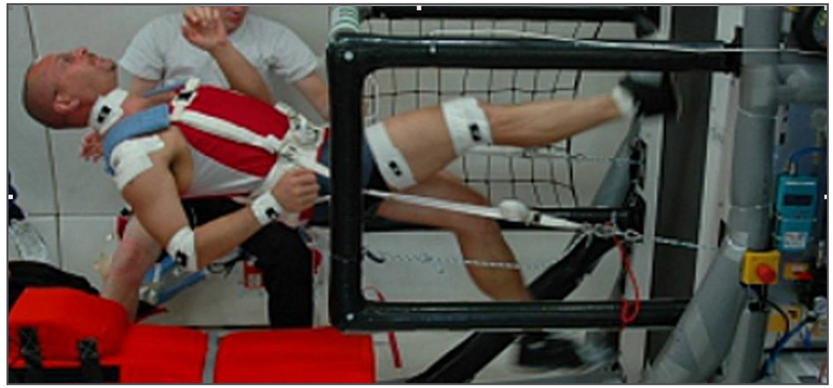
human spaceflight

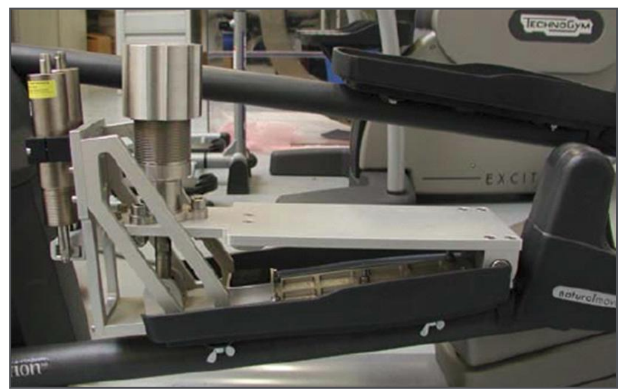
esa

ESA Exercise Countermeasures and Related Diagnostics
- Devices and Technologies

ICM Workshop
Trieste
19/06/2010

Training devices and related R&D





Flywheel Exercise Device

Description:

- Flywheel Exercise Device was developed as an experiment that could provide resistance exercises for coupled concentric and eccentric muscle actions.
- The functional principle of the Flywheel is characterized by the rotating inertial wheel as an energy accumulator.
- It was designed to allow for 8 different exercise movements which comprise:
  - leg press,
  - heel raise,
  - back extension,
  - seated row,
  - upright row,
  - lateral shoulder raise,
  - biceps curl
  - and reverse curl.
- Currently, arm exercises using narrow and wide handles are the only movements authorized.

Flywheel Ground & Training Unit

Functional Capabilities:

- Provide coupled concentric and eccentric resistance
- 0 to 30 Nm torque resistance
- 0- ~1500 N equivalent resistance
- 0- ~3000 N equivalent resistance when using the pulley

Major Components:

- Drive unit, flywheel, brake and cord systems
- Data management system
- Central beam and mounting legs with vibration isolation
- Seat system
- Foot rest and restraint system
- Subject handgrip system
- Subject body harness system (not authorized for use)

ISS021E016863

FM1 in Columbus

Supporting Hardware: ESA Multipurpose Laptop

Provider/Sustaining: ESA, HSF-AM

Users: **C**rew - further activities are being discussed

Countermeasure Readiness Level: 7-8

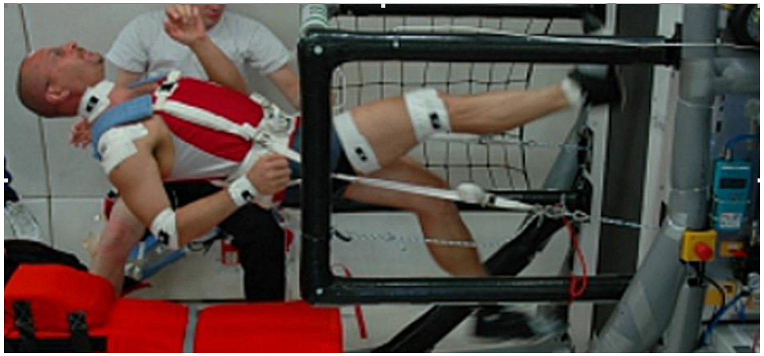
Ground/Flight: Flight

Vehicle/Location: ISS/Columbus (Stowed in D3)

Subject Loading System (SLS)

Description:

- Treadmill exercise is believed to have the most benefits for both muscles and bones of the lower limbs (legs) under weightlessness, because it places the highest possible loads on the human body and is also accompanied by eccentric muscle contractions, despite the lack of gravitational forces.
- A Subject Loading System (SLS) is required to restrain a running astronaut to the treadmill's running surface in an approximation of gravity.
- The SLS system provides a pull-down force to the subject running on the treadmill through tension preloaded ropes that are attached to the left and right side of a special harness.



