NASA TECHNICAL MEMORANDUM NASA TM-77244

BIRTH OF SPACE PLANT GROWING

A. Mashinskiy and G. Nechitaylo

Translation of "Rozhdeniye kosmicheskogo rasteniyevodstva", Tekhnika - Molodezhi, No. 4, 1983, pp. 2-7

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 NOVEMBER 1983

ORIGINAL PAGE IS
OF POOR QUALITY

STANDARD TITLE PAGE

1. Report No. NASA TM-77244	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle BIRTH OF SPACE PLANT GROWING		5. Report Date November 1983
		6. Performing Organization Code
7. Author(s) A. Mashinskiy and G. Nechitaylo, Candidates of Biological Sciences		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, California 94063		11. Contract or Grant No. NASW-3541
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D. C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Rozhdeniye kosmicheskogo rasteniyevodstva", Tekhnika - Molodezhi, No. 4, 1983, pp. 2-7.

16. Abstract

The article discusses the attempts, and final successes using orchids, to grow plants in space, and get them to fully develop, bloom and produce seeds.

The psychological advantages of the presence of plants on board space vehicles and stations is indicated, through discussions with the cosmonauts themselves.

17. Key Words (Selected by Author(s))	18. Distribution Statement This copyrighted Soviet work is reproduced and sold by NTIS under license from VAAP, the Soviet copyright agency. No further copying is permitted without permission from VAAP.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22.
Unclassified	Unclassified	18	

BIRTH OF SPACE PLANT GROWING

A. Mashinskiy and G. Nechitaylo
Candidates of Biological Sciences

At the beginning of December of last year, we, two specialists in biological experiments in space, prepared to fly off to Dzhezkazgan together with associates from the search and rescue service. /2*

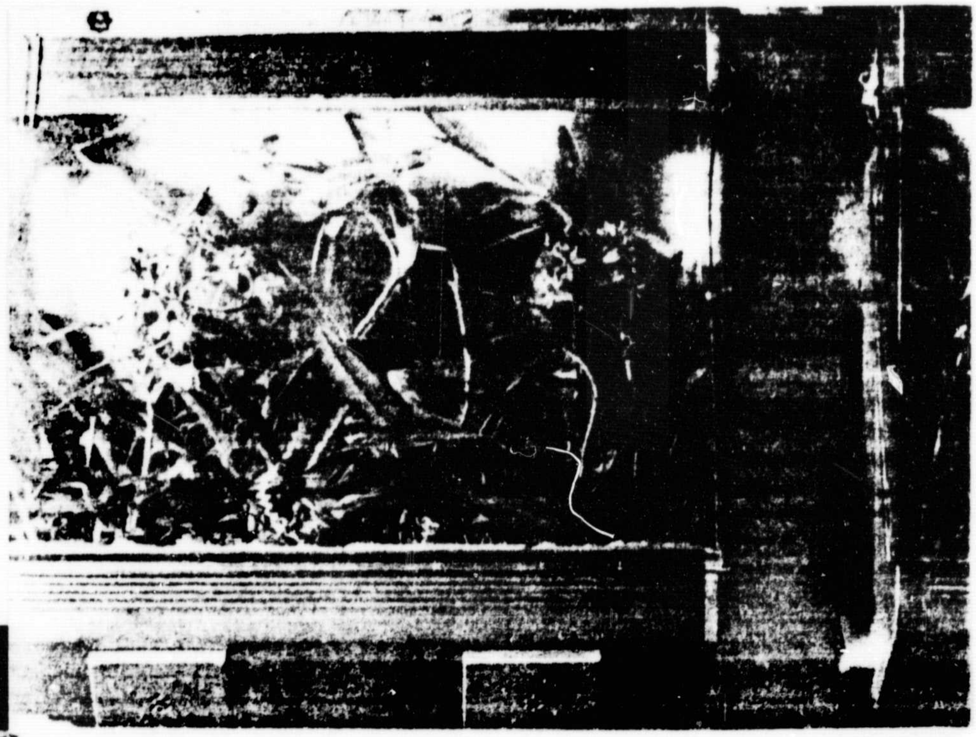
We had to meet cosmonauts Anatoliy Berezovoy and Valentin Lebedev, who had worked a record time in cosmic orbit: 211 days.

