Mini ecosystem in space
- Preliminary experiment on board STS-77 -

Yoji Ishikawa1, Grant Anderson2, Jane Poynter3, Taber MacCallum3, Robert Frye4, Yukishige Kawasaki4, Junpei Koike5, Kensei Kobayashi6, Hiroshi Mizutani7, Katsura Sugiura8, Kenichi Ijiri9, Yoshio Ishikawa10, Takeshi Saito11, and Atsushi Shiraiishi12

1Obayashi Corporation, 2-3-1 Kanda Tsukasa-cho, Chiyoda-ku, Tokyo, Japan
2Paragon Space Development Corporation, Tucson, Arizona, USA
3University of Arizona, Tucson, Arizona, USA
4Mitsubishi Kasei Institute of Life Science, 11 Minamioya, Machida-shi, Tokyo, Japan
5Tokyo Institute of Technology, Nagatsuta, Midori-ku, Kanagawa, Japan
6Yokohama National University, 156 Tokiwadai, Hodogaya-ku, Yokohama, Kanagawa, Japan
7Senju University of Ishinomaki, 1 Shinmoto, Minamisakai, Ishinomaki, Miyagi, Japan
8Sagami Woman’s University, 2-1-1 Bunkyo, Sagamihara, Kanagawa, Japan
9University of Tokyo, 2-11-16 Yayoi, Bunkyo-ku, Tokyo, Japan
10Nihon University, 7-24-1 Narashinodai, Funabashi, Chiba, Japan
11University of Tokyo, 3-2-1 Midori-machi, Tana-shi, Tokyo, Japan
12Fujitsu LTD, Kanagawa, Japan

Abstract An enclosed ecosystem which is stable on Earth will behave differently when brought into space. Micro-gravity and radiation will affect the dynamics of material circulation or the activities of small creatures of the ecosystem. One series of space experiments aiming to address such issues was planned in the United States (It is termed as ABS - Autonomous Biological System) and Japanese group has been involved with cooperating with the analysis of the flight samples. Before the ecosystem will be on board Russian Space Station “Mir” later 1996 for 3 months, a preliminary flight was carried out in May 1996 on Space Shuttle (STS-77) for 10 days flight. It was the first of such experiments to fly one whole ecosystem in space.

1. PURPOSE

The ABS (Autonomous Biological System) experimental objectives shall be to characterize the behavior of Paragon’s Enclosed Biotech System technology subjected to micro-gravity and enhanced radiation environments on the “Mir” space station. This shall include the study of the system effects through the individual study of constituents by multiple researchers. Studies of the changes of the chemical and biological structure of the ecosystem and individual organisms and plants due to the micro-gravity and enhanced radiation environments are planned.

2. MANAGEMENT

2.1. Organization

The organization assembled to fulfill the objectives of the experiment are composed of three layers; NASA and its agent, Paragon and its agent(s), and the researchers/collaborators. Each layer of organization will be providing resources for the experiment. The following is a more detailed explanation (Figure 1).

BioServe BioServe Space Technologies of Boulder, Colorado was the sponsoring organization that is contracted to NASA to provide commercially promising organizations a means of using the unique Shuttle/Space environment for research
and development. Through an agreement with NASA, BioServe is a “NASA Center for Space Commercialization.” One of BioServe’s services is to provide a “Commercial Generic Bioprocessing Apparatus” (CGPA) that is a temperature controlled removable drawer for the Space Transportation System (STS-Space Shuttle) Locker Assembly and the SpaceHab pressurized laboratory carried in the shuttle cargo bay. BioServe Space Technologies was responsible for producing the custom build cylinders to contain the ecosystem. Other BioServe responsibilities include providing the interface with NASA concerning all flight safety requirements, shuttle integration support and final prelaunch installation and post launch removal of the systems.

