Astrobee: A New Tool for ISS Operations

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ISS ROBOTIC FREE FLYER
ASTROBEE


MIT
NASA ARC
AURORA DARPA
SPHERES


To HAB

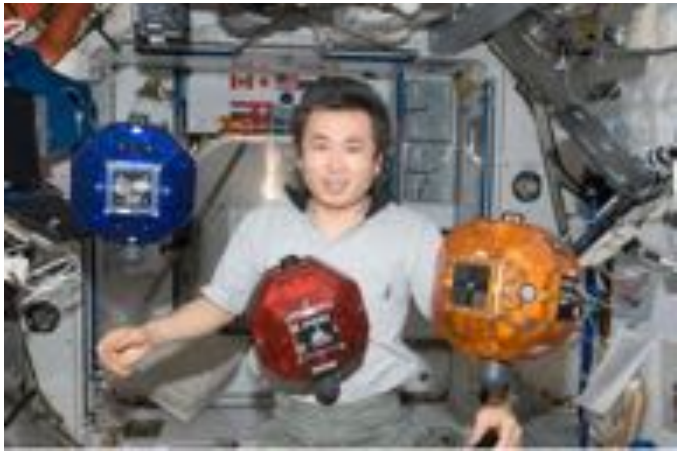

AERCam Sprint


PSA


Smart SPHERES

Current IVA Free Flyers

- SPHERES (NASA) – launched 2006
  - Highly successful research platform used for many guest science experiments
  - Astrobee will replace SPHERES, managed by the same facility team
- Int-Ball (JAXA) – launched 2017
  - Successful experiment in building an IVA free flyer with a rapid development cycle (18 months)
  - Small size (15 cm diameter) enabled by JAXA's miniaturized all-in-one CPU / IMU / 3-axis reaction wheel module
  - Joint activities between Int-Ball and Astrobee may be possible
- CIMON (DLR) – to launch later this year
  - Enable research on AI for human-robot interaction
  - International cooperation – CIMON will share from the pool of batteries that Astrobee qualified for ISS



SPHERES

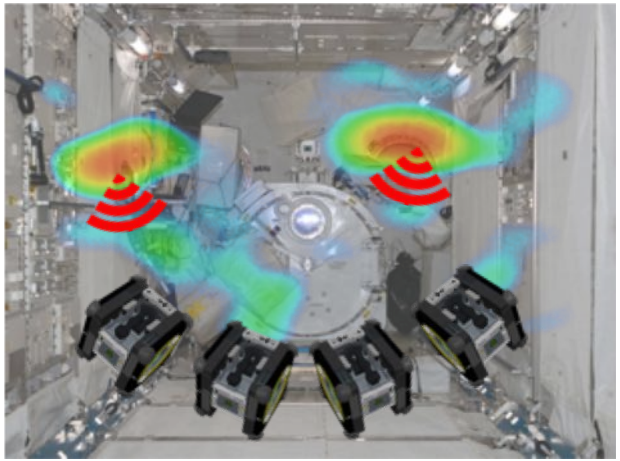
Int-Ball

Project Objectives

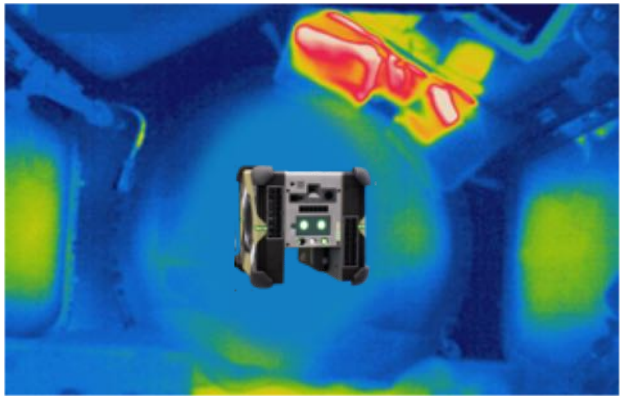
- Provide a microgravity robotic research facility in the ISS US Orbital Segment (USOS), which will replace the existing SPHERES facility
- Provide remotely operated mobile camera views of the ISS USOS to enhance the situation awareness of mission control
- Perform mobile sensor tasks in the ISS USOS

Sensing on the ISS

- Monitor the environment
  - Ensure crew health and safety
  - Maintain vehicle health and longevity
  - Sound levels, radiation, air quality
- Automate logistics
  - Increase efficiency of on-orbit operations
  - RFID localization
- Currently collected by fixed location sensors or by crew-conducted sensor surveys



Localizing signal sources by analyzing RSS spatial variation (e.g. RFID, acoustics)