After the agitations associated with the repeated postponements of our takeoff because of the capriciousness of Moscow weather, even as we flew, doubts began to trouble us. Will we succeed, will our rendezvous group work? This depended on which of several potential landing loops the space vehicle would use to start its re-entry. If, for some reason, the flight leadership delayed the re-entry, then one of the backup groups would have to go into action. But we wanted, and wanted very much, to work alone for awhile.

In practically all crews, there is a very interested attitude toward biological experiments. This is also noticeable during studies at the Training Center, as well as at the Baykonur Cosmodrome during equipping of the space vehicles prior to launching, and during the flight. At the Flight Control Center, the conversations of the crew with the biologist became habitual, when the course of some experiment or another was discussed, procedures were made more specific, and we spoke to one another about the results: the cosmonauts about what would take place in the space station, and us — about how the monitoring in the laboratory would occur.

---

*Numbers in the margin indicate pagination in the foreign text.



The "Malakhit-2" on-board glass panel hothouse provides optimal conditions for the development of even exotic orchids.

V. Lebedev works with the "auxiliary farm" on board the "Salyut-7" station.

The cosmonauts grew coriander, borage, cucumbers and radishes in the containers. Here they also placed leaves, delivered by the space truck, in order to longer preserve the freshness of this terrestrial welcome.

We will find our own group in the hotel. Its leader is very concerned. The landing will be special, and at night. This happens rarely. And, what is more, the weather is bad. Literally 10 minutes prior to take-off, fog suddenly enveloped the landing site. One helicopter after another set off for the calculated site. And, although our group was specifically included in the operation, we were hindered in our rendezvous with the cosmonauts at the touchdown point by a light snow which had recently fallen. Such a snowy whirlwind ascended from the propellors that it proved impossible to recognize where the ground itself was. We had to go out to a reserve airfield and rely upon the knowledgeable specialists of the search and rescue group. Once they could ensure normal conditions for the cosmonauts, they would be able to do the same for the biological objects as well. And, in actuality, we obtained our material in excellent condition on the following day.

This is How it Started /3

Even K. E. Tsiolkovskiy showed the necessity of the utilization of higher plants as a means for the purpose of providing respiration and nourishment of people during prolonged extraterrestrial flights. In the labors of this brilliant scientist, we find the first "technical conditions" for the creation of cosmic hothouses and living orbital facilities with a closed ecological cycle. And, as early as 1915-1917, F. A. Tsander began to conduct experiments in his Moscow room on the creation, as he put it, of a hothouse of aviation facility.

Thus, as dreamed by theoreticians of cosmonautics, it began to be translated into reality under the leadership of S. P. Korolev. Experiments on the effect of factors of space flight on plant objects were begun in 1960 on the second cosmic satellite. Then, *Tradescantia*, *Chlorella*, and seeds of various varieties of onions, peas, wheat and corn completed their own flight, and were the first to return successfully to Earth. Chlorella cultures also flew into space on the "Vostok-5" manned space vessel. After this, plant organisms traveled into space on all of our space vessels, orbital stations and the "Kosmos" series of biological satellites.

In 1962, the Chief Designer outlined an entire program of botanical and agrotechnical studies in space. He wrote: "It would be necessary to begin development of a 'Hothouse According to Tsiolkovskiy', with components or blocks grown in stages, and to begin to work on 'cosmic harvests'. What is the composition of these plantings, and what are the crops? What is their effectiveness and usefulness? What is the invertibility (repeatability) of plantings from their very own seeds, on the basis of the prolonged existence of the hothouse? What may one have on board a station or in a hothouse of decorative plants, which require a minimum of expenditures and maintenance? What organization will conduct these studies: along the path of plant growing (and matters of soil, moisture and so on), along the path of mechanization and 'light, heat and solar' technology and systems of its regulation for a hothouse, and so on?" (This fragment was published, along with other of Korolev's notes, in TM, No. 4, 1981, pp. 30-31).

