ESA Higher Plants Activities for Life Support

Why Plants in Space?

- TODAY :
- 5Kg/d.m of Metabolic consumables (O2, water, Food),
- Mission to Mars of 6 pers and 1000 days means :
  - 30 000 kg ! (current launchers allow only 9t on Moon surface)
- Recycling is mandatory,
- We can recycle Air and Water with conventional technologies,
- BUT : Food Production is not possible

Plants Interests

- Well known source of food,
- Water Recycling,
- Air Recycling,
- Probably a psychological impact (to be confirmed),

Plants Weaknesses

- Slow rates of production,
- Limited volumetric used of light,
- Needs the “proper” nutrients,
- Difficult modelling,
- High waste production (generally 50% of produced biomass),
- Sensitive to pathogens.

ESA Approach

1. Gain very high scientific understanding of plants in closed environment,
2. Study the associated technology for food preparation and instrumentation,
3. Gain technical understanding and experience on completely closed Greenhouse,
4. Demonstrate the feasibility and operability of closed higher plant chambers for life support on Earth,
5. Conduct reduced gravity research on plants,
6. Test higher plants for life support (Low Earth Orbit, Mars Transit, Mars and Moon bases)
7. Use higher plants for life support

Basic R&D

- Plants Kinetics,
- Nutrients uptake (from waste, urine,..),
- Predict organoleptic quality as well as compounds of the non-edible part,
- Valorisation of the waste
- Metabolic Modelling,

Food Issues

A limited number of plants means:

- New Recipes,
- New instrumentation,
- Acceptance study,
- Fresh consumption/Packaging/Storage,

Closed Greenhouse

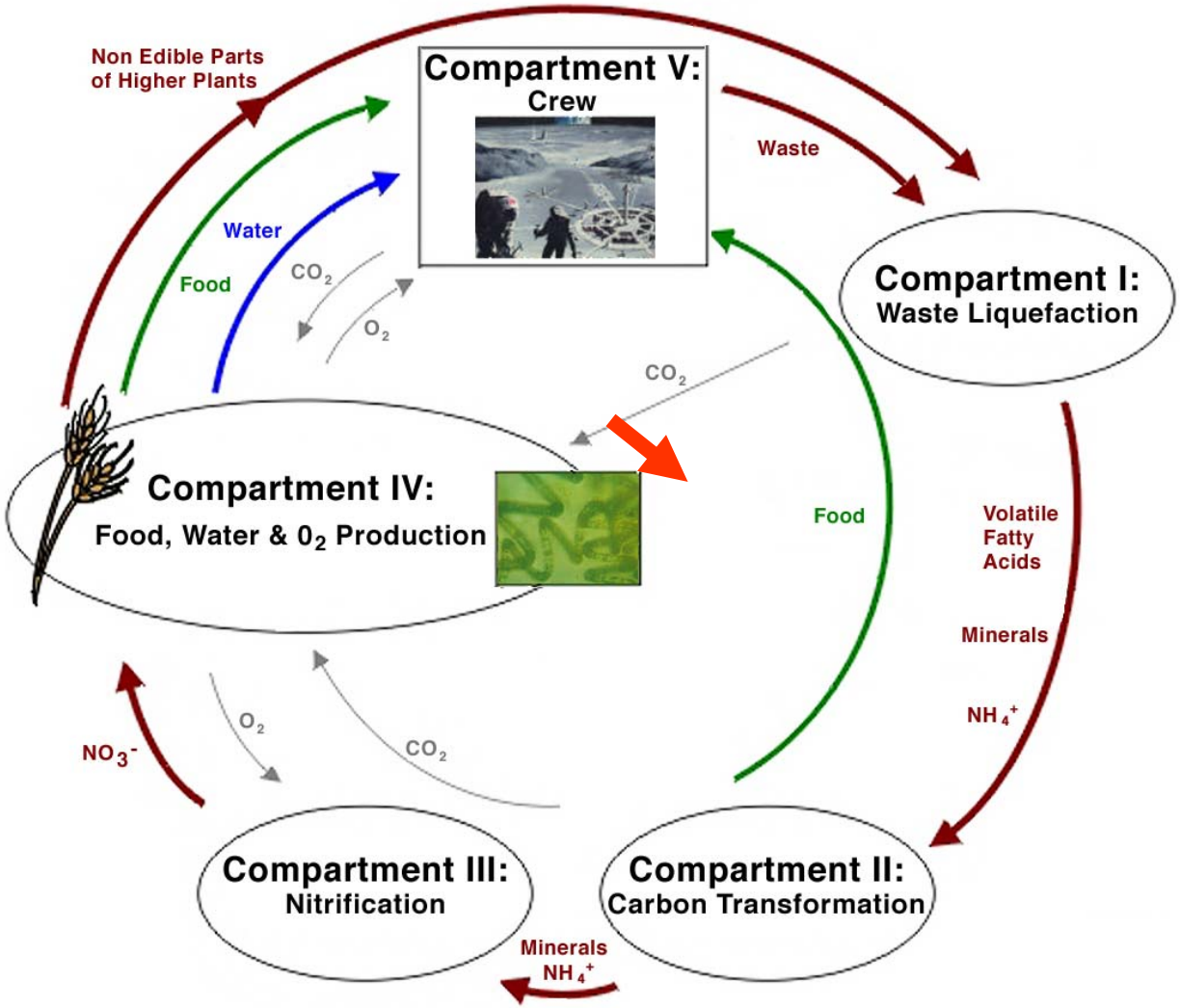
Study, Control and Optimise :

