

# LOW EARTH ORBIT SPACE FARM

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## Abstract

The paper proposes a modular low earth orbit space farm which combines the current CELSS technology with a single launch, artificial gravity space vehicle to provide fresh produce to a nearby space station crew in a balanced exchange for their biodegradable waste and carbon dioxide. While growing a substantial amount of produce, the space farm will also be developing the plant propagation technology for transfer to future lunar colonies and to accompany long range space missions, ie. interplanetary exploration. The components of the space farm will be launched by conventional booster, then manned, assembled and operated by a crew of two. Since the space farm is habitable during all stages of development, the shuttle rendezvous to deliver the crew will be brief. Adding modules will facilitate increasing crop yields.

## Nomenclature

A	=area of one farm sector
A'	=seedling's area in one farm sector
A''	=2nd stage growth area in one farm sector
A'''	=final stage growth area in one farm sector
AT	=total area of farm sectors
A'T	=total area for seedlings
A''T	=total area for 2nd stage growth
A'''T	=total area for final stage growth
CEA	=Controlled Environment Agriculture
CELSS	=Closed Environmental Life Support System
ECLSS	=Environmental Control and Life Support System
F	=Force
g	=acceleration of gravity at earth's surface (mean)
g'	=acceleration of artificial gravity farm module (mean)
l	=length of truss
l'	=length of counterbalance (2nd stage booster + fairing)
l''	=length of airlock/main module
LEO	=Low Earth Orbit
m	=total mass of space farm
n.a.	=data not available
OMV	=Orbit Maneuvering Vehicle
Pi	=3.1416
RMS	=Remote Manipulator System
RPM	=revolutions per minute
r	=radius from center of farm module to spin axis

r'	=radius inside farm module cylinder
r''	=radius of farm module access way
STS	=Space Transportation System
t	=time of burn for spin motors
v	=velocity
Vs	=volume for hydroponics equipment under one farm sector
Vt	=total volume for hydroponics equipment under all sectors

## I. Introduction

The production of food in space is critical to man's self sufficiency there. Advanced orbital, lunar and planetary mission crews will require fresh food to maintain their health and morale. As NASA states: "The increased number of crew persons coupled with extended duration mission will require innovative crew equipment systems....[one of which is]... space farming."<sup>1</sup>

This paper explores one space farm scenario, specifically a technique for growing and harvesting edible foodstuffs in a single-launch, gravity-induced space station placed in low earth orbit adjacent to the forthcoming NASA space station. In the beginning the farm produce is used to supplement food required for the space station crew, then, following a series of developmental steps, the space farm takes over the supply of all nutritional needs for the space station crew or other long mission astronauts.

## II. Design Criteria

The following criteria provide the guidelines for the LEO space farm as outlined in this paper:

PROJECT COSTS to use existing technologies to reduce the necessity for developing new technology.

SINGLE LAUNCH to decrease the capital required to get the farm in orbit.

CROP OUTPUT to secure maximum carbohydrates.

DIVERSE PRODUCE to provide dietary mineral elements and stimulate the palate of crew on long missions away from earth.

ARTIFICIAL GRAVITY of 1/6th G created by spinning the vehicle

1. to overcome the difficulty of growing of plants in a weightless environment,

2. to more easily control fluids necessary in a hydroponic facility,

3. to produce a more healthful working environment for the crew, and

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4. to simulate the gravity of the moon, a prime location for the more extensive farming required during its exploitation.

NUTRITIONAL REQUIREMENTS and CROP SPECIE SELECTIONS are taken from a NASA report by C.A. Mitchell, et al.<sup>2</sup>

EXPANDABILITY to add modules to make a larger multi-module artificial gravity space station, increasing the farming operation, and if desirable, adding living units and a multigravity manufacturing facility.

TECHNICAL DEVELOPMENT PLATFORM with interactive artificial intelligence computers to carefully monitor records and facilitate the technology transfer.