Before long, the experimental closed biotechincal complex "Bios" appeared in Krasnoyarsk, by the initiative of the Chief Designer. For a long time, researchers were supplied with oxygen, plant food and water, because of life support systems with the participation of higher plants and microalgae.

People in an Artificial Environment

The "Bios" complex consisted of four hermetically-sealed compartments, with the crew being located in one of them, phytotrons in two others, and cultivators with algae in the fourth. The entire complex was encased in a hermetically-sealed steel frame in the form of a rectangular parallelepiped, 15 m long and 2.5 m high. Its volume was 315 m^3.

Biologist A. Mashinskiy by the hatch of the space vessel prior to removal of the biological objects delivered to Earth from the orbital station.

In the crew compartment were three cabins, a kitchen-dining room, a shower, combined with a restroom, and a laboratory installation with a shop and resting place.

In each phytotron were located metallic pallets with a total area of 17 m^2 for growing wheat, and a vegetable plantation with an area of 3.5 m^2, in which beets, carrots, dill, turnips, leaf cabbage, white radishes, Welsh onions, cucumbers and dock were grown on claydite. The three Chlorella cultivators occupied 30 m^2.

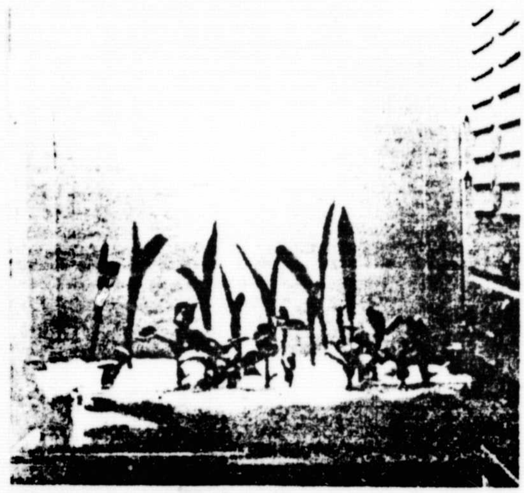
Theoretically, there were no doubts: man can live normally in such an artificial environment. However, the systems, which ensure his vital activity, must be verified in the course of ground experiments, and only then can they be created for space vehicles.

"Bios" became an arena for several successful experiments with people. The longest ran for 180 days. Here, closing of the biotechnical system by 82-95%, according to atmosphere and water, was successfully achieved. In striving to increase this percentage, the researchers encountered a rather interesting problem.

The community of organisms, if it exceeds some minimum in the number of individuals, is a self-restoring system. Speaking in technical language, living organisms, which are part of a biotechnical system, are not only maintainable, but also accessible. And there are technical assemblies, producing their own resources, which cannot restore themselves — they must be repaired. For total harmony, technology should be raised to a new level, when self-restoring machines will appear.

/4

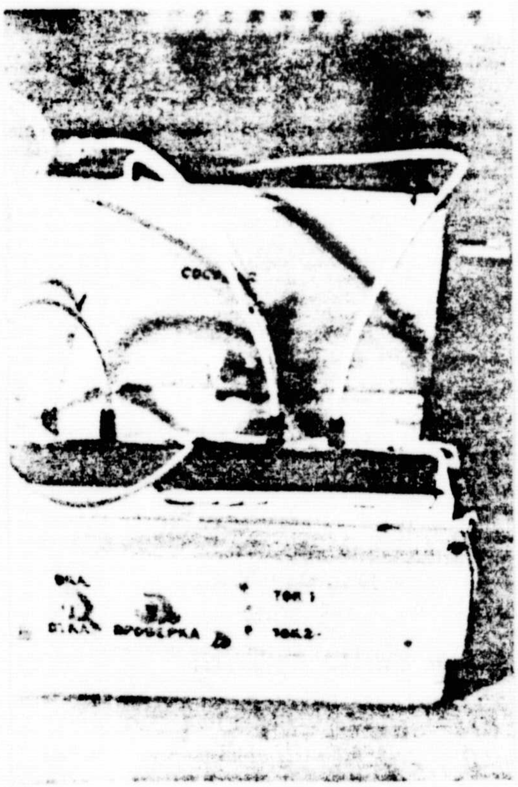
A. Berezovoy and V. Lebedev working with biological equipment at the Cosmonaut Training Center.



