Investigation into System Functionality and Decomposition as an Extension to Previous Mars Exploration Studies

Eden Dahan[1], Zachary A.C. Herman [2], Carla T. Procaccino[3], Tingyu Wang[4], Saptarshi Bandyopadhyay[5], Drew Ahern[6], Steven J. D'Urso[7]

University of Illinois at Urbana-Champaign, Urbana, IL, 61801

Abstract

The Aerospace Engineering Department at the University of Illinois established a graduate level program in Aerospace Systems Engineering in 2011. The core curriculum is framed by real-world complex systems development problems. This emphasizes systems thinking and the approaches required for defining objectives, functionality, and requirements leading to program discovery phase architecture and synthesis. The students select an aircraft or spacecraft context, through which each will be introduced to systems engineering processes and tools. Assignments investigate and report on aspects of that large complex system and their individual component systems.

This paper reports on the results of a study of Mars exploration surface systems as an extension to the NASA Mars Design Reference Mission Five. This study is a continuation of a previous Mars mission study, which focused on the in-space transit between Earth and Mars. In this previous investigation, a top-level concept of operations (ConOps) was devised and major objectives were defined, which included bringing a crew to Mars and returning them to Earth. In addition, a top-level product breakdown structure was detailed, and each team member described an element of this structure. Furthermore, a functional analysis was performed and top-level requirements were generated.

The Mars surface mission presented here is born from the objective to conduct scientific exploration on Mars to investigate life, climate, and geology in order to explore the possibility of sustained human presence. This objective is to be carried out to satisfy the needs of the stakeholders, including NASA's astronauts and planetary scientists, foreign space agencies, manufacturers, contractors, private industries in the space sector, the United States government, the United States public, and the public around the world.

The Mars surface mission has undertaken a functional decomposition approach in order to develop a system architecture and operational functional vignettes. This process creates a

[1] Master's student in Aerospace Systems Engineering, Department of Aerospace Engineering.
[2] Master's student in Aerospace Systems Engineering, Department of Aerospace Engineering.
[3] Master's student in Aerospace Systems Engineering, Department of Aerospace Engineering.
[4] Master's student in Aerospace Systems Engineering, Department of Aerospace Engineering.
[5] Doctoral student, Department of Aerospace Engineering.
[6] Doctoral student and Aerospace Systems Engineering teaching assistant, Department of Aerospace Engineering, AIAA member.
[7] Professor and Aerospace Systems Engineering Program Coordinator, Department of Aerospace Engineering, AIAA member.

foundation for accomplishing the objectives of the mission. In doing so, tasks necessary to execute pre-mission setup, scientific objectives, and post mission needs are identified. These tasks are assembled to create a functional hierarchy, and the functional segments are then employed to develop systems and requirements. Additionally, functional sequences are generated for the mission, and vignettes are derived. These scenarios help narrow down the possible approaches that could be used to meet the mission objectives.

The Mars surface mission system structure has been sub-divided into three levels. The top level is composed of systems dictated by the science objectives. These include the climate, geology, life, and ancillary systems. The segment systems, which interface with other systems (transportation, navigation, communication, life support, maintenance, and power), form the intermediate level. Some systems like life support and power are called city services as they are necessary for the entire duration of stay on Mars. Finally, mission specific systems, which include the laboratory, orbital measurement, and decontamination systems, are in the third level of the system structure. The dependence of top level systems to lower level systems is discussed in this paper.

An application of the aforementioned systems engineering approach is applied to a selected set of systems of interest to demonstrate feasibility of the proposed method. The systems of interest selected for further investigation include a drilling system, a navigation system, a transportation system, a laboratory system, and a communication system. All of the stated systems are presented as they relate to the three main sciences of interest to NASA: life, climate, and geology. In addition, interfaces between the systems of interest are investigated in order to define system boundaries that effectively derive functional requirements corresponding to each system.

Martian surface requirements are decomposed following the functional architecture, and functional requirements of certain systems of interest are derived from top level requirements and subsystem requirements. Then, performance requirements are established for each higher level function performed by the system. Moreover, since system decomposition creates new interfaces between subsystems, different interface requirements are defined, including both physical and functional interfaces, which ensure hardware and software compatibility for the entire Mars surface mission.