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THE ASTROCULTURE™-1 EXPERIMENT ON THE USML-1 MISSION

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ABSTRACT

Permanent human presence in space will require a life support system that minimizes the need for resupply of consumables from Earth resources. Plants that convert radiant energy to chemical energy via photosynthesis are a key component of a bioregenerative life support system. Providing the proper root environment for plants in reduced gravity is an essential aspect of the development of facilities for growing plants in a space environment. The ASTROCULTURE™-1 experiment, included in the USML-1 mission, successfully demonstrated the ability of the Wisconsin Center for Space Automation and Robotics porous tube water delivery system to control water movement through a rooting matrix in a microgravity environment.

INTRODUCTION

Permanent human presence in space will require a life support system that minimizes the need for resupply of consumables from Earth resources[1]. A closed loop life support system based on the integration of biological and physiochemical processes offers the potential of being a safe and reliable way of meeting human life support requirements. Plants that convert radiant energy to chemical energy via photosynthesis are a key component of a bioregenerative life support system (Fig 1).

In the process of photosynthesis, plants absorb carbon dioxide, and release oxygen while conserving the carbon in a reduced form that serves as a food source. In addition, plants can be a means of providing purified water since the water transpired (evaporated) by the leaves is essentially of potable water quality. The plant root water and nutrient source can be from the hygiene or human waste water streams. Thus, plants can serve to effectively close the food, air, and water loops of a life support system. Also, such space-based plant growing facilities are a prerequisite for the conduct of meaningful plant science research in space.

Providing the proper root environment for plants is an essential aspect of the development of a facility for growing plants in space since fluid behavior is considerably different in a microgravity environment. Of particular concern is the problem of supplying adequate water to plant roots and

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avoiding oxygen depletion in the root zone because capillary pores remain filled with water. The objective of the ASTROCULTURE™-1 (ASC-1) experiment included in the USML-1 mission was to validate during a long duration exposure to a space environment the performance of a concept developed by the Wisconsin Center for Space Automation and Robotics (WCSAR) for providing water to plants. These data would allow us to more clearly understand the physics of the concept as well as to verify the performance of the components used in the flight hardware.

I. DESCRIPTION OF THE WATER DELIVERY CONCEPT

The WCSAR porous tube water delivery concept is based on the use of an inert matrix material within which are imbedded porous tubes (Fig. 2). Water (nutrient solution) is circulated through the cavity of the porous tubes under a low level of negative pressure. The water moves through the pores of the porous tube into the matrix material via capillary action and forms a water film over the matrix particles. The larger pores of the rooting matrix remain filled with gases (air) while the smaller pores are filled with water. This results in a non-saturated environment that is desirable for effective root functioning. The degree to which the matrix is maintained in a non-saturated condition is dependent on the particle size of the matrix material and the level of negative pressure imposed on the water within the porous tube. Since the water is held by the negative pressure in the tube and by capillary forces in the root zone, the liquid cannot escape from the root chamber into the atmosphere of the microgravity environment.

II. DESCRIPTION OF THE ASTROCULTURE™-1 FLIGHT HARDWARE

The ASC-1 flight hardware was sized to be contained in a middeck locker of the Orbiter (Fig. 3). A front view of the flight unit before it was inserted into the foam liner and into the middeck locker is shown in Fig. 4. A side view diagram of the flight hardware with the various components identified is shown in Fig. 5.

The main units of the hardware included; (1) a covered cavity (manifold) containing inert material that serves as the matrix, (2) porous stainless steel tubes imbedded in the matrix material, (3) a fluid loop (identified as the "supply" loop) consisting of a reservoir, pumps, and appropriate valves for controlling the pressure and flow of the water through the porous tubes, (4) an identical fluid loop identified as the "recovery" loop, and (5) a microprocessor for control and data acquisition function.

The ASC-1 experimental configuration included a manifold containing two rooting chambers. Each rooting chamber contained two porous stainless steel tubes placed side by side. The porous tubes in chamber 1 had a pore size of 30 μm and the tubes in chamber 2 had a pore size of 13 μm, as determined with the method defined in ASTM standard E 128-89[2]. The rooting matrix material used was

a crushed calcined clay (arcillite). The material was sieved to obtain a particle size range of 0.60 to 1.0 mm. The test solution was distilled water. The flow rate through the 6.8 mm ID porous tubes was approximately 230 ml per minute. Figure 6 shows a schematic diagram of the "supply" and "recovery" fluid loops contained in the ASC-1 flight experiment.

Since the primary objectives of the ASC-1 experiment were to provide data to substantiate the physics and mechanical aspects of the concept, no plants were included. Rather, one of the fluid loops (the "recovery" loop) functioned analogous to a plant root system by extracting water from the matrix. Plants will be added in subsequent flight experiments as the various subsystems required to support plant growth are added to the ASC-1 hardware.

