The Muscle Atrophy Research and Exercise System - MARES 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 exercises, while the MARES motor puts a programmed load on the astronauts movements.
MARES' Main Box houses a powerful motor, battery, sensors, and its control electronics. The Microgravity Isolation Frame, to which the Main Box attaches, minimises disturbances to other payloads. The facility is completed by a Set of Human Adapters. These are pads and levers that adapt to different subject sizes and cover different movements. The Chair is a seat for the examined/exercising subject and is fixed to the Main Box by a pantograph arm. A Laptop computer provides the command and display interface to the subject. MARES is operated by 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.

MARES INSTRUMENTATION
Torque and angular position/velocity measurements and training of the left and right extremities are supported on the following joint movements:

### 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, Radial-ulnar deviation, Pronation-supination

### MARES LINEAR MOVEMENTS
- Arm press: One arm, Both arms
- Leg press: One leg, Both legs

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 above.

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.
  - How to restrain himself.
  - To power-on an external device.

- To perform, for example, a Maximum Voluntary Contraction.
- 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.

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

MOTOR CONTROL ALGORITHMS
Any desired limb movement can be described as a sequence of elementary steps.

These elementary steps are referred to as Basic Motion Units (BMUs), such that during any BMU the relationship between position or velocity and torque/force is governed by a single, relatively simple, mathematical formula. These BMUs 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. MARES offers fourteen predefined BMUs as listed below:

### MARES BASIC MOTION UNITS - BMUS
- isometric
- isotonic (concentric and eccentric)
- isokinetic (concentric and eccentric)
- 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

Complex combination of these modes are possible. The control algorithms for the motor are defined as so called ‘Profiles’ consisting of a linked sequence of BMUs.

GRAPHICAL EDITING OF A MARES PROFILE
MARES provides a simple graphical software tool that allows the experimenter to develop these kinds of 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 doing so, 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.

**EXTERNAL INSTRUMENTATION**

MARES is designed to work in connection with other devices like electro-miographs, electro-cardiographs, stimulators, etc.

The Percutaneous Electrical Muscle Stimulator (PEMS II), (see image above) is one of the possible external instruments, delivers electrical charge pulse stimulation to non-thoracic muscle groups of the test subject, thus eliciting contractile responses.

PEMS stimulates muscle groups on the limbs (ankle, knee, thumb, elbow, and wrist) with electrical pulses applied via skin electrodes. The pulse duration and current amplitude are programmable to either 50 µs for up to 0.8 A or 250 µs up to 0.16 A. It provides either single pulses or fully programmable pulse trains, and can be triggered either manually or remotely, typically by MARES. A typical application is to study muscle strength independently of the subject’s voluntary neural drive.

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### SPECIFICATIONS

<table>
<thead>
<tr>
<th>Maximum Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque</td>
</tr>
<tr>
<td>± 450 Nm continuous, ± 900 Nm peak (200 ms)</td>
</tr>
<tr>
<td>Force</td>
</tr>
<tr>
<td>± 240 N</td>
</tr>
<tr>
<td>Angular Velocity</td>
</tr>
<tr>
<td>± 9 rad/s (515°/s) concentric and</td>
</tr>
<tr>
<td>± 6 rad/s (343°/s) eccentric</td>
</tr>
<tr>
<td>Linear Velocity</td>
</tr>
<tr>
<td>± 0.5 m/s</td>
</tr>
<tr>
<td>Mechanical power</td>
</tr>
<tr>
<td>2700 W continuous, 4500 W peak</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>concentric and 3750 W peak eccentric</td>
</tr>
</tbody>
</table>

**Measurement Accuracy**

| Torque                                            |
| ± 0.3 Nm for low torque’s, ± 1 % 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                                    |
| ± 1 mm/s for low velocities, ± 0.1% for high velocities; 200 Hz |
| Angular Position                                  |
| ± 0.5 % ROM (Range of Motion); 200 Hz              |
| Linear Position                                    |
| ± 0.75 % ROM; 200 Hz                              |

**Interface Budgets**

<table>
<thead>
<tr>
<th>Mass, overall</th>
<th>&gt; 600 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main-Box dimensions</td>
<td>103 x 52 x 52 cm</td>
</tr>
<tr>
<td>Average Power</td>
<td>350 W</td>
</tr>
</tbody>
</table>

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.
ACCOMMODATION & TRANSPORT
MARES was launched in the HRF MARES Rack. For operation, MARES occupies the centre aisle and is attached to the ISPR.

OPERATIONAL CONCEPT
MARES is a component of the Human Research Facility in the Columbus laboratory.

MARES uses the EPM portable computer for interacting with the subject/operator.

MARES is capable of acquiring data, controlling and providing power to external devices (EPM, PEMS, EMG amplifiers, etc.), and transfers real time data to the NASA Workstation or EPM for downlink. It is also capable of stand-alone data collection.

When not in use, all of MARES’ elements are stored inside the ISPR.

The flight operations of MARES are managed by ESA via the User Support and Operations Centre (USOC) CADMOS in Toulouse.

UTILISATION SCENARIO
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.

The MARES performances are ahead of any commercial research dynamometer.

SCHEDULE
MARES was launched to the ISS on board STS-131/19A Shuttle Flight on 5 April 2010.