Paragon Space Development Corporation Paragon Space Development Corporation was founded in 1993. The business concept is to meld the work of Ecosystem and Biology with the rigors of Aerospace Engineering to produce products using life systems and perform services related to the System Engineering of complex projects involving space and biology. Paragon Space Development Corporation has signed a contract with BioServe to fly the Enclosed Biotech SystemTM technology. While initial negotiations were for the first flight to be to MIR in August of 1996, the Shuttle flight on STS 77 on May 19th of 1996 was added as an engineering test flight. The intention of the agreement is for multiple missions to space if the initial flights are successful. Paragon will be the overall coordinator of the ABS, to provide the Enclosed Biotech SystemTM technology and process knowledge garnered from 2 years of commercial production of units.

Robert Frye  Robert Frye of the University of Arizona Environmental Research Laboratory in Tucson Arizona has agreed to be the science coordinator of the ABS experiments. Robert Frye has experience in closed system research, as well as knowledge of Paragon’s capabilities and resources. As the Science coordinator, Robert Frye will be ensuring that the program from initiation through each flight maintains high scientific standards and maximizes the scientific return within the constraints of budget and resources of Paragon and its collaborators.

Collaborators  There are multiple collaborators for the ABS STS 77/79/MIR experiments. Yoji Ishikawa has agreed to assist in the coordination of the collaborators in Japan, and provide a focus for the communications between Paragon, Robert Frye and those collaborators in Japan.

2.2. Planning and Schedule
The project planning went smoothly. October 1995  Jane Poynter and Taber MacCallum visited Japan and stated their prospect to fly their Ecosystem (Bio-SphereTM) in Space at the meeting with a small group. Yukishige Kawasaki took a strong interest on it and offered the Japanese participation for the analyses of samples. Yoji Ishikawa agreed to serve as a bridge over the Pacific. Since then, the Japanese organized its interest group. Electronic communication was truly a key to the success of the international coordination of this project. Most of the communication was carried out electronically.

The beginning of 1996  Paragon started discussing with BioServe.

March 1996  Yoji Ishikawa visited Paragon at Tucson, Arizona to a preparatory meeting with Paragon and Robert Frye. Around the same time, Paragon penned agreement with BioServe only less than three months before the first Shuttle (STS-77) launch.
May 1996 The first preliminary experiment on board STS-77. Following the launch (May 19th) and the landing (May 29th), the samples were transported to Japan with on-going analyses.

August 1996 Jane Poynter visited Japan to discuss the Shuttle flight results and a possible alteration of sampling protocol for upcoming "Mir" mission.

September 1996 The launch of STS-79 (September 16th) to carry the ecosystem to "Mir".

January 1997 (scheduled) The ecosystem will be transferred to Atlantis (STS-81) after their 3 months stay, and returned back to Earth. The analyses will follow.

2.3. Resources
Regarding the collaboration between Japanese and American, as the collaboration is voluntary and no one is supposed to earn monetary profit, in principle no money flow exists over the Pacific. Only actual amounts of cost are reimbursed for the expense which the one side has paid to the other side. These expenses include apparatus costs, shipping fees, etc.. Each researcher provides his/her own resources for the analyses.

2.4. Benefit from Research
The benefits of these projects, according to the Japanese group's view, will be:

1. To acquire data for design of future CELSS system
2. Adaptation of material circulation to space environment especially in human space vehicles as one of enclosed ecosystems
3. Possibility of microbial mutation in space and its pathogenic implications for human space flight

