MICROGRAVITY RESERACH STARTS ON THE GROUND ! APPARATUSSUS FOR LONGTERM GROUND BASED HYPO- AND HYPERGRAVITY STUDIES.

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ABSTRACT

With the nearing utilization phase of the International Space Station (ISS) scientists will have the possibility to perform more sophisticated microgravity experiments and experiments of longer duration than could be performed on board pervious orbiting spacecraft. To thoroughly prepare for these ISS studies, ground based experiment tools for simulated (or real) microgravity and hypergravity will be essential.
Recently a **Random Positioning Machine**, which generates simulated microgravity, became available. The **Free Fall Machine**, which generates short but constantly repeated period of real microgravity, is in use for some time already. The latest version of this FFM has its own dedicated 1xg control. To broaden the scope for acceleration studies a **tissue culture centrifuge** (Midi-CAR) can generate static and dynamic accelerations up to 100xg and allows culture in standard tissue culture plates as well as standard flight hardware. Finally, a large radius **'animal centrifuge'** is used to study the effects of hypergravity on *e.g.* small animals like rodents or fish.
In general it might be stated that ground based research is essential in gravitational biology. Facilities for ground based research should be used to identify possible effects of gravity before performing costly and time consuming real microgravity experiments for space station.

GROUND BASED RESEARCH

Ground based research covers all the activities that may be performed on Earth as ongoing research in preparation of real microgravity experiments or as post-flight control studies.

Why would one perform ground based research studies?

In the field of acceleration research[1] there are numerous reasons to perform ground-based research studies.
Some of the reasons why ground based research is interesting or even necessary to consider are, for example:

- to perform basic scientific studies on the effects of accelerations (weight) on the system under investigation
- in preparation of real microweight experiments on board orbiting spacecraft, sounding rockets, parabolic flight aircraft
- define, more specifically, the parameters which might be changed in real microweight conditions to better define the 'flight-experiment' set-up
- test hardware performance under simulated or hypergravity (*e.g.* launch) conditions
- define the interaction of the system under study in relation to the hardware being used for a real microweight experiment
- investigate the effect of launch accelerations and vibrations on the system under study or in combination with the applied hardware.

And, most of all:

- since most ground based research facilities are readily available, studies may be performed on a day to day basis and generates sound scientific data publishable in applicable journals.

The importance of ground based research has been addressed before. In reports from the European Science Foundation (ESF)[2] as well as the American National Research Council (NRC)[3] this issue is clearly emphasized. The ESF paper states, "Adequate funding

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of ground-based research is of utmost importance for the utilization of the space station."
The ground-based facilities addressed in this paper are available for ESA and non-ESA scientists, engineers, students and others.

GROUND BASED RESEARCH FACILITIES AVAILABLE AT DESC

At the Dutch Experiment Support Center, DESC (see for additional info the end of this paper)[4] the following research facilities are available to the users.

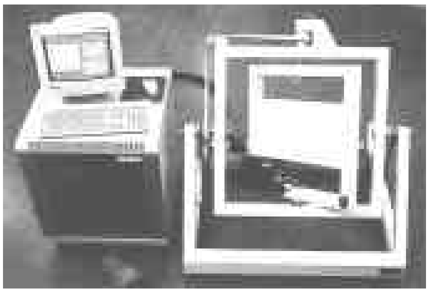
The MidiCAR centrifuge

The Medium Sized Centrifuge for Acceleration Research (MidiCAR) is a dedicated centrifuge in which samples may be exposed to accelerations up to 100 × Earth gravity.[5]
The facility is accommodated in a temperature-controlled incubator and driven by dedicated software. Gravity levels may be chosen according specific user requirements, either static or dynamic. The system may be applied for short term (seconds) or long term (weeks) studies. Dedicated experiment vessels are compatible with standard laboratory hardware but also flight specific modules may be accommodated. Data and power lines are available on the rotating and static positions. Both rotating and static control samples are housed in the same environment.

The large radius animal centrifuge

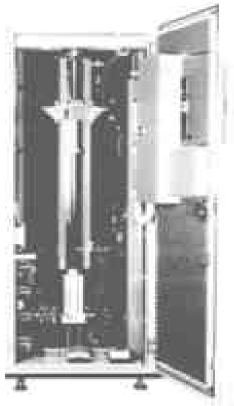
The large radius centrifuge may be used for applying access gravity to small laboratory animals (rat, mouse, hamster, rabbit, pig, fish), plants, ‘non-living’ samples, technology experiments or complete (small, locker/drawer sized) payloads for Shuttle or space station. Animals may be housed in the centrifuge for prolonged periods of time up to several life cycles.
This large diameter system (up to nearly four meters) is powered by a 3.5 kW DC motor which drives two arms on which the swing-out gondola are attached. Maximum acceleration of the system is dependent on the mass of the experiment but ranges from 1 to ~ 8 ×g.

