Paper ID: 88583
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IAF SPACE SYSTEMS SYMPOSIUM (D1)
Lessons Learned in Space Systems (7)

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LESSONS FROM EARTH FOR DESIGNING AND BUILDING SAFE EXTRATERRESTRIAL SYSTEMS

Abstract

Recent advancements in space exploration have led to growing momentum for construction projects in outer space, including space habitats and their supporting infrastructure. Such endeavors entail significant challenges to ensure the quality and performance of the systems built and operated in space. The extreme environmental conditions can magnify built-in defects and latent failures, or embedded pathogens, resulting in catastrophic consequences, while the remoteness imposes prohibitive costs for repair missions.

Previous spaceflight accidents provide helpful lessons for managing risks and preventing future accidents, but that history is relatively short. Here, we show how we can also leverage the long and extensive history of accidents in terrestrial construction projects, and translate the lessons into principles and recommendations for extraterrestrial construction. Systems-based accident modelling approaches like AcciMap and STAMP provide insights into the contribution of systemic factors, but lack emphasis on the time dimension, which is essential in capturing the dynamic and ephemeral nature of the organizations that come into being to create complex systems. In previous work, we developed a dedicated accident model—the framed and layered accident pathogen propagation (FLAPP) model—to describe construction system accidents, on or off Earth, that occur as a result of a sequence of defective processes ending up as embedded pathogens. We analyzed six construction and two space system accidents, and identified instances of how design decisions can breed pathogens when combined with inadequate organizational factors.

The present work enhances and generalizes those lessons by expanding the accident case set and translates them into the planning and design of extraterrestrial construction. The expanded set contains construction system accidents ranging from conventional buildings and civil engineering structures to offshore platforms, underground facilities, and other structures and systems in extreme environments, and accidents with crewed and uncrewed spacecraft. Upon obtaining an enhanced library of consequential implications of design decisions and underlying organizational factors, we compare how similar instances have been addressed in successful construction and spaceflight projects and collect the best practices. We further examine the similarities and differences of domains and applications to explore what is necessary to translate the lessons and best practices into construction projects in space.

This work presents forward-oriented principles and guidelines for future projects, along with a knowledge base of pitfalls that design decisions can induce that can be applied to the development of a wide range of future space systems with increased autonomy, complexity, and capabilities.