3. ECOSYSTEM

3.1. Ecosystem
Based on their technology, Paragon designed and developed an ecosystem for space experiment. The ecosystem is a fresh water aquatic system containing limited air in the head space, mainly, as pressure or gas buffer. This small ecosystem, which is enclosed in an approximately 900 cc cylindrical polycarbonate container (9.5 cm diameter and 15.5 cm height), will be illuminated with artificial light during the flight (Figure 2). Thus, the system is material tight and only energy (light and heat) is allowed to enter the system. The light source is an off-the-shelf fluorescent lamp. The system will be kept at constant temperature around 23 C.
3.2. Players of the Ecosystem
The complete ecosystem, which is considered a miniature Earth, consists of producers, consumers, and decomposers which recycle their nutrients and wastes back and forth among themselves similar to our ecological system on Earth. The producers usually converts carbon oxides to oxygen and provides food to the consumers. The consumers changes oxygen to carbon dioxides and digests food which is provided by the producers. The decomposers, commonly known as bacteria, decompose the dead bodies and wastes of the producers and consumers. The biological species will be plants, water fleas, small snails, small shrimps, and bacteria, which all contribute to the formation of ecological system just like in the case of Earth’s ecological system (Figure 3).

3.3. Phenomena Expected in Micro-gravity
The phenomena the Japanese investigators expect to encounter are:
(1) In space, there are no material hierarchy. The material hierarchy governs the ecosystem under one gravity. For example, detritus sinks to the bottom, and bacteria follow. On the other hand, in space, the material scatters throughout the system, and the material distribution becomes more uniform.
(2) In space, there is no material flow due to convection. Therefore, once, non-uniformity is formed, it stays or even develops.
(3) In space, air makes bubbles instead of forming a flat surface at the top which results in an increase of surface area. In the ecosystem, the air space is expected to act as the buffer of some recycling material (carbon dioxide and oxygen), and the change of the surface area may influence material circulation.
(4) As some space experiments using only one species (for example, E. coli) suggest, the bacterial growth rate and its antibiotic resistance may be different under space environment (Bouloc and D’Ari, 1991; Ciferr, 1986; Klaus, et al., 1994; Mattoni, 1991; Moatti, et al., 1986; Tixador, et al., 1985). The similar phenomena may be observed.

Figure 4. ICM (Isothermal Containment Module), where two ecosystem units are installed.

4. STS-77 PRELIMINARY EXPERIMENT

4.1. STS-77
The preliminary experiment was carried out in the May 1996 Space Shuttle flight. This mission was the 77th Space Shuttle flight (STS-77), and the Endeavor’s 11th flight. It was widely seen in media that this Shuttle successfully deployed an inflatable antenna. The major mission was SpaceHab/Spaeward-207. BioServe provided several payloads to this mission, and one of them were CGBA (Commercial Generic BioProcessing Apparatus). This Apparatus included ICM (Isothermal Containment Module), which consisted of a temperature-controlled, self-contained, autonomous system (Figure 4). The ICM could contain up to eight cylindrical experimental apparatus, which are usually used for fluid mixture experiment in microgravity for pharmaceutical purpose. For the present mission, two of the cylindrical apparatus were replaced with Pragon’s enclosed ecosystems. The ICM was installed in the pressurized SpaceHab module (instead of the Shuttle Middeck which the authors previously believed).

4.2. Preparation and Launch
The preparation and retrieval of the sample took place at Florida for this preliminary STS-77 mission.
May 16, 1996 (3 days before launch) Jane Poynter, Taber MacCallum, Grant Anderson, Dave Bearden and Yoji Ishikawa gathered at the
Cape Canaveral area in Florida, where the Space Shuttle is launched. Paragon’s group brought four ecosystems from Arizona, among which two would fly and the other two stayed on ground as control samples. The containers for the transport were modified temperature controlled picnic coolers. All four ecosystems were packed, and sealed several weeks before the launch, and since then the systems had been kept closed until the breakdown after landing.

May 17, 1996 (2 days before launch) The flight and control ecosystems are selected. Two cylindrical units were chosen to fly in Endeavor (Figure 5). The seal test was done. The units were located in BioServe’s ICM (Isothermal Containment Module), which can house a total of eight similar units. Each of the units was located one-by-one, and the ecosystem units were the last to be installed. The light was kept continuously on without interruption during the packing process (Figure 6). At approximately 9:30PM of May 17th, 33 hours before the scheduled launch, the ICM left the SpaceHab building to be installed in Endeavor. Within that evening the module was loaded into Endeavor.

