AUTOMATED DESIGN OF ROBOTIC PLATFORM FOR EXPLORATION OF PLANETARY CAVES, PITS AND LAVA TUBES. H. Kalita[1] and J. Thangavelautham[2], [1]Aerospace and Mechanical Engineering, University of Arizona, 1130 N Mountain Ave., Tucson, AZ 85721; hkalita@email.arizona.edu, [2]Aerospace and Mechanical Engineering, University of Arizona, 1130 N Mountain Ave., Tucson, AZ 85721; jekan@email.arizona.edu.

Introduction: The next frontier in solar system exploration will be missions targeting extreme and rugged environments such as caves, pits, and lava tubes of the Moon and Mars [1]. Exploration of these environments will provide vital clues to the past and present habitability conditions. However, current landers and rovers are unable to access these areas of high interests due to limitations in precision landing, inability to traverse rugged terrains, and operations culture where risks are minimized at all costs. So, there is a need for small, low-cost platforms that can perform high-risk, high-reward science on these extreme environments [2].

With the rapid advancement in electronics, sensors, actuators, power supplies and instruments as a result of rise of interplanetary CubeSats, it is possible to develop robotic architectures that can take high exploration risks at low costs. Taking motivation from these advancements, we present an architecture of small, low-cost, modular spherical robot called SphereX that is designed for exploring planetary caves, pits, and lava tubes [3-5]. A large rover or lander may carry several of these SphereX robots that can be tactically deployed to explore and access these rugged environments inaccessible by it.

SphereX Architecture: SphereX consists of a mobility system to perform optimal exploration of these target environments. It also consists of space-grade electronics like computer board for command and data handling, power board for power management and radio transceiver for communicating among multiple robots. Moreover, it also consists of a power system for power generation/storage, multiple UHF/S-band antennas, a thermal and shielding system for survival, an outer shell for structural rigidity and accommodates payloads in the rest of the volume as shown in Fig. 1.

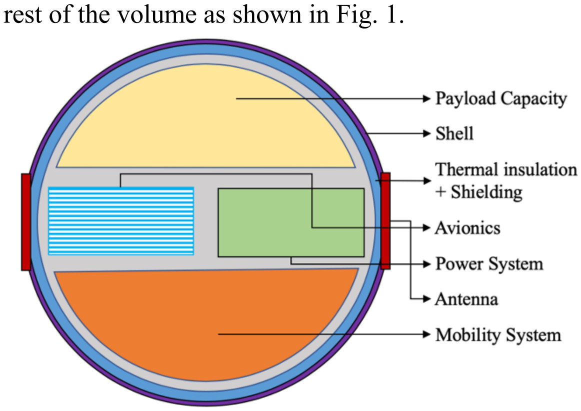

Fig. 1: SphereX Architecture.

However, the design of SphereX is a complex task that involves a large number of design variables and multiple engineering disciplines. It is a highly coupled problem between multiple disciplines and must balance payload objectives against its overall size, mass, power and control which affects its cost and operation. Moreover, each subsystem has multiple candidate options which give rise to complexity and discontinuity in the objective function and design space.

Design Optimization: Our approach to find optimal design solutions of SphereX involves using a hybrid optimization process where the search of the design space is performed with a Genetic Algorithm (GA) based multi-objective optimizer at the system level to find a set of Pareto-optimal results while using gradient-based techniques at the discipline level as shown in Fig. 2. The system level optimizer interacts with an inventory of Commercially-Off-The-Shelf (COTS) components and mathematical models of each subsystem to find pareto optimal solutions that meets predefined mission specifications in terms of exploration distance, exploration time, and target planetary body. The objective is to find optimal design of SphereX that minimizes its mass, volume and power requirements while maximizes available payload mass, volume and power [5, 6].

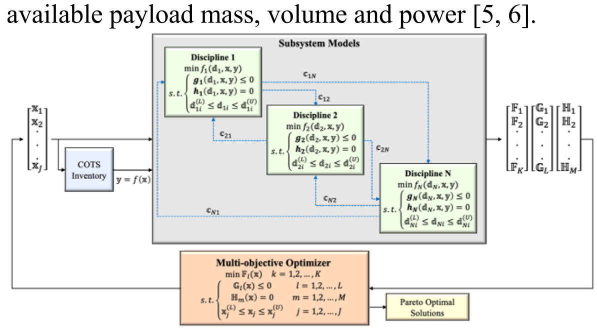

Fig. 2: Hybrid optimization approach for multidisciplinary optimization.

