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Human Spaceflight
Science Newsletter

September 2009

The ISS Utilisation Department of the Directorate of Human Spaceflight releases a Newsletter on latest science highlights

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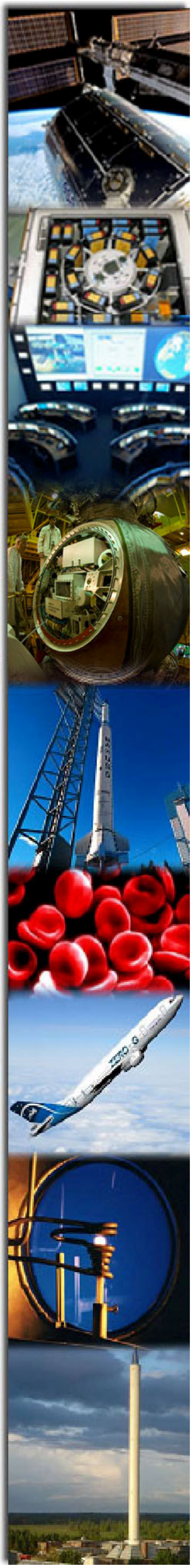
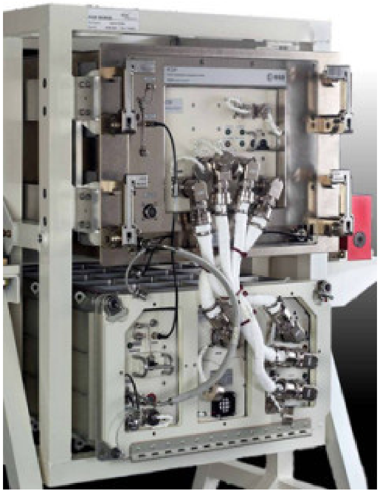
editor: B. ELMANN-LARSEN, ESA/ESTEC-HSF-US



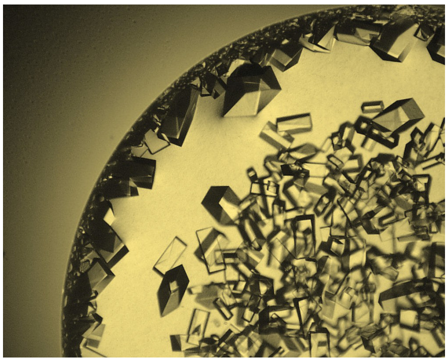


Protein Crystallisation and Diagnostics Facility: INSIGHT INTO HOW CRYSTALS GROW – AND WHAT THEY ARE USEFUL FOR ….

Good crystals are necessary for two purposes. Firstly, in order to identify the 3D atomic structure via X-ray diffraction and secondly, as a basis for management of modern 'smart medicine'. Finally, crystallisation is used as a means to purify proteins.

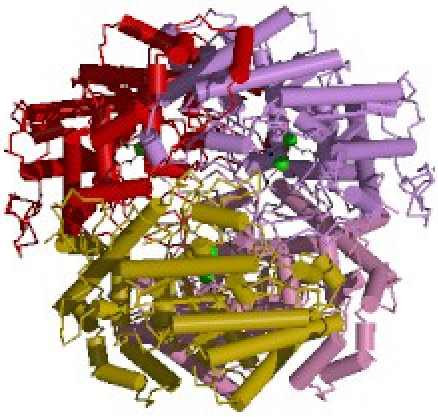
Protein crystallisation in the PCDF facility makes use of basic fluid kinetics research in the initial phase, i.e. knowledge about the way fluid behaves when weightless.

When performing protein crystallisation investigations in PCDF in ESA's Columbus laboratory, this knowledge is brought to use, and is being combined with diverse analytic approaches, leading to a better understanding of the mechanisms. As a potential spin-off from the primary crystal structure knowledge, more daring medicine administration strategies may in the future become possible. PCDF in this manner uses Fluid Physics as a discipline, to enhance the knowledge in Biochemistry and Medicine – an elegant team-work.



The crystals (above) Courtesy of Kalevi Visuri, Finland.

… and the molecular model of Glucose Isomerase or more correctly D-xylose Isomerase used for the experiments. Originating from the sugar industry Courtesy of http://www.ebi.ac.uk/thornton-srv/databases



As so often before on these pages, we again here see the fascinating effect of removal of gravity. Material that in such crystallisation experiments on Earth would gradually sediment at the bottom due to gravity, is being kept in suspension – 'floating' - as the density differences in the solution, that make things 'sink' or 'float' have much less effect in a gravity-deprived environment. Instead, the growing crystals keep growing, and the scientists can, with the PCDF facility, indirectly observe how crystals 'grab' the protein molecules from the solution in the immediate vicinity to the forming crystal, by observing the interesting fact, that actually the concentration of protein falls in that thin layer of fluid, right next to the solid crystal. The free, single molecules in

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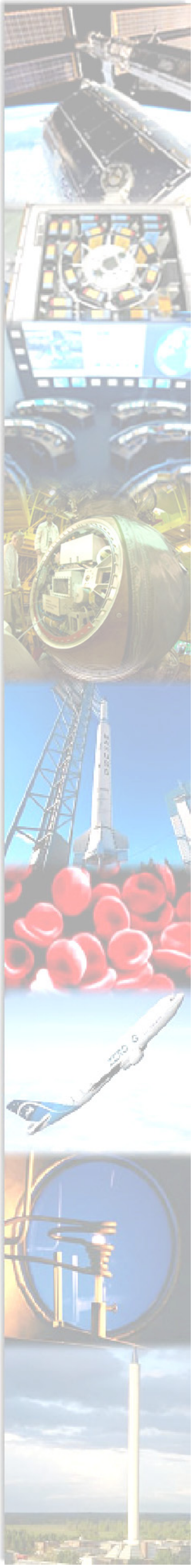
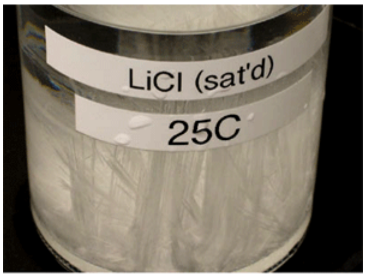




ithium Chloride (LiCl) crystals in the upersaturated container. Courtesy of ttp://chemconnections.org/crystals/photos/index.html

the fluid become adsorbed[1] to the crystal surface and gradually become incorporated into the crystal structure.

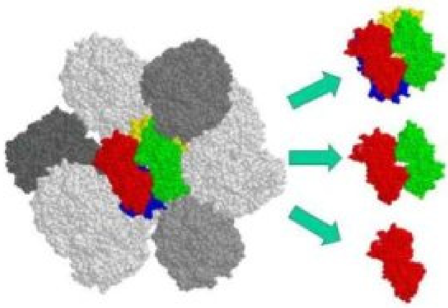
How it all starts is one of the main headaches and needs to be understood better. What is however known is, that certain borderline conditions – and several, actually - have to be fulfilled. One of those having paramount importance is the availability of a high enough concentration, so-called super-saturation[2] of the protein in solution, and another being, that some kind of start matter needs to be created - the so-called *nucleation*. That in turn is crucially dependant on the saturation and temperature environment. Finally, for crystallisation to happen, the right pH needs to be offered in the medium.

Nucleation is the beginning, and that requires energy, thus energy needs to be added somehow. Once the nucleus is over a certain size, that relation turns and energy is actually released when consecutive layers are added to the crystal. Protein molecules are brought together by tiny velocity fluctuations, created by factors such as concentration differences, local temperature differences etc. Small nuclei are formed but most grow to very small size, however, and tend to re-dissolve.

Choice of protein for the experiment.

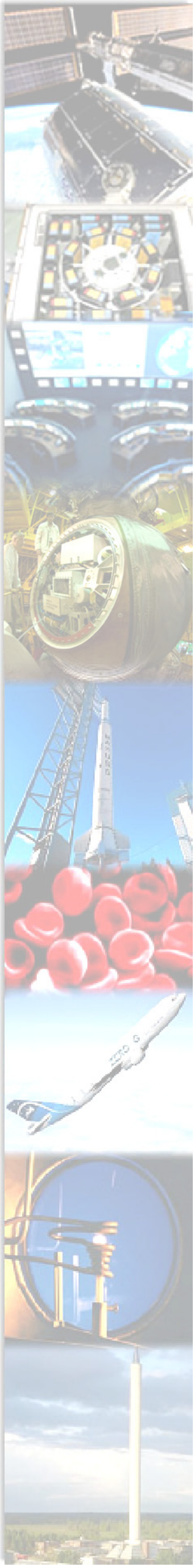
This is not quite straight forward, but the enzyme protein glucose isomerase (correct name is D-xylose isomerase), used in the sugar industry has demonstrated the qualities needed:

- stability over longer periods (as the mission on ISS is in the order of 3-6 months)
- an appropriate solubility temperature
- a protein that can be acquired in large amounts, and
- a protein that can be re-dissolved several times.



See this as a crystal composed of a number of the glucose isomerase (GI)molecules (this is actually a different molecule, but that doesn't matter here), which in turn are expressed as the colored plots to the right. One colored mass corresponds to the GI molecule at the beginning of the text.
Courtesy of the Thornton group.

Glucose isomerase has all these qualities. Crystals will re-dissolve at temperatures over 37 degrees, and thus can form the basis-fluid for a new experiment start at any time during the flight. This is particularly interesting as only four reactors are available for the PCDF experiment for the entire flight. By re-dissolving the crystals, the number of experiments will only be limited by technical and time-resources and by protein life-time. Also the impact of impurities will be examined.



[1] Adsorption means that matter is in one or the other way connecting to a surface. Absorption (chemistry) means that matter penetrates into existing material.

[2] Think of when you fill salt into your dishwasher: You poor and poor and the salt 'disappears' – it gets dissolved in the water – until the water cannot dissolve any more, and you start seeing salt proper remaining. If you put a lid on a container filled in this manner, keeping the vapour layer over the fluid from escaping, you will have 'super-saturation'.

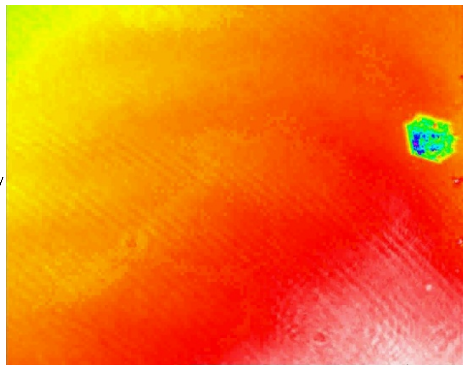
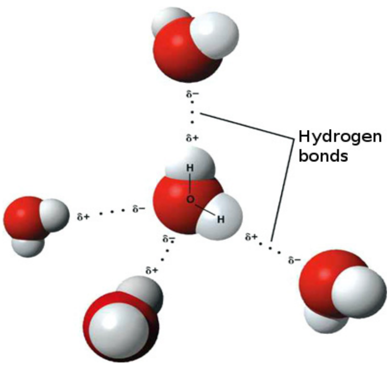


Image of a crystal of Glucose Isomerase from the PCDF ground model Mach-Zehnder Interferometer. The picture shows, in "false colour", concentration differences in the experiment volume, as an effect of differences in the refractive index of the material present in the cell. The abrupt change of colours on the upper right side reveals the presence of a material with different refractive index with respect to the solution, that modified the propagating light wave front. That is precisely the crystal.

Once nuclei are formed, crystals may begin to grow. Continuing to identify 'special effects' in 'space fluids', as one of our main focus areas in the Newsletters, we can in this context in particular observe the effect of the growing crystal 'stealing' protein from the solution: That leads to the so-called *diffusion-limited regime*, which simply means that, as the crystal grows, not enough protein can transport itself (by diffusion[3]) fast enough to keep the 'appetite' of the crystal satisfied. This is an aspect of fundamental importance for the understanding of the crystallisation process, one that can only be studied accurately under weightless conditions.

The zone where this is the case, is called the *protein depletion zone*, understandably (leaving the solvent, water there), which actually basically is 'bad', as it limits the rate with which the crystal grows, but at the same time is seen as a 'good' thing, as the assumption is that the crystal in this manner becomes more perfect[4] .

