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Development and Operations in the Dutch Utilisation Centre

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ABSTRACT
At the early beginning (1989) of implementation of the EuropeanUser SupportOrganisation (USO) concept, development and implementation of a Dutch Utilisation Centre (DUC) started at NLR premises. After development of several pilot DUC facilities, DUC participated in a Columbus simulation mission and in the 2nd International Micro-gravity Laboratory mission (IML-2). Different ground segment configurations were set up at different locations to meet the specific requirements for the missions. DUC development focuses on achieving a flexible support concept in teleoperations, telerobotics and visual (video) information processing and presentation, using different communication concepts and video equipment. The configurations are prepared for the purpose of future missions onboard International Space Station. Support will be provided to both experiments and systems operations, such as operations with the European Robotic Arm (ERA).
The paper will describe the technical set-up of the DUC, focusing on the communication infrastructure and the ground segment systems for receiving the various data streams.

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ABSTRACT. At the early beginning (1989) of implementation of the European User Support Organisation (USO) concept, development and implementation of a Dutch Utilisation Centre (DUC) started at NLR premises. After development of several pilot DUC facilities, DUC participated in a Columbus simulation mission and in the 2nd International Micro-gravity Laboratory mission (IML-2). Different ground segment configurations were set up at different locations to meet the specific requirements for the missions. DUC development focuses on achieving a flexible support concept in teleoperations, telerobotics, and visual (video) information processing and presentation, using different communication concepts and video equipment. The configurations are prepared for the purpose of future missions onboard International Space Station. Support will be provided to both experiments and systems operations, such as operations with the European Robotic Arm (ERA).
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1. INTRODUCTION

In 1989, the European Space Agency (ESA) set up an international team, with NLR participating, to establish better concepts for the utilisation of the relatively expensive research facilities on board of spacecraft. This team worked on the concept of a User Support Organisation (USO) (Ref.1). A key element in this concept is the establishment of utilisation centres relatively close to the scientific user groups, offering utilisation support services. Several ESA member states have adopted and implemented the concept of Utilisation Centres.

1.1 THE USO CONCEPT

Backbone of the defined USO concept comprises an infrastructure of co-operating and interlinked (national) elements. The idea was that each nation would realise a national point of support: the National Utilisation Centre, that would serve as an entry point for scientists, and that would provide support in the process of defining, designing, developing, operating and possibly even evaluating an experiment. Five potential fields of support were foreseen: familiarisation, administrative support, scientific support, technical support and operational support.
Each Utilisation Centre has the freedom to implement support up to a level and nature that best fulfils the national needs. In the USO concept Utilisation Centres can become Facility Responsible Centre. This implies that the centre has special expertise and operations responsibility for one or more specific multi-user facilities.
On a European level the various national Utilisation Centres would be united in a so-called E-USO.
Task of this organisation was foreseen to perform overall co-ordination of activities and maintain a certain

level of mutual awareness of the individual centres. The E-USO has not yet been realized.
Since the publication of the USO concept some years have passed. In some countries national activities to implement user support have emerged. Progress is slow, caused by the fact the Space Station, with its continuous experiment capability, is not yet available and current flight opportunities are minimal. Many countries decided to adapt the level of user support to the amount requested by the scientist.

1.2 THE DUTCH UTILISATION CENTRE

In addition to participating in the ESA-team, NLR played an active role in the establishment of the Dutch Utilisation Centre (DUC) at NLR premises (Ref.2). The DUC provides microgravity users (and other scientists interested in performing experiments on board of spacecraft) with (mainly) technical support. Various tools have been developed to facilitate among others:
- communication between crew member (astronaut) and Principal Investigator (PI);
- on-line real-time processing of scientific data;
- remote experiment operation by the ground-based PI.

The development and implementation of DUC is focused on the following utilisation aspects:
- promotion of decentralised operations support, with a strong involvement of the users;
- international cooperation, as was derived in the IML-2 mission, with ESA/ESTEC, MUSC (Germany), CADMOS (France), MARS (Italy), and other UCs in Europe;
- follow standards and practices within the European Space community concerning payload development (payload end-to-end process) and communication;
- technical and operational support, including training, payload development, and communication;
- recommendations for automation and robotics servicing, and teleoperations with crew intervention rather than crew operations.

