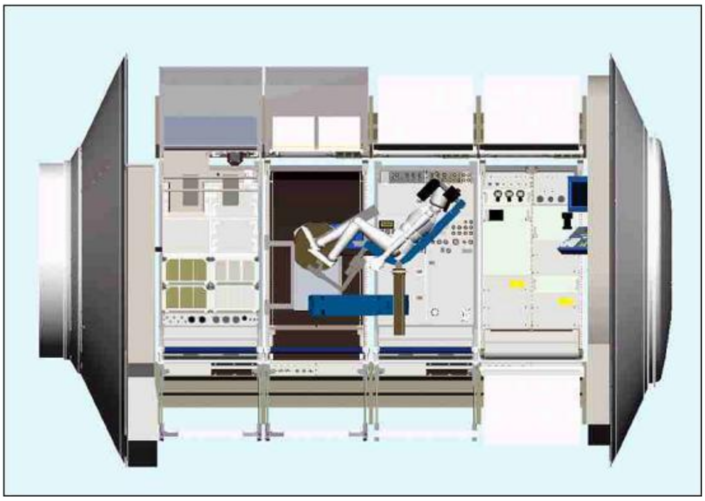
Muscle Atrophy Research & Exercise System (MARES)



MARES inside the Columbus laboratory

General description

MARES is a general-purpose instrument intended for (neuro-) muscular and exercise research on the International Space Station. This instrument 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.

MARES is aisle mounted. It has interfaces to the US Destiny laboratory or to the European Columbus laboratory. Sensors, direct drive motor, battery and electronics are housed in the 'Main Box'. Chair and human adapters provide the subject restraints. The Microgravity Isolation Frame, to which the Main Box attaches, minimises disturbances to other payloads.

MARES uses the Human Research Facility portable computer (HRF PC) for interacting with the subject/operator.

MARES is capable of acquiring data, controlling and providing power to external devices (HRF PC, PEMS, EMG amplifiers, etc.), and transfers real time data to the rack mounted Workstation for downlink. It is capable of 1 hour of stand-alone data collection.

For more information please contact:

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Scientific objectives

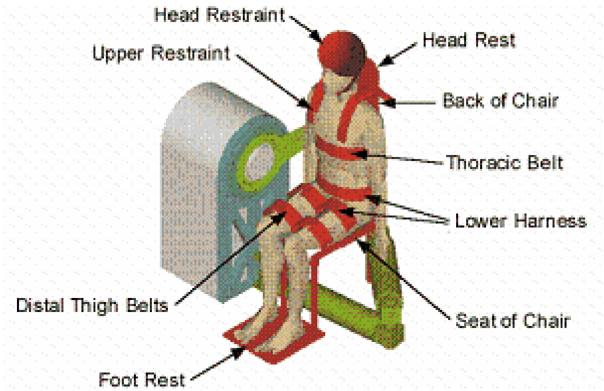
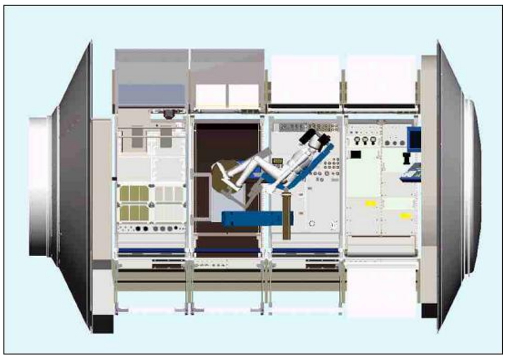


