Future Prospects of Microgravity Research in The Netherlands

Significance of scientific research onboard the International Space Station (ISS)
Gravity plays a fundamental role in the behaviour of organisms and materials. Various physical parameters, including pressure, mechanical loading and currents in cells and materials are fundamentally different in space. This allows performing experiments that are not possible on Earth. Due to the Challenger accident in 1986, the amount of microgravity experiments that were performed by ESA scientists did not live up to the expectation. However, the tide seems to have turned for microgravity research. A recent investigation of the output of the ESA Life Sciences area has shown a strong increase in the number and the quality of publications (ESA/PB-MG(99)16).

The start of the early exploitation phase (2001-2005) of the International Space Station (ISS) will allow a multiplicity of experiments to be performed. The decrease in experiment turn-around time, the possibility to perform long-term experiments and the possibility to interfere directly in experiments will only increase the scientific output of the experiments.

In addition, the amount of applications resulting from microgravity research is growing. Experiments in sounding rockets and space shuttles have increased insight into processes such as osteoporosis, blood pressure regulation and vestibular processes. Similarly, experiments on combustion, thermophysical properties of metals and material sciences have resulted in applications on Earth.

The Netherlands has performed unexpectedly well in response to the recent (1998 and 1999) announcements of opportunity (AO's) for physical sciences, life sciences, exobiology and biotechnology. The interest in the Netherlands for these AO's has increased 10-fold compared to the past five years. In addition, Dutch scientists have scored considerably higher that the average success-rate of 30%. Nineteen projects that were selected by ESA have either PI's or CO-I's from the Netherlands. Besides fundamental research projects, a large number of application-directed projects have been submitted. For the first time, the European industry has shown considerable interest in microgravity research, as over 160 different company's are involved in the research projects. These also include Dutch companies such as Shell Research, Hoogovens, Stork, Amersham-Pharmacia Biotech and Bioclear.

A justification of microgravity research should involve many issues, including spin-off for earth-applications and existing disciplines, new scientific research, new technology developments, international co-operation and industrial activities. The importance of microgravity research can not be represented in general terms, since microgravity research is a research tool rather than a scientific discipline. For every field of research, microgravity has its own specific value. In this report, Several Dutch scientists describe (in a personal capacity) the significance of microgravity research for application in several research disciplines (on Earth), such as medicine, physical sciences, biotechnology and industrial research. Most of the authors are involved in recently selected ESA research proposals, and together represent a wide variety of research topics. This document shows that the Dutch scientific community has great expectations of fundamental and applied research on the ISS. For the first time in the history of microgravity research, the ISS will offer conditions for performing experiments under microgravity for considerable periods. The ISS should therefore serve as “proof of the pudding” for microgravity research. In addition, the investments that have been put into the build-up phase of the ISS, both financial and scientific, form a justification in itself to perform research on the ISS. Participation in 2001 to the new ESA microgravity programme “Life and physical Sciences in Space” and continuation of the national microgravity support programme are almost self-evident conditions to preserve (and even extend) the excellent position of Dutch scientists in this field of research.

Dr. Rolf P. de Groot
Programme Manager External Research
Space Research Organisation Netherlands (SRON)
Contents

Preface (R.P. de Groot) 2

Life Sciences 4

Micro-weight and bone research (J.P. Veldhuijzen) 5
Microgravity and bone cell mechanosensitivity (J. Klein-Nulend) 6
The importance of Microgravity research to Neurobiology (B. Jenks) 7
Life sciences and microweight research (J.J.W.A. van Loon) 8
Importance of microgravity research for the field of biomedicine (P.T. van der Saag) 9
Human physiology research and microgravity (J.M. Karemaker) 10
Microgravity and medical sciences (W.J. Oosterveld) 11
Cardiovascular microgravity research is necessary (J.W. de Jong) 12
Immunosuppression and Microgravity Research (M.P. Peppelenbosch) 13
Biomechanics of musculoskeletal disorders (C.J. Snijders) 14
Microgravity Research, ISS and membrane protein structure (W.J. de Grip) 15

Exobiology / Astrochemistry 16

Evolution of Organic Matter in Space (P. Ehrenfreund en R. Ruiterkamp) 17
ISS and UV photoprocessing (J.M. Greenberg) 19

Physical and Material Sciences 20

Plasma Physics, Microgravity research and the ISS (G.M.W. Kroesen) 21
Microgravity and electrical discharges in molecular gases or gas mixtures (W.J. Goedheer) 22
Liquid dynamics onboard spacecraft (A.E.P. Veldman) 23
Physics of cold atoms and its applications in space (W. Vassen) 24
Microgravity and combustion research (Th.H. van der Meer) 25

Industrial Research 26

Importance of microgravity research for space application of biotechnology (J. van der Waarde) 27
Microgravity and liquid dynamics (slosh) (J.P.B. Vreeburg) 29
Foams in microgravity (M. van Dijk en G. Verbist) 30
Microgravity research and two-phase flow and heat transfer (A.A.M. Delil) 31
Life Sciences

Structure of healthy (left) and osteoporotic bone (right) in which microgravity research provides new insight

Xenopus laevis, a model system used for increasing knowledge about neural systems
Micro-weight and bone research.
Dr. J.P. Veldhuijzen, ACTA-Vrije Universiteit, dept. Oral Cell Biology, Amsterdam.

In recent years it has become increasingly clear that mechanical loading of long bones (e.g. legs and spinal column) plays an important role in the integrity of the skeleton. During ageing, bone loss can partly, and especially in woman, be attributed to hormonal changes (postmenopausal osteoporosis). However in many persons ageing is also accompanied with a reduced mobility which is thought also to be an important cause for the reduction in bone mass (disuse or immobilisation osteoporosis). Reduced mobility results in a reduced loading of especially the long bones in the legs and the vertebra in the vertebral column. This process of bone loss has severe consequences for the individual well-being, but also for society as a whole.

Against this background many groups in bone research have their research focused on the cells and mechanisms, which are crucial in the way in which bone cells can perceive mechanical loading and respond to it as a tissue. Most of this research is performed on isolated skeletal cells and tissues. However, final animal experiments with mice and rats are indispensable to translate the in vitro findings for application in man.

Our group of Oral Cell Biology at ACTA-Vrije Universiteit in Amsterdam is for many years active in this research area. In our laboratory skeletal cells and tissues are exposed to various types of mechanical loading to study which cells are primary responsible to perceive the mechanical stress (mechano-sensory cells). Another research topic is the way in which these mechano-sensory cells communicate with other cells in the bone tissue to regulate bone deposition and bone resorption in such a way that the tissue is optimal conditioned to the mechanical regimen. These research areas are internationally rapidly expanding and also members of our group are prominent in these fields.

Under earth conditions it is very well possible to apply various conditions of increased mechanical loading to skeletal tissues and cells both under in vitro and in vivo conditions. For a complete picture of the cellular mechanisms it is important to study cell and tissue responses over the whole range of loading conditions: therefore also reduced loading or absence of loading should be included. For in vivo experiments there are some methods to expose animals to reduced loading (such as “hind limb suspension”). For isolated cells and tissues under earth conditions however always the 1xg earth gravity is present, although some experimental conditions are known to provide simulated micro-weight. For these in vitro experiments the condition of complete absence of loading can only be achieved under space flight conditions. Therefore in this type of bone research both under in vivo and in vitro conditions, access to micro-weight conditions is essential.

