials-science furnace and an active astrophysical sensor on the ESEF platform).

Experiment control, as well as acquisition and storage of experiment data, was performed either by subsystems within the equipment or via a laptop computer connected to the hardware. The experiment hardware was not equipped with special diagnosis electronics, nor was the laptop configured to perform a detailed failure analysis in the event of a subsystem malfunction. Many of the experiment systems were equipped, however, with electrical connectors 'for ground test only'.

In most cases, experiment data were stored doubly-redundantly on different data carriers: primary data were either collected on the laptop's hard disk, on PCMCIA memory cards or on PCMCIA hard disks. Data compression and backup was performed automatically on PCMCIA hard disks and manually onto a magneto-optical disk via the NASA-MIPS2 (Mir Interface Payload System) controller. Data recorded manually on questionnaires or in tables were also typed into the laptop (.txt files) and backed-up electronically as described above.

Communication and telemetry

Voice communication with the Russian Flight Control Centre (TsUP) was established via three duplex channels: two UHF channels for a direct link via different ground stations and one channel via a geostationary satellite. All three channels used fixed frequencies. The ground stations were mainly located on Russian territory. On a few occasions, however, a UHF link with the TsUP was established via an American and a German ground station. Communication times ranged from 5 min to a maximum of 20 min for the direct (UHF) links, depending on orbit orientation, and up to 40 min for the satellite link. The UHF-2 channel was available to the Euromir team only occasionally and over discrete ground stations.

In parallel with the UHF voice link, the daily schedule and procedures were uplinked via modem and printed with a teletype. This operation neither interrupted nor restricted normal voice communications on that channel. Packet file transfer to and from the station was also effected via one of the three voice channels, but no voice communication was possible on that channel while a transfer was in progress.

A video link (SECAM, down, up or up/down) was nominally arranged via a geostationary satellite, with duplex voice link at the same time. Black-and-white video could also be downlinked using one of the UHF channels.

Scientific data could only be downloaded offline via the NASA MIPS2 controller, connected to the Mir telemetry system. The controller was set up for data transfer using the crew's laptop. There was no online data downlink available whilst experiments were in progress during the Euromir 95 mission.

Onboard system maintenance

As several of the station's modules have already spent a long time in orbit, planned and unplanned maintenance and repair activities absorb a considerable amount of crew time. Spare parts for all of the different ECLS systems and the electrical power-supply system were always available, with depleted stocks re-supplied via the Progress spacecraft visits.

As only a limited number of system parameters were displayed to the crew, a thorough assessment of system performance could only be made at the TsUP, where the complete telemetry data set was available. All maintenance and repair activities were therefore performed in close consultation with the respective system specialists at the TsUP.

Problems encountered during experiment operations

The combination of the specific working environment onboard the station and the designs of some of the Euromir 95 scientific equipment caused difficulties with the execution of some experiments. As a consequence, the allocated experiment time was exceeded and, in a few cases, the quantity and quality of the scientific data was degraded.

However, due to the extended mission duration and the fact that some of the time allocated for onboard engineering tasks could sometimes be used as a buffer for experiment operations, the additional unscheduled experiment time needed could be easily accommodated.

In general, three major problem areas, related to the allocation of space for equipment installation, the design of certain experiment equipment, and the technical means for communication, were identified during the Euromir 95 mission.

Allocation of space

Space for the installation and stowage of equipment proved to be one of the most critical resources aboard Mir. In a few cases, the locations foreseen for the installation of particular equipment items during the Euromir 95 flight were not available in practice, because other equipment had already been stowed there. Alternative locations therefore had to be identified and prepared on an ad-hoc basis.

One biomechanical experiment required a large working volume with an unrestricted field of view. The only area in the Mir station that came close to fulfilling these requirements was the core module. However, as the requirements were difficult to satisfy even there, excessive time was needed both for the equipment's installation and calibration and for experiment execution.

Experiment hardware design

As already mentioned, the Euromir 95 experiment equipment had to be largely self-contained. Generally speaking, it was assembled at the beginning of the mission, provisionally stowed and then installed in a suitable 'working-position' each time an experiment run had to be performed. With a few exceptions, the manufacturers had not provided their systems with adequate means for easy handling (loops, eyes etc.), nor were there sufficient aids for fixing the equipment in its storage/working location (rubber bands, belts, etc). It turned out that adhesive velcro patches could rarely be used, especially if the equipment was larger than about $30 \times 30 \times 30$ cm^3. Time was therefore lost in making improvised installations.

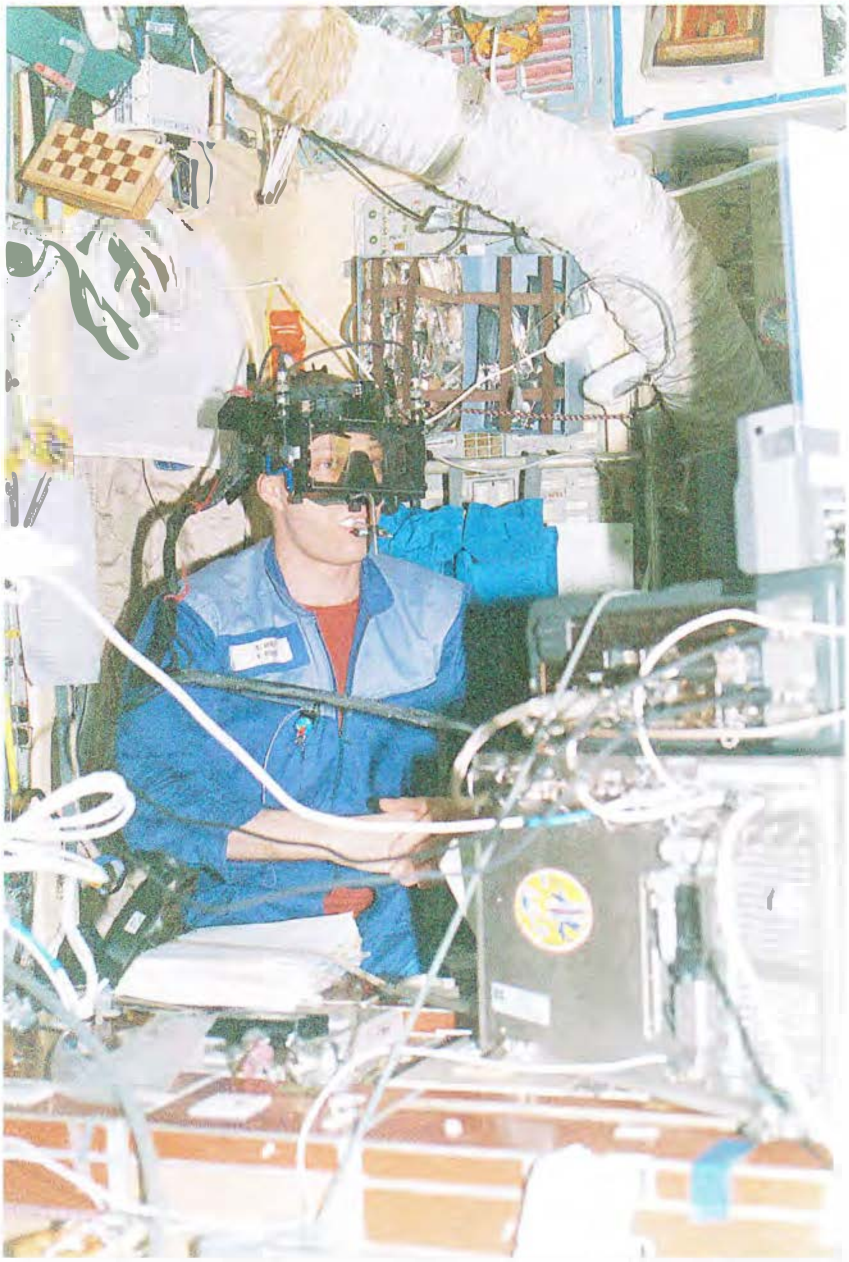


Figure 4. ESA Astronaut Thomas Reiter executing one of the many life-science experiments

The experiment hardware was operated for extended periods during this long-duration mission and consequently the probability of subsystem malfunctions increased with time. Of the total of 25 different experiment systems, 13 malfunctioned or behaved anomalously in the course of the flight. Five malfunctions were recovered exclusively with onboard means and ground support, four were resolved by uploading new equipment with Progress, and four could not be fixed at all as neither the means for an in-depth failure analysis nor appropriate tools were available. The technical documentation provided for the maintenance and repair of experiment equipment was often inadequate. In most cases the off-nominal procedures provided in the flight data file were insufficient to recover system malfunctions.