In normal gravity, the *depletion* mentioned, would be distorted, as gravity-driven movements of the fluid would create a better mixing, but at the same time, the crystal would move and sink, and in this situation be impaired in its growth and purity. The important diffusion process could not be studied under such conditions.



X-ray crystallography of a 'simple' molecule: The arrangement of five water molecules (H_2O) in ice, revealing the hydrogen bonds that hold the solid together. Courtesy of: http://en.wikipedia.org/wiki/X-ray_crystallography

How do you 'see' these things?

'Interferometry' is the word. We did describe that technology in the context of the MASER-11 / CDIC-2 experiment in Newsletter no. 1, 2009. The particular version interferometer here has a different configuration, however, namely the Mach-Zehnder interferometer.[5]

The PCDF Mission – what are the aims?

The parameters indicated earlier under 'choice of protein' are the ones allowing to perform repeated experiment runs until the goal for a specific sub-experiment have been reached. By increasing the temperature thereafter, formed crystals re-dissolve and a

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[3] Diffusion is a phenomenon that follows the principle of equalization or complete mixing of components in a fluid or a gas, if enough time is allowed. That will always happen, but it happens over a certain time. If now the crystal is very 'greedy', it will take more free molecule building blocks, than can be transported in the same time, and a depletion of building blocks next to the crystal results.

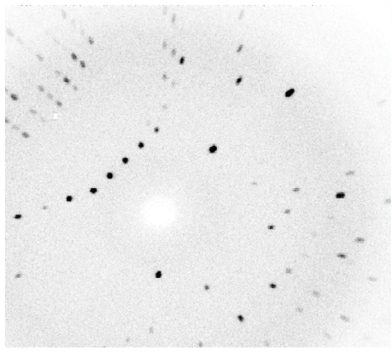
[4] The quality of the crystal, in terms of regular crystal structures and elimination of impurities is essential for the identified purposes.

[5] This is about wave theory. In short - and layman's terms – one can consider the effect similar to when incoming and outgoing water waves against a wall will act on the same water, creating interference, as the reflected waves will be acting on the same water volume as already being influenced by the incoming waves. In one extreme case of 100% synergistic effect, the waves become 'double tall' if the in and outgoing are in 'phase'. The other, that they are exactly inversed – a wave trough (valley) from one side coincides with a wave top from the other: In this case they neutralize each other. Light, which consists of electromagnetic waves – acts in the same manner, even though the interferometer readings are only partly explained by this example. But the end effect is that different gradient-phenomena in fluids, such as concentration-, temperature-, and density gradients can be visualized by Interferometry, even if invisible to the naked eye. The effect is created by the 'out-of-phase' of two light beams created by a special mirror set-up.

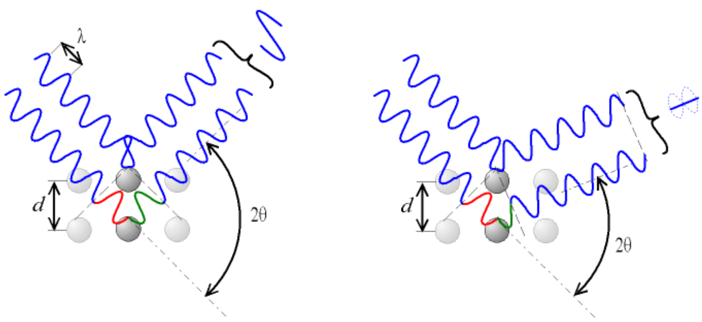
new sub-experiment can be started. After a long ground preparatory activity mainly carried out in the laboratory models of PCDF to identity the phase diagram of candidate proteins, Glucose Isomerase was selected. In addition, Glucose Isomerase labelled with a ruthenium-based fluorescent dye was used as impurity for the observation of impurity depletion zones.
At the end of these in total 20 runs, the last formed crystal were not any more dissolved but stored for post-flight analysis in Earth. On 22 July 2009 the PCDF Processing unit with it contents has been returned to Earth for that purpose. PCDF was sent to the ISS on 15 March 2009, onboard Shuttle mission STS-119.

So what is it all good for?
Well, we mentioned two areas where knowledge of crystal structure is of importance, so let us describe those here.

The first aspect, crystallography, has been a crucial tool for exploring structure of crystals since the early time. You send an X-ray beam towards and through the crystal, utilising the same principles as for a chest X-ray, at least regarding the recording method. In chest X-rays, the penetration of the tissue after hardness of radiation resistance is utilised to create a film with varying degrees of colouring. Soft matter lets the rays go right through, hard matter brakes them. In the chest X-ray the result is more or less exposure of the film, leaving overexposed parts light, and less exposed parts darker. But X-rays are also reflected, when they hit 'obstacles', and in crystallography in particular the reflection pattern is of high importance. Being 'shot at' with X-rays from one direction the crystal is rotated slowly in front of the beam, and as a result one can get a 3D impression of the reflection pattern.
The effect is that of a collision of a wave with solid matter - the X-ray is an electromagnetic wave and the 'solid matter' is here the atoms - and a scattering pattern is created, as seen in the wave-figure above, an illustration from Wikipedia.
Bragg's law deals with that phenomenon, and the Braggs (father and son) were the first to determine the structure of a crystal in 1915 (that of salt of NaCl), for which they received the Nobel prize.

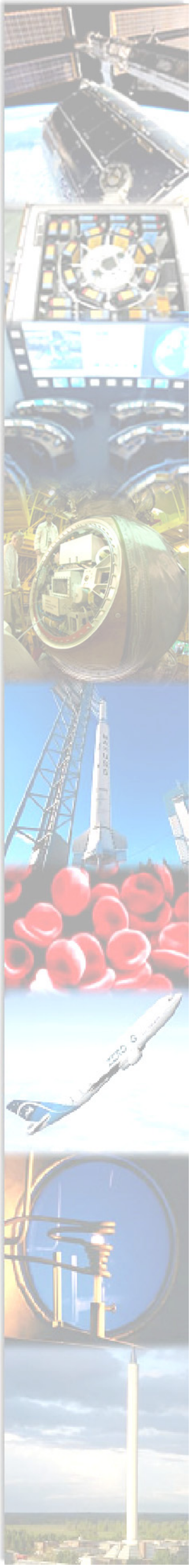


Crystallogram (dots are atoms) of the muscle oxygen transporting protein, Myoglobin. Compare to the 'cartoon' version of the same molecule opposite.
Courtesy of the Thornton Group:

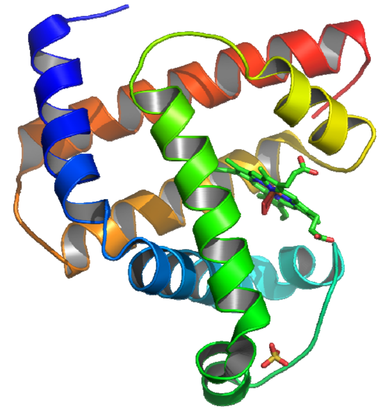


On the wave-figure left, disregard the letters and arrows, even though you need to notice the difference in the angle '2 θ' but focus on the waves. In the left of the figure, top right aspect, you see an enlarged wave form resulting, compared to the individual waves; in the right figure you see only a line resulting in the top right aspect of the figure.
In the left example, where angle indicated is a right angle or 90 degrees, the two reflected waves are 'in phase' (tops are over tops in each wave) resulting in a doubling of the amplitude[6]. In the right figure they are 'out of phase' - a trough opposes a top, and the result is that the waves cancel each other out. The reflected

[6] Amplitude of a wave is the height or the vertical dimension. Wave length is the distance between two consecutive tops or troughs in the propagation direction.



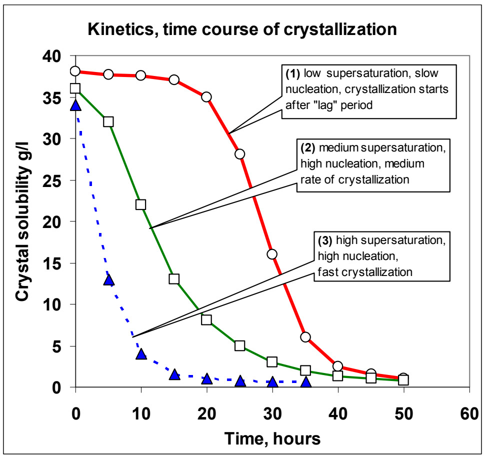
waves and a lot of additional details are registered, whereby one can finally get an image of the crystal structure by applying basic geometry. The resulting X-ray image (black & white) is indicated above.



'Cartoon' image of the muscle oxygen transporter, Myoglobin. Take a careful look: The very limited active site is the disk-like structure between the yellow and the green spiral. Courtesy of the Thornton Group:

Management of administration of medicine:

The overwhelming amount of medicine today is taken orally - as a tablet that gets dissolved in the gut, or as an injection[7], when the gut needs to be avoided. The medication is supposed to survive the route taken, in order to arrive at the target. Obviously that is like 'shooting sparrows with cannons' as the circulation spreads it evenly in the body after some time, but it works for a bulk of the medicines. If the drug in question is susceptible to the acid or enzymes in the stomach, one encapsulates the active matter in a digestible capsule, that will survive long enough not to have the active component damaged. But in modern medicine there is an increasing interest in steering the medicine administration even further - all the way to the 'target cells' , such that the medicine is delivered optimally, only at the 'end station''. That expression is actually quite appropriate, as the idea is that a certain carrier molecule, which binds and holds the active component, should travel through our organism until it finds the exact suitable 'parking slot' so to speak – a molecular structure – a 'receptor' - probably on the surface of the target cell, which is the only one the carrier molecule will bind to. There after, the carrier, which in that binding process often undergoes a structural change, will give off the medicine component that is bound to it. Check the colored figure of the Myoglobin molecule above to see where the active component could be bound in carrier structure.



Crystal forming: Typical dependence on degree of super-saturation. Courtesy of :
Kalevi Visuri, Macrocrystals Oy, Finland.

This long story is necessary to indicate the importance of understanding the three-dimensional structure of potential carrier molecules – the proteins - as accurately as possible, in order to be able to create systems that would do what we just described.

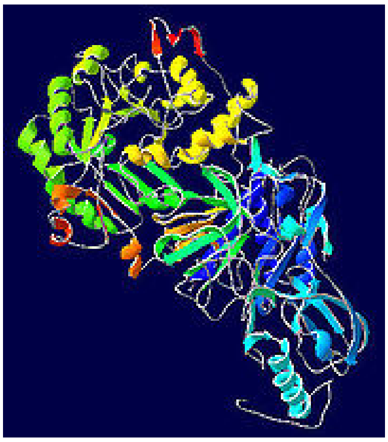
Crystals in industrial service.

The third and final aspect mentioned is purification of proteins[8], which is important for multiple reasons. Industrial enzymes are a result of large-scale protein purification. Today crystallisation is far the most economical method to produce proteins of high purity for industrial use. As a spin-off from that development, knowledge now allows to produce crystals of a size and purity optimal for research via crystallography.

[7] Or by inhalation or as a nose spray. Inhaling a spray brings the drug in immediate contact with a very large surface area of blood in the long capillaries, having only a thin membrane to cross. But also for effect on the lung tissue itself this method is used. Spray via the nose likewise takes the short-cut to the blood via the thin mucosal membrane in the nasal area.

[8] A protein is a molecule composed of one or more of the 20 known amino acids. Amino acids are acids that contain an amino group (NH_2) and in the other end a -COOH group

To give an impression of what we talk about, one of the first proteins to be isolated was urease, shown left. Despite the obvious complexity, only certain, very focused locations of the molecule participate in binding/transport/release of effector-molecules and/or when they function as enzymes, which this protein has as its job, they participate in making a certain process go faster and more efficiently. The code word is *activation energy* – the energy needed to start a certain process, as also mentioned earlier under crystallisation. Enzymes generally reduce the amount of energy needed.



