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DESIGN AND DEVELOPMENT OF A LOW-COST FRICTIONLESS AIR-BEARING TESTBED FOR ON-GROUND DOCKING AND BERTHING TESTING

Abstract

As on-orbit servicing, debris removal, and space manufacturing technologies progress, rigorous testing of docking and berthing algorithms becomes increasingly important. Sustainable space logistics and future spacecraft operations require reliable interfaces that can handle routine docking, cargo transfers, and assembly operations in microgravity. Current testing methods, such as parabolic or zero-gravity flights and drop experiments, provide only brief microgravity experiences and are limited in cost and working envelope available. This work describes a modular, low-cost, frictionless air-bearing testbed for on-ground docking mechanism testing in near-friction-free conditions. The platform employs a 2D air-bearing system that provides two translational and one rotational degree of freedom, simulating critical microgravity dynamics over lengthy periods of 10-20 minutes. While the testbed largely functions in 2D, it acts as an important link between simulation and actual micro-gravity circumstances, allowing algorithm development to be applied to complete 3D dynamics in space. To attain a high level of flatness and durability, the testbed has to be designed while keeping material properties, dependence on thermal conditions, and surface characteristics in mind. After considering choices such as granite tiles, epoxy-coated medium-density fiberboard, and porous aluminum, each with its own set of advantages and disadvantages, we chose a solution that combines friction reduction, surface consistency, and cost-effectiveness. The testbed's modular architecture accommodates a wide range of docking scenarios, including high-velocity approaches and off-nominal cases like angular misalignments, due to unique integration techniques that ensure surface flatness between modular segments. Although the platform is not fully frictionless, the low resistance acts as a controlled variable, allowing for realistic testing of docking algorithms that must correct for minor perturbations. The knowledge gained from these events helps algorithms adapt to real orbital conditions. Furthermore, the platform's low acceleration disturbances outperform parabolic flights, making it ideal for precision-oriented docking interface testing. The paper will highlight preliminary experiments indicating the platform's ability to mimic crucial dynamics for docking interface evaluation, demonstrating stability, low vibration, and repeatability. This testbed provides an accessible, scalable, and effective alternative for researching and improving autonomous docking and berthing systems, hence promoting sustainable space operations and future spacecraft assembly.