May 19, 1996 (launch day) Endeavor made a successful launch on time at 6:30AM (Figure 7).

4.3. Landing and Sampling

Since there is a possibility of Shuttle landing in California other than Kennedy Space Center, Taber MacCallum flew to California to wait at Edwards Air Force Base, the alternative Shuttle landing site. Jane Poynter, Grant Anderson, and Yoji Ishikawa waited at Kennedy Space Center area.

May 29, 1996 (landing day) The landing was on time at 7:10AM as scheduled after 10 days and 40 minutes flight. The module including the ecosystem, once retrieved from Endeavor, was delivered to the SpaceHab building at approximately 12:30PM. To simulate the vibration and turnover which the flight ecosystems encounters during the transportation from the gantry to the SpaceHab building, the ground control units were shaken in the similar way. Immediately after delivery the group picked up the ecosystems.
from the ICM. The ecosystem appeared healthy (Figure 8). The group opened one of two flight ecosystem as well as one of the ground controls to separate and store samples into small vials for co-investigators. All tasks were finished at approximately 9:30PM. The samples which should be brought to Japan were stored in the refrigerator in the hotel room for one night. Early the next morning, the samples were hand carried with Yoji Ishikawa from Orlando International Airport to Narita International Airport. Once the samples reached at Japan, they were distributed to co-investigators for further analyses.

4.4. Quarantine
In order to analyze the samples, the Japanese co-investigators had to import and retain the samples at their labs. The ecosystem appeared to contain no dangerous species, though, some species may be foreign to the Japanese environment. The Ministry of Agriculture, Forestry, and Fishery of Japan regarded the ecosystem as import inhibited material, however, they kindly issued the import permit for use on scientific purpose only. In this way, the samples were imported to Japan without problems for analysis purposes at the co-investigators' labs.

4.5. Preliminary Results
The analyses for STS-77 preliminary experiments are the followings:
Numbers and Diversity of Microorganisms and their Antibiotic Resistance (Yukishige Kawasaki and Junpei Koike) - With using his newly developed technique, fluorescent microscope method, Yukishige Kawasaki is comparing the flight and control samples (Figure 9), and also checking the cell structures of algae. Junpei Koike counts colony forming units.
Natural Isotopic Ratio (Hiroshi Mizutani) - Stable Isotopic Ratio of Carbon and Nitrogen in Solution and Algae are measured.
Daphnia (Kenichi Ijiri) - To raise descendants of Daphnia (water flea) who returned alive from space (Figure 10).
Organic Compounds (Kensei Kobayashi) - Endopeptidase activity and amino acid concentra-
tion in solution samples. Water Quality (Yoji Ishikawa) - Ions of sodium, calcium, magnesium, potassium, ammonium, nitrite, nitrate, phosphate, and sulfate. Total carbon, total organic carbon, and inorganic carbon of both unfiltered solution and filtered solution (Millipore filter of 0.2 micrometers pore size). Except for the analyses shown above, the oxygen and carbon dioxide concentration in head space air was measured by Robert Frye. In addition, the water quality just after the Shuttle flight was examined by simple pack tests for pH, DO (dissolved oxygen), and ammonium/nitrite, nitrate ions.

The overall results we have seen so far explains there are not so much difference between space and ground control mainly because this is a preliminary engineering flight just for a short flight time, ten days. There is a slight tendency showing more abundance in flight samples for microorganisms, organic materials, and carbon contents, which is coincident to the previous E.Coli experiments showing the increase of the growth rate of microorganisms. Since the analyses are still going on, and the detailed results are to be published elsewhere.

5. Future Experiments

If the “Mir” mission scheduled in later 1996 turns out to be as successful as preliminary Space Shuttle (STS-77) mission, there will be more planned experimental investigations involving the mini ecosystems for the additional “Mir” missions which will fly in foreseeable future.

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Reference