III. EXPERIMENTAL PROCEDURE

A pressure differential was established between the "supply" and "recovery" fluid loops, to obtain water movement through the porous wall of the "supply" tube, through the matrix, and into the "recovery" fluid loop. The amount of water transferred was determined by measuring volume changes in the bellows reservoirs. The experimental treatment sequence consisted of two different "supply" pressures used in combination with three different "recovery" pressures. Table 1 shows a listing of the treatment pressure combinations used in the ASC-1 flight experiment. The treatments were programmed into the microprocessor contained in the ASC-1 unit which was capable of operating the ASC-1 unit in a fully automated mode following manual activation.

Before launch, the root chambers were filled with water and the reservoirs were left empty. Upon activation of the ASC-1 unit on orbit, each root chamber was conditioned for a period of 120 minutes to transfer the water not retained by capillary forces in the matrix to the reservoirs. After this initial conditioning, the sequence of experimental pressure combinations were started. The entire treatment sequence had an elapsed time of 28 hours. A second experimental treatment sequence was repeated after a 20 hour quiescent period. The two experimental sequence runs provide a means of estimating the repeatability of the observed data.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The ASC-1 flight unit was activated on the 5th day of the USML-1 mission by Captain Bowersox and operated for 28 hours (Fig. 7). At the end of this time, the unit was deactivated for 20 hours. The unit was reactivated on the 7th day of the mission for another 28 hour run. The crew periodically (~ every 6 hours during the 28 hour run) voiced down values that were displayed by the on-board payload general support computer. This allowed for real-time tracking of the progress of the experiment.

As an indication of the water delivery function, the amount of water transferred between the "supply" and "recovery" fluid loops during each treatment was computed for the two flight runs and two post-flight ground runs. An example of the volume changes in the "supply" and "recovery" reservoirs during a typical treatment run is shown in Fig. 8. The rate at which water was transferred between the two fluid loops, generally, was constant after 30 minutes of the treatment run. However, in some cases during space flight, the rate of transfer did not reach equilibrium until after 60 minutes of the treatment run. Therefore, for both the space and ground tests, calculation of transfer rates for all treatments were based on reservoir volume changes during the last half of the treatment period when fluid transfer reached a near constant rate.

The data shown in Fig. 9 are values taken from the last hour time period of each treatment when the fluid transfer rates had reached near equilibrium. Values for the two treatment runs in microgravity and for the two post-flight runs were averaged because data from the two runs were remarkably similar. Water transfer values for the "supply" and "recovery" fluid loops indicate that water transfer rates between these fluid loops was greater in microgravity than at 1 g. This suggests that hydrostatic pressures in the fluid loops at 1 g affected the fluid transfer rates in the 1 g environment. In the microgravity environment, such as on the Space Shuttle, hydrostatic pressures are virtually eliminated and consequently are not a factor affecting the transfer rates. Therefore, capillary forces and pressure differentials become the dominant components affecting transfer rates in microgravity. However, the fact that not all treatments show higher transfer rates in microgravity than at 1 g cannot be explained and warrants further evaluation.

Treatments with a "supply" pressure of -10 cm of water showed a significant increase in transfer rates in microgravity compared with values noted at 1 g. Whereas, data from treatments with a "supply" pressure of -5 cm water, with one treatment exception, indicated only a small increase in transfer rates in microgravity compared to data obtained at 1 g. In the 1 g environment, the water film thickness around the matrix particles and hydrostatic pressures likely reduced the transfer rates observed in the ground tests at the -10 cm "supply " pressure.

Porous tubes with a larger diameter pore size appeared to transfer more fluid than tubes with a smaller diameter pore size when the "supply" pressure was -5 cm of water. When the "supply" pressure was -10 cm of water, the transfer rates for the smaller diameter pore size tubes were at least equal to, if not slightly higher than for the larger diameter pore size tubes. These data indicate that when many of the large pores in the matrix are filled with water, as was the case when the "supply" pressure was at -5 cm of water, pore size of the tubes had little effect on the rate at which the "supply" fluid loop can replace the water extracted from the matrix by the "recovery" loop. At the more negative "supply" pressure, the

smaller diameter size pores likely maintain a better capillary interface between the porous tube and the matrix than is the case if the tube has a larger diameter size pore.

Increasing the differential pressure between the "supply" and the "recovery" fluid loops when the "supply" loop was at -10 cm of water had a hindering effect on the transfer rates during the ground runs, but not during the runs made in microgravity. In contrast, when the "supply" pressure was at -5 cm of water, increasing the negative pressure of the "recovery" fluid loop resulted in an increase in transfer rates both in microgravity and during 1 g conditions. It appears that as the thickness of the water layer around the matrix particles becomes thinner and only the small pores in the matrix are filled with water, the transfer rates become more sensitive to hydrostatic pressures if they are present. Thus, at an equal differential of negative pressure in the two fluid loops, a more negative pressure in the "supply" fluid loop (-10 cm of water) reduced the water transfer rate compared to the less negative pressure in the "supply" fluid loop (-5 cm of water). This effect is likely dependent on the particle size range of the rooting matrix used in such evaluations. The effect that matrix particle size has on transfer rates will be investigated in a subsequent ASC flight experiment.