## II. Description of the Space Farm

Like its earth bound counterpart, the space farm is composed of a variety of components:

MAIN MODULE, one specially outfitted NASA space station module divided vertically: crew operations and living 32%, ECLSS 19%, and plant growing 49%;

AIRLOCK, attaches to Main Module for crew and cargo egress, EVA suit storage, and outfitted as a safe haven;

TRUSS, a structural connection between Air Lock/Main Module and Counterbalance Mass which serves as extended arm of rotation and a structure to mount necessary additional hardware;

COUNTER BALANCE MASS, the fairing and expended second stage motor of the launch booster;

ZERO-G HUB, a portion of the Truss located at the center of mass of space farm;

SOLAR PANELS, attach at the Zero-G Hub and providing electrical power which runs through out the Truss to operate the farm;

OMV, the Orbiting Maneuvering Vehicle, the pick-up truck of the space farm, travels back and forth to the nearby space station delivering produce in exchange for waste materials and expendables. The OMV is parked on the Zero-G Hub;

RMS, the Remote Manipulator System, transports material between the OMV and Main Module, initially helping to construct the space farm. The RMS is on a carriage that wheels the entire length of Truss;

HEAT RADIATORS, COMMUNICATION ANTENNAE, and TELEMETRY attach to the Zero-G Hub.

Figure 1 shows the configuration of the major components of the space farm.

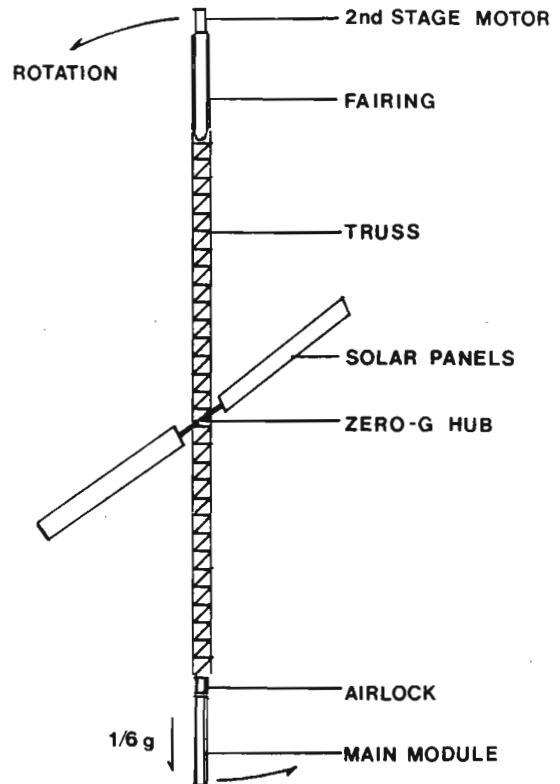


Fig. 1 LEO space farm.

## III. Launch and Rendezvous in LEO

A single launch by heavy booster is sufficient to launch all the components of the space farm. Although launch vehicles are now available in the U.S.S.R., soon the United States, China and ESA will also have a heavy booster. The NASA space shuttle cannot launch the volume of the space farm in a single launch. Because of the improbability of scheduling the component launches on two shuttles, what follows is the scenario using a Titan IV.

The Titan IV 34D7 (aka "Super Titan") is configured with two stages to put a payload of 39,000 pounds (16,783 Kg) into 28.6 degree LEO. This Titan IV with 86 ft long cargo fairing atop is loaded with the OMV vehicle (4'), the main farm module (46') attached to the airlock (14') attached temporarily to the zero-G hub (17') and solar panels folded alongside the zero-G hub. The truss members and RMS are packed in the remaining volume around and above (5') the zero-G hub. Figure 2 shows a section of the 2nd stage of a Titan IV carrying a cargo of the space farm components. Table 1 gives a detailed summary of the volume and mass of the components.

