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ENGINEERING ARTIFICIAL BIOSPHERES FOR LONG-DURATION EXPLORATION IN SPACE: DEVELOPMENT OF PLANT MODULES FOR LIFE SUPPORT STRUCTURES

Abstract

Supply for major life support commodities such as breathable air, drinkable water, and food is the most critical element of any long-duration manned space mission architecture. This complex regeneration can only be done using bio-regenerative technologies including plants as the primary producer inside materially closed systems. Previous experimental and theoretical research on advanced Life Support Systems (LSS) functionally based on higher plants has confirmed that system complexity and total structural mass correlate non-linearly with mission duration. At the same time, payload mass constraints significantly limit advanced LSS approaches because of high initial payload masses. There is a need for more detailed analysis of various life support scenarios and their evolution depending on mission duration, location, and level of mission autonomy. This research considers different scenarios for life support on long-duration manned space missions. The major categories for optimized design are discussed in comparison. Preliminary analysis is provided for missions based on the "re-supply", "physical-chemical regeneration", "bio-regenerative", and "bio-regenerative + In Situ Resource Utilization (ISRU)" approaches in order to achieve minimum use of costly re-supply missions, maximum possible efficiency for recycling of primary life support commodities, and maximum possible self-sufficiency to crewmembers on remote outposts. Important limitations are identified for missions of different durations depending on the level of technological progress and agricultural technology evolution for artificial environments. Specific attention is given to plant growth module dynamic design in order to achieve minimum hardware mass per unit of plant biomass. The modules include a number of plant cultivars selected in order to provide sufficient exchange in oxygen/carbon dioxide and water while supplementing the vegetarian part of a human diet. To provide continuity in supply for listed commodities, plants are organized into multi-stage (age) sequences of biomass growth, known as plant conveyors. The results of this research provide a set of mathematical models and methodology that give long-term space mission engineers insight into the designs necessary for habitation and LSS on other planetary surfaces.