Plantules of wheat and peas having sprouted under weightless conditions in the "Oazis" unit.

What is Geotropism?

Because of the exceptional complexity and perfection of the human body, man adapts very rapidly and ambiguously to new conditions. It is very difficult to ascertain his specific reactions to some factor or another. This is especially true since we have still not had the opportunity to simultaneously pose a sufficiently large number of experiments with people in space which are characterized by some single factor. For this purpose, much simpler models are required. Here, also, plants will come to our aid, and plants are, at times, much more convenient to work with than, for example, small laboratory animals.



The "Elektropotentsial" unit for experiments on electrostimulation of plants.

In the process of evolution, many living organisms have developed mechanisms, responsible for perceiving the force of gravity. The properties of plants for reacting to its effect are called geotropism.

Even Charles Darwin associated bending of plants, occurring under the effect of the force of gravity, with the presence of substances which slip into the zones of growth. Later, D. Sax formulated the concept of geotropic reaction, manifested in the form of sequentially occurring processes. Then, two trends were noted in these studies. The first is associated with the names Nemets and Gaberlandt, who created the so-called statolithic theory. According to this theory, a geotropic reaction occurs because of the pressure of movable granules of amyloplasts-statoliths into the protoplasm. Another hypothesis, put forth by Kholodnyy, is based on the difference in the physical and chemical properties of the protoplasm of the root and stem, as a result of which there occurs electrical polarization of the cells. Wendt supplemented this hypothesis with the assumption that growth movements are based on polar displacement of particular substances — auxins.

The first experiments for studying the geotropic reaction were carried out by scientists on centrifuges, set in motion by a grinding wheel. Thus, they managed to achieve an acceleration of 3.5 g. With an acceleration of 1 g, the roots and stems of beans were bent precisely in the direction of the vector of the equivalent gravitational and centrifugal forces. This directly proved that it is precisely the force of gravity which determines the direction of growth. But only practical cosmonautics made it possible to verify this.

Hopes and Disappointments

In 1971, the "Vazon" unit, with two tulips, was sent on the "Soyuz-10" vessel beyond the limits of the Earth. But, unfortunately, docking with the "Salyut" station did not take place, and the opened flowers could be observed on Earth only by the specialists of the recovery group.

On the "Salyut-4" orbital station was a rather improved "Oazis", equipped with telemetric and movie recording systems. The studies were carried out with peas.

"From the beginning, much did not go well", cosmonaut Georgiy Grechko tells us. "Water did not enter where it was needed, then huge drops began to break away, and we had to pursue them with napkins. But, on the whole, the experiment succeeded, and mature, twenty-three-day plants were obtained. Granted, there were not flowers, but we managed to take film with slow-motion photography of the growth dynamics of the plants".

Grechko was one of the first to witness the psychological support that cosmonauts received with the plants. He himself, especially by the end of the flight, tried to float up to the hothouse on every convenient occasion, in order to once more cast a glance at his green friends. Sometimes, he caught himself doing this without realizing it.

The analysis, carried out on Earth, showed that, in spite of the external similarity with the control experiments, the plants differed in the structure of the cells, the biochemical composition, and the growth characteristics. This seemingly corroborated the scepticism of those scientists who, prior to this, had doubted the possibility of the normal growth of plants under conditions of weightlessness. Subsequent experiments on the cultivation of plants during prolonged space expeditions also did not yield anything comforting. In wheat and peas, we in no way managed to obtain flowers, let alone seeds. The plants simply died in the stage of their formation. And this fact provided a basis to speak of the principal impossibility of growth and development of plants under the conditions of space flight. It was then that an experienced scientific group, headed by Academician N. P. Dubinin, Academician of the Academy of Sciences of the Lithuanian Soviet Socialist Republic A. I. Merkis, and Academician of the Academy of Sciences of the Ukrainian Soviet Socialist Republic K. M. Sytnik, set about solving this problem.

