

Chapter 2

Space and Ground-Based Infrastructures

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Abstract This chapter deals first with the main characteristics of the space environment, outside and inside a spacecraft. Then the space and space-related (ground-based) infrastructures are described. The most important infrastructure is the International Space Station, which holds many European facilities (for instance the European Columbus Laboratory). Some of them, such as the Columbus External Payload Facility, are located outside the ISS to benefit from external space conditions. There is only one other example of orbital platforms, the Russian Foton/Bion Recoverable Orbital Capsule. In contrast, non-orbital weightless research platforms, although limited in experimental time, are more numerous: sounding rockets, parabolic flight aircraft, drop towers and high-altitude balloons. In addition to these facilities, there are a number of ground-based facilities and space simulators, for both life sciences (for instance: bed rest, clinostats) and physical sciences (for instance: magnetic compensation of gravity). Hypergravity can also be provided by human and non-human centrifuges.

2.1 Characteristics of the Space Environment

Space is a very demanding set of characteristics [18] when we think of designing experiments and associated equipment to function in this environment. Conditions vary greatly, not only within the universe and our solar system but also around our planet. Factors such as temperature and radiation levels vary greatly at different altitudes and under the influence of Earth's magnetic field. We will consider the conditions experienced by spacecraft in low-Earth orbit as this is a principal orbital location where space research is undertaken. For explanatory purposes we will consider the International Space Station (ISS) as the orbital spacecraft.

2.1.1 External Environmental Conditions

The ISS orbits the Earth approximately every 90 min (16 times per day) at around 350–400 km above the surface of the Earth. Outside the Station there is a high quality vacuum (minimum of 3.6×10^{-11} kPa) with a temperature variation from -120 to $+120^\circ\text{C}$. Earth's low-density residual atmosphere at this altitude is primarily composed of atomic oxygen which can cause erosion of certain surfaces. Ionising radiation results from trapped electrons and protons as well as solar and galactic cosmic rays, but also heavier atomic nuclei. These particles can cause degradation and changed states in electronic devices and materials. Of particular concern are solar flares, which temporarily create an intense environment of protons and heavy ions. The trapped proton environment around the Earth dips to only a couple of 100 km above the South Atlantic, creating the 'South Atlantic Anomaly'. On half of its daily orbits the ISS will pass through this trapped proton belt for a duration of typically 5–10 min. The proton flux is then several orders of magnitude higher. With respect to electromagnetic radiation the highest power densities irradiating the ISS are from solar radiation in the ultraviolet and visible portions of the electromagnetic spectrum. Plasma is another factor present in low-Earth orbit. This quasi-neutral gas consisting of neutral and charged particles causes electrical charge accumulation when interacting with a spacecraft until electrical equilibrium is reached. Active components such as solar arrays may accumulate sufficient negative potential to produce arcing to other spacecraft elements [64].

2.1.2 Internal Spacecraft Environmental Conditions

The quality of weightlessness in spacecraft is an important factor for low-Earth orbit research and the ISS residual gravity level is to all intents and purposes a weightless environment. This is determined/affected by atmospheric drag from residual atmosphere, as well as higher magnitude vibrations caused by ISS system activity, crew movement, spacecraft docking/undocking and thruster firings etc. though ISS activities are planned to avoid unnecessary vibrational influence on experiments. This influence is further attenuated by the use of different vibration isolation systems within racks and facilities.

The pressure inside the ISS is kept at around 1 bar or ~ 100 kPa (*i.e.* normal barometric pressure at sea level) and the air composition is 78% nitrogen and 21% oxygen with a residual carbon dioxide level, which is higher than on Earth (0.05%), though kept within safe limits for crew safety by the use of CO_2 scrubbers. 1% CO_2 is allowable during crew exchanges though the ISS programme has agreed to maintain the cabin CO_2 level to 0.37% (with the goal of reaching 0.3%) for two 90-day periods each year. The temperature on board varies from 17 to 28°C , and a relative humidity varies between 25% and 75%. A residual radiation environment

roughly 50–100 times higher than on Earth at sea level does exist inside the ISS, though this is within levels considered safe for the duration of stay of crew members on the ISS.

2.2 Space Infrastructure

Europe has been a strong proponent of the utilisation of space for research purposes for many decades, however, in order to undertake major programmes in space utilisation it became a necessity to form a European-wide agency in the 1960s. This started as the European Space Research Organisation (ESRO), which was founded by ten European nations. In 1975 ESRO together with the European Launch Development Organisation (ELDO) merged to form the European Space Agency (ESA) [58] which now has 18 Member States from across Europe. Prior to this, one of the major programmes agreed upon by ESRO in 1973 together with NASA was Spacelab, the European-built pressurised laboratory module that would fly on 25 different Shuttle flights from 1983 to 1998. This major milestone in European research infrastructure development has been a stepping stone to the development of the major European pressurised modules that are core elements of the International Space Station (ISS) and European utilisation activities in space.

2.2.1 *The International Space Station*

The ISS (Fig. 2.1) is one of the most extensive civil engineering projects ever undertaken. It is the principal platform for scientists and technology developers worldwide to gain access to the environmental conditions in space for undertaking

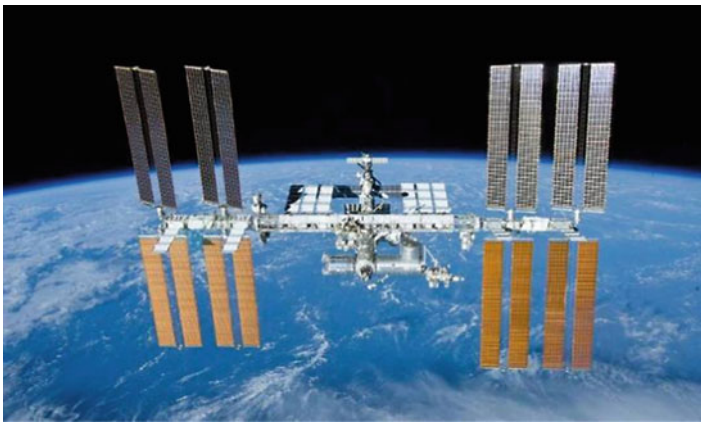


Fig. 2.1 The International Space Station photographed from STS-132 space shuttle Atlantis after shuttle undocking in May 2010 (Source: NASA)

research projects across all scientific domains and providing an important tool for education/public relations. The Station [69] is a co-operative programme between United States, Russia, Canada, Japan and 11 Member States of ESA (Belgium, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom). It is governed by an international treaty [55] signed by these International Partners which provides the framework for design, development, operation, and utilisation of a permanently inhabited civil Space Station for peaceful purposes. Utilisation rights are outlined in Memoranda of Understanding. ESA's allocation rights comprise 8.3% of the Space Station's non-Russian utilisation resources including, 8.3% of crew time. In compensation for providing resources (energy, robotics, cooling, telecommunications, etc.) to the European ISS Columbus Laboratory by the National Aeronautics and Space Administration (NASA) and the Canadian Space Agency (CSA), Europe provides 49% of the laboratory's utilisation resources to NASA and 2% to the CSA (via NASA).

2.2.1.1 The European Columbus Laboratory

Europe carried out almost 200 experiments on the ISS from 2001 until the launch of Columbus in February 2008 mainly associated with short-duration missions involving European astronauts. The related science packages reflected specific nationally sponsored Soyuz taxi flight missions from France, Italy, Belgium, Spain, and the Netherlands, with German ESA astronaut Thomas Reiter undertaking Europe's first long-duration (6-month) ISS mission in 2006. Columbus is ESA and Europe's biggest single contribution to the ISS and its arrival greatly increased Europe's research potential. Along with the European-built ISS Nodes 2 and 3, it shares its basic structure and some system elements with the Italian Space Agency's (ASI) Multi-Purpose Logistics Modules, one of which now constitutes a permanent ISS storage module called the Permanent Multi-Purpose Module (PMM).

The Columbus laboratory (Fig. 2.2) is equipped with a suite of flexible multi-user facilities that offer extensive research capabilities. During its lifespan Earth-based researchers, with the assistance of the ISS crew and an integrated network of ground control centres will be able to conduct many experiments in physiology, biology, materials science, fluid physics and a host of other disciplines. Columbus can host ten standard-sized research racks [3] which are provided with power, cooling, video and data lines. ESA developed a range of research racks, principally located in Columbus to offer European scientists full access to a weightless environment that cannot be duplicated on Earth.

During compilation of this publication the configuration of Columbus included the following ESA research rack facilities.

- **The Fluid Science Laboratory (FSL)** – accommodating experiments looking into fluid flow, heat transfer and foam stability/instability mechanisms in weightlessness, which could bring far-reaching benefits on Earth such as more efficient oil extraction processes.



Fig. 2.2 European Columbus Laboratory photographed in June 2008 during the STS-124 mission (Source: NASA)

- **The European Drawer Rack (EDR)** – a modular and flexible facility providing basic accommodation and resources for standard sized experiment modules covering a large variety of scientific disciplines,.
- **Biolab** – supporting experiments on micro-organisms, cells and tissue cultures, small plants and small animals (insects, worms).
- **The European Physiology Modules Facility (EPM)** – used to investigate the effects of long-duration spaceflight on the human body and contributing to an increased understanding of conditions such as osteoporosis and balance disorders on Earth as well as providing an insight into neurological mechanisms.
- **Muscle Atrophy Research and Exercise System (MARES)** – used for undertaking neuromuscular and exercise research on the International Space Station by assessing the strength of isolated human muscle groups around joints.

In addition to these European research racks Columbus hosts: two NASA Human Research Facility (HRF) racks for supporting physiology research; an additional NASA EXPRESS rack which incorporates ESA's European Modular Cultivation System (EMCS) for undertaking additional biological research; and the European Transport Carrier which acts as a stowage rack for supporting European research. The final rack location in temporarily Columbus housed the European-built Microgravity Science Glovebox (MSG) for undertaking a variety of materials, combustion, fluids and biotechnology experiments, though this was relocated back to the US Laboratory.

In addition to stand-alone elements of European research hardware in orbit, the full spectrum of major European research facilities inside the ISS is completed by the **Material Science Laboratory (MSL)**, which is the principal element of NASA's **Material Science Research Rack (MSRR-1)**, also in the US laboratory.

The external surface of the Space Station offers great potential for undertaking a full spectrum of exposure research and technology demonstrations in for example

astrobiology, materials science, astrophysics and Earth observation. Columbus offers four external payload locations exposed to space vacuum [4], with an unhindered view of Earth and outer space, and supplied with relevant resources (power, data). One Columbus external payload, the **European Technology Exposure Facility (EuTEF)** already returned to Earth following completion of a successful 1½ years exposure to open space in September 2009, and the **SOLAR** facility, which was also installed outside of Columbus in February 2008 remains on orbit until 2013 and possibly beyond.

With the extensive amount of research facilities on the ISS, undertaking research on the Station only involves the transport of new external payloads, experiment samples and/or ancillary equipment in many cases. This is brought to the ISS by either one of the unmanned logistics vehicles (European ATV, Japanese HTV or Russian Progress) or by one of the manned ISS vehicles (Russian Soyuz-TMA or in the past namely by the US Space Shuttle). In coming years other platforms such as the SpaceX capsule will also be used for downloading samples to Earth.

2.2.1.2 Europe's Research Facilities in Columbus

The Biolab facility [31] is designed to support biological experiments on micro-organisms, cells, tissue cultures, small plants and small invertebrates. The major objective of performing life science experiments in space is to identify the role that weightlessness plays at all levels of an organism, from the effects on single cells up to complex organisms including humans.

