

MICROGRAVITY PARTICLE REDUCTION SYSTEM

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SUMMARY

The Controlled Ecological Life Support System (CELSS) project, sponsored by NASA, is assembling the knowledge required to design, construct, and operate a system which will grow and process higher plants in space for the consumption by crew members of a space station on a long term space mission. This report addresses the problem of processing dry granular organic materials in microgravity. For the purpose of research and testing, wheat was chosen as the granular material to be ground into flour.

This report describes several possible systems which were devised to transport wheat grains into the food processor, mill the wheat into flour, and transport the flour to the food preparation system. The systems were analyzed and compared and two satisfactory systems were chosen.

Prototypes of the two preferred systems are to be fabricated next semester. They will be tested under simulated microgravity conditions and revised for maximum effectiveness.

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INTRODUCTION

Problem Description

An integral part of the CELSS project is food processing. Most of the higher plants that will be grown in CELSS will require complex food processing methods to form edible biomass into usable forms for food preparation in microgravity. Some examples are soybeans processed into soybean flakes for meat preparation, sweet potatoes mashed for dessert dishes, and wheat grains milled to flour for bread. This report addresses the problem of processing dry granular organic material in microgravity. Transporting, milling, and cleaning are some major problems to be solved.

It is assumed that the wheat has already been grown, harvested, separated for edible biomass, cleaned, and stored in a closed container. The goal of this project is to design a system to transport the grains to the mill, mill the wheat into flour, transport the flour to the food preparation station, and flush the processor for cleansing purposes.

Design Criteria

The design criteria are as follows:

1. The system must be in a sealed chamber and operate in a microgravity environment.
2. The system must be capable of batch processing approximately fifteen liters of wheat per day in order to provide each of the eight crew members with 2500 calories daily [Appendix A].
3. The system must be programmable and provide flexibility to adapt to different food preparation processes.
4. Materials used must be nonreactive and noncorrosive with respect to the chamber environment.
5. Volume and mass of the materials and equipment used should be minimized and optimized without compromising the design goals.

6. The noise and vibration should be minimized and lie within the range authorized by the NASA guidelines.
7. The system must have an effective cleaning process to avoid bacteria growth.
8. The air-to-flour ratio must remain below explosive levels and static electricity must be minimized.
9. The system must operate with minimal user interaction, servicing, and maintenance.

Background Information

Very little research has been done on food processing in microgravity. This research must be done in order to evaluate the applicability of this process for a regenerative life support system. Most of the research and fabrication which has been previously completed led to systems which far exceeded mass and volume constraints.

The current search for ways to grind dry granular materials in a low gravity environment began with an investigation of the methods used on earth by commercial flour milling factories and household milling appliances. The primary method of large-scale commercial flour milling is a system consisting of many pairs of closely-spaced corrugated cylindrical rollers. The rollers turn rapidly about their longitudinal axes with one roller of each pair turning faster than the other producing a shear to aid grinding. The wheat falls into the first pair of rollers and is coarsely ground. It then falls into the next set of rollers and is more finely ground. This process continues through several sets of rollers until the desired particle size is obtained.

Household milling devices were also studied. Household flour mills and coffee grinders are simple devices which grind in the same way as a household blender. However, in home mills, the blade is flat, not curved like a blender blade. Household

blenders and corrugated rollers rely on gravity for particle reduction and movement, so neither can be used "as is" in low gravity. These ideas may be altered and incorporated into a system which will function in microgravity.

CONCEPTS AND DESIGNS

Preliminary Designs

Corrugated Treads. Industrial milling systems which use corrugated rollers can be adapted to operate in microgravity. The basic structure of an adapted system (Figure 1) consists of a series of treadmills. The treads are corrugated by cutting grooves, perpendicular to the path of the wheat, in a thin metal sheet which forms the surface of the treadmill. Each successive tread is more finely corrugated to cut the wheat into smaller particles. Each treadmill in the series is meshed with another treadmill which turns in an opposite direction and at a different speed to produce a shear force as well as a normal force. Presumably, the wheat could be blown into the tread system from a storage area using an inert gas. According to Telesat, a satellite company which has designed a "space oven" which will be discussed later, an inert gas may be used in order to avoid explosions caused by critical mixtures of oxygen and flour dust and static electricity. At the end of the series of treads, a vacuum system could move the flour into a storage container.

