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Mini AERCam: A Free-flying Robot for Space Inspection

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The NASA Johnson Space Center Engineering Directorate is developing the Autonomous Extravehicular Robotic Camera (AERCam), a free-flying camera system for remote viewing and inspection of human spacecraft. The AERCam project team is currently developing a miniaturized version of AERCam known as Mini AERCam, a spherical nanosatellite 7.5 inches in diameter. Mini AERCam development builds on the success of AERCam Sprint, a 1997 Space Shuttle flight experiment, by integrating new on-board sensing and processing capabilities while simultaneously reducing volume by 80%. Achieving these productivity-enhancing capabilities in a smaller package depends on aggressive component miniaturization. Technology innovations being incorporated include micro electromechanical system (MEMS) gyros, “camera-on-a-chip” CMOS imagers, rechargeable xenon gas propulsion, rechargeable lithium ion battery, custom avionics based on the PowerPC 740 microprocessor, GPS relative navigation, digital radio frequency communications and tracking, micropatch antennas, digital instrumentation, and dense mechanical packaging. The Mini AERCam free-flyer will initially be integrated into an approximate flight-like configuration for laboratory demonstration on an airbearing table. A pilot-in-the-loop and hardware-in-the-loop simulation to simulate on-orbit navigation and dynamics will complement the airbearing table demonstration. The Mini AERCam lab demonstration is intended to form the basis for future development of an AERCam flight system that provides on-orbit views of the Space Shuttle and International Space Station unobtainable from fixed cameras, cameras on robotic manipulators, or cameras carried by spacewalking crewmembers.

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AERCam Concept

- AERCam = Autonomous Extravehicular Robotic Camera
- Free-flying robotic platform for visual and non-visual sensing in support of human space activities
- Emphasis on "small" and increasingly "intelligent"
- NASA JSC development activities
  - AERCam Sprint ISS Risk Mitigation Experiment (1997)
  - Crew evaluation in JSC Virtual Reality Laboratory to identify pilot aids recommended for an operational AERCam system (1998)
  - AERCam Integrated Ground Demonstration of telepresence and autonomous capabilities for increasing operator productivity (1998)
  - Mini AERCam lab demonstration of enhanced capabilities implemented in miniaturized hardware (2000 - present)

AERCam Roles in Human Space Flight

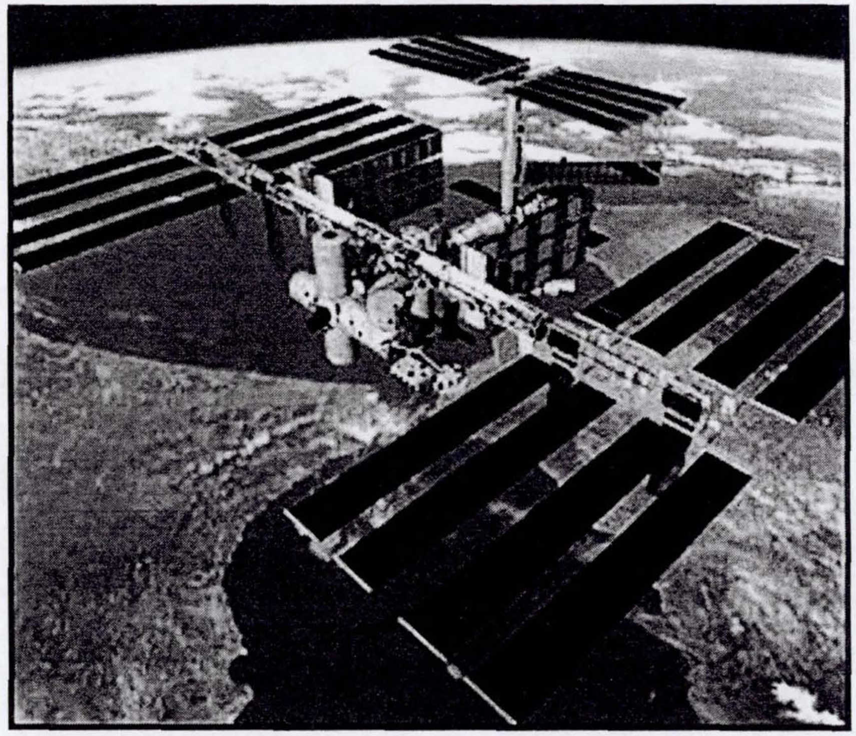
- **Enhance extravehicular activity (EVA) crew productivity**
  - Pre-EVA site reconnaissance
  - Additional camera views for IVA crew and ground controllers during EVA
  - "Flashlight" service for EVA crew
  - Post-EVA site close-out verification
- **Provide better camera views for berthing and maintenance operations**
  - Arbitrary viewing angle and range for improved situational awareness
  - Enhanced control of berthing operations with orthogonal camera views
  - Close-out photography for "as built" configuration documentation

