Acronym: SPHERES

Title: Synchronized Position Hold, Engage, Reorient, Experimental Satellites

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Sponsoring Agency: National Aeronautics and Space Administration (NASA)

Increment(s) Assigned: 8, 13, 14, 15, 16, 17, 18, 19, 20

Brief Research Summary (PAO): Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) are bowling-ball sized spherical satellites. They will be used inside the space station to test a set of well-defined instructions for spacecraft performing autonomous rendezvous and docking maneuvers. Three free-flying spheres will fly within the cabin of the station, performing flight formations. Each satellite is self-contained with power, propulsion, computers and navigation equipment. The results are important for satellite servicing, vehicle assembly and formation flying spacecraft configurations.

Research Summary:

- SPHERES uses the internal ISS environment as a test bed for the development and testing of multi-body formation flying and other multi-spacecraft control algorithms.

- Three self-contained free-flying satellites will fly within the cabin of the ISS, performing flight formations and testing control algorithms. Each satellite is self-contained with power (AA batteries), propulsion (carbon dioxide), computers, and navigation equipment.

- The satellites communicate with each other and an ISS laptop through a low-power 900 MHz wireless link.

- Position information is known by setting up five beacons in the work area for the satellites to perform ranging using ultrasound and infrared pulses.

Detailed Research Description: SPHERES is a testbed for formation flying by satellites, the theories and calculations that coordinate the motion of multiple bodies maneuvering in microgravity. To achieve this inside the ISS cabin, bowling-ball-sized spheres perform various maneuvers (or protocols), with one to three spheres operating simultaneously . The Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) experiment will test relative attitude control and station-keeping between satellites, re-targeting and image plane filling maneuvers, collision avoidance and fuel balancing algorithms, and an array of geometry estimators used in various missions.

SPHERES consists of three self-contained satellites, which are 18 sided polyhedrons that are 0.2 meter in diameter and weigh 3.5 kilograms. Each satellite contains an internal propulsion system, power, avionics, software, communications, and metrology subsystems. The propulsion system uses CO2, which is expelled through the thrusters. SPHERES satellites are powered by AA batteries. The metrology subsystem provides real-time position and attitude information. To simulate ground station-keeping, a laptop will be used to transmit navigational data and formation flying algorithms. Once these data are uploaded, the satellites will perform autonomously and hold the formation until a new command is given.

Project Type: Payload

Images and Captions:

SPHERES hardware in operation on the KC-135. Flights were in July/August 2002 and February 2003.SPHERES hardware in operation on the KC-135. Flights were in July/August 2002 and February 2003.

NASA image: ISS018E006422 - Expedition 18 crewmember Michael Fincke as he works with Synchronized Position Hold Engage Reorient Experimental Satellites (SPHERES) in the US Laboratory.

SPHERES air table testing at Marshall Space Flight Center.

NASA Image: ISS0008E19135 - Expedition 8 Commander Michael Foale holds the SPHERES Ultrasound Beacon and Beacon Tester while performing functionality checks between the Beacon/Beacon Tester and its proximity to a general luminaire assembly in Unity Node 1.

NASA Image: ISS008E19136 - Expedition 8 Commander Michael Foale works with the SPHERES Ultrasound Beacon and Beacon Tester while performing functionality checks between the Beacon/Beacon Tester and its proximity to a general luminaire assembly in Unity Node 1.

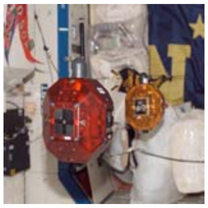
Video Screen Shot of Expedition 13 Science Officer, Jeff Williams as he closely monitors the first test flights of the SPHERES satellite in the U.S. Lab Destiny on May 18, 2006.

NASA Image: ISS013E65815 - Expedition 13 NASA Science Officer, Jeff Williams, carrying out test runs with two satellites on August 12, 2006. SPHERES began with a single satellite floating inside the cabin and going through iterative tests to "learn" how to maneuver in the cabin. STS-121 carried the second satellite to ISS for testing.

NASA Image: ISS013E68304 - Astronaut Jeffrey N. Williams, Expedition 13 NASA space station science officer and flight engineer, does a check of the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) satellites in the Destiny laboratory of the International Space Station.

NASA Image: ISS014E08025 - View of the Synchronized Position Hold,Engage,Reorient,Experimental Satellites (SPHERES) floating in the Destiny laboratory module as seen by the Expedition 14 crew. Flight Engineer Thomas Reiter is visible in the background.

