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SURFACE INFRASTRUCTURE FUNCTIONS, REQUIREMENTS, AND SUBSYSTEMS FOR A MANNED MARS MISSION

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ABSTRACT

Planning and development for a permanently manned scientific outpost on Mars requires an in-depth understanding and analysis of the functions the outpost is expected to perform. The optimum configuration that accomplishes these functions then arises during the trade studies process.

In a project this complex, it becomes necessary to use a formal methodology to document the design and planning process. The method chosen for this study is called top-down functional decomposition. This method is used to determine the functions that are needed to accomplish the overall mission, then determine what requirements and systems are needed to do each of the functions. This method facilitates automation of the trades and options process. In the example, this was done with an off-the shelf software package called TK!Solver.

The basic functions that a permanently manned outpost on Mars must accomplish are: 1) Establish the Life Critical Systems, 2) Support Planetary Sciences and Exploration, and 3) Develop and Maintain Long-term Support Functions, including those systems needed towards self-sufficiency.

The top-down functional decomposition methodology, combined with standard spreadsheet software, offers a powerful tool to quickly assess various design trades and analyze options. As the specific subsystems, and the relational rule algorithms are further refined, it will be possible to very accurately determine the implications of continually evolving mission requirements.

INTRODUCTION

Large scale systems involve a large number of often abstract variables, changing conditions and system requirements, as well as varying interpretations of definitions. It rapidly becomes difficult to assess the entire system without a formal documented process. Often, many solutions turn out to be counter-intuitive.

A carefully documented methodology also facilitates automating many facets of the process, particularly the computation of overall system parameters, subsystem by subsystem. These parameters include weight, volume, geometry and power requirements. By incorporating a set of rules that define the subsystems and their interactions with each other, the computer can be used to quickly assess the effects of various design changes, working towards the optimum configuration for a given set of mission requirements.

TOP DOWN FUNCTIONAL DECOMPOSITION

This method starts with the overall Gross System Requirement for the mission to be accomplished. The functions that need to be done to accomplish that goal are then carefully outlined in the order that they would occur. Each of these 1st level functions are broken down further into 2nd, 3rd, etc., level functions until all the necessary detail is defined, Next, the specific requirements needed to accomplish each of those functions are determined. Finally, the hardware or subsystems that are needed to meet these functional requirements are determined. This hardware has associated mass property and power requirements that can be put into a functional matrix to determine overall mass property and power requirements. These matrices, combined with the input/output interactions between the subsystems and the functional groupings, can be used to assess the affects of various mission requirements on the needed system parameters.

MAIN FUNCTIONAL GROUPS

It's clear from looking at the overall mission requirement, "To Establish and Maintain a Permanently Manned Outpost on Mars", and the functional decomposition, that the Mars surface infrastructure is driven by four main areas - Life Critical Systems, Planetary Science and Exploration Systems, Mission Support Systems and Long-Term Self Sufficiency Systems. These are defined as follows:

Life Critical Systems

These are those systems necessary to ensure survival on Mars. Currently, these systems include: Environmental Control and Life Support Systems (ECLSS), Thermal Control Systems, Crew Systems, Nutritional Needs, Radiation Exposure Protection and Monitoring, Health Maintenance, Electrical Power Processing, and Extravehicular Activity (EVA) Capability.

Planetary Science and Exploration Systems

This includes Martian chemical, physical, biological and magnetic field phenomena. Specifically, and in order of priority, the following areas are included: Local Chemical and Physical Phenomena, Local Biological Phenomena, Martian Atmosphere, Geological Phenomena, Martian Magnetic Field, Global Chemical and Physical Phenomena, and Global Biological Phenomena.

Mission Support Systems

Construction - Habitat Assembly and Protection

Construction subsystems will be used mainly for the initial establishment of the life critical systems. The major concerns in this area are design, assembly, growth flexibility, safety, and maintenance. The need for Galactic Cosmic Ray and Solar Event protection must also be looked into.

Power - As required for the entire outpost

Dependable and safe power generation must be investigated for use by the entire outpost. It also must be sufficiently flexible to allow growth, as the outpost expands. Power requirements will be determined by the needs of the other systems. As the design is further refined, power requirements can be expected to increase.

Transportation - Sample collection, experiment deployment, maintenance

Various modes of transportation must be investigated. In order to make adequate trade studies, detailed information concerning vehicle range, mass properties, payload capacity, dependability, etc., must be determined. The options should include lunar-type rover, mobile pressurized lab, rover with inflatable shelter, and remotely piloted vehicle, as well as other vehicle concepts.