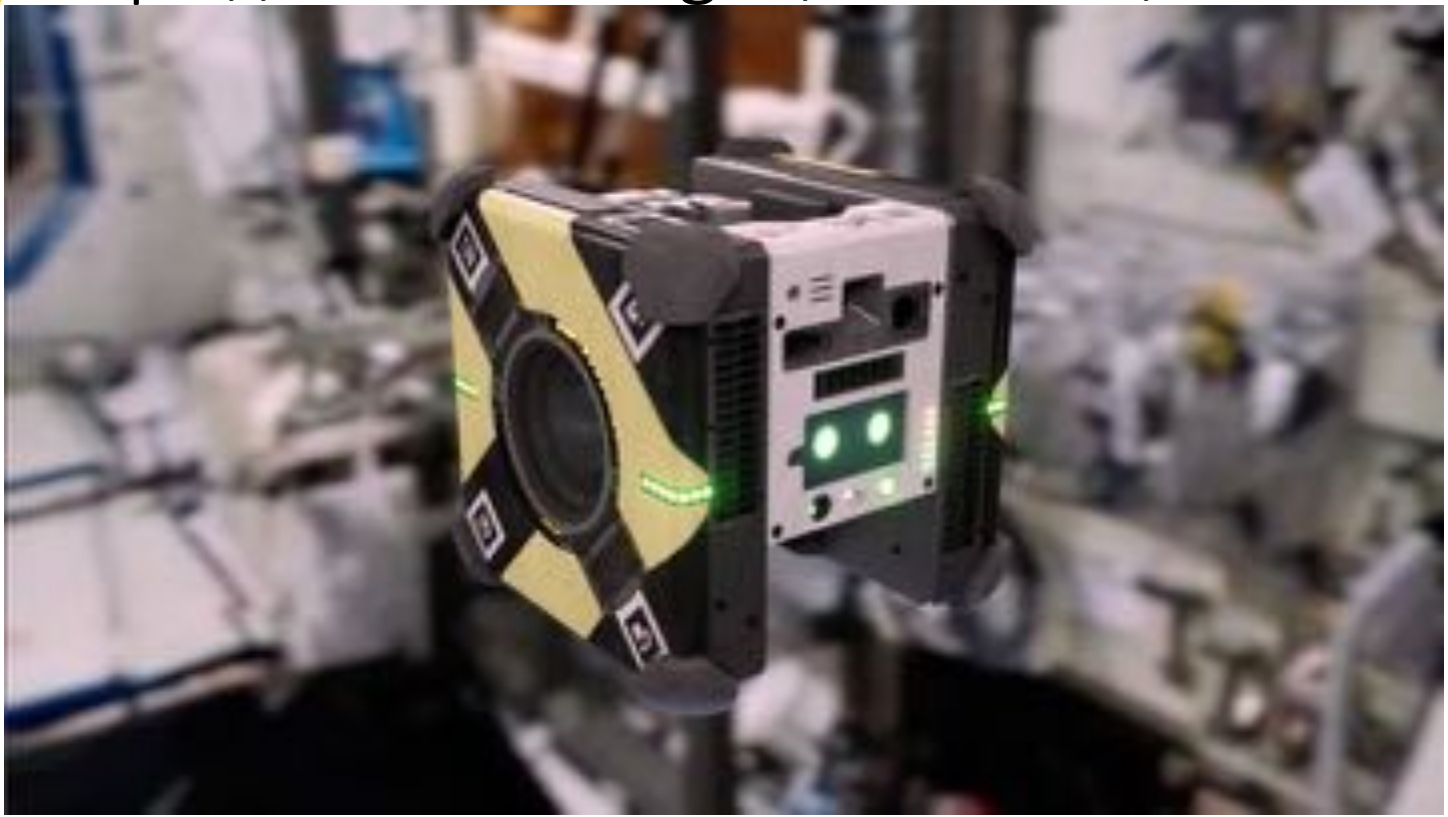


Habitat thermal mapping

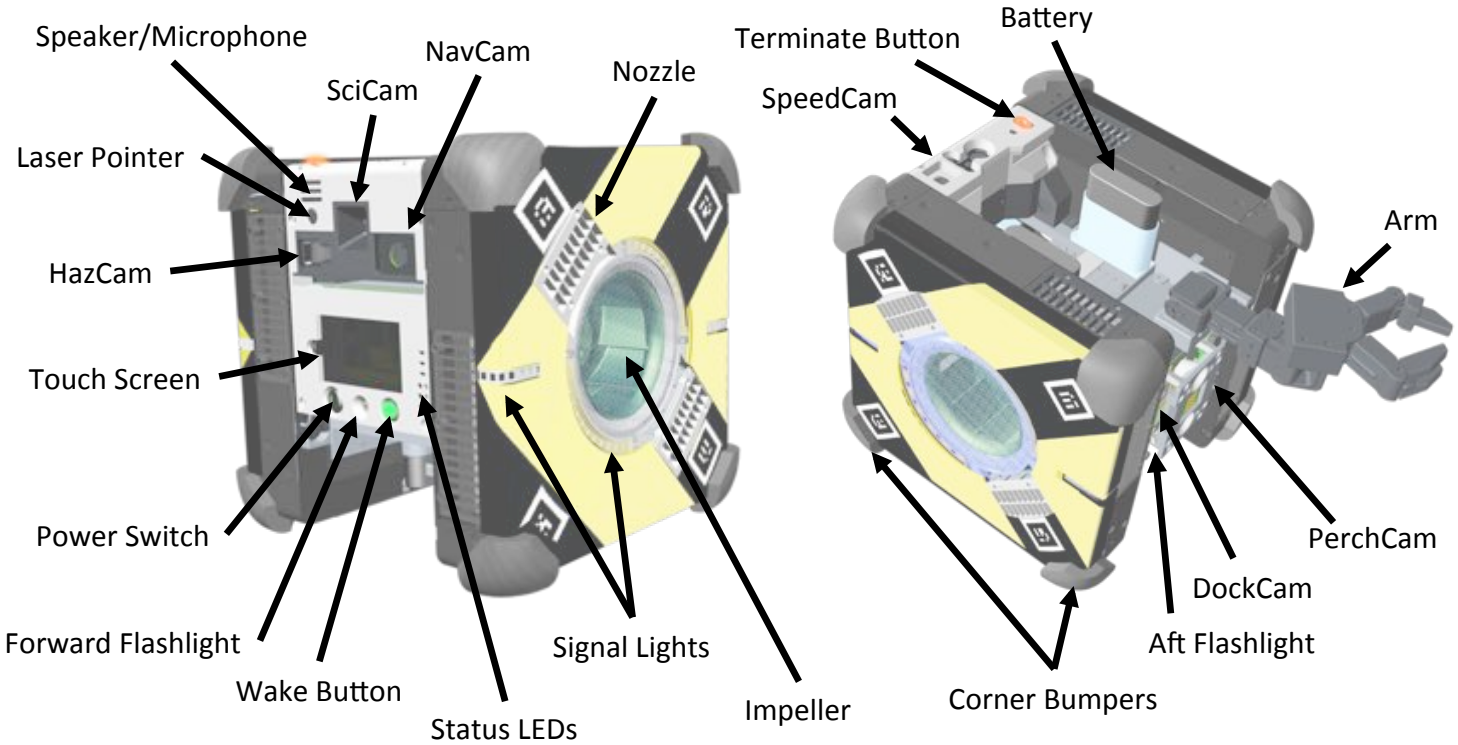
Basic Conops

- When an Astrobee is idle, it charges in its dock
- Astrobees can execute complex plans with full autonomy and no astronauts present
  - Including undock, traverse multiple modules, return to dock
- However, Astrobees run with ground operator oversight
  - When an anomaly occurs, an Astrobee generally stops and waits for operator intervention
  - It can continue operating during communication outages until it encounters an anomaly
- The operator can always take over and teleoperate
- Astronauts can also be operators, but this is rare (minimize crew time)