Subject Loading System integrated with the T2 Treadmill during Parabolic Flight testing – May 2010

Functional Capabilities:	Provide pull-down force to the subject running on the treadmill 178 N to 978.6 N pull-down force range
Major Components:	Restraining Ropes, Belt transmission mechanism, Pneumatic system, Compressor, Avionics
Supporting Hardware:	2nd generation treadmill (T2)
Provider/Sustaining:	ESA
Users:	Space Medicine, Human research Program (HRP)
Countermeasure Readiness Level:	-
Ground/Flight:	Flight
Vehicle/Location:	ISS Node 3

Gravity Loading Countermeasure Skinsuit (GLCS or Skinsuit)

Description:

- +Gz loading on the body to mimic standing
- The elastic mesh creates a loading regime that gradually increases in hundreds of stages from the shoulders to the feet,
- Prototype suits have applied ~1-g from the shoulders to the knees, and 0.6-g on the shank.
- Negligible mobility restriction and excellent comfort properties, suggesting that crewmembers should be able to work nominally, and exercise or sleep while wearing the suit.
- The suit could serve as a practical 1-g harness for exercise countermeasures and vibration applications to improve dynamic loading.

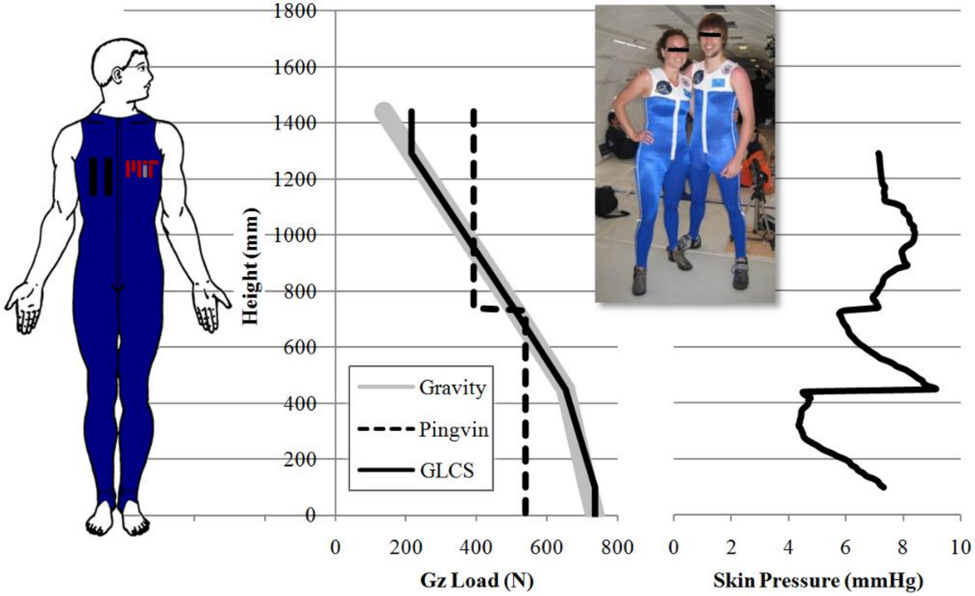
Allows high degree of mobility

Functional Capabilities:

- Provides static gravitational loading
- Assists dynamic loading as 1-g harness to treadmill/ergometer
- Provides neuromuscular stimuli to the soles of the feet
- Resists spinal elongation
- Mild compression on torso/legs may reduce orthostatic intolerance

Components:

- Single piece, bi-directional elastic mesh skinsuit
- Hard soled flight shoes



+Gz loading profile much closer to terrestrial G than Pengvin Suit

Supporting Hardware:	Nil
Provider/Sustaining:	ESA, HSF-AM
Users:	Current - R&D subjects. Future – all astronauts
Countermeasure Readiness Level:	5-6
Ground/Flight:	Flight
Vehicle/Location:	N/A

Multi-purpose Integrated Countermeasures Stimulator (M-ICS)

Description:

- A multi-purpose platform that can be used both on ground and in space to test and apply exercise countermeasures on human beings and astronauts.
- M-ICS is composed of a pre-loading device capable of producing loads of variable intensity, combined with multi-position sledge system accommodating:
    - a SAVTD (Side Alternating Vibration Training Device) including sensors for dynamic ground reaction force and vibration position measurement
    - an ITP (Impact Training Platform) measuring dynamic ground reaction forces separately for L/R foot

First ground breadboard. A second much lighter prototype is presently under construction

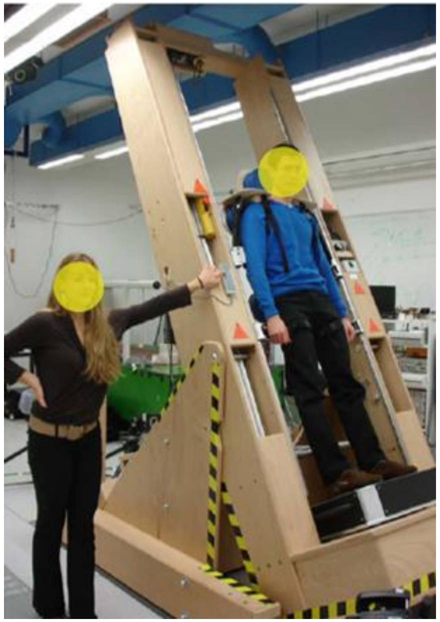
For ground use:

- The sledge can describe any angle between -10 deg w.r.t. horizontal and +10 deg w.r.t. vertical, thus enabling investigations of neuron-control of voluntary and involuntary movements of the body.