NASA Image: ISS014E17232 - Astronaut Michael E. Lopez-Alegria, Expedition 14 commander and NASA space station science officer, does a check of the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) Beacon / Beacon Tester in the Destiny laboratory of the International Space Station. SPHERES demonstrates the basics of formation flight and autonomous docking, using beacons as reference for the satellites, to fly formation with or dock to the beacon.



NASA Image: ISS014E17868 - Two satellites fly in formation as part of the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) investigation in the Destiny laboratory module.

NASA Image: ISS014E17874 - Three satellites fly in formation as part of the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) investigation. This image was taken during Expedition 14 in the Destiny laboratory module.

Operations Location: ISS Inflight

Brief Research Operations:

- The experiment includes crew controlled testing of the infrared communications interface and multiple flight sessions with one, two and three satellite units flying within the U.S. Destiny Lab on board ISS.

Operational Requirements: SPHERES will operate in a minimum of sixteen, 3.5-hour test sessions with approximately 1 month between each test session. The ten sessions will be comprised of the following:

- Approximately three sessions will use one satellite
- Approximately seven sessions will use two satellites
- Approximately six sessions will use three satellites

Provided the resources are not exhausted at the end of the 16 sessions, additional sessions may occur using two or three satellites. Approximately eight to twelve tests, each lasting 10-15 minutes, will be run during each test session. Primary location for operations will be in the U.S. Destiny Lab. Node 1 can be used as a backup. Operations are not permitted in the Russian segment due to concerns with infrared interference.

Operational Protocols: During the flight sessions there are three phases: programming SPHERES, free flying operations, and data retrieval. Programming the satellites will involve uploading the algorithms for each specific session to the SPHERES laptop from the ground crew. The laptop will be used to send the algorithms and commands to the satellites and receive data and status reports from the satellites. The data will then be down linked to the ground crew for analysis. During free-flying operations the satellites will perform various maneuvers with one to three satellites operating simultaneously. Once the test session is complete, the data will be downlinked to the ground, via the Ops LAN, for analysis by the SPHERES team. This analysis will allow new and/or modified tests to be uplinked for use in the next test session.

The crew will be responsible for unstowing the equipment, setting up the test area, loading the carbon dioxide tanks and batteries, uploading and running the protocols from the laptop and stowing the equipment at the conclusion of the session.

Review Cycle Status: PI Reviewed

Category: Technology Development

Sub-Category: Picosatellites and Control Technologies

Space Applications: Information learned from this experiment may lead to simpler autonomous docking allowing for servicing, re-supplying, reconfiguring and upgrading of space systems. The algorithms would eliminate the complicated maneuvers that require ground teams to coordinate and execute. Secondly, this formation flight technology would lead to Separated Spacecraft Interferometers (light from two or more telescopes that combine to provide a high resolution image).The results will support the development of autonomous spacecraft to carry out a variety of tasks in a space environment. Smaller autonomous spacecraft could, with the right coordination and programming, perform tasks too complicated or too expensive for larger spacecraft to execute.. Examples of these are satellite clusters, a collection of micro-satellites that operate cooperatively to perform the function of a large single satellite.

Earth Applications: The space technologies for formation flight of small satellites could influence Earth-based applications of current satellite technologies including surveillance, mapping, communications and navigation.

Manifest Status: Continuing

Supporting Organization: Space Operations Mission Directorate (SOMD)

Previous Missions: Preliminary signal testing to support SPHERES operations was performed during ISS Expedition 8. Testing with one satellite was performed early during Expedition 13. The second satellite was delivered to ISS on STS-121 which allowed testing of the two satellite configuration beginning in August 2006. The third satellite was delivered on STS-116; the three satellite configuration testing began on ISS Expedition 14.

Results: During Expedition 8, several interference tests were conducted in order to characterize the effects of lights and other sources of electromagnetic radiation. The "Beacon-Beacon Test" (SPHERES-BBT) used one beacon (with mount) and one beacon tester to demonstrate the functionality of the ultrasound/infrared positioning system of the SPHERES experiment. This portion of the investigation was a risk mitigation experiment for SPHERES to determine if any sources of infrared radiation or ultrasonic waves exist in the work area that may interfere with SPHERES operations. Infrared interference from a general lighting assembly and a laptop in Node was produced during the "Beacon-Beacon Test". Based on these results, SPHERES test sessions will use the newer laptop and the general lighting assembly will be dimmed by 25 percent in the workspace during SPHERES operations.