Communications and telemetry
Communication and telemetry turned out to be a bottleneck during the mission. In general, only the UHF-1 channel was used and the available communication time had to be shared between the crew members. Parallel use of the UHF-2 channel had to be requested separately by the Euromir 95 project team. At times when the station did not pass directly over Russian territory during daytime, only two or three communications sessions were available early in the morning or late in the evening, and total communication time was limited to a few minutes. Exceptionally, a voice/video link via the geostationary satellite could be organised during these periods.

The transmission of data for the setting-up of experiment equipment via the teletype system was not always reliable. Because transmission errors appeared as wrong alphanumeric characters on the printout, this data always had to be confirmed using the voice channel.

The file transfers from the ground to the station via one of the voice channels (usually UHF-1) and the packet controller system were reliable most of the time due to the inherent transmission error detection and correction. In the course of the mission, however, there were a few periods, of up to 7 days, when no up/down file transfers were possible at all.

The possibility to download scientific data files from the MIPS-2 controller via the Mir telemetry system was very helpful throughout the mission, even though the transmission rate was very low (in the order of a few kbit/s). However, the transfer of files larger than a few kilobytes appeared to be very prone to transmission errors. On some occasions, files had to be put into the telemetry queue up to five times before the information was correctly received on the ground, a process that could take up to two weeks.

Onboard engineering tasks

During the Euromir 95 mission, as the European astronaut I was nevertheless involved in a variety of generic onboard engineering tasks, including routine maintenance work on the thermal-control system, on life-support systems and on the preparation and conservation of all EVA equipment (space suits and onboard systems). Because not all onboard system parameters are displayed to the crew, the effects of certain steps during maintenance and repair activities had to be confirmed by the specialists in TsUP before the crew could continue their work.

A few non-nominal situations were encountered in the course of the Euromir mission, including a leak in the Kvant module's internal cooling loop, which required unplanned maintenance and repair work. These occurrences allowed experience to be acquired in the fields of overall system structure and functionality, system maintainability, man/machine interfaces and the decision-making process especially during non-nominal situations.

Conclusions

The scientific programme foreseen for the Euromir 95 mission was successfully completed during the 179-day flight. The flight extension beyond the originally planned 135 days, combined with the possibility to upload additional experiment hardware, spare parts and consumables with a Progress spacecraft, provided the scientific community with additional experiment time and allowed the Euromir 95 project team to gain additional operational experience.

Despite minor deficiencies in terms of stowage/working space, the bottlenecks in communications and data up/download capacity and the extra crew time required to maintain the onboard systems, the Mir station is without doubt a very good platform for conducting research in all of the different scientific disciplines. It is also an excellent environment in which to validate the experiment hardware and operational concepts for the forthcoming International Space Station Programme.

For future missions, however, the prevailing conditions onboard the station have to be taken into account more fully during the development of stand-alone experiment equipment. Given the increased risk of system malfunctions and non-nominal system performance during long-duration missions, the maintenance concept for scientific hardware needs to be improved to allow the crew to perform thorough failure analyses and repairs for even complex electronic systems.

Commercially available laptop computers and software were used extensively and very successfully by the crew for experiment control, data acquisition and storage during Euromir 95. Further developments in this direction, including the improvement of electronic procedures and certain onboard management tools, the provision of detailed technical reference documentation, computer-based (in-orbit) training, and the application of voice control, are therefore highly desirable in order to boost overall mission effectiveness in the future.

ESA Astronauts Thomas Reiter (left) and Christer Fuglesang (centre) with Russian Cosmonaut Yuri Gidzenko during survival training in Russia for the Euromir 95 mission

On-Board Training and Operational Support Tools Applying Web Technologies

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A computer-based training and failure-diagnosis system has been developed at the European Astronauts Centre in the context of the Mir missions. It makes extensive use of Web technologies to provide a novel and valuable environment in which astronauts can train themselves not only to carry out nominal/routine in-orbit procedures, but also to cope with non-nominal mission scenarios, in readiness for the International Space Station era.

Introduction

In preparing for the operation of the International Space Station (ISS), new approaches to astronaut on-board training are being considered. Emerging computer technologies like multi-media (usage of graphics, photographs, animation, sound and motion video) and the World Wide Web, together with the use of equipment simulators and the innovative application of instructional methodologies, are key elements in these new developments.

Mir 97, the 20-day German mission to the Russian space station Mir, scheduled for February 1997, is to be the test-bed for the Modular On-board Training Environment (MOTE), a series of experiments comprising an integrated training system that includes: a nominal-mission training lesson, a facility simulator, a non-nominal-mission training lesson, and a failure-diagnosis system. The facility chosen for these these training elements is the TITUS furnace, designed for conducting material-science experiments aboard Mir.

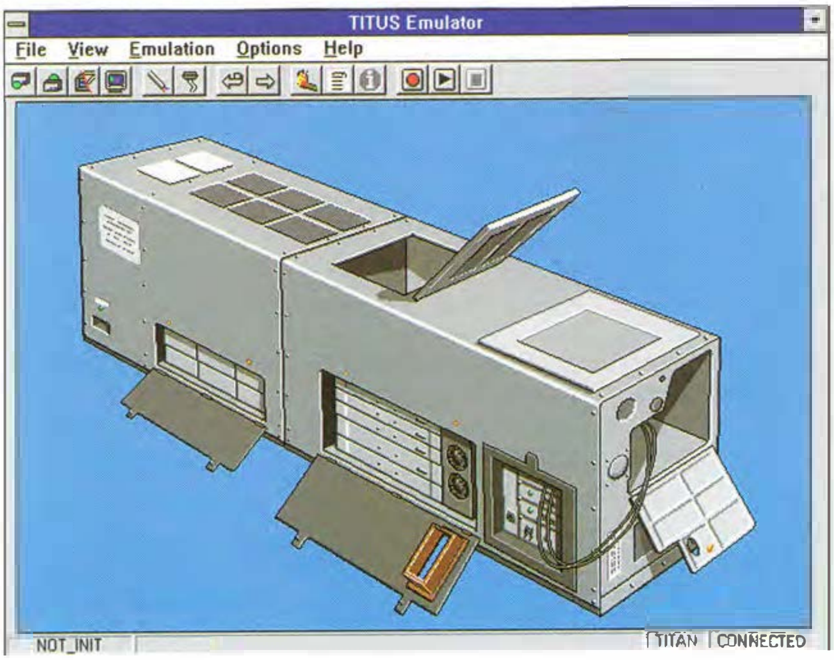


Figure 1. The facility emulator screen

The Modular On-board Training Environment (MOTE)

MOTE is the result of the integration of three originally self-standing elements:

- TITUS furnace emulator
- nominal-operations courseware
- non-nominal-operations courseware and a trouble-shooting tool.

TITUS furnace emulator

This is a high-fidelity simulation of the TITUS furnace, which receives commands from the facility-control software (TITAN, developed by DLR's Microgravity User Support Centre in Cologne, Germany) and generates responses and experiment data just like the real facility. The emulation provides a point-and-click interface to allow the astronauts to visualise, navigate around and interact with the furnace's exterior and interior. Using this emulation environment, the astronaut can perform the furnace procedures for the electrical installation and run the experiments. This includes such mechanical operations as connecting cables, installing experiment probes, opening and closing hatches, and actuating switches.

The emulator was developed by VEGA Space Systems Engineering GmbH, located in Darmstadt, Germany.

Nominal-operations courseware

This element trains the astronaut to perform nominal operations on the TITUS furnace, e.g. starting and shutting down the facility, loading and removing samples, loading an experiment run, starting the run and monitoring its progress. Much of the courseware is orientated towards the facility-control software. During the course of the experiment, some of the training material will be uploaded from the ground using Web technology.

The experiment was developed by the German Aerospace Research Establishment (DLR), located in Cologne, Germany.