First, they decided to ascertain whether it was specifically weightlessness that has an effect here, or other factors, such as the technology of cultivation, for example. After all, it was precisely this technology that was created solely for such unusual conditions. And weightlessness had a distinct effect on it. With the absence of gravity, water and gas exchange in the plants takes place differently, and the problem of the elimination of metabolites and ensuring of the /5 necessary thermal conditions occurs, insofar as natural convection is also absent. Attempts were again made to return to the cultivation of plants, in the bulbs of which nearly the entire reserve of substances, necessary for development, was concentrated.

In the summer and fall of 1978, during flight, cosmonauts V. Kovalenok and A. Ivanchenkov grew onions by two methods: the scientific method, and "as in the village of Belaya", the home of the commander of the vessel. When the cosmonauts returned to the station after going out into open space, they cautiously suggested: "How well we worked. Perhaps now they will permit us to eat the bulbs as a reward". But then, it was still early to gather the harvest.

"Onions grow in two vessels, one according to your procedure, and the other according to mine, the peasant way", reported V. Kovalenok. "If they are not trimmed at the top, they begin to rot, while if they are trimmed, they grow well, and do not rot."

"Well, that's fine. If you want, you may eat several stalks now."

"We have already done it. We have eaten six of the fourteen stalks."

In his reporting by television, the commander joked: "Agricultural technology works better, which we have verified as a result of socialist competition. Our little onions grow more rapidly than the scientific ones!" But alas, we did not manage to bring the obstinate plant to flowering by this or the other procedure.

The following year, in the Main Botanical Garden of the Academy of Sciences of the USSR, in a unit called "Lyutik", tulips were prepared for forcing aboard the "Salyut-6" station. All that remained was for them to simply open up in space, but they "did not want" to do this. Why — we did not manage to understand until now. A similar unit was at the North Pole at nearly the very same time. And when a ski expedition under the leadership of I. Shparo appeared there, the tulips gladdened the courageous travelers with the bright flame of their flowers.

Operation "Orchid"

Nevertheless, it was quite enticing to achieve blooming of plants in space. Specialists of the Central Republic Botanical Garden of the Academy of Sciences of the USSR were included in the study. They chose epiphytic tropical orchids, many of which are exceptionally decorative. The botanists assumed that the epiphytic, that is nonterrestrial, form of life of the orchids should weaken the geotropic reaction. After all, the fastening of their roots in cracks in the bark, hollows, and forks of the branches is brought about primarily by the presence of nutrient substances and water. The roots of orchids are capable of growing in lateral directions, and even upward, in search of an appropriate substrate.

These plants possess a record duration of flowering — up to six months. Eight species of orchids were selected, with regard for these circumstances.

This time, it seemed that everything was envisaged. The "Malakhit-2" system was designed, manufactured and tested: a phytocassette with two lamps and four containers for the plants. The containers were filled with an artificial ion-exchange soil, which was developed, in due course, for tests in the "Bios" complex, and then utilized in the "Oazis" and "Vazon" units.