In 1994, the use of the DUC has been demonstrated twice. The DUC was involved successfully in a realistic manned mission demonstration, simulating activities of ground-based Principal Investigators (PI) and Space Station crew. During the second International Microgravity Laboratory mission (IML-2), a critical point experiment was supported. In this experiment the DUC provided on-line support to the remote science team. In addition, DUC supported preparation of experiments onboard the D-2 mission, and later on, for the Euromir mission. Other experiments and operations have been performed in the area of Automation & Robotics (A&R). For more information, see reference 7.
Many development activities have been supported by the Netherlands Agency for Aerospace Programmes NIVR, and have been performed under contract with ESA.

2. CREW SUPPORT

One of the objectives of (operational) support is to increase the chances of successful experimentation in a space laboratory, by providing the scientist with possibilities to operate or interact with his experiment. This way the user is brought into close contact with his experiment during actual execution.
The crew is in a situation where they can interact directly with the experiment, when tasks have to be performed that cannot be done by teleoperation. In the Spacelab era, training of crew for all foreseen tasks was feasible, as the mission duration was limited. In the Space Station era, however, both mission duration and the amount of experiments will dramatically increase. Hence, thorough training of the crew for all possible situations and all experiments will not be feasible anymore. To ensure that the crew members can still support ongoing experiments, even in contingency situations, the tools and procedures must be provided on board, by means of crew support systems. Recent activities of the DUC included the development and verification, under operational circumstances, of a laptop computer for crew support

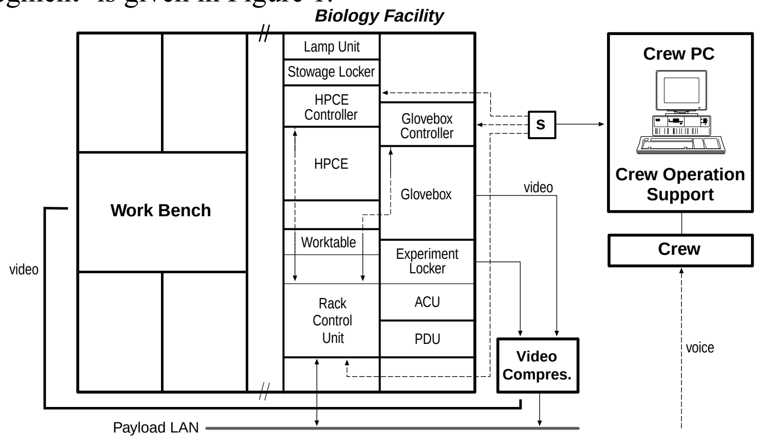
purposes: the Crew Portable Computer (CrewPC), and later the Advanced Crew Terminal-ACT. These crew support systems increase the efficiency of the communication between ground-based scientist and the crew member, and provide the crew with access to information on the experiment in the form of multimedia documentation and crew procedures (Ref.3).
By using two support systems, one on ground (the GroundPC) and one on board (the CrewPC), each containing the same applications and experiment databases, a synchronising mechanism enables easy communication between space and ground. Both systems were equipped with identical (experiment/ facility dedicated) multimedia databases, that could be controlled from ground and space. In this way it is possible for the user and the crew to communicate by means of annotations and drawings, and for the user to monitor the crew activities. During the manned mission demonstration, this synchronisation concept showed to be very efficient and indeed decreased the ambiguity in communication. Current activities, in ESA context, extend the crew support system with a speech Input/Output interface, that allows the crew to use it in an eyes- and hands-busy situation.

3. MANNED MISSION DEMONSTRATION

The Space Station crew simulation session (also known as DAMS) at NLR was an extension of ESA's earlier mission simulation activities (Ref.4). After some events, simulating one day out of the life of an astronaut, a longer period was called for, with an increased level of experiment realism and with higher payload operations complexity. In addition, a crew support concept was investigated using different control and monitoring modes for space and ground segment. The DUC, as the remote user support centre, provided ground support for payload integration, preparation, repair and maintenance of a breadboard Biology Facility which housed two multi-user payload facilities: the Glovebox and the High Performance Capillary Electrophoresis (HPCE) instrument. Identical man-machine interfaces for crew and ground terminals were implemented, according to an existing design of the Crew PC and Ground PC. The demonstration set up was developed by a Dutch consortium of industries and institutes headed by NLR (see also Ref.5).

