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OPERATIONAL DEVELOPMENT OF SMALL PLANT GROWTH SYSTEMS

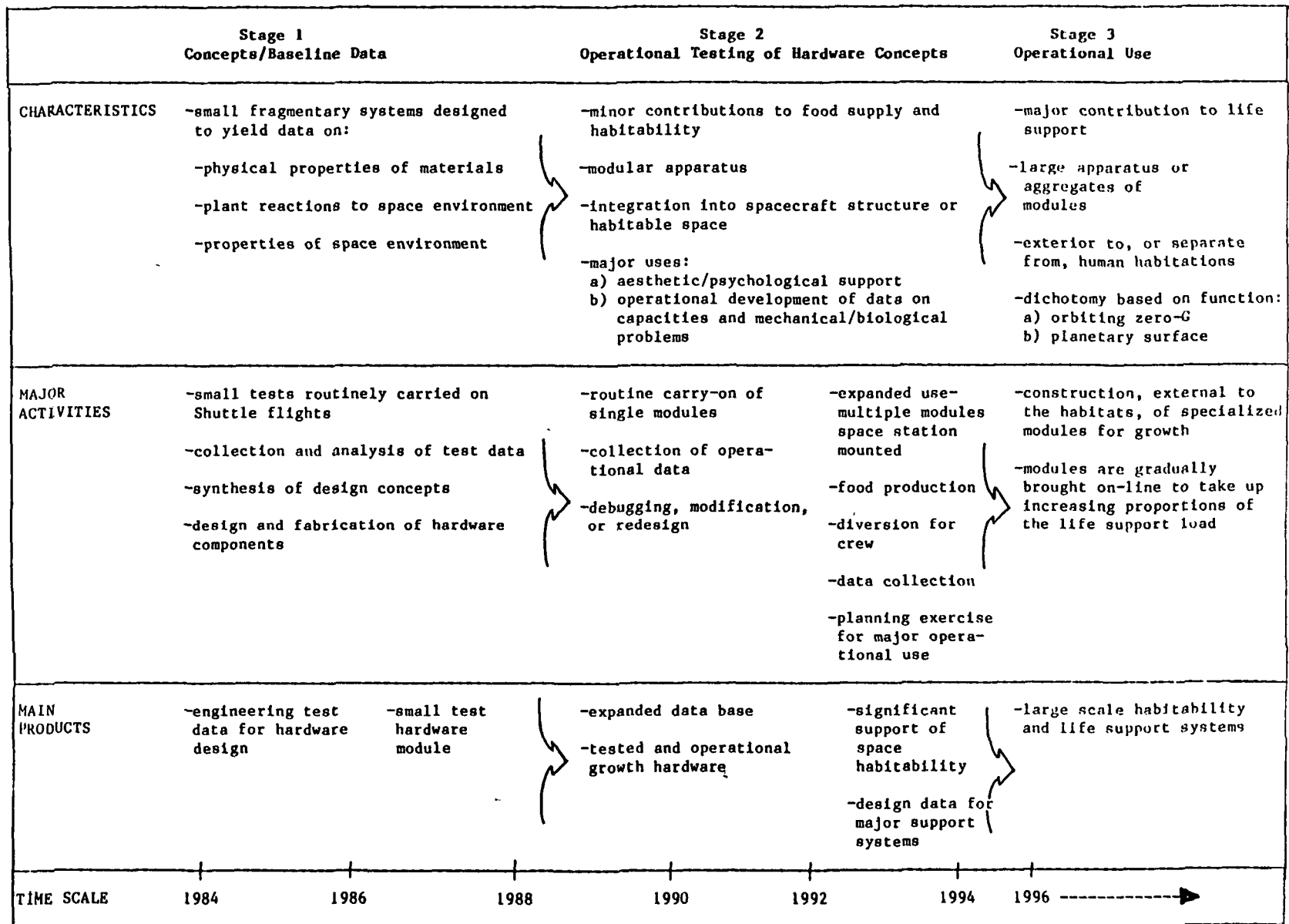
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Background

