Mini AERCam for In-Space Inspection

Dr. Steven E. Fredrickson

Abstract:

The NASA Johnson Space Center Engineering Directorate has developed the Miniature Autonomous Extravehicular Robotic Camera (Mini AERCam) as a free-flying, robotic inspection vehicle intended for future external inspection and remote viewing of human spacecraft. The Mini AERCam technology demonstration unit has been successfully integrated into the approximate form and function of a nanosatellite flight system by leveraging the success of AERCam Sprint flight system and related free-flyer technology development. The Mini AERCam free flyer can be operated via remote piloting from a control station supporting teleoperation and supervised autonomous commanding, with functions such as automatic stationkeeping, point-to-point maneuvering, and automatic docking. Free-flyer testing has been conducted on an air-bearing table and in a six degree-of-freedom closed-loop orbital simulation, and enhancements have been made to provide additional capabilities for future space-based inspection. This presentation will provide a technical overview of the Mini AERCam development, including strategies for spacecraft integration.

Mini AERCam for In-Space Inspection

29 February 2012

Dr. Steven E. Fredrickson
NASA JSC ER6

Outline

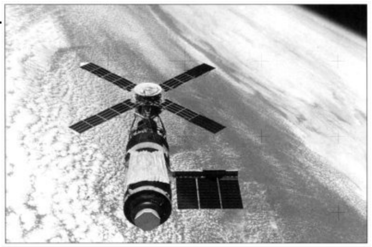
- **Motivation**
  - Historical need for better inspection and remove viewing
  - Future vision
- **AERCam overview**
  - AERCam Sprint
  - Mini AERCam Technology Development
  - Flight concepts for Shuttle and ISS
- **Flight Infusion Strategy**

Historical Examples of Need for Inspection (1 of 2)

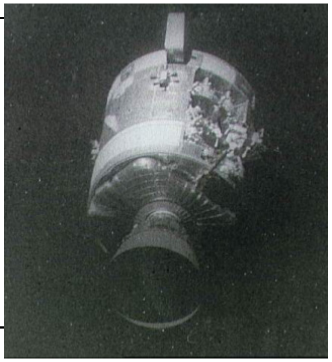
- **Historical examples of problems NASA would have wanted to learn about or inspect sooner (if inspection capability existed)**

That the launch vehicle shroud had not separated from the Agena docking adapter, prior to the launch of Gemini 9 that was supposed to dock with it (July 1966)

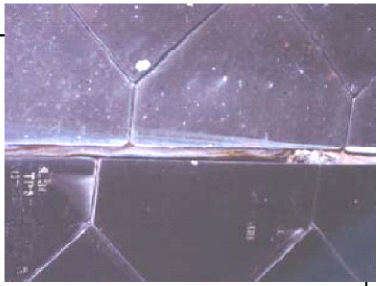
The cause for Skylab's second solar array not deploying (the first one was lost at launch) (May 1973)



The extent of the damage to the Apollo 13 Service Module during the Apollo 13 mission (April 1970)

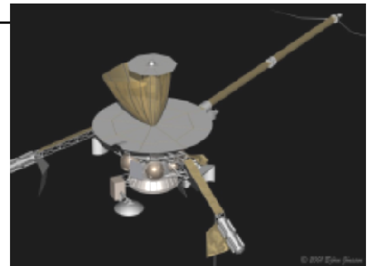


STS 51D ET door not sealed properly due to rolled thermal barrier wedged between the door and the door frame (April 1985)



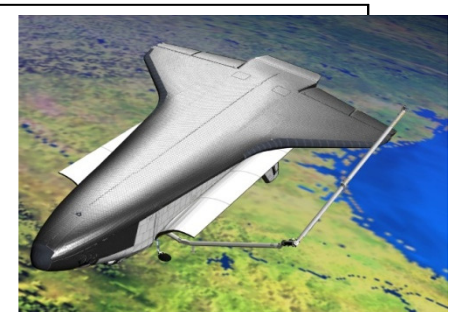
Historical Examples of Need for Inspection (2 of 2)

The cause for the Galileo spacecraft's high gain antenna's inability to deploy (April 1991)

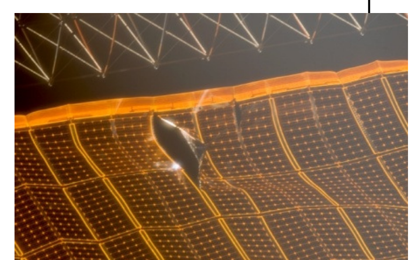


The cause for the Progress's inability to dock at the ISS Service Module aft docking port prior to Endeavour launch on STS-108 (November 2001)

TPS damage detection and inspection. The Space Shuttle was the first NASA spacecraft to develop a full on-orbit inspection capability (after loss of Columbia) but relied on a robotic arm and boom of a scale unlikely to be available for Exploration vehicles.

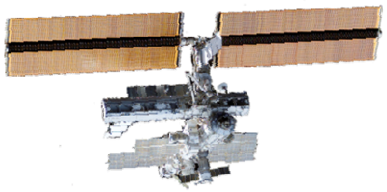


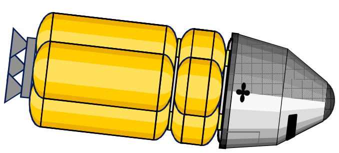
A view of a damaged P6 4B solar array wing on the International Space Station (during STS-120). NASA halted the deployment -- which was about 80 percent complete -- to evaluate the damage.

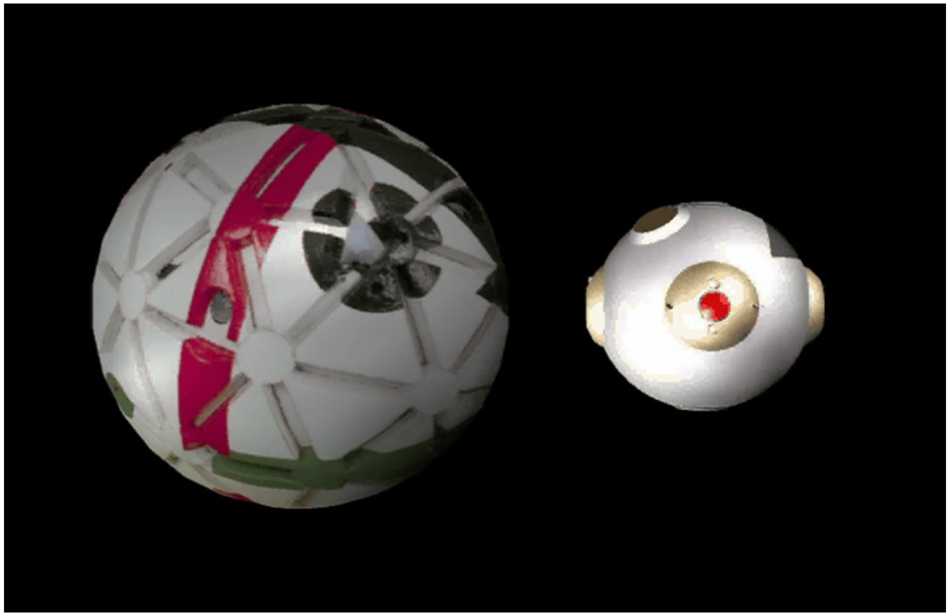


AERCam Vision for NASA

NASA programs will benefit from increased safety and enhanced mission success by carrying a deployable free flying inspection system.







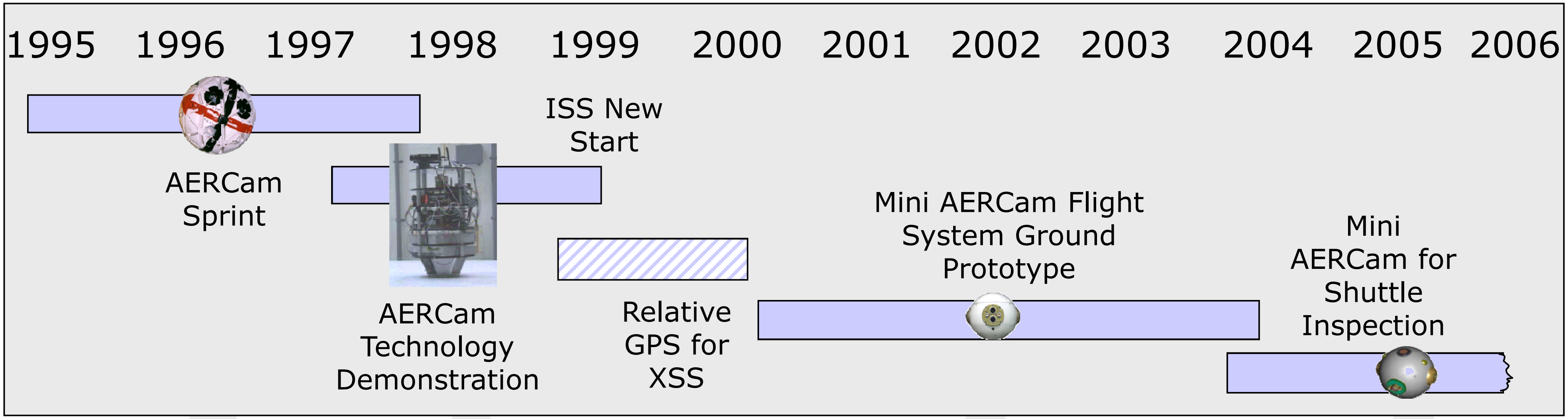
JSC Engineering pursued this vision starting with AERCam Sprint and continuing with Mini AERCam.