https://www.nasa.gov/astrobee/videos

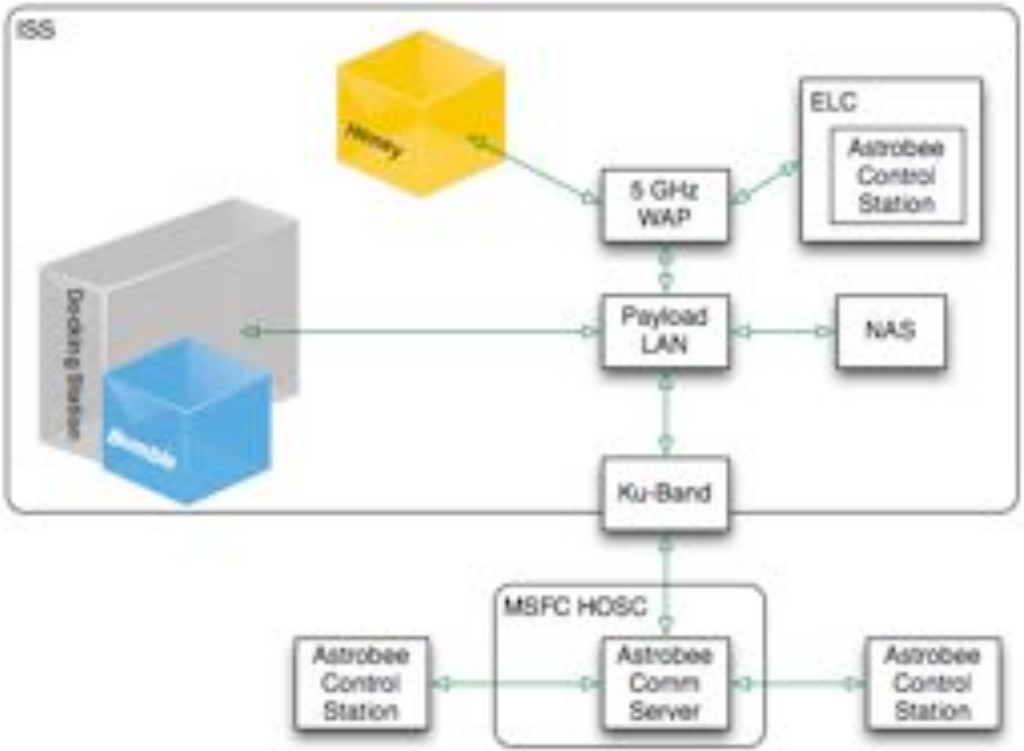


System Description: Sensors & HRI



System Description: Communications

- Communicates through ISS WiFi when flying
- Single telemetry/video stream to ground
- Multiple ground stations can connect through server
- Large file transfers and software updates through Ethernet on the dock



Astrobee communications path

System Description: Position Estimation

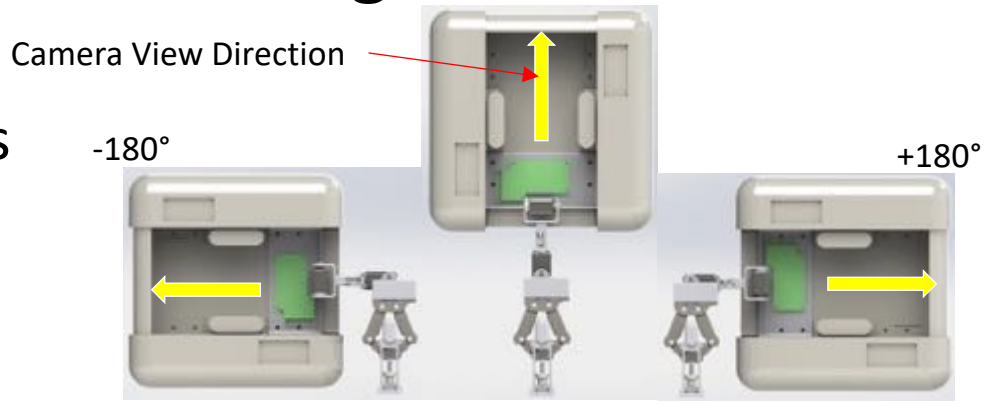
- Vision-based navigation
  - Compares features with on-board a priori map
  - Incorporates inertial measurements
- Fiducials used for autonomous docking
  - Requires approximately 1 cm position accuracy

Feature map of the JEM-PM

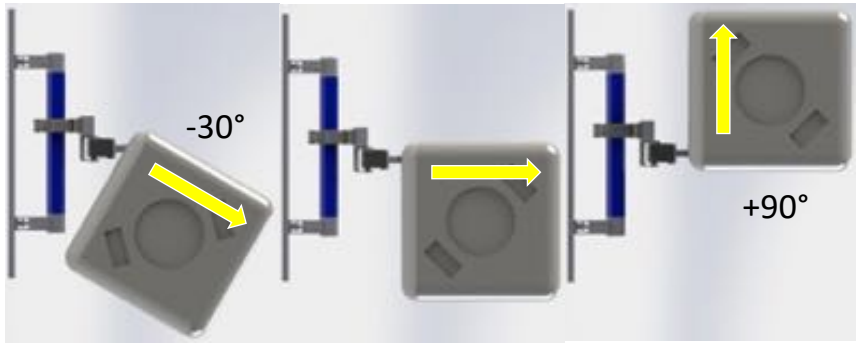
- Visual odometry
  - Robot can continue to navigate where no map features are recognized

System Description: Perching Arm

- Designed to grasp handrails
- Stows completely in payload bay
- Acts as a pan-tilt unit while perched
- Flexible and back-drivable
- May be perched manually