For ground and space use:

- The sledge offers an additional degree of freedom by providing an additional tilt axis in order to allow hip to bend relative to upper body to enable usage of Gluteus muscles. Body load is independent of body or sledge position.

First ground breadboard



Functional Capabilities:	Provide a multi-use platform to assess or test (ground) and provide (space) a variety of exercise countermeasures
Major Components:	Load Module, Sledge system – Range of motion is up to 1.5 meters, Vibration isolation system. Countermeasure units: side alternating vibration training device, Force/Impact training system (force platform), Biofeedback unit, Can be combined with enhanced Virtual-Reality biofeedback system, Power, data subsystems
Supporting Hardware:	Electrophysiology, cardio-pulmonary monitoring systems as required
Provider/Sustaining:	ESA
Users:	Space Medicine
Countermeasure Readiness Level:	TRL 4
Ground/Flight:	At the moment, ground prototype tested
Vehicle/Location:	N/A

Resisitive Vibration Exercise (RVE)

Description:

- Provide recumbent aerobic exercise (ergometer)
  - 5 – 30 Hz
  - 8 mm peak-to-peak displacement
- Elements:
  - Vibration Unit (platform)
  - Subject Loading Unit
  - Bed for Subject Support
  - Control Panel for vibration unit
  - Control Panel for subject loading unit (for force and position)
  - Measurement Unit for force and displacement
  - Electrical Power Unit

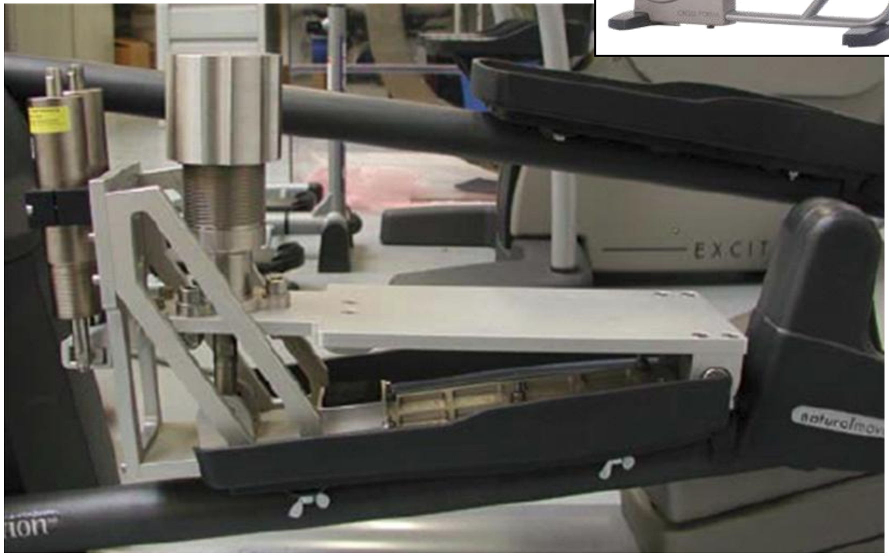
Integrated Countermeasure and Rehabilitation Exerciser (ICARE)

Description:

- Sub-system to study walk- or jump-like countermeasures in microgravity environment, addressing heel-strike like impacts combined with walking-like movements.

- Integrated countermeasure system targeting the musculo-skeletal system and the neuro-sensory system

- The prototype built and tested consisted in a cycle ergometer sub-system, a subsystem to generate impact bones (the heel-Bone Impact System or He-BIS, similar to that obtained at heel strike during walking or running) and a system to stimulate lower limbs proprioception (proprioceptive cushions).



Detail of heel bone impact system

Proprioceptive cushions

Functional Capabilities:	Sub-system to study walk- or jump-like countermeasures in microgravity environment, addressing heel-strike like impacts combined with walking-like movements.
Major Components:	Heel-strike impact system. Proprioceptive cushions (TBC)
Supporting Hardware:	SLS – adaptation TBC, Exercise device, Electrophysiology recorders, cardio-pulmonary monitoring systems as required
Provider/Sustaining:	ESA
Users:	Space Medicine
Countermeasure Readiness Level:	TRL 2-3 At the moment, ground prototype has been tested only for short-term effects.
Ground/Flight:	Ground
Vehicle/Location:	N/A at present

Short Arm Human Centrifuge - Ground units

Description:

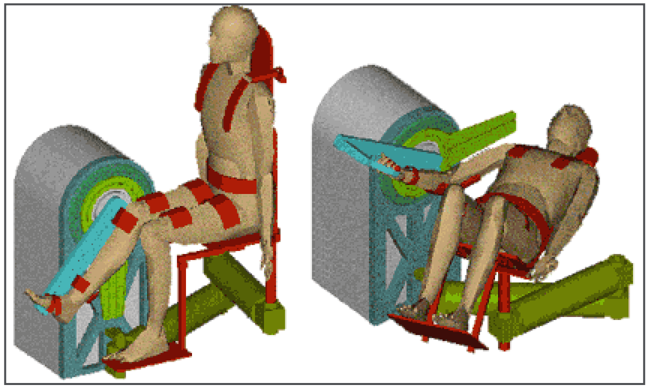
- Short Arm Human Centrifuge, 2 units, one at DLR Cologne, One at Medes, Toulouse.