Long-Term Self Sufficiency

The most economically viable scenarios are those that make use of existing resources, and recycle them as much as possible. This is considered a key area for permanent human presence in space. This section also includes systems needed for habitat expansion.

In-Situ Resources Utilization

The Martian environment contains most of the resources needed to provide complete self-sufficiency. These resources can be utilized with food production facilities such as greenhouses, hydroponics, aquaculture, etc.; an atmosphere reduction facility to produce fuel, water, air, energy storage, fertilizer and other chemicals; and a materials processing facility to make metals, glass, cement, and other structural materials.

Habitat Growth - Configurations, including Habitat Construction from Martian materials

This includes techniques such as explosives, inflatable shelters and spray sealants for the creation of pressurized shelters.

ESTABLISHING GROUNDRULES

One of the most difficult problems at this point is establishing clear guidelines without restricting promising avenues of investigation. However, some decisions will have significant impact on surface infrastructure synthesis. Three such areas are mentioned here.

Space Station Common Modules

It is cost-effective to use as much existing technology as possible. Using the proposed Space Station Common Modules could significantly bring down the cost of a Manned Mars Mission and improve system reliability. It was decided to investigate using these modules to meet mission requirements on the surface of Mars. Preliminary evidence suggests these modules will prove quite sufficient for these requirements. Unfortunately, the parameters have not been completely fixed for the Space Station Common Module. If there is much change from the reference configuration, the decision to use them on Mars will have to be reevaluated. Table 1 shows the first order weight and volume requirements for the habitation module (HAB1). It's also possible to modify an additional module to be used as the scientific laboratory (LAB1). Some redundancy of Life Critical Systems could then be integrated into the design, eliminating single point failure areas.

Mission Modules - In-transit/Surface

It is not yet clear whether the surface mission modules should be used by the crew in-transit. If so, subsystems will have to be flexible

TABLE 1

SAMPLE OF TOP LEVEL SUBSYSTEMS MASS BALANCE VARIABLES

St	Input	Name	Output	Unit	Comment
					********** MISSION PARAMETERS ******
	4	P			NUMBER OF CREW MEMBERS
	1.5	D		yr	LENGTH OF MISSION
		PD	2190		CREWSIZE * MISSION LENGTH
	0	WATRECY			PERCENT WATER RECYCLABILITY
	.2	FOODHYD			PERCENT FOOD HYDRATION
	0	FOODSIT		lb/d	IN-SITU FOOD PRODUCTION
	0	WATSIT		lb/d	IN-SITU WATER PRODUCTION
	0	POWSIT		w	IN-SITU POWER PRODUCTION
					********** MISSION PARAMETERS ******
					***********************************
		WMISS	15834.843	lb	TOTAL WEIGHT REQUIRED TO SURFACE
		VMISS	1260	ft3	TOTAL VOLUME REQUIRED TO SURFACE
		PMISS	2322	w	TOTAL SURFACE POWER REQUIREMENTS
					***********************************
					********* MISSION SUBSYSTEMS *******
		VLABEQ	181.9	ft3	LAB VOLUME FOR EQUIPMENT
		WLABEQ	749	lb	WEIGHT OF LAB EQUIPMENT
		PLABEQ	1312	w	POWER FOR LAB EQUIPMENT
					***********************************
		VLCS	4503.2824	ft3	******** LIFE CRITICAL SYSTEMS *****
	0	WLCS		lb	
	0	PLCS		w	
		VECLSS	742	ft3	ECLSS
	0	VTCS		ft3	Thermal Control System
		VCS	2811	ft3	Crew Systems
		VNUTRI	470.28239	ft3	Nutritional Needs
		WNUTRI	17958	lb	
	0	VRADEXP		ft3	Radiation Exposure
	480	VHMF		ft3	Health Maintenance Facility
	1800	WHMF		lb	
	0	VHABPOW		ft3	Electrical Power and Processing
	0	VEVACAP		ft3	EVA Capability
					*************************************
		VLCSS	0	ft3	*** LIFE CRITICAL SUPPORT SYSTEMS ***
		WLCSS	3000	lb	
		PLCSS	0	w	
		VCONSTR	0	ft3	Construction
		WCONSTR	0	lb	
		PCONSTR	0	w	
		VPOWER	0	ft3	Power
		WPOWER	3000	lb	
		PPOWER	0	w	
					*************************************
		VPS	1260	ft3	********* PLANETARY SCIENCES ********
		WPS	2005	lb	
		PPS	2322	w	
		VCHEM	1162.5	ft3	Chemical,Mineralogical,Petrological & Envir. Interact. In Local Area (F2.1)
		WCHEM	1666	lb	
		PCHEM	2060	w	