The urease molecule from the Helicobacter Pylori bacteria.Courtesy of : http://nl.wikipedia.org/wiki/Bestand:Urease-1E9Z.jpg

By looking at such a complex molecule, although we normally get around that pretty easily by using its name, *urease*[9]*,* the spontaneous feeling is that it cannot be easy to isolate that, in case many other, likewise but different proteins are present in the same solution. And that is indeed so: In order to 'purify' which basically means to 'isolate from other' proteins, tricks have to played on it, utilizing aspects such as protein size, binding affinity, and general physical or chemical characteristics the protein in question may have.

Protein purification on large scale, among others in the sugar industry, is done via crystallisation in large tanks. There is significant knowledge there regarding which reagents to use and which effect they have, and which effect different grades of super-saturation has on the crystal forming. It is known that high grade super-saturation creates a large number of small crystals over a short time period. If large and few crystals are needed, that takes longer time in a lower grade super-saturation. The specific 'right' reagent, for glucose isomerase is magnesium sulfate, $MgSO_4$, and other sulfates or phosphates are needed by other proteins. These are important regulators of the crystallisation process and increasing concentration of the reagent compound forces the process in the direction of more crystallisation, also called 'salting out' the protein of the solution. They have the effect that the protein of interest crystallizes without other, different crystals forming at the same time, and this makes the following steps of the purification very easy in principle.

Glucose isomerase crystals formed in a reagent of $MgSO_4$. in a different milieu than from same material on the first image in this article. Courtesy of Kalevi Visuri, Macrocrystals Oy, Finland.

One can assume that natural forming of crystals in hydrothermal (geysers and related geological structures) areas has been brought about by the same mechanisms. Whereas solubility of the glucose isomerase is achieved around 37 degrees C, hard minerals require very high temperatures and high pressure to be formed, but in principle governed by similar processes, where crystals start forming at the point where temperature, pH and environmental concentration of the substrate is optimal for that process to start

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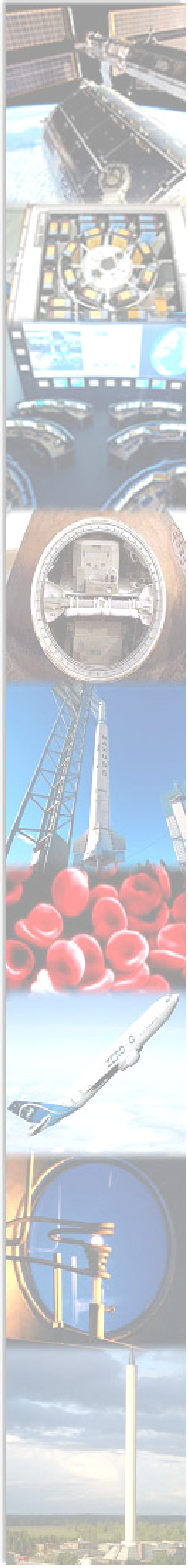


[9] - the essential compound for breaking down the biologically very abundant urea to carbon dioxide and ammonia, NH_3,

EXPOSE-R - EXPOSURE OF BIOLOGICAL MATERIAL TO OPEN SPACE.

The EXPOSE-R facility is an external facility that now is located outside of the Zvezda Service Module of ISS, after being transported to the ISS on Progress flight 31P at the end of 2008. It houses nine experiments covering the areas of photochemistry, photobiology and astrobiology, requiring exposure to the open space environment.
On the external platform of Columbus, the European technology Exposure Facility or EuTEF, described in Newsletter February 2008, EXPOSE-E has a different science sample configuration than EXPOSE-R but nevertheless some overlap.

EXPOSE-R will remain onboard ISS in open Space conditions at least until mid 2010, when the ISS crew will retrieve the experiment trays with the exobiology samples. These will in turn be returned to Earth for detailed scientific analysis.

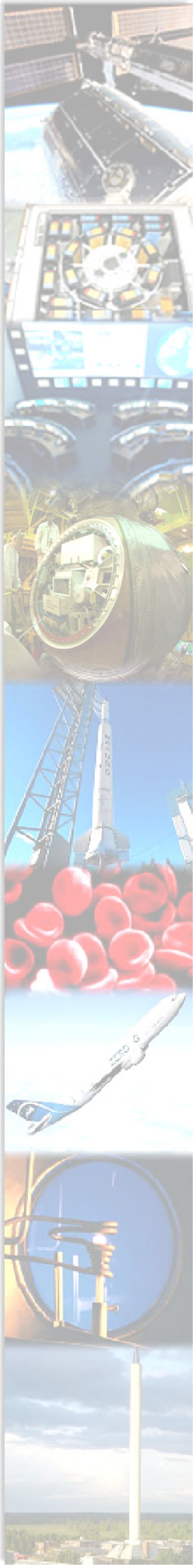
The further outlook is, that ESA later with high likelihood will deploy a further set of samples in the facility, a payload that will come out of the 2009 International Life Sciences Research Announcement solicitation, still ongoing.

Amino:

The specific title of this experiment package is Photochemical Processing of Amino Acids in Earth Orbit. The experiment package is investigating how well certain amino acids, as are the basic building stones of all living organisms resist and survive the conditions of the Space environment, in particular exposure to ultraviolet radiation, UV-C that is lethal for living matter. In addition other compounds are exposed to the UV in the AMINO experiment. Based on the findings, another building-stone in understanding the evolution, which has led to the origin of life on Earth and the possibility of the emergence of life elsewhere is investigated.
In continuation of experiments onboard the FOTON-M2 and the FOTON-M3 missions in 2005 and 2007, survivability of plant seeds in open Space is examined in EXPOSE-R as well.

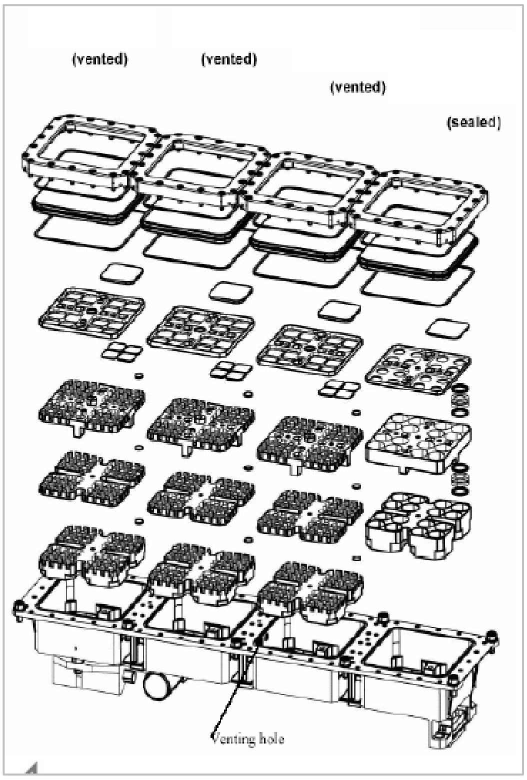
Organic:

This experiment examines the evolution of organic matter in Space on organic molecules, similar to those organic molecules that could be travelling with meteorites. In particular so-called Polycyclic aromatic hydrocarbons (PAHs) and fullerenes will be measured. PAHs represent an abundant component of interstellar and circumstellar dust



(... around stars, ed.) and have been identified in planetary environments such as meteorites.

Six experiments coordinated:



This suite of 6 separate experiments, that is coordinated under a large international research consortium, will investigate:

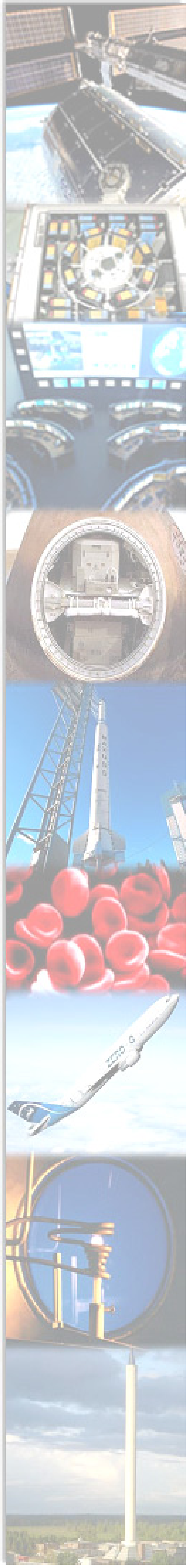
- ENDO: the survivability of Antarctic organisms in the light of UV-B and UV-C exposure. The experiment aims at assessing the likelihood that such organisms may have survived the Martian environment. More specifically the experiment will examine isolated cells of the cyano bacterium *Chroococcidiopsis*, a UV and desiccation resistant micro-organism. Special focus is on conservation of its photosynthetic ability of this organism, after having been embedded in porous rock, as one of the potential ways it could have been transferred through open Space. A conservation of that ability would be a crucial sign of survival potential

- OSMO: This experiment aims to understand the response of microbes to the vacuum of space and to solar radiation. In salty environments of high osmotic pressure, in this case *Synechococcus* (a cyanobacterium) and *Halorubrum chaoviatoris* (an archaeon). Halite salts, in which these micro-organisms live, are examined for their potential protective role of the spores' DNA.

- PHOTO: This experiment is studying the Exposure of dry DNA samples, and bacterial spores, to solar UV vacuum radiation. The samples will be exposed unprotected or in artificial meteorite materials, clays, and salt crystals. The objective is to assess the quantity and chemistry of chemical products produced.

- SUBTIL: The bacterium *Bacillus subtilis* will be exposed to Space conditions. This experiment will study the mutational pattern and repair mechanisms, both in 'wild type' and *Bacillus subtilis* with certain essential deficiencies inserted in the DNA material, in particular the ability to repair radiation damages to the DNA. This mechanism seems to be the crucial capacity of these survivors that can withstand orders of magnitude of radiation of what other living organisms can tolerate.

- PUR: Responses of virus type Phage T7 and its RNA material to Space UV radiation conditions. A phage is a bacterial virus. The particular focus here is to investigate the capacity of these organisms to function as so-called biological dosimeters for measuring UV dose in the space environment.



- SPORES: The main objective of this experiment is to study the survival of spores of bacteria (*Bacillus subtilis*), fungi (*Trichoderma koningii*) and ferns (*Athyrium filix-femina*, *Dryopteris filix-mas*) on a simulated space journey via meteorites. This includes the study of their resistance against space conditions, i.e. solar UV, vacuum and cosmic radiation, as well as the degree of protection by meteorite material. In addition, the experiment includes the dosimetry package R3DR for on-line measurement of UV and cosmic radiation and transmission by telemetry.

- IBMP: This experiment flown by Institute of Biomedical Problems, Moscow, Russia, consists of diverse samples to be exposed to the Space conditions: Seeds, spores from lower plants, etc.

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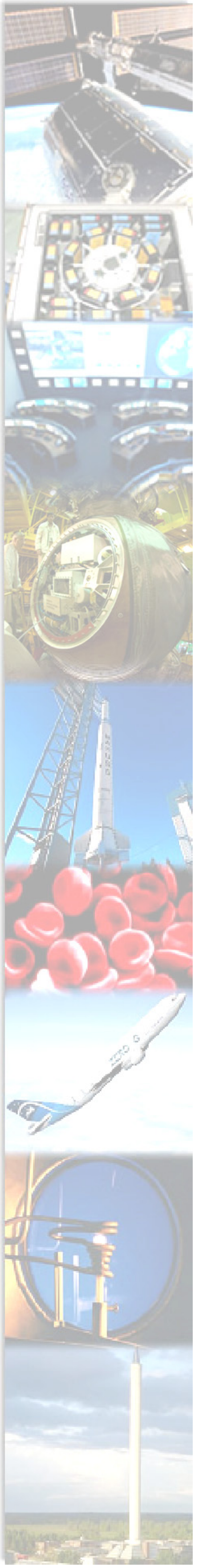


ESA Astronaut Frank de Winne with the MEEMM headcap on, in front of the Neurospat equipment. Canadian (CSA) Astronaut Bob Thirsk is injecting contact gel into the EEG electrodes with a syringe. Courtesy of NASA

NEUROSPAT – First experiment to use ESA's unique Multi-Electrode Electro Encephalograph.