Potential MPCV and Exploration Applications

- **Anytime external inspection of spacecraft surfaces**
  - Anomaly resolution aid for all mission phases: LEO, Docked at ISS (for ISS missions), Cis-Lunar cruise, Lunar orbit, Earth return
- **External view of MPCV CM/SM separation or other dynamic events**
- **Inspect TPS after SM separation**
  - Even if committed to entry, choose entry mode if TPS damage is seen and the entry profile can reduce heating profile in that area
- **Engage public with in-space views of spacecraft otherwise difficult or impossible to obtain**
  - E.g. framing spacecraft with earth or moon in scene

AERCam History

Over 10 years of development history at JSC



Flight test of protoflight unit on STS-87 in 1997

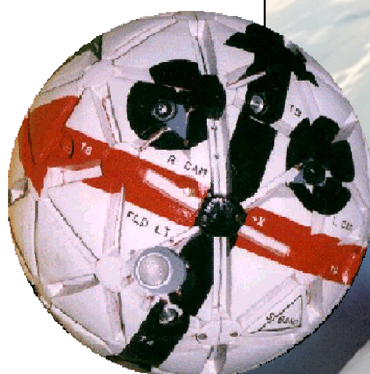
Testbed for advanced autonomous technologies

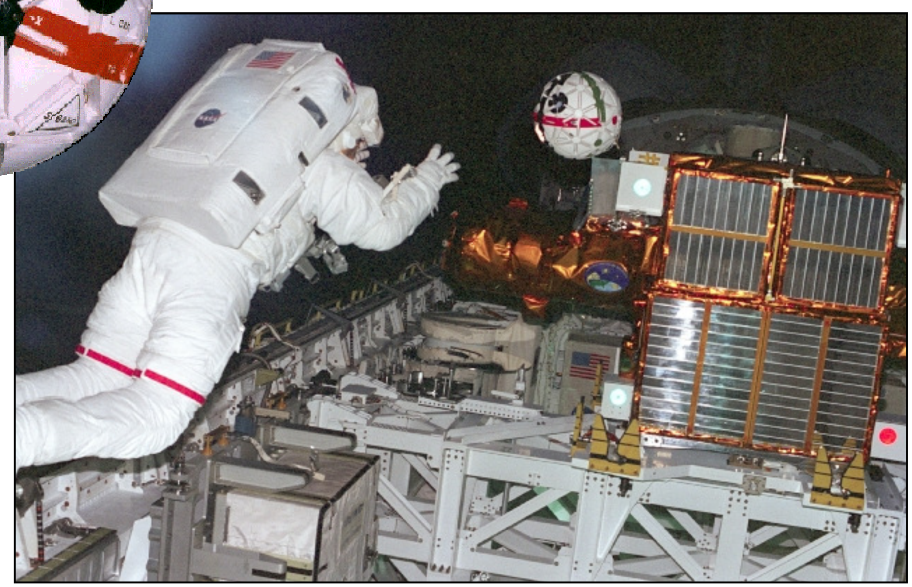
Ground demonstration of flight-like integrated design

Flight system development for Shuttle Inspection

AERCam Sprint on STS-87

- Free flying camera
- Flight tested in December 1997 on STS-87
- Released during EVA by Winston Scott
- Remotely piloted by Steve Lindsey from the Orbiter aft cockpit
- Flown for over an hour around the Payload Bay
- Sprint provided color video
- 14-inch diameter, 35 pounds
- Demonstrated capabilities included automatic attitude hold, manual maneuvers





AERCam Sprint Flight Video

Path to Operational Capability

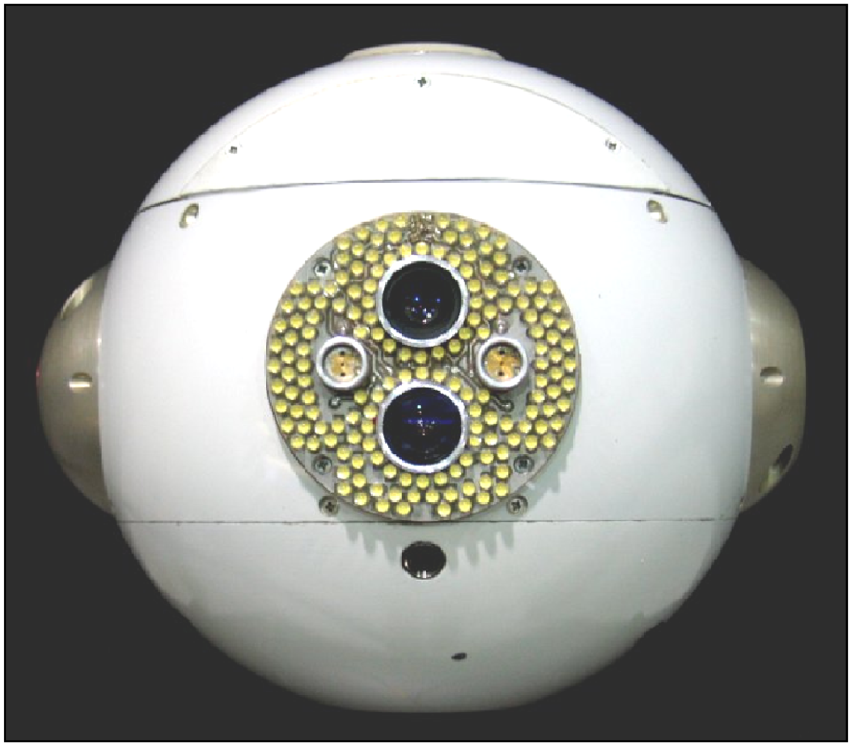
Sprint proved stable video of external points of interest can be obtained using a teleoperated free flyer.

Following Sprint, the JSC Engineering Directorate embarked on an effort to provide increased capabilities for a free flying inspection system, while maturing the needed technologies and validating requirements through crew participation.

- Follow on development project resulted in an integrated demonstration of new free flyer technologies for free flyer autonomy and operator situational awareness
  - Differential carrier phase GPS navigation
  - Autonomous maneuvering
  - Visual guidance
  - Obstacle avoidance

Mini AERCam Flight Prototype

- Nanosatellite size (lower launch mass, lower power, safer)
  - 7.5 inches in diameter, 11 lbs
- Components are “one step from flight”
- Increased technology readiness across all subsystems
- Matured overall system technology readiness

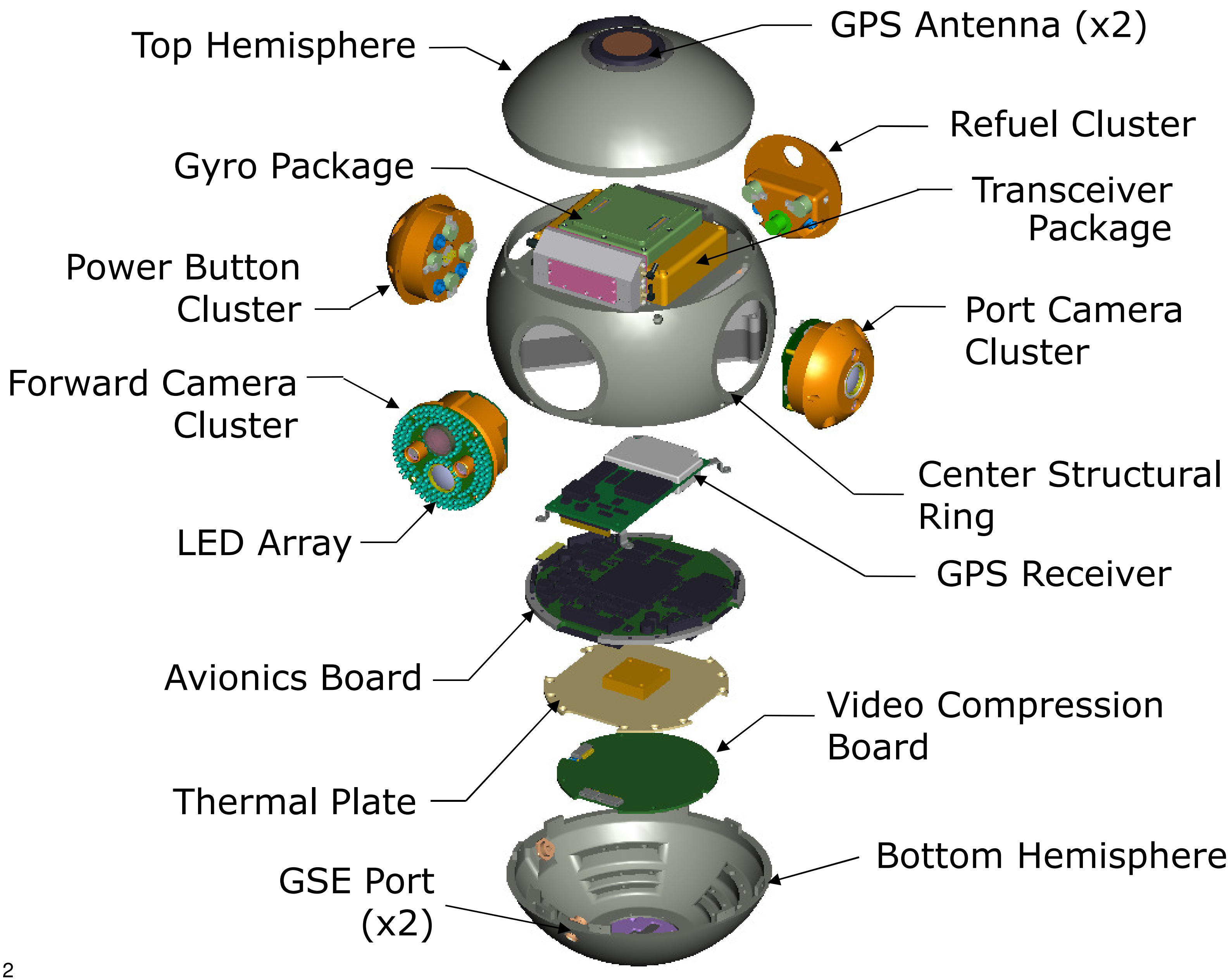


Free Flyer Capability Comparison

Sprint:
- 6-DOF manual control
- Automatic attitude hold
- Analog video

Mini AERCam:
- 6-DOF manual control
- Automatic attitude hold
- Commanded attitude maneuvers
- Automatic position hold (relative)
- Commanded translation maneuvers
- Automatic surface scans
- Situational awareness (God's Eye View)
- Digital video
- Automatic docking
- Rechargeable battery
- Rechargeable propulsion

Mini AERCam Flight Prototype Components



Mini AERCam
Free Flyer Technologies (1 of 2)

PROPULSION

- **Rechargeable pressurized xenon gas propulsion**
  - 6 DOF thrusting capability (12 thruster configuration)
  - Compatible with nitrogen for ground operations

