A Role for CubeSats in a Multi-Tier Exploration / Reconnaissance Architecture

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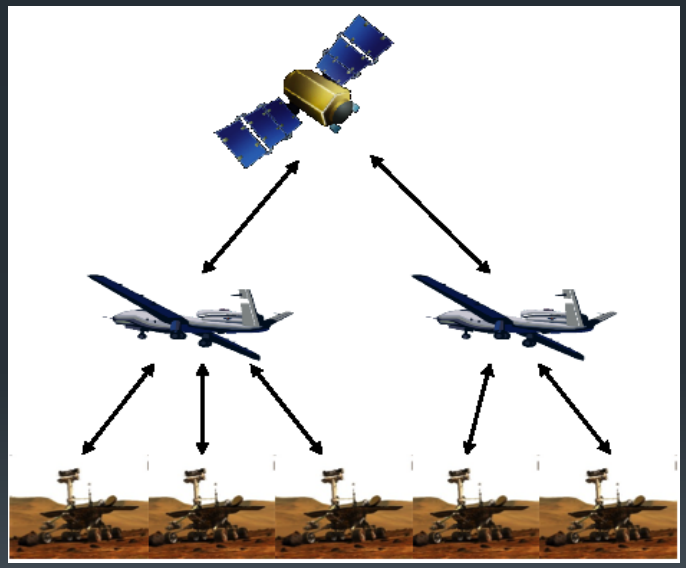
What is a Multi-Tier Exploration / Reconnaissance Architecture?

- An approach for dividing work between multiple craft has been proposed by Fink [1] [2] [3] which divides mission requirements between three tiers of exploring craft: orbital, aerial and ground.
- This approach can be used for planetary exploration, military and civilian reconnaissance and other applications
- The fundamental notion of the multi-tier architecture is that the craft on different tiers collaborate to produce a synergistic result

1. Fink, W (2006), Generic Prioritization Framework for Target Selection and Instrument Usage for Reconnaissance Mission Autonomy, Proceedings of the International Joint Conference on Neural Networks, pp. 11116-11119.
2. Fink, W, Dohm, JM, Tarbell, MA, Hare, TM, & Baker, VR (2005), Next-Generation Robotic Planetary Reconnaissance Missions: A Paradigm Shift, Planetary and Space Science, pp. 1419-1426.
3. Fink, W, et. al. (2011), Robotic Test Bed for Autonomous Surface Exploration of Titan, Mars, and other Planetary Bodies, Proceedings of the IEEE Aerospace Conference, pp. 1-11.

Tiers

- System Tier – Coordinates all orbital tier craft in designated area
- Orbital Tier – Coordinates all aerial tier craft in group; performs imaging to inform actions of aerial tier
- Aerial Tier – Coordinates all ground vehicles; performs higher resolution imaging to inform actions of ground tier
- Ground Tier – Surface (land, water) and sub-surface vehicles that perform most in-situ work



The Role of the Orbital Tier in the Multi-tier Architecture

- Under the base model[1] this was limited to deploying, sensing for and providing commands to the aerial tier which would command the ground tier
- This was based on a presumption of a single large spacecraft
- With deployable 1- or 2-U CubeSats, this role can be expanded significantly

CubeSats in the Orbital Tier Can

- Expand remote sensing spatial and temporal coverage
- Provide communications relay services to aerial and (possibly) ground vehicles
- Provide positioning services (e.g., localized GPS)

A Multi-tier Mission Timeline

1. A single large spacecraft or multiple craft arrive in orbit
2. The large spacecraft deploys several CubeSats which position themselves into desired orbits
3. The large spacecraft and CubeSats image the region or regions of interest
4. Once targets are identified, the large spacecraft deploys an aerial tier craft as close as possible to the target
5. The aerial tier craft conducts further sensing and assessment to confirm the previous analysis
6. One or more ground craft are deployed to conduct in-situ analysis, presuming aerial tier analysis confirmation

What are the benefits of a Multi-tier mission?

- Less risk aversion: multiple craft means that interesting phenomena which may pose significant risk to a craft can be explored
- More area of coverage: multiple craft & deployment strategy means that the science / reconnaissance can have a wider scope of coverage
- Less reliance on prior knowledge for mission planning: specific targets are chosen on-the-fly, based on higher-tier results & analysis

What are the challenges?

- Power: particularly for CubeSat to surface relay and positioning services for multiple craft
- Propulsion: the constellation separation and coverage is dependent on ΔV capabilities. Various sustained low thrust propulsion techniques can be used to provide separation over time
- Command & control: for this system to be effective it needs to be end-to-end autonomous

Command & Control

- Significantly upgrading onboard processing capabilities
- Offloading processing that is too intensive or time-critical to more powerful computers on the large spacecraft
- Pushing decision-making to the lowest level practical to fully use the computational resources of all tiers of craft
- Sharing knowledge learned between craft at a given tier and between tiers (e.g., task time corrections, etc.)

Current Work & Progress

- Comparing onboard processing capabilities of existing space-qualified components to the requirements for supporting technologies:
  - Super-resolution (image enhancement)
  - Mosaicking (image combination for human review & processing)
  - Analysis software (to determine targets, control commands)
- Developing & testing software to perform critical elements of the proposed mission approach

Future Work

- It is highly desirable to conduct a test of at least a three-tier system in the near future to demonstrate functionality – particularly miniaturized components

- Initial testing will utilize high altitude balloons (HABs) to perform orbital simulation and aerial testing leading to a true three-tier test

Thanks &
Any Questions