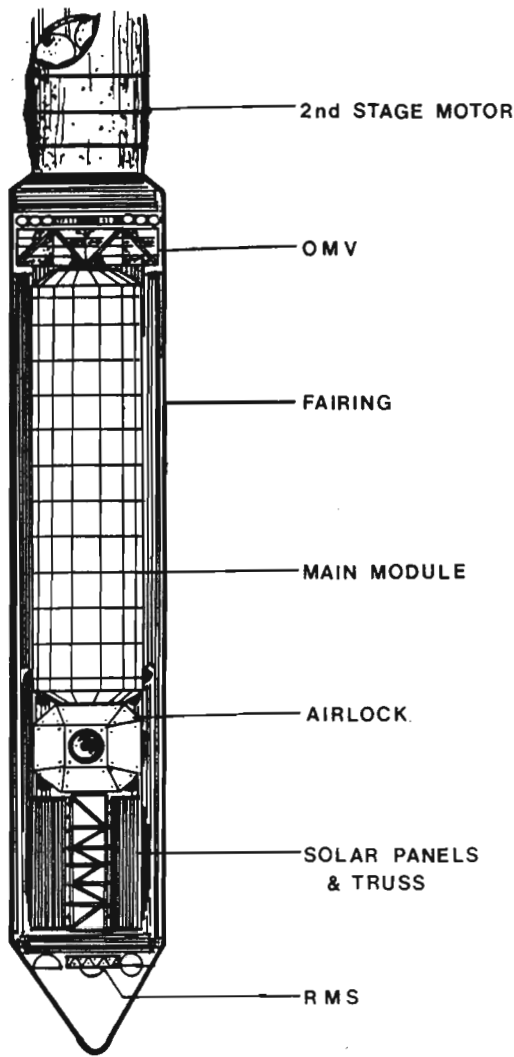


Fig. 2 Components storage.

Typically, the fairing of the Titan IV is jettisoned prior to 2nd stage ignition. But the space farm needs the expended 2nd stage booster and fairing to provide 23,000 lb of mass to counterbalance the farm module and airlock mass of 23,000 lb. With the Titan IV 2nd stage and cargo aboard in LEO, a crew of two astronaut farmers is brought up by NASA shuttle to assemble and run the farm. The farm is habitable during all stages of construction, thus freeing the space shuttle to take on additional assignments.

#### IV. Construction of Space Farm

The construction of the space farm in LEO begins with the opening of the fairing and extraction of the components. This entails first disconnecting the payload from the interior of the second stage rocket, and then pulling the farm package out of the fairing with a winch mounted to the upper end of the fairing.

After the main module and all attached components are out of the fairing, the solar panels deploy and the main module is activated. The crew enters the main module to verify that the systems are operational. Supplemental supplies are then transferred over to the main module from the shuttle and the shuttle is released to perform its other duties.

Main construction of the Space Farm starts by assembling the truss onto the zero-G hub on an axis perpendicular to the axis of the main module. This operation requires the RMS controlled by one astronaut inside the main module and one astronaut in EVA. Figure 3 shows the truss partially assembled with the zero-G hub at the midpoint, and the construction timetable is detailed in Table 2.

Table 1 Space Farm Components

Component	Length ft [m]	Diameter ft [m]	Mass lb [kg]	Stored Length ft [m]
Titan IV				
Payload fairing	86 [26]	17 [5]	12,000	
2nd stage motor	40 [12]		11,000(a)	
as Counterbalance	126 [38]	17 [5]	23,000	
Main/FARM module	46 [14]	15 [5]	20,100	46 [14]
Airlock	14 [4]	14 [4]	2,900	14 [4]
OMV	4 [1]	14 [4]	3,500	4 [1]
Truss	510 [155]	17 [5] (sq)	5,600	19 [5] folded
Solar panels			3,900	w/ Truss
RMS	3 [1]	17 [5] (sq)	3,000	3 [1]
as Payload to LEO			39,000	86 [25]
Total mass of space farm			62,000 [28,200]	

(a) burnt out mass; (sq) Truss is 17 ft square and RMS fits on truss

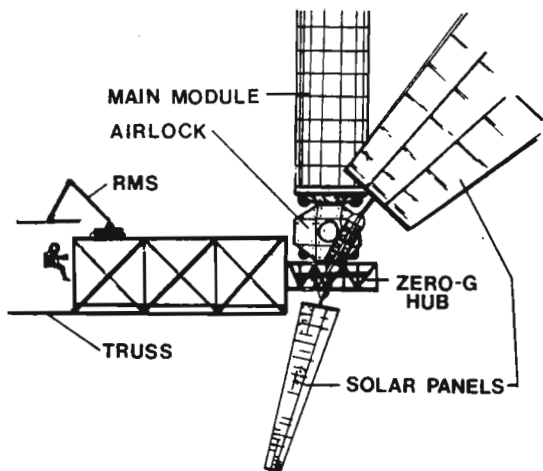


Fig. 3 Partial assembly.

After the assembly of the truss is finished, the main module and the airlock are disconnected and moved by the OMV to the end of the truss and secured in place. The electrical and thermal management systems are coupled. A shipping and receiving platform is constructed around the airlock. The 2nd stage fairing and booster are then moved to the opposite end of the truss and secured in place. The assembly of the space farm is now complete and the final step is to fire the rockets to start the vehicle spinning.