POWER

- **Rechargeable batteries (Li-Ion chemistry)**

VIDEO

- **CMOS color cameras (“Camera on a chip”)**

ILLUMINATION

- **Solid state illumination (LEDs)**

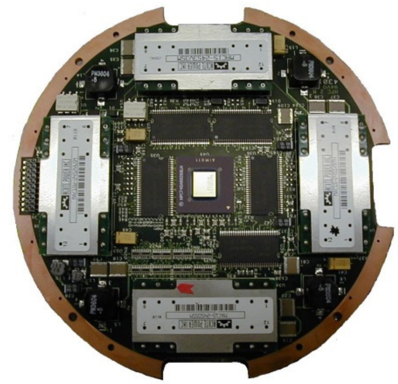
DOCKING

- **Electromagnetic docking**
- **AutoTRAC Computer Vision System (ACVS) for docking navigation**

Mini AERCam
Free Flyer Technologies (2 of 2)

AVIONICS

- **PowerPC 740/750 based design**
- **FPGA-centric architecture**



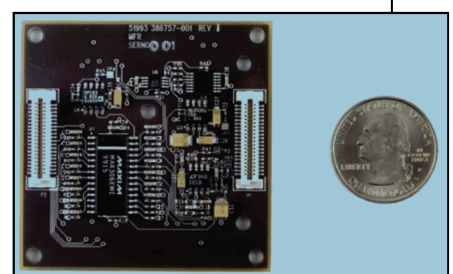
Avionics Processor Board

COMMUNICATIONS

- **Digital transceiver for video, commands, and telemetry**
- **Micro-patch antennas for communications and GPS navigation**

GN&C

- **MEMS angular rate gyros for propagated relative attitude**
- **Relative navigation via GPS mini-receiver**

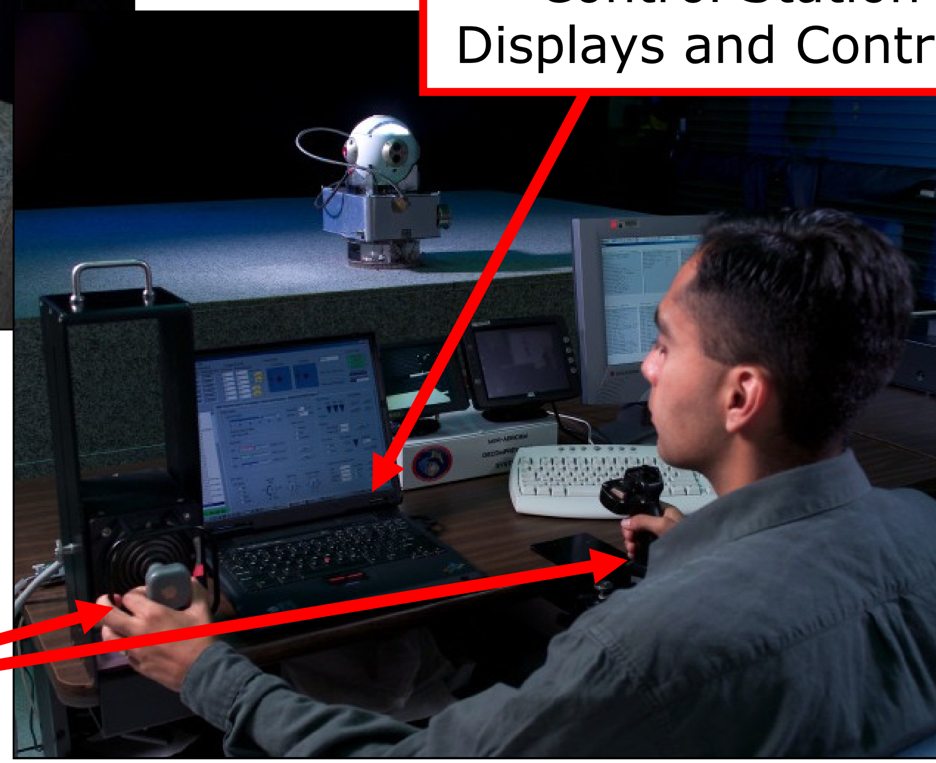


MEMS Rate Gyros

- **Pilot aids: Automatic attitude hold, LVLH hold, attitude maneuvers, translation hold, point-to-point guidance**

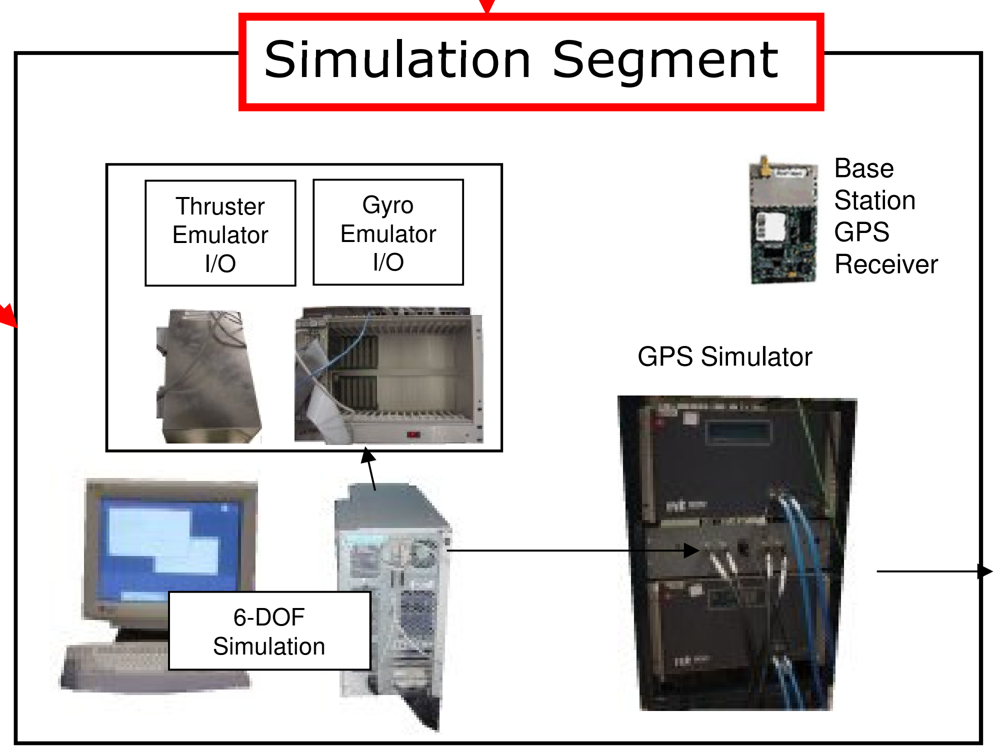
Air Bearing Table Test Facility

- Provides software and hardware testing on frictionless surface for testing in 3 degrees of freedom
- Incorporates avionics, flight software, video, MEMS gyros, communications, batteries, and propulsion.

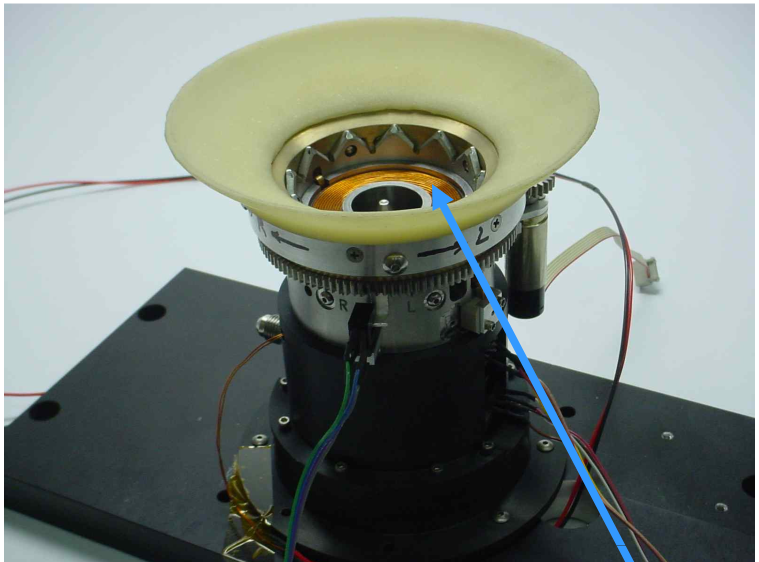


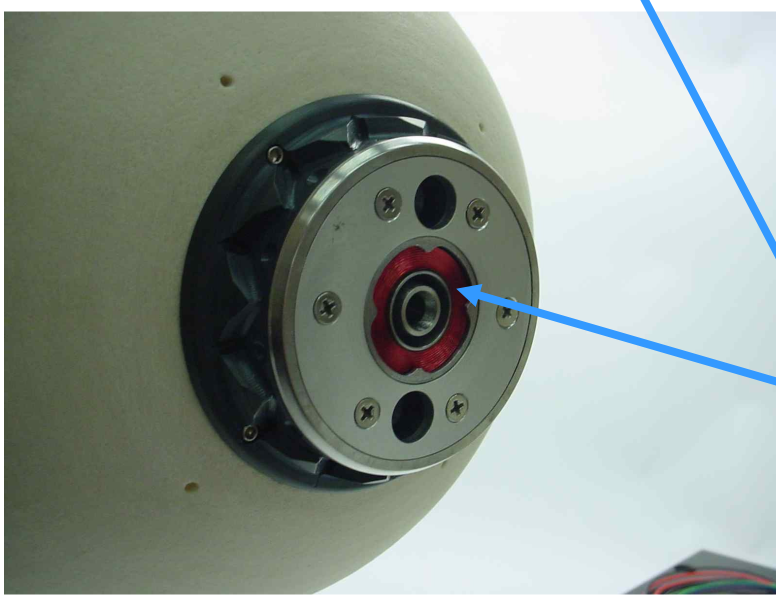
Orbital Simulation Test Facility

- Software and avionics testing in space-like environment.
- Hardware in the loop test facility, including avionics, flight software, communications, and GPS.