We have had the opportunity to study the effects of micro-weight on isolated embryonic mice bones during two missions of the American Space Shuttle and a Russian Biosatellite. In all cases these experiments were based on results of one of our normal ground based research lines. In these early years of bio-medical microgravity research much time and money was devoted to develop experiment specific hardware and define conditions to culture cells and tissues. Also flight opportunities were scarce, often very irregular and with long intervals. However with the start of the exploitation phase of the International Space Station (ISS) these pioneering years have come to an end and micro-weight experiments on a more regular basis are now possible. With the experience of the past years and after thorough ground based experiments to prepare for space flight, using ISS can indeed be very important for bone research. The Biolab facility, which is presently under development for employment in ISS, offers a unique facility to perform in vitro experiment under micro-weight conditions. Moreover, because of the presence of two centrifuges, it is also possible in Biolab to study the area between micro-weight and 1xg, which is important to find threshold values. These types of experiments are not possible at all on Earth. Besides Biolab, in ISS a large animal centrifuge is foreseen which makes it also possible, using mice or rats, to study in vivo bone tissue responses under real micro-weight conditions.

Giving these opportunities, access to the facilities in ISS is very important in the study of the mechanisms that play a crucial role in the response of mechano-sensory bone cells to changes in loading conditions. In this respect bone research with isolated cells and animals under micro-weight conditions can give an important stimulus to better understand bone loss in humans during disuse or immobilisation osteoporosis and will ultimately play a role in the formulation of preventive measurements.

Microgravity and bone cell mechanosensitivity
Dr. J. Klein-Nulend, ACTA-Vrije Universiteit, dept. Oral Cell Biology, Amsterdam.

The research at the Department of Oral Cell Biology of the Academic Centre of Dentistry Amsterdam – Vrije Universiteit is based on the following concept: 
**Mechanical stress is an important local regulator of bone metabolism and regeneration.**

The most important function of the skeleton is to resist mechanical loading. Bone tissue adapts to the prevailing loads by changes in mass and structure, but the cellular mechanosensory feedback mechanism in bone tissue is still unknown.

Knowledge of these basic biological mechanisms will stimulate the development of strategies to prevent bone loss, as in immobilisation osteoporosis and in the edentulous jaw. This knowledge is also important for the improvement of the long-term stability of tooth replacement and orthodontic implants. It might also contribute to the improvement of orthodontic treatment.

Microgravity has catabolic effects on the skeleton of astronauts. This might be explained by the following assumption: **Weightlessness is an exceptional form of immobilisation.** It is also possible that the mechanosensitivity of bone cells changes under near weightlessness conditions, and that this abnormal mechanosensation contributes to the disturbed bone metabolism in astronauts. This can only be studied in space experiments.

The rationale for performing space experiments is as follows. Microgravity has a negative effect on the skeleton; it has been shown that bone cells are directly sensitive to spaceflight conditions. The loss of bone mineral during spaceflight could be solely the effect of an unusual form of unloading of the skeleton as a result of weightlessness. In that case countermeasures developed on Earth against in vivo disuse osteoporosis should also be effective against spaceflight-related osteoporosis. Recent observations on microtubules suggest however an alternative explanation which is also worthwhile to consider.

Microtubules are an important part of the skeleton. Several observations on plant- and animal cells indicate that effects of near weightlessness are likely established via the cytoskeleton. We recently found that the cytoskeleton is involved in the transduction of the extracellular mechanosignal to the intracellular domain, and in the translation of these mechanosignals in the release of signalling molecules such as prostaglandins. Therefore an alternative explanation of the interference of near weightlessness with bone cell function may be as follows: **The mechanosensitivity of bone cells is impaired under near weightlessness.** Impaired mechanosensitivity of bone cells might subsequently lead to a negative bone balance, even when countermeasures such as strenuous exercise are taken by astronauts.

The experiments on microtubules as well as bone cell mechanosensitivity were performed on Earth and not during spaceflight. Well-controlled studies under near weightlessness conditions are therefore needed to test the hypothesis of a direct interaction of near weightlessness with cytoskeleton-mediated cellular processes. Ground-based research is necessary for the definition and preparation of the real space-experiment at for example ISS or Shuttle. Increased gravity conditions can be simulated on Earth by using centrifuges, and near weightlessness conditions with “random positioning machines” (RPM). Such studies will contribute to furthering our understanding of the role of gravity in living cells. They could shed new light on the phenomenon of near weightlessness and on-ground immobilisation osteopenia.

The motivation for performing experiments under near weightlessness conditions is thus mainly that spaceflight causes a unique condition of unloading of the skeleton.


The importance of Microgravity research to Neurobiology.
Dr. B. Jenks, Dept. Cellular animal Physiology, Nijmegen Institute for Neurosciences, University of Nijmegen

Through microgravity programs of the last 10 years, such as that of SRON, it is clear that gravity is an important factor in regulating vital processes in organisms, both in mature systems and during development. This is particularly true for the most important regulatory organ, the central nervous system. In the absence of gravity, neurons show functional deviations, their development is abnormal and important targets such as muscles are incorrectly controlled. How these effects occur, and what countermeasures can be taken to overcome them, is one of the questions of current research. This is not only important for a better fundamental understanding of the functioning of biological systems but is also of practical importance in the expectation of man’s permanent presence in space, such as in the International Space Station (ISS).

In the Nijmegen Institute for Neurosciences (NIN), the Department of Cellular Animal Physiology is studying how nerve cells communicate with each other. Interference with this communication can lead to a variety of neurological disorders. In this respect we are studying both acute and long-term effects of microgravity on brain functioning. The knowledge is primarily acquired through research on animal models, such as the clawed toad, *Xenopus laevis*. These studies contribute to the basis for clinical and cognitive research in the FC Donders Brain Imaging Centre in Nijmegen (BIC).

The microgravity research of the department began in 1992 with a literature study on the possible effects of microgravity on the development of the brain. This resulted in a project proposal to NASA/NIH as part of the “Neurolab” program. This project was selected for Neurolab in 1994 and subsequently received financial and technical support from SRON. In the project the development in the brain of a well-defined neuroendocrine reflex will be studied under microgravity conditions. It is expected that the project will have a flight opportunity in 2001. The experiment is of 5 days duration and the biological material from the flight will be analysed in 2001/2002. This data will give insight into the acute effects of microgravity on the development and functioning of neurons in space. The analysis of the flight data will only be possible if SRON will start a new Microgravity programme.

Studies on the analysis of chronic effects of microgravity on biological systems are difficult because of the short duration of the shuttle flights, the limited space for the storage of the biological material and limitations on the time astronauts can devote to experimental payloads. The coming of the ISS will be of tremendous help in this regard, making it possible to contemplate long duration multidisciplinary research on the effects of microgravity on nerve cells and brain tissue. The Department of Cellular Animal Physiology is preparing for this moment, in a SRON-subsidised project in which experimental protocols are being developed for flight hardware. This project concerns cellular and molecular aspects of the communication between nerve cells. It will be carried out in collaboration with ESA en ESTEC, enabling the co-ordination of the planned research in the ISS with other, international biomedical experiments, and consequently, will have the benefits from the development of special hardware to perform neuroscientific observations in space.


Life sciences and microweight research
Dr.ing. Jack J.W.A. van Loon, Dutch Experiment Support Center (DESC) ACTA - Vrije Universiteit, Amsterdam

Past experiments in gravitational cell biology and physiology have clearly shown that organisms, organs but also individual cells display an altered proliferation and / or differentiation or other functional adaptations to the new environment. These experiments, mostly conducted in Space Shuttle or on sounding rockets, have to be further explored in facilities such as the International Space Station, ISS, to verify these effects and to unravel the underlying mechanisms. Therefore the upcoming ISS is of utmost importance for research in which gravity plays a role. Compared to previous infrastructures, ISS provides a better suite of on-board analysis tools such as microscopes, spectrometers, various facilities for physiological studies, but also basic support facilities such as coolers and freezers.