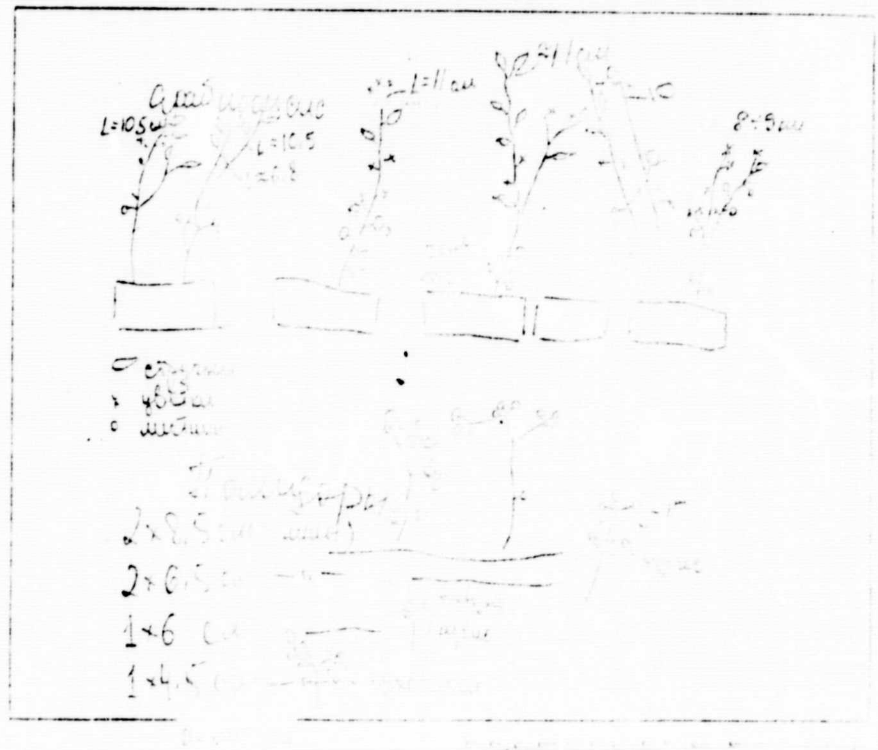
Cosmonauts V. Ryumin and L. Popov have already worked with the "Malakhit" on board the "Salyut-6" orbital station. Part of the orchids were dispatched already in bloom. The flowers fell off almost at once, but the plants themselves provided growth, with not only new leaves, but also aerial roots forming on them. Even without flowers, they gladdened the cosmonauts with their greenery. The single awareness that the plants were growing the same as on Earth, together with them, gladdened the cosmonauts, about which they spoke repeatedly during their reports from orbit.

Cosmonaut of the USSR S. Savitskaya and biologist G. Nechitaylo discuss the results of experiments with plants in orbit.

On July 30, 1980, V. Ryumin stated in his television report: "We have the 'Malakhit' system with plants. And even by the /6 arrival of our friend Fam Tuan from Vietnam, a blossom had developed in it". And he showed this blossom.

What had begun here! Then and there they reported to Kiev, and there they determined the name of this species, and, with impatience, began to await a bloom on Earth. And they got it. A beautiful pale-pink blossom appeared among the leaves in one of the containers... It was... expertly made of paper by the cosmonauts.

Operation "Orchid" taught us much. Although the exotic plants did not bloom in space, in contrast to their terrestrial doubles, which were almost continuously covered with bright flowers throughout the entire experiment in the control "Malakhit", they stayed nearly half a year on the "Salyut-6". But they need only be returned to the hothouse of their own botanical garden in Kiev, and they were immediately covered with

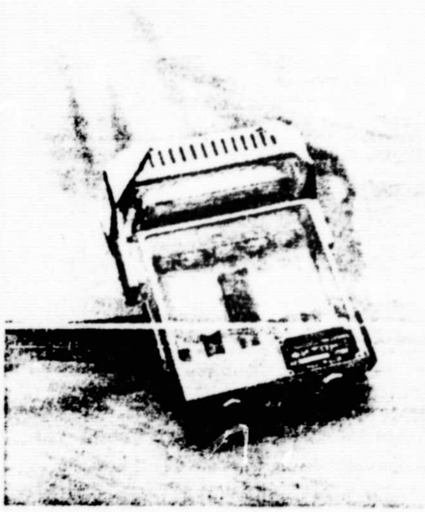


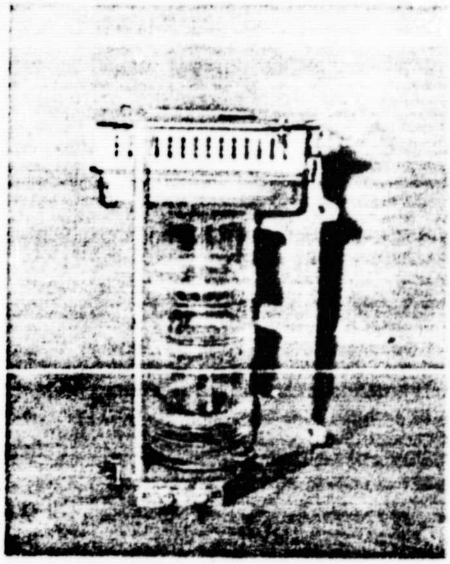
Page from the log book of the "Salyut-7" station
with the sketches of S. Savitskaya.