Magnetic Docking Mechanism

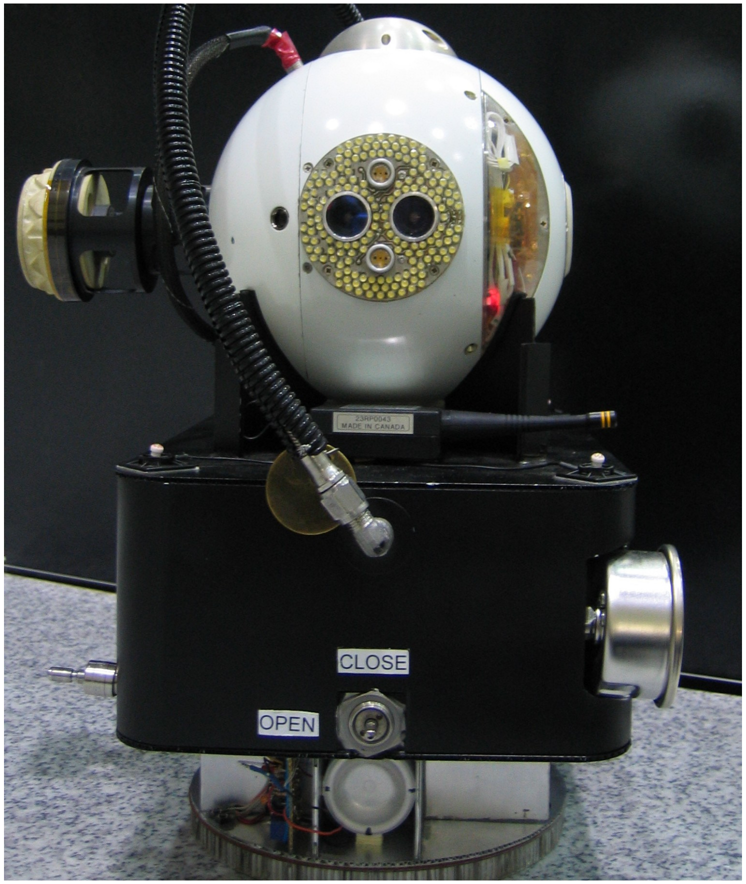




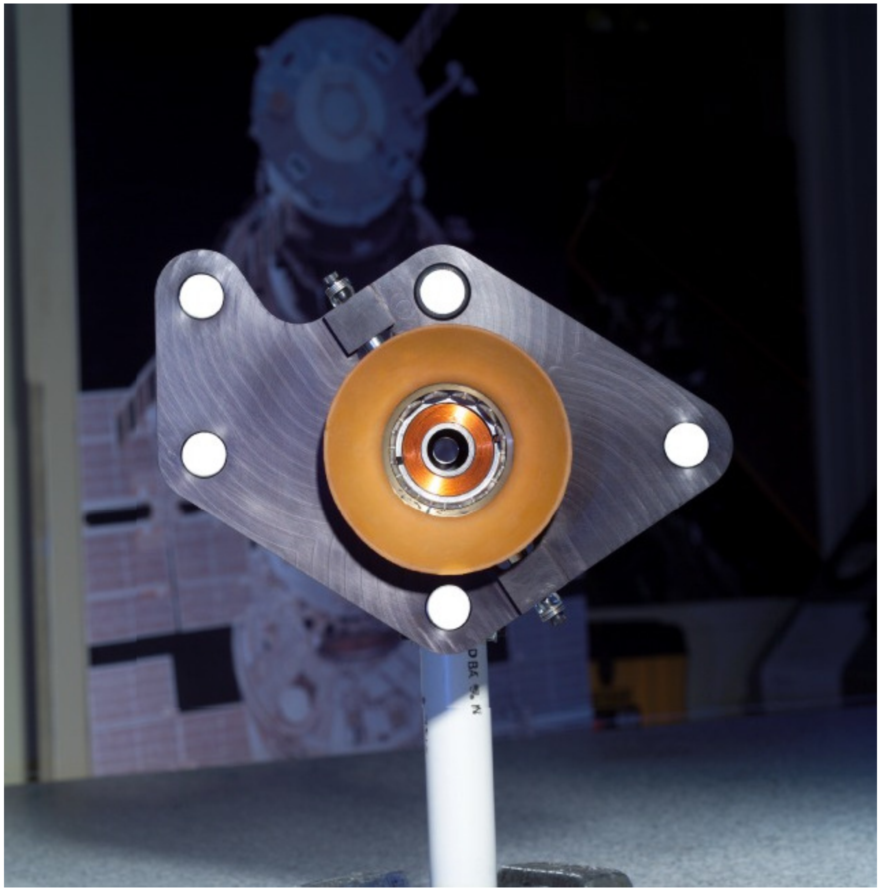
Docking Prototype Hardware on Air Bearing Table

Electromagnets on Free Flyer and Hangar

Closed-Loop Docking Airbearing Testing



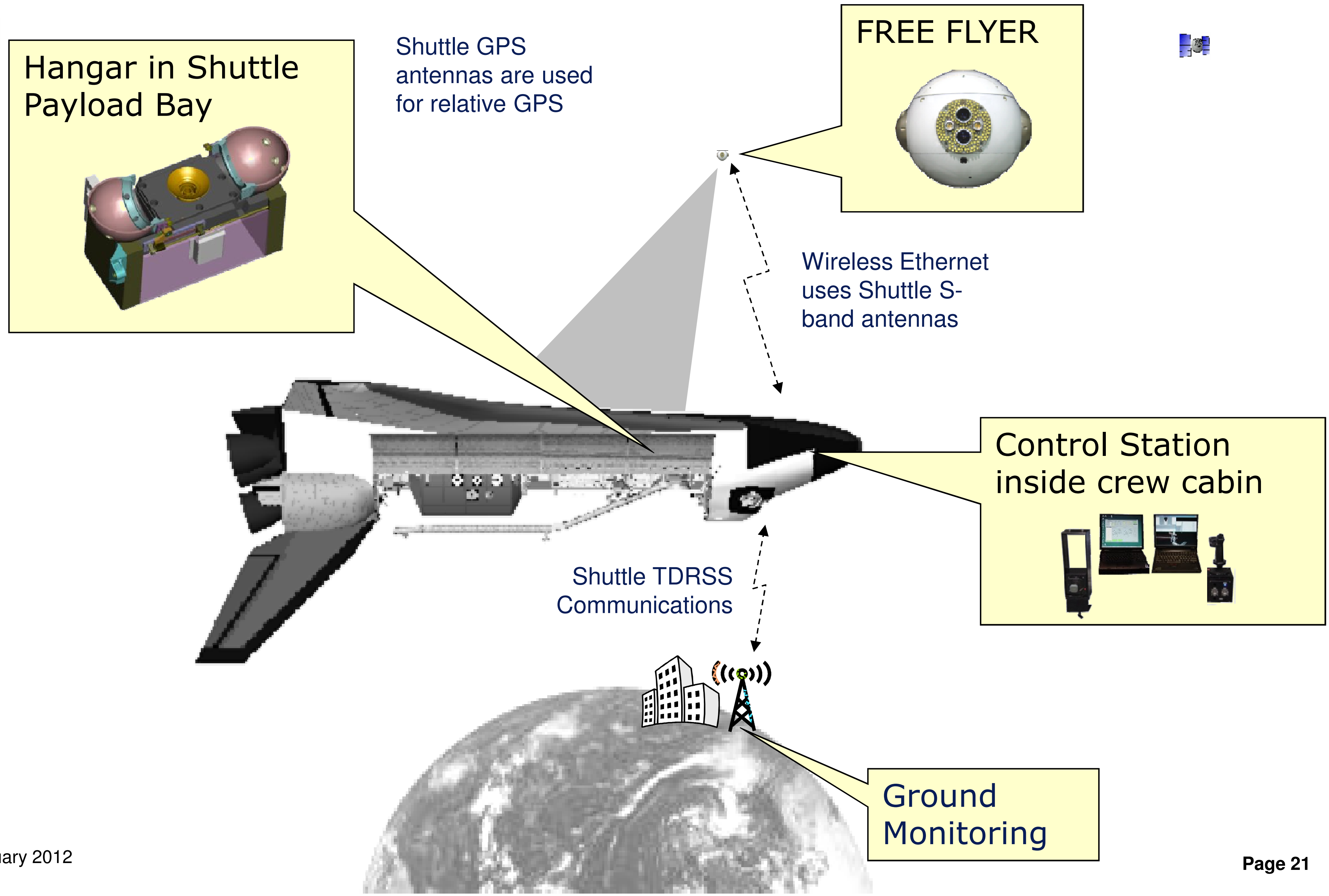
Mini AERCam Free Flyer on Airbearing Table