- Light Sources and utilisations,
- Nutrients delivery,
- Thermal and humidity control,
- Pathogens detection,
- New instruments (sensors, actuators, filtration, harvesting…)

ESA Activities

- Biological Life Support (MELISSA),
- Prospective (STEP),
- Life Sciences Research (EMCS, BIOLAB,CHECS..)
- Technology Transfer

MELiSSA Project



Overview of MELISSA

- History:
  - Project started in 1989 from the industry (MATRA !) ,
  - 1991 creation of the ESA Laboratory,
  - 1993 signature a M.O.U. between partners,
  - 1995 Inauguration of the MELISSA Pilot Plant (Spain)
  - 1997 First Study for a space experiment,
  - 1998 first continuous test with 3 linked compartments,
  - 2000 first test with animal,
  - 2002 Flight experiment,
  - 2003 Second Flight experiment,

Overview of MELISSA

- The MELISSA partners:
  - EPAS (B),
  - University of Ghent (B),
  - VITO (B),
  - SCK/CEN (B),
  - IBP/CNRS (F),
  - SHERPA (F),
  - University of Clermont Ferrand (F),
  - Autonome University of Barcelona (E),
  - University of Guelph (CND),
  - ESA.

Overview of MELISSA

- The General Approach:
  - Technologies characterisation in Batch and Continuous modes,
  - Stoichiometry studies,
  - Hydrodynamic Characterisation,
  - Static Modeling,
  - Dynamic Modeling,
  - Control Model,
  - Safety issues (chemical and microbiological)
  - Maintenance and Dependability

Overview of MELISSA

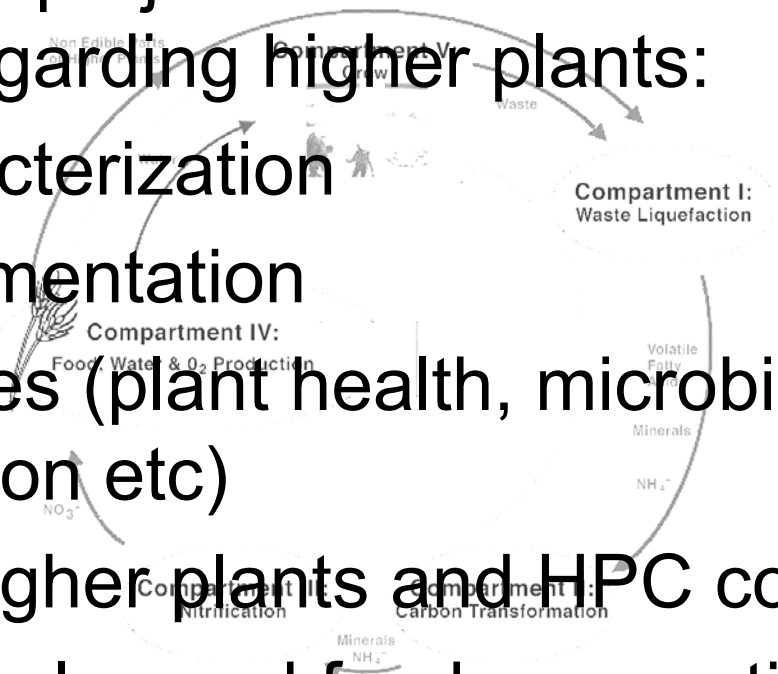
- ESA budgets:
  - T R P,
  - GSTP,
  - External laboratory,
  - D/MSM (EMIR 2, MAP),
  - Technology Transfer Programme.
  - AURORA (BWTU Concordia)

- National Support:
  - Canada,
  - Belgium,
  - France,
  - Ireland,
  - Netherlands,
  - Spain.