Figure: MARES with some elements indicated

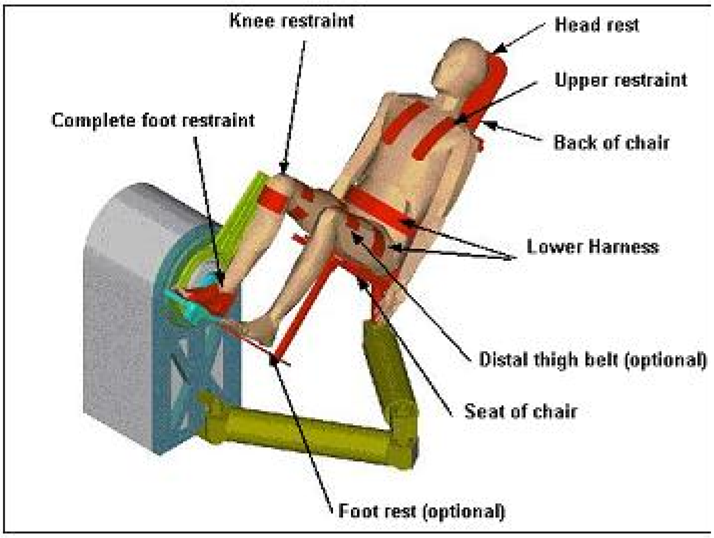
The earlier paragraphs have tried to give a brief description of the technical capabilities of MARES. The following sections try to illustrate the kind of experiments that could potentially be conducted with the aid of MARES.

In fact the experimental possibilities are almost endless. Only a few examples are given here to illustrate some of the research areas that could be supported:

- Investigations on Torque-Velocity Curves
- Investigations on Isometric target
- Investigations on Motor Control
- Investigations on Exercise Research



MARES elements



MARES with indicated elements

MARES consists of the following elements:

- **Main Box**
  Containing a powerful motor, and its control electronics.

- **Set of Human Adapters**
  These are pads and levers that adapt to different subject sizes and cover different movements.

- **Chair**
  Fixed to the Main Box by a pantograph arm.

- **Laptop computer**
  Provides the command and display interface to the subject.

- **Dedicated experiment software**
  With a minimum effort, MARES can be tailored to a specific experiment: issuing automated instructions to the subject and setting the appropriate control algorithms for the motor

Control algorithms

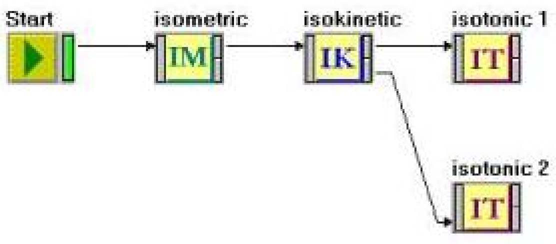
MARES Basic Motion Units
Isometric
Isotonic
Isokinetic
Spring
Friction
Additional moment of inertia/mass
Pseudogravitational
Position control
Velocity control
Torque/Force control
Power control
Physical Elements
Extended Torque/Force control
Quick Release

Table: MARES Basic Motion Units (BMUs)

Any desired limb movement can be broken down into a sequence of elementary steps.

These elementary steps are referred to as Basic Movement Units (BMUs), such that during any one BMU the relationship between position (or velocity) and torque/force is governed by a single, relatively simple, mathematical formula. MARES offers fourteen predefined BMUs as listed in the following table. These cover the three possible basic modes of muscle contraction known from physiology (isometric, isotonic, isokinetic), plus eleven more BMUs that can be used in support of more sophisticated experimental requirements.

The control algorithms for the motor are defined as Profiles consisting of a linked sequence of BMUs.



Example of the graphical editing of a MARES Profile

MARES provides a simple graphical software tool that allows the experimenter to develop Profiles according to his/her specific scientific needs. In this software tool, each BMU is graphically represented and the user can "drag and drop" any of the fourteen BMUs into a sequence, thereby creating a Profile. In so doing, the user will be prompted to define appropriate end conditions for each BMU introduced into the sequence. This tool also supports looping and branching within the Profile.

The BMU end conditions are important because they define the transition between the BMUs. These transitions can be made dependent on: time, position, torque, subject interaction, external signals, and/or any other parameter.

This level of programmability opens up a whole range of operational possibilities, for example, to simulate the changing friction of rowing (back and forth), to design a complex motor-control experiment, etc.