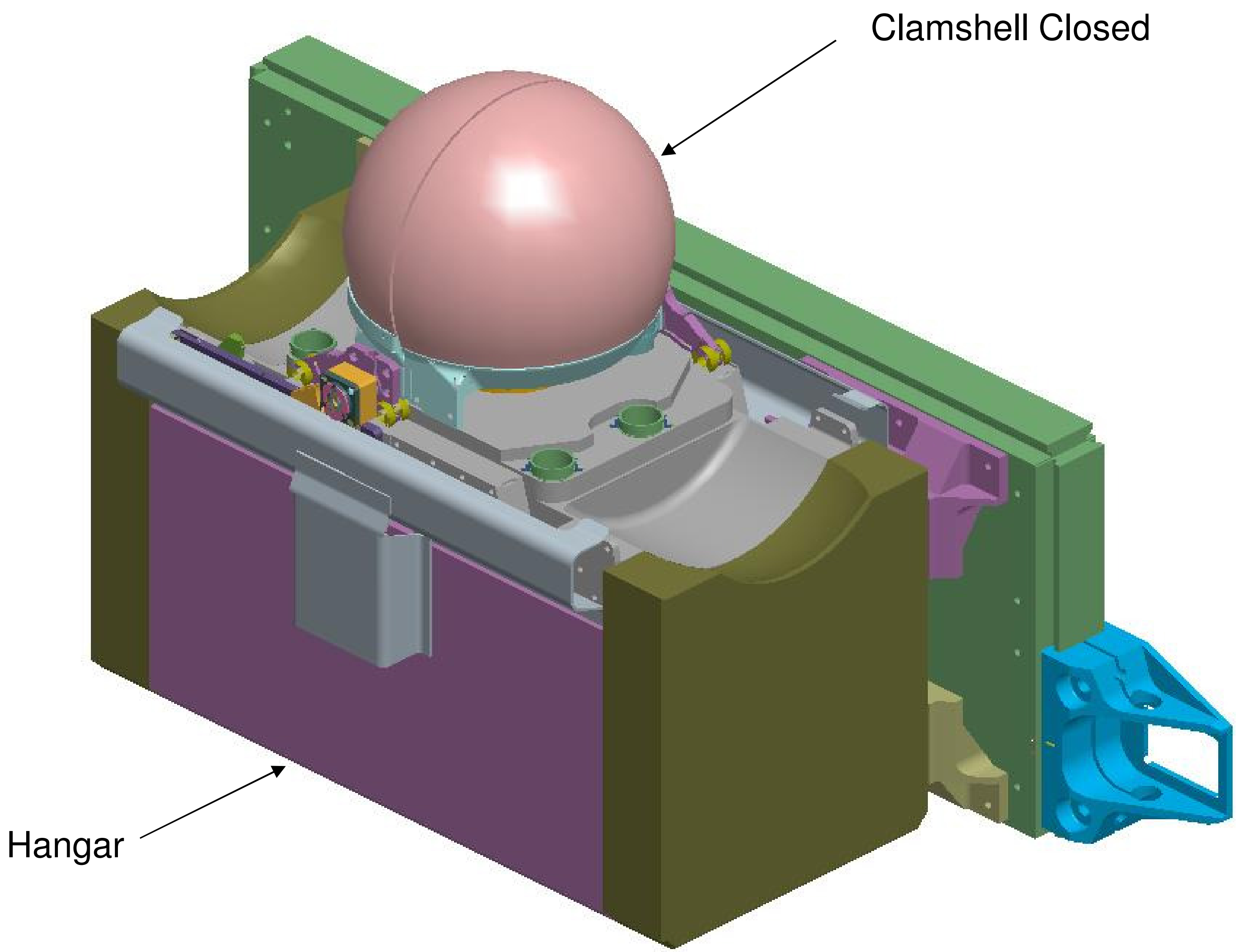
Docking port and ACVS Docking Target

Mini AERCam Docking on Air Bearing Table

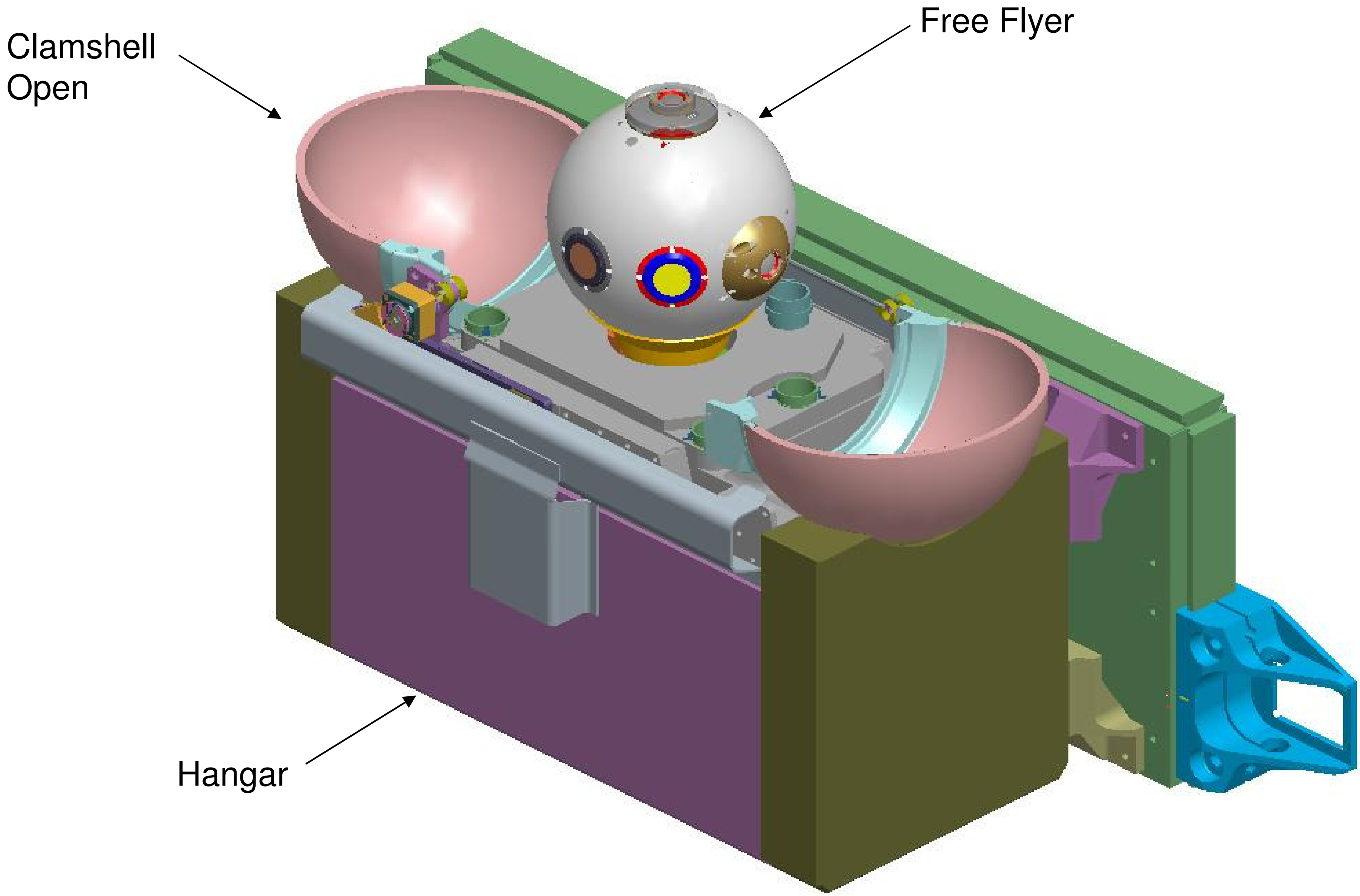
Mini AERCam Concept for Shuttle



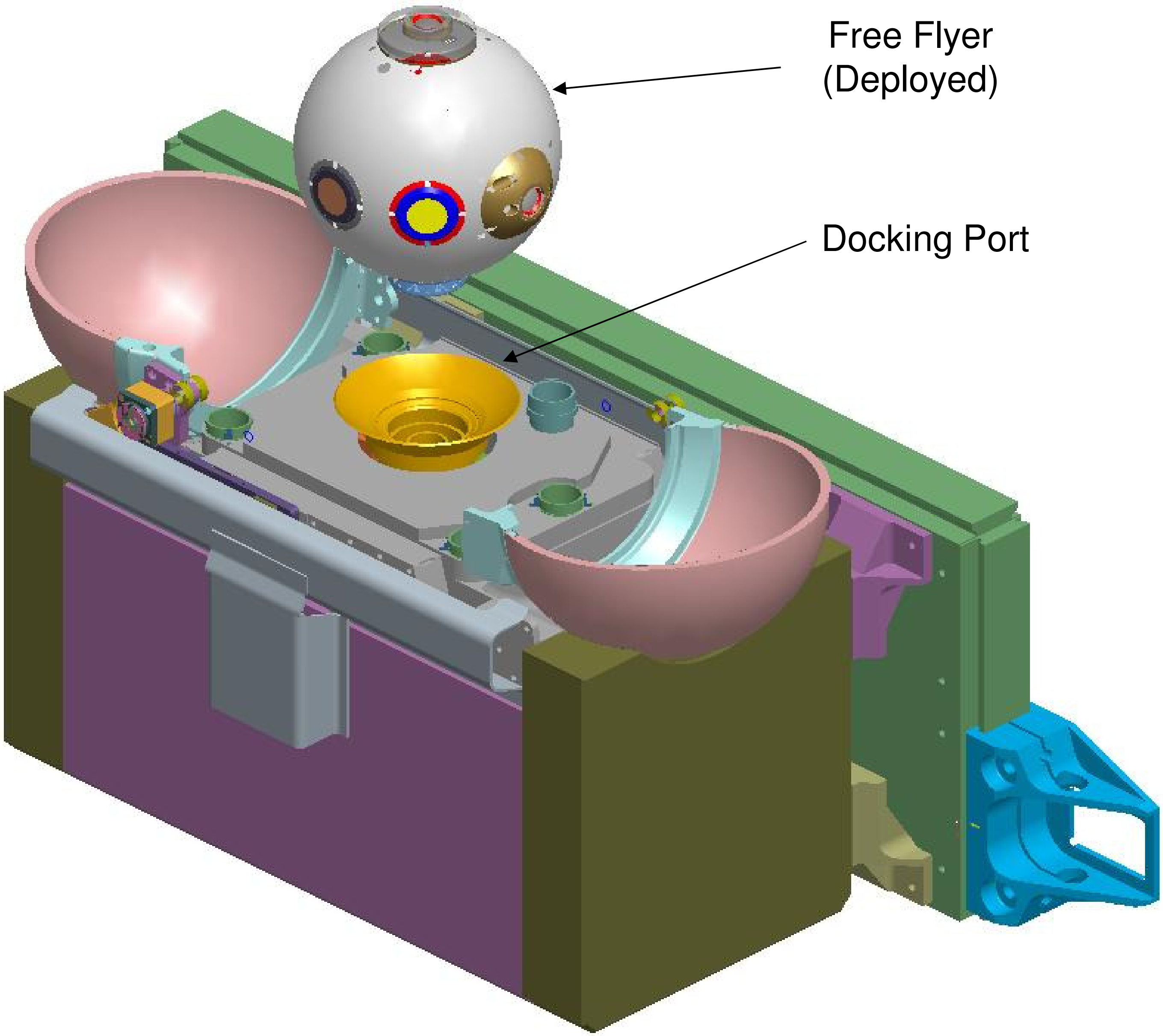
Hangar Concept (Closed Configuration)



Hangar Concept (Open Configuration)