V. SUMMARY

Although some differences were noted in specific aspects of the performance of the water and nutrient delivery system when operated in a microgravity environment compared to operation in a 1 g environment, these differences do not appear to have any significant effect on the use of this system for providing water and nutrients to plants in either environment. It has already been determined that this water and nutrient delivery system can support high rates of plant growth in a 1 g environment and should function equally well to support high plant growth rates in a microgravity or in reduced gravity environment[3].

It would be interesting to more clearly define the relationships of matrix particle size, fluid loop pressure, and porous tube pore size with water transfer rates and how these system characteristics relate to plant growth rates when using this concept for providing water and nutrients. Such information when combined with data from the ASC-1 flight experiment conducted during the USML-1 mission and planned subsequent ASC flight experiments will provide the knowledge needed to design the optimal configuration for the water and nutrient delivery system for the plant component of a bioregenerative life support system and for plant growing units for conducting plant research in a space environment.

REFERENCES

1. Stafford, T. P., et al., 1991. Report of the synthesis group on America's space exploration initiative, p. 100. U.S. Government Printing Office Washington, DC.

2. ASTM. 1989. Standard test method for maximum pore diameter and permeability of rigid porous filters for laboratory us. Designation: E 128-189.

3. Morrow, R. C., R.J. Bula, T.W. Tibbitts, and W.R. Dinauer. 1992. A matrix-based porous tube water and nutrient delivery system. SAE Technical Paper Series, Paper #921390, 22nd International Conference on Environmental Systems, Seattle, WA, July 13-16, 1992.

Table 1

Treatment Protocol Used in the ASTROCULTURE-1 Flight Experiment and Associated Ground Tests.

CHAMBER 1 Porous tube size - 30 μm

	Fluid Loop Pressure (cm w,c*)		
Treatment #	Supply	Recovery	ΔP
C1	- 10	- 10	0
1	- 10	- 10	0
2	- 10	- 15	-5
3	- 10	- 20	-10
4	- 5	- 5	0
5	- 5	- 10	-5
6	- 5	- 15	-10

CHAMBER 2 Porous tube size - 13 μm

	Fluid Loop Pressure (cm w,c*)		
Treatment #	Supply	Recovery	ΔP
C2	- 10	- 10	0
7	- 10	- 10	0
8	- 10	- 15	-5
9	- 10	- 20	-10
10	- 5	- 5	0
11	- 5	- 10	-5
12	- 5	- 15	-10

*cm water column

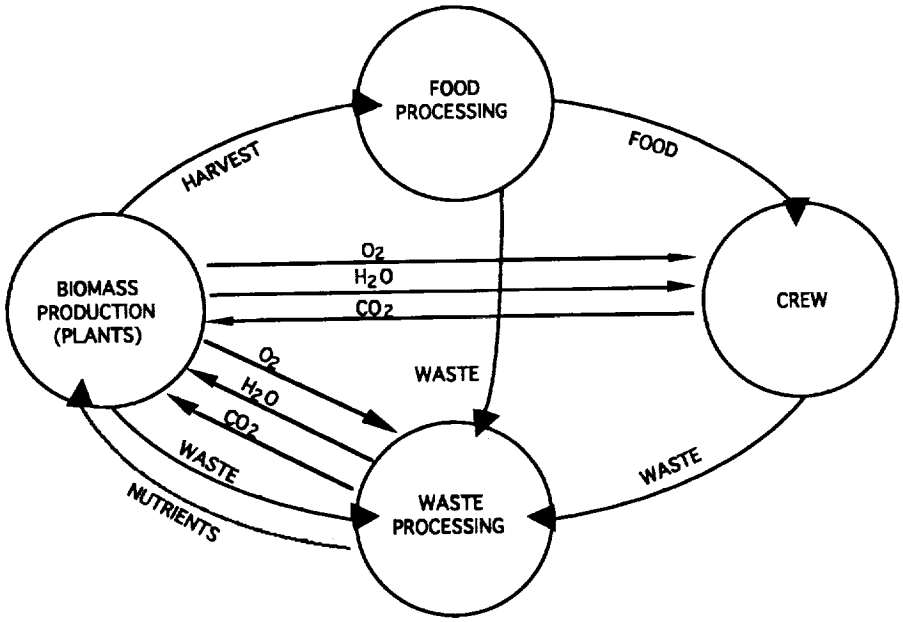

Figure 1 Diagram of a bioregenerative life support system.