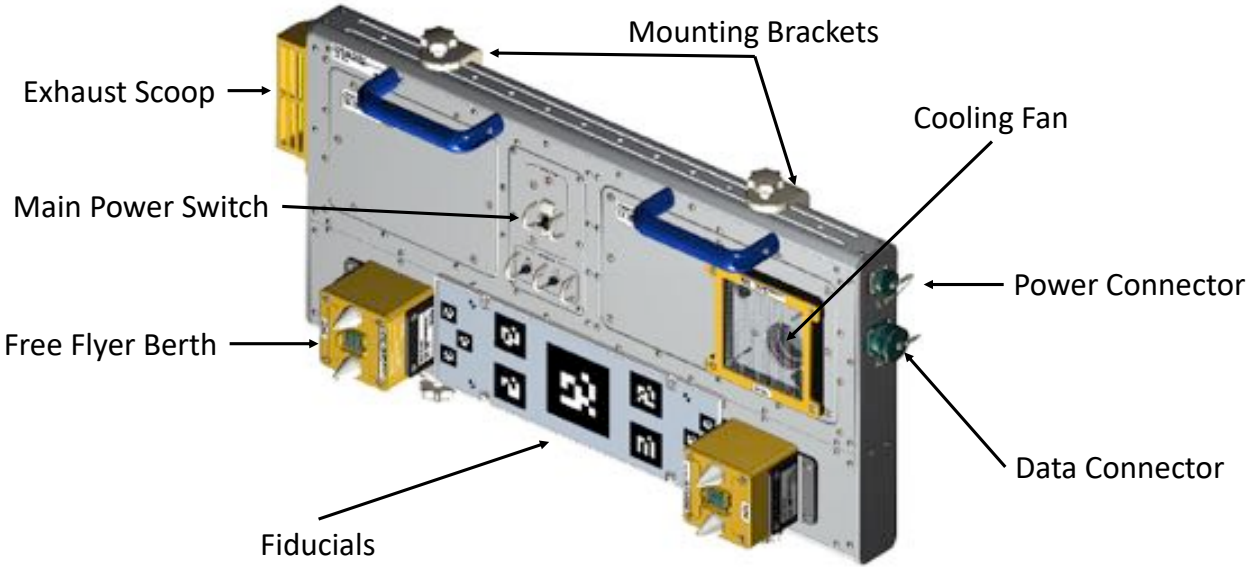


Astrobee Perching Arm pan range



Astrobee Perching Arm tilt range

System Description: Docking Station



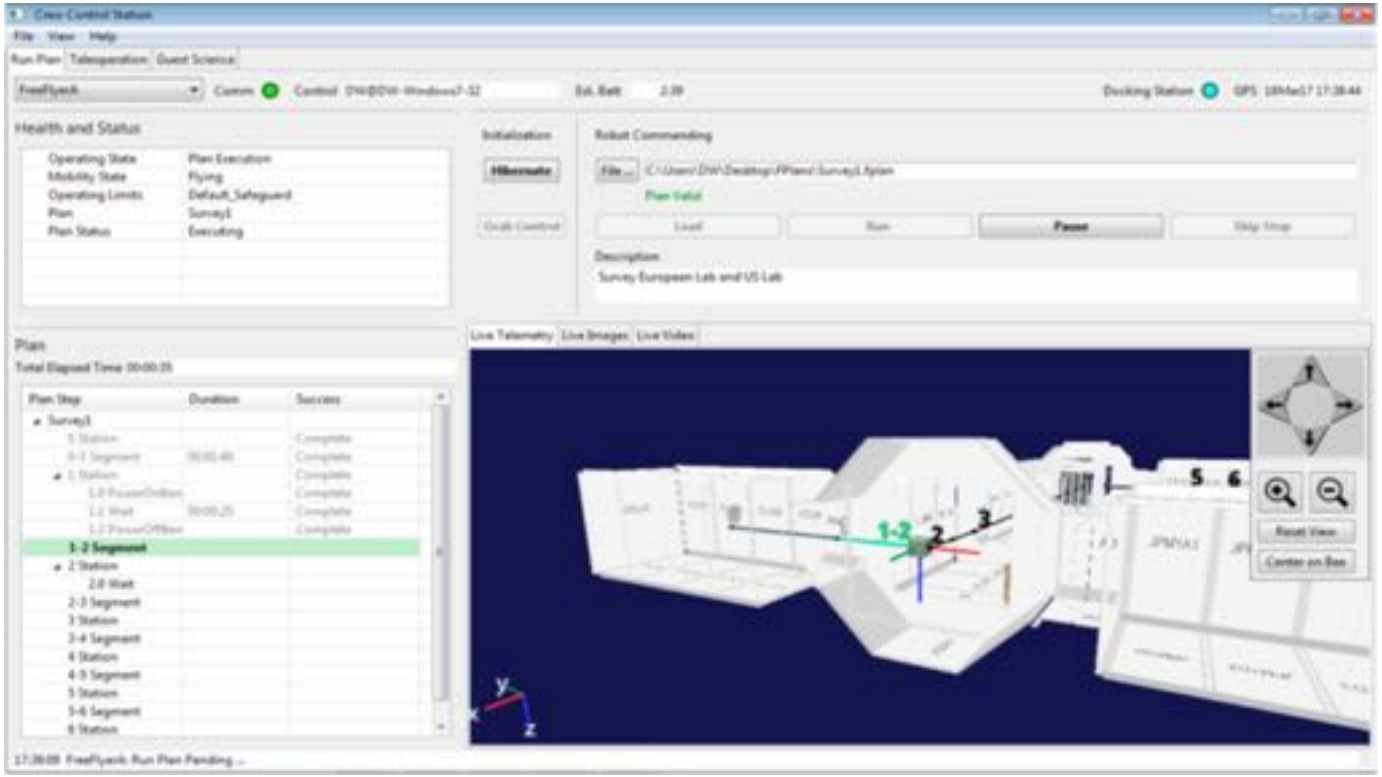
- 85 cm x 38 cm x 28 cm
- Berths for 2 free flyers
- Provides power and Ethernet