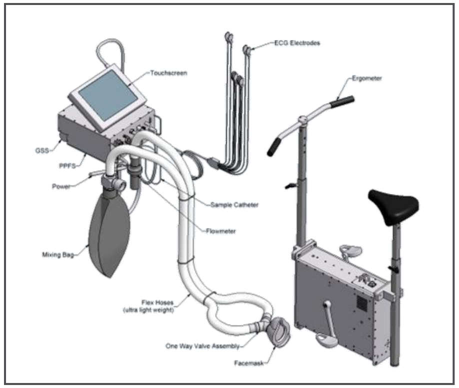
- 4 arms, 2 seats, 2 bed-like (nacelle)
  - Each nacelle can be set in different positions and angles
  - Each nacelle can be adjusted to test subjects of different sizes and proportions
  - Each nacelle has a local science platform for installation of scientific equipment

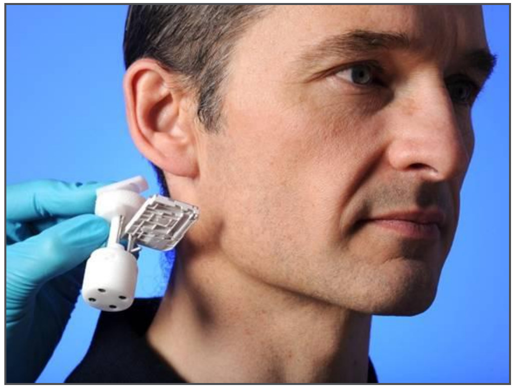
- G- level can be set up to 3 g at c.o.g of nacelle (=/- c.o.g of subject)

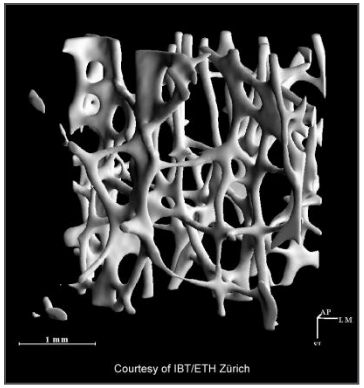
Detail of heel bone impact system

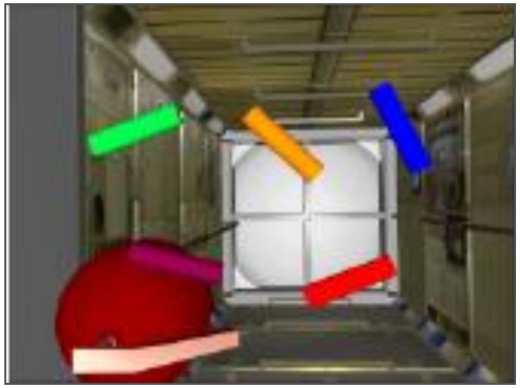
Diagnostics and related R&D







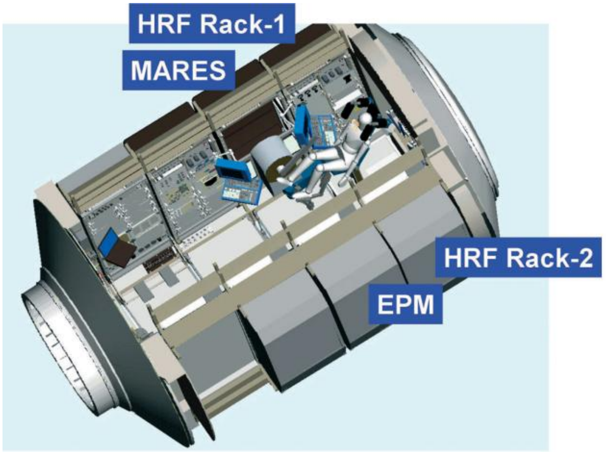


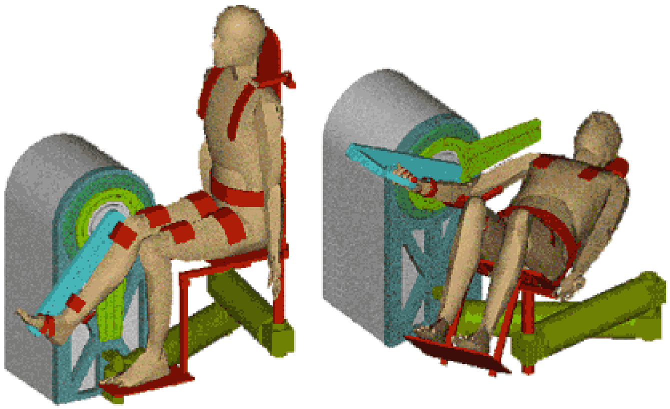


Muscle Atrophy Research and Exercise System (MARES)

Description:

- MARES can be used both: as a measurement dynamometer, or as generic tester of specific exercise-countermeasures.
- MARES measures the astronaut's reaction to programmable loads during motions.
- Typical usages are: to obtain the 'torque-velocity Hill curve' for a muscle group, for motor-control experiments, and as an exercise machine to experiment and simulate different training protocols.
- MARES can operate in single joint (angular) movements and in multi-joint (linear) movements.
- The highly programmable load can range from being as simple as maintaining a constant speed or torque (isokinetic, isotonic), to as complex as imitating: torque functions, springs, masses, frictions, etc., to replicate a specific trainer, i.e. a rower.





