SPACE APPLICATION PROGRAMME FOR WPT
TO PROVIDE ENERGY FOR MICROGRAVITY EXPERIMENTS

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Abstract
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Microgravity research is a very important activity in space science. The level of microgravity in space is limited by several factors, but providing power with a microwave beam may improve the quality of research, and such an international application power service programme is now feasible.

Microgravity research helps to a better understanding of the essential processes in the organisation of condensed matter in the Universe. Ovens operating under the unique microgravity conditions which can be found in space are the essential tools for research in the processes of solidification and crystal growth. They require electrical energy in the order of about one kilowatt for a duration in the order of one day.

The level of microgravity on board of space stations is limited to 10^{-2} or 10^{-3} g mostly because of the motions of the astronauts and also because of frequent manoeuvers, therefore quality research in microgravity must be made with the use of "free-flyer" experimental modules physically separated from the space station. In such free-flyers systems, the quality of the microgravity level may be as good as 10^{-5} g.

In a free-flyer, the microgravity level is still limited by many factors : - the gravity differential / - the photon pressure of the solar light / - the vibrations caused by mechanisms and especially the necessary rotation of the solar panels / - the air drag caused by the residual atmosphere surrounding the free-flyer, especially on the solar panels. Therefore, ways should be found to provide power to the oven without using solar panels, to reach a 10^{-6} g level.

A good solution is to provide power from an associated module, using a WPT microwave beam to transport the energy. Then, the microgravity research oven can be a passive module while the power module will do the active station keeping at a short distance. Wire rectenna arrays attached to the microgravity research module can have a very low air-drag, even for large beam collecting sections.

The WPT technology is now mature and an application programme may be now implemented in space to serve microgravity research. An international programme is advisable to share the accumulated experience and to share the costs of implementing the programme. Expertise in the field of WPT is readily available in Japan, in the United States, in Russia and in Europe, especially in France. The Japanese ETS-VII system (fig.1) could be the technological base for the design of the free-flyer. The "target" module could be adapted to carry the experimental microgravity oven facility. The microwave projector and collector could be added to the "chaser" and to the "target" modules. The size and power capabilities of the ETS-VII system are already adequate for a good microgravity operational system using WPT and a specific derived system could be implemented with a minimal development cost.

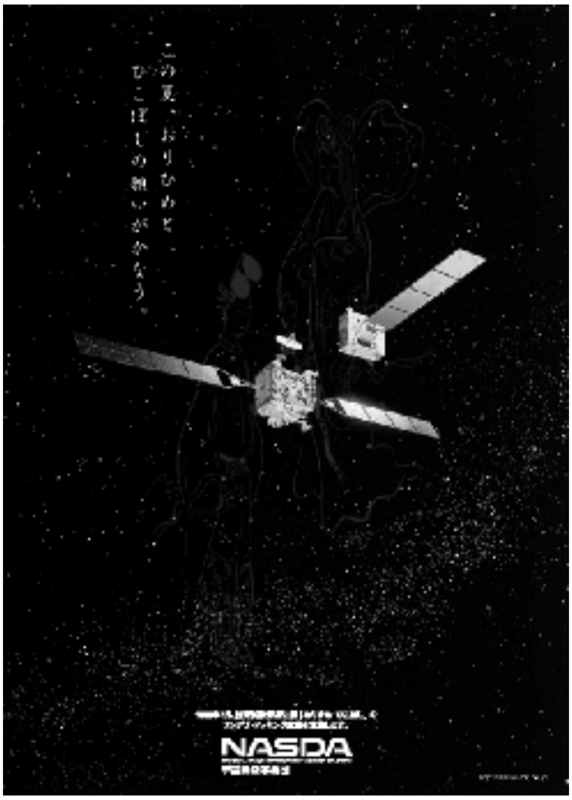

Fig. 1 : the ETS-VII "Chaser-Target" System

1. Microgravity research is an important activity
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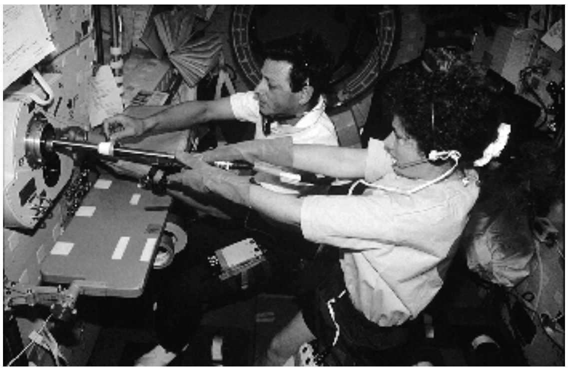

Fig. 2 : microgravity oven experiment
on board of the U.S. Space Shuttle

Outer space provides a unique environment for the study of fundamental physical phenomena which, on the surface of the Earth, are masked by gravitation. Space offers very special conditions where the effects of gravitation such as convection can be avoided during the elaboration of materials. This is especially critical in the two cases of either the quantitative measurement of very fine phenomena and for the validation of complex models, or for the elaboration of defect-free materials.