MELiSSA Project

The MELiSSA project includes a number of activities regarding higher plants:

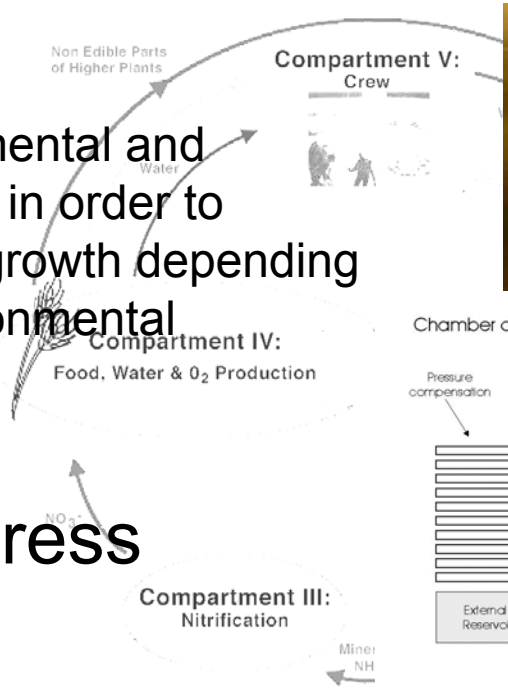
- Plant characterization
- HPC instrumentation
- Safety issues (plant health, microbial contamination etc)
- Modeling higher plants and HPC control
- Nutritional value and food preparation
- Impact of higher plants on overall life support system design

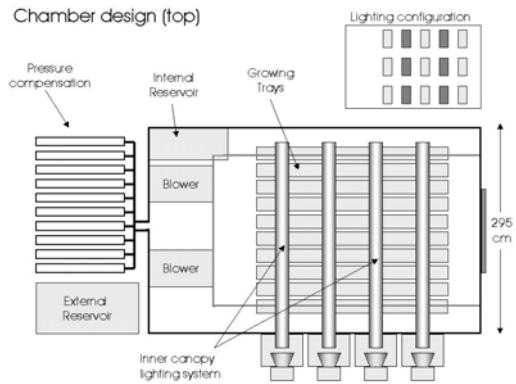


MELISSA Project - Plant Characterization

Objective:

- To conduct experimental and numerical research in order to characterize plant growth depending on controlled environmental conditions





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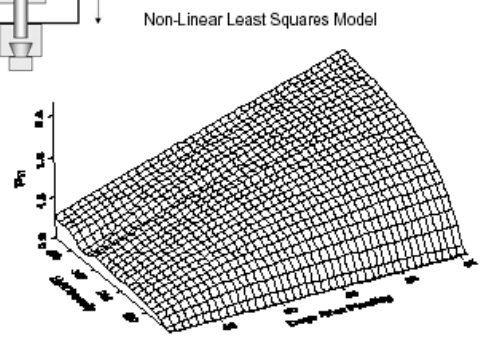
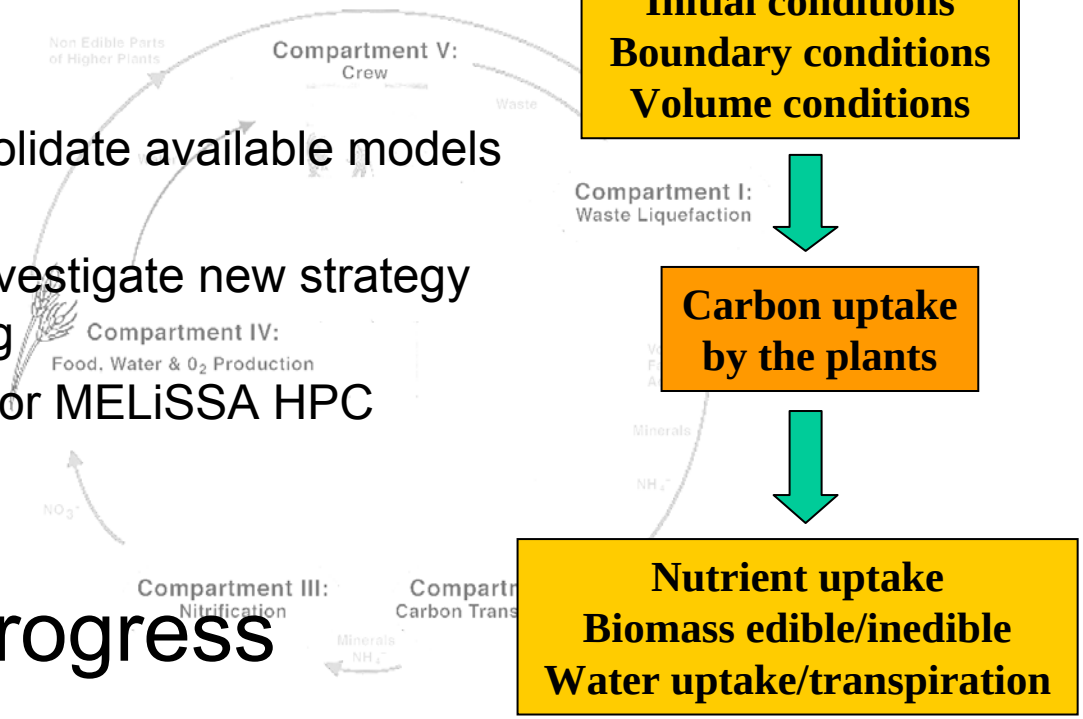