The Random Positioning Machine



The Random Positioning Machine (RPM) is a microweight (‘microgravity’) simulator that is based on the principle of ‘gravity-vector-averaging’.[6] During an experiment run in the two axes RPM the sample experiences a zero gravity simulated stimulus. The system may be compared with a classic clinostat although the clinostat has only a two dimensional averaging while the RPM provides a functional volume which is ‘exposed’ to simulated microweight. The RPM may also be configured in the future to generate partial gravity accelerations (0.1 – 0.9×g).
The system may be operated in centrifuge mode, ‘classic clinostat’ mode or random mode.

The Free Fall Machine



The Free Fall Machine (FFM) is an apparatus that provides for long duration experiment a situation of simulated microgravity.[6] The system is based on the principle of free fall. The free fall periods in the FFM is at maximum around 900 ms and is interrupted by a acceleration of about 20 ×g for about 20-80 ms.
The assumption that the FFM provides real microgravity is based on the hypothesis that experimental models may experience the FFM as a continuous free fall condition if the gravity perception time of the system is shorter than the intermediate period of 20-40 ms of 20 ×gravity. The core of the facility is a vertical bar which guides the experiment while it is goes through its free fall cycles. A control centrifuge, generating 1×g, is integrated into the system and operated while under free fall conditions.

The bench-top 2D clinostat

The bench top clinostat is a microweight ('microgravity') simulator that is based on the principle of 'gravity-vector-averaging'. During an experiment run the sample experiences a zero gravity simulated stimulus for two dimensions.
The size of the clinostat and its sample compartments dictates the use of relatively small sample volumes.
The system may be operated in a temperature and gas controlled environment.

RESULTS OBTAINED

The various ground based research tools have been used to investigate both the effects of (simulated) microgravity as well as hypergravity. For each of the facilities an example is given:

MidiCAR Centrifuge

Real microgravity experiments are preceded by launch accelerations especially in sounding rockets. In an experiment performed by Guntermann and Jones it was investigated whether hypergravitational loading leads to changes in the protein phosphorylation pattern of primary bovine osteoblasts as it does in mechanically loaded cells.[7] The second aim was to evaluate whether these processes can be minimized by reducing the ambient temperature. The cells were exposed to 11×g for two min. at 37°C and 8°C respectively. Total cellular proteins were resolved by gradient SDS-PAGE and immunoblotted using anti-phospho amino acid specific monoclonal antibodies. Primary results showed that 11×g loading can induce phosphorylation / dephosphorylation and that keeping cells at 8°C can reduce these effects.

The large radius animal centrifuge

The large radius centrifuge has been used for quite some time now. Most of the previous experiments were performed to study the effect of increased acceleration on the vestibular system. More than half a year ago a long duration, second generation rat study has been initiated. At present we have 17 rats which were conceived, born and raised under 2.5×g. At termination of this experiment these rats are around 9 months of age. Planned studies on these rats include the vestibular system, bone development, muscle development, stress proteins, collagen degradation, immune system response. Future experiments might include studies on brain development and general metabolism.
Scientists interested in participating in these studies are invited to contact DESC.

Random Positioning Machine

The best known biological systems responsive to gravity are plants. In an experiment performed by Wood and Kiss on the RPM it was investigated using various mutants of *Arabibopsis* whether the RPM can produce similar effects on seedling development as seen in real microgravity. This experiment focused on macroscopic changes in root development and orientation, as well as on a microscopic evaluation by transmission electron microscopy to evaluate the number and location of starch granules within the cell. The results obtained with the RPM are very similar as found in Shuttle experiments. Presently the RPM is used by Dr. Veldhuijzen to study the effect of gravity averaging on mouse metatarsal long bone development. These results will be correlated to the values obtained from three real microgravity experiments.

Free Fall Machine

It is known from various experiments that the cell cycle of the unicellular green alga *Chlamydomonas* is affected by gravity.[8] Preliminary experiments using the FFM with and without the 1×g centrifuge control indicate that both the mean cell diameter as well as the length of the flagella are affected by gravity. The flagellar length of flight cells appeared to be 18.5 ± 0.4 μm (N=96), ground cells 15.4±0.5 μm (N=117) and FFM 17.1±0.4 μm (N=110). These data indicate that the FFM is a very useful microgravity ground research tool.

