MarCO: Mars Cube One – Lessons Learned from Readying the First Interplanetary Cubesats for Flight. A. Klesh[1] and J. Krajewski[1], [1]Jet Propulsion Laboratory, California Institute of Technology.

Introduction: In May of 2018, the MarCO spacecraft are scheduled to launch with the Mars-bound InSight lander for a novel technology demonstration of interplanetary small spacecraft. Following InSight's separation from the launch vehicle, the two MarCO, or Mars Cube One, vehicles will deploy from from their cannisters and begin their own independent flights to Mars. Six and a half months later, the MarCO craft will fly by Mars, providing a UHF-to-X-band relay service from the InSight lander to Earth during InSight's entry, descent, and landing sequence.

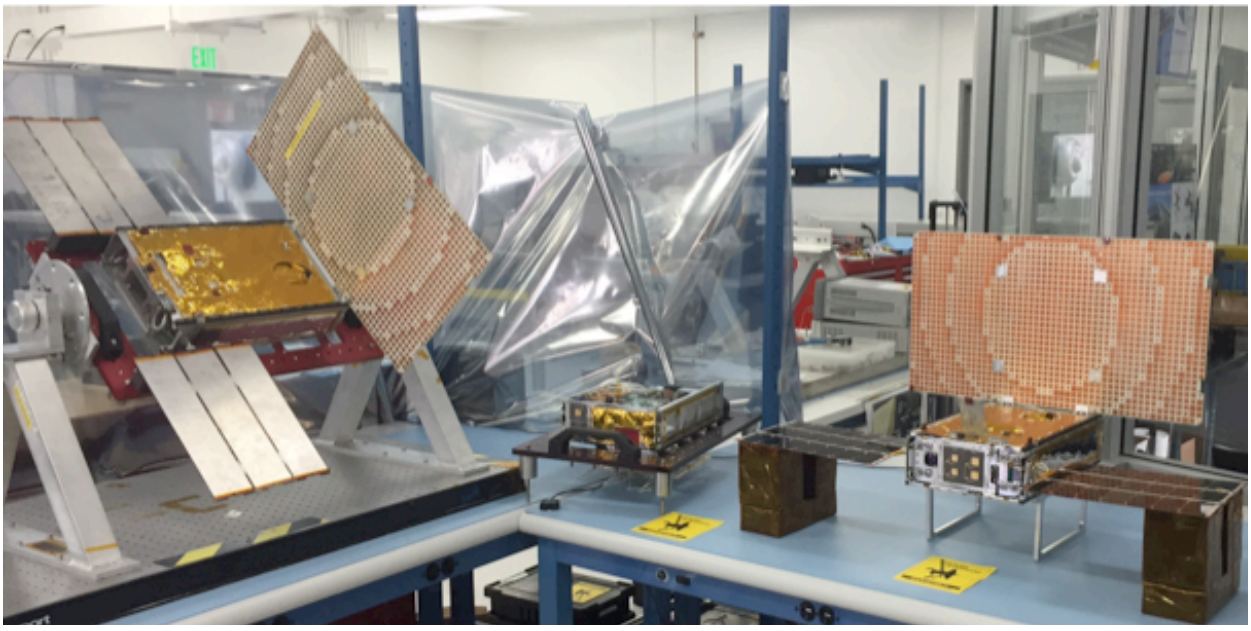
Though delayed for two years due to the InSight schedule slip, much of the integration and test of the MarCO spacecraft took place in the fall of 2015 and 2017. Significant analysis and testing included Deep Space Network (DSN) compatibility for the first CubeSat deep space transponder, Iris; planetary protection analysis of low-cost vehicles contained outside the primary spacecraft's fairing; operations planning of a 3-axis stabilized small spacecraft beyond Earth; and an aggressive I&T campaign prior to launch delivery.

Here we summarize brief lessons learned from the MarCO integration and test program. Together, these lessons provide important considerations for future interplanetary CubeSats and small spacecraft.

Deep Space Transponder: The Iris radio was tested at the DSN Test Facility (DTF) to show RF compatibility and end-to-end dataflow. It is of utmost importance to provide final firmware/software within the radio to assure that measurements taken during the test may be trusted for flight operations, including receive threshold, power output, and expected data format. Much of this information is contained within the flight-ground interface control document. The flight mission operations center should be utilized for the end-to-end test to assure minimum risk to flight operations.

Planetary Protection: To meet planetary protection requirements for Mars, early and continuous communication with the NASA planetary protection office is required. As MarCO is deployed from dispensers external to the primary fairing around InSight, the vehicle contamination is considered to be uncontrolled. MarCO analyzed the launched bioburden of contaminants, the probability of the vehicles impacting Mars over 50 years, and the burn-up and break-up analysis at Mars.

Operations Planning: Most CubeSats rely on magnetotorquers to push against the Earth's magnetic field to desaturate reaction wheels. In deep space, MarCO relies on a cold-gas thruster system to desaturate the wheels and perform trajectory correction maneuvers. The spacecraft must maintain pointing for communications as well as solar energy collection, and does not have periods of eclipse. Careful operations planning are required to achieve communication periods commensurate with these pointing and power requirements, along with scheduling periods acceptable to the Deep Space Network.



I&T Campaign: Two spacecraft, along with several testbeds of varying fidelity, were required to achieve the rapid test campaign for launch readiness. This included a near-flight identical testbed, several command and data handling boards, and critically, a software-defined radio system enabling end-to-end testing within the lab. MarCO makes use of NASA's Advanced Multi-Mission Operations System for command and control. Utilization of this system from early testing through operations allowed for team training concurrently to I&T.

Summary: The MarCO spacecraft have served as pathfinders for future small spacecraft leaving Earth orbit. Lessons from the mission, even from I&T, should be carefully considered for fture opportunities. Teams should carefully consider differences from low-Earth orbit and deep space, and interface with the DSN and planetary protection communities early in planning phases.

References: [1] A. Klesh and J. Krajewski, MarCO: CubeSats to Mars in 2016 (2016) *SmallSat.*