MARES experiments

MARES Angular Movements	
Ankle	Dorsi-plantar flexion
Knee	Flexion-extension
Hip	Flexion-extension
Trunk	Flexion-extension
Shoulder	Flexion-extension
Elbow	Flexion-extension
Wrist	Flexion-extension Radio-Ulnar deviation Prono-supination

MARES Linear Movements	
Arm press	One arm Both arms
Leg press	One leg Both legs

Table: Angular and linear movements that MARES supports

MARES supports experiments on seven different joints for a total of nine different angular movements (either left or right limb) and for two additional linear movements (upper and lower limb), see the table on the right.

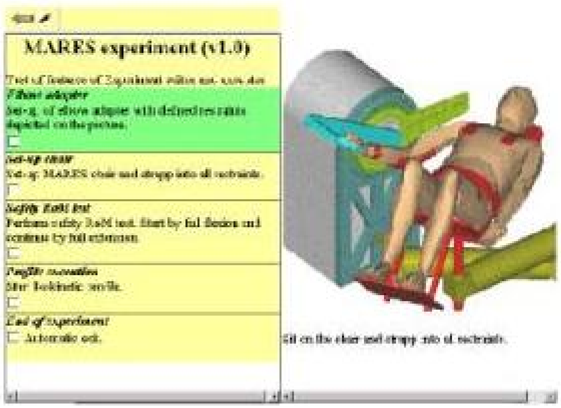
A careful coordination of the many capabilities of MARES is needed in order to ensure that measurements are made in a consistent and repeatable manner.

In MARES, this is done by translating the steps of an experiment into a set of computer-based instructions, the so-called MARES Experiment Procedures.

Instructions are available that would allow the scientist to define within an Experiment Procedure the following functions:

- To prompt (via text instructions and/or graphical messages) the test subject to perform tasks, i.e.:
    - how to set-up the limb adapters,

  - o how to restrain himself,
  - o to power-on an external device,
  - o to perform, for example, a Maximum Voluntary Contraction
  - o to perform a series of flexions / extensions
- To accept and respond to feedback from the test subject.
- To activate a MARES Profile.
- To activate data displays for assessment by the test subject.
- To perform real-time data processing, the results from which could be used to influence the execution of the Experiment.
- To programme and command external devices.
- To select data for storage and/or downlink.



Example of set-up instructions in a MARES Experiment Procedure

MARES can store internally a large number of such Experiment Procedures, with the possibility for new Experiment Procedures to be uploaded from the ground.

External instrumentation

MARES is designed to work in connection with other devices: electro-miographs, electro-cardiographs, stimulators (PEMS-II - see below), etc.

The Percutaneous Electrical Muscle Stimulator (PEMS II) delivers electrical charge pulse stimulation to non-thoracic muscle groups of the test subject, thus eliciting contractile responses.

The Percutaneous Electrical Muscle Stimulator (PEMS II)

Technical specifications:

Maximum ratings

Torque: ± 450 Nm continuous, ± 900 Nm peak (200 ms)

Force: ± 240 N

Angular Velocity: ± 9 rad/s (515° /s) concentric and ± 6 rad/s (343° /s) eccentric

Linear Velocity: ± 0.5 m/s

Mechanical power: 2700 W continuous, 4500 W peak concentric and 3750 W peak eccentric

Measurement accuracy's

Torque: ± 0.3 Nm for low torque's, ± 0.5 % for high torque's; 500 Hz

Force: ± 0.125 N for low forces, ± 1% for high forces; 500 Hz

Angular Velocity: ± 0.2° /s for low velocities, ± 0.5% for high velocities; 200 Hz

Linear Velocity: ± 1mm/s for low velocities, ± 0.1% for high velocities; 200 Hz

Angular Position: ± 0.5°; 200 Hz

Linear Position: ± 0.5 mm; 200 Hz

Interface budgets

Mass: 250 kg complete

Main-Box dimensions: 103 x 52 x 52 cm

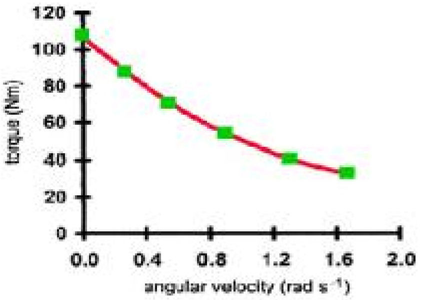
Average Power: 300 W

Peak Electrical Power: 1000 W

Torque-Velocity curves

The typical usage of a research dynamometer is to obtain the Torque-Velocity curve for a particular muscle group.