Functional Capabilities:

Movements:

Angular: Ankle, Knee, Hip, Trunk, Shoulder, Elbow, Wrist (3)

Linear (multi-joint): one/both Arms/Legs, at any inclination

Algorithms (motor loads):

Basic (BMUs: concentric and eccentric):

Isometric, Isokinetic, Isotonic, Spring, Friction, Mass, Physical elements, Pseudo-Gravitational, Position/Velocity/Force/Power Control, Quick release.

Complex profiles: complex combinations of basic BMUs and trigger events.

Mechanical stimulus:

Torque's:	from 3 Nm	to 900 Nm,
Forces:	from 1 N	to 240 N,
Angular Velocity:	from 5 °/s	to 515 °/s,
Linear Velocity:	from 5	to 500 mm/s

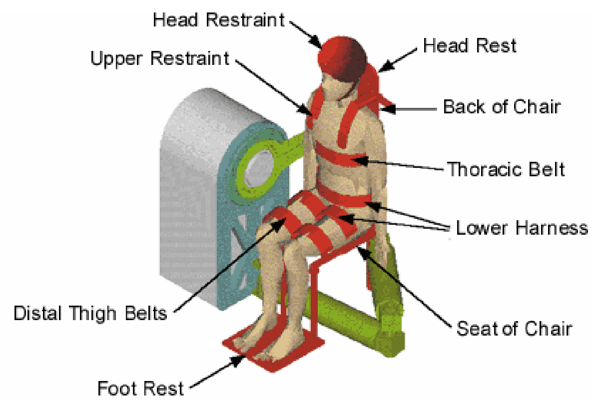
Measurement accuracy:

Torque and Velocity: +/- 0.5% of the actual value

Very precise restraint system and joint axis alignment to motor axis.

Major Components:

MARES Rack
Main Box
Laptop
Chair
Human Adapters
Vibration Isolation Frame



Supporting Hardware:

Percutaneous Electrical Muscle Stimulator (PEMS-II)
EMG amplifiers
European Physiology Modules (EPM) for data downlink

Provider/Sustaining: ESA

Users: USOC: Cadmos (Toulouse)

Countermeasure Readiness Level: N/A

Ground/Flight: Flight

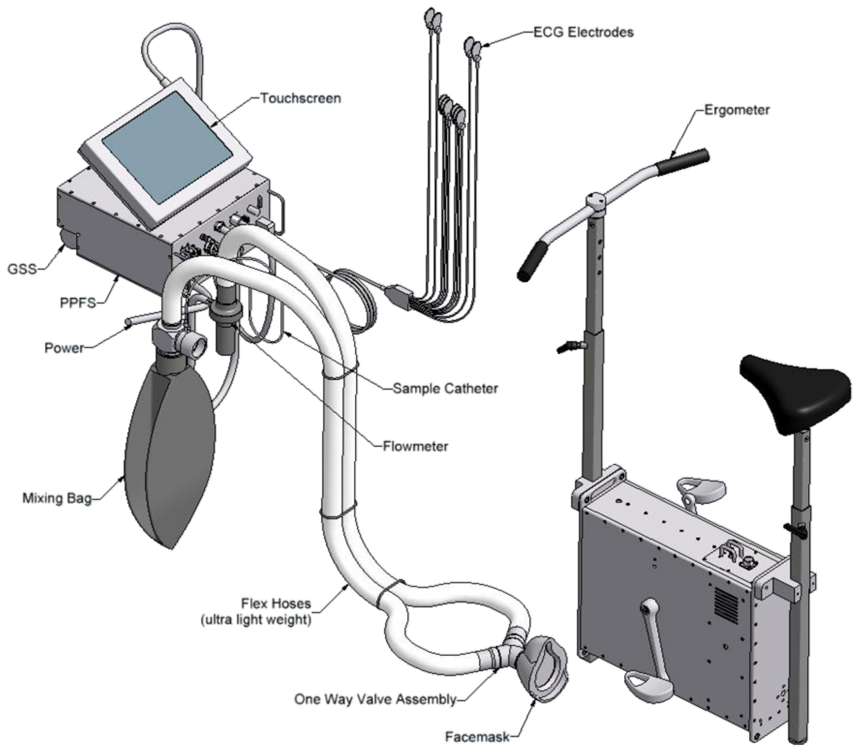
Vehicle/Location: ISS/Columbus

Portable Pulmonary Function System (PPFS)

Description:

- PPFS is supporting a wide range of *respiratory* and *cardiovascular measurements*, complementing well the capabilities of the rack-mounted PFS.
- PPFS is a versatile instrument that can be used station wide for supporting both scientific research and crew health-monitoring activities. It is currently used to assess sub-maximal VO2 during Physical Fitness Evaluations (PFE) on ISS as well as supporting three scientific experiments.
- The PPFS is an evolution to the Pulmonary Function System (PFS).