The biological samples, together with their ancillary items are transported from the ground to Biolab either already integrated within dedicated Experiment Containers or in small vials. The latter case applies if the samples require storage prior to use. On-orbit, the Experiment Containers are manually inserted into Biolab (Fig. 2.3 left) for processing, whereas the frozen sample will first be thawed out inside the BioGlovebox. Once this manual loading is accomplished, the automatic processing of the experiment can be initiated by the crewmember.

The experiments are undertaken in parallel on a microgravity and a 1 g centrifuge. The latter provides the flight reference experiment, whilst the ground reference experiment is performed at the Facility Responsible Centre (Microgravity User Support Centre in Cologne, Germany), which operates the facility according to the needs of individual Experiment Container providers. During processing of the experiment, the facility handling mechanism transports the samples to the facility's diagnostic instrumentation, where, through teleoperations, the scientist on the ground can monitor the processing of their experiments from their own User Home Bases and actively participating in preliminary in-situ analyses. Typical experiment durations range from 1 day to 3 months. One example of an experiment undertaken in Biolab is the Waving and Coiling of Arabidopsis Roots (WAICO) experiment.

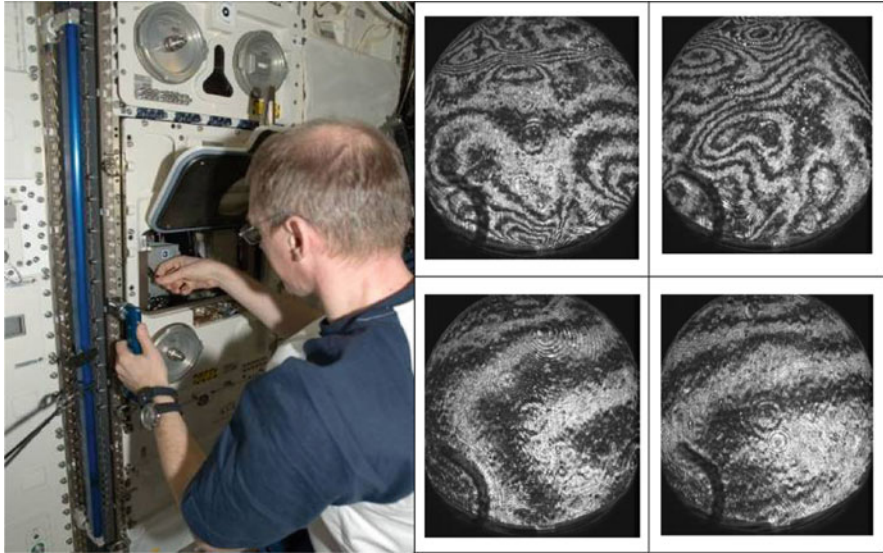


Fig. 2.3 *Left:* ESA astronaut Frank De Winne installing the Yeast experiment in the Biolab in October 2009 (Image: NASA). *Right:* Geoflow interferometric image from ESA's Fluid Science Laboratory on board the Columbus laboratory (Source: Prof. C. Egbers, BTU Cottbus)

Fluid Science Laboratory – European Rack Facility for Fluids Research on the ISS

The Fluid Science Laboratory [32] is used for studying the dynamics of fluids in the absence of gravitational forces. This allows investigation on fluid dynamic effects, phenomena that are normally masked by gravity driven convection, sedimentation, stratification and fluid static pressure. These effects include e.g. diffusion-controlled heat and mass transfer in crystallization processes, interfacial mass exchange, simulation of geophysical fluid flows, emulsion stability and many more.

An Experiment Container (individually-developed for each specific FSL experiment) is inserted into the Central Experiment Module drawer by a crewmember. Each Experiment Container holds the fluid cell assembly (including the process stimuli and control electronics) and may also be equipped with dedicated diagnostics to complement the standard Fluid Science Laboratory diagnostics. The Geoflow experiment (Fig. 2.3 right part) which is undertaking an investigation of importance for astrophysical and geophysical problems, such as global scale flow in the atmosphere and oceans took place in the Fluid Science Laboratory, with the follow-up experiment, Geoflow-2 planned in 2011.

The FSL and experiment control concept allows alternative modes of operation consisting of fully automatic, semi-automatic and fully interactive experiment processing. All these modes may be initiated either by the flight crew or from the ground. The investigators can monitor and adjust the processing of their experiments also from their own User Home Bases. The Facility Responsible

Centre for the Fluid Science Laboratory, the Microgravity Advanced Research and Support Centre (MARS) in Naples, Italy which is supported by the Facility Support Centre E-USOC in Madrid, Spain.

European Drawer Rack – Multi-discipline Experiment Rack in Columbus for Subrack Experiments

The European Drawer Rack, EDR, [30] in Columbus was developed by ESA to provide a flexible facility for accommodating medium-sized dedicated experiment equipment covering a variety of scientific disciplines. The facility can accommodate up to three standard 72 l drawers, or four standard 57 l lockers. This approach allows a quick turn-around capability, and provides increased flight opportunities. Outside of resources management the operating concept of the European Drawer Rack assumes that payloads are largely autonomous and research teams can monitor their experiments from local User Home Bases. The Facility Responsible Centre for the European Drawer Rack is the Erasmus User Support and Operations Centre at ESA's ESTEC Facility in Noordwijk, the Netherlands. The individual payloads it houses partially have different centres responsible for the associated research activities. The Belgian User Support and Operations Centre for example was responsible for the Protein Crystallisation Diagnostics Facility [34], which undertook 3½ successful months of experimentation in the European Drawer Rack in 2009 in order to help establish the conditions under which good zeolite crystals can be grown. An interface drawer was developed to allow the European Drawer Rack to host a European Kubik incubator (see below). In the future EDR will temporarily accommodate the Facility for Adsorption and Surface Tension (FASTER), and the Electro-Magnetic Levitator (details see below).

European Physiology Modules – European Facility for ISS Physiology Research

The European Physiology Modules [33] is equipped with Science Modules to investigate the effects of long-duration spaceflight on the human body. The experiment results will contribute to an increased understanding of terrestrial problems such as the ageing process, osteoporosis, balance disorders, and muscle wastage. The initial configuration of instrument modules for the facility included: the Multi-Electrode Electroencephalogram (MEEMM) which is dedicated to the study of brain activity by measuring both EEG and Evoked Potentials; the Portable Electroencephalogram Module (PORTEEM) which is a portable EEG/polysomnography module for ambulatory and sleep studies; the Cardiovascular Laboratory or Cardiolab, which is a joint French (CNES) / German (DLR) Module supporting cardiovascular research including blood pressure device, ECG or portable Doppler measurement; and equipment for blood, saliva and urine collection. Additional modules that were launched to enhance the capabilities of the European Physiology



Fig. 2.4 ISS Expedition 25 commander Doug Wheelock (NASA) using Neurospat hardware to perform the PASSAGES experiment with the European Physiology Modules (Source: NASA)

Modules include the Portable Pulmonary Function System (See below). NASA also developed physiology research racks which are complementary to the European Physiology Modules called the Human Research Facility –1 and –2 (located also in Columbus). These offer additional physiological research capabilities such as the assessment of pulmonary function (see Pulmonary Function System below), blood centrifugation, body mass measurement and ultrasound.

The Facility Responsible Centre for the European Physiology Modules rack, CADMOS in Toulouse, France has the overall responsibility to operate it according to the needs of individual Science Modules. PASSAGES (Fig. 2.4), looking into how astronauts interpret visual information is an example of an experiment utilising the capabilities of the European Physiology Modules.

Pulmonary Function System (in Human Research Facility 2)

The Pulmonary Function System [42], which was built by ESA is an ESA/NASA collaboration in the field of respiratory physiology instrumentation, analyses exhaled gas from astronauts' lungs to provide near-instant data on the state of crew health. Used previously for ESA's CARD experiment and for the Periodic Fitness Evaluation it is capable of a wide range of respiratory and cardiovascular measurements. This includes breath-by-breath measurements, diffusing capacity of the lung, expiratory reserve volume, forced expired spirometry, functional residual capacity, cardiac output, alveolar ventilation, volume of pulmonary capillary blood, and other pulmonary tests. For support of European experiments DAMEC in Odense, Denmark is the responsible User Support and Operations Centre (USOC) for the Pulmonary Function System.

Portable Pulmonary Function System

The Portable Pulmonary Function System which also falls under the operational responsibility of DAMEC has similar capabilities to the Pulmonary Function System, but is designed for use in all parts of ISS i.e. it's fully portable and not mounted in a rack. This makes it useful for metabolic measurements during exercise, for example. It has been used for undertaking ESA's Thermolab experiment, which investigates thermoregulatory and cardiovascular adaptations during rest and exercise during long-term exposure to weightlessness, in conjunction with NASA's Maximum Volume Oxygen (VO₂ Max) experiment.

KUBIK Incubator

KUBIK can function as an incubator or cooler (+6°C to +38°C temperature range). Self contained automatic biological experiments can be performed using power provided by the facility. A centrifuge insert permits 1 g control samples to be run in parallel with the weightless samples. If a centrifuge control is not needed it is possible to interface larger, dedicated experiment hardware with KUBIK via an interface plate. KUBIK incubators can be potentially operated powered in Soyuz spacecraft providing a means of maintaining controlled temperature and performing automatic experiments from a just prior to launch until docking with the Station. It was used in 2010 for processing the PADIAC and SPHINX experiments in the European Drawer Rack.

Facility for Adsorption and Surface Tension Studies (FASTER)

From 2012 FASTER will study the links between the physical chemistry of the droplets interface, the liquid films and the collective properties of an emulsion. A relevant problem in emulsion technology is the control of emulsion stability. For example high stability is necessary for emulsions in foods, cosmetics, pharmacy etc. whereas separation is required in waste water processing and oil recovery.

Electro-Magnetic Levitator (EML)

The ESA/DLR Electro-magnetic Levitator will perform containerless materials processing from 2012, involving melting and solidification of electrically conductive, spherical samples, under ultra-high vacuum and/or high gas purity conditions. Heating and positioning of the sample is achieved by electromagnetic fields generated by a coil system. EML will support research in the field of meta-stable states and phases and in the measurement of high-accuracy thermo-physical properties of liquid metallic alloys at high temperatures up to 2,000°C. The former covers investigations of nucleation and solidification kinetics in under-cooled melts and microstructure formation for instance.

Solution Crystallisation Diagnostics Facility (SCDF)

Biolab – European Rack Facility for Biological Experiments on the ISS

Following the successful completion of the Protein Crystallisation Diagnostics Facility experiments in 2009, the facility will be ‘refurbished’ as an instrument capable of providing a range of optical techniques of general interest for nucleation, growth and solidification studies within projects dealing with the growth of crystalline and amorphous structures from solutions. The Solution Crystallisation Diagnostics Facility will be hosted in the European Drawer Rack as an advanced light scattering instrument that combines state of the art static and dynamic light scattering, ultra low angle scattering and more recent multi-speckle techniques based on cameras.

European Modular Cultivation System

The European Modular Cultivation System [44] is an ESA gravitational biology payload installed inside a NASA EXPRESS rack in Columbus. The facility is dedicated to experiments on plants, especially multi-generation (seed-to-seed) experiments and studies gravity effects on early development and growth, on signal perception and transduction in plant tropisms. Experiments with insects or amphibia as well as studies with cell and tissue cultures can also be conducted.