3.1 DEMONSTRATION SET-UP

A three-day mission demonstration was set up at NLR. The set-up comprised two different sites: a 'space segment', where the experiment and facility hardware was located and where the simulation crew performed their activities, and a 'ground segment', the DUC, where Principal Investigators (PIs) and support personnel monitored and operated the experiments and communicated with the crew. An overview of the 'Space Segment' is given in Figure 1.



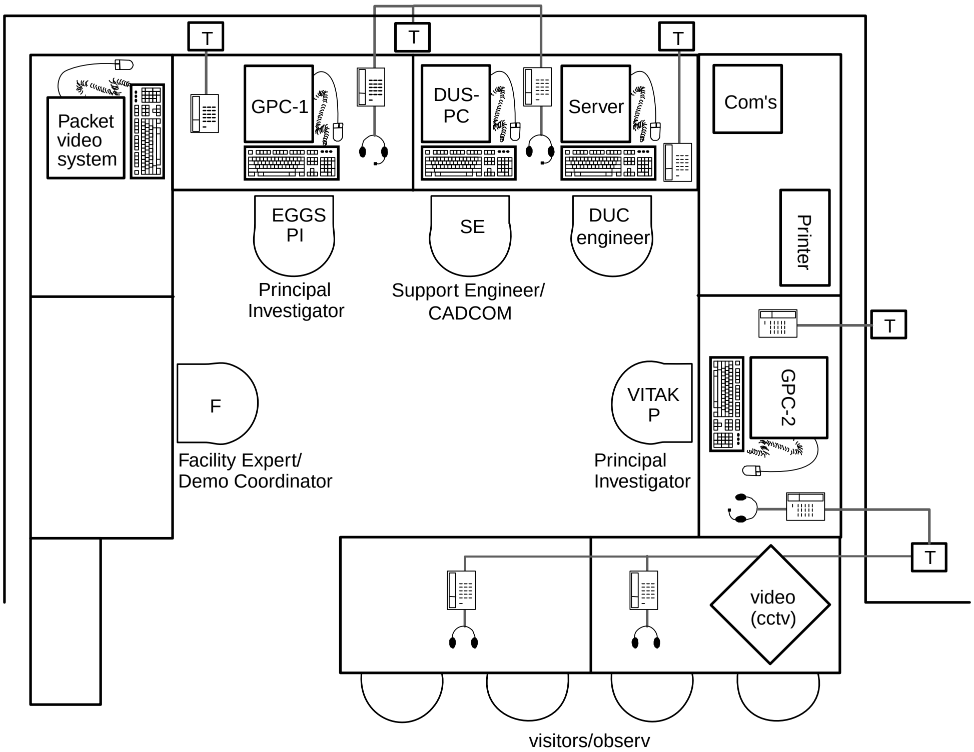
(Figure 1 - Set-up of the 'space segment')

The communication of voice, data and video images between a (simulated) space segment and ground segment were based on a realistic communication set-up.
The payload data communication was based on a standard path service protocol on Ethernet. The ESA Packet Utilisation Standard was used to identify payload and video data packages.
Voice communication was implemented on the NLR telephone network in a conference mode.
A closed circuit television system from space segment to DUC-site was installed for observers.

Two PIs were active during the demonstration, performing two different experiments.
One PI performed an experiment involving the fertilisation of toad eggs and the observation of their development 'on board'.
The other PI performed an experiment related to the study of bone demineralisation in microgravity. For this experiment, urine samples of the crew were prepared and analysed with the HPCE.