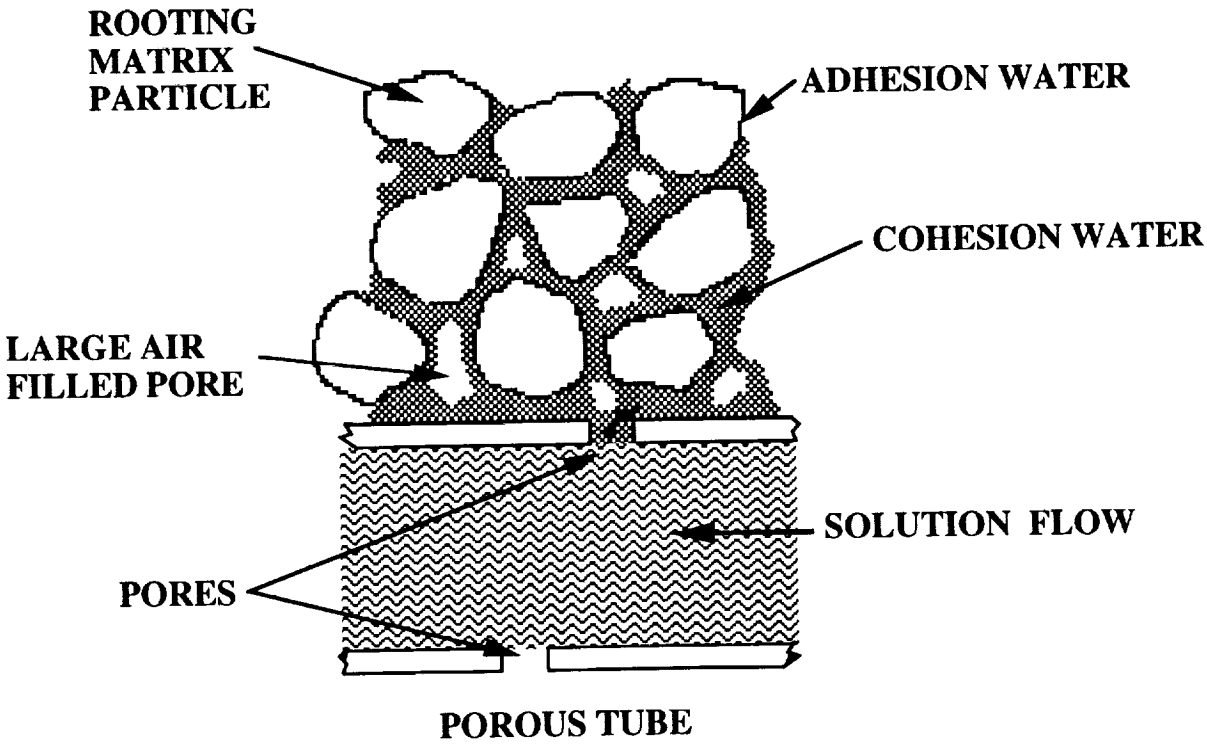

Figure 2 Diagram illustrating the concept of the water delivery system evaluated in the ASTROCULTURE-1 flight experiment.