### V. Propulsion

There are three propulsion systems planned for the space farm:

#### Attitude Control Jets

The space farm uses attitude control jets for precision maneuvering and flight

Table 2 Construction and Operation Timetable  
Beginning with crew rendezvous in LEO and finishing with first delivery of crops

Description of event	Activity	Minimum		Maximum	
		hours	days	hours	days
<b>INITIAL OPERATION:</b>					
Open booster fairing, extract all components as one unit	2 men EVA	1		4	
Enter Main Module		2		2	
Deploy solar panels, telemetry and communication	2 men inside	0.2		1	
Verify systems operation		4	1	12	2
-----					
<b>ASSEMBLE SPACE FARM:</b>					
Construct truss					
248 longerons	1 man EVA.	(joint/min)		(joint/5min)	
120 diagonals w/ hubs	1 man RMS	(616 min)		(3,080 min)	
368 struts (616 joints)		10		51	
Decking around airlock	1 EVA/1 RMS	1		4	
Power & heat pipe run	2 RMS	2		12	
Move main module to truss end					
Dis/reconnect power/thermal	OMV/RMS	2		6	
Systems check		4		8	
Move counterbalance to opposite end of truss	OMV/RMS	2		6	
Verify/inspect all systems	1 EVA	4		12	
Orient space farm (attitude jets)					
Spin vehicle (spin engines)		2		2	
Verify all systems at 1/6th g		12	6	12	17
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<b>FARMING:</b>					
Pull wrappers off plant flats		4		8	
Initiate hydroponics		4		8	
Deliver first crops			45		45
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Estimated days to first delivered crop (EVA at 6hr/day, other work 8hr/day)		Min:	52 days	Max:	64 days

path corrections. The standard space industry units already developed for LEO missions are mounted on both ends of the truss.

#### Solid Fuel Spin Engines

Solid fuel engines are mounted on opposite ends of the truss, pointed to optimally spin the space farm, and designed to fire simultaneously. A cluster of three engines at each position is contemplated, each engine of equal power, the firing of any two opposing engines provides enough thrust to put the farm into a spin creating a 1/6th G artificial gravity in the main module, and on the counterbalance. The attitude control jets are used then to adjust and smooth the spinning flight path. Three sets of engines were chosen because after the initial firing of one set of engines to spin the space farm, the second set is reserved to de-spin, and the third set remains as a back-up system. It is contemplated that de-spin will be necessary to expand the space farm when adding additional modules, or for major servicing after a period of approximately ten years, or in case of structural emergency. The power requirements for each engine are as follows:

Assume the center of mass of the counterbalance and the airlock/main module are at their respective geometric centers, then

$$r = (l' + l''/2 + l''/2)/2 \quad (1)$$

$$r = (510 + (126/2) + (60/2))/2 \quad (1a)$$

$$r = 302 \text{ ft} \quad [91.5 \text{ m}] \quad (1b)$$

and for artificial gravity of 1/6th g

$$g' = g/6 \quad (2)$$

where

$$g = 32.17 \text{ ft/sec}^2 \quad (2a)$$

then

$$g' = 5.36 \text{ ft/sec}^2 \quad [1.62 \text{ m/sec}^2] \quad (2b)$$

therefore the velocity of rotation

$$v = \text{sqrt}(g'r) = 40.73 \text{ ft/sec} \quad (3)$$

$$[2.34 \text{ m/sec}] \quad (3a)$$

and

$$\text{RPM} = v(60 \text{ sec/min})/r2\text{Pi} \quad (4)$$

$$\text{RPM} = 1.27 \quad (4a)$$

therefore the force needed to spin the space farm to achieve 1/6th g is

$$F = mv/t \quad (5)$$

where m = 28,200 kg from Table 1 (5a)

and v = 12.34 m/sec (3a) (5b)

and t = 120 second burn (5c)

$$F = 2900 \text{ Newtons}$$

(5d)

therefore with two opposing engines at opposite ends of the truss to spin (or de-spin) the space farm, two 1450 Newton rockets burning 120 seconds are required.