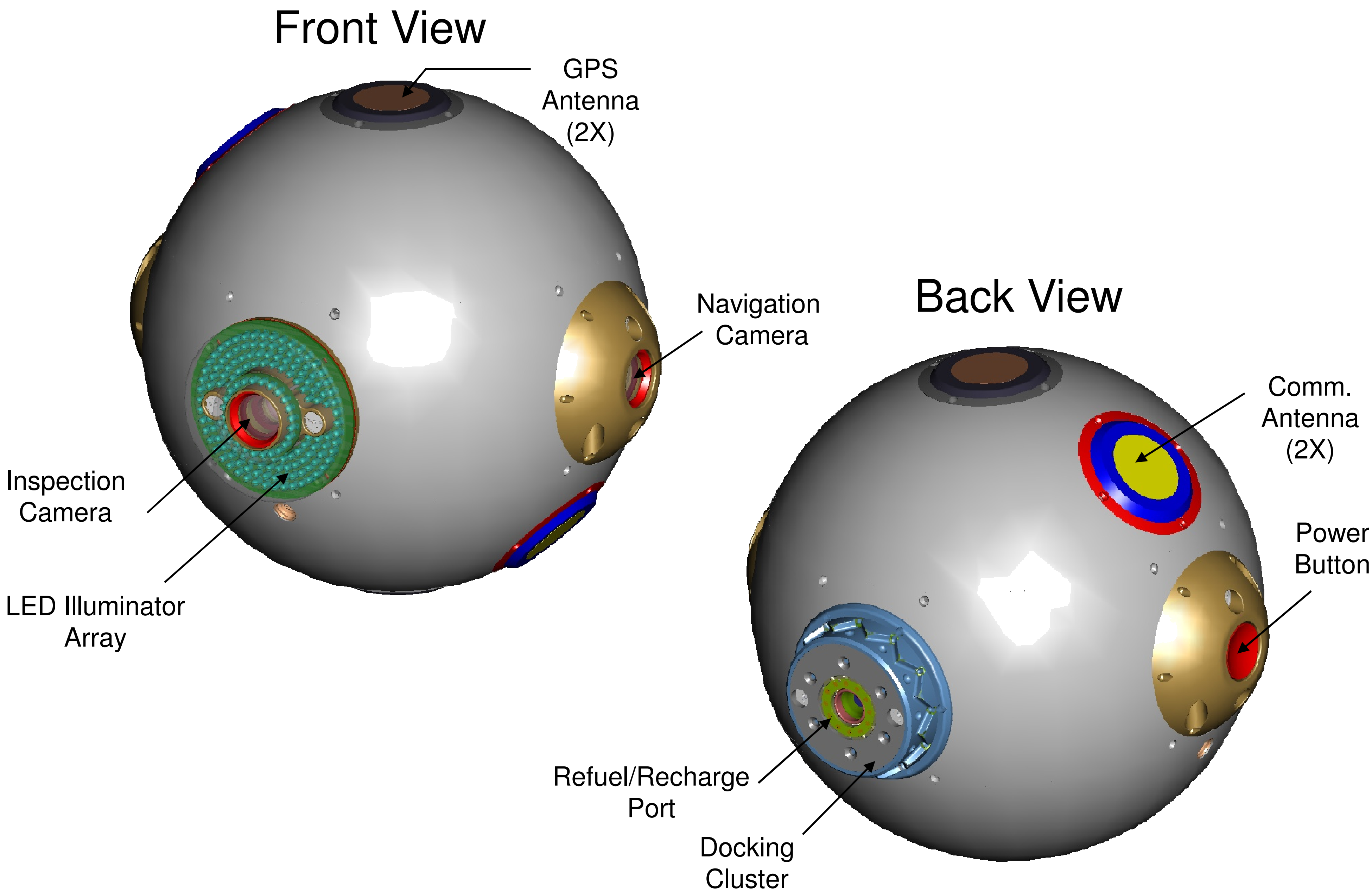
Free Flyer Deployment from Hangar



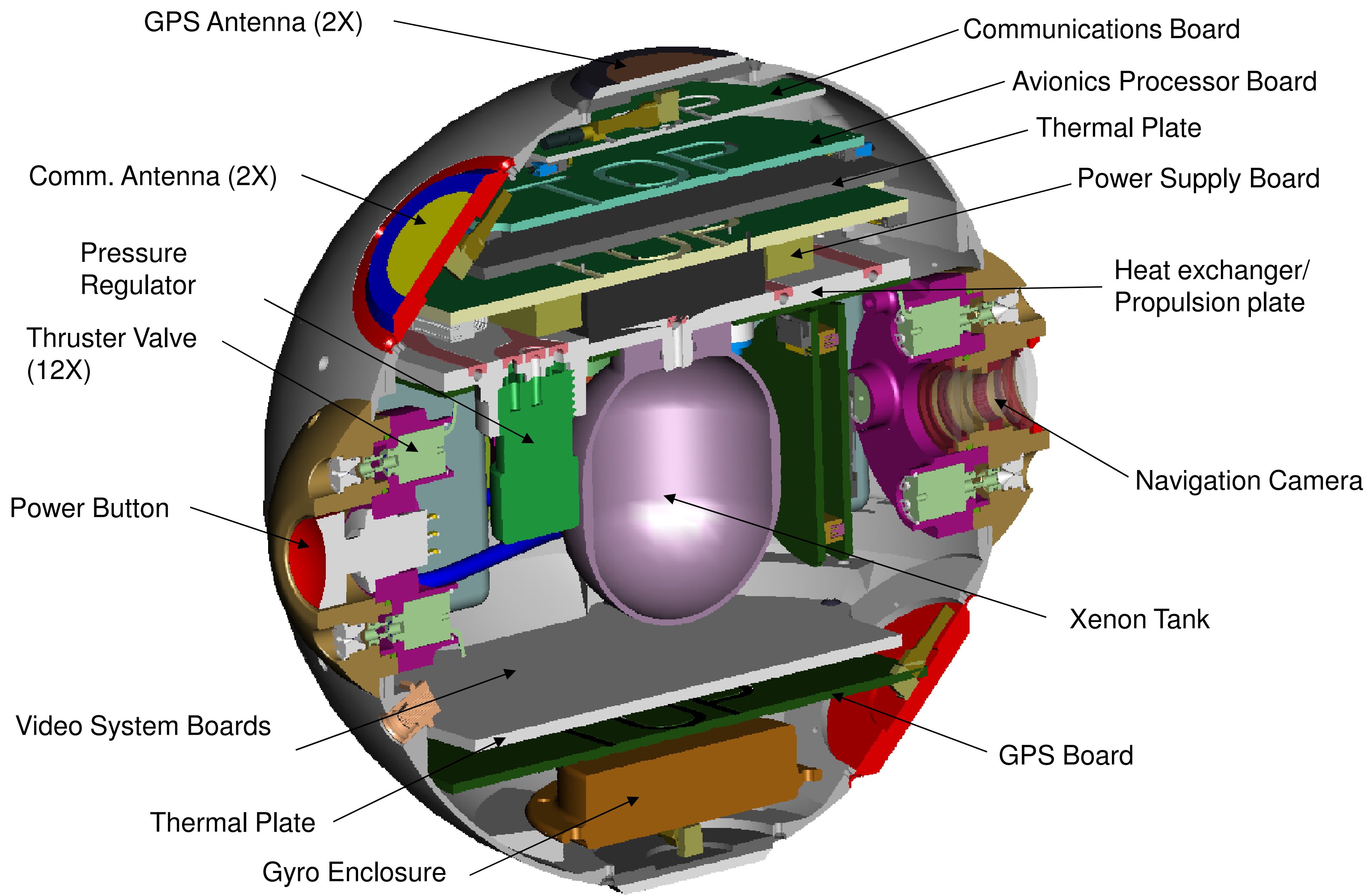
Free Flyer Enhancements for Potential Shuttle Applications

- **Free flyer Design Verification Test Unit (DVTU) development**
  - Imager board designs updated to accommodate higher resolution imagers
    - » Quad HD high resolution imager (8.3 megapixel)
    - » HD resolution color video (2.1 megapixel)
  - Flight avionics design updated for increased radiation tolerance
  - Communication design upgraded to 802.11g (from 802.11b) for higher video bandwidth
  - In-house GPS receiver design developed to replace marginal COTS alternative
  - Mechanical packaging design updated for flight components
  - Updated thermal analysis for flight packaging and confirmed passive thermal design