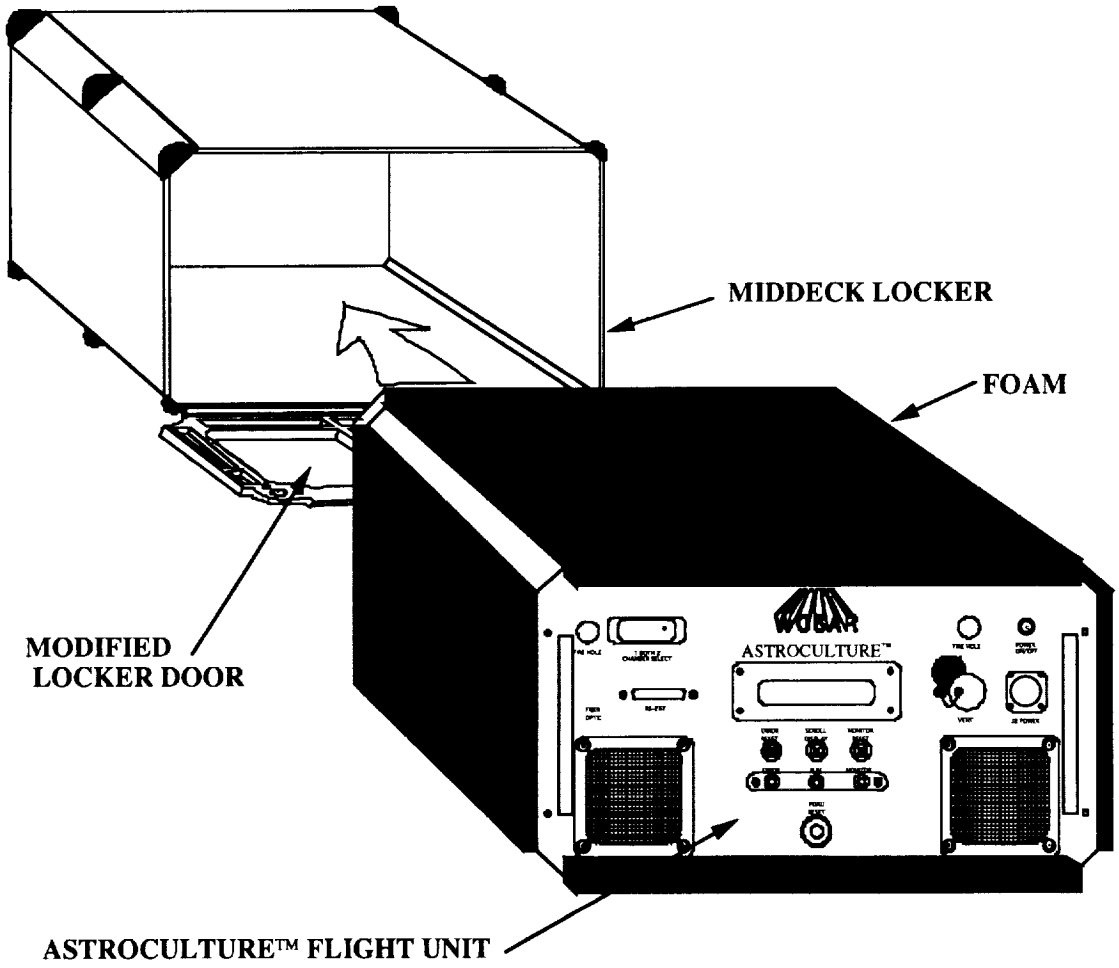

Figure 3 Diagram showing the integration of the ASTROCULTURE-1 flight unit into a middeck locker of the Space Shuttle.

Figure 4 Front view of the ASTROCULTURE-1 flight unit before being inserted into a middeck locker.

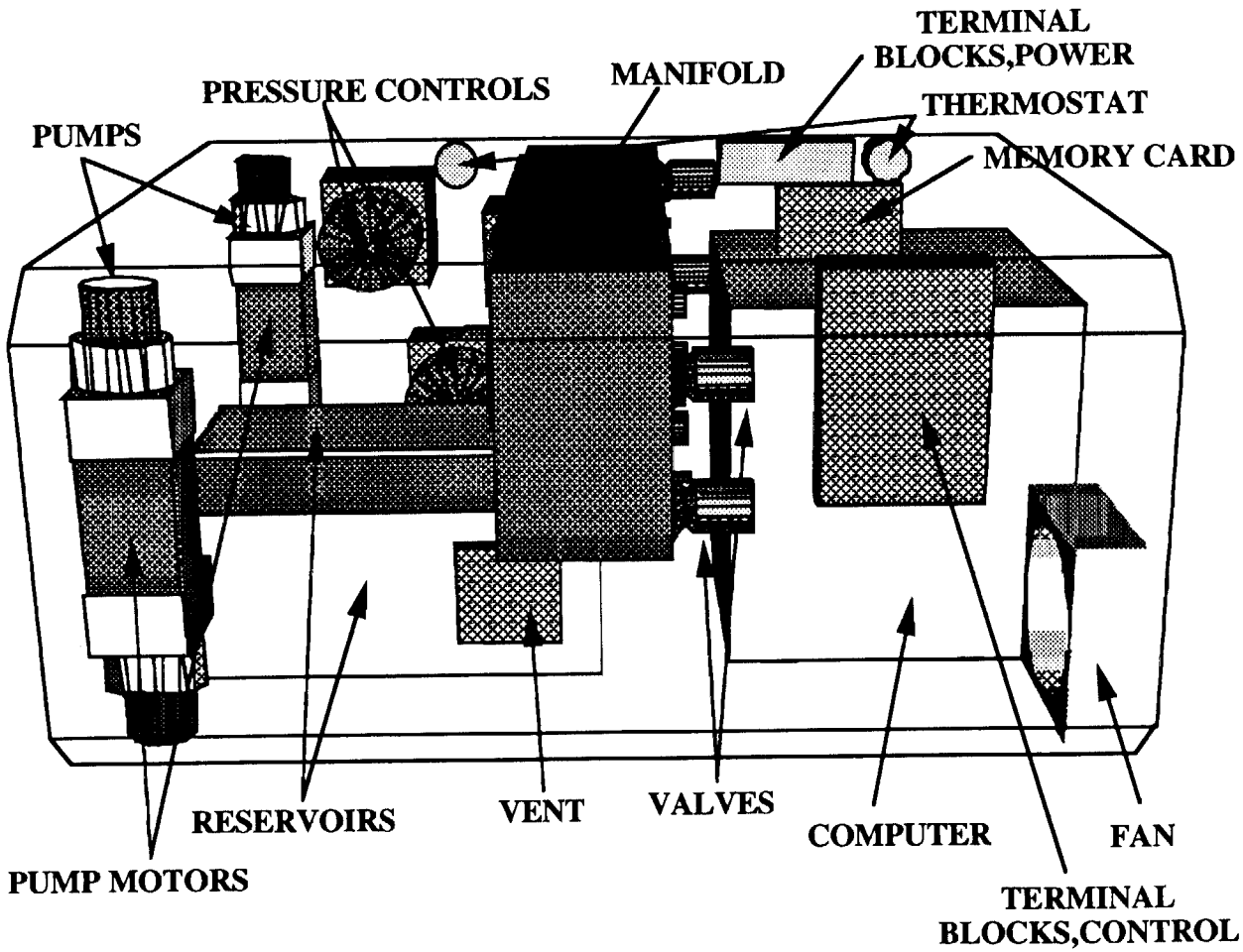

Figure 5 Side view diagram of the ASTROCULTURE-1 flight unit showing the layout of the various components.

