# NASA STTR 2020 Phase I Solicitation

## T4.03 Coordination and Control of Swarms of Space Vehicles

**Lead Center: JPL**

**Participating Center(s): LaRC**

**Technology Area: TA4 Robotics, Telerobotics and Autonomous Systems**

### Scope Title

Enabling Technologies for Swarm of Space Vehicles

### Scope Description

This subtopic is focused on developing and demonstrating technologies that enable cooperative operation of swarms of space vehicles in a dynamic environment. Primary interest is in technologies appropriate for low-cardinality (4-15 vehicle) swarms of small spacecraft, as well as planetary rovers and flyers (e.g., Mars helicopter). Large swarms and other platforms are of interest if well motivated in connection to NASA's strategic plan and needs identified in decadal surveys.

The proposed technology should be motivated by a well-defined design reference mission presented in the proposal.

Possible areas of interest include but are not limited to:

- High precision relative localization and time synchronization in orbit and on planet surface.
- Coordinated task planning, operation, and execution with realistic communication limitations.
- Fast, real-time, coordinated motion planning in areas densely crowded by other agents and obstacles.
- Operations concepts and tools that provide situational awareness and commanding capability for a team of spacecraft or swarm of robots on another planet.
- Communication-less coordination by observing and estimating the actions of other agents in the multi-agent system.
- Cooperative manipulation and in-space construction
- Cooperative information gathering and estimation for exploration and inspection of a target object (large space structure or small asteroid).

Phase I awards will be expected to develop theoretical frameworks, algorithms, software simulation and demonstrate feasibility (TRL 2-3). Phase II awards will be expected to demonstrate capability on a hardware testbed (TRL 4-6).

NASA has plans to purchase services for delivery of payloads to the Moon through the Commercial Lunar Payload Services (CLPS) contract. Under this subtopic, proposals may include efforts to develop payloads for flight

demonstration of relevant technologies in the lunar environment. The CLPS payload accommodations will vary depending on the particular service provider and mission characteristics. Additional information on the CLPS program and providers can be found at this link: https://www.nasa.gov/content/commercial-lunar-payload-services. CLPS missions will typically carry multiple payloads for multiple customers. Smaller, simpler, and more self-sufficient payloads are more easily accommodated and would be more likely to be considered for a NASA-sponsored flight opportunity. Commercial payload delivery services may begin as early as 2020 and flight opportunities are expected to continue well into the future. In future years it is expected that larger and more complex payloads will be accommodated. Selection for award under this solicitation will not guarantee selection for a lunar flight opportunity.

**References**

[1] D. P. Scharf, F. Y. Hadaegh and S. R. Ploen, "A survey of spacecraft formation flying guidance and control (part 1): guidance," Proceedings of the 2003 American Control Conference, 2003. Denver, CO, USA, 2003, pp. 1733-1739.

[2] D. P. Scharf, F. Y. Hadaegh and S. R. Ploen, "A survey of spacecraft formation flying guidance and control. Part II: control," Proceedings of the 2004 American Control Conference, Boston, MA, USA, 2004, pp. 2976-2985 vol.4.

[3] Evan Ackerman, "PUFFER: JPL's Pop-Up Exploring Robot; This little robot can go where other robots fear to roll," https://spectrum.ieee.org/automaton/robotics/space-robots/puffer-jpl-popup-exploring-robot

[4] "Precision Formation Flying," https://scienceandtechnology.jpl.nasa.gov/precision-formation-flying

[5] "Mars Helicopter to Fly on NASA's Next Red Planet Rover Mission," https://www.nasa.gov/press-release/mars-helicopter-to-fly-on-nasa-s-next-red-planet-rover-mission/

[6] Miller, Duncan, Alvar Saenz-Otero, J. Wertz, Alan Chen, George Berkowski, Charles F. Brodel, S. Carlson, Dana Carpenter, S. Chen, Shiliang Cheng, David Feller, Spence Jackson, B. Pitts, Francisco Pérez, J. Szuminski and S. Sell. "SPHERES: A Testbed for Long Duration Satellite Formation Flying In MicroGravity Conditions." Proceedings of the AAS/AIAA Space Flight Mechanics Meeting, AAS 00-110, Clearwater, FL, Jan. 2000.

[7] S. Bandyopadhyay, R. Foust, G. P. Subramanian, S.-J. Chung, and F. Y. Hadaegh, "Review of Formation Flying and Constellation Missions Using Nanosatellites," Journal of Spacecraft and Rockets, vol. 53, no. 3, 2016, pp. 567-578.

[8] S. Kidder, J. Kankiewicz, and T. Vonder Haar. "The A-Train: How Formation Flying is Transforming Remote Sensing," https://atrain.nasa.gov/publications.php

[9] T. Huntsberger, A. Trebi-Ollennu, H. Aghazarian, P. Schenker, P. Pirjanian, and H. Nayar. "Distributed Control of Multi-Robot Systems Engaged in Tightly Coupled Tasks," Autonomous Robots 17, 79–92, 2004.

[10] Space Studies Board, "Achieving Science with CubeSats: Thinking Inside the Box," National Academies of Sciences, Engineering, and Medicine, 2016. http://sites.nationalacademies.org/SSB/CompletedProjects/SSB_160539

**Expected TRL or TRL range at completion of the project**: 3 to 6

**Desired Deliverables of Phase II**

Prototype, Software, Hardware, Research

**Desired Deliverables Description**

- Algorithms and research results clearly depicting metrics and performance of the developed technology in comparison to state of the art (SOA).
- Software implementation of the developed solution along with simulation platform.
- Prototype of the sensor or similar if proposal is to develop such subsystem.

**State of the Art and Critical Gaps**

Technologies developed under this subtopic enable and are critical for multi-robot missions (rovers and flying vehicles such as Mars helicopter) for collaborative planetary exploration, e.g., a team of small pop-up rovers (PUFFERS) that can collaboratively create a mesh network and explore high risk and hard to reach areas such as lava tubes, etc.

These technologies also enable successful formation flying spacecraft for multi-spacecraft synthetic aperture radar and interferometry (distributed space telescope) purposes, a team of smallsats forming a convoy which the lead triggers detailed measurements on the following spacecraft of a phenomena identified by the lead, or a team of smallsats collaboratively manipulating a defunct spacecraft or small asteroid.

**Relevance / Science Traceability**

Subtopic technology directly supports NASA Space Technology Roadmap TA4 (4.5.4 Multi-Agent Coordination, 4.2.7 Collaborative Mobility, 4.3.5 Collaborative Manipulation) and Strategic Space Technology Investment Plan (Robotic and Autonomous Systems: Relative GNC and Supervisory control of an S/C team), and is relevant to the following concepts:

- Multi-robot follow-on to the Mars 2020 and Mars Helicopter programs are likely to necessitate close collaboration among flying robots as advance scouts and rovers.
- Pop-Up Flat-Folding Explorer Robots (PUFFERs) are being developed at Jet Propulsion Laboratory (JPL) and promise a low-cost swarm of networked robots that can collaboratively explore lava-tubes and other hard to reach areas on planet surfaces.
- A convoy of spacecraft is being considered, in which the lead spacecraft triggers detailed measurement of a very dynamic event by the following spacecraft.

Multiple concepts for distributed space telescopes and distributed synthetic apertures are proposed that rely heavily on coordination and control technologies developed under this subtopic.