Model Predictive Control and Integrating with the Autonomy Stack of the Astrobee Free-Flyer. M. Ekal[1*] K. Albee[2*], B. Coltin[3], R. Ventura[1], R. Linares[2], and D. W. Miller[2], [1]Institute for Systems and Robotics, Instituto Superior Técnico, {mekal, rodrigo.ventura}@isr.tecnico.ulisboa.pt, [2]Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, {albee, linaresr, millerd}@mit.edu, [3]SGT Inc., NASA Ames Research Center, brian.coltin@nasa.gov, [*]Both authors contributed equally to this work.

Introduction: Autonomous microgravity robots must often interact with dynamic environments and systems with uncertain properties. When it comes to ensuring the safe and precise execution of these tasks, the ability to perform receding horizon planning and control---such as model predictive control (MPC)---can enhance system performance by determining control actions online, when the most recent system parameters, constraints, and uncertainty realizations are available.

NASA's Astrobee [1], [2], is one such robotic free-flyer that has recently been deployed on-board the International Space Station. Potential tasks for Astrobee include payload transportation and taking inventory, all the while working alongside astronauts and other floating cargo. An online replanning algorithm is thus relevant for Astrobee and future autonomous microgravity robots.

This paper details the implementation and testing of an algorithm that performs goal-driven planning in an online, receding horizon fashion on an Astrobee robot using the Astrobee ground testing facility. A brief overview of model predictive control and its potential benefits for autonomous microgravity robots is provided, and its relation to receding horizon planning is discussed. Software integration details of the algorithm on the Astrobee platform are presented, and repurposing of Astrobee's flight software for guidance navigation and control (GNC) research is illustrated. Replacing the SPHERES GNC microgravity testbed [3], Astrobee is taking the mantle of dedicated GNC testbed and the lessons learned from this work are expected to be helpful for scientists testing on Astrobee hardware in the future. This work also resulted in a guide [4] with detailed information about integration with Astrobee's autonomy stack.

Model Predictive Control (MPC): MPC is a control scheme that casts an optimal control problem as an optimization problem that is solved repeatedly online. Using, for example, discrete inputs as decision variables, inputs are solved to minimize a cost function while satisfying constraints. A simple MPC scheme is presented for Astrobee's three degree of freedom dynamics and some of the practical implementation details are discussed. An experimental scenario consisting of simple waypoint planning is presented, with the MPC repurposed as a planning method, resulting in control over Astrobee's translational and rotational degrees of freedom on the Astrobee ground test facility.

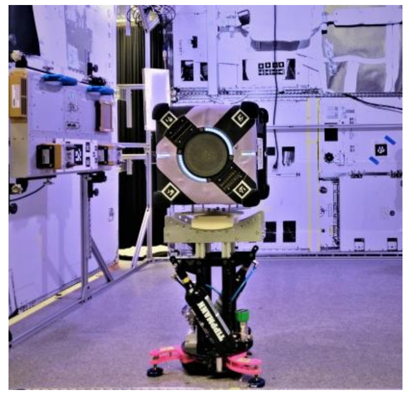

Fig 1. Astrobee on a planar air bearing at the ground test facility.

Astrobee as a GNC Testbed: Aside from the MPC control/planning method itself, a variety of practical integration hurdles were overcome to integrate with Astrobee's autonomy stack. A summary of this implementation information is provided, in order to bring Astrobee's GNC testbed capabilities to realization. Working within the Astrobee Flight Software's ROS framework, some of these modifications include: suppressing default control nodelets; using proper messages and topics; the frequency of topic publishing; integrating outside C libraries and MATLAB GNC code (e.g., using the ACADO toolkit [5]).

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References: [1] Smith, T. et al. (2016) Astrobee: A new platform for free-flying robotics on the international space station. [2] Fluckiger, L. et. al. (2018). Astrobee robot software: a modern software system for space. [3] Miller, D. et al., "Spheres: A testbed for long duration satellite formation flying in micro-gravity conditions," Adv. Astronaut. Sci., vol. 105 I, pp. 167–179, 2000. [4] Albee, K. and Ekal, M. (2020). A Brief Guide to Astrobee's Flight Software. [5] Houska, B. et. al. (2011). ACADO toolkit—An open-source framework for automatic control and dynamic optimization. *Optimal Control Applications and Methods*, 32(3), 298-312.