THE FIRST TOPICAL TEAM IN LIFE SCIENCES WAS STARTED OFF IN NEUROSCIENCES. TOPICAL TEAMS ARE PUT TOGETHER BY ESA HUMAN SPACEFLIGHT IN ORDER TO PAVE THE WAY FOR FUTURE SCIENCE AND RELATED TECHNOLOGY. THIS TEAM WAS COMPOSED OF A MULTIDISCIPLINARY GROUP OF SPECIALISTS IN NEUROLOGY AND NEUROLOGICAL METHODS, AND THE TASK WAS TO DEFINE TECHNIQUES AND DEVICES FOR FUTURE USE ONBOARD THE ISS. THE TARGET WAS TO HAVE THAT AS A PART OF THE EUROPEAN PHYSIOLOGY MODULES OR EPM WHICH WOULD BE THE NAME OF THE FACILITY FOR RESEARCH INTO HUMAN PHYSIOLOGY IN ESA'S SPACE STATION MODULE, COLUMBUS. MANUFACTURING OF THE SELECTED INSTRUMENT TECHNOLOGY WAS FINALLY INITIATED IN 2001 AND COMPLETED WITH FLIGHT READINESS TESTING IN 2005.

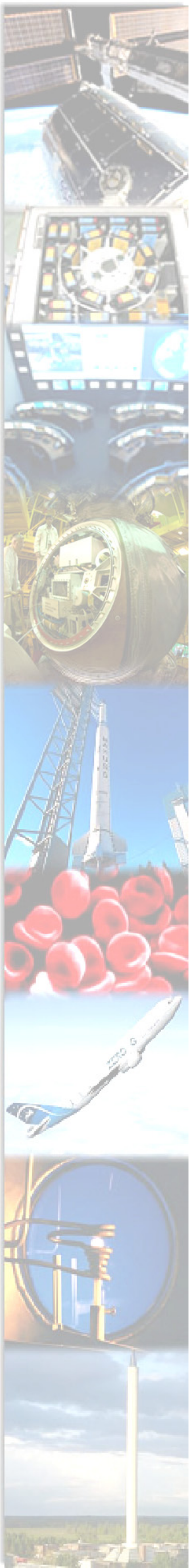
Now the equipment is ready for the first larger experiment, unrelated to the initial Topical Team, but profiting from their ambitious work back then.
Since the launch in February 2008, Columbus became the home for a number of experiments, using mostly the ESA provided facilities, Biolab, European Drawer Rack (EDR), Fluid Science Lab (FSL) and now latest the European Physiology Modules (EPM).

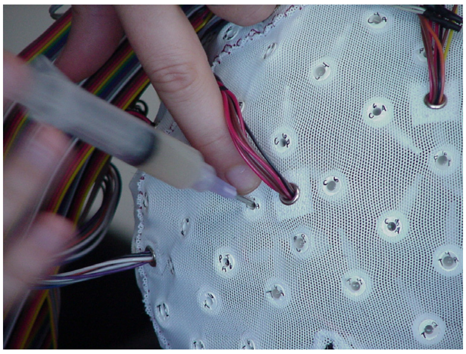
The Neurosciences Topical Team (NSTT) started its work in 1996, and after one year, suggestions for which equipment to build was on the table. These projects obviously had a rather futuristic character, and the equipment asked for was not to any extent flyable in the form of commercially available versions. In addition this would in many areas be 'new technology'. Apart from the prohibitive mass and volume of commercially available devices, also the technology had to be upgraded to make such experiments possible in Space.

Now the MEEMM[10] – short-name for this EEG device - is to demonstrate its performance although not in this full potential. This article is describing the first experiment that this unique piece of equipment is going to support, the NEUROSPAT experiment. MEEMM rightly is considered state-of-the-art, top perfiemance in that equipment field, and is expected to have a bright commercial future.

EEG and other techniques

[10] MEEMM: Multi-Electrode Electroncephalogram Monitoring Module





In order to monitor the activity of the brain, Electroencephalography (EEG) is still one of the best ways to go. The NSTT knew that from the beginning, although there were many contenders to the winning position, for qualifying for being included in the EPM facility. And there were many challenges, one being the time it takes to prepare the experiment onboard. This has earlier been another prohibitive factor for EEG application in particular, considering the strict limitation on so-called crew time. Another is crew comfort, or rather, reducing crew-discomfort.

In its full application, all available 128 electrodes in the cap must be manually filled with gel and contact parameters checked, as seen in the close up here. MEEMM has a novel system for 'geographical' electrode location and identification, in addition to automated contact check. In this aspect MEEMM is vastly superior to all other existing systems.

EEG has been used onboard orbiting spacecraft and stations since decades, as it allows stydying what is not otherwise easily revealed, namely the specific electrical activity in the brain of a person in different context. Some of the aspects investigated are listed below:

- Cognition[11], focus and concentration
- Memory functions
- Sleep
- Stress
- Programming and support of performance of motor tasks (i.e. muscle action)
- Responses to feed back from peripheral nerve sensors
- Interpretation of visual inputs
- Reconstruction of geometrical shapes
- etc.

Most of these and many more are essential for understanding what weightlessness does to the human brain, if at all anything. Apart from the circulatory aspects (the way blood flow changes when there is no gravity), where early Space researchers did have certain worries over what would happen (nothing much health threatening actually seems to happen in that area). The functioning of the nervous system was another focus of interest

ESA Astronaut Frank de Winne with the NEUROSPAT Virtual Reality equipment. Courtesy of NASA

[11] The mental process of knowing, including aspects such as awareness, perception, reasoning, and judgment. Ref. http://www.thefreedictionary.com

and concern, not the least in order to investigate if pilots returning the Shuttle from Space would have unhampered function of all necessary skills. In that context in particular the effect of re-entering the gravity field after one or two weeks in weightlessness was in focus, to register if it would have any negative effect on the performance, which in turn could would create hazards.

One of the more exciting applications of the MEEMM is made possible by the rapid development over the last 5-7 years of Virtual Reality environments (an unavoidable effect coming via the computer game industry), which we have also seen utilised in the 3-D SPACE experiment, described in the February Newsletter this year. Virtual Reality offers almost unlimited opportunities for comparing the brain response via EEG activity recording to the visual and auditive inputs given by the VR system, thereby demonstrating how the brain reacts to diverse visual stimuli.

"What we see, we try to understand!" And if we have a certain experimental instruction, which could be a question like: "Determine if the sides in the box you see on the computer screen are equally long", we will try to perform that task. In this case we automatically use relevant parts of the brain to answer the question, we compare. In the process, we may focus, look and maybe look again, and also the time it takes to arrive at an answer, reveals if we are performing the task as easily in Space as on Earth. Longer time may indicate that we found it less easy to arrive at an acceptable certainty level for us to answer the question clearly with a "yes" or a "no". And this judgement, differentiation and the decision process is what is thought to take place in the so-called pre-frontal area of the brain, that is the focus of the NEUROSPAT experiment.

A real VR situation would present the subject with a full-field-of-view scene (see above image) that could be stationary or might be moving. By covering the entire field of view, a 'Virtual Visual Reality' is created, and that offers a host of potentials for utilising what we with one word can call 'illusions'. The scenarios used in the NEUROSPAT experiment are:

- Visuo-motor tracking
- Perception of self orientation
- 3D navigation, and
- Discrimination of the orientation of objects

In line with the example given above, the qualities in the observation, judgement and decision processes examined are:

- Perception
- Attention
- Memory function
- Decision making and
- Action.

Similar techniques are now being observed in clinical examination on the ground in what is called 'functional MRI', in which the patient is given visual or mental objective, by looking at an image of some kind or being asked to think of particular things, whilst being positioned in the voluminous MRI facility in a hospital. The newest techniques in that field make it possible to 'see' the brain reaction to such situations[12] - a valuable tool

[12] Contrary to EEG, MRI (Magnetic Resonance Imaging) measures both certain clinical reactions, indicating metabolic processes (energy consumption) and changes in perfusion (more or less blood flowing in the observed region). EEG measures the electrical potentials of the 'working' nervous network.

in furthering understanding of mental brain function. The MRI equipment normally represents a mass of several tonnes, pulls a very large amount of current and in addition works with very strong magnetic fields – all things that make flying such a device prohibitive.

How easily do we cope?

At first glance it may not seem evident how important these technical EEG details are, but if the setup is not sophisticated enough, we will not have any indication of the relative load, as the brain always tries to cope. So it is the tricky business finding out HOW much the load is.
A bit similar to the CPU[13] in a computer, mostly one does not see how much capacity is left, as the speed with which it processes data seems unchanged, until a certain point. But when we look at the CPU load figure (given in %), we get an impression of if it is close to saturation (100**%)** or if there is plenty left. We use that as an assessment of how much more load we can expect to put on the computer.
The combination of MEEMM and Virtual Reality is hoped to give an impression of what we could call 'the human CPU load' in different, typical ISS situations.

Earlier experiments of this kind mostly relied on the feedback via diverse reaction actions via joystick, reaction time or the like, whereas the simultaneous recording of the brain activity together with the stimulus and reaction patterns gives the entire package. These recordings are unique in terms of what has earlier been done in Space, and are hoped to give better understanding of how the brain adapts to the absence of gravity and how much stress we are talking about.
Stress is postulated by some to be a significant factor for humans in Space. Others allocate that much less importance, assuming that operating in Space for the brain is almost representing the same load as on Earth in 1-g. NEUROSPAT may make us wiser!

The scenarios for NEUROSPAT are such chosen, as to try to get the brain reveal if it is 'difficult' to handle the task at hand or if it is easy. In order to find that out, one can on one side increase the difficulty regarding the specific task, and on the other measure the five quality parameters that have been indicated above.

The EEG recordings during these tasks allow comparing the problem solving reality in Space to what has been recorded on Earth. Changes is pattern between the situations being what the scientists look for, as an indication of how the system registers the difficulty.

In particular the part of the brain that is involved in complex cognitive activities, actions and decision making, the part that executes decisions and makes comparisons of all kinds and performs decisions, is considered. Those questions form the centrepiece of the scientific investigation of the NEUROSPAT experiment, and this activity is located at the very frontal part of the brain, the so-called pre-frontal area.

Status now is that ESA astronaut Frank de Winne has completed the first experiment session. Four more sessions with different test subjects are foreseen in the coming time.

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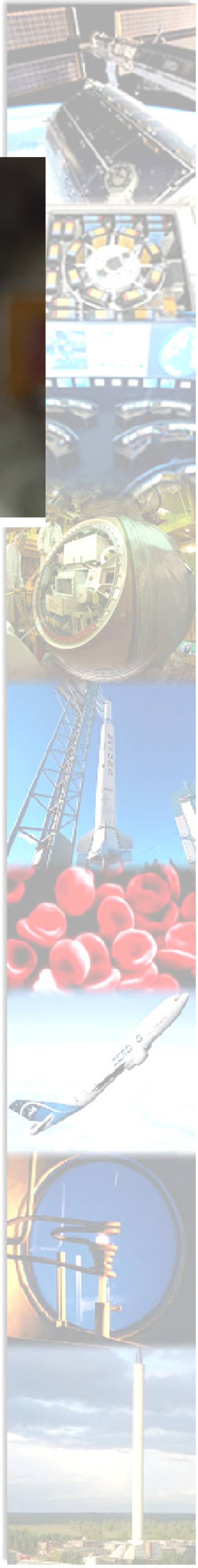
[c] Central Processing Unit of a computer – the computer internal processes controller or 'brain'



FLUID PHYSICS:

WHEN AN ENTIRE FUEL TANK BEHAVES LIKE A CAPILLARY … OR … THE MAGIC OF A WATER DROP

ESA astronaut Pedro Duque seen through a water drop onboard the International Space Station. Courtesy NASA

This article gives an overview of ESA's research in the area Fluid Physics, after first having described the forces that influence fluid, in particular what governs fluid volumes when gravity is absent. Nature has created solutions tailored to a myriad of situations over millions of years of evolution, but the basic forces of course remain universal.

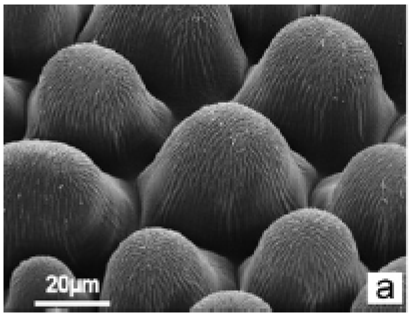
When in Space, fluid handling becomes tricky, as the very dominant gravitational force on Earth has no impact in orbiting systems. Instead the 'small forces' as we often deal with here, are dominant, and as a consequence different fluid control strategies need to be developed. This was known already at the beginning of the Space Age, but we are still learning lessons in the large variety of situations where the small forces govern large and small volumes of hot or cold fluids in Space.