This report summarizes the results of a study undertaken on the first phase of an empirical effort in the development of small plant growth chambers for production of salad type vegetables on Space Shuttle or Space Station. The overall effort is visualized as providing the underpinning of practical experience in handling of plant systems in space which will provide major support for future efforts in planning, design, and construction of plant-based (phytomechanical) systems for support of human habitation in space. The assumptions underlying the effort hold that large scale phytomechanical habitability support systems for future space stations must evolve from the simple to the complex. The highly complex final systems will be developed from the accumulated experience and data gathered from repetitive tests and trials of fragments or subsystems of the whole in an operational mode. These developing system components will, meanwhile, serve a useful operational function in providing psychological

Figure 1. Time course for development of space-borne habitability support systems.



support and diversion for the crews, and/or some modest contribution to the food supply.

Rationale

An empirical approach appears entirely justified based upon our quite limited knowledge of the space flight environment and the responses of plants in that environment. It is useful to remember that the basis of what we consider to be modern terrestrial agriculture and horticulture was laid over the centuries in empiricism and art. Modern science and engineering have produced some remarkable advances, but none of these would have been possible without the ability to build upon the ancient foundation. That same foundation of experience is not yet available to those who wish to culture plants in space. We, therefore, will only be able to make appreciable progress if we have some reasonable body of empirically derived data upon which to build.

A general scenario for the long-term development of plant culture systems for space is presented in Figure 1. There is nothing about the target system or the pathway to its development that specifies precise configurations or technologies employed. We are, in effect, deferring specific questions related to the selection of final system concepts and approaches until we have gained sufficient data and operational experience in the handling of plants in space to support rational decisions. The present report summarizes the

results of efforts in definition of plant growth systems which will provide the needed operational experience and data on handling plant systems in space as well as some practical support of the flight food system.

The focus of this effort has been upon, as indicated in the Introduction, the examination of the practical problems of in-flight plant growth systems at the simplest useful level. It began with a given set of constraints and requirements and explored the possibilities within the envelope of these requirements. A relatively large number of dead-ends were encountered and while these are useful to know, a detailed account will largely detract from a discussion of the concept development. The discussions and diagrams which follow outline the major steps in the process of developing approaches to small plant growth systems for Shuttle.

Design Criteria

The following constraints were placed on the plant growth system:

A. Functional Requirements

1. to provide useful contributions to the food system - prime requirement;
2. to test empirically the "best guess" of what a growth system should be;
3. to provide a test bed for acquisition of experience and data.

B. Hardware Configuration

1. must fit into a standard slot in the orbiter; the bulkhead storage locker system;
2. must have simple, low cost construction;
3. must use the least complex growth systems consistent with adequate function; and
4. must be configured to grow salad-type vegetable plants.

After an examination of the various possibilities within the constraint envelope, three general approaches were adopted and pursued. The first, and simplest, was in the use of seed sprouts as a low cost, low technology means of producing fresh salad vegetable material. The second was, more conventionally, the use of standard green vegetable plants in a small, lighted growth chamber. The third was a test bed configuration for acquisition of basic data on plant response in zero-G.

Sprouting Systems

Seed sprouts offer a number of advantages both as a quick and easy way of providing fresh vegetable material in short Shuttle flights and as a more routine food for much longer duration space flights (Table 1). Seeds of various vegetables and field and forage crops can be stored dry for considerable periods of time. When fresh sprouts are required, water is the only input needed to bring about a five to seven-fold increase in fresh weight. The most important characteristic

Table 1. Comparative characteristics of seed sprouts and mature salad vegetable plants as candidates for testing and use in small, in-flight fresh food systems.

CHARACTERISTIC	SPROUTS	MATURE PLANTS
Time to Maturity	4 - 6 days	Up to 90 days
Complexity of Apparatus	Simple and compact: Necessity only for water and aeration; orientation not problematic.	More complex and larger: Provision for soil and nutrients, light and temperature control, orientation of plant parts.
Variety of Food Items	Limited: A single type of item with limitations in taste texture and range of uses.	Variety large: Limited only by ability to contain and grow the plant.
Popularity/Aesthetic Appeal	Limited because of food habits of general population. Not aesthetically appealing.	Wide popularity; high aesthetic appeal both during growth and at consumption.
Nutritional Value	Limited on amount which can be consumed raw without complications.	Adequate.
Processing/Use	Very simple. No waste, no mess.	Not complex, but with significant waste disposal problems.
Experimental Value	Useful for development of fluid/air handling and control technology.	Useful for development of soil, nutrient and microbiological technology. Useful for light and energy technology development and for study of air/gas handling.

is the marked increase in food value associated with sprouting (Table 2). Vitamin content increases dramatically, fat and carbohydrate content are reduced while relatively little protein is lost, fiber content increases, and many of the inhibitors and toxicants associated with seeds appear to be lost or reduced significantly.