For physiological experiments, a big advantage of ISS over previous facilities is the possibility to conduct animal research using rats and mice. However, ISS does not need to be the only microgravity infrastructure. For some experiments the use of Shuttle or sounding rockets is a far better or even the only possibility to perform good science. Facilities such as CIS or Biopack provide a good infrastructure for such experiments.

Ground research is, in preparation for an actual microweight experiment, of utmost importance. Regular ongoing research that uses hypo-weight simulators and hyper-weight centrifuges provide useful and significant information of the effects of weight (i.e. gravity or acceleration) on a system. Doing so, ground research studies will improve the preparations and performance of costly and time-consuming spaceflight experiments. This ‘efficiency approach’ has been pursuit and implemented via DESC. DESC is operational for the last 18 months and is supported by both Dutch space agencies NIVR (National Agency for Aerospace Programmes) and SRON. Additional information on can be found @ http://www.desc.med.vu.nl.

Gravitational biology is a promising field for fundamental research. Questions on what and how the link is between the changed physical parameter, gravity, and the actual (bio)chemical response, a process also known as ‘mechanotransduction’, are still very much open. In vivo mechanotransduction plays an important role in systems like bone (osteopenia / osteoporosis), in cartilage, muscle (atrophy), in our vascular system via the role of endothelial cells in maintaining blood pressure but also in the cellular basis for graviperception in plants and unicellular systems. For in vitro applications, (simulated) microweight may be applied to study or even produce 3D tissue constructs. Candidate tissues for such applications are cartilage, skin, muscle and bone. Tissue engineering is one of the promising areas of application in the upcoming ‘century of biology’.

In previous years, promising (preliminary) science has been conducted in the field of gravitational biology / physiology within the Netherlands. Gravity is, like other physical environmental factors such as temperature, light and pressure, one of the parameters that play a role in biology and physiology. The possibility to vary this specific entity with regard to the always-present Earth’s gravity provides significant knowledge on various processes in living systems.

The discussions regarding (micro-)weight research are mostly dominated by the significant amount of money inherent to this type of research. As pointed out above, these costs may be reduced by the establishment and application of ground research facilities. In addition, a better balance has to be found for between science and industrial related activities. Hardware and operations are important issues within spaceflight activities but high standard scientific or technological experiments should be the main driver of such a program. Although in previous years a ‘look and see’ approach was sometimes necessary, in future studies exploring science using the possibilities of ground research tools are a necessity to established sound hypotheses for an actual flight experiment. It should be considered to fund real microweight and space flight experiments only after sound and successful ground based research studies.


Importance of microgravity research for the field of biomedicine
Dr. P.T. van der Saag, deputy director, Hubrecht Laboratorium, NIOB, Utrecht

Biological microgravity research as carried out during the past fifteen years in the Hubrecht Laboratory - the Netherlands Institute for Developmental Biology (NIOB) - and in collaboration with the Department of Molecular Cell Biology of Utrecht University (Dr. J. Boonstra) has produced important results. Signal transduction which is the total of biological processes in command of the cell, determining go or no-go decisions with respect to cell division, is normally exposed to gravity. Experiments under microgravity have shown convincingly that under these conditions signal transduction processes in animal cells are affected. Obviously this type of experiments has (and will continue to) contribute(d) to our understanding of signal transduction under normal conditions.

However, there are also areas of modern biomedical research where biological microgravity research provides wider opportunities. This holds especially true for research into causes and treatment of osteoporosis, the problem of decalcification in a large group of the elderly, mainly in postmenopausal women, but also increasingly in elderly males. As has been observed after long manned spaceflight, enhanced bone turnover can cause osteoporosis in astronauts. Thus it will be clear that ISS could be used as a tool to induce osteoporosis in astronauts (or experimental animals) and at the same time medicines could be tested to prevent it. In fact this is exactly the aim of a consortium of six European research groups (among which our group), actively engaged in the ERISTO (European Research in Space and Terrestrial Osteoporosis) Project, as part of the ESA Microgravity Applications Promotion Program. In the field of bone biology and physiology a better understanding of the processes leading up to osteoporosis is of great importance for present medicine as the ageing population in the Western world is increasingly facing this problem. It is very fortunate that microgravity can be used as a tool to cause and enhance osteoporosis and it seems therefore difficult to think of a better example where exploitation of microgravity could potentially help to solve an important terrestrial health concern and possibly also will find solutions for the problems of astronauts in this respect. Despite participation in ERISTO by private enterprises and despite the emphasis ESA is putting on co-operation between industry and academia, a lot needs to be done in this area. In this respect I am optimistic concerning the future of participation of Organon N.V. in Oss. We have a long-standing collaboration with this company in the field of steroids and their use in hormone replacement therapy, and it seems possible to awaken their interest in microgravity research in the field of bone biology. Obviously this would be more difficult if ISS was non-existing.

Also from the point of view of microgravity research per se the development and exploitation of ISS will finally produce a breakthrough in the reliability/reproducibility of microgravity research, as larger series of experiments can be carried out without the effects of launch etc. In any case other possibilities for microgravity research will gradually disappear, while experiments on sounding rockets are inherently limiting given their short duration. Finally I want to emphasise that participation in microgravity research by academic groups from the Netherlands should be effected only within European networks after international peer reviewing in which primarily excellence in the terrestrial research should be taken into account.


Human physiology research and microgravity
John M. Karemaker, PhD., Associate professor of Physiology, AMC, Amsterdam

Our jump into space came when Finapres, a now worldwide-established method for non-invasive continuous blood pressure measurement developed by BMI-TNO, was selected as part of Anthrorack, ESA’s state-of-the art medical-technical equipment rack for the D2-mission. Pushed by Dutch space authorities the AMC-research group, specifically Dr. Karemaker of the dept. of Physiology, joined the experimenter group for cardiovascular research on D2. Formally this was only possible by Co-Investigatorships in various focus groups. However, since none of the PI’s had working experience with Finapres, the new tool onboard D2, this international collaboration found a warm welcome.

The participation in D2 has brought international recognition in the world of space medicine. For BMI-TNO it has meant years of work in development of equipment for MIR and various shuttle flights (ESA, CNES, NASA). However, since the experimenter role was limited to that of Co-I it did not bring very much reward in the form of publications. Therefore, in the later (and present) microgravity experiments it was decided only to participate as PI or Co-I on those occasions where our own research could benefit from the space environment. Our focus of everyday research is in the adaptation of the circulation to changes in demand in the course of daily life, specifically as they occur by changes of posture. On the side of the dept. of Physiology this entails analysis of adaptation in healthy humans: blood pressure, heart rate, brain perfusion and computer modelling of the underlying mechanisms. The insight gained from this research is applied in the clinical setting where patients are met who are unable to stand upright or lose consciousness after variable periods in the upright posture. Since a stay in space is a sure way to bring healthy subjects in the same situation as our patients, astronauts are a group of special interest to us.

The astronauts onboard ISS have the normal changes in activity over the working day and sleep-periods. However, due to the lack of gravity, the 24-hr patterns of blood pressure and heart rate are unlike those on the ground. The daytime increase in pressure is much less outspoken, as is the drop in pressure during sleep. Main causes for the remaining changes are the demands of the various tasks: these demands may be physical or emotional. In view of the lack of gravitational loading, on average the cardiovascular system is much less taxed in space. This leads to cardiovascular deconditioning, a situation that must be remedied by regular exercise, more than one would normally do for fitness on the ground. Still cardiac problems may occur even in the originally healthiest of crew, as has been reported by the Russian IBMP-clinicians who have long-lasting experience with cosmonauts onboard MIR.

As research lines for the future on ISS we foresee:
1. Studies into prevention of cardiovascular deconditioning by well-chosen countermeasures,
2. Studies into neuro-humoral control of the circulation over the working day – 24 hr patterns of key-hormones and cytokines;
3. Development of ways to influence the production of these hormones and cytokines, this may be by drugs or changes in lifestyle (food, exercise);
4. Development of non-invasive sensors for cardiac loading conditions that do not obstruct the use of one hand as Finapres does.