Basics - The water drop

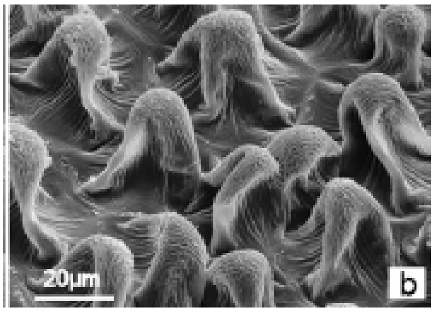
Here in a 'cradle', a water drop is caught. The view is occasionally stunning but we also wonder how this 'wonder' is brought about. The physical forces that work in a liquid drop – called cohesion forces - are central to so much of our life and of the physical sciences being performed on diverse Space vehicles.

The handy aspect of forces is, that, physically, any matter responds to the force it is exposed to at any time, so also when forces suddenly withdraw. This is particularly evident in liquids, as even small changes in forces will change the appearance of a fluid volume.With the example here, this – overly large - drop stays intact on top of the petals of the flower, as the mass of the water drop itself is too small to force it to disintegrate or flow out. The surface characteristics of the petals has the effect that the water surface is not impaired. The water volume is conserved as a large drop as it has settled into the space between the petals, in this manner resting on a supportive ring. This arrangement allows the 'too large' drop to remain intact, because the supporting surface thereby becomes larger, and the pressure per petal against the drop therefore relatively smaller. This is a balance which appears critical in many contexts.

Drops on the side of the petals – of a 'more normal' size - demonstrate the water repelling surface the petals are equipped with, but also at the same time has the ability to hold drops under a certain size. As an effect there is no 'mixing' of the petals and the water - the drop remains intact. A Scanning Electron Microscope (SEM) Image of a Dahlie petal can be seen to the right here.



Scanning Electronic Micrographs (SEM) of the upper side of a flower leaf of a Dahlia petal leaf. The structure in figure (a) may surprise the reader, as it would not look as water repellent as it is in reality, but it is here the specific dimensions and structure that in particular are effective against the water drops that land on it. Due to the specific surface tension in water, this particular structure ensures that water is rolling off or at the worst attaches very loosely. And water penetration is abolished by the waxy surface characteristic. When the petal loose water tension, as when they wither, they look as in figure (b). In this situation rain water and dew is not kept away, but will bind to the material and gradually stimulate the break down. Courtesy of Kerstin Koch et al.

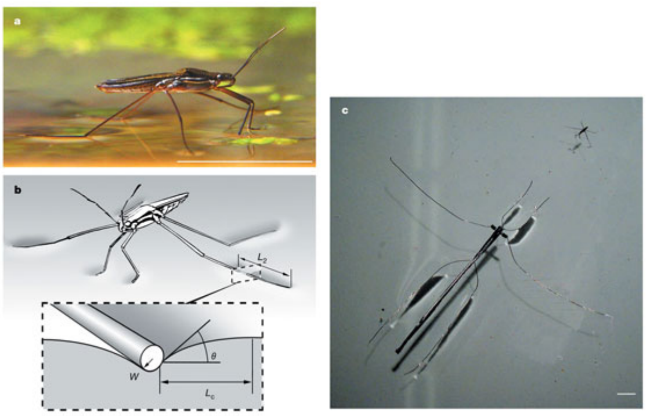


Fluid in contact with solid matter

Take as another example, water drops, which rest on top of your car, before and after it has been through a washing lane, having been finished off with a layer of wax.

Before the wash, drops may be not well defined, whilst with the wax layer, tiny well defined droplets can be seen all over. A newly waxed car repels water much more efficiently – the surface has been made optimally even (and therefore shiny and dirt repelling).The surface of a not washed and waxed car seen under microscope, would demonstrate a 'moon landscape' of an uneven surface with microscopic scratches and bumps, and above all, dirt, which impacts the drop-forming negatively. Car wax, which repels water – i.e. being 'hydrophobic' - is often based on plant-wax, and comes in a form dissolved in solvents that allow this extremely fine grained material - one of the special qualities of wax - to even out the 'defects' thereby minimising what is called adhesion tension, the forces involved when fluid is in contact with a solid surface.

Put popularly, when adhesion forces are high, water 'sticks' – the surface is 'wetting' and in that situation a water drop flattens on the surface. Adhesion forces are high when a large area of the water drop is in firm contact with the solid surface, and low when the opposite is the case. If wax is a good example on a 'non-wetting' surface, a soft contact lens with a drop of water on it is a good example of a 'super-wetting' surface.

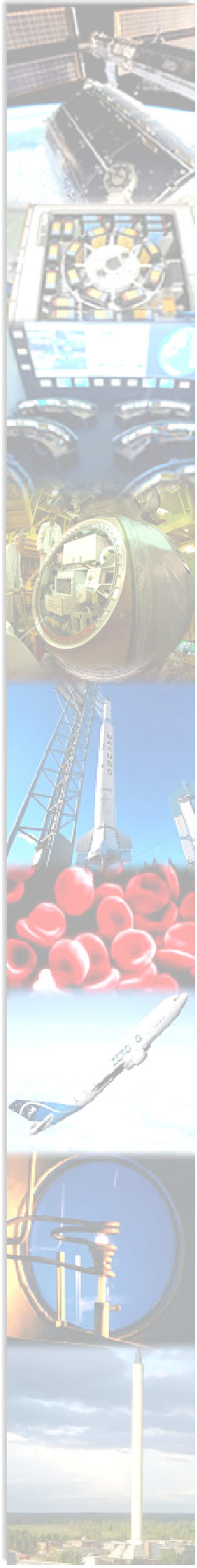


Water striders. Courtesy of Hu et al. in Nature 2003

Water striders – Nature's 'trial and error' has given result

Another example of the effect of surface tensile forces of water is the case of the water strider sitting and moving on top of a water surface.

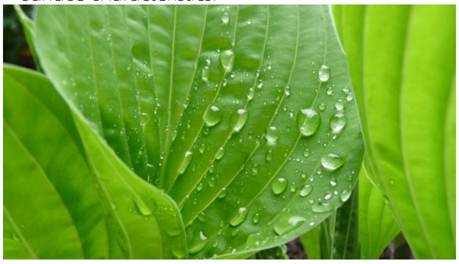
Like the hydrophobic leaves of the Lotus flower, see next page, the legs of the water strider are of such a nature that they do not 'wet', meaning effectively that the forces keeping the leg of the insect together with the water are too small to



stop the leg 'skating' over the water surface.

The drawing insert bottom left in the figure from Hu et al. in Nature 2003 indicates that the curvature angle created by the weight of the leg of the strider need to be under a certain size in order for the surface not to break. The basic rule for an object to float in water is that the mass of the object needs to be lower than the mass of the water it displaces. That amount of water can here be calculated as the volume between the original water surface and that of the depression curve the insect leg forms. But if we in addition want the surface to stay intact, the pre-conditions are 1) that the insect leg is 'not wetting' and 2) that the pressure that support surface, e.g. leg of an insect, imposes on the water surface, is smaller than the water-coherence force created by the surface tension. Surface tension is a sum of the cohesive energy per molecule, but on a surface, it will only be half. Surface tension in oil is around 20 dynes/cm, in water around 70 and in mercury around 500. Surface tension always tries to form the smallest volume surface.

Two "vertical" leaves, below from Hosta and above from the Lotus. Water drops are held below and let go above, due to the particular surface characteristics.



FLUID HANDLING IN SPACE

So why do we discuss this in relation to space? Well, we have two aspects that immediately become essential, and they are both related to gravity:

- The physical equations that can be used to describe different aspects of a water drop, such as size and curvature, deduct that gravity plays an overly dominant role.
- Secondly, as this is the case, microgravity must offer opportunities to study what happens to fluid systems when gravity is gone.

And why is that important?

One good reason is, that as soon as we are dealing with fluids in Space, which we cannot avoid (drinking water and water for hygiene, rocket fuels, other applied fluids), we need to know if their behaviour is significantly different from what we know on Earth. And this certainly is the case, so research is very focused on how to control fluids in Space effectively.

As we have indicated earlier, surface characteristics in that situation and a multitude of 'smaller forces' become very important.

So let us take a look at the forces involved:

- Surface tension is what works on the surface of the droplet in contact with air. It tries to maintain a spherical shape, which is geometrically the smallest surface area. That force is independent of gravity. Surface tension - if allowed - will try to make a perfect ball out of any liquid.
- Gravity significantly influences the size and thereby the curvature on Earth - imagine the difference of the curvature of a small water drop and that of the Earth itself: we see that the drop is very curved, but only see that the Earth is curved when we look over the horizon, so a larger sphere is less curved.

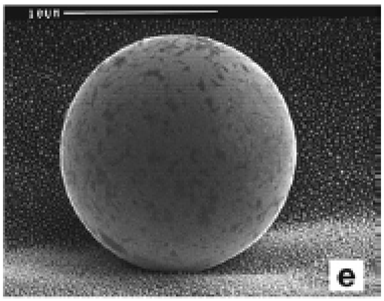
  In a very simplified version, when gravitation forces diminish, surface tension becomes relatively more important. The influence of gravity can be seen in the effect on a large drop, which, if enlarged will 'collapse' in the middle portion, but if one could make it smaller gradually, by removing water, one would see that it gradually regains a spherical shape. The balance between surface tension and

normal Earth gravity – where we start obtaining a perfect sphere - is a droplet diameter of around 2 mm on a hydrophobic surface. When it becomes smaller than that on Earth, surface tension gradually becomes more important for the fluid dynamics than gravity, and as an effect we see the surface in a straw in a glass of water rise to a level over the water level in the glass.

Influence of surface characteristics and gravity.
Animation photo courtesy of William Thielicke

- Characteristics of the solid surface

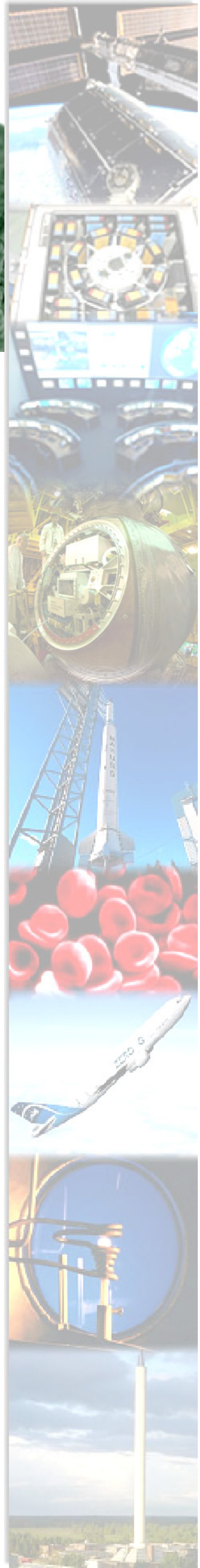
Hydrophobic surfaces with the so-called 'Lotus Effect' – or self-cleaning surfaces – in general have a structure and texture that on one side has contact with a very limited area of the water drop, and on the other, as an effect of the first, either traps air between the contact points or provides a 100% complete repelling effect. The two images of plant leaves earlier are examples of different strategies. Hydrophobicity has the effect that 1) the water drop does not 'stick' and therefore remains intact as a sphere, and 2) as an effect of 1) will tend to move with gravity as if there were no friction. For a short video of this fascinating effect, click above on 'Lotus Effect'. The animation has been produced based on software modules where values have been entered for weight, friction, and bounciness, paired with the effect of gravity on a sloping surface. The appearance of the surface is quite correctly shown, but the proportions between water drops and surface details are magnified – those have to be as indicated in the small Scanning Electron Microscope image inserted as 'fig e' to the left in this section. That is an image of a perfect tiny water drop on a Lotus leaf, and the theory seems to be correct, so far, in assuming that the drop rolls, due to a very limited water area in contact with the 'studs' on the leave surface, helped by air trapped between the studs and the water surface. We are fooled, by the - physically incorrect - persuasive animation, which nevertheless is impressive.