Plant	DRY SEEDS												SPROUTS											
	Nutritional Value				Vitamins				Minerals				Nutritional Value				Vitamins				Minerals			
	Cal	Pro	Fib	Fat	A	B1	B2	C	P	K	Ca	Fe	Cal	Pro	Fib	Fat	A	B1	B2	C	P	K	Ca	Fe
Amaranth		16.7	4.2	7.5	.21	.09	2.25		3750	1701	93.4		246	24.0		6918	.54	1.08	546	456	2796	1818	26.4	
Lentil	340	24.7	3.9	1.1	60	.37	.22	t	337	790	79	6.8	304	23.8	1.0		.50	.20	t	240	670	39	7.6	
Mung	340	24.2	4.4	1.3	80	.38	.21	—	340	1028	118	7.7	245	26.6	4.9	1.4	140	.91	.91	133	448	1561	133	9.1
Soybean	403	34.1	4.9	17.1	80	1.1	.31	—	554	1677	226	8.4	276	37.2	4.8	8.4	480	1.4	1.20	78	402	—	288	6.0

Table 2. Nutritional value of dry seeds and their sprouts.

Apparatus necessary for seed sprouting is minimal. Light, soil, and the containers necessary for whole plant cultivation are not necessary; water and a well drained, aerated container are the major requirements. The space environment with the altered conditions of fluid movement places some constraints upon the process, but once recognized, elimination of these constraints is merely an engineering problem.

A number of potential issues were addressed and resolved during the development effort. These will only be listed here:

1. microbial contamination;
2. toxicant content of seeds and sprouts;
3. selection of species for use in flight conditions;
4. sources of water and water addition schedules particularly as they related to flight conditions;
and
5. storage and/or pre-germination of seeds.

None of these were seen as having an appreciable impact upon the use of seed sprouts in Shuttle or extended missions.

The systems depicted in Figure 2 represent the end point of an exercise which considered several different approaches to the problem of routinely producing salad sprouts on Shuttle. It utilizes the storage locker and the configuration of the standard half-locker tray (NASA, 1984) as a structural envelope. A number of issues related to operation remain to be worked out; many will depend upon flight testing for resolution.

The general features of the systems are as follows:

1. The seed sprout container is the standard six ounce Shuttle food system pack. Seeds are packaged and stored dry under vacuum in the same manner as the dehydrated foods.
2. The dry packs are installed in the unit as needed.

The first system uses a tool which perforates the bottom of the food pack, and the flexible cover is either perforated or removed. The second system connects to the standard "drinking straw" of the food pack.

3. Water is added to the dry seeds to initiate germination and is added periodically, as required, to maintain sprouting. Watering could be accomplished by hand, but a system for sensing moisture content and adding water as needed could be utilized.
4. In operation at micro-G, the system uses either a fan to pull a low flow of air down through the seeds into the space below or a microprocessor controlled water and air metering system connected to the standard "drinking straw". In the first system, the small air flow serves to aerate the seeds and in micro-G, theoretically, should be adequate to prevent the seeds or sprouts from floating out into the cabin environment. In the second system, no opening to the cabin is permitted.

The configurations shown in Figure 2 have been built and operated on the ground as a nonflight-qualified items. Issues such as watering practice, air flow, and general workability of the apparatus in micro-G will only be resolved by flight experience.