Non-nominal-operations courseware and trouble-shooting tool

This courseware and trouble-shooting tool is used by the astronauts to identify the causes of failures in the TITUS furnace and to train in how to resolve them. It also provides instructions for a previously untrained-for maintenance activity on the furnace (tube heater cleaning operation).

This tool has been developed by EAC itself.

The MOTE architecture

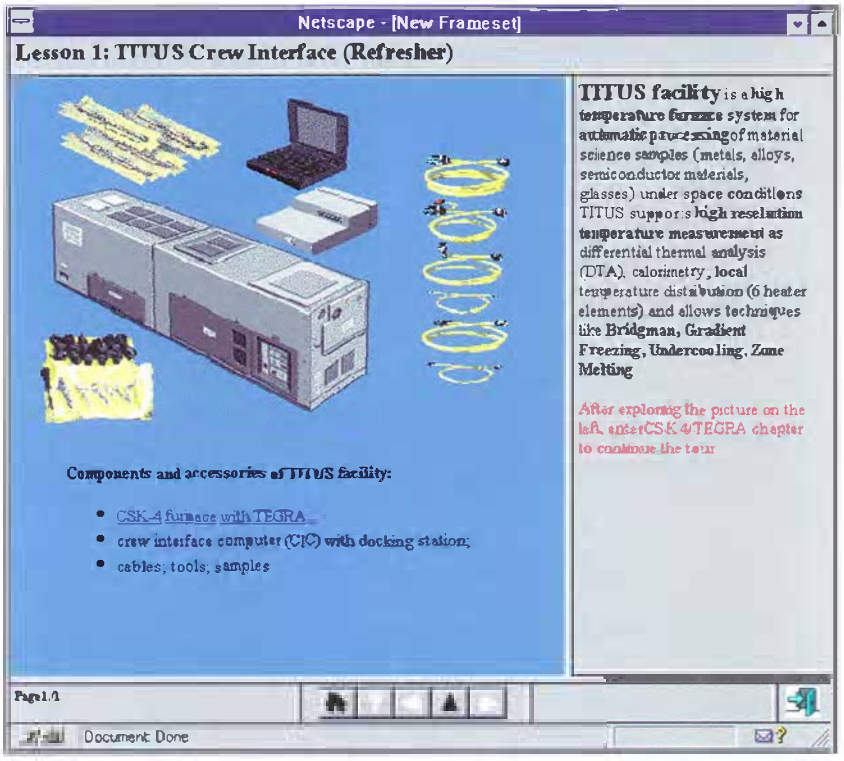
Whilst the above-described experiments will be performed in three separate sessions on-board (see below), their integration allows each of the components to make use of the other two. This interaction between components is illustrated in Figure 4.

The MOTE system, which runs under the Windows NT 3.51 operating system on the Mir 97 laptop (a 75 MHz 486 with 32 MB of RAM), contains the following software components:

1. Web-based courseware

This includes both nominal- and non-nominal-operations lessons, a typical lesson being based on:

- *Instructional material:* A set of lesson pages (HTML documents) containing text, graphics, animations and links to other pages
- *A lesson engine:* a program that is loaded when the lesson is called and which provides all of the elements necessary for the lesson's execution, including the user interface, page navigation, progress and contextual information, glossary of terms, etc. The lesson engine has been programmed in Javascript, a scripting language that is embedded in an HTML document and executed by a Web browser when received.



Lesson 1: TITUS Crew Interface (Refresher)

TITUS facility is a high temperature furnace system for automatic processing of material science samples (metals, alloys, semiconductor materials, glasses) under space conditions TITUS supports **high resolution temperature measurement** as differential thermal analysis (DTA), calorimetry, **local** temperature distribution (6 heater elements) and allows techniques like **Bridgman, Gradient Freezing, Undercooling, Zone Melting**

After exploring the picture on the left, enter CSK 4/TEGRA chapter to continue the tour

Components and accessories of TITUS facility:

- CSK-4 furnace with TEGRA
- crew interface computer (CIC) with docking station;
- cables; tools; samples

Figure 2. Nominal-operations courseware screen

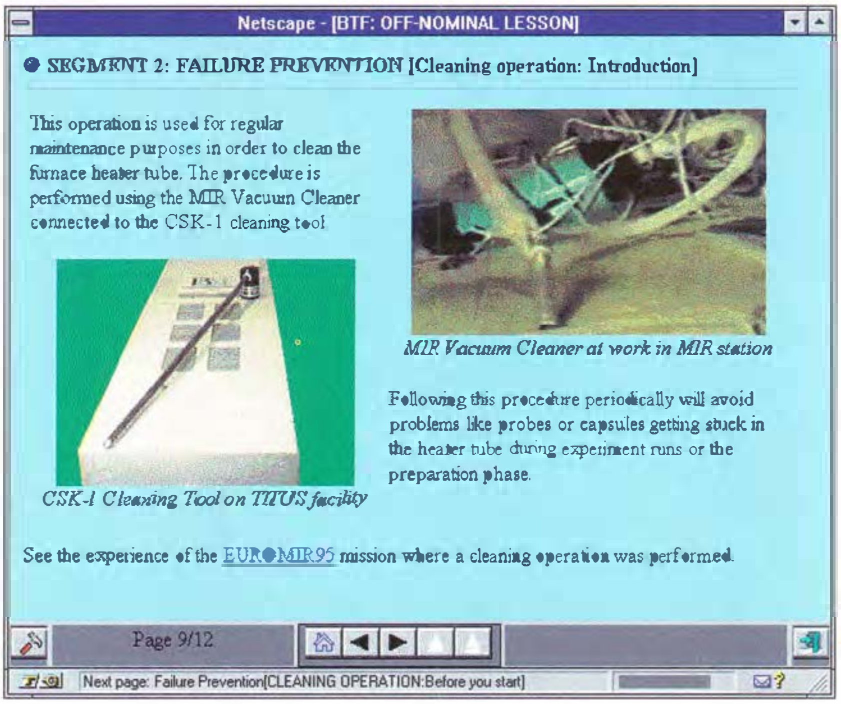
2. Web-based trouble-shooting

The trouble-shooting engine is a Javascript based program that contains all the components of the failure-diagnosis system (user interface, failure symptoms and failure estimations, symptom selection mechanism, estimation mechanism). The tool dynamically generates failure estimations and presents available reference material and non-nominal-operation courseware.

3. Web server

This off-the-shelf application gathers and distributes the above-described elements –

Figure 3. Non-nominal-operations courseware screen



● SEGMENT 2: FAILURE PREVENTION [Cleaning operation: Introduction]

This operation is used for regular maintenance purposes in order to clean the furnace heater tube. The procedure is performed using the MIR Vacuum Cleaner connected to the CSK-1 cleaning tool

MIR Vacuum Cleaner at work in MIR station

Following this procedure periodically will avoid problems like probes or capsules getting stuck in the heater tube during experiment runs or the preparation phase.