In view of the research interest at the AMC we expect our own activities to be centered around items 2, (3) and 4. This research will be relevant for astronauts and patients alike, since these items are very relevant in the ageing population where cardiac ischemia is an increasing problem.


Microgravity and medical sciences
Prof.dr. W.J. Oosterveld, Vestibular Department ENT, AMC, Amsterdam

Since the beginning of manned space flight studies have been performed by Dutch scientists who made use of facilities offered by NASA, and later by ESA. This concerned amongst others the use of micro- as well as macro-gravity conditions. As microgravity studies in parabolic flight could far better be planned, many scientific institutes have made use of the offered facilities for both technical and biotechnological research. The results of these studies are published in known scientific journals. In the planning of further research programmes the financial support of Dutch projects means a progress as well as an enforcement of the participation in the wide area of research that was carried out in recent years. Proper data collection in combination with integration are for all physiological systems of great importance in order to stabilise eye-movements, but also for spatial orientation and for head-neck co-ordination as well as for body position management. The plasticity of the central nervous system function allows individuals an adaptation with respect to the input of changing information data from the sensory systems.

At the beginning of manned spaceflight in the sixties hardly anything was known of the physiological effects of weightlessness in general nor of the effects on human beings in particular. There were at that time some assumptions mainly with respect to the vestibular system and the skeletal motility; of all the other physiological systems the function was thought not to be affected. However, the puffy faces and chicken legs of the first astronauts during and following a space flight gave way to the suppositions that the effect of weightlessness concerned nearly all physiological systems. The first research projects provided more questions than answers. In 1990 the statement was made “when in 1961 the knowledge of today should have been available with respect to the effects of space flight on human beings, manned space flight was never developed and there should never have been people walking on the moon”.

Aerospace medicine, in the widest sense and including all the efforts in macro- and microgravity research, has broadened the insight into the functioning of the cardiovascular system, the skeletal system, the balance system and many more systems. All this knowledge has benefited clinical medicine. Nobody has ever presumed the importance of gravity for all living organisms. The fact that the immune system as well as the central nervous system was not able to function properly in a microgravity environment did not arise in anyone's mind.

Short microgravity conditions, as is provided in parabolic flight, offer useful and interesting results. However, long-lasting microgravity as exists in the ISS gives much more information for all life sciences related research. Short microgravity periods are tolerated by all living organisms as they are to some extent part of a daily natural stimulation process (bed rest). Long-lasting microgravity as is present in ISS initiates however an adaptation process for all biological systems in all living organisms. Without the possibility of research in long-lasting microgravity the results obtained in short microgravity research have a limited value for the prediction of what will happen to biological systems exposed to long-lasting microgravity. Anno 2000 the results of spaceflight research are present in several aspects of medical sciences.


Cardiovascular microgravity research is necessary
Dr. J.W. de Jong, Associate professor, Thoraxcenter, Erasmus University Rotterdam

Until now, space flights offered limited experimental possibilities to carry out cardiovascular research regarding microgravity. This has often led to descriptive publications. The construction of the international space station ISS opens avenues for biological research based on fundamentally better designs. The new research facilities allow cardiovascular research that 1) is hypothesis driven; 2) includes control experiments, replicate measurements and adequate sampling; 3) uses animals and cultured cells, in addition to analyses on astronauts.

Recently, the independent Cardiovascular Topical Team of the European Space Agency concluded that the ISS offers unique possibilities to answer a number of crucial basic questions in the area of cardiovascular physiology. The committee mentioned for instance the mechanisms related to deregulation of the cardiovascular apparatus (‘deconditioning’), which occurs exceedingly due to aging of the population. As long as these mechanisms remain a mystery, countermeasures will only be of limited value. An international panel recently characterized cardiovascular research in the Netherlands as “among the best in the world” [1]. The undersigned believes that this country should use enthusiastically the possibilities offered by the ISS to conduct cardiovascular microgravity research. By answering fundamental questions, one may possibly get insight in cause (and treatment) of life-threatening heart diseases that afflict a rapidly growing portion of the Western population.


Immunosuppression and Microgravity Research
Dr. M.P. Peppelenbosch, Laboratorium Experimentele Inwendige Geneeskunde, AMC/UvA

The last decades of the past century have seen tremendous progress with respect to the eternal battle of mankind with disease. In the Western world, infectious diseases do not pose serious threads to mankind anymore, while in the meantime also curative medicine with respect to cardiovascular and cancerous disease has substantially been improved. In strong contrast with this rosy picture, however, is the rising incidence of autoimmune-related disease (which include asthmatic disease, rheumatoid arthritis, inflammatory bowel disease, allergy etc.). Although most often not life-threatening, this class of diseases imposes ever greater burdens on the quality of life of an increasing segment of the population. Remarkably, in the last forty years hardly any avenue for therapy for this group of diseases has been developed. Hence, the quest for novel (non-dangerous) immune suppressive treatments is one of the major challenges in contemporary biomedical research.

We feel it is important to note that astronauts during space flight acquire the kind of immune suppression we seek in the laboratory and we are thus pursuing the underlying molecular details of this immune suppression. Although it is evidently impossible to bring patients into microgravity, the mere phenomenon demonstrates that the kind immunosuppression to which our quest is directed is not incompatible with laws of physiology. Furthermore, identification of the molecular targets of microgravity in the immune response will evidently greatly enhance the defining of putative targets for immune suppressive therapy. For this reason, we recently have launched a Microgravity Research Initiative at the Academic Medical Centre in Amsterdam, which aims to identify the molecular mechanisms underlying the effect of microgravity on immune function. Our research will at first focus on the role of NF-κB, a transcription factor that is essential for functioning of the immune system. The possibilities of ISS seem exiting with respect to this Research Initiative, but also the other expertise and experimental possibilities available through SRON and ESA are of obvious importance for this line of research.


Biomechanics of musculoskeletal disorders
Prof.dr. C.J. Snijders, Head of the department Biomedical Physics and Technology, Erasmus University Rotterdam

The bone and joint decade 2000-2010 has been introduced world-wide and aims at the mobilisation of fundamental and applied research in the field of musculoskeletal problems. In the past decade it became known that “musculoskeletal disorders form the single most expensive disease in society”. These disorders are a leading cause of disability and result in huge costs associated with lost productivity and treatment. It is not a health problem of the elderly, but particularly concerns people in the most productive phase of their life. Low back pain forms the largest contribution and costs in the Netherlands amount to 5 billion € per annum. Again and again ample studies are financed by policy makers to make inventories of the problem. This occurs in all industrialised countries with always the same conclusion that the problem increases. Fundamental research in this field, however, is in proportion small, if not negligible. A solution of the low back pain problem is only possible by fundamental research. In this, the microgravity research can be decisive for deriving hard conclusions.

The research group in the field of the musculoskeletal system at the Faculty of Medicine in Rotterdam, in co-operation with the Delft University of Technology, needs the unique possibility of in vivo studies without the influence of gravity. This regards fundamental research which will find its application in diagnostics, treatment and prevention as well as the related development of new apparatus for measurement and exercise. Two subjects are distinguished: a) low back pain and b) thickness of bones during growth.

Low back pain
Since the description of the human genome one of the last remaining major questions about the evolution of mankind may be the following: what is precisely the cause of low back pain? Obvious is the transition from quadruped to biped, but what precisely went wrong has not yet been defined. For the explanation several models are proposed about overload of bone, collagenous tissue or muscles. The model on intradiscal pressure finds most general favour, although this physical quantity could not be related to pain. From the low back pain cases 80 to 90% is non-specific, which means that no cause can be found or assumed. This resulted in massive support of the model on psychic causes of back sprain. But even this does not stop the raising costs for western society.