- Fiducials used for visual servoing to autonomously dock
- Magnets provide retention force

System Description: Ground Data System

- Astrobee Control Station
  - Sortie planning tool
  - Execution monitoring
    - Live telemetry
    - Image and video streams
    - 3D virtual display
  - Supervisory control (run plans or single commands)
  - Typically used by ground operators
- Crew Control Station (used rarely) runs on an EXPRESS Laptop Computer (ELC)
- Server for archiving and distributing Astrobee data
- Suite of engineering tools to support maintenance and software upgrades

Astrobee Control Station



Control Centers

- Astrobee can be operated from almost anywhere
  - Flight controllers at Mission Control Center (JSC)
  - Payload controllers at Payload Operations Integration Center (MSFC)
  - Guest scientists at Multi-Mission Operations Center (ARC) or home institutions
- Provides operators with a mobile camera for improved ground situation awareness during crew activities
  - Optimize viewing angles using the pan/tilt or by relocating Astrobee
- Supervisory control means 100% of operator's attention is not required

Camera Scenario: OSO observes crew maintenance task

- Schedule Astrobee activity
- Use Plan Editor to create 1) a plan that moves Astrobee to crew activity site, and 2) a plan that returns Astrobee to the Dock
- Shortly before crew activity, execute 1st plan
- At start of crew activity, switch to Teleoperate to begin streaming HD video and adjust pan and tilt
- If crew blocks camera view, teleoperate Astrobee to unperch, fly to new handrail, re-perch.
- During LOS, Astrobee will continue to record video
- At conclusion of crew activity, end HD video streaming and execute 2nd plan to return to dock
- Once Astrobee is docked, if desired, downlink recorded video file.

Concept of Astrobee perching for crew activity documentation

Other Operational Considerations

- 3 Astrobees will be on orbit, but only 2 Docking Station berths are available
  - Third free flyer will be stowed and will require crew to charge and install batteries before use
- Multiple free flyer operations
  - Each Astrobee accepts commands from only one Control Station at a time
  - Any Control Station may monitor telemetry from multiple Astrobees
  - Allows operators to watch for interference between multiple Astrobee activities
- ISS operators must schedule use of Astrobee with the Astrobee Facility

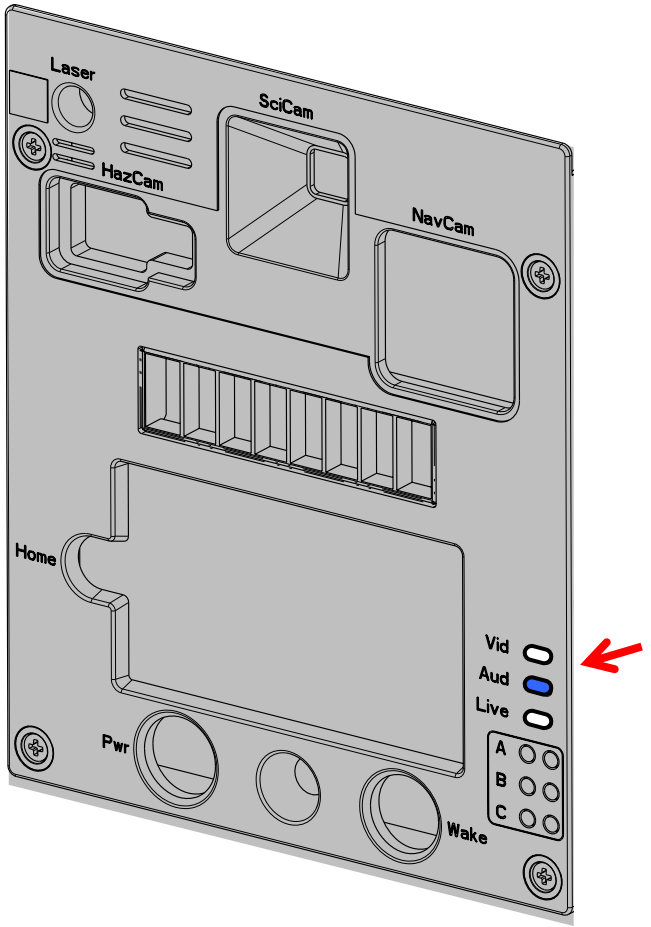
Challenges: Safety

- Unique collision hazards: Crew can move faster than Astrobee can move out of the way
- Mitigations
  - Light (low mass, ~10 kg)
  - Slow (max speed 0.5 m/s)
  - Soft (corner bumpers and foam padding)
  - Signal lights/noise when entering hatchway
  - Keep crew aware through operational techniques
    - Daily Plan
    - Daily conferences
    - CapCom calls as needed
- Screens cover intakes
- Grills cover nozzle flaps