PPFS



Functional Capabilities:	Cardiac output, Pulmonary Blood Flow Functional Residual Capacity Lung Tissue volume (Volume of pulmonary capillary blood) Oxygen uptake, VO2 Total Lung Capacity Breath-by-breath measurements of VO2, VCO2, VE Respiratory exchange ratio VO2/VCO2 Alveolar Ventilation Vital Capacity Dead Space Volume Fractional inspiratory and expiratory volumes, FIO 2 and FEO 2 , FICO 2 and FECO 2 Etc…
Major Components:	Data Management and Power Distribution System Metabolic Gas Analyser System (MGAS) Gas Supply System (GSS) Respiratory Valve System (RVS) Flowmeter System (FS) Mixing Bag System (MBS) 12 lead ECG System Non-Invasive Blood Pressure System (NIBP) Pulse Oximeter, SpO2
Provider/Sustaining:	ESA, NASA, MedOps /DAMEC
Countermeasure Readiness Level:	9
Ground/Flight:	Flight
Vehicle/Location:	ISS/currently in US Lab

Earlobe Arterialised Blood Collector (EAB C)

Description:

- Developed to obtain samples of blood from the arterioles of the ear in a microgravity environment.
- Arterialised blood measurements under certain circumstances are equivalent to arterial blood measures and thus offer a clinical diagnostic capability without the need for puncturing arteries.
- The device has been developed to work in conjunction with the i-STAT portable blood analyzer, currently in use on ISS.
- Obtaining blood in this manner from the ear does not require a physician or detailed training and offers not only a clinical benefit but also health monitoring potential for example through the acquisition of blood lactates measurements during exercise.
- Device currently undergoing R&D, with plans for scientific assessment on ISS in 2011.

Current model of the Earlobe Arterialised Blood Collector

Functional Capabilities:

- Perform standardized Arterialized Blood Collection
- Simple operation for collection
- Embedded cutting, collection and analyses modules
- Grip & Rotate operation
- 4mm x 2mm incisions (L x D)

Major Components

- Main Body
- Front Clip for earlobe fixation
- Module compartment with spring
- Inner Shaft for device closing
- Cutting Module
- Ophthalmic Blade
- Blade Adaptor
- Collection Module
- Metal clip adaptor
- Capillary tube adaptor for blood conduction
- Blood Analyses Cartridge (Abbott)

Blood sampling with Mk 5 EAB C device

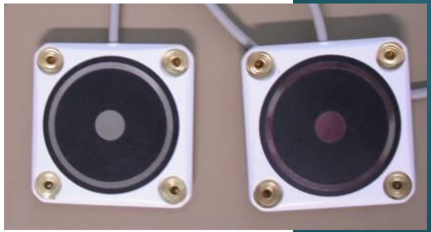
Supporting Hardware:	Abbott i-STAT portable blood analyzer associated cartridges.
Provider/Sustaining:	ESA, HSF-AM
Users:	R&D subjects. Future – all crew
Countermeasure Readiness Level:	6-7
Ground/Flight:	Flight
Vehicle/Location:	N/A

Long-Term Medical Survey System (LTMS)

Description:

- Ambulatory, wired or wire-less minimally obtrusive recorder of physiology parameters that records for up to 24 hours
  - *SpO2*
  - 2 channels (2-lead) *ECG*
  - *breath rate*
  - *blood-pressure*
  - *body temperature*
- The system offers the possibility to accommodate commercially available sensors e.g. fingertip or forehead SpO2, ECG gel electrodes, axillary or ear temperature probes, and also custom-made probes for SaO2 chest measurement, chest core-body temperature index computation and long-duration, low artifact dry ECG electrodes.

LTMS active electrodes

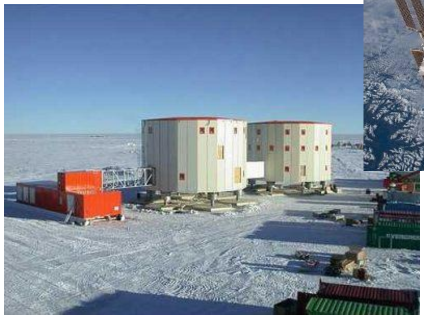


Subject equipped with LTMS

LTMS SaO2 and core temperature sensor

- The body network is wired, hence compatible with use in an ISS-like environment; communication with the data acquisition and processing unit accommodates both wired and wireless capabilities.
- The ambulatory part of the system is accommodated in a custom-made shirt and can be donned/doffed by one subject without any external help. A ground version accommodates also weight and 4-segment impedance body composition measurement (COTS system).
- The system is planned to be operational at the Antarctic station Concordia starting 2011.