At present in Rotterdam a biomechanical model has been developed that 1) describes what went wrong during evolution, 2) includes back sprain as well as disc herniation and 3) gives indications for prevention. By measurements on astronauts before, during and after flight the unique possibility would be given to verify the model. The idea is, in short, that changing the direction of gravity on back and pelvis raised a problem against which the body developed a protection mechanism. In space this protection mechanism will not be activated because of the lack of gravity force.

Bone during growth and movement control
A fundamental problem, caused by the increasing amount of elderly in the population in the Western countries, is the risk of bone fractures at high age. It was demonstrated that those who made much bone during their youth experience lower fracture risk when being old. By means of fundamental research dominating factors which promote bone growth during youth should be mapped out. We formulated a law of scale with respect to the thickness of bones during growth. Although precise description of this law is outside the scope of this document, gravity clearly plays an essential role in it.

In vivo microgravity research offers the unique possibility to verify the above mentioned interrelated models. Absence of gravity force can be introduced in the equations and being verified in space experiments.


Drug development only will be affordable in the future when it can be based upon “rational drug design”. This approach will utilise “in silico modelling” supported by very high resolution knowledge of the three-dimensional structure of the target-protein, whenever possible also of the target-protein with a natural ligand in its binding-site.

For the majority of drugs under development such an approach currently is not feasible. One of the most important class of membrane receptors in this respect is the superfamily of G-protein coupled receptors. Over 60% of the drugs currently prescribed have members of this family as a target, either as an inhibitor of their activity or as a (partial) agonist, depending on the pathological symptom. A three-dimensional structure of sufficient detail, however, is still not available for this protein family. This requires relatively large and highly ordered three-dimensional crystals, that allow to derive the protein structure via X-ray diffraction. After long and intensive research in top-groups in Europe, the United States and Japan, only very recently conditions have been reported, that might produce suitable crystals of one specific G-protein coupled receptor, the visual pigment rhodopsin. This appears to be a general problem of membrane proteins. The number of high-resolution structures of membrane proteins is extremely small in comparison to that of soluble proteins (about ten versus several thousand).

My research group has been actively involved in this area for some time already, investigating the photoreceptor protein rhodopsin as a prototype of the G-protein coupled receptor family. While we have made gradual progress, an important step ahead was recently reported by an American-Japanese consortium, that achieved to resolve about 90% of the rhodopsin structure at 2.8 Å resolution. This still needs to be substantially improved, however, since detailed structural and mechanistic analysis requires a resolution better than 2.0 Å. Such a breakthrough might very well be realised by means of microgravity research.

In spite of the as yet restricted flight opportunities, increasing evidence is available that in microgravity better quality protein crystals can be obtained than in ground-based experiments. In view of the tests that we have flown in NASA shuttles with support from ESA and SRON and using hardware developed under the auspices of ESA, we may conclude that this is also true for rhodopsin. The experiments in the shuttle however last only up to two weeks, which is much too short for optimal growth and production of crystals of membrane proteins. On the ground, periods of at least four to eight weeks are required to grow crystals of membrane proteins to a reasonable size, and even longer crystallisation times are not exceptional. Hence, other microgravity carriers (sounding rockets, FOTON) do not offer an alternative.

Considering such characteristics it will be obvious that experiments on the ISS will offer unique prospects for our research. No longer we will be seriously restricted with respect to the length of time of our crystallisation experiments in microgravity. In addition, micro-analytical tools are in development, that will allow us to monitor in situ the progress of crystallisation and probably on board even the final crystal quality. Also, the number of experiments will no longer be severely restricted, allowing optimisation of conditions for crystallisation in microgravity, as well. This will enable us to optimally exploit the advantages that microgravity offers in the crystallisation of proteins.

In conclusion I dare say that the generation of a highly detailed structure of rhodopsin will be another breakthrough in the G-protein coupled receptor field. This will allow to produce more reliable models for the entire receptor family and will have a major impact on pharmacological and medical applications. I am strongly convinced that microgravity research on board of the ISS will provide an important contribution to these developments.


Lange, F de, Bovee-Geurts, PHM, Oostrum, J van, Portier, MD, Verdegem, PJE, Lugtenburg, J, Grip, WJ de (1998) An additional methyl group at the 10-position of retinal dramatically slows down the kinetics of the rhodopsin photocascade", Biochemistry U.S.A. 37, 1411-1420.

Exobiology / Astrobiology

Chemical / physical signature of planetary life

Mars Mobile Lander “Rover” (2003) as part of research on life conditions in our solar system
Evolution of Organic Matter in Space
Dr. Pascale Ehrenfreund & Drs. Richard Ruiterkamp, Leiden University

In the last decade a growing interest in the search for the origin of life on Earth has developed. Recent research in "life sciences" have strongly increased our knowledge in the processes of prebiotic evolution.

The current field is divided into three parts that emphasise the main steps in the evolution of life in the universe:
1. The formation of the extraterrestrial organic matter and the subsequent delivery to the early Earth.
2. The formation of the first structures that resemble living cells as we know them.
3. The evolution of these cells to modern organisms.

The Astrochemistry group of the Leiden University is strongly involved in the research field investigating the chemical evolution of the universe and plays a leading role in this international research topic. As part of the ESA Microgravity program, the Astrochemistry group are involved in a few space experiments. In this document we will provide a short introduction of these experiments and their position in the international scientific community.

Since the 1970’s a new view has emerged on the chemical composition of the universe. New techniques have made it possible for the first time to observe molecules and atoms in space. The number of molecules found in the gas and dust in the universe is reaching 150. Apart from Hydrogen and Helium, that make up the bulk of the matter in our universe, carbon bearing (organic) molecules have been detected in the interstellar medium and in gas and dust around stars. Moreover we know that the Earth annually captures tons of interplanetary organic matter. How this organic matter is formed and how it evolves in space is one of today’s hot topics in astronomy.

Stars are born from huge clouds of gas and dust in our galaxy. Parts of these clouds contract as a result of the force of gravity. The cores of these clumps of contracting gas can collapse into a new star that burns Hydrogen and Helium and in the process forms heavier elements. At the end of the star’s life it ejects the bulk of its mass back into the interstellar medium. Ultimately the ejected matter mixes with the interstellar gas and dust to form new clouds out of which new stars form. The result of many cycles of star birth and death is that the interstellar medium is enriched in heavier elements such as carbon.

Cold gas and dust in interstellar clouds are constantly bombarded with energetic particles and ultraviolet light that alter the structure of this material significantly and drive a rich chemistry that also produces complex organic molecules. During star formation part of the gas and dust that surround the young star is flattened into a rotating accretion disk. Out of this accretion disk planets can condense. The remaining material that is left after planetary formation is integrated in small bodies such as comets, asteroids, meteorites and interplanetary dust particles that bombarded the early planets vigorously. This so called “heavy early bombardment” phase resulted in the delivery of organic matter to the early planets. Current models predict that the formation of organic matter on the primordial Earth itself may have been limited due to the non-reducing atmosphere.

In the Astrochemistry group at Leiden University interstellar chemistry is studied with the help of laboratory simulations. Controlled irradiation experiments under simulated laboratory conditions (i.e. high vacuum and low temperatures), allow us to investigate the evolution of molecules in interstellar clouds and comets. Limiting factors of these simulations are the physical performances of laboratory equipment that make long duration experiments impossible. Therefore we are involved in a long duration exposure experiment on the SEBA/EXPOSE platform of the International Space Station (ISS). This project, titled “Evolution of Organic Matter in Space”, is conducted in co-operation with a great number of international institutes including the European Space Agency, NASA Ames Research Center California, USA, the Laboratoire de Mineralogie Paris, France and the Institut Für Planetologie in Muenster, Germany.