Courtesy of Kerstin Koch et al.

ESA's Fluid Research projects

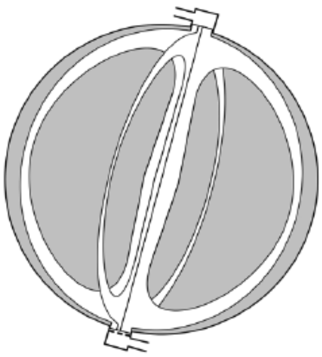
After this introduction to forces at work in fluids, the following will give a short review of some of ESA's research projects on fluid mechanics and forces. Most project utilise the fast-turn-around Parabolic Flight platform that ESA offers as preparation for and sophistication of experiment setups for the later experiment phase onboard the International Space Station, ISS.



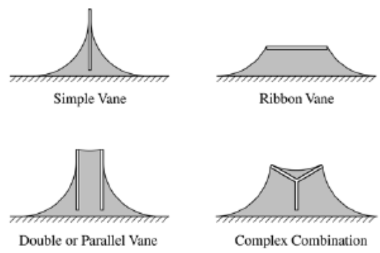
SPACECRAFT FUEL TANKS AND OTHER LARGE FLUID CONTAINERS.

Convective boiling and condensation: Local analysis and modelling of dynamics and transfers. *Coordinator: C. Colin / MAP project: 2004 -111*

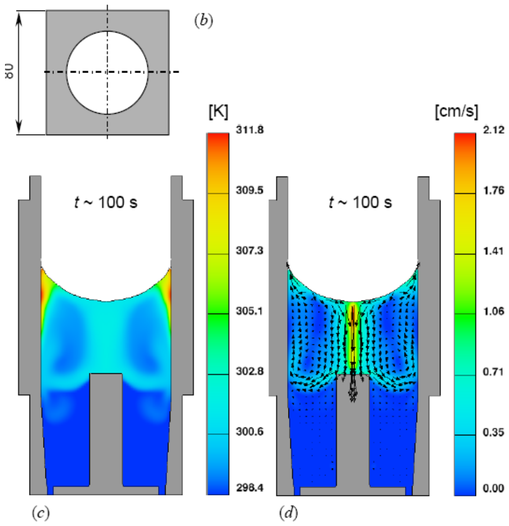
Research done by the Colin & Dreyer group, with the SOURCE experiment is focusing on surface tension forces in relation to spacecraft fuel tanks. We reported on their MASER-11 experiment in the January 2009 Newsletter.



When gravity is no longer governing, fuel in a fuel tank under Space conditions becomes less simple to control. Since the early Space days where fuel tanks were necessary, different systems – Propellant Management Devices or PMDs - have been implemented, which utilise the surface tension of the fuel for fluid control. On the figure a so-called Vane concept tank is illustrated. Fuel will accumulate in the interface angle between the 90 degree vane and the tank wall – called the 'wick'-ing effect -, and be led to the outlet port, where often a sponge-like arrangement would make sure that the outlet line would receive fuel that is gas-bubble free - capillary forces active in different settings. Tank systems with a centre post with a vane-like construction will deliver fuel to the outlet at twice the rate compared to tanks with no centre post. In addition, vanes along the sides of the tank contribute. Vane types are indicated in the figure to the right here, the lighter grey representing the fuel that gathers due to surface tension forces around the structures. In particular a concept like the 'ribbon vane' is used by this group for examination of fluid behaviour under Space conditions. An earlier quoted ESA experiment, the SOURCE experiment onboard the Sounding Rocket MASER-11 in 2008 studied also contact angle changes as an effect of temperature gradients. This experiment is the basis for next section



Vane concepts for a Flexible Demand System. Courtesy of this and opposite figure: D. E. Jaekle, Jr.



Microgravity experiment simulation: Left temperatures in the fluid after100 seconds. Right arrows indicate direction of flow and colours flow velocity. Flows moves away from the hot-sport at the wall. Courtesy of Fuhrmann et al. 2008

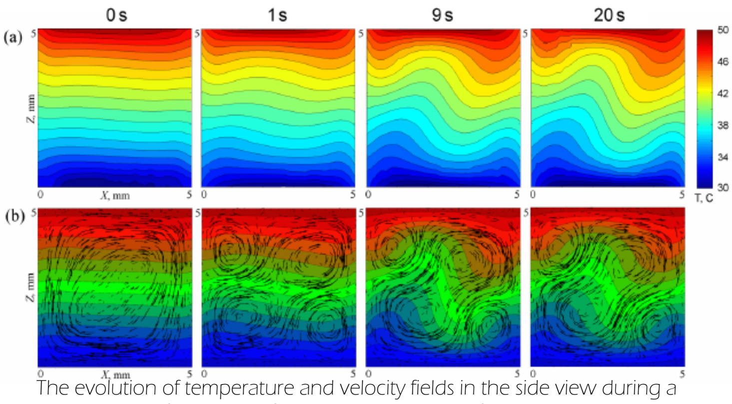
Impact of temperature differences

Besides the boiling and condensation phenomena, a group of scientists is aiming at providing basic knowledge and means to predict behaviour of cryogenic propellants of e.g. future Ariane 5 upper stages. The particular focus here, over and above the shear fluid behaviour under constant conditions, is what happens when temperature differences between the tank wall and the fluid occur, see figure the left. Temperature gradients are also strong drivers of fluid motion, in particular in a low gravity environment, and it is therefore necessary to provide capacity to describe as well as possibly predict how fuel behaves in half empty or nearly empty tanks in weightlessness.

In the figure, which is a preliminary numerical simulation result, associated to the SOURCE experiment - thus no gravity component is determining what is up and down - one interesting

conclusion is that, as fluid has a lower initial temperature than the heated walls, developing temperature gradient across the gas-liquid interface creates non-homogeneous surface tension distribution and thus drives fluid particles away from the hottest zone, creating a 'donut shaped' vortical movement 'downwards' in the figure. Note that the left aspect of the figure Is colour coded for temperature, whereas the right aspect is coded for fluid movement velocity, in cm/s.

Impact of vibration of fluid on movement and kinetic parameters (Legros et al.)
MAP project AO-2000-096



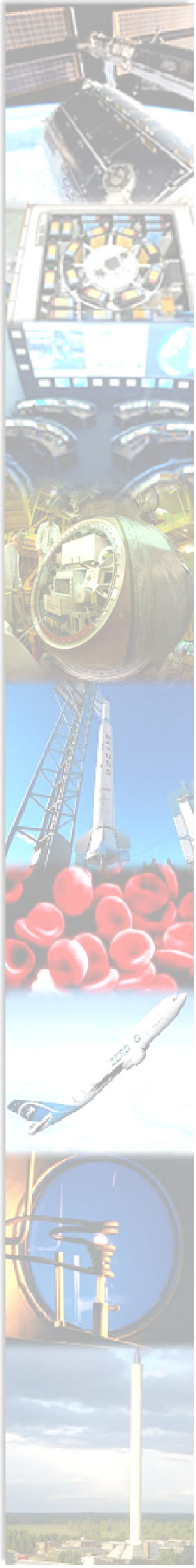
The evolution of temperature and velocity fields in the side view during a parabola with frequency of 4 Hz, and amplitude of 45 mm. Temperature difference top-bottom is 20 K,. Comparison between experiment (a) and numerical simulation (b). Courtesy of Shevtsova et al. 2008

The Shevtsova & Legros group has started out on ESA's Parabolic Flight (PF) campaigns no. 46 and 48. This experiment is in the process of preparing for the eventual ISS experiment.
The data from these PF campaigns has been extremely successful and in itself led to no less than five publications in high level reviewed journals in 2008, of which at least one landed in one off the top journals for Physics, the 'Physical Reviews Letters'.

The focus of these flights was on the phenomenon of vibration induced convection, as preparation for the IVIDIL (Influence of vibrations on diffusion in liquids) experiment on ISS. In the figure above from a microgravity period onboard an ESA PF campaign, the top panel is colour coded for temperature differences and represents the observations during the flight, whereas the numerical simulation performed by the group before the flight (lower panel) has fluid particle movements indication overlaid (black arrows). What can be seen is that over the 20 sec weightlessness created by the plane, the induced vibration to a very high degree demonstrates the perturbation as predicted in the computer model.

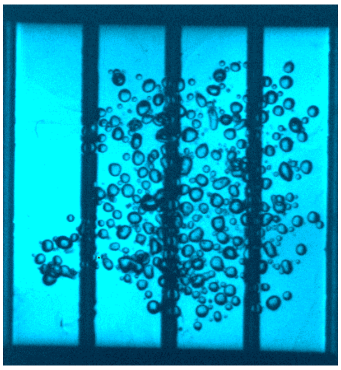

ESA astronaut Frank de Winne working the SODI hardware, located in the Microgravity Science Glovebox (MSG), during ground preparation and training, at the ESTEC ERASMUS User Centre, Noordwijk, The Netherlands.

Onboard the 50th PF campaign in May 2009, the focus was on mixing by vibrations.



Impact of an imposed electrostatic field (Coordinator Tadrist et al.)
MAP project AO-99-045

The purpose of this "ARIEL" project (or BOIL-1, one of four sub-experiment in the FluidPac, see later) is to address this not well understood mechanism responsible for the influence of an electric field on the heat transfer in single-phase convection[14], and in pool boiling[15] processes. In line with the topic of this article, the experiment seeks to explore the possibility of utilising electric fields to improve fluid management and heat transfer equipment in space.



Pool Boiling in the FluidPac onboard FOTON M2. Courtesy of

The experiment has been worked on for a long period, counting numerous PF campaigns, Drop Tower experiments as well as the FOTON M2 Satellite. The final goal is to further study the phenomena in the Fluid Science Lab onboard the ISS, from 2012 and onwards. Prior to the FOTON M2 mission, preparatory experiments had been conducted onboard the Sounding Rocket (SR) flights as experiment 'ITEL' on MASER-9 and MASER-10.

The most exciting aspect of this experiment has been, that

gas forming on heated surfaces in Space, represent a problem, as the buoyancy and convection we have in a gravity field, such as the one on Earth, does not work in Space. The vapour stays where it is formed unless other dynamic forces somehow move it away. In a fluid, this means that gas bubbles are generated and gradually would form an insulating layer between the heater and the fluid, because the fluid in contact with the heater evaporates once it has reached the boiling point.
On the FOTON M2 flight in 2005, this experiment was one of four housed by ESA's FluidPac facility and at that occasion it was demonstrated that an electrostatic field placed across the heating fluid cell, acts on the gas bubbles, somewhat similar to bouyancy. This is good news, as in the context of fluid handling and control in Space, gas bubbles forming in this manner evidently represent a serious problem - they do not detach from the heating surface as we are used to.
The coming experiments will investigate reasons for this effect which is not yet well understood. For a more detailed description of the 'ARIEL' project, please visit this location (web-link in electronic version)

Integrated MAP Projects – large-scale research
In the Fluid Science Laboratory, experiments associated to a conglomerate of several coordinated and related single projects, including the ones just mentioned are performed. Integrated projects are as well the standard approach taken by the European Commission, which funds larger endeavours under the Framework Programmes. Integrated projects are promoted in order to attempt a significant knowledge push, relative to the present research front. ESA takes this approach, when relevant.