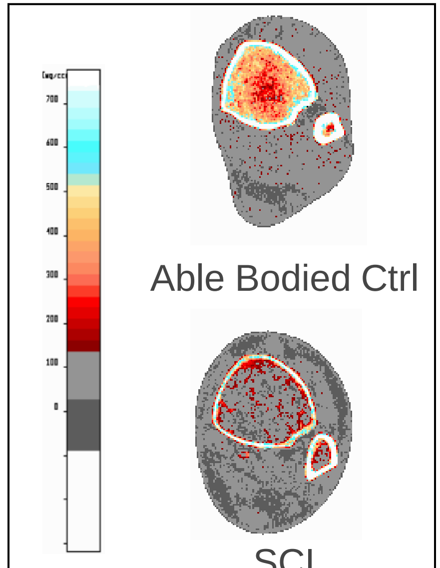
ISS



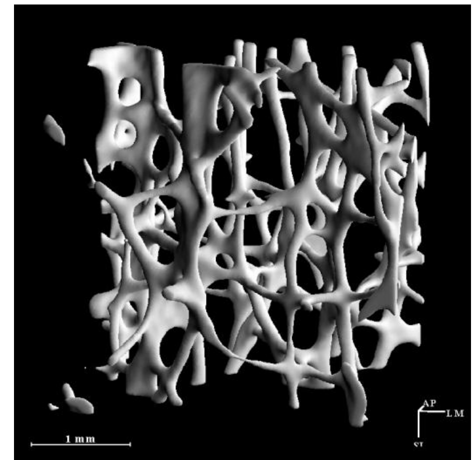
Concordia Station in Antarctica

Functional Capabilities:	Provide a multi-use platform to measure non-invasively and non obtrusively a suite of physiological parameters – 2-lead ECG, oxygen saturation, blood pressure, index of core body temperature, and body composition.
Major Components:	Prototype, ambulatory unit: shirt, active electrodes, active SaO2 sensor, active body temperature sensing unit, blood pressure holter, data processing and datalogger unit, battery pack. Possibility to interface COTS sensors for ECG, SaO2, temperature. Data download and processing station (PC with custom software)
Supporting Hardware:	N/A. A possible, future space version, not currently planned, could interface with EPM or similar, for data download and processing, and for the battery charger.
Provider/Sustaining:	ESA, IPEV, PNRA
Users:	Space Medicine
Countermeasure Readiness Level:	TRL 3. TRL 4 targeted by end 2010 and TRL 5 by end 2011.
Ground/Flight:	At the moment, ground use only - prototype with specific electrodes being built, testing and evaluation planned to start by July 2010.
Vehicle/Location:	N/A

ISS-compatible X-Ray Imaging system



Courtesy J. Rittweger - DLR



Courtesy of IBT/ETH Zürich

Description:

- X-ray based analytical device for human physiology with imaging capabilities and integrated shielding
- Also potential applications of x-rays in the field of *physical sciences* and exploration
- Developing a consistent concept for the multidisciplinary application of x-ray based analytical and imaging methods in the context of exploration.
- Defining requirements and building a demonstrator of an ISS-compatible device

Functional Capabilities:	ISS-compatible very low dose X-Ray system [higher limit: 20 microSievert/exam, target: close to 12 microSievert/exam] to measure at least [localized] bone loss and muscle composition changes. Demonstrate at prototype level the compatibility with ISS requirements especially for power/cooling and radiation/shielding.
Major Components:	X-Ray imaging and dataprocessing system
Supporting Hardware:	Space version: Vibration Isolation Device, EDR or EPM racks.
Provider/Sustaining:	ESA
Users:	Space Medicine
Countermeasure Readiness Level:	Activity has just started. TRL 3-4 targeted at end of present phase of activity, by Q1 2012.
Ground/Flight:	Ground prototype to be available at end of technology development activity.
Vehicle/Location:	N/A at present

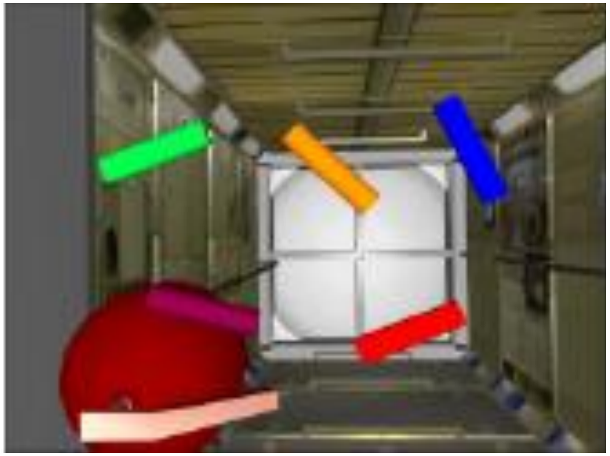
Biofeedback and Virtual-reality systems: Enhanced Virtual-Reality System - eVRS

Description:

- A flexible, intuitive and user friendly software and hardware system, based on the use of *Virtual Reality* and *multimedia technologies and capabilities*. It supports the implementation of a wide range of experiments protocols in the fields of cognitive neurophysiology.