Bumper collision test rig

Challenges: Privacy

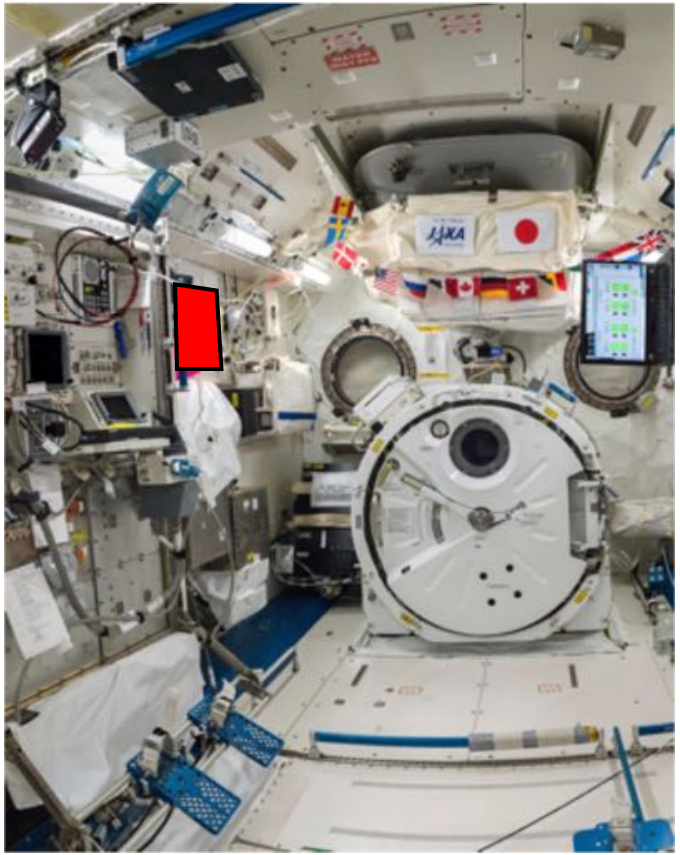
- Some cameras always on whenever Astrobee is operating
  - Privacy status LEDs on forward and aft faces indicate when cameras or mic are on and/or streaming
- Crew actually most concerned about live audio
  - In addition to privacy status LEDs, signal lights on left/right Prop Modules will shine blue when mic is on
- Keep-Out Zones (KOZ) can be used to keep Astrobee out of areas where:
  - A crew member is exercising
  - A medical experiment is in progress
  - A sensitive payload is operating
  - An exhaust vent creates fast-moving air that might blow Astrobee off course



Astrobee forward bezel privacy status LEDs

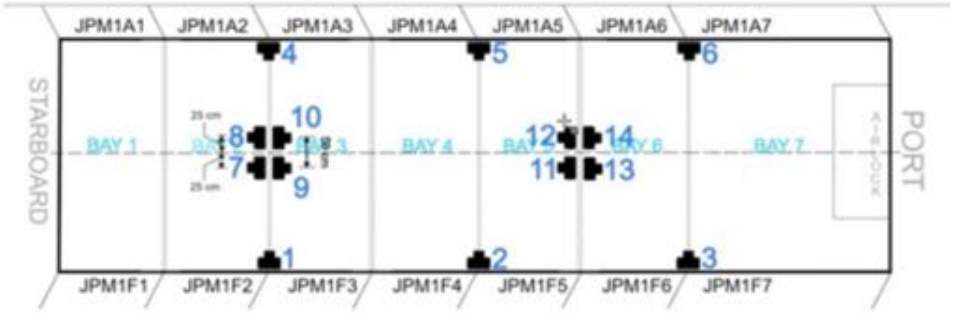
Challenges: Placement

- Difficult to find a “permanent” location for the Docking Station
  - Occupies significant space
  - Want to avoid high traffic areas
  - Anticipated service life until 2024, will last through many changes to ISS
- Lesson learned: expect to be moved, and be flexible
  - Dock design now has many mounting configurations with adjustable brackets, based on both seat track and hook-and-loop
  - Accommodates many possible mounting locations
- Initial location: JAXA has agreed to host the Astrobee dock in the JEM-Pressurized Module Port Endcone, Aft



Initial dock location in red, JPM1A7

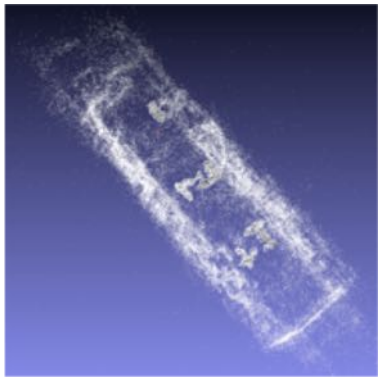
Status: First ISS Activity (Pre-Launch)