In this project a selection of organic compounds of astrophysical and exobiological interest will be mounted on the outside of the ISS. For approximately two years these molecules will be exposed to space conditions and the solar ultraviolet radiation. The results of this long duration exposure experiment will be an important contribution to our understanding on the evolution of organic matter in our universe and the origin of life.

Additionally these results can contribute to ecological research of industrial pollution. The chemical substances we use in this experiment are identical to a number of known polluting combustion
products that are found in the Earth atmosphere. Our results will allow us to make predictions on the
stability of these compounds in such environments.

In continuation of the project on the ISS, we play a leading role in a planetary simulation experiment. In this project a simulation tank will be equipped to simulate and control the atmospheric conditions of bodies such as Mars in terms of chemical composition, temperature and solar spectrum. In this experiment we will study the effects of conditions on Mars, the Moon and the Earth on the chemical evolution of organic matter after delivery on a planetary surface. This project is closely linked to future ESA Mars missions and will provide an Earth based test platform for new and future techniques and materials. This project is also conducted in co-operation with a great number of national and international universities and institutes, including ESA and NASA.

The leading role of Leiden University in the fast developing international field of the chemical evolution of organic matter in the universe will be impossible to attain without the possibility of additional microgravity research. The experiment on ISS provides an essential contribution to our research by avoiding the limitations imposed by Earth laboratory conditions. Although both projects are primarily designed to answer a number of important fundamental questions there is a strong link with the Earth studies.

The interdisciplinary scientific field unified by the term Exobiology is a new and developing research area. The Astrochemistry group is one of the few laboratories in the world that is able to perform interstellar simulation experiments and has played an important role in the development of interstellar chemistry as a scientific research discipline. Supplementary microgravity research is essential to maintain and support this leading position.


ISS and UV photoprocessing
J. Mayo Greenberg, Raymond and Beverly Laboratory for Astrophysics, Leiden Observatory

My particular interest in the SS has to do with the development of a new kind of facility to study ultraviolet irradiation effects on materials at cryogenic temperatures. The basic idea involves placing the sample in the shadow region on ISS and with the use of concave mirrors and diffraction gratings simultaneously amplify the solar ultraviolet radiation and reject the unwanted visual and infrared. By being in the shadow and rejecting unwanted energy it becomes much easier to maintain the sample at cryogenic temperatures even down to 10 K. I am currently a co-investigator with a group in Japan working on a design based on my concept. The application we are working on has to do with the chemical evolution in interplanetary and interstellar space driven by ultraviolet photoprocessing. But there many other conceivable applications to the effects on clean dielectric surfaces and generally the scaled measurement of simulated long term irradiation -simulated because the mirror arrangement allows for amplification of 100 or higher- thus permitting useful results in relatively short times. I think it would be a powerful advantage to make the project a joint Netherlands Japanese venture. It is proposed to mount the facility on the Japanese module of the ISS. Of course my initial motivation for this work was the application to the study of interstellar and comet chemistry which is currently one of the projects to which the Leiden laboratory is heavily committed. I believe the proposed ISS facility in which we are involved can have much broader applicability in material and surface science .The long term research of which this forms an integral part should continue to involve the Leiden astrochemistry group for many years to come.


Physical and Material Sciences

Flame on Earth (left) and under microgravity conditions (right)

Simulation of liquid behaviour inside a 3-D tank under microgravity conditions in support of flight experiments.
The group EPG (Elementary Processes in Gas discharges) at the Eindhoven University of Technology concentrates on low temperature plasma physics. One of the emerging research areas is the field of the presence of dust particles in a gas discharge. The dust particles will be charged electrically by the free electrons in the plasma. Subsequently, the dust cloud will be trapped in the plasma glow because of the presence of the electrical field in the space charge region which surrounds the plasma. These dust particles can then be treated: a coating can be deposited on the surface, changing the functionality. This new way for coating particles offers interesting perspectives: enhanced thermal stability, catalytic activity, etc. Furthermore it is possible to double the efficiency of solar cells by incorporating dust particles, this time with a size of a few nm, in the growing amorphous silicon film. It is not surprising to see that the research in my group on this topic is supported by FOM, STW, and the European Commission. The industry (Océ, SHELL, Akzo-Nobel, Philips) is following the research closely and also contributes financially.

The biggest problem in the research is the presence of gravity, which typically dominates the force balance on the particles, and which also introduces phenomena like convection. On the ground gravity cannot be “switched off”. This makes it impossible to carefully study the complex phenomena which take place when dust particles are introduced in the plasma. This in turn hampers the (pre) development of new powder processing techniques. It is necessary to be able to perform dusty plasma experiments under microgravity conditions on a regular basis, during several years. This is not possible with the present possibilities like parabolic flights, sounding rockets, space shuttle flights. This is why I joined the IMPF-project (International Microgravity Plasma Facility): an ESA-project which aims at installing a plasma facility in the ISS. Participation of the Netherlands to the new ESA microgravity programme is vital for my participation to IMPF, which concentrates on the application oriented research topics.


Microgravity and electrical discharges in molecular gases or gas mixtures
Dr. W.J. Goedheer, FOM-Instituut voor Plasmaphysica "Rijnhuizen"

Many techniques used to create or modify thin solid layers on surfaces are based on electrical (glow)discharges in molecular gases or gas mixtures. Often clusters are created in these discharges, ranging in size from a few nanometers up to microns. These clusters play an important role because they will not only influence the behaviour of the discharge, but they can also be incorporated in the growing layer deposited on a surface, thus creating new materials.

An important application is the production of so-called polymorphous layers of hydrogenated silicon, which consists of crystalline clusters embedded in amorphous material. Research has shown that this material can be used to produce stable solar cells. Important for a cost-effective and reliable production is knowledge of how to manipulate the behaviour of the clusters.

Many forces affect the motion of the clusters. In laboratory discharges the electric force (clusters carry a negative charge) and gravity are usually the most important forces, especially when the clusters are large. Microgravity research is essential to enhance our knowledge regarding the other forces, such as the drag by neutral gas, by positive ions escaping from the discharge, and the thermophoretic force resulting from a temperature gradient in the discharge. We rely on these forces to transport small clusters from the discharge to the growing layer.

Without microgravity research is will be difficult to unravel the effect of the various forces, since on earth everything will be dominated by gravity. A stable experiment is essential; with the infrastructure available at present (parabolic flights, sounding rockets) it will not be possible to perform the required experiments. The ISS therefore offers unique possibilities for advancing knowledge in this research area.

Knowledge of liquid dynamics onboard spacecraft is still far from complete. For instance, in a (partially filled) fuel tank, the local cohesive forces near the moving contact line between the liquid fuel and the solid container wall are not well known; still they have a considerable influence on the liquid dynamics. Also, a global phenomenon as the damping of the liquid's sloshing motion and its effect on the dynamics of the spacecraft cannot be predicted reliably. Experiments remain necessary to understand the physics of the coupled liquid/solid body system.

At various occasions the mentioned knowledge gap has led to serious problems during space flights. A recent example concerns NASA's Near Earth Asteroid Rendezvous (NEAR) satellite, intended to shoot close-up images of the asteroid Eros. During one of the orbital manoeuvres the engines were automatically shut down, after which control over the spacecraft was lost. Reconstruction of this incident showed that during the manoeuvre the lateral acceleration had exceeded the predetermined safety limits, after which the spacecraft defaulted to a safe mode. The inadequacy of these safety limits was due to an inaccurate prediction of the response of the liquid fuel onboard the spacecraft. It took considerable effort to regain control over NEAR; eventually the spacecraft reached its orbit around Eros in February 2000, 13 months behind schedule.