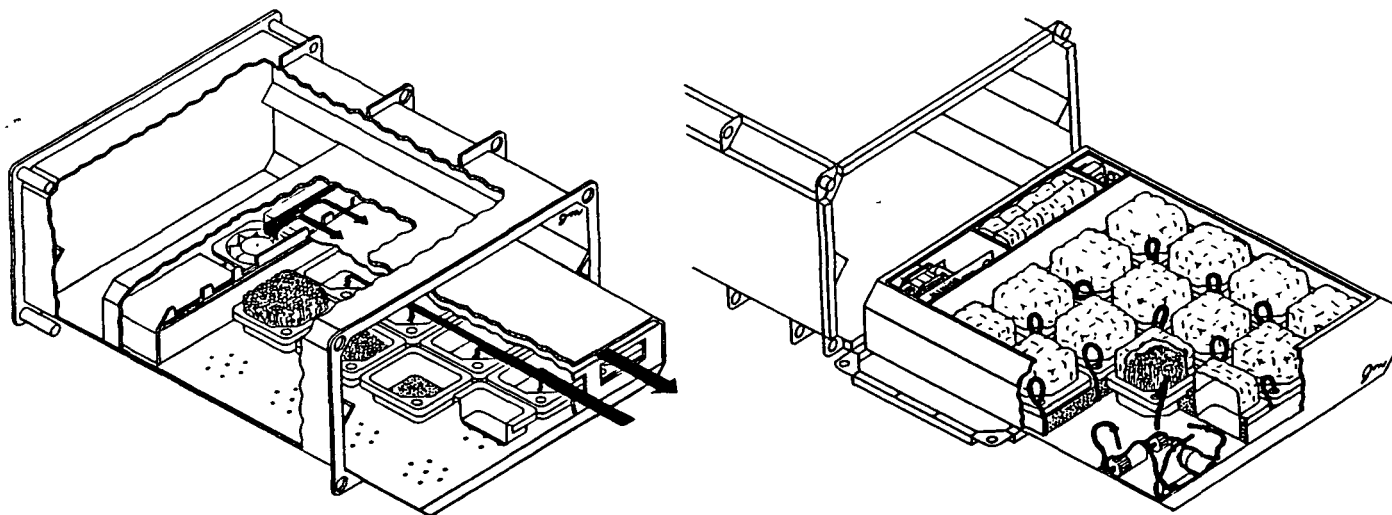


Figure 2. Configuration of Shuttle Middeck locker-based seed sprouting systems. Units are sized to a half-locker tray.

Whole Plant Chambers

The more conventional approach to growth has taken, as a starting point, the envelope of one middeck forward bulkhead locker, the exterior middeck dimensions of which are 21.062 in. x 10.757 in. x 18.125 in. A detailed description of the locker is included in the Orbiter Middeck Payload Provisions Handbook (Hix, 1984). Because of the practical approach taken in this effort, many of the orientation and space constraints of an earlier effort (Maine et al., 1979; Cowles et al., 1982, 1984) do not apply and thus more optimal use could be made of the available space.

The general effort had two thrusts:

1. A study of optimized configuration for the envisioned use; and
2. Consideration of the general array of technology to be taken into account in development of a growth system.

Figure 3 schematically summarizes the various issues as outlined below:

1. Optimal configuration of the container.
 - a. Geometry - which may be very dependent upon tests in a zero-G environment.
 - b. Volume of contained area - related to plant size and species.
2. Composition of the growth/support medium.
 - a. Synthetic, versus natural materials, versus a modified hydroponic/aeroponic system.
 - b. Porosity and affinity for water.
 - c. Fertilizer delivery system -slow release, versus ion exchange, versus hydroponic solution.
3. Operating parameters.
 - a. Air and liquid movement rates.
 - b. Temperature regulation of the root zone.
 - c. The role of microorganisms - important because of disease, human and plant, but also because microbes could function in atmosphere scrubbing.
4. Mechanical systems.
 - a. Air and water handling, zero-G separation of the two being the main problem.

- b. Water cleanup and conditioning.
 - i. Nutrient adjustment.
 - .. Removal of root and microbial metabolites.
- 5. The adaptability of various plant species to the system.