Mathematical Modeling

Objective:

- Today : To consolidate available models and data
- Tomorrow; to investigate new strategy for plant modeling
- To create frame for MELiSSA HPC definition

Status: In progress

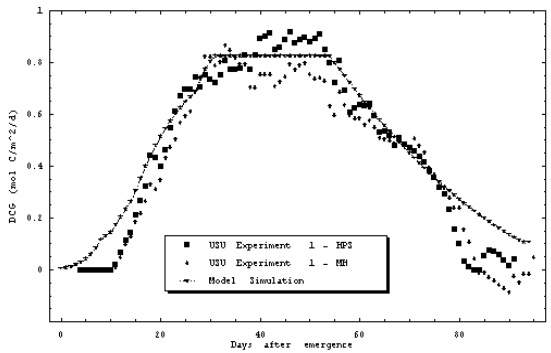


Mathematical Modeling

MEC – Modified Energy Cascade Model

The "Energy Cascade" model, which was originally developed for wheat (Volk *et al*., 1995), has been modified for several advanced life support (*ALS*) candidate crops for use in *ALS* system studies. The original model calculates daily crop growth rates using the following trends: an exponential increase in canopy light absorption from emergence through canopy closure (occurring at time t_A); a constant (maximum) light absorption after t_A; a constant canopy quantum yield (CQY_{MAX}) through the onset of senescence (occurring at time t_Q), then decreasing linearly thereafter until crop maturity (occurring at time t_M); a constant carbon use efficiency. The parameters t_A, t_Q and t_M are temperature dependant.

The parameter carbon use efficiency (CUE) has been modified in the newer versions of the model (multivariable polynomial regression)

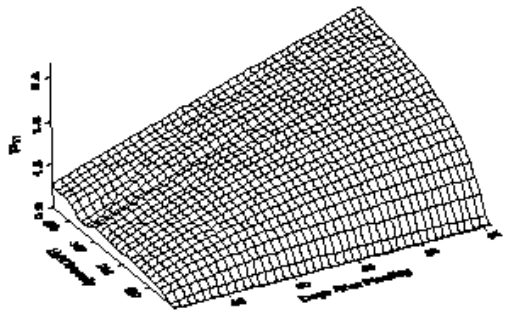


UoG Hyperbola Model

A rectangular hyperbola (non-linear, parametric) model was applied to the photosynthesis data collected for lettuce and beet in the greenhouse chambers over the range of crop development and under a range of ambient light intensities. This model is similar to the model presented by Iqbal *et al*, (1996) but allows for dynamic maximum gross photosynthesis and dark respiration rates in relation to crop age.

$$Pn = \frac{\alpha I(\beta_0 + \beta_1 DAP)}{\alpha I + (\beta_0 + \beta_1 DAP)} + (\beta_2 + \beta_3 DAP)$$