3.2 THE GROUND SEGMENT

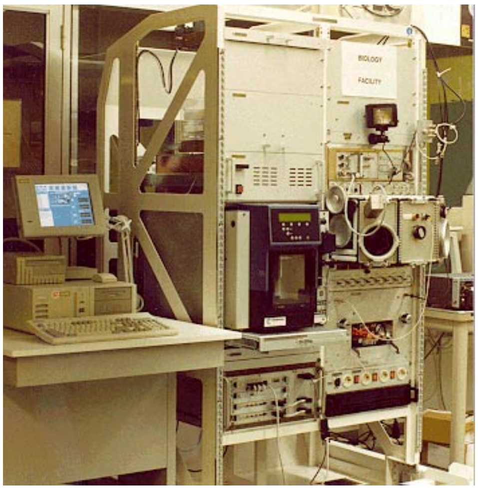
Experiment and facility operations were performed from three functional positions at the DUC-site. The PI, the originator of the experiment, performed on-line operation and monitoring of the experiment. A Support Engineer, assigned to assist the PI, was responsible for crew communication and on-line support to the PI. A Facility Expert was responsible for support to dedicated on-board facility operations and maintenance.
The DUC lay-out (see Fig. 2) included two Ground PCs, a DUC User Support system for off-line experiment analysis, a Server Station, and a Video PC. The server dealt with the DUC internal data distribution, while the DUS-PC provided special applications for experiment data processing. The Video PC was dedicated to the presentation of toad egg experiment video images. A Packet Video System allowed video images to be transmitted to the ground segment (Ref.6).



(Figure 2 - Set-up of the 'ground segment' (DUC))

3.3 THE SPACE SEGMENT

The space segment comprised the breadboard Biology Facility and some general purpose facilities, such as the Portable Workbench, and the Crew PC. The Biology Facility houses the two multi-user facilities, and one experiment-dedicated facility, the Experiment Locker. Figure 3 presents the hardware configuration the Biology Facility and the Crew PC. Major activities of the crew in the space segment are the operation of the experiments and facilities as part of the execution of the experiments. The Crew PC is the crew's major tool for performing these tasks.



(Figure 3 - Breadboard Biology Facility and Crew Portable Computer)

The CrewPC is the interface between the astronaut and the on-board systems. It includes a number of dedicated crew support tools. A Crew Procedure Execution Support system assisted the crew in the step-by-step execution of on-board procedures. At each step, the required support could be obtained from a Document Filing System that provided direct access to text information, engineering drawings, explanatory photographs or video clips.
Virtual Control Panels were used to enable payload control by crew and ground and to read-out payload status by parameter values via the PC.

3.4 EXPERIMENT FACILITIES

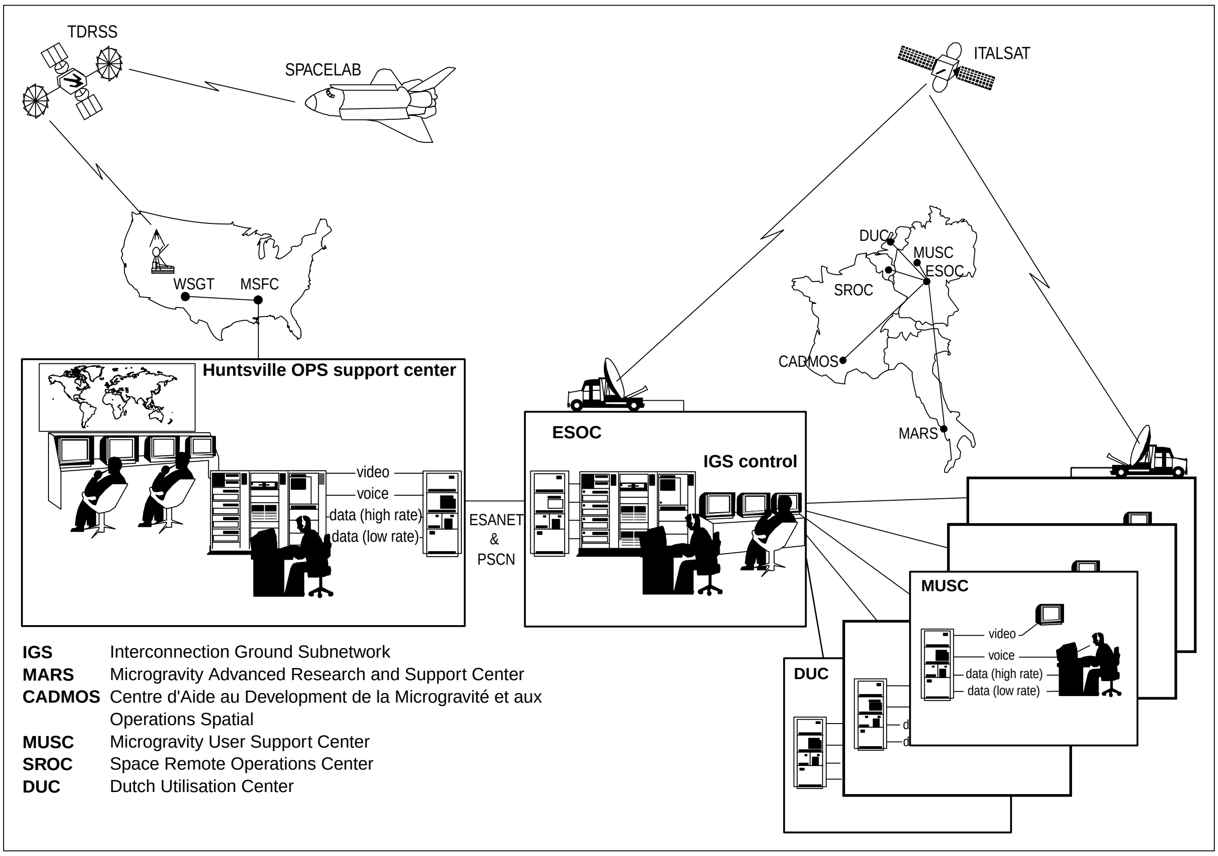
The HPCE system implemented in the Biology Facility, based on a commercially available 1-g system, was used for the analysis of crew urine samples, reflecting the process of bone demineralisation.