Typical experiments are built for investigating:

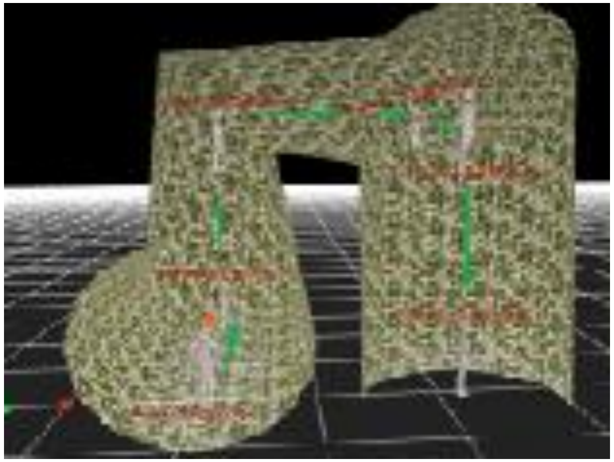
- orientation, depth and motion perception
- navigation abilities in 3D environments
- multi-sensory integration capabilities
- vestibulo-ocular coordination in micro-gravity
- reaction time measurements visual, aural, on simple and combined stimuli. Reaction time accuracy <= 5 ms



Examples of scenes

A second phase will integrate new stimulations and features e.g.:

- Enhanced reaction time measurement
- Update of stimulations and environments as e.g. 3D audio stimulations
- Integration of biofeedback loop to allow for e.g. studying response to stress and workload
- Adding and optimising "haptic" stimulation, eye tracking and see-through capabilities.
- Design aim: assess the implementation of Clinical Protocols of Evoked Potentials.



Example of scene

Functional Capabilities:	Ground prototype of ISS-compatible virtual reality System.
Major Components:	Headset (VR or see-through), joystick, glove, tracking system, software, computer, recording devices such as EEG, EMG, ECG, eye-tracking device, subject response input device.
Supporting Hardware:	In a potential space version: Space version: EDR, EMP
Provider/Sustaining:	ESA
Users:	Space Medicine
Countermeasure Readiness Level:	Activity will start Q3 2010. Presently TRL 3. TRL 4-5 targeted at end of phase 2, by Q1 2012.
Ground/Flight:	Ground prototype to be available at end of technology development activity.
Vehicle/Location:	N/A at present

esa

- Main Requirements ICS
  - 5.1.3 ICS technologies shall include the appropriate combination of:
  - 5.1.3.1 Countermeasures active on bone, muscle and connective tissues, such as:
  - 5.1.3.1.1 Impact systems (systems delivering impacts on the lower limbs similar to those produced by the heel strike during walking
  - 5.1.3.1.2 Vibratory systems applied to bone and connective tissues (direct mechanical vibrations and/or ultrasound-based vibrations)
  - 5.1.3.1.3 Systems for loading the entire body, or for loading body parts, not changing the inertial characteristics of the human body;
  - 5.1.3.1.4 Electro-stimulation (TBC)
  - 5.1.3.2 Countermeasures active on muscle and neuro-sensory systems
  - 5.1.3.5 Countermeasure technologies to improve the head/neck/trunk coordination, that could include, vibro-tactile devices.

esa

- **Requirements X-RAI**
- A.2.1.9XRAI : imaging and analysis of the human body.
- A.2.1.10 Body parts : at least the limbs and the head. Baseline for imaging is without contrast agents.
- A.2.1.11 Design aim, image all parts of the human body,
- A.2.1.12 Analysis of body parts shall include:
- A.2.1.12.1 Classical measurement packages (distances, areas, density…)
- A.2.1.12.2 Analysis of bone:
- A.2.1.12.2.1 Global, and separately for trabecular and for cancellous bone: Bone Mineral density, bone morphometry.
- A.2.1.12.2.2 Design aim: trabecular number per volume, trabecular density, trabecular thickness - Cortical thickness,
- A.2.1.12.2.4 Analysis of (bone) marrow, assessment of marrow/fat ratio within bone
- A.2.1.12.3 Analysis of muscle and soft tissues: muscle size; design aim: lean/fat mass ratio, muscle composition (slow/fast fibers),
- A.2.1.13 Resolution: With adequate contrast settings, resolution shall allow to see details in the range of 1 mm or less
- A.2.1.13.2 Spatial resolution, bone/muscle/tendon: with adequate contrast settings, spatial resolution shall be of at least 100 microns. Design aim: 70 microns.
- A.2.1.13.3 Density: For trabecular bone, 0.3% or better - For cancellous bone, 0.2% or better
- Dose, nominal – 12 microS – up to 20 tolerated.
- FOV 130 mm
- DICOM

Reserve slide 3

- **Summary Requirements VRS**
- Generation of visual and aural stimuli
  - Simple, complex, combined. Stimuli type (frequency, pitch, shape, color, duration, sequence…) can be set by user
  - Shapes can be 2D or 3D, fix or animated, at same position or random
  - System to measure subject reaction time (less than 5 ms) and performance
- Generation 3d maze and navigation tracking
  - Maze shape, texture etc can b e chosen amongst default library or created by user
  - Measures subject nav performance
  - AV stimuli can be superimposed
- All this either on screens or HMD, with eye tracking
  - Haptics explored
- Interface with EEG or other electrophysioogy recorders