JEM Mapping: Locations of 14 panoramas

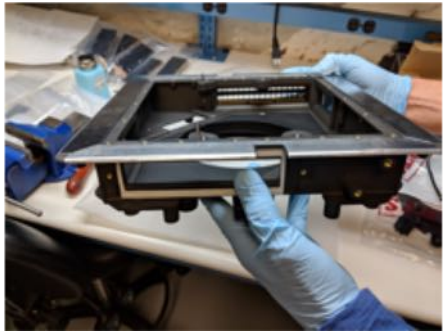
ISS CDR Bresnik taking photos, 2017/11/06

Panorama stitched from 9 photos



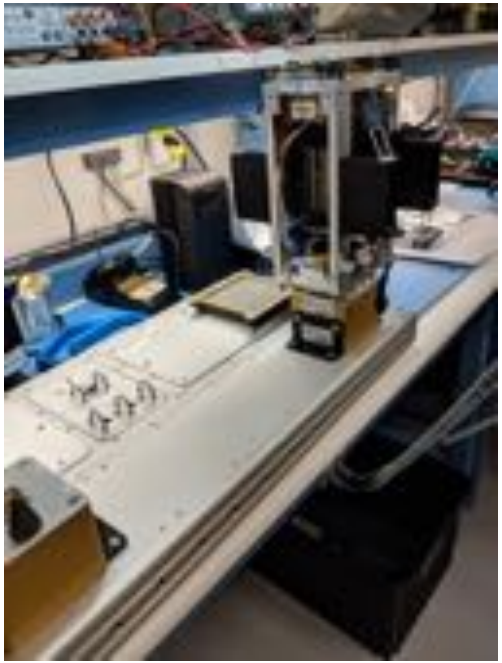
Resulting 3D map of visual landmarks

Status: Integration in Progress



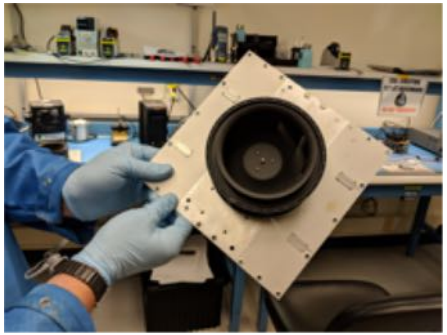
Propulsion Module Plenum

Core Avionics Burn-In



Fit Check – Free Flyer Core with Dock

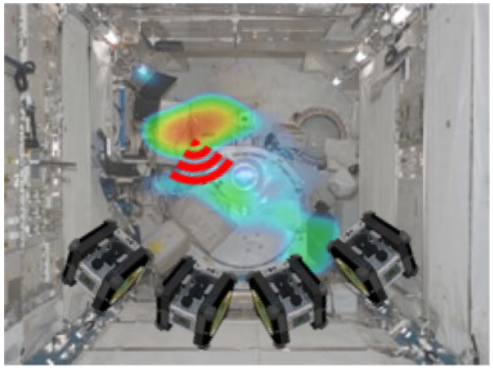
Nozzle Mechanism



Propulsion Impeller

Future Applications

- Astrobee will help prove out the concept of “Caretaker Robots” for future exploration architectures
- Allows monitoring, maintenance and repair of a facility before and between crews
  - Gateway may be crewed just six weeks per year!
  - Critical need to care for spacecraft when crew are not present
- Inspection functions can include:
  - Spot checks
  - Surveys
  - Automated change detection and trending
  - Localizing problems
- With dexterous robotic manipulation capabilities, future tasks could include:
  - Maintenance
  - Repair
  - Cargo transfer

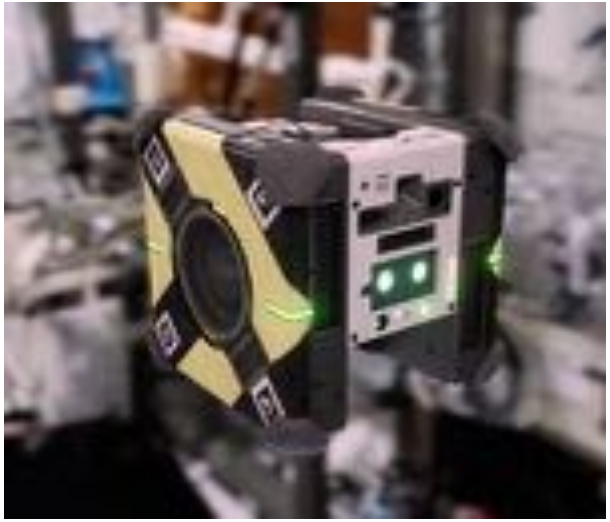


Isolating faults: Ultrasonic leak detection

Off-load routine astronaut tasks: Robotic cargo transfer

Conclusion

- Increases efficiency of flight and payload operations
- Improves crew safety
- Mobility caused unique operational challenges
- Launch: November 2018
- Commissioned: mid-2019
- Current status: Integration



Acknowledgments

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Questions?

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