3. The OMV serves as the third source of propulsion and performs many operations. In the construction phase it serves to move major components into position. When the space farming is spinning, the OMV can land only at the zero-G hub. In the operation of the farm the OMV flies to the NASA space station delivering produce in exchange for the biodegradable wastes and carbon dioxide of the NASA space station crew. To maintain orbital position, periodically, the OMV will push the space farm into higher orbit. The OMV can also be used to transport the astronauts, and will be part of the emergency back-up system.

The chemicals and/or engines of all the above propulsion systems need servicing and/or replacement depending on their various work loads, the exact schedule of servicing to be determined.

### VI. Benefits of Artificial Gravity Environment

#### Hydroponics

Hydroponic growing systems have proven themselves in many applications on earth. Hydroponic agriculture, or variations thereof, seem to be the most viable method for growing food in space. In the weightless environment, the chemical fertilizers in the hydroponic fluids used to wash the roots of the plants can more easily drift and come in contact with the leaf area of the plants, causing serious crop damage. These same droplets drifting in a zero-G atmosphere can also harm exposed crew. These fluids are more easily controlled, pumped and stored using conventional hydroponic equipment in an artificial gravity environment. In addition, maintenance and cleanup are easier when centrifugal forces act on the debris to push it down, and plant flats remain on their shelves without tie-down equipment.

#### Crew

Artificial gravity produces a more healthful working environment for the crew. Current research indicates that prolonged habitation of crew members in a weightless environment produces serious unhealthy side effects, ie. loss of calcium, loss of blood volume, weakening of the heart muscles, and near elimination of the immune system. Crew members can work more efficiently when they are not constantly attaching themselves to the floor or ceiling to avoid drifting away from their tasks in a weightless environment. A more profitable return on the investment in the crew members training can be achieved when they are

permitted to remain in orbit for two years and longer as is possible with an artificial gravity environment.

### VII. Layout of Space Farm

After the crew verifies all systems are working in the 1/6th g space farm, the farming begins. See Figure 4 for layout of the airlock and main module.

#### Airlock

A standard NASA space station airlock serves as crew and cargo egress. Around the exterior of the airlock is a shipping and receiving platform used to temporarily store materials in transit through the airlock. The RMS reaches into the airlock, allowing for transfer of supplies and cargo without EVA. The airlock stores the EVA suits and contains equipment for their resupply. The airlock is outfitted as a safe haven in case of crew emergency, and has a duplicate of the ship's control console to operate the OMV, RMS and all on-board systems.

#### Main Module

A standard NASA space station module is specially modified for vertical use with living and operations in the two decks closest to the airlock. One half of the ECLSS unit separates the crew quarters from the plant growing area in the bottom portion of the module. The balance of the ECLSS is under the lowest floor of the module.

#### Farm Sectors

The growing area is divided into 7 farm sectors. Each farm sector is 3.3 feet high, 14 feet in diameter with 3 foot diameter access hole through the center of the plant bed. Each farm sector is divided into sixteen pie shape flats, 112 flats total. Figure 5 shows the two seedlings flats closest to the light source, the next highest are five flats for second stage growth plants, while the nine lowest flats contain plants in their final stage of growth. The plants are rotated continually to insure constant yields. Furthermore the area under the seedling and mid-growth sections can hold the necessary hydroponic equipment for each farm sector. To define the growing area for one sector

$$A = r'^2 2\pi - r''^2 2\pi \quad (6)$$

for  $r' = 6.75$  ft inside module radius (6a) and  $r'' = 1.5$  ft radius of access way (6b) then