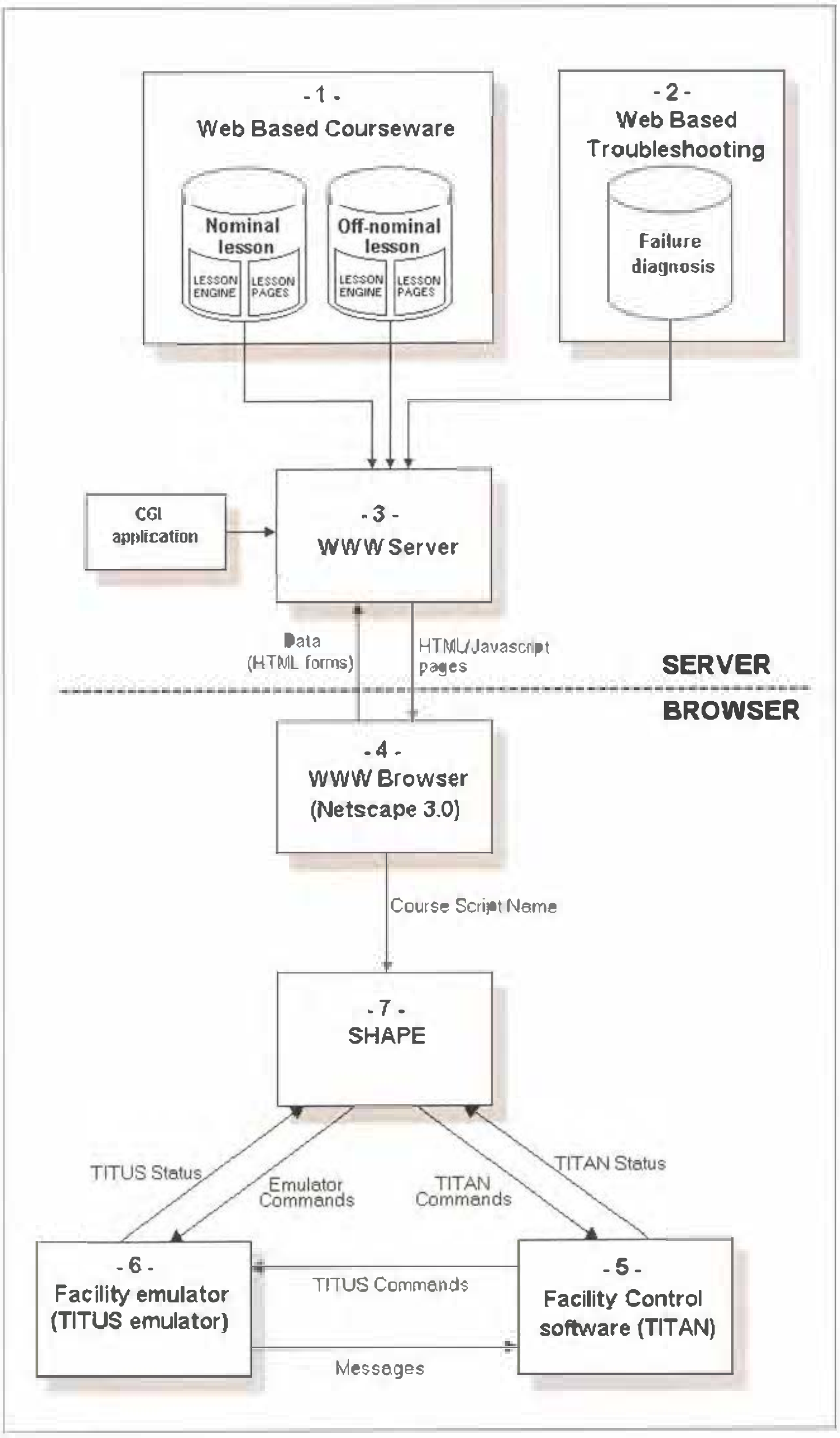
CSK-1 Cleaning Tool on TITUS facility

See the experience of the EUROMIR95 mission where a cleaning operation was performed.

lesson pages, lesson engine, trouble-shooting engine – when requested by Web browsers. In addition, a Web server can receive data coming from a Web browser and process it by executing a server-side application (CGI script).

4. Web browser (Netscape 3.0)
This commercial off-the-shelf application requests data from the Web server and processes it when received. Different actions will be performed by the browser based on the nature of the incoming data: a Javascript-based lesson or trouble-shooting engine will be executed; an HTML-based lesson page will be displayed on the screen; and a facility/control-software emulation session will be started when an emulation script is received.

Figure 4. MOTE system components



5. Facility-control software (TITAN)
This application provides the user interface for the complete control and monitoring of the TITUS furnace. With TITAN, users can define automated procedures to operate the furnace and subsequently load them in to be executed.

6. Facility emulator (TITUS furnace emulator)
This application can be run in stand-alone mode or can be controlled via the facility-control software, whereby the emulator substitutes for the real facility. In addition, both the emulator and the facility-control software can be controlled by scripts launched by both the nominal- and non-nominal-operation courseware.

7. Scripting Helper Application Engine (SHAPE)
SHAPE provides the interface between the courseware, facility emulator and the facility-control software. It allows authors to create scripts that can be launched from an HTML link in the courseware and execute the emulator and/or the control software. These scripts can be used to run a simple animation of a procedure in the emulator, or to ask the astronaut to perform a complex task (with guidance and help between each step) using the emulator and/or the control software, allowing the astronauts to continue only when they have performed it correctly.

Web-Based Training
Computer-Based Training (CBT: training delivered on a computer) is rapidly taking advantage of all of the emerging technologies in the form of Web-Based Training (WBT), an innovative approach in which the WWW is the vehicle for delivering training. An increasing number of organisations, universities and industrial corporations have already chosen WBT to implement their training strategy due to its many advantages, which can be summarised as follows:

Time- and place-independence
Users can access the training system whenever and wherever they want. A team of trainees can be brought together from around the globe, and/or instructors can coordinate instruction with colleagues from other locations. All of this provides a new scenario for collaborative training which is difficult to implement using instructional settings other than WBT.

The World Wide Web (WWW)

The WWW (or Web, for short) is a wide-area client/server architecture for exchanging hypermedia information across the Internet network. In this distributed environment, the information is transferred between Web servers (information providers that store and distribute WWW documents) and Web browsers (client applications such as Netscape™ or Mosaic™ that retrieve and display these data).

Web pages (WWW documents) are formatted in HTML (HyperText Markup Language), which consists of a set of tags to create hypermedia documents i.e. multimedia pages containingtext, graphics, sound and video, that include hyperlinks (clickable areas on the screen linking to other documents).

Figure 5 shows an example of the interaction between Web servers and browsers. A user in Computer-A accesses a Web page which is served by Computer-B. The loaded Web page can contain hyperlinks to other pages that may be in the same Web server or anywhere else on the Internet. 'Navigating' through the WWW, information is accessed in a non-linear way, unlike 'traditional' book-like documents where the text must be read sequentially (from top to bottom).

A special feature of the WWW is that it is a heterogeneous, flexible environment; i.e.

- Different available communication protocols can be used to retrieve documents over the network, including: FTP (File Transfer Protocol), SMTP (Simple Mail Transfer Protocol), and HTTP (HyperText Transfer Protocol), the latter being specifically designed for the transmission of WWW documents between Web servers and browsers.
- Platform independence: Several operating systems (UNIX, OS/2, Windows 3.1/95/NT, Macintosh) have their own version of a Web browser. This means that it does not matter which platform is used to generate the HTML documents, or the environment where the Web server resides – the information is equally accessible by a Web browser.

Evolution of WWW

Since its birth in the late 1980s at CERN (European Centre for Nuclear Research), the WWW has become tremendously popular and has evolved quickly, adopting new technologies along the way. The most significant ones include:

- Helper applications

  A helper application is an external program that can handle a specific type of file (e.g. an MS Word document) that the Web browser is not able to 'understand' by itself. These external applications are not integrated into the Web browser program and therefore require a new window to be opened when launched (data cannot be embedded in the HTML page).

  MOTE uses this feature to run SHAPE as an external (helper) application when an emulation script is received by the Web browser.

- Plug-in technology

  Like helper applications, plug-in technology extends Web browser compatibility with new types of data; the difference is that plug-ins are dynamic software modules that are completely integrated into the browser program. A plug-in allows the information to be presented as a part of a larger HTML document (e.g. multi-media animations or videos). Since their introduction, a growing number of independent software developers are creating new plug-ins to make Web browsers compatible with their own applications.
- Server-side processing

  CGI (Common Gateway Interface) technology allows the Web server to process information coming from the browser, dynamically create an HTML page, and send it back to the client, thereby adding more interaction between Web servers and browsers. CGI programs are located on the server side and can be written in several programming languages.

  In MOTE, a CGI Perl script stores information that the browser sends to the server (questionnaire responses).

- Client-side processing

  Languages like Java or Javascript represent the next logical step in the WWW's evolution. In the past, a Web browser was only able to display incoming information from Web servers (and eventually send information by using forms). With Java, client-side applications are embedded in the HTML document and, once loaded in the Web browser, are executed using the client's own computer processing power. The result is more dynamic and interactive Web pages and optimisation of data transfer between server and client.

  The lesson and trouble-shooting engines used in MOTE make use of this technology.

- Virtual reality

  VRML (Virtual-Reality Modelling Language) has become the standard language for the representation of three-dimensional virtual worlds within the World Wide Web. With VRML-enabled Web browsers, users can author and view interactive 3D scenes that include text, pictures, animations, sound and video. Moreover, the same world can be 'interacted with' by multiple users located at different sites.

