Growing Plants for Supplemental Food Production on a Mars Fly-By Mission

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MISSION TIMES

OUTBOUND 150 days
STAY 619 days
RETURN 110 days
TOTAL MISSION 879 days
## Human Life Support Requirements:

### Inputs

<table>
<thead>
<tr>
<th>Daily Rqmt.</th>
<th>(% total mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>0.83 kg 2.7%</td>
</tr>
<tr>
<td>Food</td>
<td>0.62 kg 2.0%</td>
</tr>
<tr>
<td>Water (drink and food prep.)</td>
<td>3.56 kg 11.4%</td>
</tr>
<tr>
<td>Water (hygiene, flush laundry, dishes)</td>
<td>26.0 kg 83.9%</td>
</tr>
</tbody>
</table>

**TOTAL 31.0 kg**

### Outputs

<table>
<thead>
<tr>
<th>Daily</th>
<th>(% total mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>1.00 kg 3.2%</td>
</tr>
<tr>
<td>Metabolic solids</td>
<td>0.11 kg 0.35%</td>
</tr>
<tr>
<td>Water (metabolic / urine)</td>
<td>29.95 kg 96.5%</td>
</tr>
<tr>
<td>(hygiene / flush)</td>
<td></td>
</tr>
<tr>
<td>(laundry / dish)</td>
<td></td>
</tr>
<tr>
<td>(latent)</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL 31.0 kg**

Source: NASA SPP 30262 Space Station ECLSS Architectural Control Document

Food assumed to be dry except for chemically-bound water.
Why Plants for a Mars Mission?

- Currently, food consumed by astronauts is all preserved or thermo-stabilized, package food
- Plants could supply of fresh foods to supplement the packaged food diet
  - Improve nutrition for the crew through bio-available nutrients and antioxidants as radiation countermeasure
  - Improve the acceptability of the meals
    - Add textures, flavors, and colors of fresh vegetables
  - Improve crew morale through the presence of plants
  - Depending on size of the plant growth system, help supply $O_2$ production and remove $CO_2$
Fresh Foods for Long Space Missions

- **Colors**
- **Textures**
- **Aromas**

Cherry Tomato

Strawberry

Red and Green Leaf Lettuce

Dwarf Pepper
Antioxidants and Supplemental Nutrients

Anthocyanin induced by blue and UV light in red-leaf lettuce; Others might include lycopene, lutein, Vit. K, Ca and phenolics.
Crew Morale: Plants could provide comfort to crew

(Photo from US South Pole Plant Chamber)
Challenges for Growing Plants for a Mars Mission?

- **Microgravity**
  - Watering, thermal mixing, plant physiological responses
- **Lighting**
  - Power for electric lighting; interference with crew ops
- **Atmospheric Closure**
  - Trace contaminants, e.g., ethylene
  - Super-elevated CO₂ (e.g., > 5000 ppm)
- **Radiation Exposure**
- **Food Safety Issues**
Watering Systems for Weightlessness

Porous ceramic or steel tubes to contain the water which then moves by capillary forces to the roots.

Biomass Production System (BPS)

Porous steel tubes surrounded by arcillite rooting media with time-release fertilizer
Rotating Plant Growth System for Artificial Gravity?
Perhaps even and a larger rotating system within a space module?
# The Importance of Lighting

--- *Electric Lamp Options*

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>Conversion Efficiency</th>
<th>Lamp Life (hrs)</th>
<th>Spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent/Tungsten**</td>
<td>5-10%</td>
<td>2000</td>
<td>Intermd.</td>
</tr>
<tr>
<td>Xenon</td>
<td>5-10%</td>
<td>2000</td>
<td>Broad</td>
</tr>
<tr>
<td>Fluorescent***</td>
<td>20%</td>
<td>5,000-20,000</td>
<td>Broad</td>
</tr>
<tr>
<td>Metal Halide</td>
<td>25%</td>
<td>20,000</td>
<td>Broad</td>
</tr>
<tr>
<td>High Pressure Sodium</td>
<td>30%</td>
<td>25,000</td>
<td>Intermd.</td>
</tr>
<tr>
<td>Low Pressure Sodium</td>
<td>35%</td>
<td>25,000</td>
<td>Narrow</td>
</tr>
<tr>
<td>Microwave Sulfur</td>
<td>35-40%+</td>
<td>?</td>
<td>Broad</td>
</tr>
<tr>
<td>LEDs (red and blue)****</td>
<td>&gt;40%</td>
<td>100,000 ?</td>
<td>Narrow</td>
</tr>
</tbody>
</table>

* Approximate values.