$$A = 138 \text{ ft}^2 \quad (6c)$$

which sub-divided for seedlings 2/16 as

$$A' = A2/16 = 17 \text{ ft}^2 \quad (7)$$

and for the 2nd stage growth 5/16 as

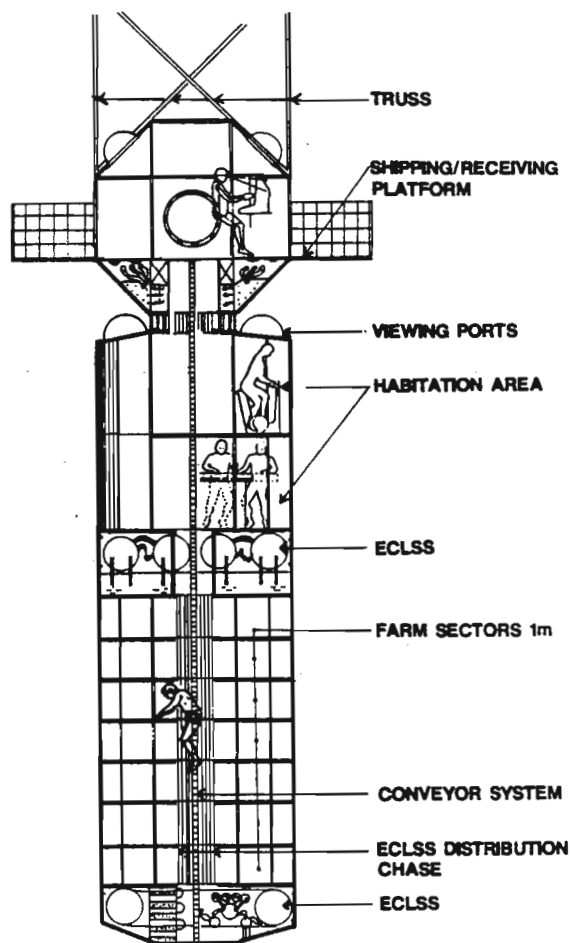


Fig. 4 Airlock/main module.

$$A'' = A5/16 = 43 \text{ ft}^2 \quad (8)$$

and for the final stage growth 9/16 as

$$A''' = A9/16 = 78 \text{ ft}^2 \quad (9)$$

The sector flats are divided into sixteenths for ease of maintenance, crop division and to be able pass them through the access way. The seedling flats and second growth flats are variously raised to bring them closer to the source of grow lights. The volume under the seedling and second stage flats is for hydroponic systems storage and equipment: water, pumps, liquid fertilizer, biodegradable wastes, carbon dioxide. The volume for one sector of this hydroponic system is

$$V_s = A'h' + A''h'' \quad (10)$$

for seedlings  $h' = 2$  ft (10a)

and 2nd stage growth  $h'' = 1$  ft (10b)

$$V_s = 77 \text{ ft}^3 \quad (10c)$$

therefore the total volume for hydroponic systems is

$$V_t = 7V_s = 539 \text{ ft}^3 \quad (11)$$

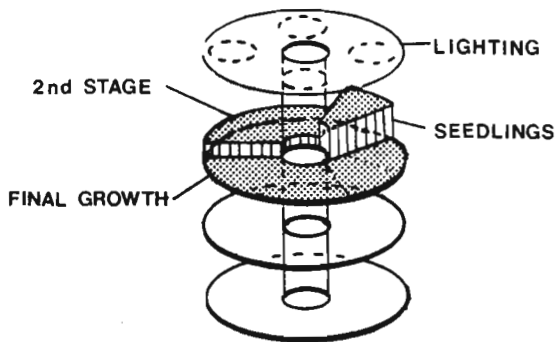


Fig. 5 Divided plant sector.

and the total area under cultivation

$$AT = 7A = 966 \text{ ft}^2 \quad (12)$$

Each farm sector can be autonomous from the others above and below it so that the optimum growing conditions can be regulated for each crop specie. Variations from this sector approach are made where appropriate to the crop.

#### VIII. Lighting

##### Power from Two Solar Panels

The space farm is launched with two folded solar panels which are deployed immediately after the crew extracts the space farm components from the booster fairing. The solar panels are attached at the zero-G hub of the truss. The solar panels are modeled after the flexible solar array wings of the Solar Array Flight Experiment (SAFE), flown aboard the STS shuttle flight of September 1984. Space Industries plans to use these solar panels on their Industrial Space Facility. In full sunlight each panel is capable of generating 14 kilowatts of power, therefore the space farm deploying 2 panels generates 28 kilowatts. 17.5 kilowatts is reserved for plant

illumination (2.5 kilowatts per sector, 236 watts per square meter or 18.1 watts per square foot). The remaining 10.5 kilowatts available from the solar panels powers all other space farm systems, including habitation areas, work stations, hydroponics and battery charging.

##### Savings in Battery Supplies

Initial experiments by Medaris Industries show that a variety of plants will grow under the photoperiod conditions of LEO. On a 90 minute LEO, approximately 60 minutes is spent in full sunlight, while 30 minutes is in sunset, night and sunrise. On this space farm crops are grown under artificial light working only when the solar panels are in sunlight, therefore the 17.5 kilowatts reserved for plant illumination does not need to be stored in batteries. From the original 28 kilowatts generated subtracting the power for plant illumination, 10.5 kilowatts remain. Except for the plant illumination, all other space farm systems must be able to function at any time. Therefore power management reserves 4,200 watts, 40% of 10.5 kilowatts, for battery charging and reserve, while 6,300 watts is the average continuous amount of power available to all systems. The weight and maintenance of a large battery power supply is mediated by having a smaller amount of power to be stored. More research is needed to refine the power requirements and its distribution.