The Glovebox system implemented in the Biology Facility was a model based on the Shuttle Middeck Locker type. Three video cameras were available to enable monitoring of operations in the Glovebox work area. The control and monitoring of the Glovebox can be performed not only by the crew, via the Glovebox front panel and the Crew PC, but also by operators on the ground via the Ground PC. Most of the Glovebox operations during the mission demonstration were focused on maintenance and in-flight payload integration.

The Experiment Locker provided a temperature controlled environment for the Toad Eggs modules. A video system was implemented that allowed observation of the eggs in the modules. The crew could move the camera over the various modules such that different eggs could be selected for detailed observation. The video images were transmitted to the dedicated Video PC in the DUC.

4. REMOTE SUPPORT TO IML-2 MISSION

The Van der Waals-Zeeman laboratory and NLR/DUC were working together to prepare the DUC for remote support of experiment operations and to enhance the scientific return of an experiment. This experiment was conducted in the Critical Point Facility (CPF) carried by Spacelab in the second International Microgravity Laboratory (IML-2). The DUC was one of five European user centres involved in remote support of operation of European facilities and experiments.



(Figure 4 - Overview of the communications for the IML-2 mission.)

4.1 THE CRITICAL POINT FACILITY

The CPF is an multi-user facility of ESA, offering investigators opportunities to conduct research on critical point phenomena in a microgravity environment in Spacelab.
The inherent instability of the phenomena, even in microgravity, and the long time to achieve equilibrium, requires any temperature changes to be carried out in very small increments, resulting in long duration experiments. Experiment runs of 40 to 60 hours are normal, and require missions such as provided by the Space Shuttle and Spacelab.

The PI used the CPF to study the processes of heat transport in a pure fluid (SF6) near its critical point, and their fundamental relation to the density profile.
The experiment started 2 days and 4 hours after the launch of the Space Shuttle, and lasted 56 hours. During this time, full support from the DUC was available.

4.2 COMMUNICATION

The end-to-end communication layout for the concept is depicted in Figure 4. Three different data communication streams can be distinguished.

- Data from Space Shuttle to Marshall Space Flight Centre (MSFC), Huntsville

The Telemetry and Data Relay Satellite (TDRS) system of geosynchronous satellites allowed the orbiter to have line-of-sight transmission capability with at least one of the TDRS satellites at most times.

- Data from MSFC to ESOC, Darmstadt

ESA had installed a single physical link to ESOC, Darmstadt, with all the different data streams of the remote centres integrated. A transatlantic data connection was provided by ESA.