[14] Single-phase boiling means that the gas bubbles developed contain the vapour of the fluid boiling.
[15] Boiling of a liquid whose flow results from natural convection, meaning the heating surface is submerged in a large body of stagnant liquid, where the vapour produced near the heater moved through the fluid of a closed container. Source: http://www.answers.com/topic/pool-boiling, and http://wins.engr.wisc.edu/teaching/mpfBook/node26.html

CIMEX -1 also severs as input to the following projects:

Basic Research:

- AO-2004-132: DOLFIN: Dynamics of Liquid Film/Wall Interactions
- AO-2004-072: "Mixtures": Fluid Dynamics and Physico-Chemical Effects in Heat Transfer Devices with Binary Mixtures

Microgravity Application projects (MAP):

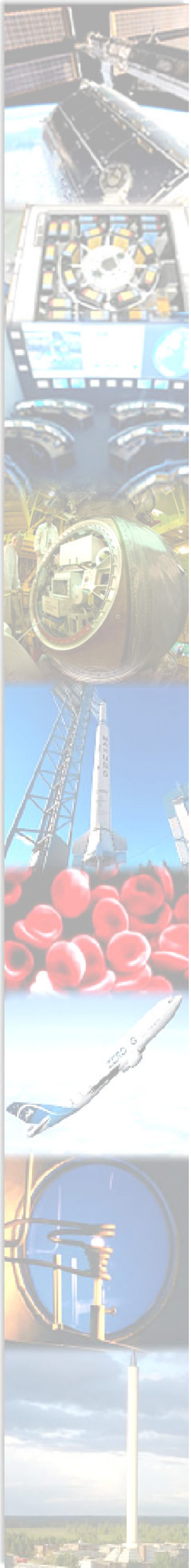
- AO-99-110: Convection and Interfacial Mass Exchange
- AO-99-045: BOILING: Boiling, Heat Transfer and Fluids Management
- AO-2004-111: CBC: Convective Boiling and Condensation
- AO-2004-096: ENCOM: Enhanced Condensers for Microgravity

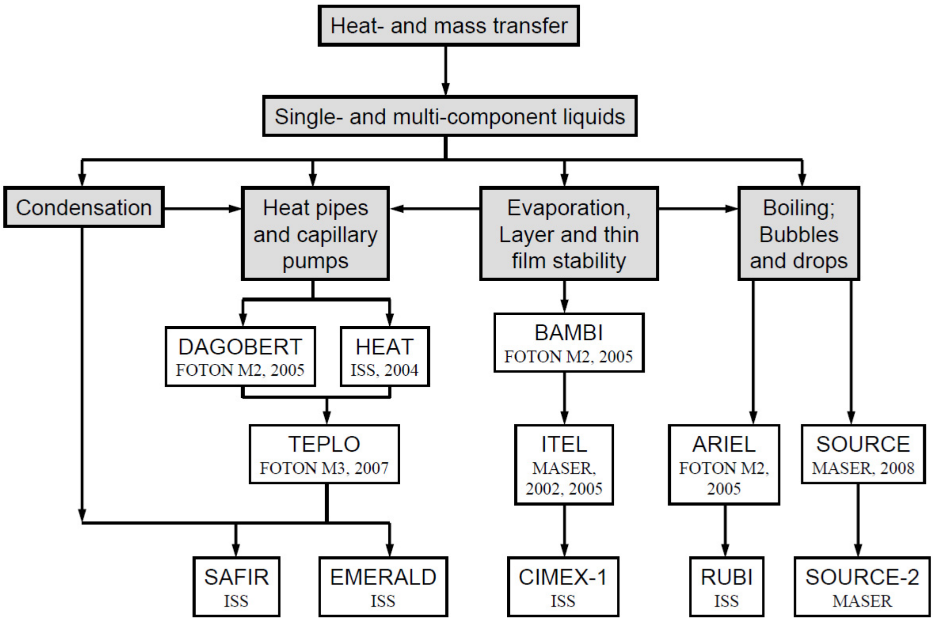
GEOFLOW, the first project on the list, is running onboard the ISS since 2008, and was described in the Newsletter February 2009. FSL EC Batch-1 covers a large number of sub-activities and part-experiments, all contributing to the broad preparation process leading up to the final ISS experiment suite. It is basically spilt over six researcher groups, namely the groups of Egbers et al.
Experiments utilise both the Parabolic Flight platform as well as Sounding Rocket Systems TEXUS, MASER and MAXUS available to ESA, with the final goal of flying the mature and focused experiment set onboard the ISS, utilising the Fluid Science Lab, FSL.

CIMEX-1 being the next heat transfer experiment onboard the ISS will probably be performed in 2011.

The overall objectives of CIMEX-1 1 include the observation of a gas-liquid interface properties during evaporation and the measurement of the temperature field in the liquid layer in the absence and presence of an inert gas. Both a pure liquid and a mixture are considered as test liquids. The findings can be potentially applied in heat pipes (increase in power and decrease in size), cold plate heat exchangers; coating and drying technologies and, distillation.

As can be seen from these highlights, fluid physics in the frame of FSL experiments is investigated regarding interaction of a large number of different fluid behaviour phenomena, demonstrating how broad this field in reality is when a thorough approach to a scientific problem is taken.

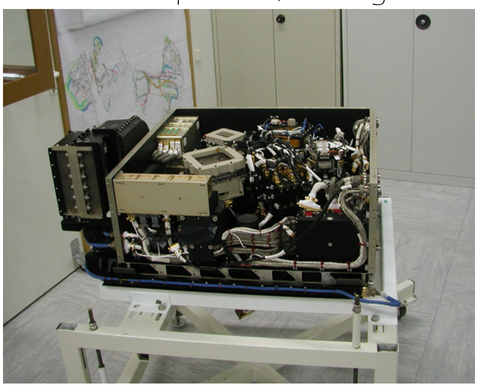




Structure of the "Fluid Dynamics and Heat Transfer"" Project = CIMEX Project with its sub-components

FluidPac experiments on FOTON-M2

The three other FluidPac experiments on FOTON M2 researching fluid behaviour were:
BAMBI– "Bifurcation Anomalies in Marangoni-Bénard Instabilities", investigating how instabilities created by heating a fluid layer, leading to movements in the fluid will influence the detailed fluid movements. Heating creates heat driven convection even in the absence of gravity and the details of this are studied.
DAGOBERT– "Design of an Advanced Grooved Board Evaporator", investigates how heat dissipation could be improved by evaporating fluid from a large area, thin film, thereby enlarging the exposed fluid surface. This is among others a central problem in electronics, as the smaller and smaller units still produce considerable heat, which needs to be dissipated effectively to keep the electronics alive, so to speak.
SIMBA – "Soret Investigations for Marangoni-Bénard Applications". The diffusion in liquids brought about by a variation in temperature across the liquids, is called the Soret effect. This is in particular interesting in mixed fluids.



FluidPac Flight Model - FOTON M2 – square frame in the middle left are observation windows.

References.
1) David L. Hu, Brian Chan and John W. M. Bush *Nature* 424, 663-666(7 August 2003)
2) Fuhrmann et al. Heat Transfer by Thermo-Capillary Convection. Sounding Rocket Experiment SOURCE.
4) MAP proposals dealing with fluid dynamics and surface tensile forces: Dreyer, Colin, Tropea

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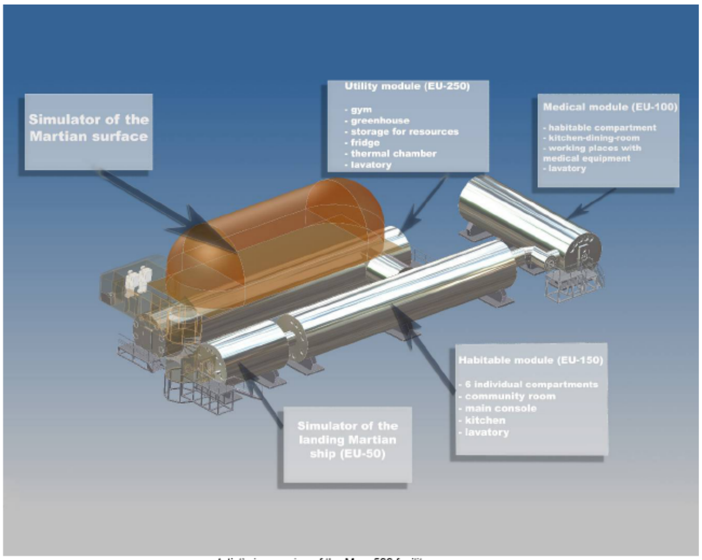
TRAVEL TO MARS IN 105 DAYS:

PREPARATION FOR THE FULL 520 DAYS LONG SIMULATION,

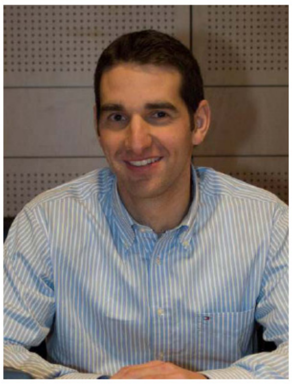


Artist's impression of the Mars 500 facility (Image: IBMP)

WITH A CREW OF SIX – FOUR RUSSIANS AND TWO EUROPEANS – IS ON ITS WAY TO MARS ON A MISSION THAT STAYS ON THE SURFACE OF THE EARTH. APART FROM THE FLIGHT ITSELF, MANY ASPECTS OF SUCH A MISSION ARE SIMULATED WITH THE SIX ONBOARD THE SIMULATION FACILITY IN MOSCOW, RUSSIA.
THIS IS THE FORERUNNER FOR THE 'REAL' MISSION, THE FULL 520 DAYS SIMULATION OF A HUMAN MISSION TO MARS AND BACK[16], INCLUDING A 30 DAY' STAY ON MARS' SURFACE. WITH MARS AS FAR AWAY AS 380 MILLION KM WHEN IT IS FARTHEST AWAY FROM EARTH, RADIO WAVES NEED 20 MINUTES TO GET FROM THERE TO EARTH AND THE SAME THE OTHER WAY. COMPARED TO 'LOW EARTH ORBIT' FLIGHTS SUCH AS ONBOARD THE ISS, A MARS MISSION LEAVES THE CREW TO A LIFE WITHOUT POSSIBILITIES TO RETURN UNTIL IT IS PLANNED – AND A NEED TO MAINTAIN HEALTH AND PERFORMANCE THROUGHOUT THAT PERIOD.

Cyrille Fournier

Oliver Knickel



The European Crew members, Fournier and Knickel. Courtesy ESA

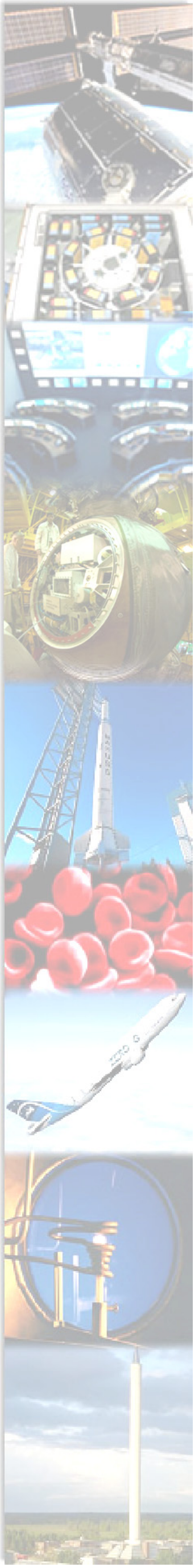
On 31 March 2009, the crew of six entered the Mars isolation facility in Moscow. More than 5,600 Europeans had applied to be amongst the chosen crew members. Of these 290 met the basic requirements, and after the medical screening 32 highly qualified candidates were considered. Four persons were needed - two prime crew members, seen to the left here, and two as back-up crew.

The Crew Tasks and Scientific Programme

The 105 days were busy. The crew were responsible for many aspects of the mission, as would also be the case in a real mars mission, such as maintenance of the facility, equipment, life support system, implementation of scientific programme, exercise regimen, medical checks etc.

Nine ESA experiments with special relevance for a Mars mission had

[16] There are a multitude of options for duration of a roundtrip to Mars. The one chosen here assumes a 30 days' stay on Mars, which in turn implies that the mission in question assumes a Venus 'swing-by'' i.e. a close passing of Venus to make use of its gravitational pull to bend the travel path. It also assumes 'aero-capture' – a way to brake the spacecraft down to a velocity that allows the Gravity field of Mars to 'capture' the spacecraft into Low Mars Orbit.



been selected, after an Research Announcement had been release in 2007, among those are:

- Immune response

Being isolated both from the outside world and the constant bombardment of environmental factors, such as virus, bacteria, dust, pollution etc., the status and development of the immune response was studied.
Onboard a spacecraft, on a long term mission, changes are seen in this area and this study is the opportunity to investigate if the changes are due to a combination of isolation and weightlessness or if isolation alone could create the same changes.