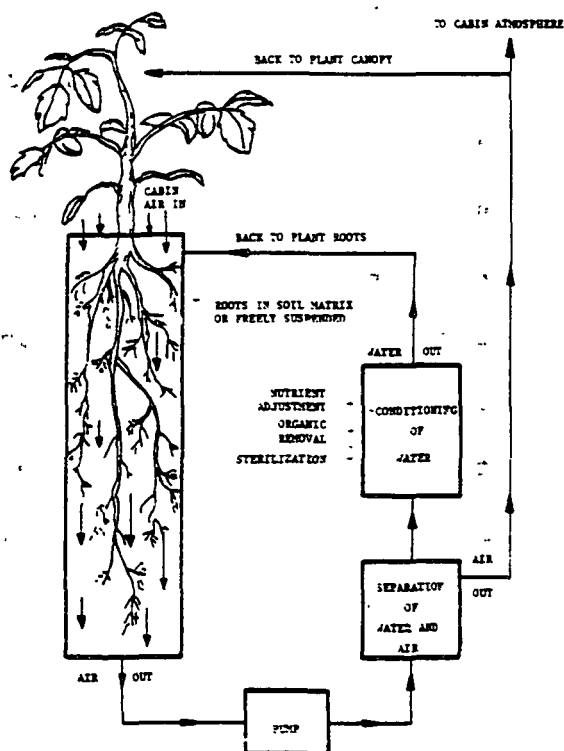


Figure 3. Concepts for control of watering and aeration in a zero-gravity environment.

All of the points listed are subjects of continuing efforts. This report and the growth chamber concepts it presents are merely single frozen moments in an evolving field. Much of what we add will depend on flight test data and experience.

Growth Chamber Concepts

The growth chambers, shown in Figure 4, embodies most of

the issues listed above. Figure 4-b depicts a configuration appropriate for dwarf varieties of small, bush-type plants such as tomatoes or peppers. Figure 4-a depicts the configuration more appropriate for a low profile leaf or root vegetables such as lettuce, onions, or radishes. In all tests it has been used to grow "feldsalat" style lettuce. All exterior dimensions of the chambers shown are the dimensions of the Shuttle locker. Materials are yet to be determined by flight configuration. In the models depicted, all materials are off-the-shelf foamcore, plexiglas or lexan for the shells with standard fluorescent light and electronic components. Units currently under construction utilize light metal and plastic sized to fit inside a standard locker which provides the primary structural strength and containment. Air inlets and outlets, power cables, and control panels are mounted in the modified locker access door provided as an alternative to the standard locker door (Hix, 1984).

Air flow is set to move across the plant from the Shuttle environment and to exit across the lamps to provide cooling. Growth media and roots are aerated and water is controlled by positive movement of air down through the growth substrate area aided by a small vacuum pump. Water is metered into the growth substrate area under control of a microprocessor controlled system that limits overwatering and movement of excess fluid.