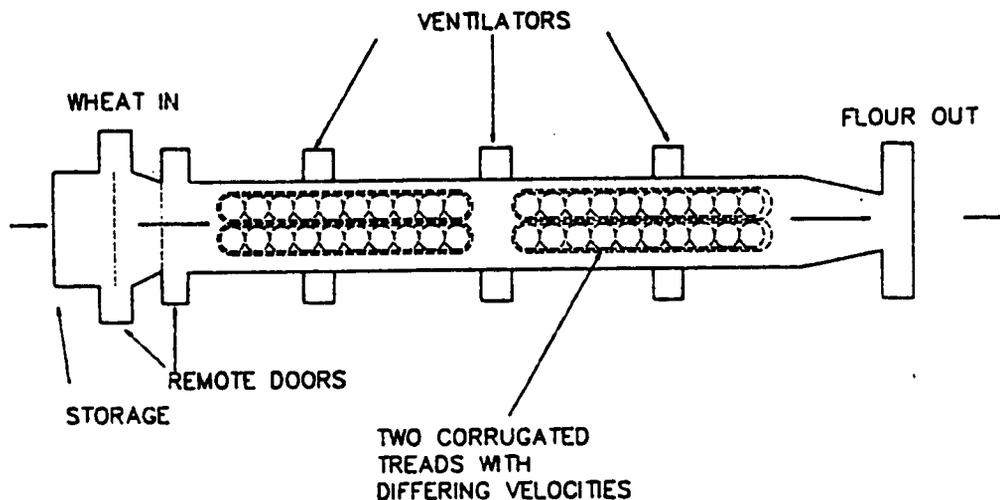


Figure 1. Corrugated Tread Milling System

A primary benefit of this tread system is successive particle reduction. The treads produce fine particles of consistent size. The advantage of the system for application in a low gravity environment is the flow induced by the rotating treads. This flow aids the movement of particles towards the storage container.

Disadvantages of this system are evident. First, metals satisfactory for the construction of this system would probably result in the system's weight exceeding acceptable values. Also, the structure of the system does not allow for easy control of the volume of wheat to be ground. Additionally, cleaning the system may be difficult due to the tendency of particles to lodge in the grooves of the treads.

This system was not tested due to the unavailability of materials required and cost limitations. However, detailed analysis of the system indicates that problems with the system would probably make it an inefficient choice for milling on a space station.

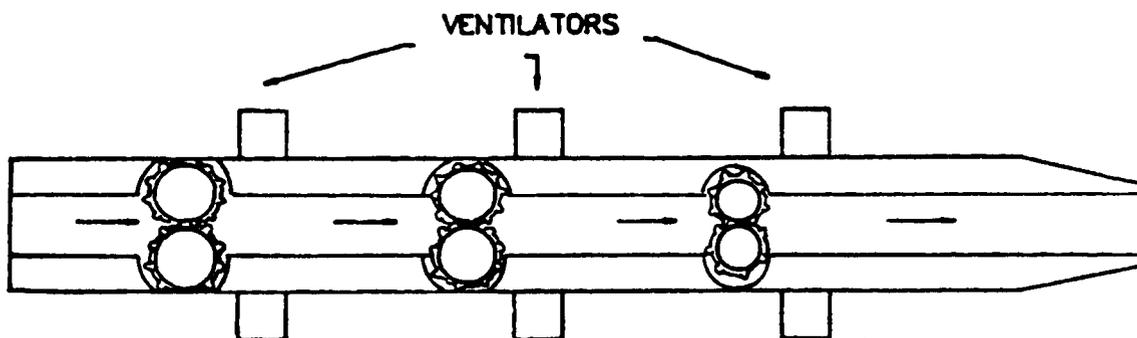


Figure 2. Worm Gear Milling System

Meshing Worm Gears. A series of meshing worm gears can be used as an alternative grinding method to the corrugated treads. This grinding system consists of a series of gear pairs of decreasing diameter (Figure 2). This method also has the

advantages of inducing flow of the particles and producing particles of consistent size. However, the gears would likely exceed the maximum allowable weight of the system.

A system of meshing worm gears was not practical for testing due to the cost and difficulty involved in fabricating gears. An analysis of this system led to the conclusion that, like the corrugated tread system, it is not an efficient method for use on a long term space mission.