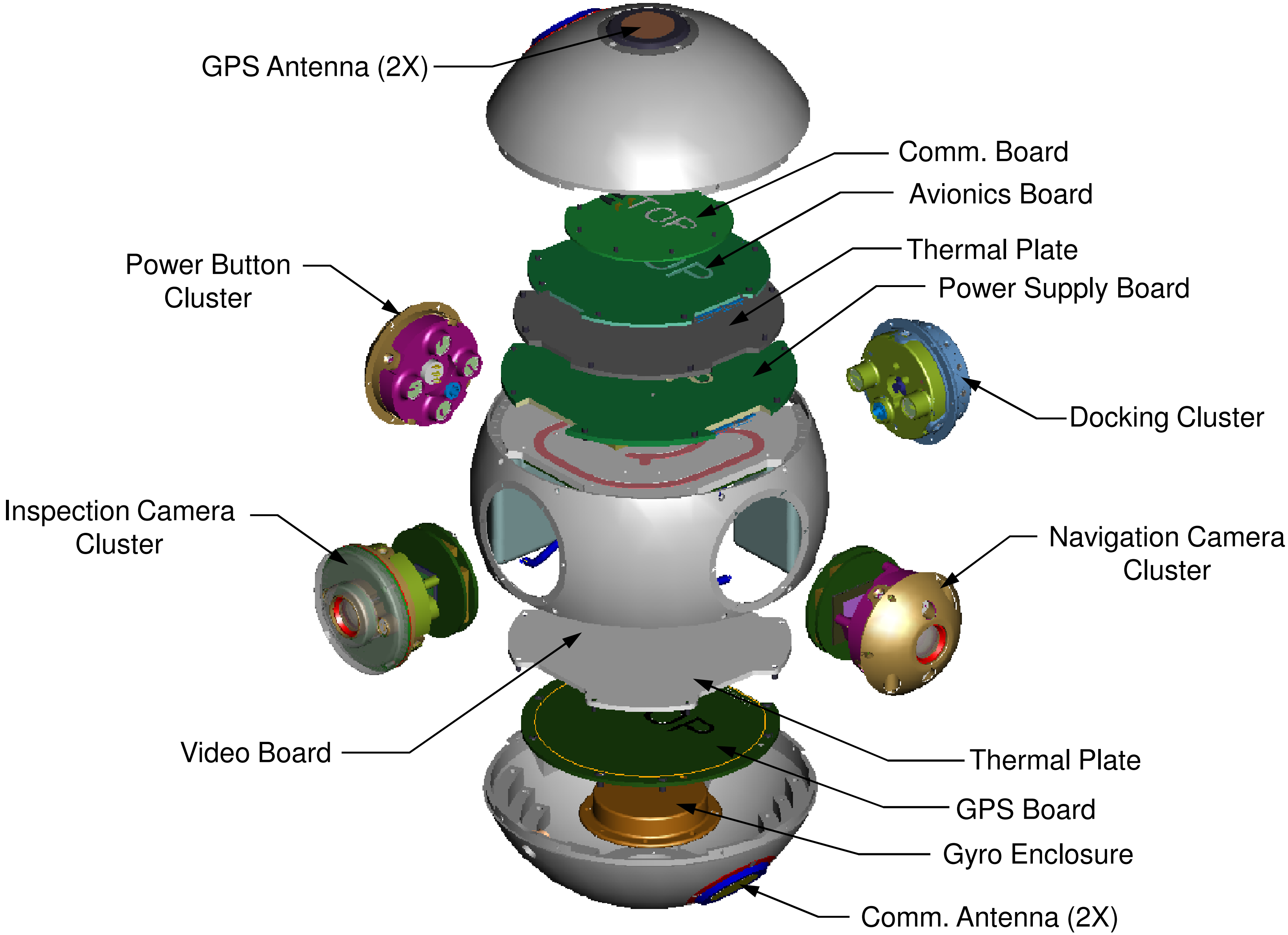
Free Flyer Mechanical Design



Free Flyer Mechanical Design



Free Flyer Mechanical Design



Flight-Oriented Design Validation Activities

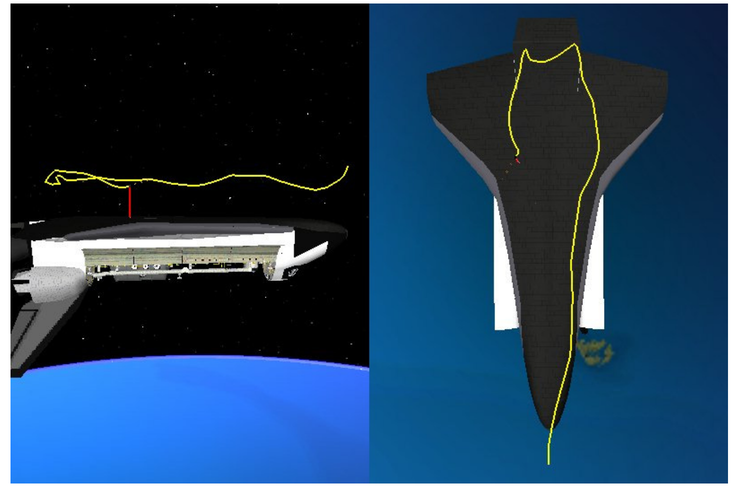
- **Thermal vacuum testing completed**
  - Vehicle functioned for the duration of a 36 hour test (three representative orbital thermal conditions – cold, normal, hot)
  - All measured component temperatures were within limits
- **Radiation testing performed at University of Indiana**
  - Validated core avionics design
- **Wireless communication link range test performed at B14**
  - Full bandwidth link with commands, telemetry and video successful at 300ft with single free flyer antenna rotated 180 degrees from base station antenna
- **Lighting lab tests conducted**
- **Preliminary analyses performed for a Shuttle mission**
  - Shuttle communications coverage
  - Shuttle GPS navigation coverage
  - Preliminary Shuttle thermal analysis
  - Shuttle inspection delta-V analysis
    - MAGIK-generated trajectories used for GN&C analysis of Shuttle tile (belly) and RCC (WLE and nose-cap) scanning

Flight-Oriented Design Validation Activities (Cont.)

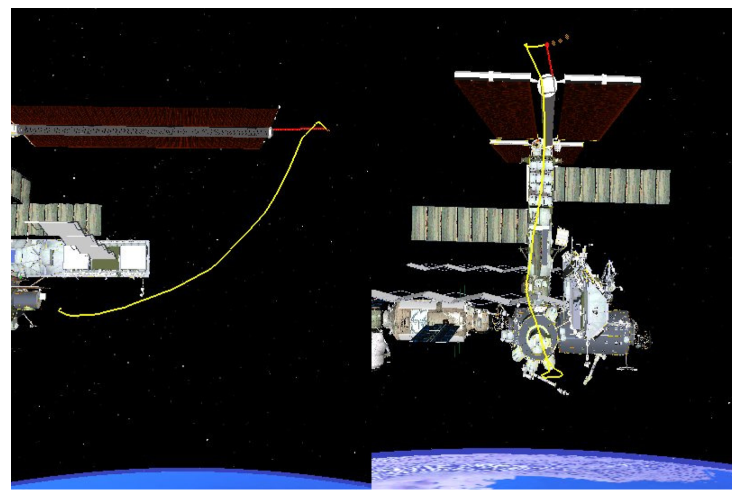
- **Xenon propulsion performance testing**
  - Xenon is an inert gas that provides 3x the delta-velocity of nitrogen in same volume, but has different thermodynamic properties
  - Hot, ambient and cold case tests confirmed suitability of xenon for free flyer application
- **Battery performance testing for rechargeable Li-Ion battery cells**
  - Cell testing confirmed high performance over temperature range
- **Crew evaluation – Displays (2003)**
  - Nancy Currie and the Astronaut Office made significant recommendations for improving displays during crew evaluation preparations
    - » All tasks completed successfully with no significant problems identified
- **Crew evaluation – Hand controller (2005)**
  - Conducted evaluation of a hand-held control pad input device concept that would eliminate requirement for hard-mounting hand controllers in the Orbiter

Mini AERCam Crew Evaluation

- **Tests conducted over six weeks in September-October 2003**
- **7 Crew Test Participants**
  - **Tony Antonelli**
  - **Drew Feustel**
  - **Scott Parazynski**
  - **Steve Lindsey (piloted Sprint on STS-87)**
  - Steve Swanson
  - Koichi Wakata
  - George Zamka
- **Seven test cases**
  - **3 Shuttle**
  - **3 ISS**
  - **1 docking**
- **Crew evaluated handling qualities and situational awareness; providing favorable real-time comments**



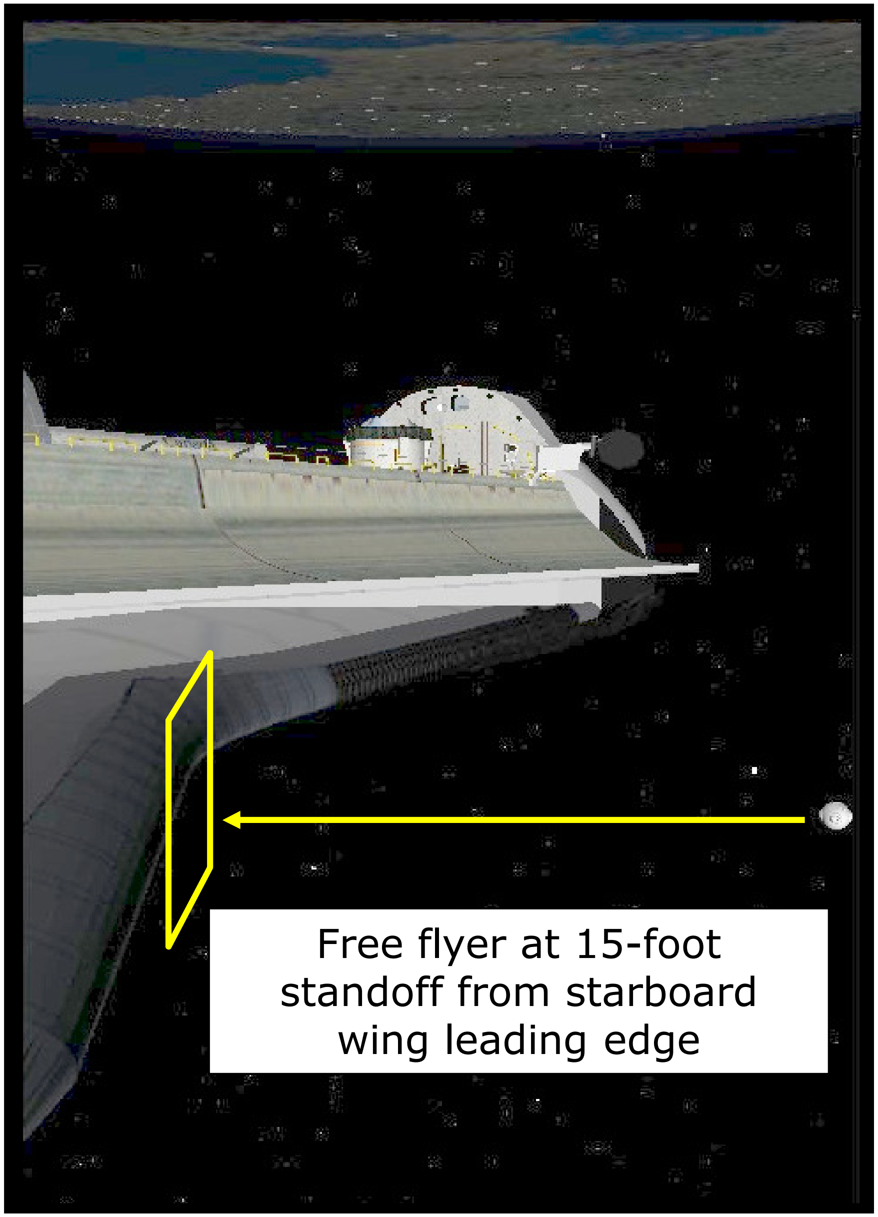
Test Case 2: Scan Orbiter Surface
Scan/inspect Orbiter landing gear doors, external tank doors, and aileron hinge.