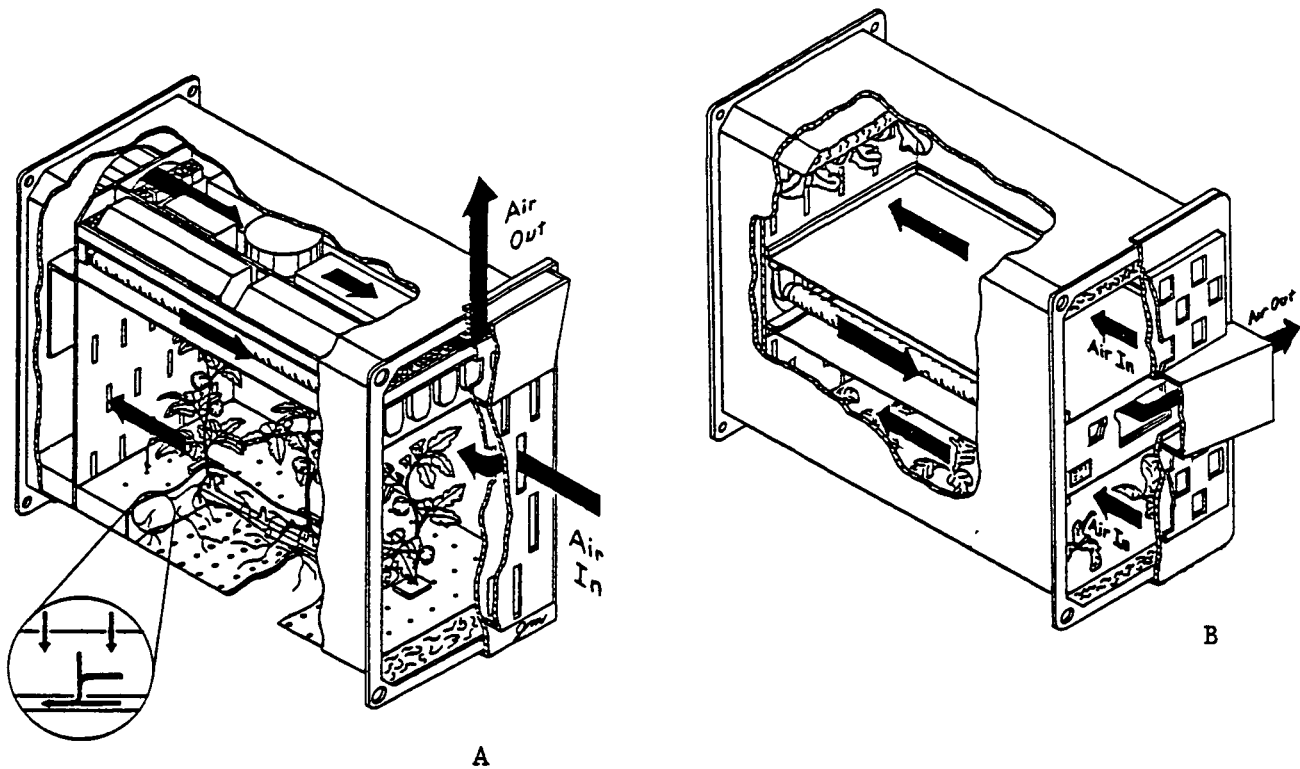


Figure 4. Configuration of shuttle middeck locker based growth chambers for salad vegetables. A - Dwarf fruit bearing plants. B - Leaf and root vegetables.

Working models of both configurations have been built and tested in the 1-G configuration with orientation of the lights, and other components, 90° to the flight orientation as the instruments would be mounted in a Shuttle locker. These configurations thus form a baseline and starting point for an effort aimed at flight development and testing of small growth systems.

Test Bed Configuration

Thus far two different plant growth chamber designs have flown on Shuttle. These instruments were essentially single

purpose, built to test specific hypotheses in gravitational biology. Published results from these experiments show in agreement with a number of reports from the Soviet experiments, that root growth had been affected in ways that were visible at the microscopic level (Cowles et al., 1982, 1984; Krikorian and O'Connor, 1982, 1984; Slocum et al., 1982, 1984). This provides some circumstantial evidence to support the intuitive expectations -- which are based on ample experimental evidence at one-G (Gates, 1975) -- that absence of gravity-driven convection will have a considerable impact upon the normal gas and heat exchange phenomena that are important to plant functions.

With the expectation that a thorough understanding of air and fluid movement phenomena in lower-G will be important to effective design of advanced plant culture systems, an effort was begun to develop a test bed system in which such phenomena could be studied. One of the instruments referred to above, the PGU, which was used in plant growth experiments on the STS-3 flight and was scheduled again in slightly modified form on SL-2, was evaluated first for its potential use in supporting such experiments.

The PGU was originally designed for simple containment of a large number of small growing plants with only a minor amount of monitoring or manipulation during flight. The requirements of an engineering data acquisition effort are, on

the other hand, for containment of one to a few highly instrumented plants. The problem is thus to replace much of the growth space to contain instrumentation for monitoring plant response. Figure 5 shows the original PGU flight package. Figure 6 shows an analysis of the availability of space for components of the expected experimental systems. The space available without major modification is the cavity occupied by the six PGCs (plant growth chambers). If only one or two of the PGCs are needed for containment of experimental organisms, then the remainder of the space is available for mounting of monitoring or experiment control instrumentation. There are a number of experimental operations involving primarily aspects of biochemistry or tropistic behavior which can be accommodated in the PGU under these conditions. Except for preliminary experiments on monitoring, it is of somewhat limited use in physical testing, particularly of the sort that employs optical measurements. Because it is difficult to modify for highly instrumented experiments that would require extensive rearrangement of the interior, the needs of a much broader range of tests can be better served by a more open structure. Other deficiencies of the PGU are in the absence of temperature control below ambient and in the control over quality and quantity of light.