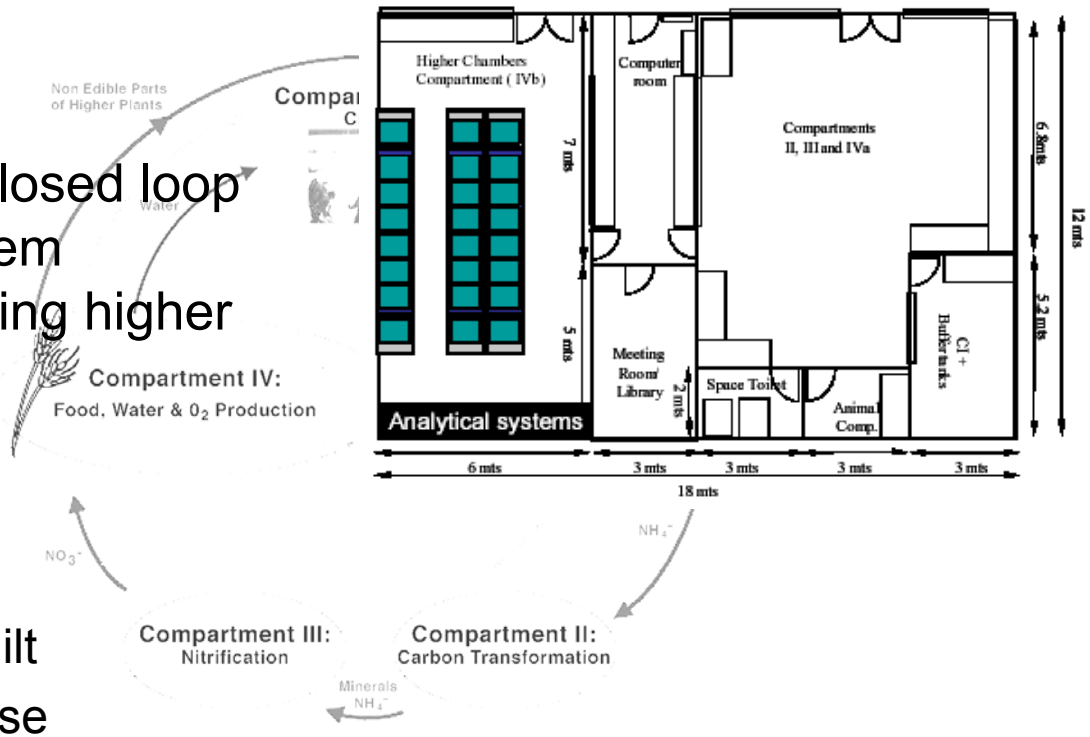
Non-Linear Least Squares Model



MELiSSA Project Pilot Plant

Objective:

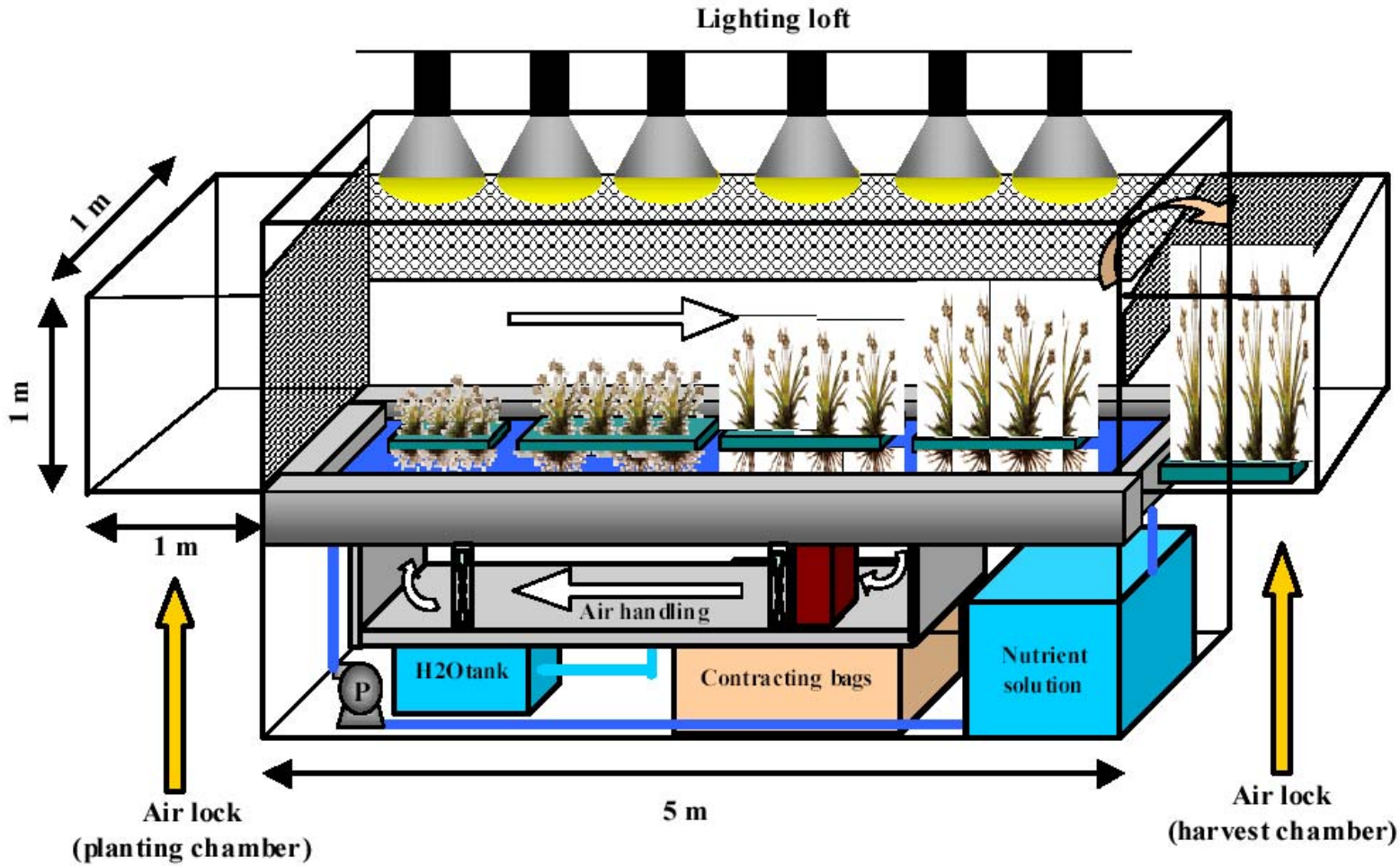
- To construct a closed loop life support system precursor including higher plant chambers