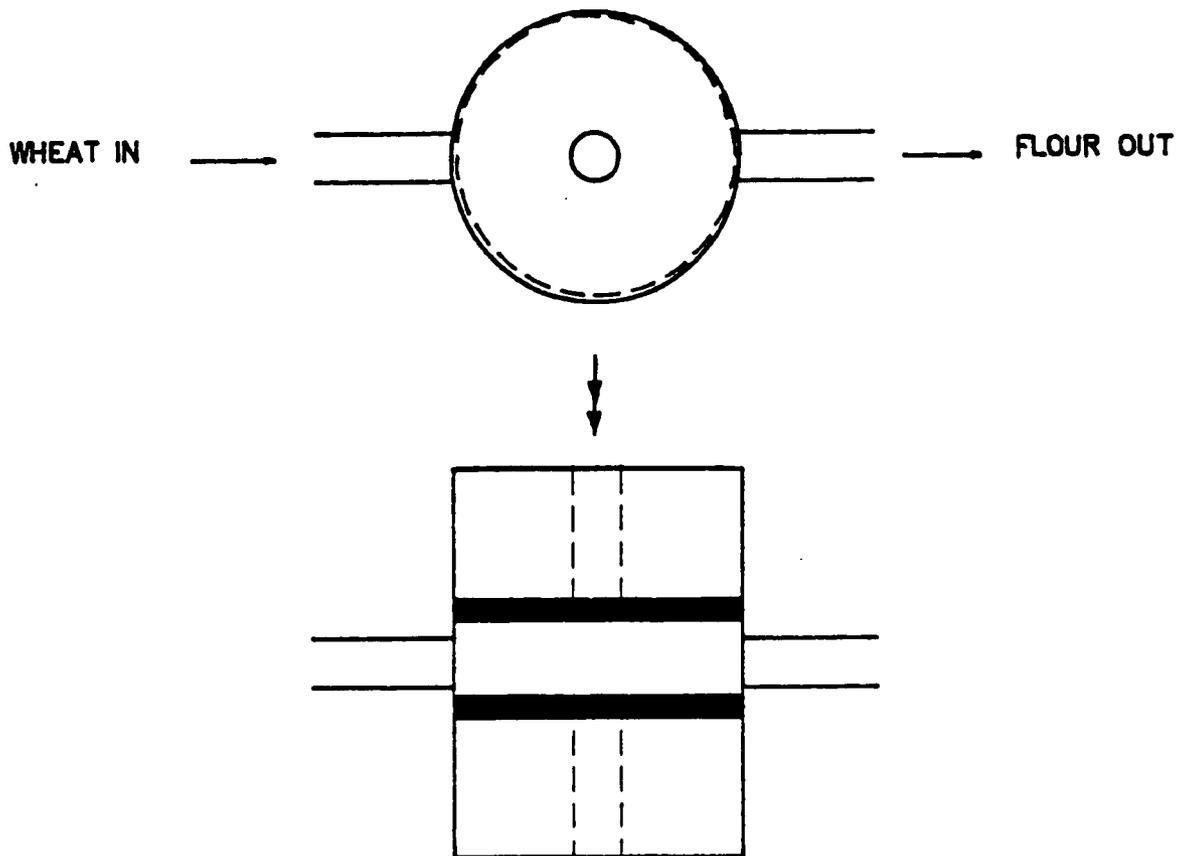


Figure 3. Disc Grinder Milling System

Disc Grinders. Another method considered for grinding wheat consists of rotating corrugated discs (Figure 3). Wheat is blown into the closed container which houses the discs. The discs are then forced together and rotated using shafts. The discs rotate in opposite directions and with different velocities producing a shear force which grinds the wheat.

This system has the advantage of weighing less than the corrugated tread system or worm gear system. However, the major disadvantage of this system is that it can only grind a small volume of wheat per batch compared to the amount which could be ground by the other systems. During small-scale testing, metal particles were chipped off the grinding disks, thus providing a possible source of contaminants. It was concluded that disc grinders were an inefficient method of grinding wheat if large volume output is desired.

Double-ended Blending System. A system adapted from household wheat mills, coffee grinders, and blenders was analyzed for low gravity particle reduction. In conventional systems, the Earth's gravitational field forces the unground wheat to contact the blades at the base of the blender. In low gravity the wheat may float freely about the container without contacting the blades. To simulate low gravity, a horizontal grinding container was designed (Figure 4). It was hypothesized that if the container was filled, rapidly rotating blades might induce a circulating flow of ground and unground material towards the blades. Thus, even in low gravity, all the wheat in the container would be ground.