The facility consists of a gas tight incubator with two centrifuges and space for four Experiment Containers on each rotor. The rotors contain systems for life support, water supply, illumination and observation. A facility laptop, gas supply module and thermal control system are located outside the incubator. The crew will set up experiments and exchange containers for resupply of consumables such as gas and water. Otherwise, the facility operates autonomously and can be controlled from the ground or by the crew. Ground and on-orbit reference experiments can be undertaken. A Test Bench with EMCS ground models is established at the University of Trondheim, Norway (location of the User Support and Operations Centre for the European Modular Cultivation System) to validate various aspects of experiment development.

Portable Glovebox

The Portable Glovebox has been used for the handling of various biology experiments with the European Modular Cultivation System and the Kubik incubators. It provides an adequate enclosure to perform manual operations during safety critical steps of any experiment. The Glovebox has an airtight volume of 21 l,

with two gloves mounted on standard glove rings for handling the experiment equipments inside.

Muscle Atrophy Research and Exercise System (MARES)

MARES [45], is a general-purpose facility for (neuro-)muscular and exercise research. It is capable of assessing the strength of isolated muscle groups around joints by controlling and measuring relationships between position/velocity and torque/force as a function of time. This is done during passive exercises on MARES, while its motor puts a programmed load on the astronauts' extremities movements. It is an ideal tool for research on the countermeasure efficiency and a vast improvement on current muscle research facilities on the ISS. MARES consists of an adjustable chair with a system of pads and levers that fit to each astronaut and a main box containing the facility motor and control electronics. MARES is capable of acquiring data, controlling and providing power to external devices (such as the Percutaneous Electrical Muscle Stimulator, see below) and transferring real time data for downlink. Research teams can monitor the execution of their experiments from local User Home Bases. The Facility Responsible Centre for the European Physiology Modules facility, CADMOS in Toulouse, France has the overall responsibility to operate it according to the needs of individual experiments.

Percutaneous Electrical Muscle Stimulator (PEMS)

PEMS is a second generation of a device which already flew on the Space Shuttle in 1996 and which has been also deployed on ISS as part of EPM/HRF. Its purpose is to deliver electrical charge pulse stimulation to non-thoracic muscle groups of the human test subject, thereby creating contractile responses from the muscles. Its main purpose is to support human neuromuscular research.

Flywheel Exercise Device

The Flywheel Exercise Device (Fig. 2.5) [43] is an advanced exercise device for ISS astronauts and for human physiology investigations in the area of advanced crew countermeasures. Acting to counter muscle atrophy, bone loss, and impairment of muscle function in astronauts during long duration spaceflights, the exercise device uses a rotating flywheel that replaces weight plates and other means of resistance training that rely on gravity. The resistance is provided by spinning flywheels with a cord being wound and unwound around the axle of a fixed flywheel.

Eye Tracking Device

The Eye Tracking Device (ETD), which was developed by DLR, consists consists of a headset that includes two camera modules for binocular recording of horizontal,



Fig. 2.5 ESA astronaut and ISS Expedition 21 Commander Frank De Winne checking out the ESA Flywheel Exercise Device, with the in the Columbus laboratory of the International Space Station (Source: NASA)

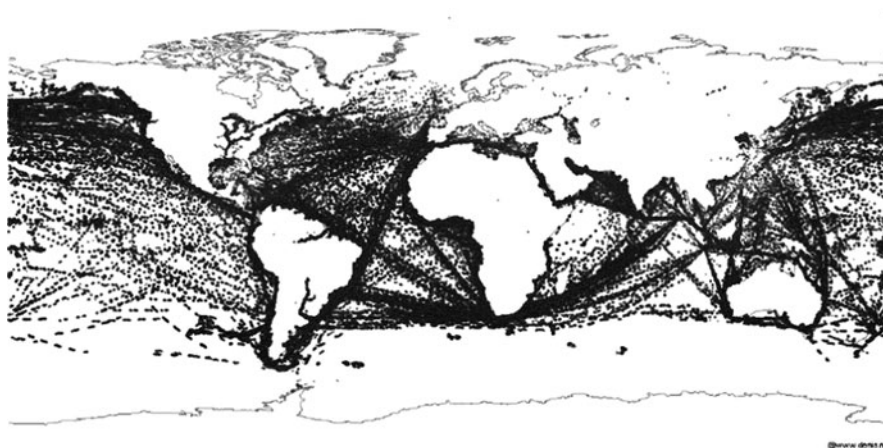


Fig. 2.6 Accumulated plot of AIS position reports received from 2 to 7 June 2010. Ship routes appear clearly (Source: FFI)

vertical and rotational eye movements. The device also includes a laptop to record and process results including continuous images of the subject's eyes. The device was first used as part of the Dutch / ESA DELTA mission in 2004 and has been used subsequently on numerous occasions. Meanwhile ETD has been disposed.

Vessel Identification System

The Vessel Identification System is testing the means to track global maritime traffic from space by picking up signals from standard AIS transponders carried

by all international ships over 300 tonnes, cargo vessels over 500 tonnes and all types of passenger carriers (Fig. 2.6). The system consists of two different receivers (NORAIS and LuxAIS), which are alternated every 3 months or so, and the ERNO-Box, which is used as a data relay for the Vessel Identification System, whose antenna is located on the outside of Columbus. Data is received by the Norwegian User Support and Operation Centre (N-USOC) in Trondheim via ESA's Columbus Control Centre in Germany. The success of this technology opens other possibilities for global tracking from space in other areas.

2.2.1.3 Other European Research Facilities on the ISS

Microgravity Science Glovebox

The Microgravity Science Glovebox (Fig. 2.7) [37] was the first European-built research rack facility to be launched to the ISS in 2002. It was developed by ESA within a barter agreement with NASA. The Glovebox provides the ability to perform a wide range of experiments in the fields of material science, biotechnology, fluid science, combustion science and crystal growth research, in a fully sealed and controlled environment. The facility was relocated from Columbus back to the US laboratory in October 2010. The 'gloves' are the access points through which astronauts can manipulate experiments. The facility can maintain an inert atmosphere with dry nitrogen and less than 10% oxygen and offers many different command and control capabilities to allow performance of investigations attended or not by the crew. The Core Facility occupies the upper half of the overall rack and



Fig. 2.7 ESA astronaut Frank De Winne during installation of the selectable optical diagnostic instrument hardware into the Microgravity Science Glovebox in 2009 (Source: NASA)

includes the large sealed working volume, an airlock, and electronics for control, housekeeping and investigation resources. The Command and Monitoring Panel monitors the facility status and performance and provides all means for the manual operation of the facility by the crew. Numerous experiments have taken place in the facility, an example of which is the SODI series of experiments (See below).

- SODI Instrument and Experiments

The Selectable Optical Diagnostic Instrument (SODI) combines different optical techniques in a single instrument. It is equipped with two Mach-Zehnder interferometers that can be operated at two wavelengths and allow for scanning of multiple cells in a cell array as well as a piezo-activated mirror which allows stepping for phase determination. SODI can also be equipped with a Near Field Scattering instrument. The experiments to date have covered the influence of vibrations on diffusion in liquids (SODI-IVIDIL) and the study on growth and properties of advanced photonic materials within colloidal solutions (SODI-Colloid).

- Directional Solidification (DIRSOL) experiment

The DIRSOL facility (under development) aims to perform DIRectional SOLidification experiments of transparent materials using the Bridgman technique and will complement the capabilities of DECLIC (See below). DIRSOL will be available from the end of 2011 and will be positioned in the Microgravity Science Glovebox. The main diagnostics element of DIRSOL is optical observation with high resolution. The observation camera can observe the transparent samples between the hot and cold zones of the Bridgman assembly at variable positions and viewing angles.

Material Science Laboratory in the Material Science Research Rack

The Material Science Laboratory [36] is the primary research facility located in NASA's Materials Science Research Rack-1, which was launched on STS-128/17A, together with a total of six sample cartridges for NASA and for ESA's MICAST and CETSOL projects under a cooperation agreement with NASA and is now installed in the US Laboratory on the ISS. The Core Facility of the Material Science Laboratory is a sealed stainless steel cylinder (the Process Chamber) capable of accommodating different individual furnace inserts, within which sample processing is carried out. Processing conditions are normally either a vacuum or an inert gas (*e.g.*, Argon). The different inserts are the Low Gradient Furnace and the Solidification and Quenching Furnace, which are based on the Bridgman Technique with a hot and a cold zone and an adiabatic zone in between. The crew insert an experiment cartridge (holding a sample to be processed) into the furnace (Fig. 2.8 left). Following process chamber evacuation, an experiment sequence is initiated, consisting of a number of steps with pre-defined parameters. Though experiment execution is automatic, processing parameters can be altered from ground.

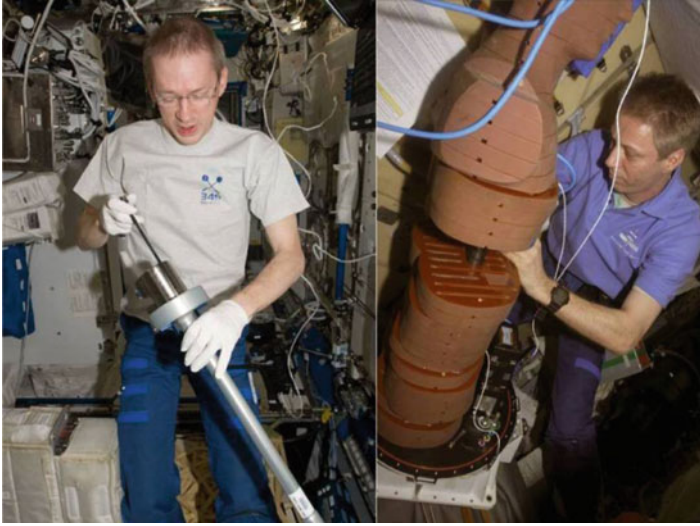


Fig. 2.8 *Left:* ESA astronaut and ISS Expedition 21 Commander Frank De Winne, exchanging samples of the CETSOL/MICAST experiments in November 2009. *Right:* ESA astronaut and Expedition 14 Flight Engineer Thomas Reiter working with the European Matroshka Phantom on the International Space Station (Source: NASA)

The Facility Responsible Centre for the Material Science Laboratory, the Microgravity User Support Centre (MUSC) in Cologne, Germany, has the overall responsibility to operate it according to the needs of individual research objectives.

DECLIC

The DEvice for the study of Critical Liquids and Crystallization (DECLIC) is an apparatus developed by CNES for a NASA EXPRESS rack to support the study of material growth and liquids behaviour near their critical point. It provides all subsystems required to operate an experiment dedicated insert installed on an optical bench. To date three experiment modules have been developed for DECLIC: the former ALICE Like Insert, dedicated to the observation of gas-liquid transformation near the critical point of pure fluids at low (near-room) temperatures; the High Temperature Insert for heat and mass transfer at high temperature and pressure, and the Directional Solidification Insert for observation of microstructures that form at the liquid-solid interface when transparent material solidifies. The instrument will allow observing the interaction of supercritical water in presence of a liquid or solid solute (dissolution, mixing, jet injection, cold combustion, and nucleation) through imaging and interferometric optical techniques.