enough to adapt to gravity differences that may exist between in-transit and surface environments. Having the same effective gravity in both the in-transit and Mars surface phases could solve this problem. However, the obvious question is once the modules are deployed on the surface, how does the crew return to Earth.

Radiation Considerations

Initially, it was thought that to be protected from Galactic Cosmic Radiation (GCR), the habitat would need to be buried under at least two meters of Martian soil. Recent data indicate that satisfactory short term (up to 4 years) radiation protection from GCR can be achieved with no external shielding. Any intermediate amount of shielding is unsatisfactory. This counter-intuitive development is due to the heavily ionizing heavy particles that are produced as secondary emissions as the lesser ionizing protons and electrons pass through the shielding. The GCR radiation dosage is approximately 50 REMS/yr in-transit and 25 REMS/yr on the surface of Mars (unprotected) during Solar minimum. On a 3 year mission with 1 1/2 years on the surface, this would give 75 REMS in transit and 38 REMS on the surface, for a total of 118 REMS, well below the current limit of 400 REMS career exposure limit. These numbers would be lower during Solar maximum (20 and 10 REMS/yr) since the increased magnetic field of the sun keeps out more of the non-solar cosmic rays. If this assumption remains valid, much of the construction and assembly equipment can be scaled down or eliminated.

The exposure dosages above assume no solar events (solar flares) during the entire mission. For the long transit and surface stay time involved, this assumption is not reasonable. Short-term solar event protection must be provided. For example, the August 1972 solar event would have given an unprotected astronaut in free space a lethal dose of 150,000 REMS. Fortunately, this extremely high dosage is very short term. Radiation protection to withstand this dosage need only be provided for about 12 hours. The equivalent of 4 1/2 inches of aluminum shielding would bring the dosage down to under 4 REMS (this corresponds to general shielding requirements of 30 grams/sq. cm.).

FUNCTIONAL BREAKDOWN

Table 1 shows a mass balance example of the top level subsystems. The infrastructure system is nowhere near completion, but the basic framework is established. This framework is useful in showing the subsystems developed using the functional analysis methodology. Of less importance are the present values of the variables. In many cases, the values were not known. In this case, a zero will appear either in the input or output column. Input variables are assigned by the user. Output variables are computed from the input variables, according to the rules on the rules sheet. The rules sheet is used to express the interactions among the various subsystems. As the method and subsystems are further refined, these will be reflected by additions and modifications to the rules sheet.

The top of the variables sheet shows the overall mission parameters. These input variables can be changed dynamically to show the total changes to the mission mass properties (volume, mass, and power requirements). These variables can be adjusted for changes in mission length, number of crew, as well as the percent of water recycling and food hydration. Variables can also be added to account for in-situ food, water or power production.

In establishing the functional framework, much effort was given to keeping it as general as possible. No assumptions have been made regarding for example, construction or transportation trade options. Specific trades will be studied via the various sets of inputs that can be used. This general approach has the added benefit that this framework can be used to examine trade options of any surface infrastructure system (lunar, for example). There is no breakdown for making flight manifest assignments for multiflight scenarios. This is a relatively easy addition and can be made when needed.

CONCLUSIONS

The most critical mission elements are those that involve the Life Critical Systems. Although the numbers shown are only the first rough pass, they do answer some fundamental questions. The proposed Space Station Common Module can be used to meet basic mission requirements for a permanently manned outpost on Mars. The module has a usable volume of 3980 cubic feet. The basic volume requirements for 4 crew members, 1 1/2 years on the surface, is about 4500 cubic feet. The additional needed volume can either be taken care of by modifying requirements or can be contained in the lab module, which will have excess volume, according to current science requirements.

The top-down functional decomposition methodology, combined with standard spreadsheet software, offers a powerful tool to quickly assess various design trades and analyze options. As the specific subsystems and the relational rules algorithms are further refined, it will be possible to very accurately determine the implications of continually evolving mission requirements.