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A HISTORICAL ANALYSIS OF EARTH-INDEPENDENCE IN HUMAN SPACEFLIGHT MISSIONS

Abstract

NASA's current goals for human spaceflight include missions to deep space locations such as the Moon or Mars, with some plans including periods of uninhabited spacecraft operations between crewed expeditions. These future missions into deep space will require higher levels of self-reliance, and subsequently Earth-independence, as the distance from Earth increases along with mission duration. Historically, human spaceflight missions have been enabled through some combination of communication with ground support, logistical resupply, and the capabilities of the system, which includes the habitat and the onboard crew. While some previous missions such as Mercury, Gemini, and Apollo operated without resupply, these missions were limited in duration and maintained near-continuous communication with Earth for diagnostics of anomalies as well as hierarchical decision-making. More recently, space stations in Low Earth Orbit such as Skylab, Mir, and the International Space Station have operated with mission durations on the order of months, enabled through consistent resupply as well as near-continuous communication with ground support. In contrast, future missions to deep space will have to contend with long communication latency of 12- 44 minutes round-trip for Mars and extended transit times of close to six months for resupply spacecraft. This work examines historical human spaceflight missions through the lens of Earth-dependence in order to identify what technological innovations have contributed most to mission self-reliance. Logistical dependence is assessed through figures of merit such as number of resupply flights per mission and percent of up-mass reclaimed or regenerated. Innovations in ECLSS technologies and the standardization of component parts are discussed with respect to their contribution to decreasing resupply requirements. Communication dependence is assessed in conjunction with the operational dependence on ground support. This dependence includes reliance on ground for anomaly diagnostics, decision-making, scheduling, subject-matter expertise, teleoperation, commands, or other information acquired through a communications link with Earth. Considerations such as bandwidth and time delay are also discussed. Finally, a summary of key advancements throughout the past 50+ years of human spaceflight are provided along with recommendations for future technology investment toward enabling Earth-independent deep space operations.