Radiation Monitoring Facilities and Devices

It is of key importance to monitor and understand the cosmic radiation levels that are experienced by astronauts in orbit. The dosimetric facilities and equipment are key to building our fundamental knowledge of the radiation environment and help to test new types of shielding material for use on future human spaceflight missions and possibly for applications on Earth. In addition to various radiation monitoring devices developed by the non-European ISS partners, Europe has also developed a suite of instruments and facilities related to radiation research:

- **Matroshka**
Matroshka [38] is a special ESA payload that has been in use on the ISS since 2004 to determine radiation levels affecting astronauts at different depths in the human body either inside the ISS or during spacewalks. Matroshka experiments consist of a simulated human body (head and torso) called the Phantom (Fig. 2.8 right) which simulates the human body with relation to its size, shape, position, mass, density and nuclear interactions. It is composed of natural bone and a material resembling natural tissue, built up in layers. A lower-density material simulates the lungs. The Phantom is covered with a simulated skin layer and can be housed in an external container, to represent a spacesuit. The facility is equipped with several active and hundreds of passive dosimeters located at various positions to measure doses of all different types of radiation at key organ sites. The active dosimeters provide time-dependent measurements, whilst the passive dosimeters are analysed after flight to determine accumulated doses. During its time on the ISS the facility has undertaken extensive measurement campaigns both outside and inside various ISS modules.
- **Alteino/SilEye-3**
This active cosmic ray detector developed nationally in Italy is built upon research with two previous SilEye cosmic ray detectors and associated research that was undertaken on the Mir Space Station from 1995 to 1999. The Alteino device (which consisted of the SilEye-3 detector and an Electroencephalograph) was flown to the ISS as part of the ESA/ASI Marco Polo mission in 2002 and was central to an experiment to test the effects of radiation on the electrical activity of the brain. Subsequently the Alteino device played a central role in additional experiments such as ALTCRISS (ALTEINO Long Term monitoring of Cosmic Rays on the ISS).
- **ALTEA**
The follow-up to the Alteino device was the Anomalous Long Term Effects in Astronauts' Central Nervous System (ALTEA) device (Fig. 2.9) which consisted of a helmet-shaped structure consisting of six silicon particle detectors and an EEG to measure brain activity. The hardware was developed by ASI and has been used in a number of previous experiments including ESA's ALTEA-Shield experiment, which aims to improve understanding of the light flash phenomenon, tests the effectiveness of different types of shielding material, and is undertaking a 3-dimensional survey of the radiation environment in the ISS.



Fig. 2.9 NASA astronaut and Expeditions 14 and 15 Flight Engineer, Sunita Williams, wears the anomalous long term effects in astronauts' central nervous system (ALTEA) experiment helmet while conducting the experiment in the US laboratory (Source: NASA)

In the Columbus laboratory itself two active **DOSTEL radiation dosimeters** are located inside the European Physiology Modules facility for taking part in experiments such as the Dose Distribution inside the ISS (DOSIS) experiment.

Plasma Kristall-4 and -3 Plus (PK-4 and PK-3 Plus) Payloads

The PK-4 payload will perform novel research in the field of 'Complex Dusty Plasmas'. These are low-temperature gaseous mixtures composed of ionized gas, neutral gas and micron-sized particles. The micro-particles become highly charged in the plasma and interact strongly with each other through the Coulomb force. These interactions can, in specific conditions, lead to a self-organized structure of the micro-particles: so-called plasma crystals. PK-4 will consist of a glass-made DC discharge plasma chamber. The elongated DC-plasma chamber of PK-4 is especially suited for investigations of complex plasmas in the fluid phase. On ground such experiments are distorted by gravity. This builds on previous complex plasma research in weightlessness which has been ongoing since 1998 and includes the ISS PK-3 plus experiment (and hardware) which is still ongoing and was developed by DLR.

Cardiomed

Cardiomed is CNES supplied and consists of Cardiolab type instruments which measure parameters such as muscular activity of the myocardium (electrocardiogram), blood pressure and arterial blood flow, being monitored in real time from

the Mission Control Centre in Moscow (MCC-M). Data gathered will identify mechanisms related to the effects of weightlessness on the cardiovascular system. This can help in the development of countermeasures to keep the crew in good health.

Elaborator of Televised Images in Space (ELITE-S2)

ELITE-S2 is an ASI system for observations on body motor control during long term exposure to microgravity and to perform quantitative data collection and analysis on board the ISS. Launched in 2007, ELITE-S2 studies the strategies for dynamic control of posture and body motion and adaptive mechanisms which allow adjustment of motor control strategies resulting from exposure to microgravity. It can allow investigations on the effects of weightlessness on breathing mechanisms, studies on the adaptive mechanisms which allow dynamic adjustment of motor control and posture control strategies resulting from exposure to microgravity, and applications of ergonomics findings in the design of spacecraft.

Hand Grip Dynamometer/Pinch Force Dynamometer

The Handgrip Dynamometer is a handheld device capable of measuring instantaneous hand strength as a function of time. The principal components are a handgrip, instrumentation amplifier and cables. The Pinch Force Dynamometer is a handheld device capable of measuring instantaneous strength of the thumb and opposing finger or groupings of fingers as a function of time. The principal components are a pinch force transducer, instrumentation amplifier and cables.

Mice Drawer System

The ASI Mice Drawer System is a general purpose compact animal research facility mainly for use with small rodents (mice). It can provide the habitats for six mice for up to 100 days (with possible extension up to 180 days). During its first flight it supported research into human bone formation and osteoporosis prevention countermeasures.

Minus Eighty Degrees Laboratory Freezer for the ISS (MELFI)

The frozen and refrigerated capabilities on the ISS are very extensive and of high importance namely for life sciences. MELFI (Fig. 2.10) [39] is the principal facility, developed in Europe, offering these capabilities on the ISS. Currently there are three European-built MELFI freezers on the ISS: two in the Japanese laboratory and one in the US laboratory. The MELFI freezers are rack-sized units



Fig. 2.10 ESA astronaut and ISS Engineer Paolo Nespoli, services the Minus Eighty *deg* Laboratory Freezer for ISS (MELFI-1) in the ISS Kibo laboratory in December 2010 (Source: NASA)

with four individual dewars that can be used for storage or fast freezing physiological and biological samples with a total capacity of 300 l. Each vacuum-insulated dewar can independently be set to one of the three different operating temperatures (-80 , -26 and $+4^{\circ}\text{C}$).

2.2.1.4 European Space Exposure Research Outside the ISS

Columbus External Payload Facility

The Columbus laboratory is also fitted with an external facility for attachment of research equipment requiring exposure to the open space environment. This has four locations: one pointing towards the Earth (NADIR), one pointing away from the Earth (ZENITH) and two pointing in a starboard direction to the direction of flight (LIMB) of the ISS. Payloads are integrated onto Columbus External Payload Adapters (CEPA) prior to launch to the Station. Once installed by EVA or robotic means payloads can be automatically supplied with power and data connections.

External Facilities

When Columbus was first installed on the ISS it was initially outfitted with the European Technology Exposure Facility (EuTEF) [40], which carried a suite of nine different payloads with 13 different experiments in materials research, space physics, astrobiology, radiation, and space technology.

- DEBIE-2: 'DEBris In orbit Evaluator'
- MEDET: Materials Exposure and Degradation Experiment orbit.
- TRIBOLAB: Experiments for research in tribology.
- FIPEX: Sensor for measurement of atomic oxygen
- PLEGPAY: PLasma Electron Gun PAYload
- DOSTEL: DOSimetric radiation TELescope
- EXPOSE: Five exobiology experiments
- EuTEMP: Multi-input thermometer
- EVC: Earth Viewing Camera

SOLAR Facility

The SOLAR payload facility (Fig. 2.11) [35] has been studying the Sun's irradiation with unprecedented accuracy across most of its spectral range since 2008, producing excellent scientific data during a series of Sun observation cycles. It will continue to gather science data in a period of increasing solar activity up to 2013 and possibly beyond. SOLAR consists of three instruments complementing each other to allow measurement of the solar flux throughout virtually the whole electromagnetic spectrum – from 17 to 3,000 nm – in which 99% of the solar energy is emitted. The instruments are mounted on a device for accurate Sun pointing and are controlled by a Control Unit. The scientific instruments are: SOVIM (Solar Variable & Irradiance Monitor) which covers near UV, visible and thermal regimes (200 nm–100 μ m) SOLSPEC (SOLar SPECtral Irradiance measurements) which covers the 180–3,000 nm range with high spectral resolution and SOL-ACES (SOLar Auto-Calibrating EUV/UV Spectrophotometers) which measures the EUV/UV spectral regime (17–220 nm) with moderate spectral resolution.



Fig. 2.11 The solar payload facility pictured on the Columbus laboratory during the STS-124 mission (Source: NASA)

EXPOSE-R

The Expose-R facility hosts a suite of nine astrobiology experiments (eight from ESA, one from the Russian Institute for Biomedical Problems (IBMP), in Moscow), some of which could help understand how life originated on Earth. The facility accommodates experiments in three special sample trays, which are loaded with a variety of biological samples including plant seeds and spores of bacteria, fungi and ferns, which are exposed to the harsh space environment (Solar UV, cosmic radiation, vacuum and microgravity), for about 2 years.

In the future the Columbus External Payload Facility will accommodate:

Atomic Clock Ensemble in Space (ACES)

ACES [41] accommodates two atomic clocks: PHARAO ('Projet d'Horloge Atomique par Refroidissement d'Atomes en Orbit') is a primary frequency standard based on samples of laser cooled cesium atoms developed by CNES; SHM (Space H-Maser) is an active hydrogen maser for space applications developed by ESA. The functionality and performance of this new generation of atomic clocks will be tested on the ISS for at least two years. Comparisons between distant clocks both space-to-ground and ground-to-ground will be performed worldwide with unprecedented resolution. These comparisons will be used to perform precision tests of the special and general theory of relativity. ASIM has national co-funding from Denmark, Norway, and Spain.

Atmospheric Space Interactions Monitoring Instrument (ASIM)

ASIM will study giant electrical discharges (lightning) in the high-altitude atmosphere above thunderstorms and their role in Earth's climate. The external payload is composed of light detectors, sensitive in the optical range (cameras, photometers) and in the X-ray to Gamma-ray ranges (imaging spectrometer).

2.2.1.5 European Control Centre Network

To harness the diverse European involvement in the International Space Station, Europe through the European Space Agency defined a network of ground control centres across the continent to control Europe's infrastructure on the ISS [22].

Columbus Control Centre

The Columbus Control Centre (Fig. 2.12) is located at the German Space Operations Centre of the German Aerospace Center (DLR), in Oberpfaffenhofen,



Fig. 2.12 Overview of room K4 at the Columbus control centre in Oberpfaffenhofen, Germany (Source: DLR)

near Munich, Germany. Operational 24 h a day, 7 days a week, the Columbus Control Centre operates Europe's Columbus laboratory on the ISS with responsibility for coordinating all the Columbus system and research activities. It is in close contact with the Mission Control Centre in Houston, USA, which has overall responsibility for the ISS, together with the Mission Control Centre in Moscow, Russia. In addition, the Columbus Control Centre coordinates operations with the ISS Payload Operations and Integration Centre at the Marshall Space Flight Centre in Huntsville, Alabama, USA, which is responsible for the overall US utilisation activities namely in the Destiny laboratory and other partner laboratories.

The Columbus Control Centre provides the ground services for Columbus operations including communication services (voice, video and data) to all sites responsible for control and coordination of individual European facilities and experiments on the ISS, including the network of User Support and Operations Centres across Europe, industrial support sites, home bases of research teams, as well as ESA management and associated ESA locations.