A likely microgravity experiment would be to compare T-V curves determined at different time points during the on-orbit stay of the astronaut to corresponding T-V curves determined prior to the mission (the baseline). This would permit the quantification of the extent of the zero-g adaptation (or the effectiveness of a countermeasure against that adaptation). Furthermore, measurements made at intervals following the return of the astronaut to Earth would allow the re-adaptation to 1-g to be followed.



Typical Torque-Velocity curve for the ankle muscle group

MARES can help in the creation of these graphs for comparison, as illustrated on the left. This capability is not intended to replace the detailed analysis by the scientist, but it can give a quick feedback to the test subject, for example, so that he can decide whether or not a repetition is needed; or so that he can see his trend in performance and perhaps adjust his exercise regime accordingly; etc.

The T-V curve could, for example, be obtained by performing a series of isokinetic concentric flexions at different velocities, using a very simple Profile. Alternatively, a more complex Profile could be employed in which the return movements are used to get the eccentric points of the graph. Yet again, the subject could be synchronously instructed to reverse to extension to get the concentric/extension graph as well.

All these motions will be governed by an Experiment Procedure instructing the subject what to do in each part of the measurement phase: push, pull, rest, etc. Prior to the measurement phase, the same Experiment Procedure would have instructed him/her with regard to which elements of the restraint system are to be used, where to find these items, how to mount them and how to configure them to his/her own subject-specific anatomical settings.

The scientific data will only be acquired during the motions, thereby optimizing the data storage and down-link requirements, both scarce resources. MARES maintains synchronisation of the data from the different sources (sensors: torque, velocity; external: EMG, etc.) during their acquisition.

The following tries to illustrate the previously mentioned quick-look processing capability of MARES. For example, the value of the torque could be averaged, in real-time, during the steady-state phase of the motions. This average torque value could then be stored in a results-table together with the set-velocity and other context-relevant information (date, time, subject, etc.). At the end of the current measurement sequence, this data, representing the T-V curve derived in the current measurement, could be displayed to the subject/operator. The results-table can also hold corresponding data from earlier measurement sessions and this data could be simultaneously displayed for comparison. All these quick-look functions can be called up / controlled via the Experiment Procedure.

Isometric target

In this second example, it is assumed that the objective is to explore the synchronization of the subject's motor units and its role in the determination of the muscular forces. In particular, the capability to maintain a steady force is to be investigated before, during, and three months after the period aboard the ISS.

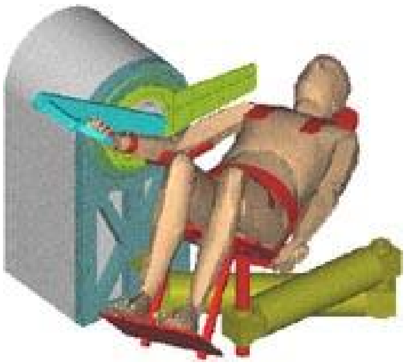


Figure: MARES settings for the right elbow flexion-extension movement

Simultaneously to the exerted torque, EMG motor-units activity is to be recorded while the astronaut is performing a sequence of low-force isometric contractions.

As before, the MARES computer will, via the Experiment Procedure, guide the subject on how to set up the machine for his/her anthropometric dimensions and how to restrain him-/herself. Following this set-up, the scientific protocol will start with the determination of the Maximum Voluntary Contraction (MVC) at 90° of elbow flexion.