SPHERES test sessions begun during Expedition 13, demonstrated maneuvers that would lead to the docking of a satellite to a beacon, tested algorithms which automatically determine the mass properties of the satellites and performed initial two sphere satellite tests. During these sessions the docking maneuvers were completed successfully and updated to the estimator (calculation of the satellite's location with respect to the beacon) which helped achieve successful approaches. The two satellite tests were successful; these tests demonstrated the functionality of the new satellite and the ability of the satellites to maintain both angular formation (i.e., they point in the same direction all the time) as well as position formation (if one translates the other does too).

Other SPHERES test sessions performed during Expedition 13 demonstrated the functionality of the Global Metrology System (during all previous sessions the satellites calculated their position with respect to a single beacon or with respect to other satellites, but not with respect to the U.S. Laboratory frame). This session setup the complete metrology system so that the satellites could know their location and pointing with respect to the U.S. Laboratory. The tests included collection of large amounts of data to process on the ground to test for the functionality of all the transmitters and receivers in the system as well as the presence of any noise (such as reflections on unexpected objects). The test also demonstrated the functionality of the astronaut interface to indicate to the satellite the location of the beacons in the U.S. Laboratory. All the necessary data was collected. Secondary tests included successful demonstration of two satellites docking (controlled contact between the two satellites). These tests will ultimately enable scientists to assemble large space structures and make autonomous resupply of consumables and upgrades a reality (Saenz-Otero Alvar. "Latest SPHERES Results" E-mail to Judy Tate. 10 Oct. 2006).

Results Status: Pending More Information

Results Review Status: PI Reviewed

Results Publications:

Saenz-Otero A, Katz JG, Miller DW. SPHERES Demonstrations of Satellite Formations aboard the ISS. AAS Guidance and Navigation Conference. Jan 30 - Feb 4, 2009 .

Nolet S, Saenz-Otero A, Miller DW, Fejzic A. SPHERES Operations aboard the ISS: Maturation of GN&C Algorithms in Microgravity. AAS Guidance, Navigation & Control, Breckeridge, CO. 3-7 February, 2007 ;AAS 07-042.

Saenz-Otero A, Katz JG, Miller DW. SPHERES Demonstrations of Satellite Formations aboard the ISS. 32nd Annual American Asronautical Society Guidance and Navigation Conference. Breckenridge, CO. Jan 30 - Feb 4, 2009 .

Fejzic A, Nolet S, Breger L, How JP, Miller DW. Results of SPHERES Microgravity Autonomous Docking Experiments in the Presence of Anomalies. 59th International Astronautical Congress. Glasgow, Scotland. Sep 29 -Oct 3, 2008 ;IAC-08-C1.5.1.

Saenz-Otero A, Aoude G, Jefrey MM, Mohan S, Fejzic A, Katz J, Edwards C, Miller DW. Distributed Satellite Systems Algorithm Maturation with SPHERES Aboard the ISS. 59th International Astronautical Congress.Glasgow, Scotland. Sep 29 -Oct 3, 2008 ;IAC-08-A2.6.B4.

Mohan S, Miller DW. SPHERES Reconfigurable Control Allocation for Autonomous Assembly. AIAA Guidance, Navigation, and Control Conference. Aug, 2008 .

Aoude GS, How JP, Miller DW. Reconfiguration Maneuver Experiments using the SPHERES tesbed onboard the ISS. 3rd International Symposium on Formation Flying, Missions and Technologies. April, 2008 .

Mohan S, Saenz-Otero A, Nolet S, Miller DW, Sell S. SPHERES Flight Operations Testing and Execution. 58th International Astronautical Congress, Hyderabad, India. 24-28 Sept, 2007 ;IAC-07-A2.6.03.

Mandy Ch, Sakamoto H, Saenz-Otero A, Miller DW. Implementation of Satellite Formation Flight Algorithms Using SPHERES aboard the International Space Station. International Symposium on Space Flight Dynamics, Annapolis, MD. 24-28 Sept, 2007 .

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Nolet S. The SPHERES Navigation System: from Early Developmen to On-Orbit Testing. AIAA Guidance, Navigation & Control, Hilton Head, SC. 20-23 Aug, 2007 .

Saenz-Otero A, Miller DW. Initial SPHERES Operations aboard the International Space Station. IAA Small Satellites for Earth Observation VI, Berlin, Germany. 23-26 Apr, 2007 ;IAA-B6-0701.

Nolet S, Saenz-Otero A, Miller DW, Fejzic A. SPHERES Operations aboard the ISS: Maturation of GN&C Algorithms in Microgravity. AAS Guidance, Navigation & Control, Breckeridge, CO. 3-7 February, 2007 ;AAS 07-042.

Web Sites:
MIT Space Systems Laboratory

Related Payload(s): MACE-II

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