User Support and Operations Centres (USOCs)

USOCs are based in national centres throughout Europe and are responsible for the use and operation of European payloads on board the ISS. On behalf of users (i.e. scientists, technology developers, education specialists etc.) and under ESA contract, the USOCs conduct the tasks needed to prepare and operate the research facilities and experiments on board the ISS. The USOCs act as the link between the user and their ISS research, and are the focal point for the preparation and operation of ESA payloads on the ISS. All European USOCs are centrally linked to the ISS via the Columbus Control Centre or control centres of ISS partner agencies for ESA

payloads located outside of Columbus. There are three levels of responsibility for USOCs. The first is as a Facility Responsible Centre which has the responsibility for a specific multi-user rack level facility such as the European Drawer Rack for example and includes assisting scientists with payload operations. The next level of responsibility is the Facility Support Centre that is responsible for a subrack payload in a rack facility such as the Electro-Magnetic Levitator that will fly in the future and be located within the European Drawer Rack. The last level of responsibility is the Experiment Support Centre which has the responsibility for single experiments either as self-standing experiments or within a facility, and mainly focuses on science and experiment operational matters. Dedicated User Home Bases can also be set up where scientists can carry out real-time data monitoring and control of their respective experiments.

The current network of User Support and Operations Centres includes the Belgian User Support and Operation Centre (B.USOC) in Brussels, Belgium; the Biotechnology Space Support Centre (BIOTESC) in Zurich, Switzerland; the Centre d'Aide au Développement des activités en Micro-pesanteur et des Opérations Spatiales (CADMOS) in Toulouse, France; DAMEC Research Aps (DAMEC) in Odense Denmark; the Erasmus User Support and Operations Centre in Noordwijk, the Netherlands; the Spanish User Support and Operations Centre (E-USOC) in Madrid, Spain; the Microgravity Advanced Research and Support Centre (MARS) in Naples, Italy; the Microgravity User Support Centre (MUSC) in Cologne, Germany, and the Norwegian User Support and Operations Centre (N-USOC) in Trondheim, Norway. In addition to the research-related control centres mentioned above, the European Space Agency also has an ATV Control Centre based on the premises of the French space agency, CNES, in Toulouse, France, which is responsible for operating Europe's Automated Transfer Vehicle, Europe's logistics supply spacecraft for the ISS.

2.2.2 Foton/Bion Recoverable Capsules

Europe has been an extensive user of the Russian Foton, Bion and Resurs-F type of recoverable unmanned capsules [17] for carrying out research in low Earth orbit since 1975. They were based on the Vostok spacecraft, which carried Gagarin as the first man into space in 1961 and the Zenit military reconnaissance satellite. A typical Foton mission lasts about 12–18 days and as the mission is unmanned all dedicated experiments have to be fully automated with telemetry allowing for up and downlink capabilities for command and control of payloads and experiment parameters. After being put into orbit by a Soyuz-U launcher from the Baikonur Cosmodrome in Kazakhstan (previously the Plesetsk Cosmodrome in Russia) the spacecraft places itself in the correct orientation using attitude control thrusters, before undertaking a free-flying period which will last until the final day of the mission when the re-entry procedures start. The up to 650 kg of research and support equipment for experiments are housed in the spacecraft's Re-entry Module

GradFlex	(ESA-55kg)	2 fluid physics experiments
TeleSupport	(ESA-24kg)	assists all payloads on board
Biopan	(ESA-27kg)	10 experiments in exobiology and radiation exposure
SCCO	(ESA/CSA-28kg)	3 experiments on diffusion effects in crude oil
Biobox	(ESA-67kg)	5 experiments on cellular biology
Eristo/Osteo	(CSA/ESA-71kg)	6 experiments on bone growth and yield
AquaHab	(DLR/ESA-18kg)	2 experiments in biology of water organisms
Polizon	(KBOM-182kg)*	7 cooperative experiments on material science
Stone	(ESA-1kg)	2 meteoritic re-entry experiment
Granada	(ESA-5kg)	growth of several protein crystals (2 exp.)
Freqbone	(B/ESA-12kg)	countermeasures for bone losses in μg (1 exp.)
YES-2	(ESA-40kg)	student payload, tether-assisted re-entry demonstrator
DataLogger	(ESA/TsSKB-2kg)*	measurement of shocks, temperature, and RH in Foton
Dimac	(ESA-9 kg)*	tri-axial accelerometer system (true DC to 200Hz)
Battery	(ESA-15kg)*	Li-ion primary batteries for re-entry and landing
Teplo	(B/ESA-17kg)**	low-g performances of new design (loop) heat pipes
OWLS	(ESA-0.5kg)*	wireless technology demonstrator (<u>part of TeleSupport</u>)
SEEK	(ESA-0.2kg)*	measurement of g-loads (<u>part of Gradflex</u>)
Photo-II	(ASI/ESA-4kg)**	space radiation effects on photosynthesis
Total	348 (394) kg	(*) not contractually accounted (**) nationally covered flight

Fig. 2.13 European Scientific payload on Foton-M3

(or outside the module in the case of astrobiology/exposure experiments). The spacecraft also includes a Service Module responsible for attitude control and deorbit retroboost of the whole spacecraft and a Battery Module supplying electrical power to the spacecraft and research equipment. Prior to re-entry the three modules separate and the Re-entry Module, which is covered in an ablative material, re-enters the Earth's atmosphere, undertaking a parachute-assisted landing where it is retrieved. The other two modules burn up in the atmosphere as planned.

Foton was envisaged as a platform for physics and materials science to complement the Bion capsules that were aimed at life science studies. However, in later years increasing numbers of experiments were transferred to Foton, while the Bion programme was temporarily discontinued in 1996. Scientific payloads from western Europe have regularly flown on Foton. On the flights of Foton-M2 and Foton-M3 for example there was an extensive amount of research equipment totalling 660 kg (Fig. 2.13) across both flights. This included experiments such as Gradflex which was looking into density/concentration fluctuations in fluids exposed to thermal gradients in weightlessness; and exposure experiments in the Biopan facility which was trying to answer fundamental questions about the origin and spreading of life forms in space.

2.3 Non-orbital Weightless Research Platforms

Outside of the orbital infrastructure discussed in the previous section, Europe (and other space-faring nations) make use of additional research platforms that provide access to varying degrees of weightlessness. These can either be a sufficient end

point for research goals or may act as a precursor to flying experiments and hardware in orbit. The principal platforms for this area of research are:

2.3.1 *Sounding Rockets*

Originally conceived to sound the physical properties of the upper atmosphere, hence the name ‘sounding’ rockets, their use since the late 1950s has been extended beyond Meteorological and Upper Atmosphere studies to provide ‘weightless’ conditions for experimental research in physical and life sciences. Sounding rockets [16] are a sort of ballistic missile able to launch a few hundred kilograms to altitudes of 250–750 km, with almost vertical ascent and descent trajectories.

Excellent weightless conditions are met during the freefall phase of the rocket’s payload once the rocket motors have exhausted their thrust and separated from the payload. The rocket’s payload continues to rise under the momentum built up during the launch phase before falling back towards Earth. The period of weightlessness ends just prior to its re-entry phase. The freefall ends with the re-entry in the Earth atmosphere and finally the deployment of the parachute that lowers the payload to the ground with appropriate impact speeds (Fig. 2.14 right).

This microgravity research platform provides a great flexibility as there are a variety of different sounding rockets available to be utilised by the European scientific, industrial, commercial and education communities. This makes them excellent candidates for performing a experiments with different requirements as well as providing a means of testing experiments and equipment to be undertaken or used in orbit. Sounding rocket missions are a valuable means to undertake

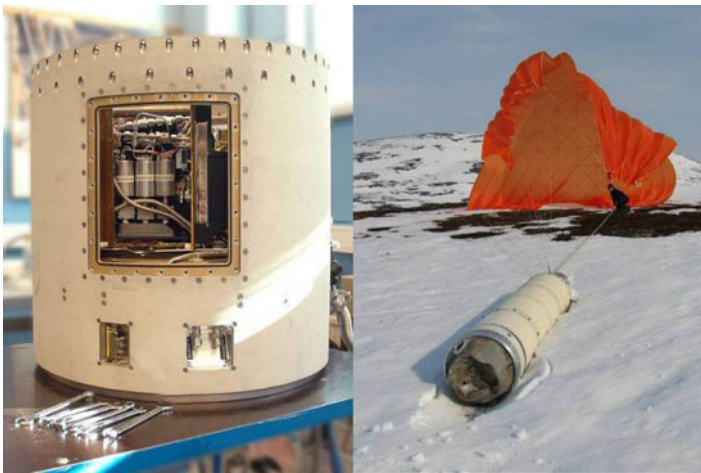


Fig. 2.14 (Left) the XRMON-Diff module (prior to launch) which flew on MAXUS 8 in March 2010. (Right) MAXUS 7 payload following landing on 2 May 2006 (Source: SSC)

experiments having stringent pre-/post-flight experiment logistics and may use hazardous materials or equipment (e.g. radiation sources for in-situ visualisation). They are also advantageous for high-temperature materials experiments as the heater/furnace materials degrade quickly and as such do not make them candidates for long-term ISS experiments. The duration of weightlessness provided by different sounding rockets ranges from 6 to 12 min with a payload mass of up to 800 kg.

From a European perspective a majority of sounding rocket launches are undertaken at the Esrange launch site in Northern Sweden. It is owned and managed by the Swedish Space Corporation (SSC) with ESA as a regular user and major research partner along with other national organisations and partners such as DLR. The location, just within the Arctic Circle, is excellent for the investigation of polar phenomena. It has a safe impact area of 9,000 km²; and the launch site has excellent transport links. Sounding rocket services are also offered by the Andoya Rocket Range in Norway. Both Esrange and Andoya have a full range of capabilities at their launch sites for testing and preparation of experiment payloads (Fig. 2.14 left) prior to launch and monitoring them in flight. The availability of real-time data allows experimenters to follow and if necessary direct the course of their experiments. Launch preparation activities allow for a late access to the experiment modules.

Besides the experiment modules other functional modules complement each sounding rocket mission, such as the service module for telemetries and telecommands as well for the rocket attitude control, the video module to relay multiple video channels to the receiving ground stations, the recovery system that commands the deployment of the parachute packet in the nosecone of the rockets, and the separation module needed to detach from the payload stack when the rocket motors are at the end of their thrust (Fig. 2.14 left).

Sounding Rockets that are and have been central to European weightless research activities include TEXUS which has been launched 48 times since 1977 the last launch being TEXUS-47 in November 2009; MASER which has been launched 11 times since 1987, the last launch being MASER-11 in May 2008; and MAXUS which has been launched nine times since 1991, the last occasion being MAXUS 8 in March 2010. At the time of compilation the launch of MASER-12 is scheduled for November 2011 and the launch of TEXUS-49 was scheduled for March 2011 (with TEXUS-48 following in November 2011). The launch of MAXUS-9 is planned for 2013 with an experiment complement of four modules in materials research and biology. The REXUS rocket programme is also a central component of educational activities (together with the BEXUS high-altitude balloon programme) having flown eight times in total. The launches of REXUS 9 and 10 are scheduled for March 2011.

2.3.2 *Parabolic Flight Airplanes*

Parabolic flights [15] are used to conduct short-term scientific and technological investigations in weightlessness and reduced gravity, to test instrumentation prior to



Fig. 2.15 A view inside the ‘Zero G’ cabin during the weightless phase of a parabola as part of the 49th ESA Parabolic Flight Campaign (Source: ESA – A. Le Floch)

use in space, to validate operational and experimental procedures, and to train astronauts for a future human spaceflight missions. In Europe this service is supplied by NoveSpace (a subsidiary of CNES) in Bordeaux, France using an Airbus A300 0-g aircraft with ESA, CNES, DLR all using their services. Such flights are conducted on specially-configured aircraft, and provide repetitive periods of weightlessness. During a campaign, which normally consists of three individual flights, some 30 parabolas are flown on each flight, around 90 parabolas in total. On each parabola, there is a period of increased gravity (1.8–2 g) which lasts for about 20 s immediately prior to and following a 20 s period of weightlessness (Fig. 2.15).