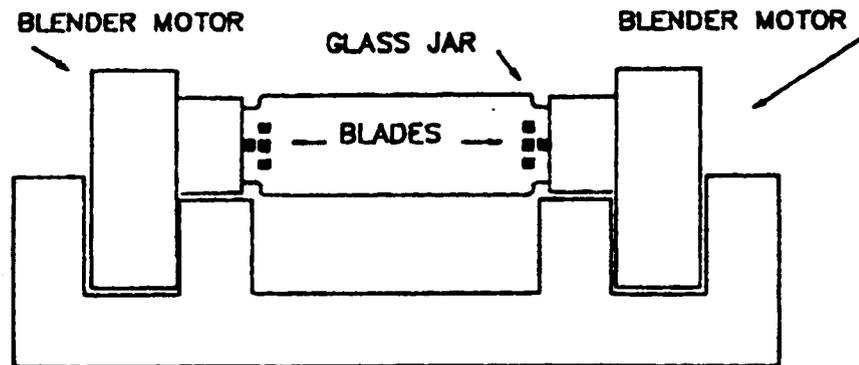


Figure 4. Double-ended Blending System

For testing, the container was filled six-sevenths full of wheat grains and household blenders were attached to each end of the container. Test results showed that the hypothesis was invalid. No flow was induced and only the wheat within about two inches of the blades was ground. The results of this test led to the design of a grinding method in which a shaft with multiple blades replaces the single blade. Systems using multiple blades as the grinding mechanism are presented in the next section.

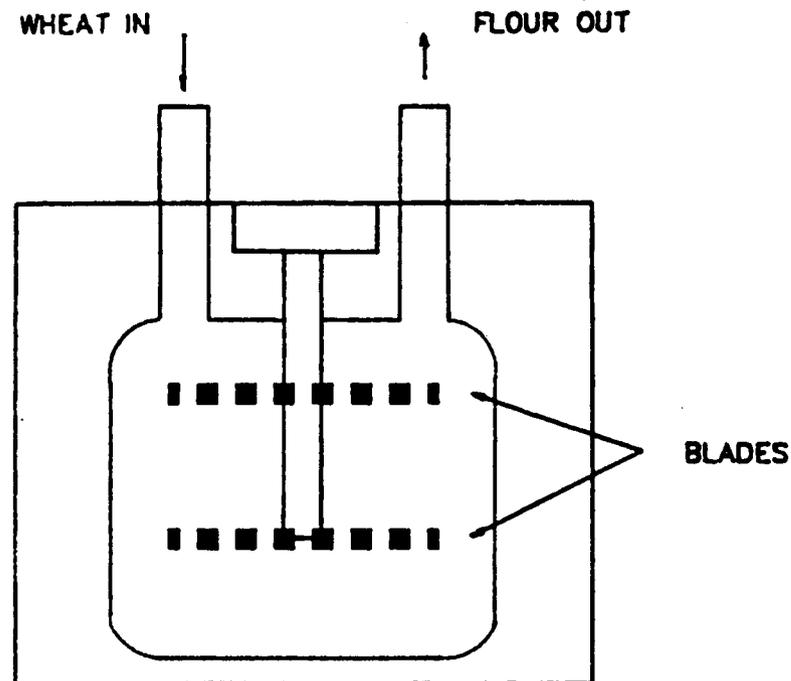


Figure 5. Blending Chamber Design

Proposed Final Designs

Blending Chamber. The blending method was chosen as the most effective of the preliminary designs. The double-ended blending system failed to grind the wheat grains in the central area of the container. The system presented solves this problem by incorporating multiple blades on a rotating shaft which extends to the base of the container (Figure 5). The

blades are flat and extend across the diameter of the container, leaving a clearance for rotation. The use of flat blades was suggested by Doug Bonebrake, an expert on milling systems. The optimal blade length and container size have not yet been determined, but may also depend on the amount of flour required per day by the crew. Preliminary calculations indicate that the system must be capable of batch processing approximately fifteen liters of wheat grain daily for the consumption of eight astronauts [Appendix A].

Based on the test results of the double-ended blending chamber detailed in the previous section, it was concluded that the blending chamber must be filled approximately six-sevenths full for effective grinding in microgravity, if a system of this type is used. The wheat grains would be blown into the chamber using an inert gas, to deter explosions due to static build up, and excess gas is vacuumed out through a filter attachment. When grinding is complete, the flour is vacuumed to the food preparation site.

