Two Stage CubeSat Docking with Visual Cues

Athip Thirupathi Raj, Connor Sturgeon, Jekan Thangavelautham
Space and Terrestrial Robotic Exploration (SpaceTREx) Laboratory, University of Arizona
athipt@email.arizona.edu, csturgeon@email.arizona.edu, jekan@email.arizona.edu

SpaceTREx

Motivation

Kickstarting a space economy will require technologies to facilitate trade of goods and services in space much like how the shipping container has standardized global trade via the oceans. (Figure 1) Small satellites are undergoing exponential growth, yet their full capabilities are not realized, nor are they in position to facilitate trading of goods and services in space as they are still not in a position to be assembled on-orbit into larger satellite or rearranged into specialized modules meeting customer needs. Reliance on human intervention for On-orbit servicing and construction (eg. Hubble, ISS). These limitations can be traced down to the limited advancement of autonomous rendezvous, docking and assembly of small satellites in space.

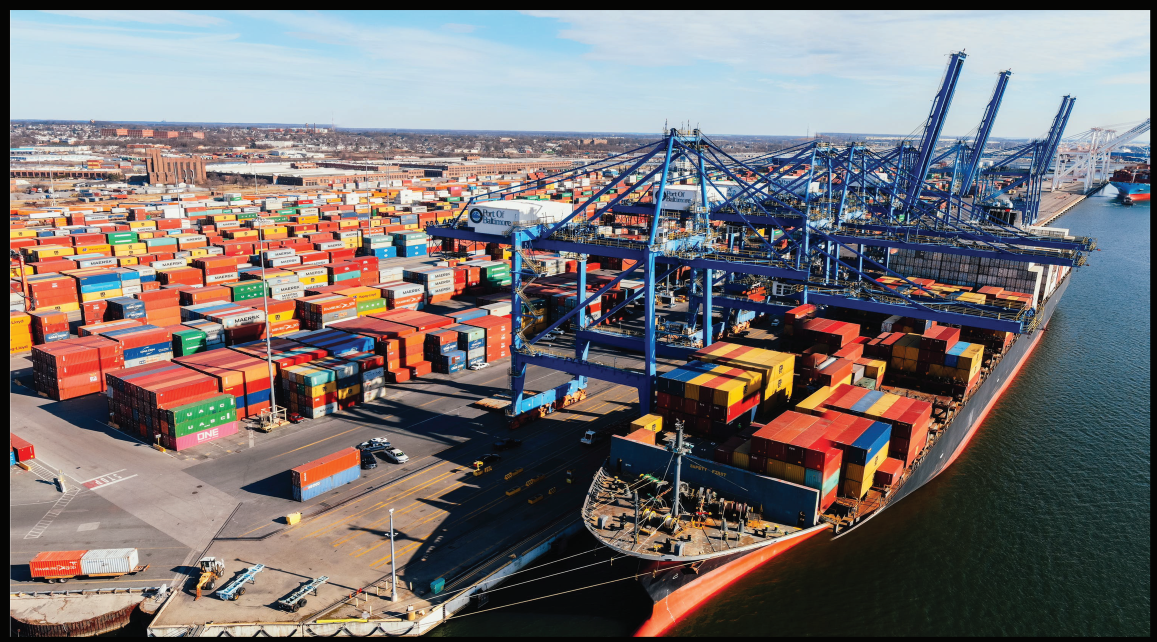


Figure 1: Shipping cargo containers on a ship

Mission Objectives

The primary mission objective is to perform rendezvous, docking, and release operations of 2 CubeSats in Low Earth Orbit (LEO) as a technology demonstrator. The sensors and actuators involved in the docking process are assumed to take up 2U in volume and the supporting systems in the bus shall take up 1U in volume. Thus the minimum required volume to perform the docking operations is 3U. The mission objectives are listed as follows:

- Rendezvous, Dock and Release two 3U CubeSats in Low Earth Orbit. (LEO)
- To perform Two-Stage Docking for future servicing operations.
- The system shall use Visual Cues for initial rendezvous.