Status:

Pilot plant partially built

HPC in definition phase

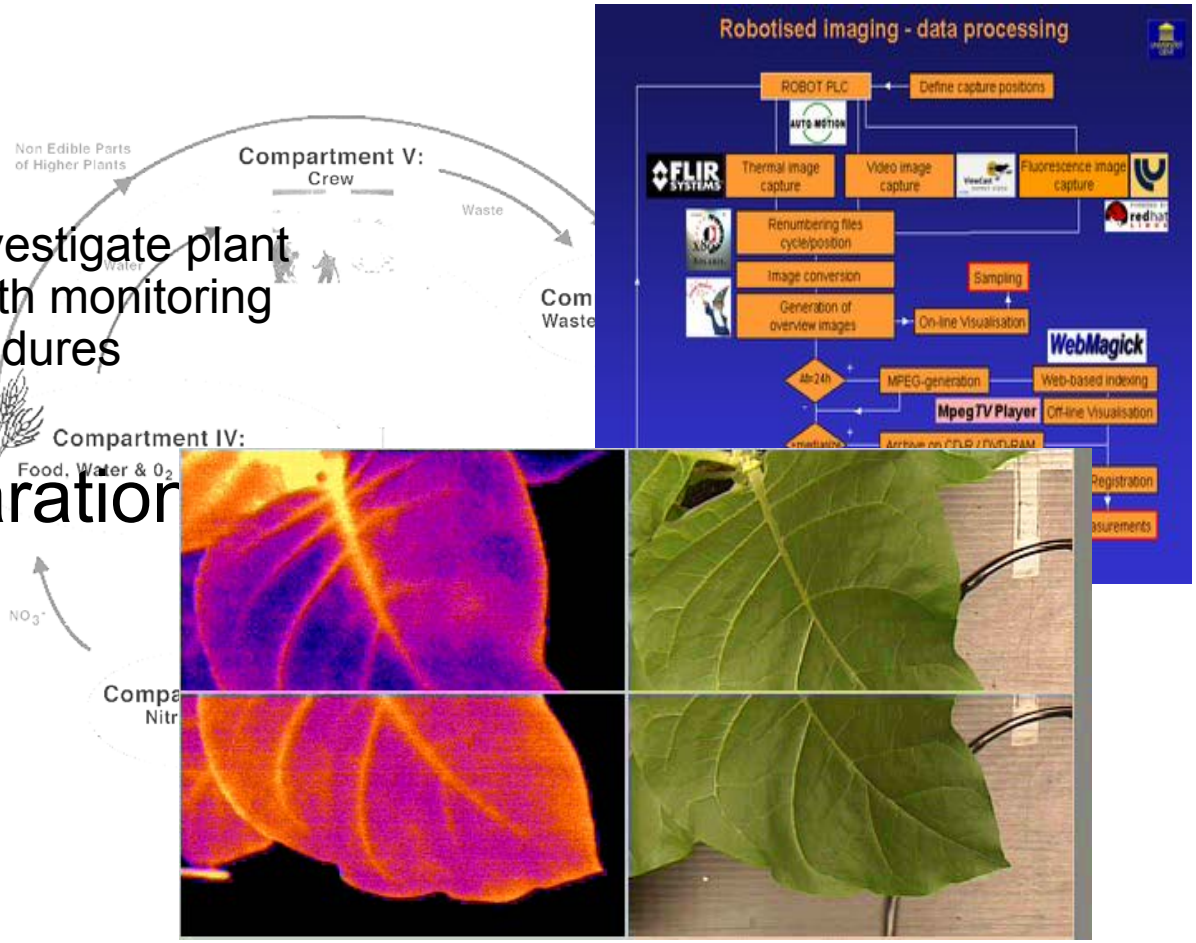

Lighting loft
1 m
1 m
1 m
Air handling
H2Otank
P
Contracting bags
Nutrient solution
Air lock
(planting chamber)
5 m
Air lock
(harvest chamber)