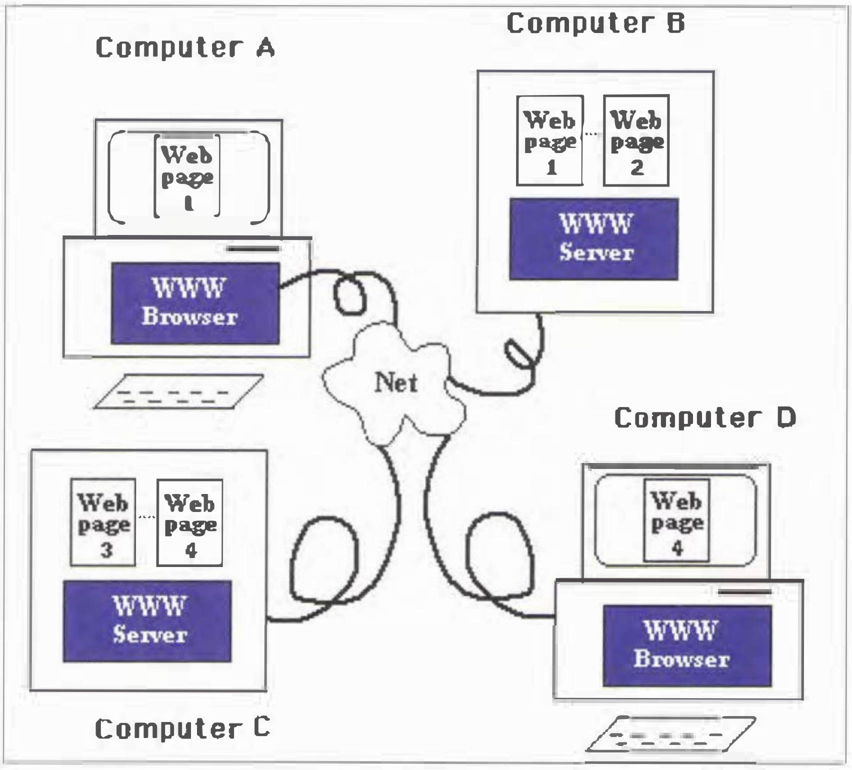


Figure 5. Example of the interaction between Web servers and Web browsers

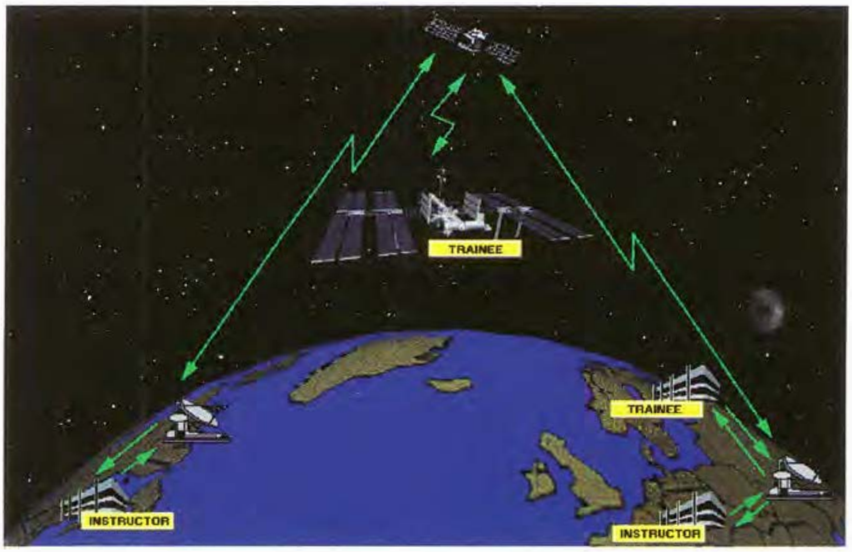
Multi-platform capabilities

The WWW is platform-independent by nature in that the browsers are developed for the different platforms but making use of the same data formats and protocols. Users at different locations can be using different systems (operating systems, computers) without affecting training efficiency and performance.

Easy updating of instructional material

Updating Web-based instructional material (Web pages) is easier and quicker – and therefore cheaper – than other kinds of delivery support (eg. CD-ROM). On-line access minimises redundancy of information, in that the lesson contents are stored on a reduced number of Web servers, and consequently also the effort spent on updating.

Figure 6. Example scenario for WBT



Interactive environment

A good application of multi-media and instructional methodologies results in highly interactive user interfaces that enhance training efficiency A networked environment adds the possibility of interaction between users (instructor – trainee, trainee – trainee, and instructor – instructor).

Performance control

Web technologies allow the immediate monitoring of trainees' activity (logging access, training-session performance, test evaluation). This can only increase feedback and improve the quality of training.

Use of existing tools

An Internet-based environment such as WBT provides a number of utilities that complement the training activity, including: use of e-mail, BBS (Bulletin Board Systems) or WWW itself to search for additional information, and real-time conferencing (text or video based).

On the other hand, the current state of development of such a new technology also has disadvantages:

Limited bandwidth

A growing number of WWW users, the use of memory-intensive data (sound, motion video, sophisticated graphics), and the limited bandwidth of the Internet connections results in slower performance For this reason, today's Computer-Based Training platforms that require high multi-media capabilities are based on stand-alone platforms and CD-ROM media delivery. Meanwhile WBT developers are combining techniques like data compression, efficient Web page design, and server/client-side programming to cope with this limitation.

Advances in computer network technology and improved bandwidth will result in capabilities for better multi-media access. Already available WWW-based features like 3D virtual reality, animations, conferencing, and real-time audio and video will be powered with these improvements.

In this direction, the Internet-II project (a recent agreement between several US universities, supported by the US government and industry) will be developed to exploit the capacity of broadband networks to support multi-media communications, real-time collaboration, and other functions that can advance distance education. The network is expected to be developed over the next 3 to 5 years.

Security

Being a worldwide public network, the Internet allows the sharing of information among users distributed around the world. This feature can also be seen as a disadvantage when the information must be protected against misuse and unauthorised access.

The use of Intranets (private networks contained within an enterprise using Internet protocols) is common among organisations which want their information secured against external intruders. Large enterprises allow connection beyond the Intranet to the Internet through firewalls (servers that have the ability to screen messages in both directions so that company security is maintained). Another safety strategy is the use of 'tunnelling' protocols that allow the creation of a secure network through 'tunnels' over the public Internet.

Poor authoring environments

Today's authoring environments for WBT are currently far less evolved than those provided for multimedia CBT, but this is changing very rapidly. Authoring software for WBT is currently following two approaches:

- The first approach is that followed by companies and research organisations which develop WBT courseware using the WWW as a scenario. They employ WYSIWYG HTML editors (Web-page designers that do not require knowledge of HTML) and client/server programming (i.e. CGI, Java and Javascript applications).
- The second approach is being followed by CBT/multi-media experienced companies that already have powerful authoring environments. By developing interfaces between these applications and the WWW (using plug-in technology), they solve the problems of authoring and Web delivery concurrently.

We will now move on to analyse some of the special requirements imposed by the new International Space Station (ISS) distributed and on-board training scenarios, and then show how Computer-Based Training, and in particular Web-Based Training, are well-suited to meeting these requirements.

Training in the ISS era

The International Space Station (ISS) Programme is a joint effort involving five international partners: NASA, RSA, ESA, NASDA and CSA. A primary purpose of the Station is to provide a permanent low Earth orbit research facility with which to perform microgravity experiments in a variety of disciplines: life sciences, materials science, technology, etc.

During the Station's planned operational lifetime of some 15 years, its on-board science facilities will be used continuously in orbit by scientists and astronauts for long periods of time. It will also be the focus of activity for thousands of researchers across the world who will monitor and operate experiments from the ground.

Thus, the personnel involved in ISS training activities span a wide range of cultures, locations and individuals: astronauts (payload specialists, mission specialists), ground-based scientists and ground support personnel must know how to perform the experiments for a particular mission and be familiar with the on-board and on-ground facilities. The training materials required to achieve this can include simulators and Computer-Based Training that will be used at different locations around the world many times. The multi-national nature of the ISS means that the different individuals involved in training (subject-matter experts, scientists, instructors, astronauts) and the training material can be located in different countries.