AERCam Roles in Human Space Flight (continued)

- **Provide telepresence inspection**
  - Close-up visual inspection of solar arrays, radiators, etc.
  - Routine autonomous scanning
  - Anomaly detection and reporting
  - Photogrammetry
- **Provide platform for sensor positioning in areas potentially inaccessible to EVA crew**
  - Chemical leak detection
  - Infrared camera (e.g. thermal mapping)
  - ISS plume impingement modeling (manometer)
  - ISS structural model verification (laser vibrometer)

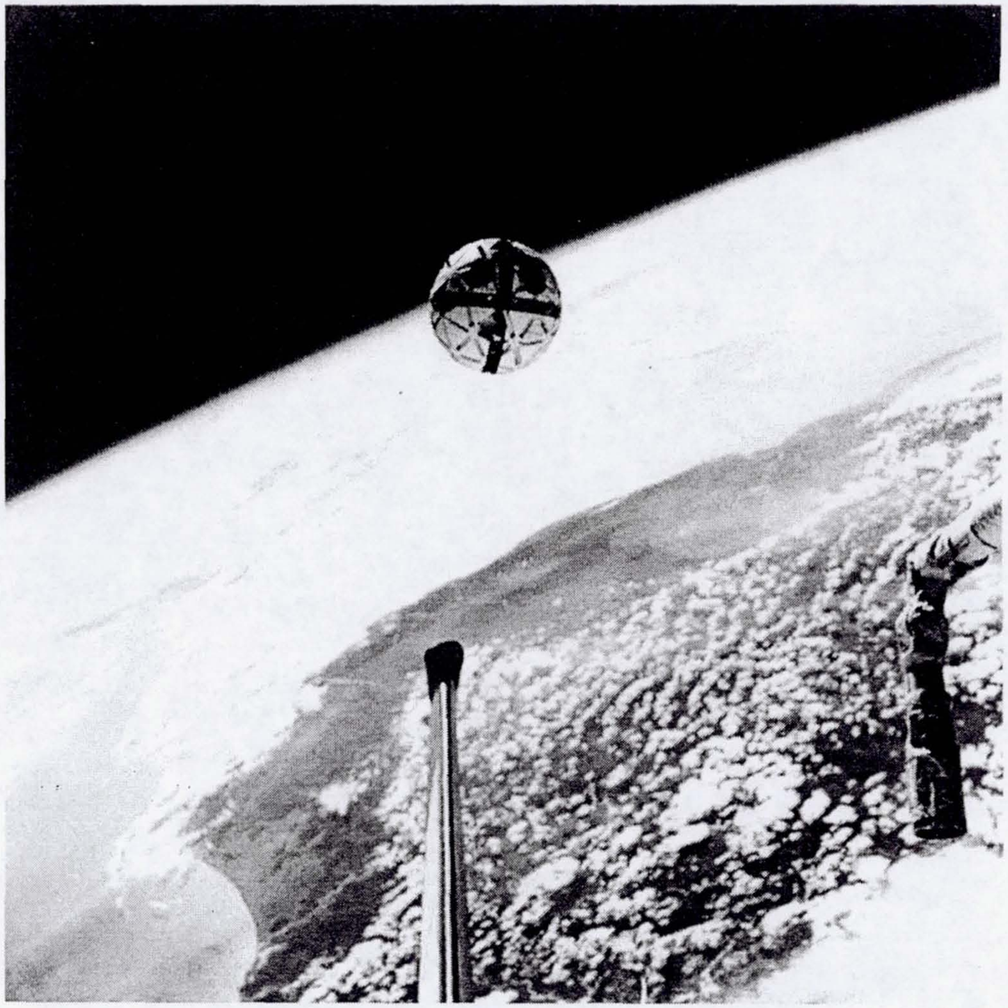
Anticipated AERCam Mission Scenario for ISS

- Mission scenario under either teleoperation or autonomous control:
  - Deploy from home base
  - Maneuver to region of interest while avoiding obstacles
  - Perform desired inspection or viewing
    - » Provide views while stationkeeping
    - » Capture visual mosaic of region for future analysis
    - » Conduct real-time visual or non-visual inspection of region
  - Return to home base
  - Recharge power and propulsion