Phase 1: Rendezvous

In order to avoid reliance on GPS and other navigation systems (for potential future interplanetary missions), or inter-cubesat RF communications, a system of LEDs and Light-to-Digital converters is used in the initial rendezvous process (Figure 4)

- Use of "LED Blinks" as visual cues to transmit and receive messages across both the CubeSats.
- Identification using Light-to-Digital converters.
- Each Spacecraft enters different modes based on the messages received.
- If a Spacecraft does not exit "Searching" mode after a set time, it executes a manual spin using thrusters or magnetorquers.

Blink Frequency	Message
1 Hz	"Searching"
2 Hz	"Identified"
3 Hz	"Contact Established"
4 Hz	"Distance = TBD - TBD meters"
5 Hz	"Distance = TBD - TBD meters; Close contact, switching to fine attitude adjustments"
Off	"End of Rendezvous Phase; Switching to Soft Capture Phase"

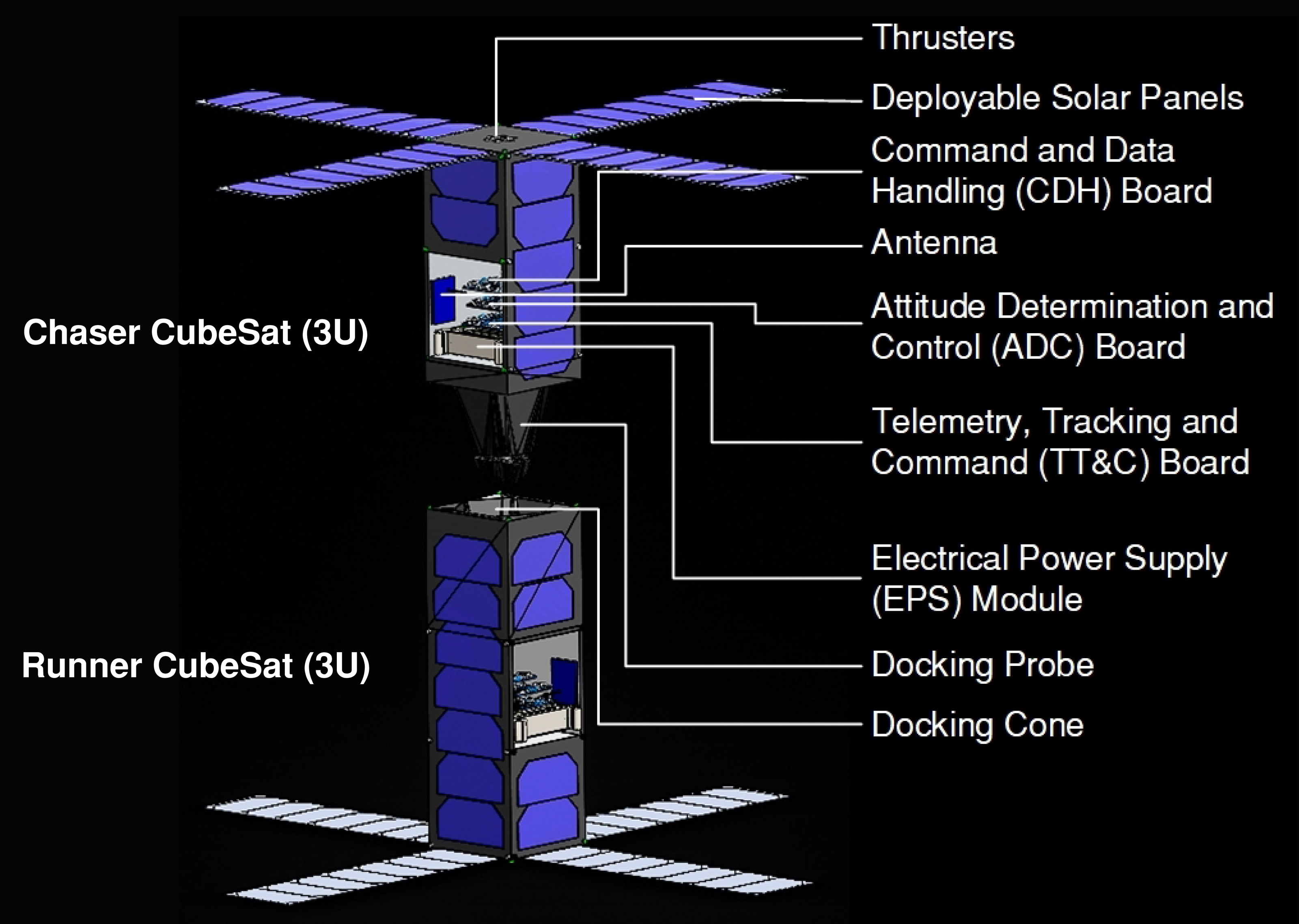


Figure 2: System Level Design of the Runner (Bottom) and Chaser (Top) CubeSats

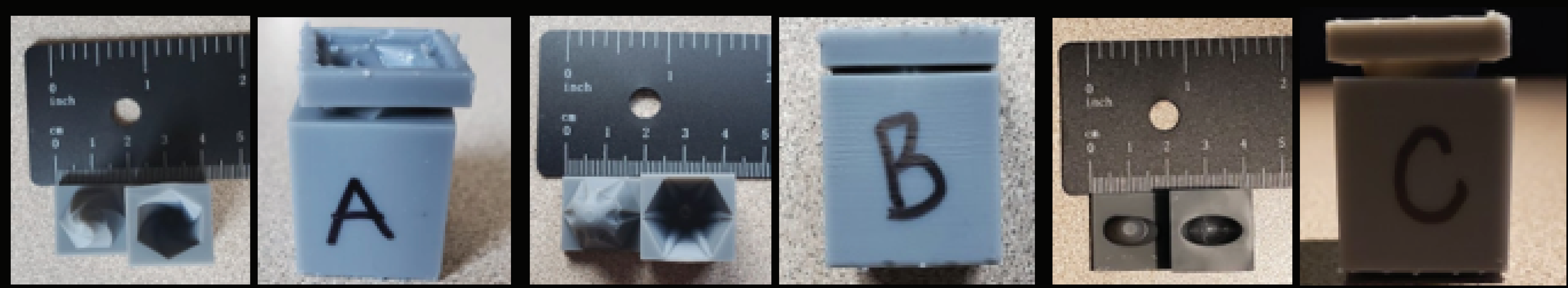


Figure 3: SLA 3D Printed Cone and Probe Combinations (Scale = 1:5)