- Light exposure

The influence of artificial light, which the crew has been exposed to, and its specific wavelength has been another investigation. It is known that in particular light in the blue spectrum helps separating the sleep and wake cycle in the hormonal system. For this reason light with enriched energy in the blue spectrum was applied.

- General hormonal adaptation

Apart from the adaptation to light-dark cycle, which basically is hormone controlled, other hormone systems are thought to be influenced by isolation. Studying those in this study offers an opportunity for better preparation of the real mission, the Mars Space flight.

- Nutrition and activity level

In particular the poly-unsaturated fatty acids, omega-3 and its influence on the metabolic status of the crew has been investigated. Another study looked at the potential link between exercise and serotonergic system of the brain, which plays a role in mood forming. On long duration missions like the one to Mars, mood and wellbeing evidently are central aspects to optimise.

- Psychological studies

Three studies were specific psychological studies, whilst one other studied the effect of psychological status on physiological factors.
Psychological aspects studied are inter-personal function and dynamics, development of loneliness and emotional adaptation, and finally the impact of individual personal values on the development of the psychology of the group as a whole.
One further experiment has tried to make a link between psychological and cardio-pulmonary functioning.

The Complete Crew half way through: Fournier and Knickel, ESA, Cdr. Ryazansky, Artemyev, and Baravov, Russia. Courtesy ESA

Mission successfully completed

The mission successfully ended on 14 July "We had an outstanding team spirit throughout the entire 105 days," said Cyrille Fournier. "Living for that long in a confined environment can only work if the crew is really getting along with each other. The crew is the crucial key to mission success, which became very evident to me during the 105 days."
The scientists are currently evaluating the results from the 105 day study and are now preparing for the next step – the 520 day study, which is planned to start in the first half of 2010.

The real mission….

The difference between a long duration mission onboard the ISS, which is normally in the order of 6 months, and a mission to Mars is considerable in almost all aspects. Duration is longer, self-sufficiency becomes a central issue, the trip to Mars is a mission where return will only be possible under very specific conditions, and the spacecraft with its crew has to be of such a character that it can exist without help from other side for more than 900 days, if the 'least-energy' scenario is chosen, the alternative - a nuclear powered based, short-stay on Mars surface - being in the order of 5-600 days, dependant on detailed specifics[17].

Artists impression of future Mars Transfer Vehicle Module . Courtesy ESA

Space habitats and transportation systems at the present time are not able to provide for such a reality and still many new technologies need to be developed before a travel to Mars and back again will be feasible for a human crew, that is supposed to explore the red planet.

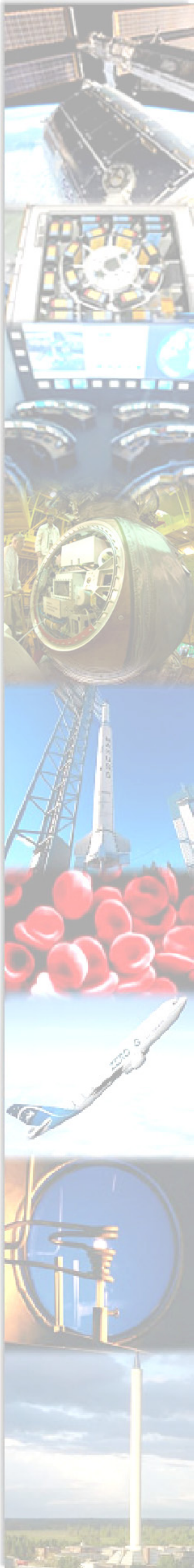
One area of concern it the massive radiation load that the crew will receive once the protective umbrella of the van Allen Belt – the protective magnetic field, some thousand kilometres over the surface of the Earth - has been left, and that will need new technologies to be developed, as the radiation intensity and spectrum beyond low Earth orbit is not acceptable for a safe and unharmed survival of the crew.

Another area is nutrition and not the least water: Present day reality is, that despite the fact that most of the water used onboard the International Space Station is recycled, still water needs to be brought up every 3 months. Food for the crew is likewise a heavy occupier of up-load and these provisions obviously one way or the other will need to be given such a form and nature that no re-supply will be necessary – another area of significant concern. Requirements to such solutions can rather easily be given, whereas the solutions still are not in sight. This means that we have considerable challenges in front of us, which on the other side will have the effect that we will mobilise all available creativity and technology knowledge on the way to finding the solution. This in itself will probably be one of the most significant 'technological journeys' ever travelled by Man, and will eventually have far reaching effects on our life on Earth as well.

MARS 500

How to maintain good health in weightlessness, which will be reality for the crew for most of the travel to Mars, is an area where we have significant knowledge. But when the mission becomes that long, with

[17] A multitude of optional mission scenarios exist. The basic split is between whether the crew will rely on an outpost being established partly before their arrival, or if they stay in Low Mars Orbit (LMO). **Least-energy** missions only work with a waiting time of more than a year around or on Mars, due to celestial mechanics. Mission scenarios with a **short duration stay**, will be based on Nuclear Thermal Propulsion (NTP) Rocket Upper Stage and a Venus swing-by that in turn puts increased requirements on heat shielding and other aspects – heat load being 4 times as large due to Venus closeness to the Sun (Venus' distance to the Sun in the order of 0.7 astronomical units (AU)). 1 AU = distance Earth-Sun). The latter mission scenarios are very propulsion-heavy, as the braking if the spacecraft to a velocity that matches the LMO is necessary. And in addition there seems to be a paradox in the fact that fast-transit times seem to be available only for long-stay missions. In future Newsletters we will elaborate on a broad spectrum of Mars mission related material.



the requirements to have well functioning, strong and durable muscles and skeleton as well as balance function in the end, makes it necessary that we think of alternatives to the present day ISS reality.
Crews coming back from months in Space, presently need days and in some cases even weeks to recover, and in particular to readapt to gravity.

When arriving at Mars, many scenarios can be imagined, but it seems to be of interest to keep the decay of the essential functions mentioned above, as a limited as possible, as this would lead to minimising the time the astronauts would need before being ready to leave the Mars Lander. In addition that would be the model of choice – maintenance – as this will be the one with the least risk built in; and risk mitigation is a concern that will play the central role in all choices made when it comes to choice of solutions.
The image inserted here indicates a few arrangements that could be imagined to be beneficial for that purpose, onboard a mission to Mars. We will elaborate on those and other aspects in future issues of the Human Spaceflight Science Newsletter.

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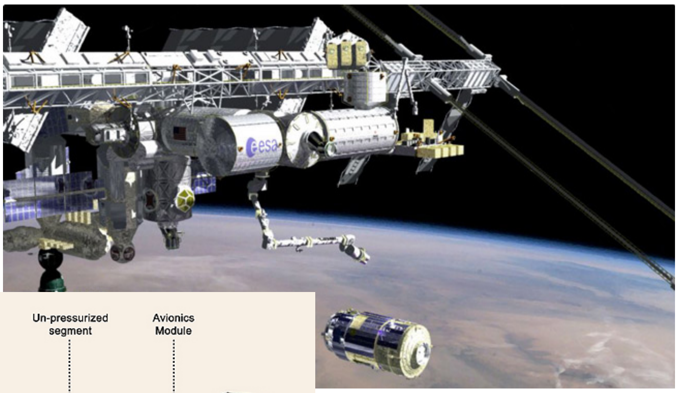
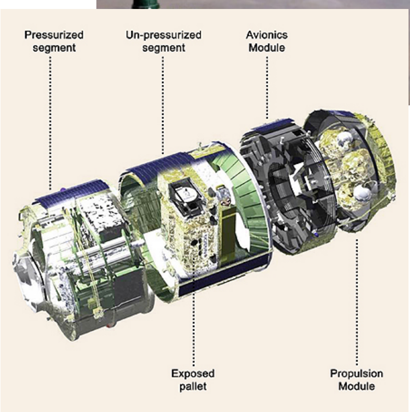
DATES FOR THE AGENDA …

– AND UPCOMING MILESTONES, STATUS 12 SEPTEMBER 2009

- **29 August: 17A, STS-128** brought ESA Astronaut Christer Fugelsang, the MPLM with ESA's' Material Science Lab (MSL) and first set of sample cartridges, the MELFI-FM 2, as well as the SODI-IVIDIL experiment , consumables for the SOLO+CARD experiments to the ISS. The same mission returned EuTEF.
  Space Shuttle Discovery landed on 12 September at alternative landing site Edwards Air Force Base, California, at 02:53 CEST – one day late due to bad weather conditions at Kennedy Space Centre, Florida. More here … (link 1)

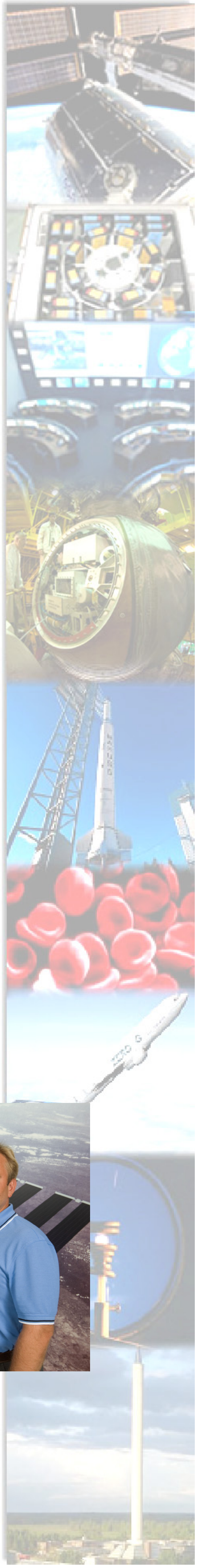
STS-128 Crew. Courtesy of NASA
Commander Rick Sturckow, John "Danny" Olivas (MS), Christer Fuglesang (MS), ESA, Pilot Kevin Ford, Nicole Stott (MS), Patrick Forrester (MS), and José Hernández (MS)





- **10 September, Japanese HTV-1 launch,** has been successfully launched on 10 September. HTV slowly approached the ISS and berthed at the ISS on the Thursday17 Sept. Berthing action seen here in an artist's impression before being docked at Node 2 by the help of the ISS Robotic arm, SSRMS[18],. More here (link 2)

- **30 September: Soyuz 20 S launch,** of a three person crew
  Jeff Williams, NASA
  Maxim Suraev, RSA
  ,Commander, Guy Laliberté, Spaceflight Participant.Docking will take place on Oct. 2, 2009Landing: March 18, 2010.
  The Increment 18 crew will return to Earth on 11 October.



[18] SSRMS stands for 'Space Station Remote Manipulator System'

02-05 November, ESA's 51st Parabolic Flight Campaign.

Programme overview in next Newsletter. The image shows one 'work-less' parabola in the IMPRESS team.

The not yet loaded TEXUS launch pad to the right of the location from where a Student Rocket Campaign launched on 17 March this year. Students from Delft University in the Netherlands set a new European student launch record. The rocket reached an altitude of 12551 meters.

13 November TEXUS-46 Sounding Rocket launching from Kiruna, Sweden,

for short term microgravity experiments: Two modules are onboard this time, as they together are slightly bigger than the TEXUS 45 modules:

- Electro-Magnetic Levitation Module, EML, this time called EML-3 for the third flight
- Japanese Combustion Module, or JCM in cooperation with the Japanese Space Agency, JAXA,

More here ....

12 November ULF-3, STS-129

will launch a cargo that is characterised by re-supply and spares. Spares for a multitude of mechanisms on the ISS. The crew, is here busy with a so-called taste panel, always held for flight crews in time for the preferred food items to be loaded and brought up. Right STS-129 patch inserted.

The Crew: From left to right Pilot Barry Willmore, Mission Specialist (MS) Mike Foreman, commander Charlie Hobaugh, Leland Melvin, (MS), Randolph Bresnik, and Robert Satcher, (MS)

See the STS-129 Launch Video here ...

More here .....(link 3)

Link 1: http://www.esa.int/SPECIALS/Alisse/index.html
Link 2: http://www.jaxa.jp/countdown/h2bf1/index_e.html
Link 3: http://www.nasa.gov/topics/shuttle_station/index.html

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