THERMOMECHANICAL REAL-TIME HYBRID SIMULATION: DEVELOPMENT AND EXECUTION

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Over the past decade, the space community has focused on enabling long-term habitats for human presence and exploration on the Moon and Mars. It is essential for these habitat systems to function effectively under challenging conditions and to have sufficient autonomy technologies for fault identification and intervention. Thus, testing these complex habitats is vital to understanding the complexities these systems will face.

Real-time hybrid simulation (RTHS) is an enabling technology that has transformed engineering experimentation and helped researchers expand testing capabilities. This cost-effective cyber-physical testing method enables the simultaneous experimental and computational modeling of systems, allowing for a comprehensive observation of their behavior under extreme dynamic conditions. However, evaluating space habitats poses challenges due to their complex interconnections and the harsh environmental conditions they must withstand. Significant breakthroughs are needed to develop a realistic RTHS framework that can effectively replicate disruptive conditions, such as damage and degradation, in order to advance RTHS for space habitats.

This dissertation presents the development and experimental execution of a novel thermomechanical RTHS method to evaluate the multi-physics response of lunar habitat systems due to disruptive events. These disruptive scenarios are designed to study the thermomechanical cascading effects in a lunar habitat due to a micrometeorite impact damaging its structural protective layer. Experimental RTHS validation is achieved through prototype scenarios, leading to complex case studies that couple a system-of-systems lunar habitat with fault detection and decision-making systems.

Through these illustrative case studies, this thermomechanical RTHS framework is the first of its kind to experimentally execute the effects of damage and repair intervention strategies in real-time on a numerical subsystem while simultaneously imposing the cascading effects on a physical specimen. The thermomechanical RTHS framework in this dissertation offers a cost-effective and accessible method to test novel ideas and technologies further empowering researchers in the fields of space resilience and autonomy.