The Airbus A300 zero-g aircraft is now also certified for flying reduced gravity parabolas of 0.16 g for approximately 23 s and 0.38 g for approximately 30 s, which correspond to Lunar and Martian gravity levels. In June 2011 ESA undertook jointly with CNES and DLR the first partial gravity parabolic flight campaign in preparation for future exploration activities. Parabolic flights are the only sub-orbital carrier to provide the opportunity for the science community to carry out medical and physiological experiments on human subjects under conditions of weightlessness or reduced gravity, complementing studies conducted in space, and in simulated conditions on ground (*e.g.* immersion, bed-rest). They also provide physicists with the opportunity of carrying out hands-on investigations on processes characterised by short time scales. These flights offer a flexible approach and short lead-times for researchers, as well as the opportunity to modify their experiments during a flight campaign. Organisations, such as ESA for example, also cover the cost of such flights for research proposals that are selected.

ESA and CNES have had a close partnership on parabolic flights from 1988 when CNES made their Caravelle zero-g aircraft available to ESA for parabolic flight campaigns. This accounted for 15 campaigns until 1995. To date ESA have

undertaken more than 54 parabolic flight campaigns covering research and education. CNES have also undertaken around 50 parabolic flight campaigns. The German Aerospace Agency (DLR) have undertaken almost 20 campaigns on the A300 aircraft since 1999 (which included the 10,000th parabola by the A300 0-g aircraft).

2.3.3 Drop Towers

Drop Towers [14] offer the opportunity to undertake a variety of experiments in fields such as fluid dynamics, process engineering, combustion, material science, biology and biotechnology requiring only a limited exposure to weightlessness to the extent of a few seconds either due to this suiting experiment requirements or as a precursor to the experiment being flown on a different weightless platform. In Europe the principal exponent of this is at the University of Bremen in Germany within the Center of Applied Space Technology and Microgravity (ZARM) which celebrated its 25 anniversary (and 20th of the Drop Tower) in 2010.

The ZARM Institute houses a variety of experiment facilities and laboratories that are available for ZARM scientists but also for researchers from other universities and organizations. Among these facilities are vibration and aerodynamics test labs as well as facilities that allow performing experiments under micro or hyper gravity conditions. The main laboratory is the 146 m drop tower which, in comparison to orbital systems, represents an economic alternative with permanent access. It serves as an important supplement to either existing or planned orbital or

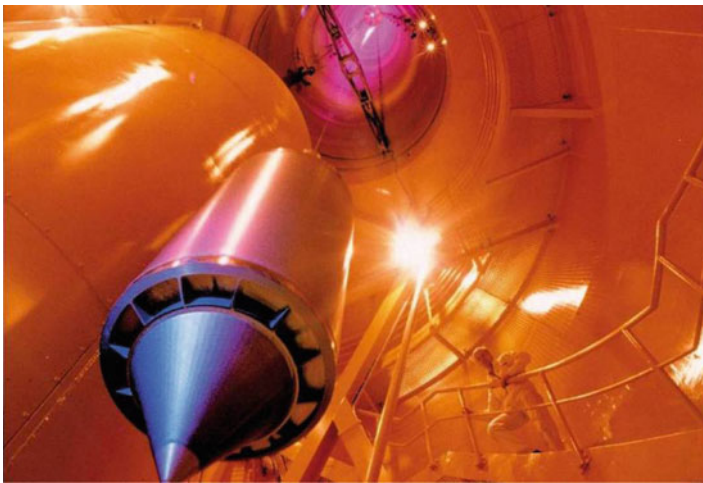


Fig. 2.16 Internal view of the ZARM drop tower in Bremen, Germany. The drop tower capsule being prepared (Source: ZARM)

suborbital platforms for microgravity research. As of October 2008, 5,000 drop experiments had successfully been carried out since it started operation in 1990.

The installation delivers 4.74 s of near-weightlessness for a single drop up to three times a day. In order to double the microgravity time to 9.3 s, a catapult system was implemented into the drop tower operation routine. With the drop tower catapult, the capsule (Fig. 2.16) performs a quasi-vertical parabola instead of being dropped. Experiments are held in a cylindrical 80 cm wide capsule which is closed pressure-tight. For a drop the capsule is winched up to a height of 120 m. The 1,700 m³ tube and the deceleration chamber are then evacuated to eliminate aerodynamic forces on the falling capsule. The capsule is then released. A deceleration unit, filled with polystyrene pellets, decelerates the vehicle. For retrieval, the vacuum chamber is reflooded with preconditioned air within 20 min. The experiment and results are hereafter immediately at the scientists' disposal.

At the National Institute for Aerospace Technology in Madrid, Spain a 21 m drop tower, which offers 2.1 s of weightlessness is also available. Experiment payloads can either be placed in a double capsule (for smaller experiments) which offers increased quality weightlessness as the outer capsule acts as a drag shield, or placed in a single capsule for accommodating comparatively larger experiments.

2.3.4 High-Altitude Balloons

High-altitude balloons have been used for decades and the improvement in their capabilities has increased their reliability and potential for undertaking different forms of research such as Ozone studies, circum polar flights, astronomical studies, astrophysical studies, microgravity studies and educational purposes etc. Many different agencies/countries have their own national programmes offering access to high-altitude balloons such as CNES in France, ASI in Italy, DLR in Germany, SSC in Sweden and the Andoya Rocket Range in Norway. As with sounding rockets, two examples of launch sites for high-altitude balloons are the Esrange launch site in Northern Sweden and the Andoya Rocket Range's launch site on the Norwegian Svalbard archipelago.

Many different balloons exist for offering different conditions to the payload that it is carrying with relation to different factors/parameters required such as altitude ranging from ~15–45 km, data measurement time required, and payload mass flown which can vary from a couple of kg to a few tonnes. Launch sites have the necessary facilities to prepare payloads prior to launch, and monitoring payload telemetry. Most balloon systems are used for communication with different service systems or for data transmission from the payload to the ground station.

One example of the use of high-altitude balloons is in the BEXUS (Balloon-borne EXperiments for University Students) programme, which is a collaboration between the Swedish National Space Board and DLR providing students the possibility to undertake their experiments on high-altitude balloons (or on sounding

rockets as part of the REXUS Programme). The Swedish share of the payload has been made available to students from other European countries through a collaboration with the European Space Agency.

A typical balloon configuration could consist of a helium-filled balloon, a gondola holding experimental payloads, a cutter to cut the gondola away from the balloon, a parachute system and systems covering altitude control, flight termination, Global Positioning System (GPS), temperature and air pressure sensors, systems for experiment data and control and telemetry. The gondola would typically be retrieved by a helicopter after landing. The last flight of BEXUS was BEXUS 11 which was launched in November 2010. The next scheduled campaign is for BEXUS 12 and 13 in October 2011.

2.4 Ground-Based Facilities and Space Simulators

2.4.1 *Bed Rest, Hypokinesia and Metabolic Balance Facilities*

Bed rest studies are an invaluable method for simulating the effects of spaceflight on the human body. The physiological effect of lying in bed tilted at 6° for an extended period with the head lower than the feet produces bone/muscle mass loss and fluid shifts similar to those seen in human spaceflight. As such these studies are a cost-effective means of undertaking an analysis of the underlying mechanisms causing these effects and testing different countermeasures (Fig. 2.17) to alleviate the negative physiological effects such as nutritional supplements, exercise

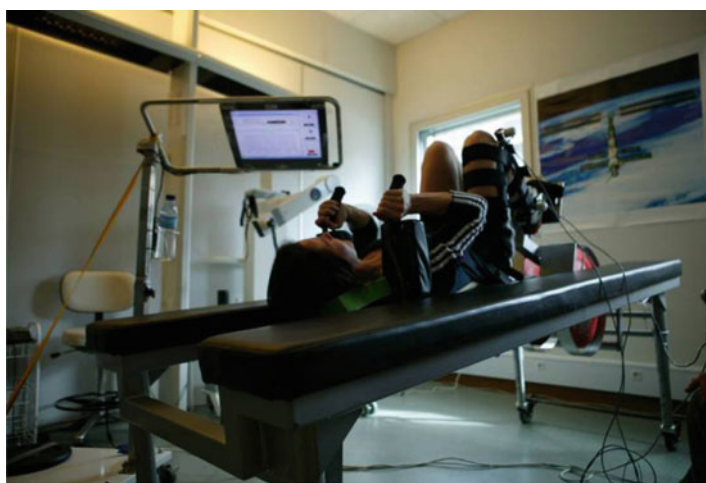


Fig. 2.17 Flywheel exercise device being used as part of experiment protocol during WISE 2005 bed rest study (Source: CNES/Stéphane LEVIN)

protocols and equipment or artificial gravity [27, 28, 50, 51, 71]. The confinement of bed rest subjects also holds similarities with the confinement experienced by astronauts on mission and thus makes these studies helpful in testing psychological protocols.

The **Medes Clinical Research Facility, in Toulouse, France** conducts clinical research studies in a unique European research facility housed within the Rangueil university hospital in Toulouse, mainly in the areas of physiology, pharmacology and the evaluation of biomedical devices. It undertakes experiments which simulate the effects of the space environment (involving bed rest, confinement, circadian rhythms, *etc*) in order to study its physiological effects and to develop preventive methods. A similar facility to Medes is the **Simulation Facility for Occupational Medicine Research (AMSAN), at the DLR Institute of Aerospace Medicine in Cologne**. This multi purpose research facility undertakes bed rest studies with respect to evaluation of protocols/countermeasures though the primary focus of AMSAN is in nutritional studies.

2.4.2 Isolation and Confinement, Pressure Chambers and Climate Chambers

Based on experience gained from isolation studies, combined with other terrestrial-based simulation facilities and data from human spaceflight missions in low Earth orbit, especially within the last two decades, the European scientific and technology community has gained substantial experience in assessing the risks for humans in the space environment. In addition to being helpful in determining psychological aspects of space flight such as the psychology of group dynamics and individual performance under isolation and confinement, this research combined with knowledge obtained from human spaceflight missions has been invaluable in determining human adaptation to conditions in space, as well as in the development of life support systems. Previous space-related isolation studies have included the ISEMSI study in Norway in 1990, the EXEMSI study in 1992 in Cologne Germany, both performed in shore-based hyperbaric chambers, the Human Behaviour in Extended Spaceflight (HUBES) study which modelled aspects of the long-duration Euromir 95 mission and the ‘Simulation of the Flight of the International Crew on Space Station’ (SFINCSS) from 1999 to 2000.

The **Mars 500 Isolation Facility, in Moscow, Russia** facility is a Russian Institute for Biomedical Problems (IBMP) facility though many IBMP studies have European involvement, one of the most prominent being MARS 500. A purpose built isolation facility was outfitted in order to simulate a human spaceflight mission to Mars (Fig. 2.18). The Mars500 isolation facility in which the crew is based is located in a special building which comprises the isolation facility itself, as well as the operations room, technical facilities and offices. The isolation facility comprises one external module, which is used to simulate the ‘Martian surface’ and



Fig. 2.18 Mars500 crew has a computer simulator for practicing docking, undocking and maneuvering their spaceship. It was also used when ship ‘left’ Earth orbit for interplanetary cruise on 14 June (Source: ESA)

four hermetically sealed interconnected habitat modules which simulate the spacecraft that take the crew on the simulated journey to Mars and back.