MELISSA Project – Plant Health Monitoring

Objective:

- To experimentally investigate plant health and plant health monitoring equipment and procedures

Status: In preparation

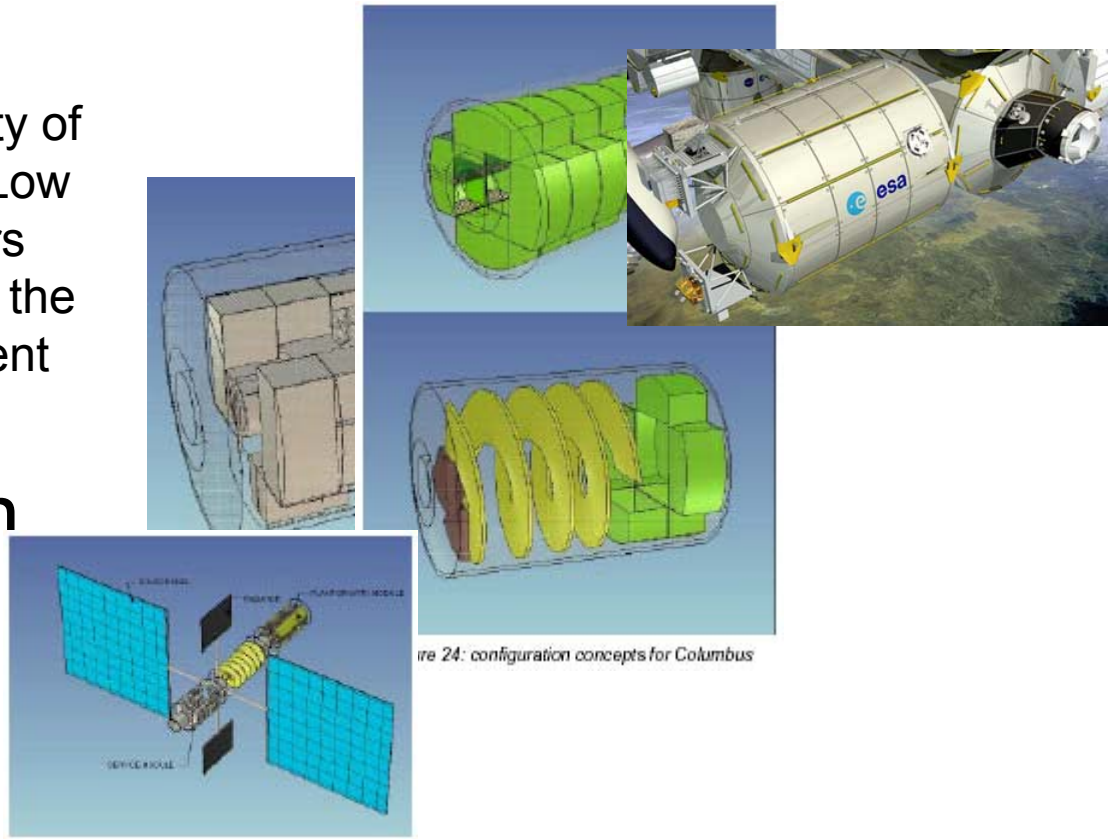


Closed Loop Food System

Objective

- To investigate the feasibility of a food production unit for Low Earth Orbit (LEO) and Mars transit flight and to identify the technology gaps with current ground developments

Status: Mid-Term

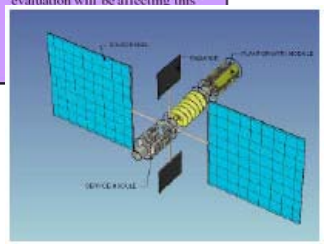


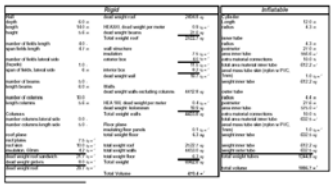
re 24: configuration concepts for Columbus