French Astronaut Jean-Jacques Favier, a specialist of microgravity research, stresses that the gravitation field must be low-level, well known and stable in time. Whereas the remote control of the experiments is very useful in maintaining the stability of the experimental conditions, it is also necessary to take benefit from human assistance in the conduct of the operations (fig. 2). However, the level of the microgravity on board of space stations is limited to 10^{-2} or 10^{-3} g, mostly because of the motions of the astronauts and because of the necessary frequent manoeuvers of the space station

Therefore, the ideal configuration is when we have a free-flier microgravity facility which can be easily tended from a manned space station. The free-flier should have a minimum of active sub-systems, which all are sources of noise and g-perturbations. In particular, solar panels should be avoided, because the residual atmospheric drag on the panels is the cause of noticeable g-jitter and of a cyclic variation of the residual g-vector with the orientation on the orbital trajectory.

2. Ovens are the basic tools for material research
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Electrical ovens operating in microgravity are the essential tools for research in the growth of crystals and solidification processes under the unique conditions of microgravity which can be found in space.

Typically, oven facilities (fig.3) require electrical energy in the order of about one kilowatt for a duration that can extend to one day or more. This is a lot of energy. Studies have been made, especially by Dr. Frank Little of the NASA Space Power Center, to compare the use of solar panels, on-board batteries and wireless transportation of power from an external source. While the storage batteries avoid many of the mentioned inconveniences of the solar panels, they are generally heavy and if a large quantity of energy is needed, which is the case for ovens, the cost of transport of the batteries can be prohibitive.

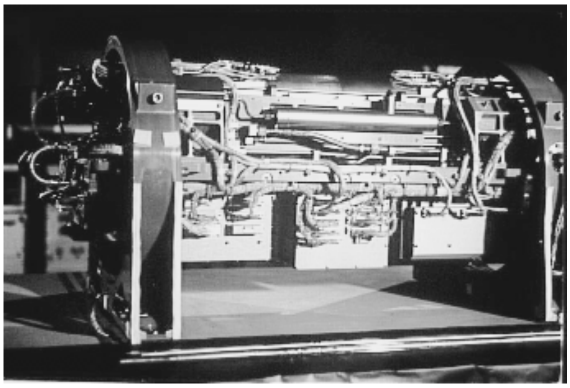

Fig. 3 : the Mephisto microgravity oven
used by French Astronaut J.J. Favier

Therefore, the preferred solution would be to use wireless power transportation with a microwave beam.

3. Improving the quality of microgravity
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The current state of the art, with free-fliers powered by solar panels, allows for microgravity levels as good as 10^{-5} g. The microgravity level is still limited by many factors :

- the gravity differential
- the photon pressure of the solar light
- the vibrations caused by mechanisms, and especially the necessary rotation of the solar panels,
- the air drag caused by the residual, atmosphere surrounding the free-flyer, especially on the solar panels.

It was estimated by microgravity experts from France and from Russia that if the solar panels can be avoided, then the quality of microgravity can improve one order of magnitude to 10^{-6} g, which is quite significant. If the power for the oven can be provided from an associated module, using a WPT microwave beam to transport the energy, then the microgravity research oven can be an almost totally passive module while the power module will do the active station keeping at a short distance.

4) A microwave beam to send power to the oven
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The microwave power system would include a beam projector and a beam collector.