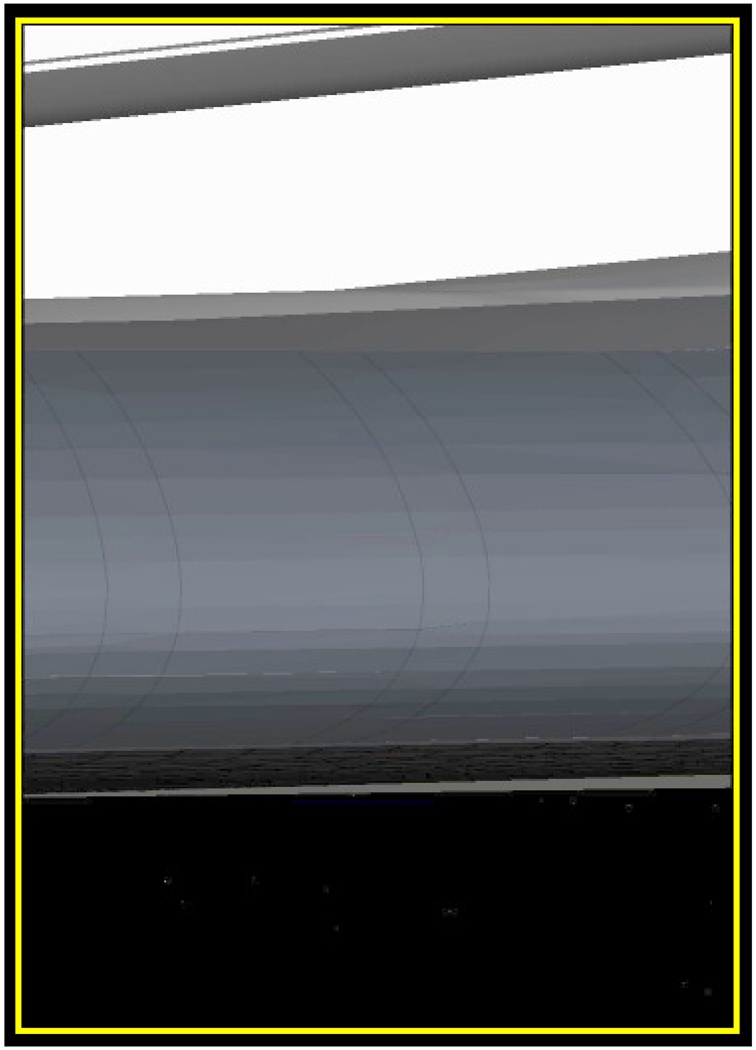


Test Case 4: Traverse to Point on ISS
Starting out at the ISS airlock, fly to the tip of the starboard solar array, then hold position.

Orbital Simulation

Free Flying Shuttle RCC Inspection Capability



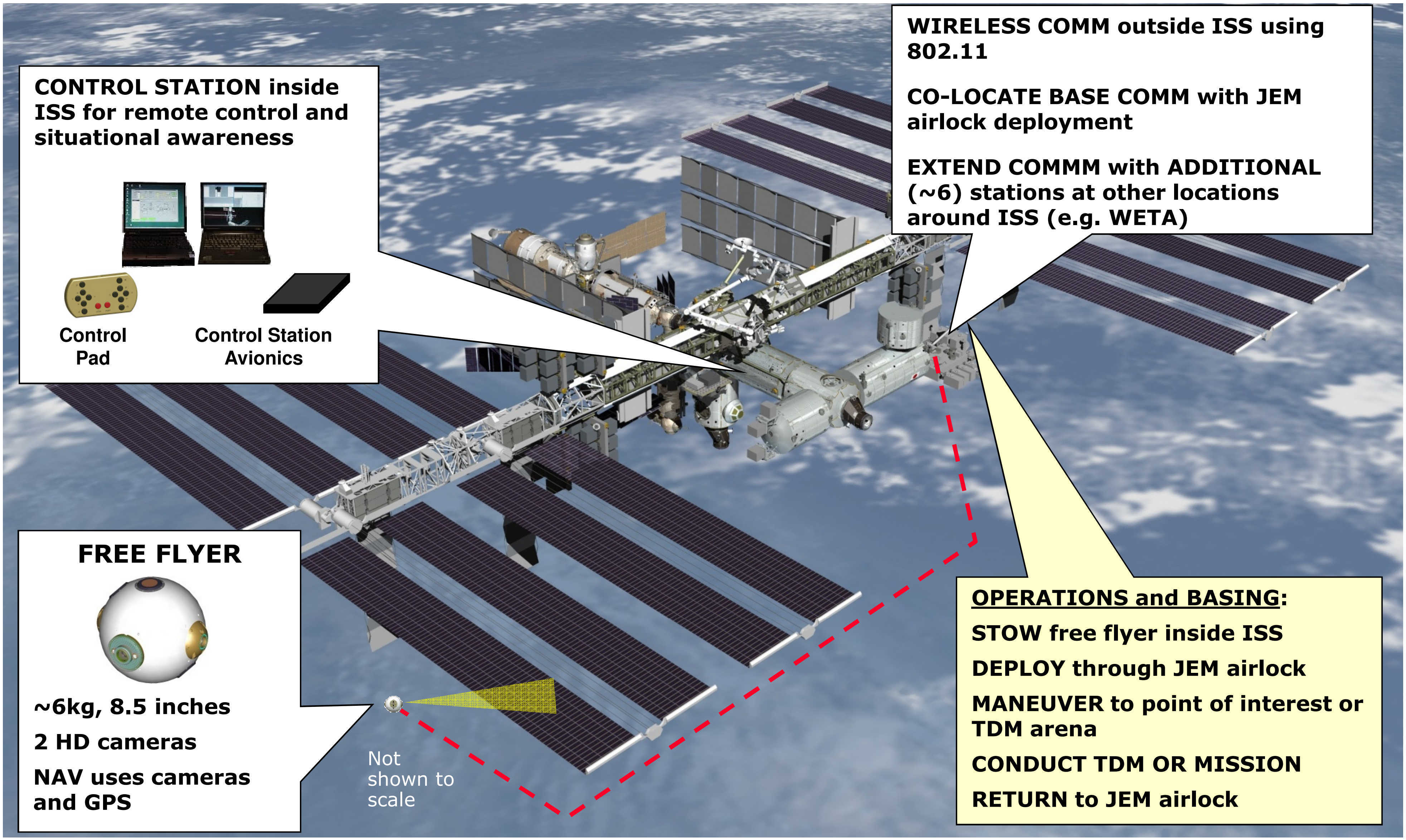


Simulated view of RCC from free flyer inspection camera

Related development and testing continued under other sponsorship

- Avionics processor board firmware development and VxWorks hosting for ETDP AR&D
- DRAGON GPS re-spin and development for University Cubesat application
- Video board assembly and software development using a TI DSP development board and an in-house frame grabber (Co-op project)
- Hangar DVTU/prototype integration for NextFest
- ACVS testing for ETDP AR&D
- Natural Features Identification and Recognition (NFIR) navigation testing for ETDP AR&D – applicable to AERCam navigation beyond GPS range (e.g. lunar orbit)
- Miniature Xenon fluid system integration/operations (CDDF project)

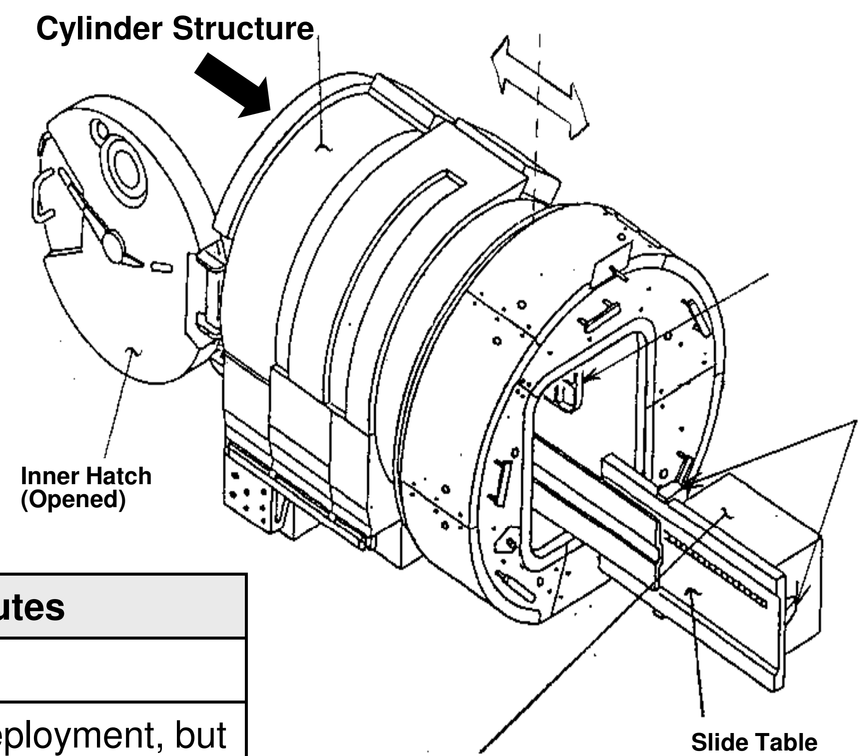
Notional Mini AERCam ISS Integration



ISS Stowage, Deployment, Retrieval, and Reuse Options
JEM Option in Yellow

Stowage / Deployment / Retrieval Options	Attributes
EVA	IVA stowage; requires crew EVA for deployment
Experiment airlock (JEM)	IVA stowage of free flyer; deploy through experiment airlock
Externally based hangar	No crew handling of free flyer during operations; immediate deployment

Use/Re-use Options	Attributes
Single use - disposable	No recovery
Single use between ground servicing	Recover after deployment, but no recharge on-orbit
Multiple use – Manual recharge/refuel on-orbit	Crew manually performs recharge/refuel
Multiple use – Automatic Recharge/refuel on-orbit at permanent hangar	Automatic recharge/refuel after every deployment



JEM Experiment Airlock

Flight Infusion Strategy
Where do Mini AERCam class Free Flyers Fit?

- **Safety design for human spaceflight**
  - Make harmless and prevent uncommanded acceleration
- **Exploit reusability advantages vs. disposable free flyer**
  - Magnetic docking system for multiple sorties with recharge between sorties
    - » AVCS-based precise docking navigation
- **Relative navigation with low integration impact**
  - Use precise GPS for LEO if readily available
  - Otherwise (or in addition) utilize Vision-based Navigation
    - » e.g. JSC Natural Features Image Recognition - NFIR
- **ISS basing for iterative technology demonstration and maturation**
- **Variable level of automation**
  - Teleoperation versus supervised autonomy
  - Role of time-delay for ground-based commanding