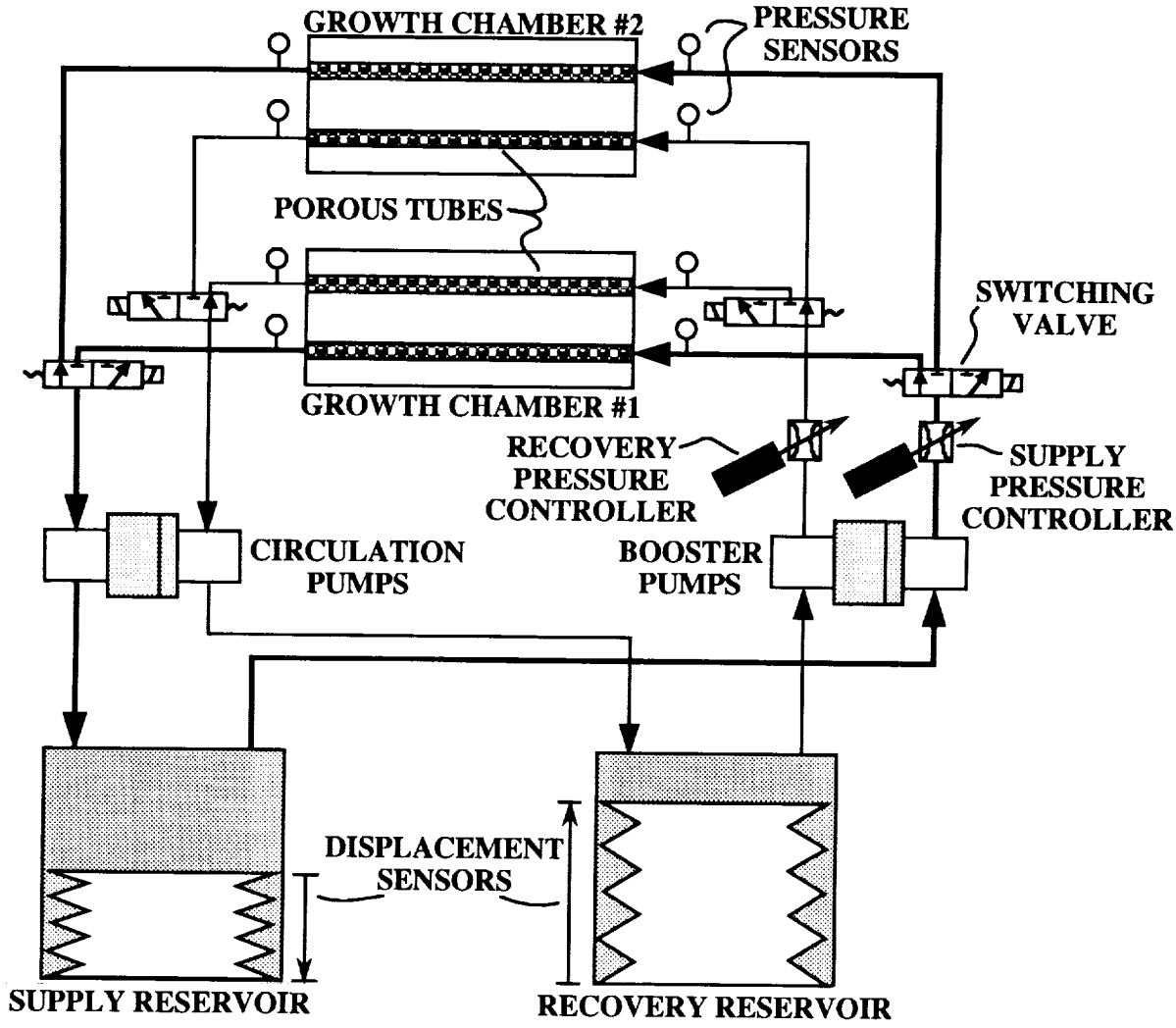

Figure 6 Diagram of the "supply" and "recovery" fluid loops in the ASTROCULTURE-1 flight experiment.