The MVC is prone to central and subjective factors. First, an objective measurement of this maximal isometric force is determined via the stimulation of the muscle with the PEMS II. This value will be used as the reference against which the MVC, determined as the average of three voluntary maximal isometric contractions, will be compared.

Figure: Display of actual Torque and target Torque

Following the determination of MVC, the Experiment Procedure will instruct the subject to rest for a few minutes. At the same time, MARES will store this MVC figure for further use, for example, to calculate the visual targets required in the following steps.

The astronaut, via the Experiment procedure, will be guided to perform six isometric contractions at five different levels of isometric force: 5%, 10%, 15%, 20%, and 30% of MVC. To help the subject, the actual exerted torque will be graphically displayed simultaneously with the required target value.

MARES provides the capability to automatically calculate and display the maximum and mean deviations from the targets.

This complete protocol could be repeated at 45° of elbow flexion.

Motor control

With MARES, it is possible to easily set up an experiment to investigate the effect of the adaptation of the neuromotor control system to microgravity, as follows.

For example, consider an investigation to look at the capability of a human subject to regulate his muscular force in order to follow a predetermined positional target, while being challenged by changing loads of three different kinds: a randomly varying inertial load, a randomly varying viscous load, and a randomly varying elastic load.

Because daily life trains us to perform motor-control motions in a linear fashion, rather than angular, and with a single joint, this experiment will be performed using the linear adapter and employing the subject's dominant arm.

The loads the subject will feel will be equivalent to:

- Holding a mass that suddenly changes in weight,
- Moving through a liquid of varying viscosity,
- Pulling a spring with changing rigidity.

Furthermore, the Experiment Procedure will switch between load types without a perceivable gap.

Under these circumstances the subject will not be able to anticipate (central arm of the motor control) the force to be performed. The central control output will be reflected in the EMG with a latency time.

The random value option helps creating unforeseen stimuli.

Such an investigation would yield information about the EMG activation pattern of the agonist and antagonist for different kinds of loads, their mutual relationship, and the contribution of the reflex mechanism to the generation of the activation pattern during voluntary movements, the different contributions of central and peripheral mechanism of motor control.

Further complexity can easily be added to the experiment. For example, the target does not need to be a static position, but could move as a sinusoidal function of time. Similarly to the previous experiment, the actual position could be displayed to the subject simultaneously to this dynamic target position, as a feedback to the subject.

The subject could be asked to perform a series of voluntary movements of arm flexion including quick accelerations that he will have to follow as fast as possible.

Seventy percent of these movements would have a constant load. The remaining thirty percent would include the changes described before. The subject will not know in advance either the position target or the sequence of the changing loads.

The obtained results could be used to compare the reaction to predictable and unpredictable loads.

From the interrelationship between kinematic parameters, EMG patterns, imposed loads and exerted force, it should be possible to assess:

- How agonist and antagonist are modulated to provide respectively adequate acceleration and deceleration to fulfil the imposed task,
- Which kinematic components are influenced by the implicit control of the muscle (i.e. force velocity relationship) and which derive from the central command and appear with a longer latency.

The repetition of the experiment after different periods of exposure to microgravity would yield an insight into the plasticity of central and peripheral parts of the neuromotor control system.

Exercise research

MARES is mainly intended for research, but it can work as well as an exercising device. It is an ideal tool to do research on the efficacy of countermeasures.

For example, it would be possible with MARES to include in a countermeasure exercise routine an exercise based on the bench press movement.

An appropriate Experiment Procedure could guide the astronaut through four series of movements consisting of ten repetitions each:

- The subject prompted to perform 10 concentric isokinetic flexion movements at 0.5 m/s.
- Then 10 eccentric isokinetic flexion movements, aiming for a target force of 200 Newton.
- After each flexion movement MARES will bring back the bar to the full extension position.
- Followed by two series of similar extension movements.

The efficacy of different types and/or levels of resistances, using different BMU's (isotonic, spring, inertial, friction, etc.), could be investigated.

At the end of the exercise, a report would appear on the laptop screen presenting also data from previous training sessions. This would allow the subject to monitor the evolution of his/her performance.