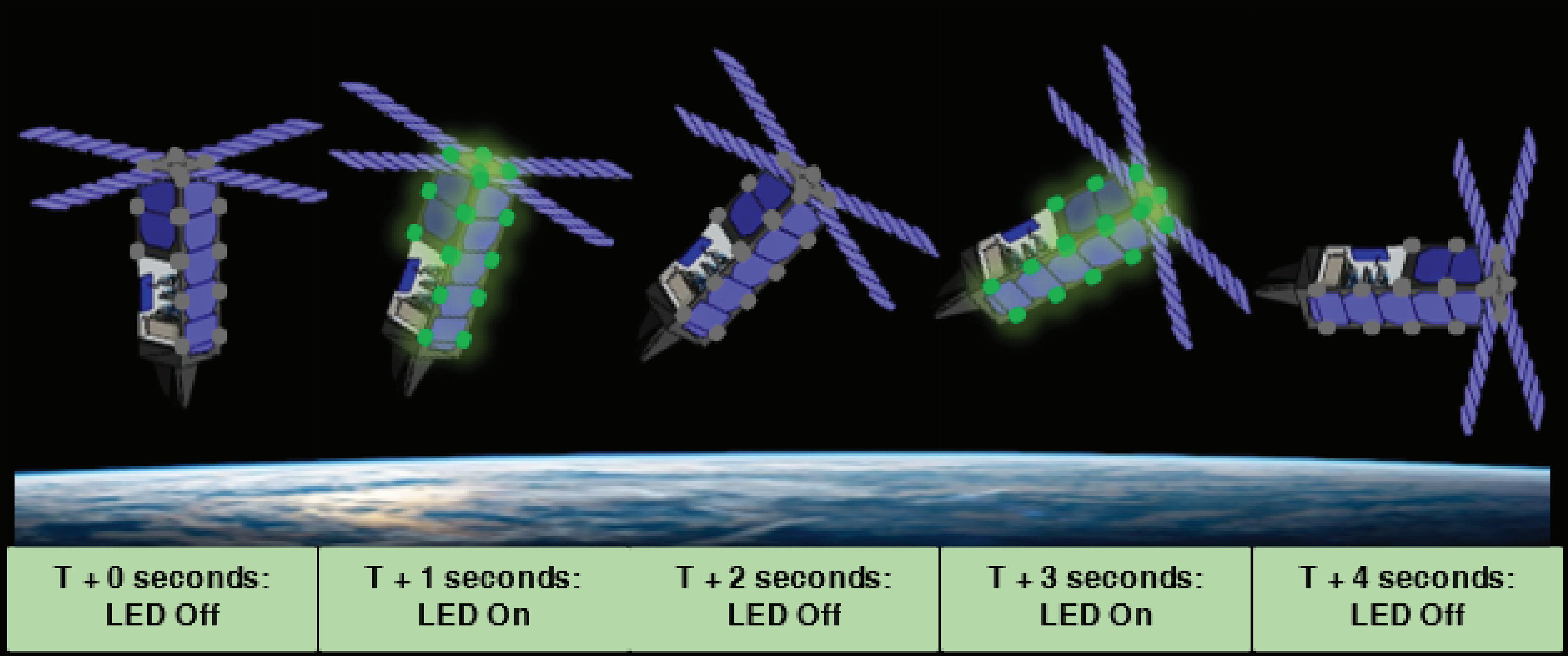
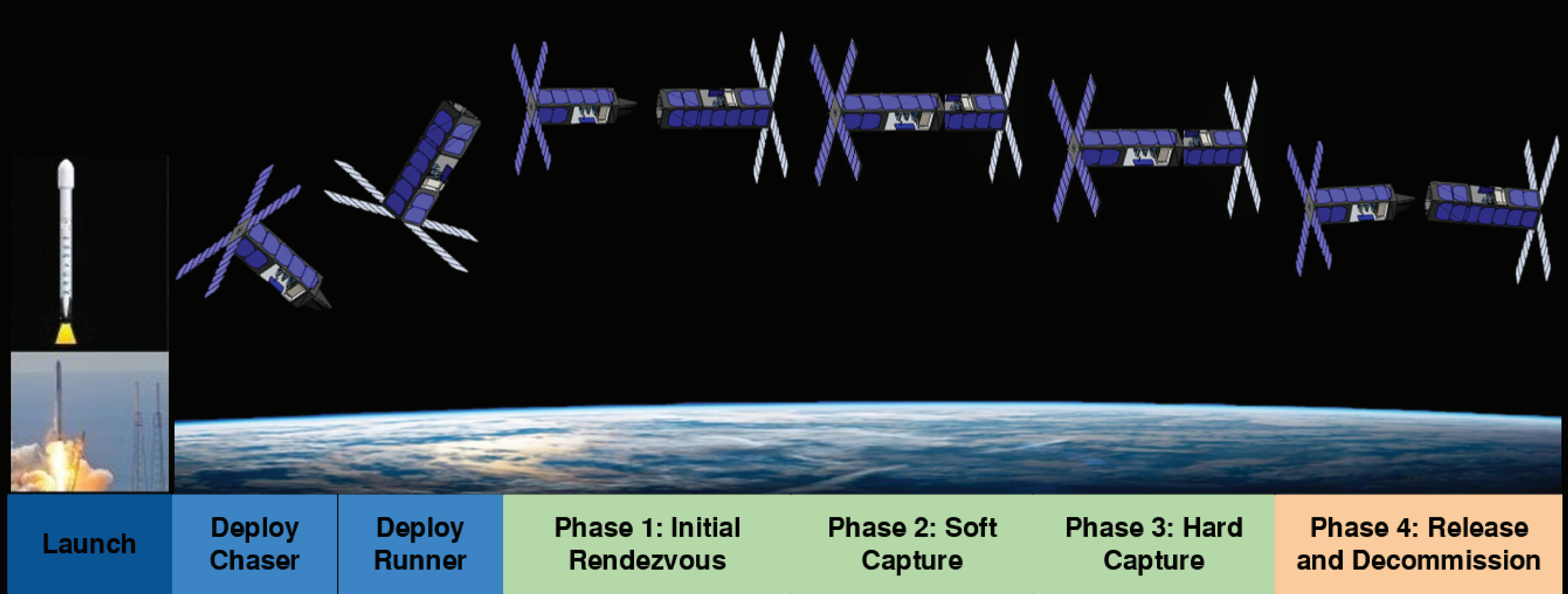