This example shows that terrestrial experiments provide insufficient information about the dynamic behaviour of liquid under microgravity conditions (micro-g). This is due to the fact that in space liquid dynamics is dominated by capillary forces, whereas on earth these forces are ‘overwhelmed’ by gravity. Experiments in microgravity are required to make the influence of capillary forces visible. During parabolic flight, in drop towers and with sounding rockets limited periods of microgravity can be attained, however insufficient for detailed research. A longer period of microgravity is necessary, as will be possible onboard the International Space Station (ISS).

My research group participates in a European project, supervised by the National Aerospace Laboratory NLR, in which a small spacecraft is built especially for carrying out research on microgravity liquid dynamics: Sloshsat FLEVO. During a 10-day mission, various experiments will be carried out with this satellite. These experiments will be supported by means of a theoretical study, in which the liquid dynamics is modelled and predicted via computer simulation. In turn, the results from Sloshsat will be used to validate the theoretical flow modelling. We also participate in a EU-funded Topical Team on ‘Liquid Management in Space’, in which research projects to be carried out onboard ISS will be defined and prepared.

The amount of liquid onboard spacecraft, fuel as well as cargo, will steadily increase. High demands on manoeuvring precision remain required, e.g. for rendezvous and docking manoeuvres of manned and unmanned shuttles (such as the Automated Transfer Vehicle) with space stations. The coming years (decades) the above indicated problems will remain a highly relevant technological area, for which much detailed scientific research is required, preferably in a suitable microgravity environment like ISS.


Physics of cold atoms and its applications in space.
Dr. W. Vassen, Vrije Universiteit, afdeling Natuurkunde en Sterrenkunde

My research concentrates on the physics of cold atoms and its applications. Cold atoms move with extremely low velocities. Their temperature is less than 1/1000 of a degree above absolute zero. This is realised in high vacuum by cooling of the atoms with laser light, a new field of research that was awarded the Nobel prize in physics in 1997. The low velocity allows observation of atoms over very long time thus realising very high measurement precision. This is, for instance, of importance when building the most accurate clocks in the world. It also allows high accuracy gyroscopes and rotation measurements. On earth this is a very active field of research. In my group we study the feasibility of an atomic clock based on helium-3, partly financed by SRON.

An important limiting factor in this field is gravitation, simply due to the fact that atoms fall down under the influence of gravity and so disappear from the observation volume. In space one can measure much longer and therefore more accurate measurements are possible in principle. Atomic clocks in space are anticipated to be 10-100 fold more precise that on Earth. This is the major reason to perform these kind of measurements in space. I foresee a strong growth of cold atom research in space in the near future. One example of this growth is the ESA ACES (Atomic Clock Ensemble in Space) program on the ISS (launch anticipated in 2004), and the recently started projects financed by the US that will also fly on the ISS.


Microgravity and combustion research
Prof.dr.ir. Th.H. van der Meer, Mechanical Engineering, Twente University

A turbulent combustion process is very complex in its detailed theoretical description. It concerns a large number of coupled chemical reactions between ten to hundred chemical species. The equations describing these reactions are coupled to the equations describing the turbulent fluid flow of the gases. Even for isothermal turbulent flows without chemical reactions the flow equations (the Navier Stokes equations) cannot be solved exactly. In fluid mechanics as well as in combustion technology models are used in order to reduce the complexity of the exact equations. In these models gravitational effects are included.

A lot of combustion research is devoted to the validation of the models used in numerical simulations, such as turbulence models, combustion models and models for the interactions between turbulence and the combustion chemistry. The effects of gravity on turbulent combustion processes can only be investigated by doing well defined experiments in gravitational and non-gravitational circumstances. In contrast to past and present infrastructures in space, the ISS offers optimal conditions for this research. These experiments will enlarge our knowledge of turbulent combustion and extend the capabilities of the models used for optimisations of combustion processes related to efficiency and production of pollutants. In this way microgravity research on turbulent combustion will contribute to a better use (clean and efficient) of our fossil fuels and of fuels from durable sources, like biomass.


Industrial Research

Microgravity research may contribute in cost reductions for oil-refinery.

Microgravity research motivated new instrument development and development of a small satellite (Sloshsat FLEVO)
Importance of microgravity research for space application of biotechnology
Dr. Jaap van der Waarde, Bioclear Environmental Biotechnology, Groningen

Bioclear is a research and consultancy company specialised in environmental biotechnology. Since 1988 Bioclear has been active in projects that are aimed at the application of biotechnology in space and microgravity research plays an important role in these projects. The development of a Biological Air Filter for application in manned space craft has been performed in a consortium of Dutch enterprises and universities and has received financial support from ESA and NIVR. Microgravity research is important in these development projects since critical systems like environmental control that are essential to the performance of a manned space system will only reach a full scale application if all potential possibilities, limitations and risks are thoroughly understood. Research into the behaviour of micro-organisms under microgravity is therefore important for the acceptance of application of biotechnology in a Space Station.

It is important for Bioclear to place the space related activities in the framework of our more regular work and potential spin-off to ‘Earth’ applications. This is focused in the mission statement of Bioclear: ‘The creation of a sustainable society with the aid of biotechnology’. Important fields of application are soil, water, air and industry.

We expect that the potential for biotechnology will increase tremendously in the near future and that biotechnology will find applications in many parts of society. Reoccurring issues will include decrease of environmental pressure, less energy consumption, less waste, reuse and recycling of raw materials. In addition to end-of-pipe techniques we expect that biological processes will become incorporated into industrial processes and will be used to close industrial process loops to allow sustainable production and consumption with increasing welfare and world population. Biotechnology will therefore become one of the key technologies to create a balance between economy and ecology.

Many applications are still far from reality and much research and development will be needed. Our experience with space research is that it can form a first step to the development of technologies that in a period of several years can result in commercially attractive Earth applications. A good example from Bioclear’s experience is the development of molecular techniques for the detection and identification of bacteria. Financed by ESA/NIVR a literature study was performed in 1993 and 5 years later this type of research was incorporated in our core business like waste water treatment and monitoring and control of biological soil remediation.

We expect that biotechnology will take a leading role in the creation of a sustainable society. Since several issues like recycling of raw materials, decrease in energy consumption and sustainability are crucial to long term manned space missions, space research can play a leading role in the development of technologies that will be needed on Earth. We perform projects in the field of space research in the expectation that these projects will benefit Earth applications. A consistent and adequate support of biotechnological research for space applications, including microgravity research, is essential. Collaboration between universities, research institutes and companies offers the best conditions for top level research that may lead to applications of biotechnology in space and on Earth and active support of this collaboration from the national government is needed.

Microgravity and the Development of Life Support Systems
W.G.J. Pasteuning, Manager Stork Product Engineering.

Stork Product Engineering (SPE) is for years involved in microgravity research. For SPE, this research is important for a number of reasons.

At first, SPE is directing on the development of Life Support Systems for both long space travel as well as planetary basis. Most of these systems are based on bio(techno)logical processes and in these developments often questions arise which only can be answered by fundamental scientific (microgravity) research.

An example is the development of biological air filtration, a proved and mature Earthbound technology. But, at use in space, in a low gravity environment a thorough knowledge of the applied microorganisms is necessary. The arrival of the International Space Station (ISS) offers the possibility for research periods of long duration, over many generations organisms, and is therefore of great importance.

A second example is the FOOD: Fungus on Orbit Demonstration project, which SPE is performing under contract by ESA, and in close co-operation with the Agrotechnological Research Institute (ATO). Aim of this project is research on the application of fungi for the breakdown of fibrous materials. These materials form a problem in closed ecological life support systems, in our opinion the only solution for long duration space missions. The results of these investigations will not only of use at planetary settlements but also for a better use of materials on Earth.

In addition, space can be seen as one of the cradles of the development of microsystems technology (MST). SPE is active in this area. MST will become of great importance for space technology and will offer tremendous opportunities for Earth bound spin-off.