WBT appears to be an ideal training instrument in such a distributed environment.

In-orbit/On-Board Training (OBT)

Once fully operational, the ISS will host from three to six people at a time, a typical astronaut mission lasting from 3 to 5 months in orbit. In this scenario, crew members will combine station maintenance tasks with the development of research activities, and will eventually have to deal with non-nominal situations (due to unexpected experiment results, changing environments or facility malfunctions with different potential hazard levels).

Although most on-board activities will be the subject of pre-flight training, On-Board Training will still play a key role in many cases:

- *Proficiency/refresher training:* In the context of a long-duration mission, OBT must be applied to maintain astronaut skills in terms of theoretical/practical knowledge of systems and payloads, immediate/automated response in emergency situations, and proficiency training for psycho-motor skills for robotics, EVA and time-critical tasks.
- *Non-nominal situations and malfunctions:* Training is needed for activities not easily practised on the ground in normal gravity, such as emergency egress (fire,

contamination), hatch opening/closing, or moving large masses during IVA/EVA.
- *Just-in-time training:* This covers tasks requiring little or no previous training and/or knowledge. Here, most objectives can be accomplished with training just prior to or during the execution of a given task. This approach will be targetted primarily at low-criticality, low-complexity, non-safety-related, and unforeseen in-orbit tasks,
- *Handover training:* Task-specific training will be required for shift or flight-crew handovers.

On-Board Training applying WBT

WBT is especially well-suited for implementing certain types of on-board training – proficiency training, refresher training, training on non-nominal situations and malfunctions – benefiting from both CBT and Web technologies. To justify this claim, we must address key requirements that the ISS framework will present:

Req. 1: Flexibility (easy updating of training and reference material)

The available computer-based material developed to train ISS crew members will evolve continuously as more experience is gained in the use of the Station. New lessons (nominal and non-nominal) will be identified and developed continuously and existing lessons will be subject to revision. The same logic can be applied to systems and payload reference information. In a Web-based environment, this updating is immediate.

Req. 2: On-ground/on-board common information

The sharing of information between ground-based personnel and crew members not only avoids data inconsistencies and facilitates updating, but also improves communication between the different users. Assistance during training is optimised when both the instructor and the trainees have exactly the same information on the screen. The same situation occurs when using any kind of software application that may require supervision or support from a remote expert.

Req. 3: On-ground/on-board common user interface

OBT is best achieved when the trainee is already familiar with the training environment. WBT has been presented in this context as a suitable element with which to train ISS on-ground personnel (including astronaut pre-flight training). Its extension to on-board training means that crew members will not need to adapt to a new training environment.

Req. 4: Access to ground-based scientific information

Accessing ground-based scientific material and communication with ground-based scientists will be common requirements for ISS crew members. The WWW provides an integrated environment in which the worldwide scientific community can communicate and share information (e-mail, file transfer, Web access).

Req. 5: Integration of training with on-board operational environment

WWW applications are already present on millions of computer desktops distributed around the world. The computer industry is evolving very quickly towards an integrated platform where all software applications are structured on a WWW foundation. Training and operational support tools are no exception and their level of integration with the WWW will increase in the coming years.

Req. 6: Platform independence

The worldwide community that is contributing (and will contribute) to the ISS project is a very heterogeneous one. Taking advantage of its inherent multi-platform capabilities, the WWW allows users to design, develop and deliver training regardless of the operating system or computer used.

Req. 7: High level of security

The operationally controlled environment of a Space Station requires a high level of access and security control that MUST be enforced. A great deal of effort has to be devoted in order to foresee controlled, monitored updating of onboard electronic information. Whilst this implies an additional effort in the development phase, it will guarantee that information exchanges with the Station are free from the hazards of unforeseen and unplanned communication.

Web-Based Training, despite its current limitations (Internet's limited bandwidth presently being the most prevalent), meets the requirements presented above, making it a very valuable candidate for both ISS on-ground and on-board training.

Mir 97 on-board experiment: a WBT test case

One of the European Astronauts Centre's contributions to the Mir 97 mission is an on-board training experiment consisting of a non-nominal-operations lesson and a trouble-shooting tool, as mentioned earlier in this article. The goals that led to the development of this experiment were:

- the validation of CBT as a suitable tool for supporting astronauts during long-duration missions
- the validation of the ability of computer-based tools to provide operational support to astronauts in non-nominal situations
- the testing of these capabilities on a manned spaceflight mission in preparation for the International Space Station
- the promotion of the World Wide Web as a tool for delivering on-board CBT for manned spaceflight
- the promotion of the use of integrated training environments where facility emulators are used, together with nominal- and non-nominal-operation courseware and failure-diagnosis tools.

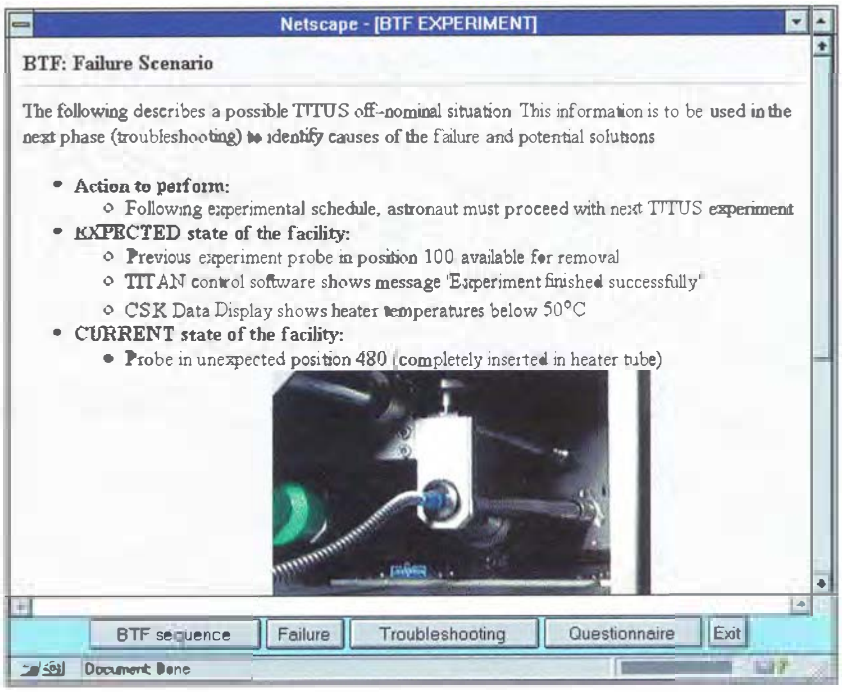
Experiment execution

The software will be uploaded to Mir via Soyuz TM-25 at the start of the Mir 97 mission. The experiment itself is scheduled for flight day 10 and has five phases divided over two sessions: an on-board session comprising failure presentation, failure identification, presentation of failure solution and questionnaire, and a later post-flight session:

- *Phase 1: Failure presentation (on-board, approx. 10 min)*
  The astronaut is confronted for the first time with a non-nominal situation which involves a TITUS furnace failure. The scenario is presented in the form of a description and does not involve the real facility.

- *Phase 2: Failure identification (on-board, approx. 15 min)*
  A trouble-shooting session is started in which the astronaut can look for symptoms presented in a structured list, select the ones matching the failure and request a diagnosis. The system will provide a list of failure estimations (sorted by probability) with possible causes, required actions and reference material. One of the elements available in the reference material is in fact a link to a non-nominal-situation lesson that provides all information necessary to cope with the failure.

- *Phase 3: Presentation of failure solution (on-board, approx. 25 min)*
  A non-nominal lesson starts loading the lesson engine, which provides the lesson user interface and contains the lesson structure. Using the navigation bar and lesson hyperlinks, the user will access the instructional material in order to understand what caused the failure, how to solve it and how to avoid it in the future.