The PGU, either in its present or derivative forms, has one other major deficiency: it is too complex and expensive to build for the number of units which are needed for routine experiment development. A basic need of nearly all flight

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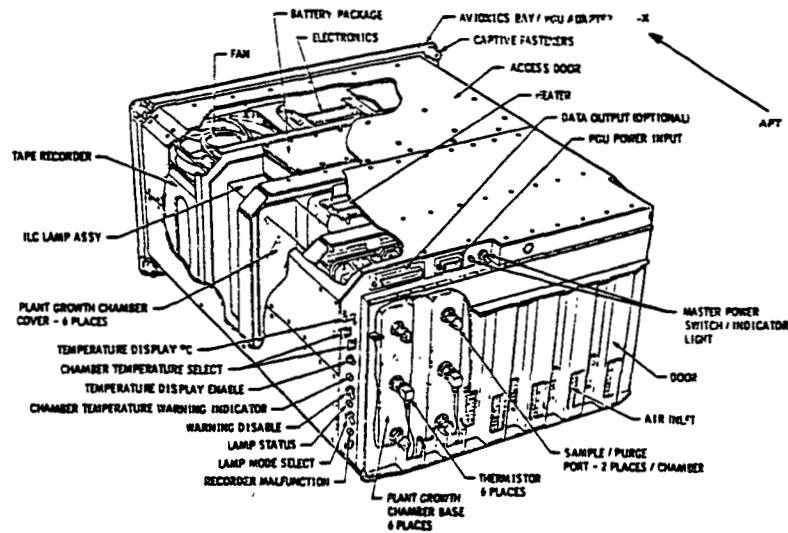


Figure 5. The Plant Growth Unit (PGU) of the STS-3 and SL-2 Lignification Experiments. Dimensions - 56 x 36 x 27 cm and sized to fit a standard middeck locker space. Weight as used on STS-3, approximately 24 Kg. Average Power as used on STS-3, 52 W at 28 Vdc. Power interface by single power cable to an outlet in the ceiling of the shuttle middeck. Source: V.S. Clifton, 1982. Spacelab Mission 2 Experiment Descriptions-Second Edition. NASA TM-82477. NASA George C. Marshall Spaceflight Center.

experimenters is for an easily obtainable, inexpensive, and well-standardized experiment container which can be used in the laboratory for experiment development and then integrated into a flight program with minimal effort.

The design shown in Figure 7 is a first attempt at meet-

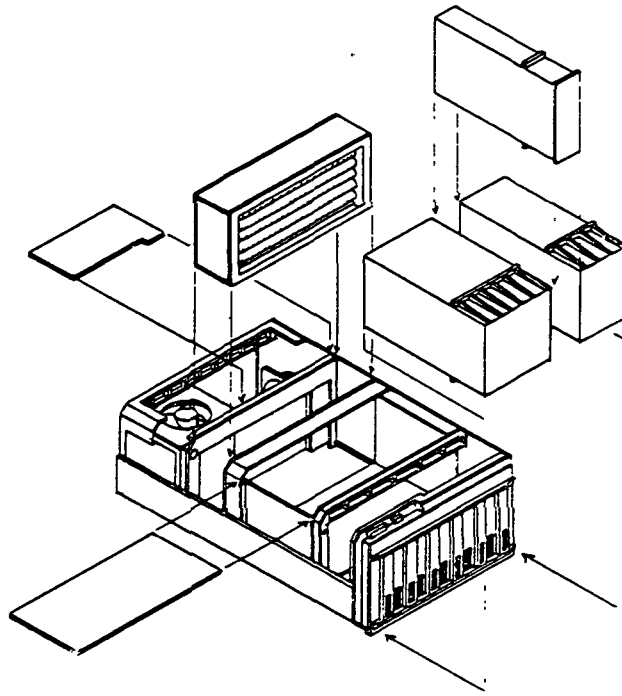


Figure 6. Blow-up analysis of space available for use in the PGU. Drawing is not to scale.