Circular Track. A new system was designed which minimizes the volume and energy required by the food processing equipment, and also decreases the problems involved with transporting the wheat and flour in low gravity. Instead of transporting by blowing, the entire closed container can be moved along a circular track (Figure 6). The circular track has six ports, each having a particular function. The container travels along the circular track by means of a programmable motor and stops at each port. First, at Port 1, a pre-measured volume will be inserted into the container by blowing. Then the container travels to Port 2 where the multiple-bladed shaft is inserted and milling is performed. At Ports 3 and 4, food preparation systems can be installed. The container is emptied at Port 5. Finally, at Port 6, the container is cleansed by a high pressure inert gas purging method.

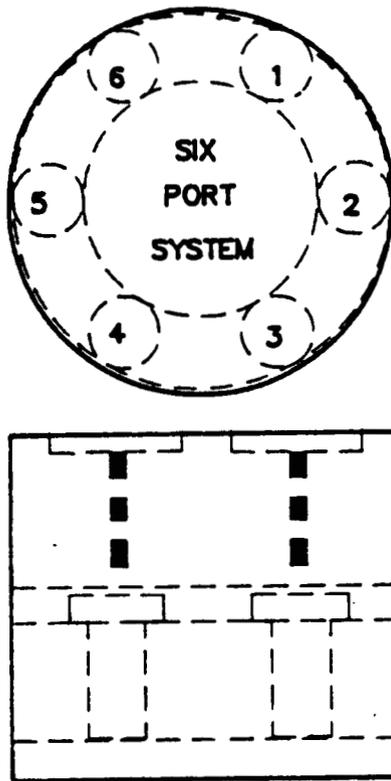


Figure 6. Circular Track Blending System

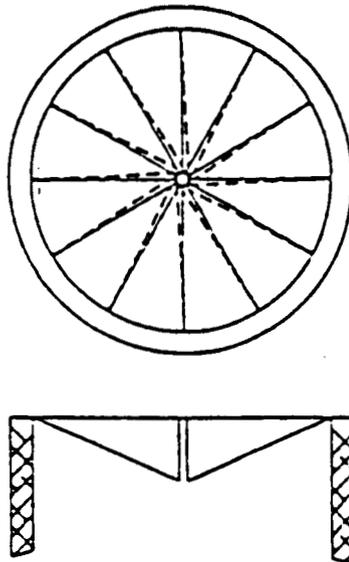


Figure 7. Rubber Gate Port Cover

Leakage is a critical problem to be considered in this system. The mechanisms which perform the functions at each port must be inserted into the container without permitting leakage. One possible solution has been tested to date. The rubber gate (Figure 7) was attached to the end of a full container of flour. To test the effectiveness of the rubber gate in preventing leakage, the container was then inverted and a shaft inserted into and withdrawn from the container. The only flour which leaked out was the small amount resting on top of the shaft. Further ideas for container openings are being developed and will be considered next semester.

The bladed shaft also requires special adaptation for use in this system. In order for the shaft to be inserted through the gate, the blades need to retract. This function may be accomplished by a spring hinge which allows the blades to be extended only when they are rotating rapidly. The rate of rotation of the bladed shaft has also been studied. A rate of at least 12,000 rpm is needed to ensure an efficient milling operation.

One important advantage of the circular track system is its versatility. It was designed so that further food processing operations may be easily performed. For example, Telesat, a communications satellite manufacturer based in Toronto, Canada, has designed and built an oven for baking bread in low gravity. If this oven is proven effective after low-gravity testing, it could be placed in the track system at Port 4. Port 3 would be designed to add water to the flour and mix the dough. Further information on this space oven may be obtained next semester.

RESULTS TO DATE

The research and testing completed to date has led to the design of two seemingly appropriate systems for use as microgravity food processors, the blending chamber and the circular track system. Both systems satisfy the design criteria and seem to satisfy the restraints placed on any equipment which must operate in low gravity. However, problems with these systems may not be apparent until they are built and tested.

PLANS FOR SECOND SEMESTER EFFORT

The primary objective for next semester is to fabricate a complete prototype system for processing dry granular materials in microgravity. The proposed solutions discussed in this report are the candidate designs for fabrication. The current plan is to construct the blending equipment, container, and gasket opening in order to evaluate the efficiency of blending and the prevention of leakage of particles upon equipment retraction. This prototype will then be altered to produce results within the project guidelines.

Once the blending operation is refined, the problem of building the transport system for the grains and flour will be approached. Finally, a cleansing method for the entire system will be developed. Fabrication of the final system will involve further research as problems arise and time will be allowed for altering and testing the system for low gravity applications.