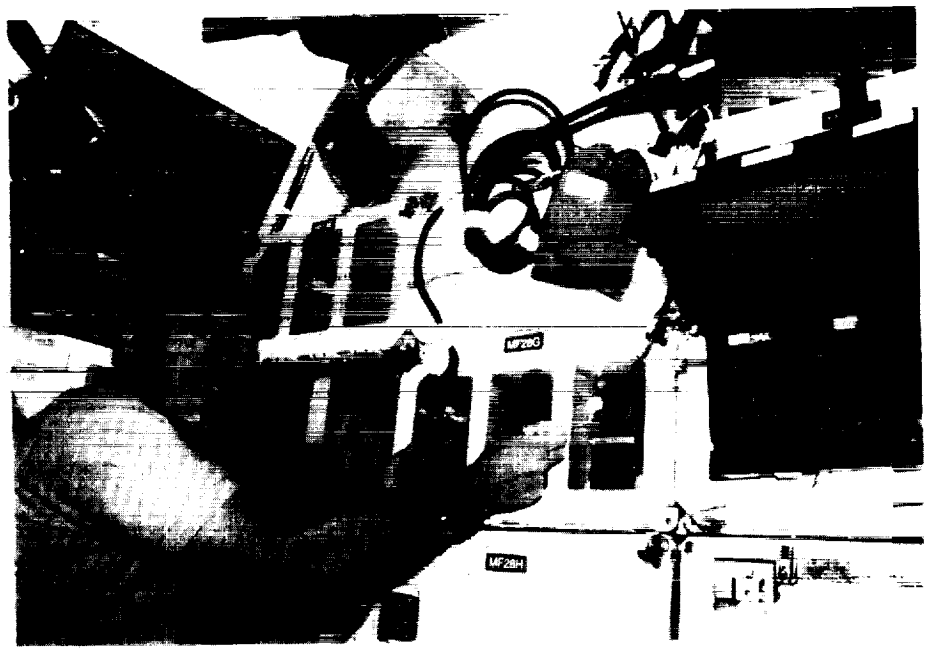

Figure 7 Pilot Ken Bowersox shown activating the ASTROCULTURE-1 flight experiment aboard Space Shuttle Columbia during the USML-1 mission.

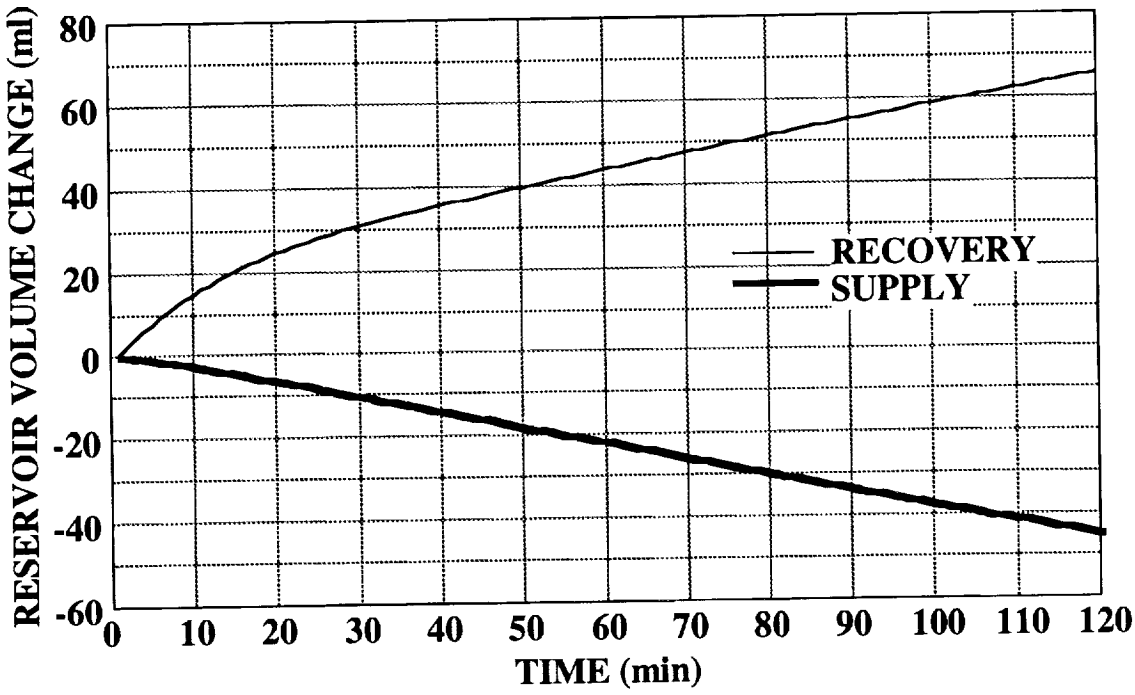

Figure 8 Example of typical "supply" and "recovery" reservoir volume changes observed during a 2 hour treatment period.