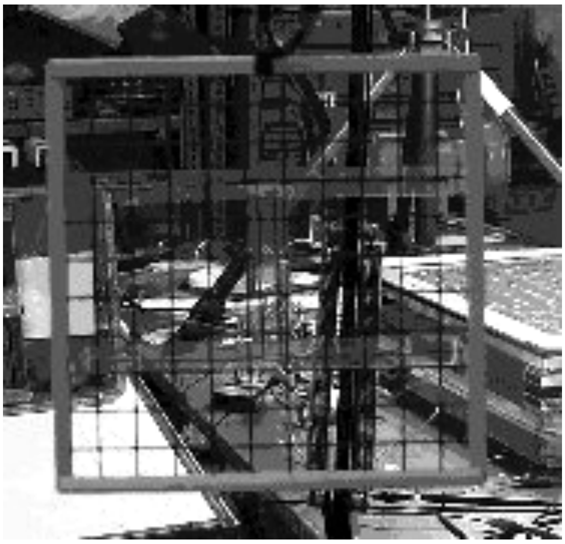

Fig. 4 : a typical "see through" wire rectenna as used in test for a SPS demonstration model; the visible grid is the reflector and drag section is minimal compared with equivalent solar panel.

Most critical for the improvement of the microgravity level would be the beam collector system. Wire rectenna arrays (fig. 4) attached to the microgravity research module can have a very low air-drag, even for large beam collecting sections. Such system is now under study in France for the Grand-Bassin project (fig. 5), where for environmental visual compatibility reasons, minimal cross area rectenna systems are investigated by the research team at the University of La Reunion.

Fig. 5 : an operational WPT system is now

under study for the village of Grand Bassin

Considering the projector, a system is now studied at the University of Kobe in Japan, for the automatic control of the direction (fig.6) of the microwave beam. This will allow the energy module of the twin free-flier to keep the power link without excessive requirements on the position or the attitude of the energy module.

Fig. 6 : the directionally controlled beam projector system designed by the WPT research group of the University of Kobe

5. An international cooperation programme
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The WPT technology is now mature enough that an application programme may be now implemented in outer space to serve microgravity research. An international programme is advisable to share the accumulated experience and to share the costs of implementing the programme.

Expertise in the field of WPT is readily available in Japan, in the United States, in Russia and in Europe, especially in France.

While Japan and France could provide most of the components of the WPT system, Russia and the United States could bring valuable expertise and means to help set up the system in the first place (fig.7) and operate it from the space station, especially for experiment preparation and for the associated complex logistics.

Fig. 7 : the teams from the Russian space community have the necessary capability to help build the experimental microgravity facility, and they could send the twin free-flier system readily in orbit with cost-effective means such as the "Strela" launcher.

6. An operational system derived from ETS-VII

It was found that the Japanese ETS-VII experimental system could be the base to design a dedicated microwave powered free-flier system for the service of microgravity research.

Microwave projector and collector could be added to the "chaser" and to the "target" modules (fig. 8) with minimal redesign of the system. The size and power capabilities of the ETS-VII system are already adequate for a good microgravity operational system using WPT.

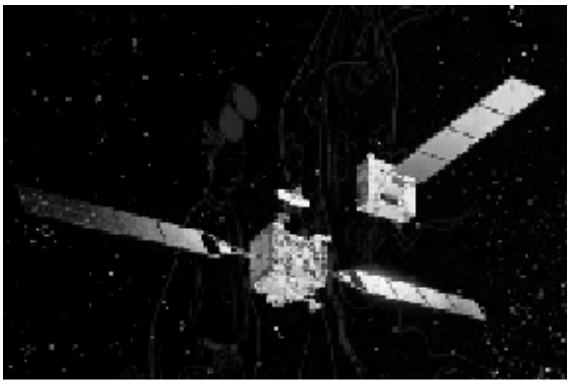

Fig. 8 : ETS-VII - the "chaser" and "target" modules could be the base for the design of a specific microgravity system

The next operational step in the development of the concept may now be the continuation of technical investigations with the teams who have built and operated ETS-VII, to see how a specific application system for microgravity could be derived (fig. 9) from this very successful technological experiment.

7. Acknowledgements

I would like to thank all the experts who contribute to the advancement of this study, and especially :

- Dr. Frank Little and Dr. John Mankins from the United States,

- Dr. Andrei Smakhtin, Dr. Vladimir Savvin, Dr. Victor Zemskov of Russia,

- Dr. Nobuyuki Kaya of Japan,

- Dr. Jean-Jacques Favier and Dr. Alain Celeste of France,

and all the many contributors who have brought the useful information and hints that made possible the development of this microgravity WPT free-flier concept.

I have special thanks for Dr. Kenji Ogimoto and Dr. Mitsushige Oda of Japan, who have introduced me to the ETS-VII system.

I would like also to thank particularly Dr. Didier Vassaux of CNES, Dr. Susumu Sasaki and Dr. Motoki Hinada of ISAS, who have organised the conditions that have made this study possible.

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Fig. 9 : Microgravity with Wireless Power System