BTF: Failure Scenario

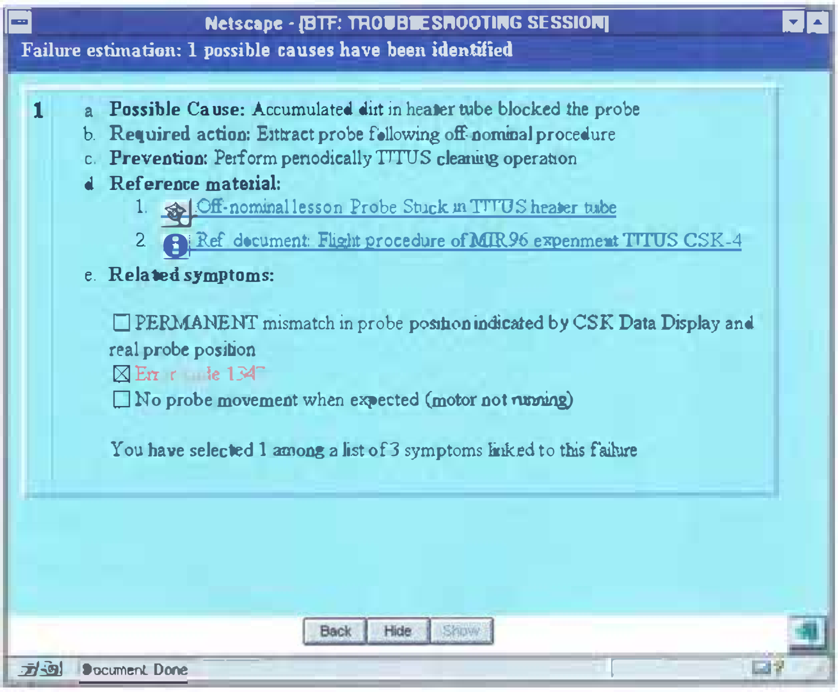
The following describes a possible TITUS off-nominal situation. This information is to be used in the next phase (troubleshooting) to identify causes of the failure and potential solutions

- **Action to perform:**
  - Following experimental schedule, astronaut must proceed with next TITUS experiment
- **EXPECTED state of the facility:**
  - Previous experiment probe in position 100 available for removal
  - TITAN control software shows message 'Experiment finished successfully'
  - CSK Data Display shows heater temperatures below 50°C
- **CURRENT state of the facility:**
  - Probe in unexpected position 480 (completely inserted in heater tube)

Figure 7. Failure presentation

- *Phase 4: Experiment questionnaire (on-board, approx. 10 min)*
  The astronaut is asked to complete a questionnaire about the experiment itself (trouble-shooting tool, lesson layout, navigation concept).

- *Phase 5: Post-flight session*
  The astronaut performs the non-nominal procedure to solve the problem (the ground-engineering model of TITUS facility is used here) and provides more detailed feedback about the overall failure-recovery environment.



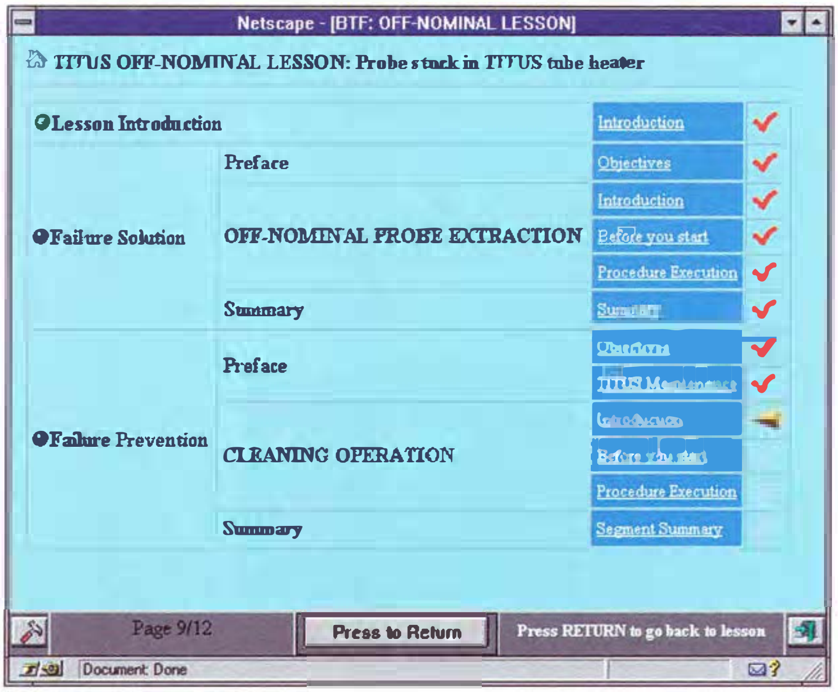
Failure estimation: 1 possible causes have been identified

1
a. **Possible Cause:** Accumulated dirt in heater tube blocked the probe
b. **Required action:** Extract probe following off-nominal procedure
c. **Prevention:** Perform periodically TITUS cleaning operation
d. **Reference material:**
   1. Off-nominal lesson Probe Stuck in TITUS heater tube
   2. Ref. document: Flight procedure of MIR96 experiment TITUS CSK-4
e. **Related symptoms:**

☐ PERMANENT mismatch in probe position indicated by CSK Data Display and real probe position
☒ Error code 1347
☐ No probe movement when expected (motor not running)

You have selected 1 among a list of 3 symptoms linked to this failure

Figure 8. Trouble-shooting session



TITUS OFF-NOMINAL LESSON: Probe stuck in TITUS tube heater

Lesson Introduction		Introduction	✓
Failure Solution	Preface	Objectives	✓
	OFF-NOMINAL PROBE EXTRACTION	Introduction	✓
		Before you start	✓
		Procedure Execution	✓
	Summary	Summary	✓
Failure Prevention	Preface	Objectives	✓
		TITUS Maintenance	✓
	CLEANING OPERATION	Introduction	
		Before you start	
		Procedure Execution	
	Summary	Segment Summary	

Press RETURN to go back to lesson

Figure 9. Non-nominal-operation lesson (table of contents)

Main experiment features

Web-Based Training

The information used in the experiment is provided by a Web server and accessed and displayed by a Web browser. All the elements have been developed using Web technologies (HTML, Javascript, CGI). However, in the on-board environment, the experiment itself is not integrated on a computer network (server and browser are in the same machine) because of the station's limited resources in terms of available computers and ground connections.

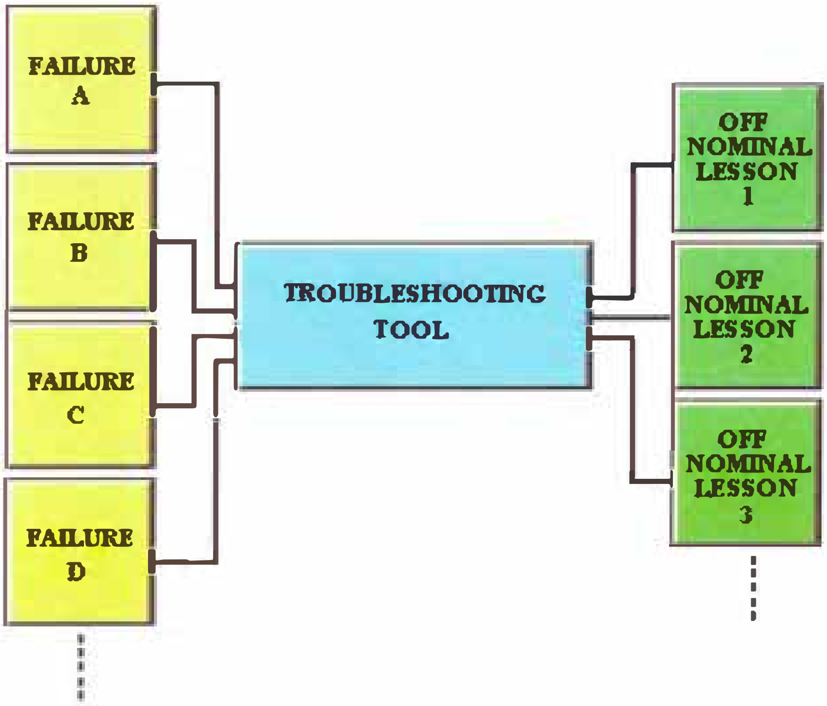


Figure 10. Experiment architecture
N failures, 1 trouble-shoot, and M lessons

Modularity

The main elements of the experiment (failure presentation, trouble-shooting and non-nominal lesson) are completely independent modules that are interconnected. The system can grow, adding new failure scenarios, and non-nominal lessons will trouble-shoot the connection between them.