Figure 4: Chaser CubeSat in "Searching" mode, executing a manual spin with LED blink frequency of 1 Hz

Concept of Operations (ConOps)



Two 3U CubeSats, the Runner and the Chaser, will be launched and deployed in Low Earth Orbit (LEO). After deployment, the Two Stage CubeSat Docking process commences. There are 4 phases in this process, namely Initial Rendezvous, Soft Capture, Hard Capture and Release and Decommission.

Phase 2: Soft Capture

Different "Cone and Probe" designs for the mating surfaces (Figure 5) have been designed and a trade study is to be performed to select the best deisign based on factors such as ease of manufacturability, fault tolerance, sturctural rigidity, etc. The mating face are designed in such a way that any minor misalignment shall be automatically corrected by virtue of the geometry of the cone and probe.

The mating force for Soft Docking may be provided by Electromagnetes in addition to the thrusters if necessary. Blunt tips are preferred to sharper tips of the probe to prevent breakage due to impact.

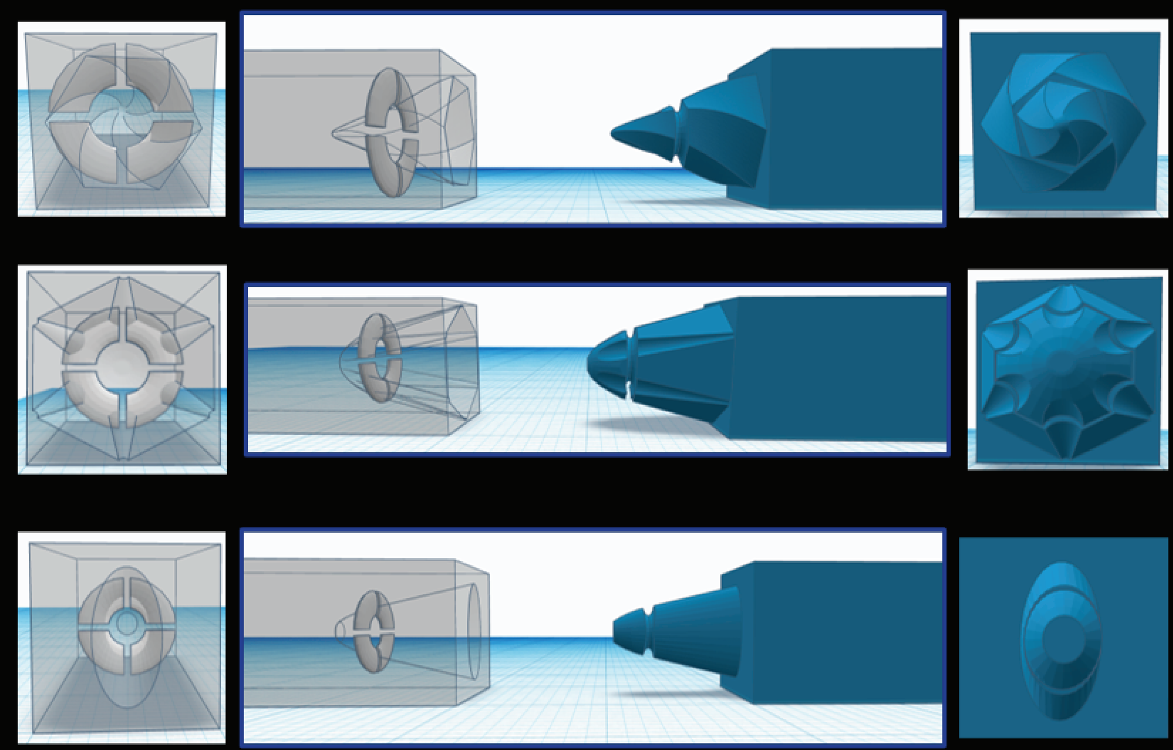


Figure 5: Cone and Probe geometry designs A (top), B (middle), and C (bottom) for soft docking

