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BEYOND EARTH: A COMPREHENSIVE REVIEW OF SPACE STATIONS AND THEIR CHALLENGES

Abstract

Space stations have played a significant role in advancing space exploration and scientific research, providing unique environments for studying the effects of microgravity and developing technologies for future missions. Ever since the launch of the first space station, Salyut 1, and the establishment of the International Space Station (ISS), space stations have become central to long-term human presence in space. Over the years, there have been many remarkable advancements in space station technology, ranging from the first successful docking achieved with a 'dead' space station in Salyut 7, to the launch of Mir, the first modular space station, and followed by the ISS and the Tiangong Space Station (TSS). As of 2024, the two operational space stations, ISS and TSS, symbolize the current state of human presence in space. However, maintaining and operating these stations presents significant challenges, including resource sustainability, cost, life support systems, orbital environment, radiation exposure, and astronaut health.

From Salyut 1 launched in 1971, to future space stations planned for launch by 2030, such as Axiom (planned for 2026), Orbital Reef (2027), Starlab (2028), and the Bharatiya Antariksha Station (2028), this review systematically analyses space stations over a period of 60 years. The Mir had a compact configuration allowing different flight modes, including gravity potential, whereas the ISS's truss backbone architecture ensures early operational capabilities, high electrical power, and high heat rejection performance. Moreover, the upcoming space stations compared to their predecessors will also have higher gravity gradient stabilisation and higher growth potential.

This review critically discusses the history, present scenario, and future challenges in the development of space stations. The different types of space stations based on the present classification, their advantages and disadvantages, along with the performance of each with case studies have been presented here. The materials used in space stations, their duration, scope with objectives, as well as the key technologies required, including Human Space Vehicle Systems, Environmental Control and Life Support Systems (ECLSS), Extravehicular Activity (EVA) Systems, Flight Design, Robotics, and Integrated Environment Testing, are discussed.

The present work also provides insights into future prospects for research and development, emphasizing the necessity of innovation and collaboration in overcoming the barriers to sustainable human

presence in space. By addressing these multifaceted challenges, this work can pave the way for a new era of exploration and discovery beyond Earth.