Two European stations undertaking space-relevant research are based in the Antarctic peninsula. The Italian/French Concordia base which supports remote isolation studies and is open for research groups from all over Europe. ESA’s Directorate of Human Spaceflight uses Concordia’s special environment to prepare for future human missions to the Moon or Mars, and ESA supports the French Polar Institute and the Italian Antarctic Programme in medical monitoring, operational validation of life-support technologies and psychological training. The Rothera Research Station is the principal British Antarctic Survey logistics centre for support of Antarctic field science.

In addition to the facilities above **COMEX’s Hyperbaric Experimental Centre** in France features hypobaric and hyperbaric chambers which can be used for the qualification of equipment, and human intervention methods in hostile environments; a Neutral Buoyancy Facility (Pool) for undertaking Microgravity, Lunar or Martian gravity training; and a cellular biology laboratory. **TNO, based in Soesterberg, the Netherlands** have different **Climate Chambers** for undertaking thermal physiology research of humans in extreme environments.

2.4.3 Centrifuges

The use of hypergravity devices plays an important role in many research areas from physiology and biology to materials science and technology [23, 25, 65, 70,

73, 74, 79]. Using human centrifuges in astronautics play an important role in astronaut selection by testing the capability to withstand hypergravity as a simulation to conditions of launch and re-entry. During the first minutes of a Shuttle launch for example, astronauts are exposed to accelerations of 4 g max. in a supine position. Centrifuges further hold applicability to human physiology research for example with testing centrifugation as a means of countering bone mass loss. This type of research can also impact on vestibular-related disorders in space and on Earth. Taking non-human centrifuges into account these devices are a key element in, for example, plant and cellular biology for determining the gravisensing mechanisms and thresholds in plants which could impact on cultivation processes on Earth and for future human spaceflight exploration missions beyond low-Earth orbit.

2.4.3.1 Human Centrifuges

A number of human centrifuges exist around Europe for undertaking human physiology research in hypergravity. DLR, in Cologne, Germany and the Medes Space Clinic, in Toulouse, France have similar short-arm human centrifuges (Fig. 2.19) which go up to 6 g and are used in countermeasure studies for astronauts. The centrifuges can accommodate two reclining and two seated subjects. Additional human centrifuges are in place at the Netherlands Aeromedical Institute, in Soesterberg, the Netherlands which can hold up to 175 kg in payload mass, and at the Karolinska Institute, in Stockholm, Sweden which can expose up to 300 kg of payload mass to up to nine times gravity (15 times gravity for just equipment). TNO in Soesterberg, the Netherlands also has a facility called Desdemona [8]. This is a

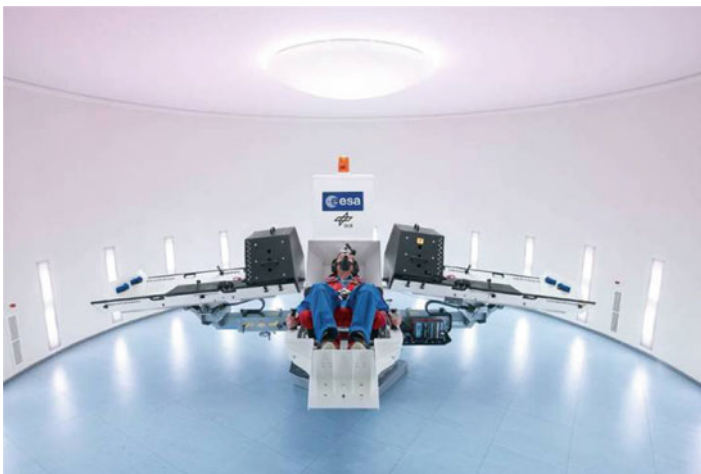


Fig. 2.19 The short-arm human centrifuge at DLR in Cologne (Source: DLR/Markus Steur)



Fig. 2.20 The ESA Large Diameter Centrifuge (LDC) at ESA-ESTEC, Noordwijk, the Netherlands (Source: ESA)

six degrees-of-freedom motion base that is capable of rotation in three axes, linear motion along an 8 m track, and sustained centrifugation up to 3 g.

2.4.3.2 Non-human Centrifuges

Non-human centrifuges around Europe vary considerably depending on their purpose. Larger radius centrifuges are in situ at the Academic Medical Center, in Amsterdam, the Netherlands and at ESA/ESTEC, Noordwijk, the Netherlands providing 8 g and up to 20 g environments respectively for a variety of biological, biotechnological, biochemical, physical, material and fluid science, geology and plasma physics experiments. The ESTEC Large Diameter Centrifuge (LDC) [80] can hold experiments (up to 80 kg) lasting from 1 min to 6 months (Fig. 2.20). DLR also has the smaller NIZEMI Centrifuge which consists of a Slow Rotating Centrifuge Microscope for hyper-g experimentation up to 5 g and allowing for observation of small organisms, and the Dutch Experiment Support Centre has the Medium sized Centrifuge for Acceleration Research (MidiCAR) which is a dedicated cell/tissue culture centrifuge in which samples may be exposed to accelerations up to 100 g.

2.4.4 Human-Rated Linear and Angular Accelerators

In a similar way to the centrifuges listed above, the Human-rated Linear and Angular Accelerators play an important role in understanding the activity and



Fig. 2.21 Roscosmos cosmonaut Yuri Malenchenko seated on the visual and vestibular investigation system in star city in Moscow, undergoing a final check before centrifugation (Source: GCTC Moscow)

mechanisms underlying the vestibular system in weightlessness [6, 9, 10, 24, 48, 66, 67]. With the vestibular system relying on gravitational stimuli on Earth in order to hold proper posture and balance, the understanding of the mechanisms that underly the lack of these stimuli in space can help to provide an insight into the problems associated with special awareness and orientation in space as well as balance disorders on Earth.

TNO, in Soesterberg, the Netherlands has a vestibular laboratory with a 3-D rotating chair, Linear Track (the ESA Space Sled), Tilting Room, and Ship Motion Simulator while the **Medes Space Clinic, Toulouse, France** has a **Visual and Vestibular Investigation System** (Fig. 2.21), ESA-developed for NEUROLAB for investigating the role of the inner ear in detecting changes in motion and orientation. Outside of these two facilities the **Centre for Human Sciences Impact Facility in Farnborough, UK**, has a **Deceleration Track** for the Impact testing.

2.4.5 Clinostats, Free Fall Machines, and Random Positioning Devices

These devices provide/simulate weightlessness in a variety of ways [11, 13, 52–54, 68, 75, 78] for different periods of time. A clinostat (Fig. 2.22 left) uses rotation to negate the effects of gravitational pull on plant growth (gravitropism) and development (gravimorphism). It has been used to study the effects of simulated

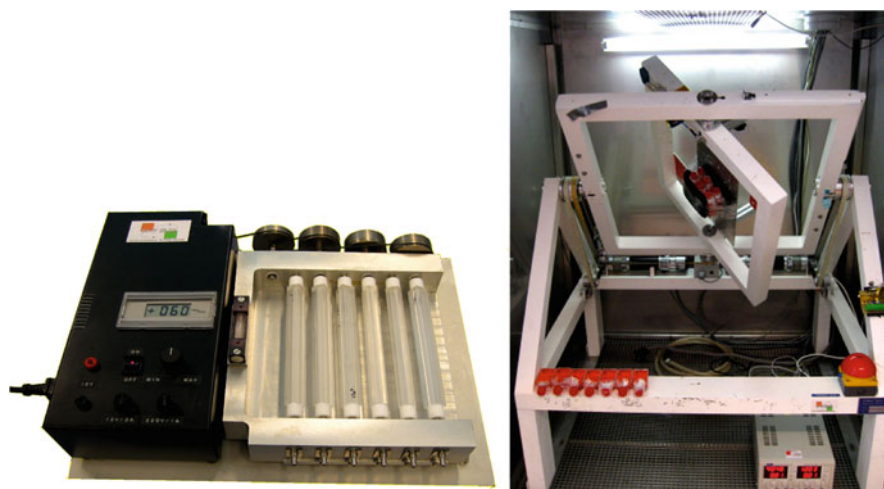


Fig. 2.22 *Left* a classical fast rotating clinostat. *Right*: the random positioning machine developed by Dutch Space (Source: DESC, J. van Loon)

microgravity on e.g. cell cultures and animal embryos. The core of the Free Fall Machine is a vertical bar which guides the experiment while it goes through its free fall cycles. After each cycle the experiment experiences a far shorter acceleration cycle at multiple g levels to return the experiment to its initial position. Random Positioning Machines (Fig. 2.22 right) rotate in a way to simulate weightlessness by removing the effect of gravity in any specific direction. Clinostat facilities are available at DLR in Cologne, the DESC Laboratory at the Free University of Amsterdam, and at the Space Biology Group of the Swiss Federal Institute of Technology in Zurich. The two latter institutions have the availability of Free Fall Machines and Random Positioning Machines.

2.4.6 Telemedicine, Behaviour and Metrics

Telemedicine can be defined as the delivery of healthcare services, where distance is a critical factor, by healthcare professionals using information and communications technologies for the exchange of valid information for diagnosis, treatment and prevention of diseases and injuries, research and evaluation, and for the continuing education of healthcare providers, all in the interest of advancing the health and their communities (WHO, 1997). The rapid advances of Information and Communications Technology offers the possibility of improving health services and making the best use of limited and valuable resources.

Within the areas of telemedicine, behaviour and metrics capabilities include: the **Telemedicine Portable Workstation developed at MEDES, Toulouse, France**, which collects biomedical patient data and can transmit them to a medical expert

for a first aid medical consultation or a second opinion advice; **3-D body scanning, at TNO, Soesterberg, the Netherlands** for digitally recording exact shape and body dimensions of humans and objects which can be used in computer-aided design to construct made-to-measure apparel for example; and **Usability Engineering, at TNO Soesterberg** where equipment and human-factors know-how are available for the design and test of user interface for space applications. The services include the specification of user requirements, interface prototypes (e.g. storyboards), expert reviews and user tests (in the lab, on location or remotely).

2.4.7 Integrated Bio-Processing, Tissue Engineering

Developments in the multidisciplinary field of tissue engineering have yielded a novel set of tissue replacement parts and implementation strategies. Scientific advances in biomaterials, stem cells, growth and differentiation factors, and biomimetic environments have created unique opportunities to fabricate tissues in the laboratory from combinations of engineered extracellular matrices (“scaffolds”), cells, and biologically active molecules. Among the major challenges facing tissue engineering is the need for more complex functionality, as well as functional and biomechanical stability in laboratory-grown tissues destined for transplantation.

The Charité Institute for Transplantation and Organ Replacement, which forms part of the Charité, Medical Faculty of the Humboldt University in Berlin offers a scientific environment in the fields of tissue engineering, biomedical technology and transplantation medicine.

Equipment and know-how are available at **Bio-up, at the Blaise Pascal University, in Clermont-Ferrand, France** for the experimental determination of capabilities of various biological transformations, including aerobic and photosynthetic cultures of microorganisms, which are of interest in Life Support Systems for long duration space missions.

The **ERISTO (“European Research in Space and Terrestrial Osteoporosis”)** project is funded by ESA, national space agencies and the ERISTO partners within the frame of the ESA Microgravity Application Promotion programme. The objectives of ERISTO are to develop innovative models of osteoporosis either using the space environment to provide “mechanical stress free” experimental conditions and to improve diagnosis, prevention and treatments of this disease. The ERISTO team has the expertise and provides access to facilities and services covering the main field of research in bone remodelling and osteoporosis [2, 12, 56, 57, 59, 62].