Computer-Based Training standards

The non-nominal-situation lessons (two have been developed for the experiment) are designed in a modular fashion, with the instructional material (lesson pages) independent from the 'lesson engine' (lesson layout, navigation mechanism, tools), thereby facilitating updating and the creation of new lessons. The design of the lesson user interface and the lesson structure is based in current CBT guidelines (NASA standards) that have been carefully reviewed and adapted.

Experiment development

Web browsers/servers employed

The experiment is based on the popular Web browser from Netscape^{TM}, taking advantage of the new features included in its latest version (3.0, released in August 1996 and available on 16 different platforms). On the server side, the EMWAC (European Microsoft Windows NT Academic Centre) HTTP server provides all of the information requested by the browser. The experiment has been developed in a networked environment and successfully tested using Netscape 3.0 for the following three platforms: Windows 3.1/95/NT, Macintosh and UNIX.

Trouble-shooting implementation

The 'trouble-shooting engine' is a piece of software completely programmed in Javascript (object-based scripting language embedded in a HTML page), and takes advantage of the new features present in its latest version (included in Netscape 3.0). It performs the following tasks:

- definition of all data structures (tables) with failures, symptoms, estimations and relations between them
- provision of a user interface to allow trouble-shooting (display/selection of failure symptoms and failure estimations)
- diagnosis of possible failures based on user-selected symptoms and presentation of failure estimations sorted by probability (this is done by scanning the relational symptom-failures tables)
- generation of HTML pages 'on-the-fly' that contain hyperlinks to non-nominal lessons and/or reference material (e.g. 'Mir 97 flight procedure for TITUS facility').

Non-nominal lesson implementation
As previously mentioned, the non-nominal lesson is based on two modules: the instructional material (lesson pages) and the lesson engine:
- the lesson pages are formatted in HTML version 3.0 and make extensive use of Netscape™ frames (a recent extension of HTML that makes it possible to divide Web pages into multiple, independent, scrollable regions); to create these pages, the 'HTML Assistant Pro 2' authoring tool has been used
- the lesson engine, like the trouble-shooting engine, has been programmed using Javascript; it provides contextual information to guide the user during the course of a training session.

Future improvements

The implementation of an interface between engines and external databases will increase modularity and flexibility, allowing the trouble-shooting engine to be independent of actual symptoms, failures and estimations, and the lesson engine to be independent of lesson structure and content. It will also allow the dynamic updating of troubleshooting and lesson elements by different users.

New elements can be added to the lesson engine to improve lesson layouts and hence training efficiency, e.g. a graphical representation of the overall lesson and the trainee's position therein at any given time.

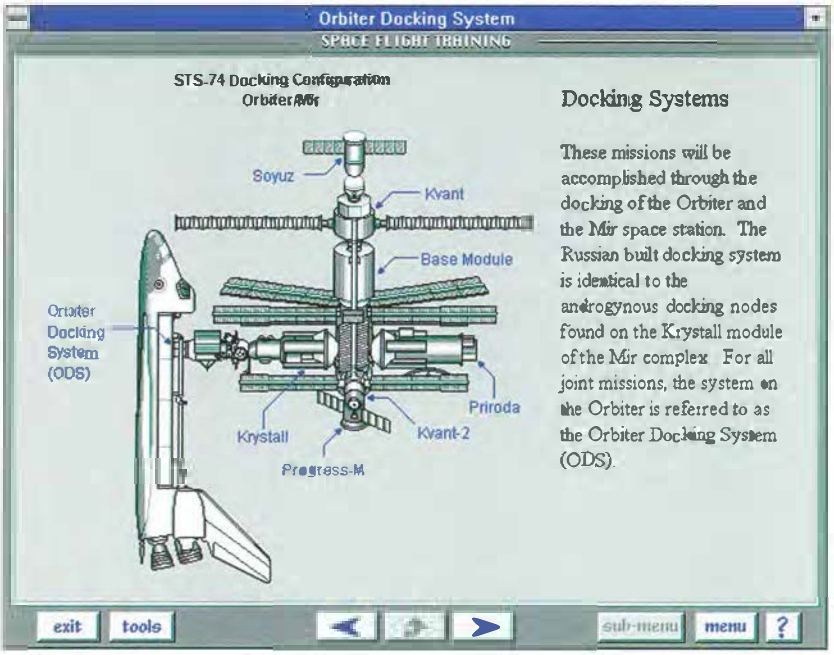
The trouble-shooting engine can be improved by the inclusion of more 'intelligent' diagnosis methodologies (e.g. use of neural-network technology, assigning dynamic weights to symptoms or groups of symptoms when related to different failures and assigning thresholds to estimations that will only be activated when a given number of associated symptoms are selected).

Tutor support and communication between users can be upgraded by the inclusion of a type of Bulletin Board System (BBS) in the lesson environment to allow users to exchange messages at any time.

The development of an authoring environment that allows one to easily define and include new lessons and non-nominal scenarios will complement the lesson/trouble-shooting engines, allowing the system to grow with contributions from different lesson authors.

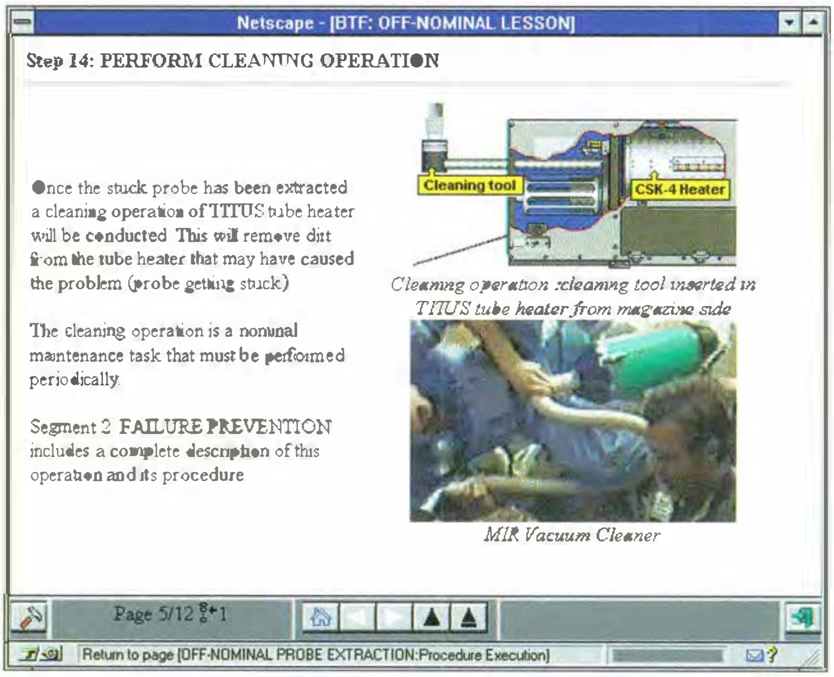
Conclusion

Web-Based Training is an emerging multi-media, distributed, interactive, platform-independent technology for the preparation, delivery and implementation of training in a distributed and heterogeneous environment.



Docking Systems

These missions will be accomplished through the docking of the Orbiter and the Mir space station. The Russian built docking system is identical to the androgynous docking nodes found on the Krystall module of the Mir complex. For all joint missions, the system on the Orbiter is referred to as the Orbiter Docking System (ODS).



Step 14: PERFORM CLEANING OPERATION

Once the stuck probe has been extracted a cleaning operation of TITUS tube heater will be conducted. This will remove dirt from the tube heater that may have caused the problem (probe getting stuck)

The cleaning operation is a nominal maintenance task that must be performed periodically.

Segment 2 FAILURE PREVENTION includes a complete description of this operation and its procedure

Cleaning operation :cleaning tool inserted in TITUS tube heater from magazine side

MIR Vacuum Cleaner

Return to page [OFF-NOMINAL PROBE EXTRACTION:Procedure Execution]

Figures 11a,b. A NASA CBT lesson page and an EAC experiment lesson page

In this article, we have shown how Web technologies can be applied to a Space Station on-board facility to provide an integrated operational support environment that the astronauts and ground personnel can use cooperatively to cope effectively and efficiently with both nominal and non-nominal mission situations.

Acknowledgement

The authors would like to thank A. Pidgeon, R. Henderson and W. Peeters for their kind support during the preparation of this article.

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