Moreover, the design of the robot takes into account environmental factors such as temperature, radiation, gravity and surface interaction to provide the optimal designs. Mathematical models of each subsystem are developed that include mobility system, power system, thermal system, shielding, communication system, avionics and shell. Three types of mobility system (hopping, rolling, wheeled) and two types of power system (Li-ion batteries, fuel cell) are used in the design process. The optimizer is capable of providing the optimal choice of mobility system type and power system type along with the optimal design of each subsystem based on the mission specifications.

Results: We performed a simulation to execute subsurface exploration of Mare Tranquilitatis Pit on the Moon at 8.33°N 33.22°E. Lunar Reconnaissance Orbiter Camera (LROC) images reveal that the pit diameter ranges from 86 to 100m with a maximum depth from shadow measures of ~107m and that it opens into a sublunarean void of at least 20meters in extent [7, 8]. However, the sublunarean void might extend to a few kilometers in length and so mission specification is to explore 1000m of the sublunarean void. The con-ops for performing this mission is shown in Fig. 3. A lander carrying multiple SphereX robots would descent nearby Mare Tranquilitatis Pit and deploy the robots one by one. Each robot will have three phases 1. Surface operation to approach the pit entrance, 2. Pit entrance maneuver, and 3. Sub-surface operation to explore the pit. The mission target is to explore 2000m on the surface in 10 hours, 50m in 10 minutes to enter the pit and 1000m inside the pit in 5 hours as seen in Figure 16(Right).

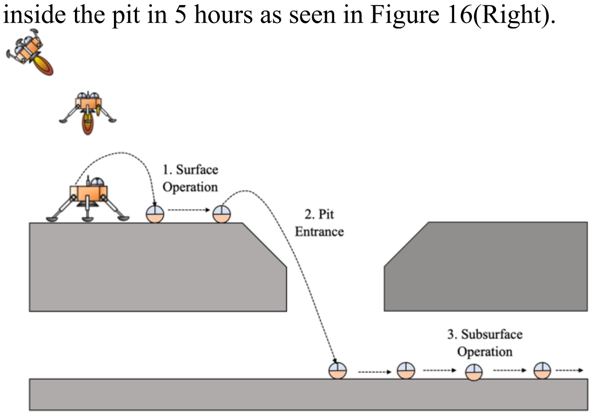

Fig. 3: Concept of Operations for exploring Lunar pits.

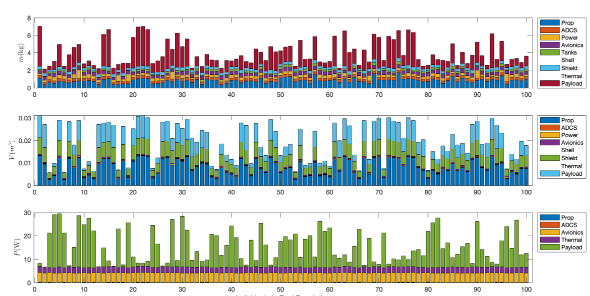

Fig. 4: Mass, volume and power budget of the 100 individuals in the pareto optimal front.

Fig. 4 shows the mass, volume, and power budget of the pareto-optimal solutions of SphereX for the above mission specifications. An important result found in the pareto front is propulsive hopping was selected as the optimal choice of mobility and Li-ion battery was selected as the optimal choice of power system for short duration missions while fuel cell was selected as the optimal choice of power system for long duration missions. Fig. 5 shows 3D visualization of a few selected designs from the pareto front developed using MATLAB VRML.

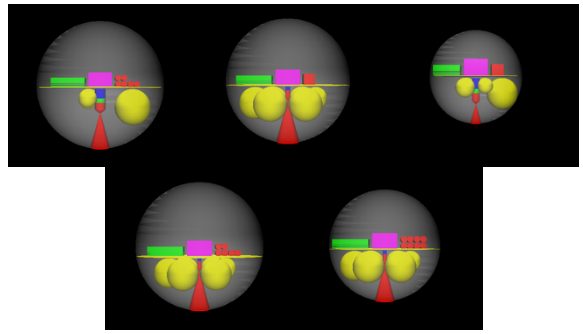

Fig. 5: 3D visualization of the designs in the pareto front.

Conclusion: We presented a robotic architecture for exploring planetary caves, pits and lava tubes. The design of complex systems like SphereX needs a multidisciplinary optimization approach because of involvement of multiple engineering disciplines. Our approach provides a system-level perspective of SphereX with sufficient depth to capture high-level trade-offs and reveal insights that are perhaps not obvious at the discipline level. The solution provides a geometric solution that is useful for ground development of SphereX taking into consideration its operational and exploration goals on a target environment.

References:

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