The main services and the expertise provided by ERISTO are: Innovative analytical tools, in particular, a system able to measure bone micro-architecture and calculate bone strength *in-vivo*. ERISTO also masters the main tools required to cultivate and study bone cells and tissues in a controlled environment; provide *in vitro* and *in-vivo* models (for example cultivation of *ex-vivo* bone cells) and

provide access to ERISTO partner facilities and to new facilities developed within the project.

2.4.8 Magnetic Resonance Facilities

Magnetic resonance techniques are extremely useful within spaceflight-related programmes and projects for determining/imaging some of the physiological effects on soft and hard body tissues. This can either be associated with actual spaceflight missions or in simulated weightlessness such as in bed rest studies. For magnetic resonance techniques related to spaceflight there are facilities within the University of Trieste within the Dept. of Biochemistry, Biophysics and Macromolecular Chemistry (at the Cattinara Hospital in Trieste) and at the Muscle Lab of DLR's Physiology Laboratory. The Muscle Lab is available to in-house researchers and external scientists (under certain circumstances).

2.4.9 Movement Analysis, Physical and Skills Training

2.4.9.1 CAR (Centre d'alt Rendiment) Barcelona, Spain

The CAR center has been specifically designed to support the improvement of performances of top athletes and to characterize the physiological and general training conditions contributing to such improvement. The Olympic Training Centre is providing all necessary equipment and know-how that is necessary for the improvement of performances of top athletes. In addition to sports, educational and residential facilities, CAR offers services in biomechanics including 2D and 3D videographic analysis of movement and training, and strength development control through electrical activity (electromyography); services in physiology such as analysis of body composition, lactic acid and pH level tests, strength/force testing (dynamometry), MRI assessment of body/weight distribution and Muscular metabolism study; as well as psychology, nutrition, and physical training and evaluation. CAR is a public company of the Government of Generalitat de Catalunya with an agreement with Spanish Sports Council.

2.4.10 Additional Animal Physiology Facilities

In addition to the ERISTO facilities mentioned previously (encompassing mice and rat research), the developmental space biology group at the University of Nancy offers help for preparation and conditioning of embryos, larvae or adults for a space flight. In their laboratory, the reproduction and rearing of model amphibian

Pleurodeles waltl [1, 26, 29, 72] can be routinely performed. In Germany the AquaHab, owned by OHB-System AG, in Bremen is an aquatic research module based on hardware developed for DLR and flown successfully in space. Dedicated mainly to ground based research, Aquahab is supported by complex technology and a laboratory facility for operating the modules including a standard biochemical laboratory environment, hardware development and test laboratory, as well as in-house hatchery capabilities and expert personnel support.

2.4.11 Additional Plant Physiology Facilities

In addition to the facilities and equipment mentioned previously (Centrifuges, Magnetic Resonance, Clinostats, Aquahab etc.) principal facilities for plant physiology research [19–21, 77] related to space applications are:

2.4.11.1 Plant Biocentre and Norwegian User Support and Operations Centre, University of Science and Technology, Trondheim, Norway

The Plant Biocentre has the necessary laboratory facilities for cultivation and analysis for plant biology research, while the User Support and Operations Centre for the European Modular Cultivation System (discussed previously), is used for testing the design concept of planned experiment hardware and selected plant material before the performance of experiment in space.

2.4.11.2 Multispectral Plant Imaging, University of Ghent, Belgium

At this facility which is part of the Department of Molecular Genetics the automated thermography setup permits time-lapse thermal imaging of leaves of multiple plants. Combined thermographic and video imaging is available to obtain spatial correlation of visible and thermal stress symptoms as a function of time. On the software side, automated generation of overview images and movies for rapid visualisation of changes was developed.

2.4.12 Magnetic Levitation

Every element (in the periodic system) is magnetic from the smallest effect known as diamagnetism which is a property of elements like copper and carbon to the largest magnetic effect known as ferromagnetism, which in our daily lives is the most common form of magnetism and found in elements such as iron, cobalt, and nickel. Ferromagnetism is about 109 times larger compared to diamagnetism. Diamagnetic

materials, need a much higher gradient magnetic field strength in order to be levitated (and simulate weightlessness). This can be carried out on organic materials or even living biological samples [5, 7, 81]. Such facilities are available at the **High Field Magnet Laboratory of the University of Nijmegen, in the Netherlands** with proposals processed by the Dutch Experiment Support Centre, or via an international ‘Announcements of Opportunities’ generally issued annually by ESA or other space agencies. You may also apply via an unsolicited proposal to ESA via the ‘fast track’ Continuously Open Research Announcements or via the EC FP-7 program EuroMagNET II: Research Infrastructures for High Magnetic Field in Europe. Similar facilities for fluid sciences, material sciences, and fundamental physics research are present at the French government funded **Alternative Energies and Atomic Energy Commission, in Grenoble, France**.

2.4.13 Biotechnology and Life Support Systems

With the prospect of future human spaceflight exploration missions, the need to reduce launch/upload mass is an essential part in mission planning. Biotechnology could have a significant effect on this with the development of regenerative life support systems, thus reducing the need to launch, for example, large quantities of drinking water or atmospheric gases. The **Micro-Ecological Life Support System Alternative (MelISSA)**, which is a collaborative project managed by ESA is conceived as a micro-organisms and higher plants based ecosystem intended as a tool to gain understanding of the behaviour of artificial ecosystems (see also Sect. 3.2.9 of this book). Based on the principle of an aquatic ecosystem the second-generation **MeLISSA pilot plant at the University Autònoma of Barcelona, Spain** is testing regenerative life support system technologies. In addition the **Sub-department of Environmental Technology of the University of Wageningen in the Netherlands** has facilities to study (microbiologically mediated) conversions of organic and inorganic matter under simulated planetary atmosphere environments. The expertise of the facility can also support research on the development of more efficient and environment friendly technologies needed for space exploration.

2.4.14 Extreme Environments

Simulation of environmental conditions in space [60, 61], and on other planets and orbital bodies can be an important precursor in astrobiological experiments in order to determine the survivability of different species under these conditions. It can also help in the planning of future missions, by testing different equipment and technologies to verify that it can deal with the conditions in which it has to function. **The Planetary (Mars) simulation facilities at the DLR “Mars-complex” in**

Cologne provide the following simulated Martian environment for physical and exobiological studies: atmosphere, UV-radiation climate, surface/subsurface temperature, controlled with regard to diurnal/seasonal fluctuation. Announcements of Opportunity are made at a European level and about 50% of the facility resources can be made available to visiting scientists. At **the Organics under Simulated Interstellar Conditions (OSIC) at the University of Leiden in the Netherlands** there is a model chamber dedicated to the study of carbonaceous material in ultra-high vacuum at low temperature and under UV irradiation.

2.4.15 Radiation Testing

Similar to the section on extreme environments above, facilities testing the effects of radiation in different environments are a vital part of planning for future spaceflight missions, with the testing of different components, equipment and technologies verifying that it can deal with exposure to the different levels of radiation in orbit in which it has to function. Developments in this area can also have an impact in areas of medicine such as within heavy ion therapies for cancer treatment.

Numerous facilities are present around Europe: ESA operates **Internal Radiation Test Facilities at ESTEC, Noordwijk, the Netherlands**, which has a Co-60 gamma source for testing as well as the CASE (Californium-252 Assessment of Single-event Effects) laboratory test system, which is an alternative to the conventional heavy ion accelerator; The **GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany** can simulate cosmic radiation, in particular the galactic cosmic radiation, and has the accelerators UNILAC and SIS-18 that deliver ion beams of high quality of many chemical elements (including iron) in the energy range of 1 MeV–1 GeV per nucleon and can accelerate light ions (up to neon) to 2 GeV per nucleon; **DLR's Integrated Space Environment Factors Simulator – KOBE in Berlin Germany** offers interstellar and planetary environment simulation such as high vacuum, Martian climate conditions, solar irradiation and ultraviolet radiation; the **Grand Accélérateur National d'Ions Lourds (GANIL) in Caen, France** offers production of accelerated ions from helium to uranium of medium energy (20–100 MeV/amu) which can be used for studies in fundamental physics, but also in radiobiology and material sciences as simulating the exposition of biological systems or materials to cosmic heavy ions; the accelerator facility at the **Paul Scherrer Institute, Switzerland** is used to accelerate protons which can be used within research into the smallest fundamental constituents of matter, the investigation of innovative materials, the development of new products for medical diagnosis and unique methods of treating tumours; the **Heavy Ion Irradiation Facility, at the Centre de Recherches du Cyclotron, Louvain-la-Neuve, in Belgium** is used for studies in Single Event Effects in collaboration with ESA; and the **RADIation Effects Facility (RADEF)**, which is located in the Accelerator

Laboratory of the University of Jyväskylä, Finland includes beam lines dedicated to proton and heavy ion irradiation studies of semiconductor materials and devices.

2.4.16 Fluid Science Facilities: Surface Tension

The **SMT-laboratory, University of Genoa, Italy** is composed of a number of dedicated pieces of equipment, which allow measurement to be made from near-ambient temperatures up to 1,500°C. Measurements relevant to fluid and materials science can be made at both the liquid-gas interface and liquid-liquid interface. Special software treats, in real time, all relevant input data so that even fast interfacial phenomena, like those governed by adsorption and diffusion can be traced. Surface and interfacial tension data, both at equilibrium and in dynamic conditions are of basic importance for studies related to solidification, crystal growth, joining, detergency, foams and emulsion stability etc.

2.4.17 Materials Science Facilities: Crystallisation

The **Universidad Autónoma de Madrid, Spain** offers equipment for sample preparation and growth of single crystals at high temperature, in air or controlled atmosphere, melt and vapour techniques; as well as capabilities for cutting, polishing and orientation of single crystals; and methods of sample characterization techniques. The timeline for performing an experiment is 3–12 months depending on the adaptation of equipment to a required experiment.

2.4.18 Materials Science Facilities: Solar Power

In operation since 1991, the **Solar Furnaces in Almeria, Spain** [46, 47, 49, 63, 76] have been fully devoted to materials treatment in the framework of European Union-funded research programmes. The main components are: the mirrored, mobile heliostats, which reflect sunlight; the mirrored parabolic concentrator onto which sunlight from the heliostats is reflected; a louvered shutter to control sunlight concentration; and a movable test table, which in turn concentrates sunlight onto the focal spot where specimens are held. **DLR has a 25 kW Solar Furnace, a high power radiation source (20 kW) and further solar test facilities in Cologne, Germany.** Well equipped laboratories, workshops and simulation tools in Stuttgart and Cologne allow for thermal, chemical, optical R&D activities as well as system analyses.

2.4.19 *Materials Science Facilities: Wind Tunnels*

At **CORIA, at the University of Rouen, France** three wind tunnels have been built to **simulate re-entry conditions** of different planetary atmospheres. Numerous measurement techniques, in particular optical diagnostics, have been developed to study high enthalpy flows and supersonic plasma flow can also be generated. A similar wind tunnel exists at the **Von Karman Institute Sint-Genesius-Rode, Belgium**. Temperatures up to 10,000 K can be achieved.

At the University of Aarhus, in Denmark simulation of the Martian aerosol is performed in a unique re-circulating wind tunnel enclosed in a low pressure atmospheric chamber. Importantly such a system allows the atmosphere to be carefully controlled and monitored and the dust to be stored for long periods of time compared to flow-through systems. Typical wind speeds of 0–10 m/s can be reproduced with variable dust density. A liquid nitrogen cooling system allows the extreme low temperatures on Mars to be achieved, this also allows the low humidity to be reproduced. In the 2 years of research it has been found that dust sticks readily to any and all surfaces invariably forming aggregates as the dust sticks to itself.

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