- Data from ESOC to DUC, Amsterdam

To transfer data between ESOC and DUC, seven ISDN channels were used The ISDN connection was used only when necessary, keeping the communications costs for DUC low.

4.3 DUC SET-UP

At the DUC all experiment data from the CPF were received and stored. The most important data streams were extracted from the incoming data and immediately processed for (near) real time analysis:

- the still video information, giving every six seconds an updated interferogram;
- the data from the experiment computer including temperature data and light scattering data.

The processed data were observed and verified by the remote science team at the DUC in Amsterdam (Fig.5). They discussed their findings over a voice connection with Dr. Michels, who was at the POCC in Huntsville. The DUC used the NASA Voice Distributed System for the communication with the POCC. This voice matrix system groups all voice loops used to conduct a space mission. Electronic data could be transferred by means of an Ethernet connection between the POCC and the DUC.

The advantage of the set up at the DUC over Huntsville was the possibility for the remote support team to have all the scientific data available in digital form (as opposed to the PI team in Huntsville, who had to work with analog slow-scan video). Furthermore, the DUC offered the possibility to the scientists to work in an environment provided with all they needed at hand.

Another advantage of the DUC was the capability of correlating the different measurement systems of the CPF.

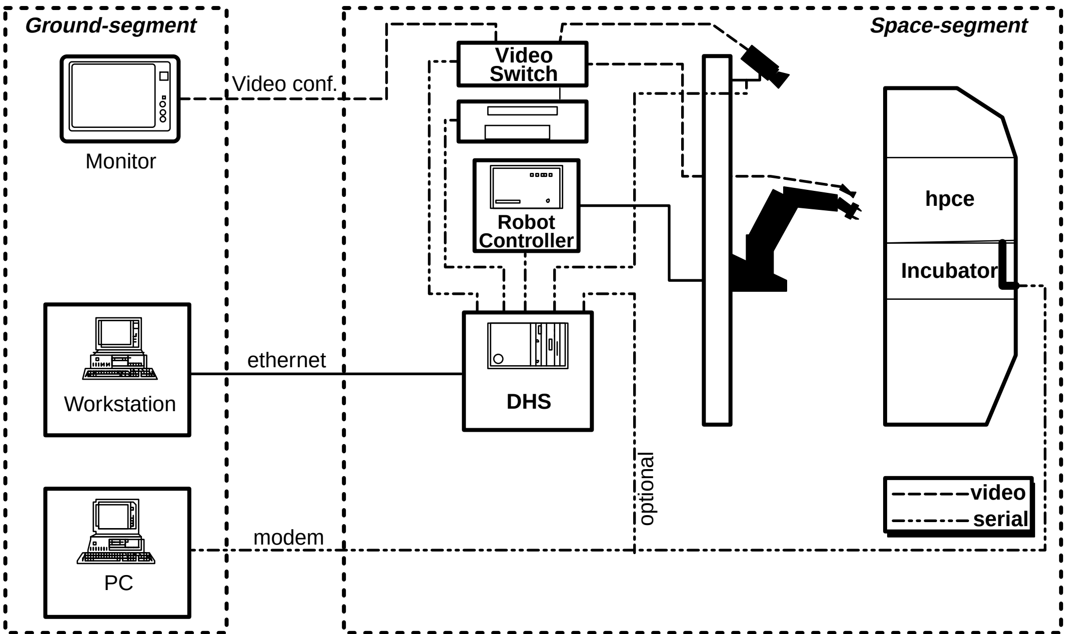
(Figure 5 - The DUC team)

5. TELEROBOTICS AND AUTOMATION CONCEPTS

In order to be able to support development and operations of experiments and payloads for future (partly) automated facilities, national projects have been set up in the area of Automation & Robotics, headed by NLR.
For payload development, standards and methods developed under contract with ESA have been re-used, such as Space A&R Controller (SPARCO), Integrated Payload Automation (IPA), Interactive Autonomy (IA), and Control Development Method (CDM).