Phase 3: Hard Capture

A secondary hard-locking mechanism is necessary for reliable docking for on-orbit transfer, servicing or assembly operations. Different hard-locking mechanisms based on Shape Memory Alloys (SMA) and special materials to provide friction in a space environment have been designed to reduce complexity due to high amount of moving parts (Figure 6).

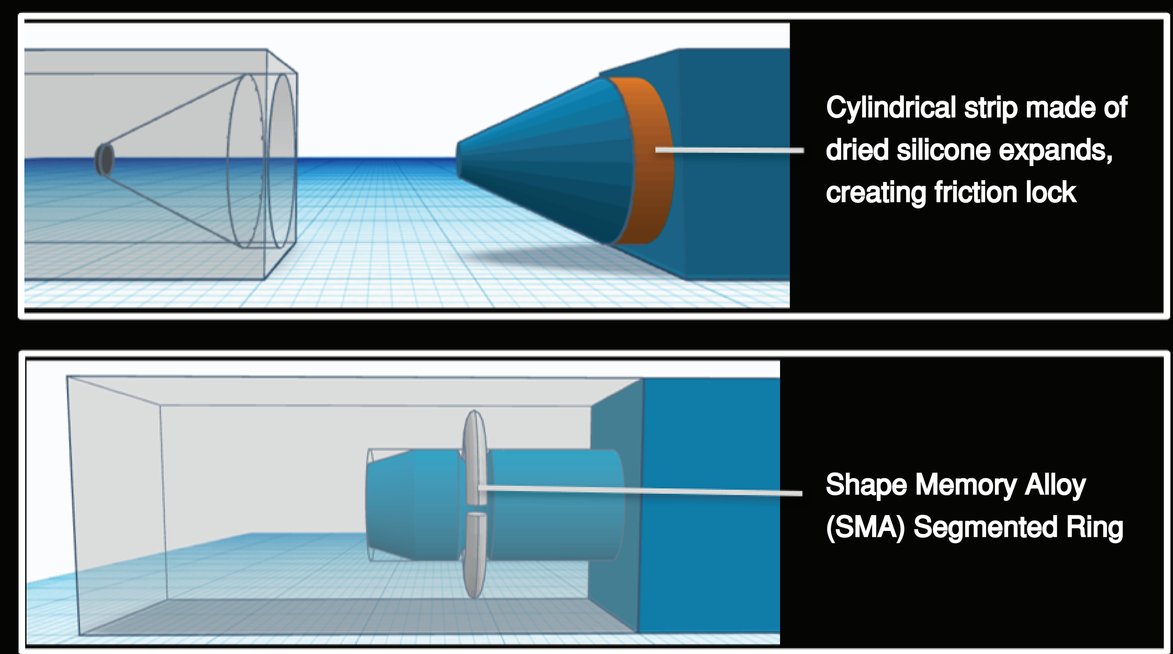


Figure 6: Friction Locking (top) and SMA Segmented Ring locking (bottom) designs

- Trade study pending between Friction Locking and Shape Memory Alloys based hard docking
- Dried Silicone expands when heated, creating a friction based lock
- SMA contracts into a ring shaped groove (lock and key)

Conclusions

Based the mission concept, a preliminary sysltem level design for the 3U runner and chaser CubeSats have been completed. Different designs of cone and probe pairs have been 3D printed using Stereolithography (Figure 3). The following work remains to be completed:

- Subsystem design
- Hardware Selection
- Manufacture of high precision components for soft capture
- Subsystem / System testing in simulated space environment.

Acknowledgements

We thank our colleagues Harsh Bansal, Kairav Kukkala, and Yinan Xu from the SpaceTREx lab, University of Arizona for their help and contributions to this project.