#### IX. Crop Specie Selection

Using the modest scenario proposed by Hoff, Howe and Mitchell, the plant species selected for this project are soybean, peanut, wheat, rice, potato, carrot, chard, cabbage, lettuce, and tomato.<sup>2</sup> These ten species comprise a minimum number of foodstuff elements needed to create a varied and balanced diet for the astronaut crews. It is contemplated that during initial operation of the space farm

Table 3 Crop Distribution

Plant <sup>2</sup> species	CEA area <sup>2</sup> required ft <sup>2</sup> /person	Space Farm		with added 2nd Farm Module	
		Grow area ft <sup>2</sup>	Sector flats	Grow area ft <sup>2</sup>	Sector flats
Soybean	45.8	173	20	440	51
Peanut	51.2	190	22	492	57
Wheat	52.3	198	23	509	59
Rice	50.1	190	22	483	56
Potatoe	43.6	164	19	423	49
Carrot	1.1	4	0.5	10	1.2
Chard	1.1	4	0.5	10	1.2
Cabbage	3.3	13	1.5	32	3.7
Lettuce	1.1	4	0.5	11	1.3
Tomato	7.7	26	3.0	74	8.6
	257.3	966	112.0	2,484	288.0

these food crop species will be supplemented by other foods launched from earth to feed the crew of the nearby space station.

Table 3 shows the area required for each crop to produce the food necessary to meet the nutritional needs of one person. Table 3 also shows the number of sector flats on the space farm that are devoted to growing each crop, and the total cultivation area for each crop. Approximately one half of one sector is devoted to the mineral crops, while six and half sectors are devoted to carbohydrate and protein crops. Based on 966 ft<sup>2</sup> as the total area under cultivation, the space farm can provide 100% of the nutritional needs for 3.75 persons, or 60% of the nutritional needs for 6.25 persons. In this initial configuration the space farm is used to supplement the diet of the two space farm workers, as well as four space station crew. But when a second farm module is launched and added, and this farm module has 11 levels, since the crew quarters and operations center is already incorporated into the first farm module, the area under cultivation increases to 138 \* 18 = 2484 ft<sup>2</sup>, which can provide 100% of the nutritional needs of 9.7 persons, or 80% of the nutritional needs to 12.1 persons. As further research is done it is anticipated that such productivity will improve.

The exact distribution of crops in farm sectors has not yet been determined because of the many overlapping considerations that require more research. For example, could the natural arrangement of the seven farm sectors be used to promote crop production by putting the more heat-loving crops in the upper sectors and the more cool-loving crops below? Would carbon dioxide tend to accumulate at the lower farm sectors, and could that be used to better advantage? Could certain crops be grouped together if they share hydroponic solutions? Should the seedlings all be grouped together?

#### X. Space Farm Operation

After the space farm is spun and the crops started, the crew works in a regular routine of monitoring the growth of the plants. This data is continuously logged into an artificial intelligence program of a computer that can assemble a data base toward designing robotic systems to take over as much of the future space farmers' work as soon as possible. The farm is parked within visual range of the space station to facilitate moves by the OMV between the two vehicles. It can not interfere with space station operations, but is near enough for ease of transportation. After forty five days the first crops are delivered, and following that a convenient schedule is made for the delivery of produce and pick up of biodegradable wastes. Although the system of delivering produce and receiving wastes

in return maintains the balance of water, minerals and other necessary elements that continuously recycle in the space farm, some materials will be lost, therefore methods of resupply from earth via the space station or by direct delivery from shuttle or booster are periodically necessary. In the beginning stages when the space farm is supplementing the diet of the crew, the balance of the food will be need to shipped in from earth.