5.1 AUTOMATION & ROBOTICS FOR MICROGRAVITY PAYLOADS

The national study ARMADE - Automation and Robotics (A&R) for Microgravity Applications Demonstrator supported the development of the Columbus A&R Testbed (CAT) at ESTEC.
The objective of this project was the development and demonstration of a microgravity model payload for automatic, robot manipulator supported, experiment execution.
The experiment facility consists of an incubator and an analysis instrument, and between these two a sample cartridge has to be transferred by a robotic arm. It has enhanced CAT with a more realistic payload - the first one with actual ‘science’ data output -.



(Figure 6 - Telerobotics system configuration)

5.2 TELEROBOTICS EXPERIMENTS

During the CEAS Symposium on Simulation Technologies 1995, the concept of remote payload operations supported by A&R was further demonstrated as a ‘ground-based simulation with hardware-in-the-loop’ (Ref.9). At the same time the demonstration was an experiment with different forms of modern communication technologies. The demonstration configuration consisted of three major elements. Firstly, the ground segment, containing equipment for preparation, operation and monitoring of the experiment. Secondly, the space robotics laboratory, containing a 7 degrees of freedom robot system, a payload rack and remotely controlled video system. And thirdly, communication equipment connecting the two sites consisting of a high speed ATM link (>30 Mbs), an ISDN connection and a standard internet connection.

The ATM connection was realized with real-time, high quality video equipment from AT&T.
The ISDN connection was used by a desktop video conferencing system as a means for crew support. The internet connection was used for a simplified TM/TC protocol (over TCP/IP) to control the different elements in the remote laboratory. The concept of multiplexing several control paths into one TM/TC link was maintained.
Experiences gained during the demonstration could be valid for both the tele-operation of a remote laboratory as for the case of a distributed ground support for which the used communication technologies are more readily available. For critical tele-robotic operations the higher image quality of the ATM system was a clear advantage (eg. inspection tasks), while for cooperative work between the two sites the lack of a delay in the ATM system was shown to be a major improvement over ISDN. Further the use of a TM/TC link over TCP/IP using the internet infrastructure, demonstrated the possibilities thereof.
Figure 6 shows the whole system set-up.

6. USER SUPPORT AND CREW SUPPORT IN THE SPACE STATION ERA

The support provided to scientists in the context of the manned mission demonstration and the IML-2 experiment demonstrated that user support as implemented in the DUC fulfils the expectations. The participating users were enthusiastic about the offered interaction with their experiment and with the added scientific value that was gained by the immediate presentation of the experiment results (instead of after the mission).
The direct involvement of the users, combined with user support during the entire development path, is also the way to go for the Space Station era. For experimental use the Space Station has two important characteristics:
- the capacity for scientific experiments is increased (comparing with Spacelab) due to its continuous operation;
- the crew members will be less trained for experiment handling due to the large amount of experiments performed during their period on board.

The problems associated with these two characteristics, where do the experiments come from and how can proper operation and interaction be guaranteed, are more or less solved by the support concept described above. Hence the Netherlands will, in context of DUC, continue their activities in development of tools for user support. The activities foreseen comprise the extension of the support offered to the other fields mentioned. Still the effort introduced in user support will be tuned to the amount of Dutch users actually flying experiments and requiring support.

7. CONCLUSIONS

Since 1989 NLR has been involved in studies concerning the preparation and organisation of a national user support organisation and the Dutch Utilisation Centre (DUC). The DUC, located at NLR premises, is preparing itself for support activities for the Space Station era, focusing on technological support. A number of experiments have been supported, in real missions and demonstration environments. Crew and user support technologies have been developed in a national consortium.

The manned mission demonstration using the DUC appeared to be very realistic. Payload utilisation, stowage locations, integrated experiment operations, time-lines, and operational procedures could be tested very well. The demonstration yielded many recommendations for improvements on payloads, crew and ground procedures, crew interfaces, and communication.

During the IML-2 flight all data from the Critical Point Facility were received by the DUC, enabling the remote science team to analyse the data in real time or near real time. The PI team in Huntsville could be provided with a sound basis for real time decisions concerning the execution of the experiment, so that the valuable experiment time was used to the largest possible extend.

In addition, NLR is preparing to support the development of payloads to be operated by crew or to be compliant with A&R concepts, re-using ESA's payload development and A&R concepts.

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