TRADE SPACE ANALYSIS OF MARS SURFACE EXPLORERS. J. J. Marquez[1], M. O. Hilstad[1], E. K. Hines[1], J. A. Lamamy[1], [1]Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, jjm@mit.edu.

NASA's Mars Exploration Program seeks to answer the question of whether Mars has ever been a habitable world, through study of how geologic, climatic, and other processes have interacted to shape the Martian environment. Alternating orbiter and lander vehicles are planned for upcoming biannual launch windows, potentially resulting in a surface mission once every four years. This infrequency of surface missions makes it important to maximize the potential for useful science return of each landed mission through carefully directed mission design. The motivation for this project arose from the need for a tool to rapidly create and compare system-level Mars rover designs. Specifically, the project resulted in a trade space design and analysis tool that is able to render rover designs applicable to the architecture and design selection of the 2009 Mars mission – the Mars Science Laboratory (MSL) – and to future robotic surface explorers.

Graduate students[2] in the Department of Aeronautics and Astronautics at MIT developed a Mars rover modeling tool as a semester-long project in a space systems engineering course. The project was supported by engineers and scientists from the Jet Propulsion Laboratory (JPL), who provided insight into rover design drivers, information on existing rover designs, and suggestions as to the appropriate scope of the project. The project scope was limited to the design of independent rovers, and emphasis was placed on design drivers that are related to surface operations, disregarding launch and entry/descent/landing. Focus was placed on architectural and system-level trades, rather than on detailed engineering decisions. Active landers were not considered in the trade space, and only a very limited set of prior-to-landing considerations was taken into account.

Figure 1 depicts the process followed by the trade space tool in creating a set of rover designs. The process begins with a user-defined mission scenario represented by a set of parameters in the science and design vectors. The science vector includes those parameters that are held constant for all designs in a particular trade space. Examples of science vector parameters include the science payload (instruments and acquisitions tools) and landing site parameters such as rock distribution, latitude, and the expected distance between interesting samples. The design vector includes the set of architectural and system-level parameters that uniquely identify a particular rover design within the trade space. Design vector parameters include mission duration, power system type, wheel diameter, and several indicators of autonomous capability. The user provides a range of allowable values for each parameter in the design vector, and iteration through all allowable instances of the design vector results in a trade space of rover point designs.

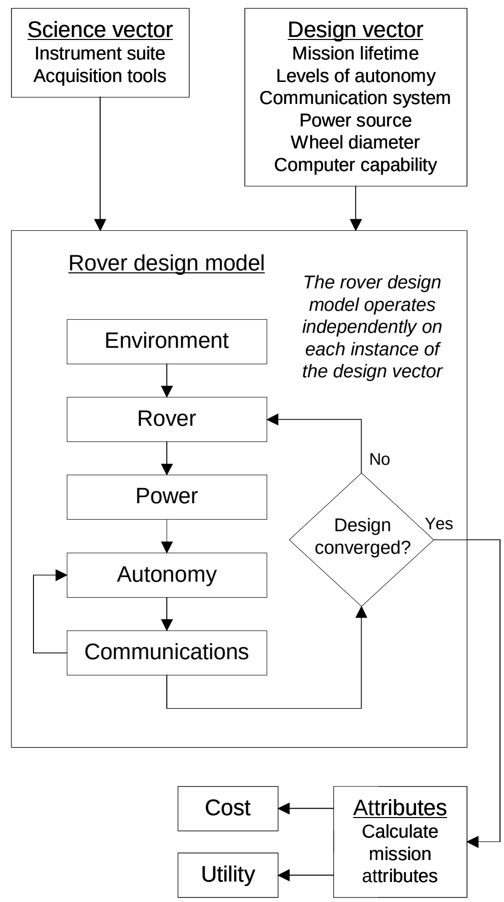

Figure 1: Trade space analysis process flow.

The design and science vectors are taken as inputs by the rover design model, which outputs a corresponding system-level rover design. As shown in Figure 1, the rover design model is divided into five algorithm modules, and contains two high-level iterative loops. The environment module models rock frequency and determines the solar energy available to the rover. The rover module models the structural, mobility, and thermal infrastructure necessary to integrate and support the onboard hardware. The power module sizes the power system components to meet the needs of the instruments, communications system, drive motors, and other electronic systems. The autonomy module determines how many samples can be obtained over the mission lifetime based on design vector parameters such as the levels of autonomy, and considerations such as available power. Examples of the levels of autonomy are specifications for autonomous short and long distance traverse capability: each of these may be described by A1, the level of autonomy used by the Mars Exploration Rovers, or by A3, an advanced level of autonomous operation identified by NASA for possible use in future rovers. The communications module sizes the communications system to provide appropriate data transfer rates, given the levels of autonomy of the rover. When a design has converged, the data describing that design are saved, and the next instance of the design vector is evaluated.

When iteration through all allowable instances of the design vector is complete, each design in the trade space is evaluated for its utility and cost based on a pre-determined set of desired mission attributes. The utility describes the ability of the rover design to fulfill a set of mission goals – in essence, it is a measure of the potential for science and engineering return offered by a particular design.

By varying the values of the parameters in the design vector, the effects of both simple and compound architectural decisions on mission utility can be shown. The ability to identify optimal architectures in a diverse trade space will provide insight applicable to future mission plans, and will direct mission planners toward locally optimal regions of the trade space suitable for in-depth study. As an example, the modeling tool has the potential to reveal the benefits of investing in higher levels of autonomy, and to make clear the specific applications in which increased autonomy can influence scientific return. The ability for mission planners to design and compare rover architectures spanning a diverse trade space will help ensure that future surface missions to Mars are cost effective and scientifically rewarding.

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