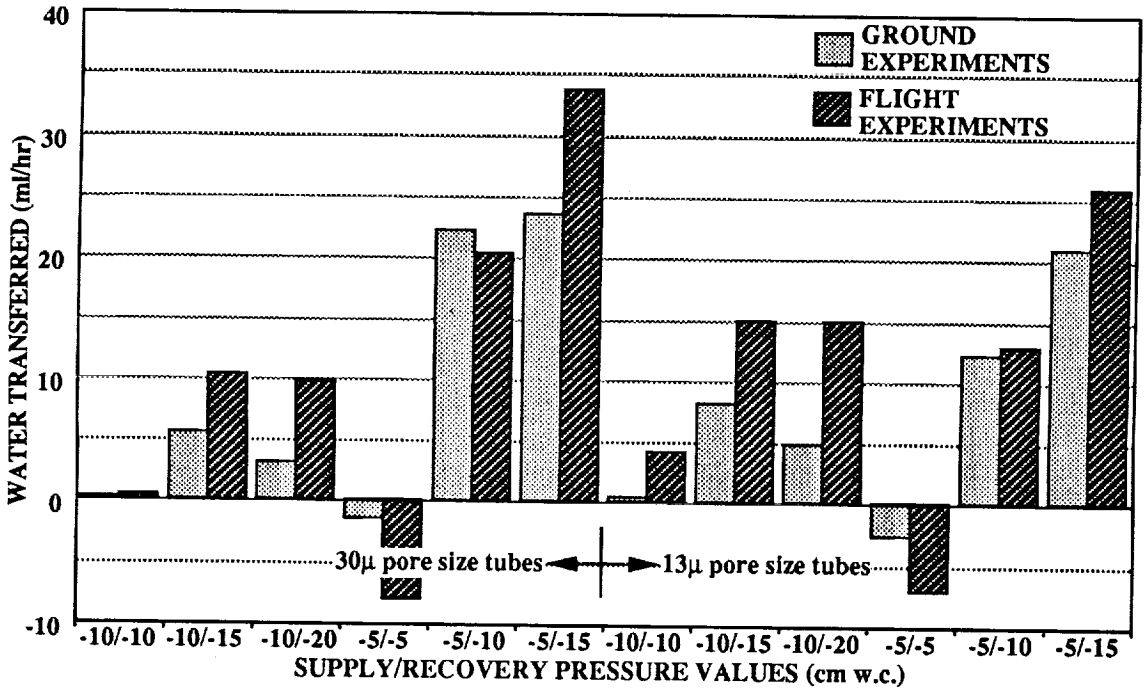

Figure 9 Graphic representation of the amount of volume increase in the "recovery" reservoir of the ASTROCULTURE flight unit during the last 60 minutes of the flight and ground treatment runs. Data are averages of two flight and two post-flight ground runs.

Discussion

Question: *Characterizing these tubes that simulated roots through their porosity, you are just describing them with core diameter that you used on these stainless steel tubes. There has got to be more to the characterization of the porosity of those tubes than just the holes that are in them. What about the density of those pores or their distribution and could you say a little bit more about that ?*

Answer: Bob, do you know about the size of the particles that are used in this. I didn't know that we know the size of the particles of the tubes. Stainless steel is ground up and then we reconstituted it by putting some resin where they have been pressurized. But in no way are we trying to simulate a root with that. We are only simulating a root with it being something that is taking up water and pulling it up.

Question: *I fully understand what the simulation concept is. The only problem is that you have a sintered structure; that is how those stainless steel tubes are made, from stainless steel powder and they are sintered into a structure. Somebody does metallography on it and tells you the model has 10 micron pores or 2 micron pores and so on. But the structure of that thing has what is called a permeability. The permeability establishes a relationship between the pressure difference in and out of that tube and the flux per area of the tube. Unless that permeability figure is known, it has to be calibrated because every sintered structure is different. Some of the differences you may be seeing are strictly of permeability effect which will only loosely correlate with the mean core diameter ?*

Answer: We basically calibrated our porosity by air entry. We have a porosity of about 50 %, I don't know if that is the kind of figure you are looking for.

Question: *I am looking for permeability. This is different from porosity.*

Answer: We know we checked this statement saying 50% porosity. We were very concerned with what we call an air entry value: how much negative pressure we could pull on those tubes before air would enter. We were in the range with the big pores of 25 cm water tension and then they start pulling air in.

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13. ABSTRACT *(Maximum 200 words)*

On September 22-24, 1993, investigators from the First United States Microgravity Laboratory (USML-1) and the First United States Microgravity Payload (USMP-1) Missions met with the Microgravity Measurement Group (MGMG) in Huntsville, Alabama, to discuss science results and the microgravity environments from the respective missions. USML-1 was launched June 1992, and USMP-1 was launched October 1992. This document summarizes from the various investigations, the comprehensive results and highlights, and also serves as a combined mission report for the two missions. USML-1 was the first totally U.S.-sponsored mission dedicated to microgravity research and included 31 investigations in fluid dynamics, crystal growth, combustion, biotechnology, and technology demonstrations supported by 11 facilities. The papers in these proceedings attest to the wealth of information gleaned from the highly successful mission. On the USMP-1 mission, both the MEPHISTO and the Lambda Point experiments exceeded by over 100% their planned science objectives. The mission also marked the first time that acceleration data were down-linked and analyzed in real-time. The meeting, which concentrated on flight results, brought low-gravity investigators, accelerometer designers, and acceleration data analysis experts together. This format facilitated a tremendous amount of information exchange between these varied groups. Several of the experimenters showed results, some for the very first time, of the effects of residual accelerations on their experiment. The proceedings which are published in two volumes also contain transcriptions of the discussion periods following talks and also submittals from a simultaneous poster session.

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