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HUMAN EXPLORATION OF THE SOLAR SYSTEM SYMPOSIUM (A5)
Human Exploration of the Moon and Cislunar Space (1)

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MULTI-CROP GREENHOUSE DESIGN TO INTEGRATE THE LIFE SUPPORT SYSTEM OF COMPLEX MANNED SPACE SYSTEMS

Abstract

Biological components, particularly plants, can be engineered into the Environmental Control and Life Support System (ECLSS) of a manned space vehicle to recycle oxygen, water and to produce food, exploiting the balancing effects of photosynthesis and respiration. Although the concept is simple, the actual implementation presents many issues to be faced and requirements to be met, the most risen from different scientific disciplines.

First of all, the greenhouse shall satisfy the principal goal of producing a given amount of biomass within a certain schedule, providing the correct energy intake to astronauts and differentiate human diet. Such a goal is strongly affected by the plants natural life cycle and feeding constraints in terms of water, salts, temperature and illumination, asking for the design of dedicated crop growth chambers which, in their turns, must be compliant with the typical space system design constraints: among others, mass and power demand containment, redundancy and reliability maximization are here mentioned to highlight the multidisciplinarity and complexity of the greenhouse design task.

The paper discusses the general-purpose tool implemented at Politecnico di Milano to identify a set of preliminary designs for the greenhouse, assuming a set of sizing variables as large as possible: in particular it includes number of greenhouse modules and stocks, type of crops inside each module, cropped surface for each module, environmental parameters (air composition, temperature, humidity) and illumination parameters for each module (photoperiod, light intensity). The tool leans on the Modified Energy Cascade model (Cavazzoni, 2003) and Non-Rectangular Hyperbola model (Thornley, 1998) to simulate the crop growth dynamics as a function of the environmental parameters and the plant typology. The crop dynamic model is nested in the constraint set of a multi-objective optimization architecture, here managed by exploiting a MOPSO (Multi-Objective Particle Swarm Optimization) architecture, well-tailored for mixed integer-continuous variable domains and multi-criteria design scenarios. As an example, the tool allows identifying a feasible greenhouse with 7 crop types, 5 greenhouse modules for 5-6 astronauts staying in a Moon base for 700 days, with a total greenhouse mass of 35 tons.

It is here remarked that focusing on multicrop growth chambers enhances the exploitation of volume and mass: modules can be designed with similar size, resulting in a modular architecture, definitely preferred with respect to maintainability, reliability and complexity reduction. The logistic is enhanced, interfaces are simplified, incremental assembly strategy and higher system redundancy are preserved, without sacrificing astronauts feeding variety.