Just now, when NASA is looking in Europe for support and co-operation to enable deep space missions and manned missions to Mars, a continuation of the present support is necessary and should even be increased. This is also of importance because the Netherlands has (still) a good position in the field of biotechnology. It is our opinion that the ISS will strongly boost this type of research.

Stork Product Engineering would greatly regret if the Dutch government would decide to decrease or even stop their support to this research. Even more, SPE would advocate that this support would be increased.
Microgravity and liquid dynamics (slosh)
Dr. J.P.B. Vreeburg, National Aerospace Laboratory (NLR)

Microgravity provides opportunities for the study of the dynamics of unsupported systems and for the testing of such systems. On earth such study is necessarily limited by the short duration of terrestrial free fall. If the system is partially liquid, as a fuel tank, microgravity allows also the study of capillary effects. These are often dominant in space engineering subjects like liquid management and tanker motion control.

Various institutes and universities seek to improve existing models for liquid dynamic behaviour by using microgravity. These models are used primarily for terrestrial applications, e.g. for tanker dynamics simulation, or free-surface (slosh) problems. The interest of NLR is directed to space applications, in particular the investigation of the dynamics of spacecraft with a large liquid mass fraction in a partially filled tank. Such spacecraft become more prominent, typical are exploration satellites like NEAR or STARDUST, and ISS service vehicles. Use of these systems motivates fluid dynamic sloshing experiments with the goal to improve models until valid for practical application. The knowledge gained by this process has been found applicable to problems on Earth as well.

Specific subjects in liquid dynamics where knowledge is lacking and modelling is not validated, are damping and contact line behaviour. Computational difficulties are encountered to ensure the stability of CFD (Computational Fluid Dynamics) codes and in the accurate description of moving capillary surfaces. Experiments are complicated by the lack of appropriate, and tested, methods and techniques. Required are means of diagnosis for the distribution of liquid in a partially filled tank, and for the determination of the force and torque generated by the liquid on the tank.

Already in 1976, inspired by the IRAS spacecraft and anticipated slosh problems, NLR submitted proposals for experiments in this field. These were to be conducted using small transparent containers, and some have been executed during the Spacelab-1 and D-1 missions in the Fluid Physics Module. Since then more investigations followed, during parabolic aircraft flight, with sounding rocket (the ‘Wet Satellite Model’ or WSM) and recently, on a small dedicated spacecraft. It is Sloshsat FLEVO (“Facility for Liquid Experimentation and Verification in Orbit”), now in its final stage of testing before launch with the Space Shuttle. The programme of experiments has been detailed based on input from an Investigators Working Group with members from the Netherlands, USA and Israel. Simulations of expected dynamic behaviour have been generated, and published, in support of the preparation of Sloshsat FLEVO operations.

The accumulated time devoted to experimental investigations of capillary slosh has been little. However, actual and anticipated problems with the operation of the ISS have led to various initiatives for more research in this area. The technology and knowledge generated by the Sloshsat FLEVO project will allow NLR to make valuable contributions to spacecraft control and liquid management issues.

Specific activities include the participation in the ESA Topical Team for “Liquid management in Space”. For future research opportunities, concepts are being developed for a “Free Float Facility” on ISS. Different uses have been identified, mostly related to the diagnosis of body force fields by distributed arrangements of accelerometers. Data from such a, gradiometric, device can be processed to yield various inertial and geometrical properties of a body that carries the instrument.


Foams in microgravity
Dr. Menno van Dijk & Dr. Guy Verbist, Shell Global Solutions International B.V., Exploratory Research

Foams have widespread use within the petrochemical industry as resulting products (polyurethane mattresses, polystyrene insulation, etc.) as well as (intermediate) processing steps in gas/liquid contacting equipment (e.g. distillation columns). During processing foaming occurs temporarily or transiently and is -for that reason- inherently difficult to study, although the economic incentives are substantial. As an example one may consider distillation columns that are overdesigned to correct for the much larger volume taken up by a foam compared to a clear liquid (in the worst case scenario of excessive foaming). Capital expenditure rises because of the larger column to be build and operating costs are enhanced while maintaining the pressure differential over the higher column. It becomes a nightmare when excessive foaming “floods” the trays within the column. Since distillation is one of the first processes at a refinery, an entire process chain might suffer. The type of foam research needed suffers from many complications due to the fact that foam structure as well as rheology are inherently intricate. Gently moving a saucer won’t disturb the “mousse au chocolat” on it, which reacts as an elastic solid. A more forceful - if not hungry- attack with a spoon makes the mousse yield resembling a viscous fluid.

Idealised models describe foam as having a homogeneous density, i.e., the liquid is dispersed evenly throughout the foam. Earthly reality -however- dictates the liquid to flow downwards under the action of gravity resulting in a foam that is dry above and wet below. As a result (i) comparison between theory and experiment is complicated and (ii) little is known about the error of the “ideal” approximation made. In order to tackle this gap in knowledge, the foam cluster within Shell Global Solutions has taken the initiative to formulate an ESA proposal for the study of foam in a microgravity environment. Initial testing in parabolic flights will provide a basis for an experiment in the ISS, where microgravity duration as well as quality can be guaranteed to a sufficient extent.

It is our hope that the generated knowledge will allow us to better control and design for the occurrence of foaming in petrochemical industry by optimised operational procedures for existing processes and sharper design rules for new equipment.

The support of the Dutch microgravity community including SRON and the Dutch Experiment Support Center (DESC) has been of great value to establish awareness and contacts in this territory new to us. Further we acknowledge the ESA topical team on foams and capillary flow as a timely and focused initiative.

In summary: microgravity research is a unique opportunity for foam science and its industrial applications to the extent that we have actively engaged ourselves for an ESA project on the matter.

Two-phase flow and heat transfer in microgravity and on Earth is expected to be substantially different. Carrying out dedicated experiments in microgravity will lead to fine-tuning of models for terrestrial applications and to the possibility of extrapolation to the space environment.

NLR's theoretical and experimental research activities yielded:

- A better understanding and models of the gravity level dependence of two-phase flow and heat transfer.
- Expertise in thermal-gravitational modelling & scaling of two-phase flow and heat transfer.
- Models for complicated, mechanically and capillary pumped, two-phase heat transport systems.

Though there was some spin-off for terrestrial applications (e.g. NLR’s Vapour Quality Sensor and some advanced cooling systems), the research focused on aerospace applications.

The work done included:

- The design and development, and the execution of the Dutch-Belgian Two-Phase eXperiments, TPX I&II (being two versions of a reduced-size capillary pumped two-phase ammonia heat transport loop), in two Space Shuttle flights.
- Contributing to the development and participation during the Space Shuttle flight of the Hitchhiker Loop Heat Pipe Flight eXperiment, LHPFX, an ammonia Loop Heat Pipe experiment by several research laboratories and industries in the USA, and NLR.

The current expertise is based on shuttle missions with very limited flight opportunities and flight duration. More and better opportunities will be offered by the International Space Station (ISS). Therefore, continuity will increase and hence ISS will stimulate the microgravity research.

Two-phase heat transfer research is also being done, in co-operation with NIKHEF, for the Alpha Magnetic Spectrometer AMS-2, a charged particle detection experiment on ISS, by an international team led by MIT and CERN, consisting of experimental contributions of the universities of Zurich, Geneva, Perugia and Aachen.

Recently the Convection and Interfacial Mass eXchange (CIMEX) proposal was accepted by ESA. The CIMEX experiments will be executed in the Fluid Sciences Laboratory (FSL) on ISS. NLR's contribution, CIMEX-3, mainly pertains to experiments in a versatile two-phase test loop (to be developed) for a systematic validation of the existing models, in combination with novel research issues.