DISCUSSION / CONCLUSION

ESA has, compared to other agencies involved in gravitational research such as NASA and NASDA, no specific ground based research program. Part of it is due to the different science funding channels within these agencies and part of it because there is no coherent policy for this topic. In various ESA member states ground based facilities are available to, mostly, national users. This include, among others, facilities at the Danish DAMEC, the German MUSC, the French MEDES and the above facilities at DESC. At present it is difficult for non-national scientist to find the possibilities to use these facilities. General funding should be made available to provide scientists access to these facilities either through ESA or through general European research programs,[9,10] similar to the 'Large-Scale Facilities'[11] program. And since ground-based research should be part of microgravity research similar funding schemes as for the 'flight programs' should be made for 'ground programs'.

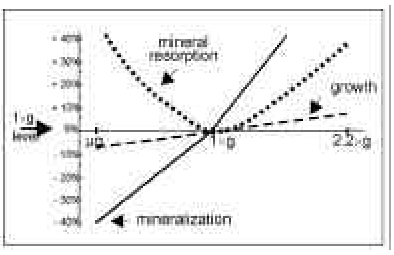


Figure 1: Fetal mouse long bones response to gravity ranging from micro-gravity to 2.2×g hyper-gravity after 4 to 5 days in tissue culture.

Ground based research provides a way to test working hypothesis and generates more knowledge on the system under study. It should identify, more precisely, the parameters that might change under real microgravity conditions. However, as the results in Figure 1 clearly show, data generated in *e.g.* hypergravity experiments cannot be directly extrapolated towards microgravity values. In this figure the data of both real microgravity (IML-1 mission)[12] and ground based hypergravity[13] experiments on growth, mineralisation and mineral resorption in fetal mouse metatarsal long bones are shown. And although for mineralisation there seems to be some linear relation with gravity this relation does not exist for mineral resorption, which seems to have an optimum at 1 × g.

An active ground based research program will generate more data hence science papers then can be expected from the present situation. Ground based research should be incorporated in student programs. This will generate a young and active basis of future gravitational biologists and physiologists. They will make more use of ground based research tools in concert with the facilities available in the International Space Station.

Spaceflight experiments are very costly and time consuming. Also the flight opportunities are very limited. It could be considered to handle spaceflight experiment proposals in a two-step process. First a peer reviewed proposal has to be tested in microgravity simulators on ground as well as in hypergravity facilities to test the proposed hypothesis. If the system under study does not respond to any of the gravity regimes on ground it might be considered to disqualify this study for a real microgravity flight experiment. This would be in favor for experiments that have been proven to be responsive to gravity.

The use of ground based microgravity simulators as well as the extension of the acceleration gamma from hypogravity to hypergravity greatly attributes to the understanding of the effects of weight on living systems and the mechanisms involved, as has been described above. More detailed hypothesis of the effects of (micro-) gravity may be generated using ground based facilities. However, these hypotheses have to be verified under real microgravity conditions.

NOTES & REFERENCES

1: Acceleration research covers the total area of research from hypoweight ('hypogravity') and hyperweight ('hypergravity'). This includes real microweight aboard orbiting spacecraft, sounding rockets or parabolic flight aircraft, hypoweight ranging from microweight up to normal weight conditions (='1×g') and hyperweight

generated by centrifuges. Also hypoweight simulations using dedicated machines are considered as acceleration research. For ground based acceleration studies is applicable to centrifuges and microweight simulators.
The term weight is used in stead of, the common term, gravity, since especially in orbiting spacecraft it is the weight, which is brought to a minimum, while the gravity levels are only slightly reduced.

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NLR: http://www.nlr.nl/public/
Bradford Engineering: http://wbn.concepts.nl/bradford/
Fokker Space: http://www.fokkerspace.nl/
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DESC

The Dutch Experiment Support Center (DESC) is a new Dutch initiative which main objective is to increase the scientific output for acceleration research. To accomplish this, DESC supports, initiates and facilitates acceleration research by providing know-how and access to ground based research facilities and by offering services and (laboratory-) assistance for ground based and flight experiments. DESC is part of a broader user support entity named DUC, the Dutch Utilisation Center. Other entities within DUC are the Dutch Operations Center (DOC) mainly located at the NLR and the associated industrial partners for hardware and software development (Bradford Engineering, Fokker Space, Stork Engineering, Origin and many others).
The main location for DESC is the Vrije Universiteit in Amsterdam. DUC is a combined initiative for user support and is governed by the Netherlands Agency for Aerospace Programs (NIVR) and the Space Research Organisation of the Netherlands (SRON).

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