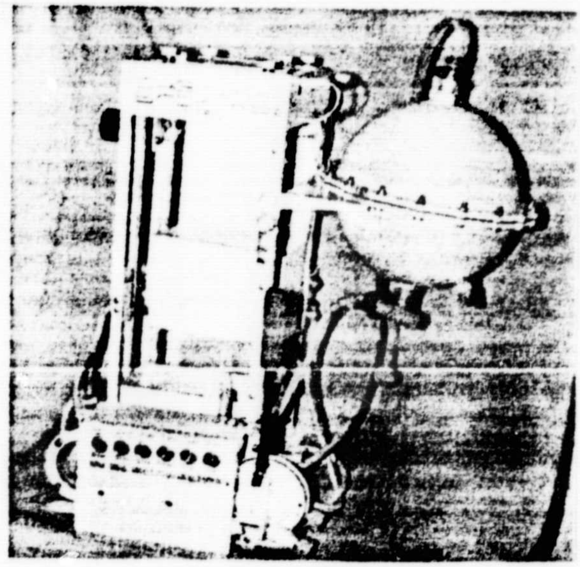
flowers once again.

And the dry swim of the cosmonauts, on the one hand, again showed us how great their desire was to see the blooming plants on board the station, which, hence, were satisfied with the created conditions, and, on the other hand — it cautioned them against taking that which is desired, and even visible, for that which is actually achieved.

But why, then, did the plants not bloom? In order to answer this question, many experiments were carried out during the last expeditions on "Salyut-6", and on the new station "Salyut-7", with a whole collection of original devices for cultivating plants.







Small orbital hothouse "Fiton" on board the "Salyut-7" station. It was here that Arabidopsis first went through a complete cycle of development and provided seeds.

Small orbital hothouse "Svetoblok". It was in this unit that Arabidopsis first bloomed on board the "Salyut-6" station.

On-board hothouse "Oazis-1A" of the "Salyut-7" station. The designers and botanists envisaged a system of dosed semi-automatic watering and aeration, electrical stimulation of the root zone, and replacement and movement of the vegetation vessels with the plants relative to the source of autonomous illumination.

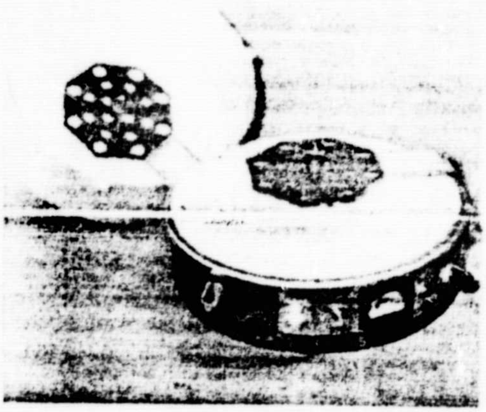
The Searches Lead to Success

It was necessary to help the plants cope with weightlessness. First of all, in the "Oazis", attempts were made to use stimulation with an electrical field. In this case, we proceeded from the assumption that the geotropic reaction is associated with the bioelectrical polarity of the tissues, evoked by the electromagnetic field of the Earth.

In space experiments, this assumption was only partially corroborated.

The studies were carried out in other directions as well. For example, plantules of some plants were grown in a small

"Biogravistat" centrifuge. It created a constant acceleration of up to 1 g on board the station. It turned out that, in the physiological sense, the centrifugal forces are equal to the force of gravity. In the centrifuge, the plantules were clearly oriented along the vector of the centrifugal force. In a stationary block, conversely, total disorientation of the seedlings was observed.