Closed Loop Food System

Main requirements of selection

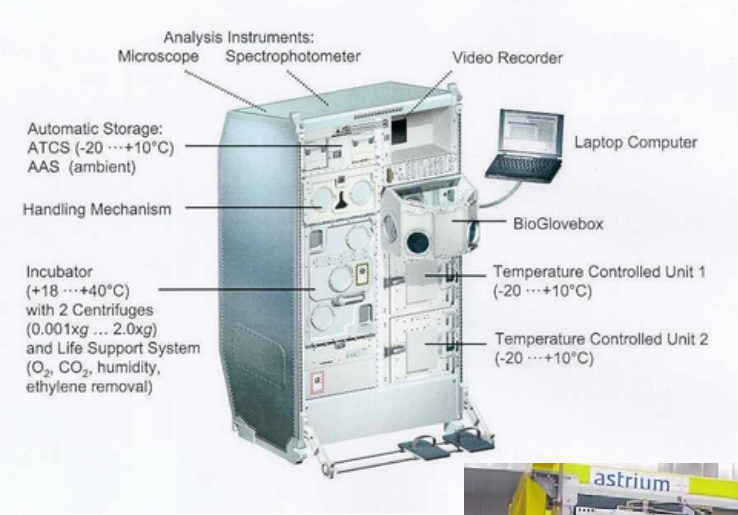
1. Aim: the crops selected shall account for supplementing a maximum 40% of a crewmember diet
2. The selection process shall be updated after feedback on systems evaluation
3. No subjective parameters shall be used in the selection. All the parameters are to be referenced to a value or objectively calculated
4. In this crop selection, no systems parameters shall be included. The suitability of the selection with respect to systems requirements will be analysed in further work. The results of the systems evaluation will be affecting this





- Food Strategy Definition (% and recipes)
- Food Production Unit (FPU) Potential Designs
- Modeling, Simulation and Trade-off of the Selected Designs
- Inputs to the MELiSSA Project
- Identification and Documentation of Space Technology Gaps

ESA Facility Biolab

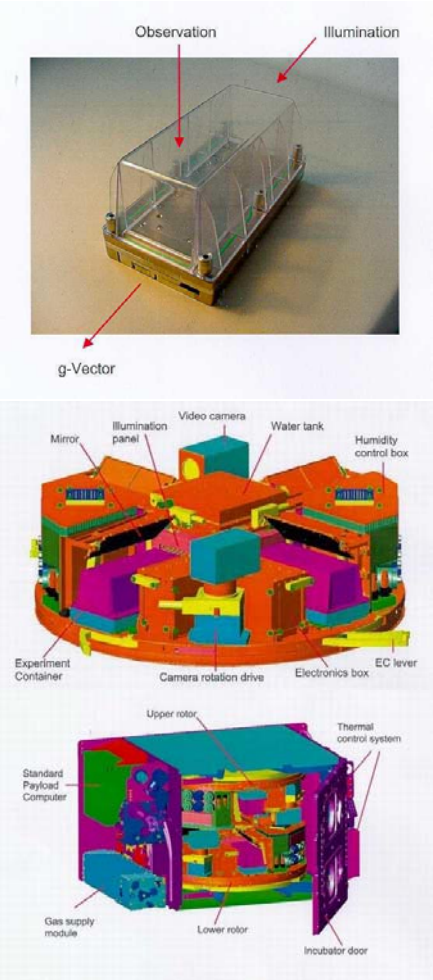


- The BIOLAB facility on board the Columbus Module is designed for research in the following areas of biological studies:

  - regulatory mechanisms of proliferation and differentiation;
  - role of the cytoskeleton;
  - mechanical loading;
  - graviperception and thresholds;
  - mechanism of radiation damage and repair in cells and tissues.

- This applies to research subjects such as cell cultures, tissues, micro-organisms, small plants, and small animals.

ESA facility EMCS



- EMCS is dedicated to experiments on plants, especially multi-generation (seed-to-seed) experiments and studies on gravity effects on early development and growth, on signal perception and transduction in plant tropisms.

- MAIN FOCUS: PLANT BIOLOGY

  Long term growth stability in plants including multi-generation studies (seed to seed)
  - Early development events in plants
  - Gravity influence on early development and growth (g-level threshold research)
  - Perception and signal transduction in plant tropism
  - Possibility for research on small animals, tissues and cell cultures, also on radiation effects.

Technology transfer

ESA a Strong experience in T&T (Pierre Brisson),

HPC presents many opportunities:

- New Material (structure, light transfer,…),
- Plants Understanding & modelling, crops strategy,
- Instrumentation (N, K, P, Na, ..),
- Control algorithms,
- Pathogens/ disease detection,
- Waste valorisation (I.e.nutrients cost) and environmental issues,
- Ecotoxicology (pesticides, bactericides,…),

Conclusions

- ESA investigates the use of higher plants for life support for 8 years,
- A LOT of research and development needs to be performed before using higher plants for life support,
- Need of :
  - Generic facilities,
  - New research & engineering groups,
  - Collaborations with terrestrial research.

Goal