** Tungsten halogen lamps have broader spectrum.

*** For VHO lamps: lower power lamps with electronic ballasts last up to ~20,000 hrs.

**** State-of-Art Blue and Red LEDs most efficient.
LED for Plants in Spaceflight Chambers

Red...photosynthesis
Blue...photomorphogenesis
Green...human vision

John Sager, KSC, Testing Prototype Flight Plant Chambers with LEDs
Russian Phytoconveyor (IMBP)—Proposed for Vegetable Production for the ISS and Mars Transit

Chief Engineer: Yuliy Berkovich, IMBP, Moscow
Can Direct Solar Lighting Be Used for Mars Missions?

2 m² of collectors on solar tracking drive -- roof of Space Life Sciences Lab, KSC

Up to 400 W of solar light delivered to a plant chamber (40-50% of incident light)

How would plant growth systems fit within human habitats or spacecraft?
NASA’s Biomass Production Chamber (BPC)
Smaller Scale Lab Testing
Testing of Plants in NASA’s Habitat Demonstration Unit

Plant Atrium In HDU 2011 with Red/Blue LED lighting

Plant Atrium In HDU 2012 With White LED lighting

Habitat Demonstration Unit, Near Flagstaff Arizona
Plant Growth Testing in Space
(mostly with seedlings or small plants)

• Early Russian and US Testing (60s through 80s)
  – Wheat, peppers, duckweed, carrot

• NASA Sky Lab
  – Rice

• Shuttle
  – Sunflower, potato, brassica, mung bean, oat, soybean, others

• Russian Mir Space Station
  – Wheat, mizuna, Chinese cabbage, brassica, others

• International Space Station
  – Wheat, mizuna, pea, barley, soybean, others
Plant Chambers for Space Shuttle and ISS

SVET on Mir

BPS on ISS

PGBA on Shuttle
Life Science Space Flight Experiments

Potato Tubers in Space (STS 73)

Photosynthesis in µ-gravity (STS 110 / 8A)

Plant / Bacterial Nitrogen Fixation In Space (STS 135)

Russian “Lada” Plant Chamber on ISS

Mizuna Plants (Japanese Mustard)
Plants in Tightly Closed Atmospheres: 

*Ethylene Effects*

- Epinastic (rolled) Wheat Leaves
  Ethylene at ~120 ppb

- Epinastic Potato Leaves
  Ethylene at ~40 ppb
Food Safety Considerations

- Plants have to meet microbiological safety (e.g., coliform bacteria)
- Levels of biocides from water might be a concern (e.g., iodine and silver)

Top, Cosmonaut harvesting Mizuna on the ISS

Bottom, sanitizing lettuce leaves

In NASA HDU study in 2010
Constraints for Crop Production for Mars Flyby or any Space Mission:

- Energy Requirements
- System Mass
- System Volume
- Crew Time
- System Reliability

These apply for all life support technologies, including the use of plants.
Plants for Future Space Missions

- **2005**: Shuttle (plant experiments)
- **2010**: Crew Expl. Vehicle (supplemental crops Mars transit / flyby)
- **2015**: Intnl. Space Station (plant experiments—possible salad crops)
- **2020**: Lunar Lander (probably no plants)
- **2025**: Lunar Outpost (supplemental foods)
- **2030**: Martian Outpost (supplemental foods, life support)
- **2035**:
- **2040**:
- **2045**:

Timeline:
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Hopefully plants will accompany humans on their missions to Mars!
Thanks to my colleagues at NASA’s Kennedy Space Center