On-board unit "Biogravistat", with rotating and fixed disks for experiments on the germination of seeds under conditions of artificial gravity.

"Malakhit" hothouse on board the "Salyut-6" station after a three-month stay in orbit.

And in the "Magnitogravistat" unit, we studied the orienting effect of another factor — a heterogeneous magnetic field. Its effect on plantules of crepis, flax and pine also compensated the absence of a gravitational field.

In a word, the persistence of the researchers was enviable.

Finally, success came. And it fell to the share of the small, plain plant <u>Arabidopsis</u>. Having a development cycle of a total of about 30 days, it grows beautifully in artificial soils. During the last expedition on "Salyut-6", <u>Arabidopsis</u>

bloomed in the chamber of the "Svetoblok" unit.

On the "Salyut-7" station, where A. Berezovoy and V. Lebedev worked, the experiment on the cultivation of Arabidopsis was prepared especially carefully. There was a hermetically-sealed "Fiton-3" chamber with five cells and its own light source. In the cells was an agar substrate, containing up to 98% water. In proportion to the growth of the plants, they could move away from the light source. Using seeding guns, the seeds were sown by the cosmonauts themselves. At first, the plants grew slowly. But then, on August 2, 1982, V. Lebedev reported:

"Many, many buds have appeared, and the first flowers."

And on August 19, he inquired from orbit:

"Can Arabidopsis have pods?"

"Of course."

"And what color are they?"

"Green at first, and then they darken to light-brown."

"Then you and we are to be congratulated with success. /7
There are seven mature pods and many maturing. A genuine success!"

The cosmonauts presented a small bouquet of Arabidopsis flowers to Svetlana Savitskaya, who was present on the station. She carefully sketched it. In the drawing are seven blooming plants up to 10 cm in height, with 27 pods on them. Through calculation on Earth, 200 seeds were observed in the pods.

This experiment refuted the opinion of the impossibility of the passage, by plants in weightless conditions, through all stages of development — from seed to seed.

Granted, Arabidopsis is a self-pollinator, and pollination in it takes place even prior to opening of the bud. But, nevertheless, it was a huge success. And this was not only a success for the scientific staff of the Institute of Botany of the Academy of Sciences of the Lithuanian Soviet Socialist Republic, headed by Academician A. I. Merkis, but also for cosmonauts Anatoliy Berezovoy and Valentin Lebedev. Now, one may say that space plant growing originated practically, and may evaluate its prospects.

To the Extraterrestrial Hothouses of the Future

"Let us fantasize", we proposed to Valentin Lebedev, who had returned from a 211-day flight. "Is a hothouse necessary in a prolonged flight?"

"Without a doubt, it is necessary. In tending the plants, in repairing, and thereby improving, our botanical units, we understood that, without plants, prolonged space expeditions are impossible. Before returning to Earth, it was simply a pity to dig out the plants. We removed them very carefully, so as not to harm even a single rootlet."

Finally, we had sufficient time to discuss not only the results of the conducted experiments, along with a program of new experiments, but also the most diverse designs of space hothouses of the future.

"These hothouses", the cosmonaut thinks, "will occupy entire compartments of extraterrestrial stations. After all, the plants need a different atmosphere than do people, with an increased content of carbon dioxide and water vapors. Surely, the temperature which is optimal for producing the greatest harvest should be different, as well as the duration of the illuminated day. And the most important thing is that they need actual sun light.

To make very large illuminators, or entire glass walls, is still technically impossible. Evidently, together with a slight increase in the dimenions of the illuminators, one should use mirror concentrators. The light flow, collected by them and directed inside the compartment, can be delivered, through a system of light guides, to the plants, similar to the way that moisture with nutrient substances may be delivered to them. Then, the prediction of Tsiolkovskiy that, with the selection of the most productive crops and the optimal conditions for their development, each square meter of extraterrestrial plantation may completely feed one inhabitant of the space population, will be fulfilled.

We are all convinced that this will come to pass!