#### XI. Growth

##### Second Farm Module

As the need for a larger farm develops, the existing farm can be expanded by the addition of more farm modules to a total of five. The limitation in expansion comes from the mechanical limit of centrifugal forces exerted on the truss by the modules and their respective counterbalances. The expansion of the space farm begins with the delivery of a second booster with cargo containing:

- 2nd farm module
- 2nd airlock
- Connecting passageway
- Solar panels
- 2nd OMV
- Robotics to automate farm
- Spin Rockets
- Consumables

##### Expansion Construction Technique

The assembly of a larger space farm begins by securing all systems for zero-G in the present module and draining all of the hydroponic fluids from the flats and other open areas. The farming sectors are sealed and kept at a high humidity and low light level so that the plants will enter into a period of dormancy. Next, the space farm vehicle is de-spun to coincide with the arrival of the additional module(s), again using the fairing and booster rocket(s) as mass for the counterbalance. The new modules are interconnected to the existing farm module by the passageway between their air locks. The additional solar panels are deployed from the zero-G hub and the additional electrical and heat distribution systems connected. The additional fairing and booster are attached alongside the existing countermass. After verifying all systems, the crew fires the spin rockets to obtain 1/6th gravity, reactivating the enlarged space farm.

##### Robotics To Automate Farm

Robotics are intergrated into the system at this point in the space farm's expansion in order to relieve the astronauts and to eventually automate as much of the farming operation as possible. The farm sectors in the newly delivered farm module are modified to accommodate robotic space farming techniques. The information gathered from the initial farming efforts are applied to the design of the robotic system.

## XII. Summary of Current Research

Research into space farming techniques is being pursued in a number of different locales:

Cary Mitchell at Purdue - leaf lettuce, soon beginning oil seed crops: rape, peanut, safflower and sesame.

Theodore Tibbets at University of Wisconsin - white potatoes.

David Raper at North Carolina State - soy beans.

Walter Hill at Tuskegee - sweet potato.

Frank Salisbury at Utah State - dwarf wheat.

While University of California Davis - wheat grown in primary processed human waste.

Environmental Research Lab in Tucson - the Biosphere II Project, a living CELSS experiment.

Boeing requests \$140 million for zero-G farming experiments on half a module in LEO.

EPCOT grows plants in simulation lunar soil.

## XII. Further Research

This is an outline of other research needed:

### A. CROP SPECIES SELECTION

1. Evaluate chosen species for growth in 1/6th G environment.
2. Identify the species best suited to robotic farming.
3. What quantity for each species.
4. Dwarf species

### B. GROWING METHODS

1. Light source -
  - a. Space sunlight - Deck prisms  
Light pipes
  - b. Artificial - Sodium Vapor  
Mercury Vapor  
Flourescent  
HID lamps  
Incandescent  
Mixed light sources
  - c. Quantitative amounts by species -  
Which light, which species  
Photo periods
2. Growth Medium -
  - a. Organic
  - b. Inorganic
  - c. Determine root space for each species
3. Moisture -
  - a. Hydroponic misting
  - b. Alternatives
  - c. Water recycling method
4. Nutrients -
  - a. Requirements for each species
  - b. Recycling

5. Temperature -
  - a. Requirements for each species
  - b. Method for dissipating unwanted heat
6. Atmosphere -
  - a. Requirements for each species
  - b. Accelerated growth techniques
  - c. Recycling within space farm
  - d. Recycling with space station
7. Harvesting -
  - a. Bulk
  - b. Weekly
  - c. Monthly

### C. DISTRIBUTION

1. Preparation
2. Processing
  - a. on board space farm
  - b. on board space station
3. Packaging
4. Delivery to space station
5. Resupply space farm with expendables
6. Changes in mass, outbound lettuce 98% water

### D. HOUSEKEEPING OPERATIONS

1. Crew comfort and morale
2. Crew rotation
3. De-spinning the station
4. Emergency procedures
5. Computer control
6. Robot operation

## XIV. Conclusions

This LEO space farm simulates the gravity of the moon, a prime location for the more extensive farming required during its exploitation. The technology developed on the LEO space farm can easily be transferred to the lunar colonies, and to more elaborate space farms that would accompany the crew on long duration missions, such as interplanetary exploration. When crews can break with earth for their dependency for food and materials, their time and range for exploration, adaptation and work will increase. These advanced orbital, lunar and planetary mission crews will require fresh food to maintain their health and morale. A continuous supply of good, nutritious and fresh food can contribute to a more alert and hard working crew, for example submariners. Self-sufficiency will encourage further innovations toward man adapting to this new environment.

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