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APPENDIX A

CALCULATIONS FOR DAILY FLOUR PRODUCTION

In reference to Table 30 (Appendix B), the minimum quantity of flour needed for a 2505 kcal per person per day diet is calculated as follows:

$$\frac{(681 \text{ kcal})}{(405 \text{ g wheat})} = 1.68 \text{ kcal/g wheat}$$

$$\frac{(2505 \text{ kcal/day})}{(1.68 \text{ kcal/g wheat})} = 1491 \text{ g wheat/day}$$

$$1491 \text{ g/day} * 8 \text{ people} = 11.928 \text{ kg/day}$$

$$48 \text{ lb/ft}^3 = \text{density of wheat}$$

$$(11.928 \text{ kg/day}) * (1 \text{ lb}/0.4536 \text{ kg}) * (\text{ft}^3/48 \text{ lb}) = 0.5478 \text{ ft}^3/\text{day}$$

$$(0.5478 \text{ ft}^3/\text{day}) * (2.8317 \times 10^{-2} \text{ m}^3/\text{ft}^3) = 0.0155 \text{ m}^3/\text{day}$$

$$(0.0155 \text{ m}^3/\text{day}) * (100^3 \text{ cm}^3/\text{m}^3) * (1 \text{ ml}/1 \text{ cm}^3) = 15,500 \text{ ml/day}$$

Amount of wheat needed per day for 8 people if only wheat is eaten is 15.5 liters per day.

Table 30. An Example of a "Modest" Diet Scenario, the so-called "Minimum" Diet (Quantities per person per day).

Species	No. of Servings	Weight as served, g	Food Energy, kcal	Protein, g	Fat, g	Carbohydrate, g	Calcium, mg	Magnesium, mg	Phosphorus, mg	Sodium, mg	Potassium, mg	Iron, mg	Vitamin A, IU	Thiamin, mg	Riboflavin, mg	Niacin, mg	Ascorbic Acid, mg
Soybean	2	180	234	19.8	10.2	19.4	131	58	322	4	971	4.9	50	0.38	0.16	1.1	-
Dry bean	2	190	212	14.0	1.0	38.2	90	72	265	12	746	4.9	-	0.41	0.14	1.5	-
Peanut	2	72	419	18.9	35.1	14.9	54	126	293	2	504	1.6	-	0.23	0.10	12.3	-
Wheat	6	405	681	25.2	2.7	141.9	81	326	810	-	351	5.4	-	0.21	0.12	9.6	-
Rice	4	390	464	9.8	2.4	99.4	46	113	284	-	274	2.0	-	0.36	0.08	5.4	-
Potato	4	600	416	11.6	0.4	93.2	40	132	282	8	2224	3.2	-	0.48	0.20	0.8	88
Carrot	1/4	19	6	0.2	0.1	1.3	6	5	6	6	41	0.1	1903	0.01	0.01	0.1	1
Chard	1/4	22	4	0.4	0.1	0.8	16	15	5	19	70	0.4	1182	0.02	0.05	0.1	4
Cabbage	1	145	29	1.6	0.3	6.2	64	19	29	20	336	0.4	180	0.06	0.06	0.4	48
Tomato	2	200	40	2.0	0.4	8.6	24	28	50	6	444	1.0	1640	0.10	0.08	1.2	42
Totals	2223	2505	52.7	324.1	552	762	2346	77	4999	23.9	4955	2.26	1.00	32.5	183		
Percent of RDA	93	185	69	218	293	5	(150)	170	100	101	63	181	305				
Caloric Distribution, %	15	20	65														

APPENDIX B

OVERALL CONCLUSION

Good progress was made this semester on the topics studied. The design for variable spacing between soybean plants is adaptable to a number of plant, and allows for seeding, harvesting, and refurbishment mechanisms. Initial calculations indicate that using the tray and chamber configurations developed, a substantial reduction in the volume needed for the growth of a soybean crop was achieved.

During the development of the automated seeding design, it was found that the direct charging of wheat seeds with electricity is not practical. The seeds did move within an electric field when placed in air, thereby recommending this technique for seed movement to a planting device. A mechanical technique which used the difference in pressure between the inside and outside of a container to hold seeds before transfer to a planting device was developed. The development of a gear-head seeder met with moderate success.

The three plant health sensing technologies chosen for further investigation show great promise for fulfilling the needs for a good remote sensing technique in the production of food crops in space habitats.

The problem of processing food grains in microgravity will involve the careful management of the materials, and the design of a closed container with sequential processing steps should fulfill that need.

The implementation of the designs developed this semester will be the focus of next semester. The quality of the people involved and their enthusiasm for the project should made next semester's work as successful as this one.