ing a set of requirements common to both our own specific line of experimentation and the general run of basic science flight experimentation with small plants. Our own experiments require a flexibly open space in which to mount a variety of test fixtures. The system used in development and exercising of the design is a system for optical monitoring of small plants, plant surrogates, gas or fluid experiments in which differences in density occur. The experimental support platform consists of a monocoque frame of aluminum sheet and honeycomb plastic built to the dimensions of a full locker tray and thus capable of being inserted into a standard locker. Side members of sheet aluminum formed into tubes serve as air channels for cooling of the interior. Inlet and exhaust screens are mounted in the modified locker door. The end caps

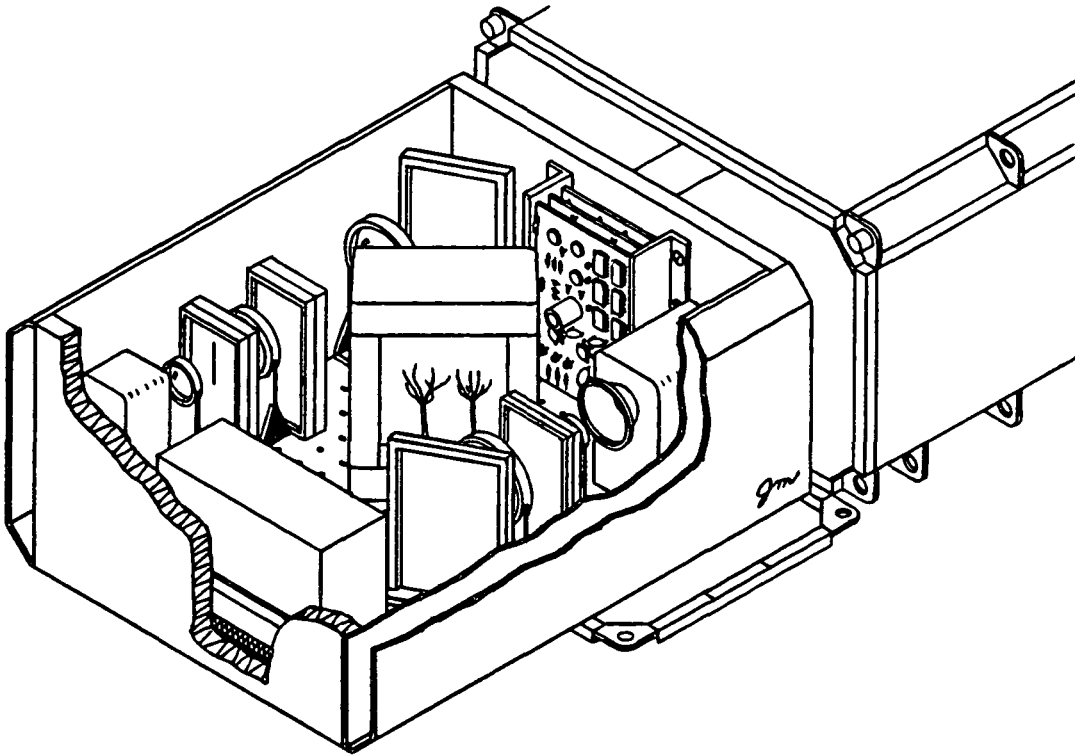


Figure 7. Plant experiment platform designed to support engineering data acquisition on the interaction of plants with the zero-g environment. The optical system is based upon a design by W. M. Poteet of System Specialists, Tucson, Arizona.

of aluminum covered lexan honeycomb provide additional rigidity. The side frame and the end caps are mounted with a regular array of channels or brackets which serve as attachment points for a variety of instruments. The version shown mounts an optical bench configured for color Schlieren optical monitoring of air movements around small plants mounted in a small wind tunnel instrumented for control of air velocity, temperature, humidity and atmospheric gas composition. The optical system was designed by W. M. Poteet of System Specialists, Tucson, Arizona. Continued development is aimed at the incorporation of microprocessor control of experiment functions and data acquisition.

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