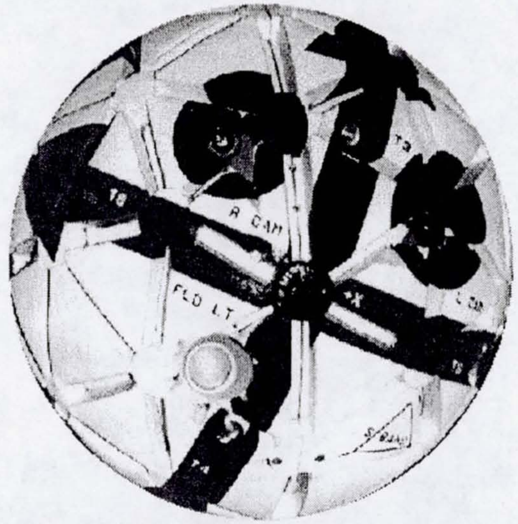


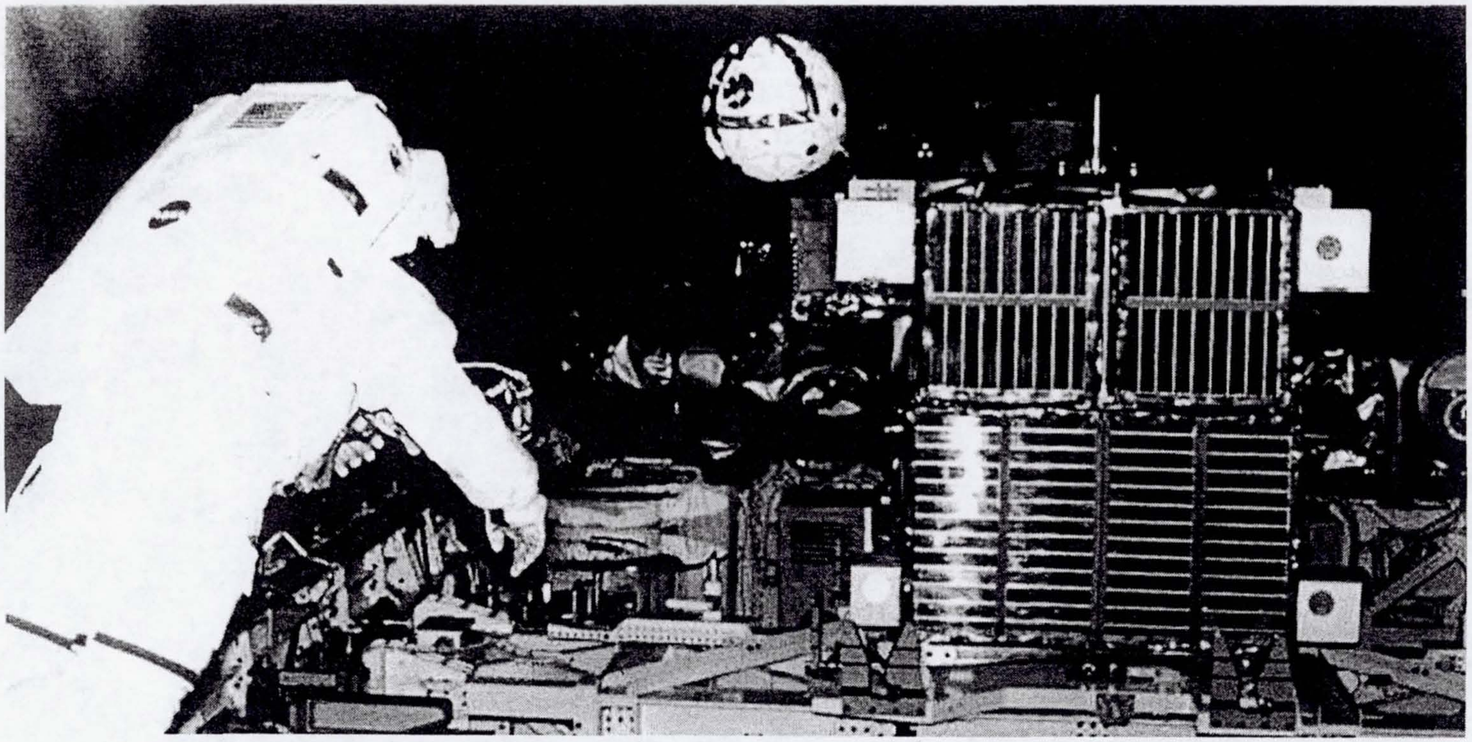
AERCam Sprint

- AERCam Sprint completed a successful ISS Risk Mitigation Experiment (RME) on STS-87 in December 1997
  - Hand launched/retrieved by EVA crew
  - Teleoperated from aft flight deck
  - Proved feasibility of free flyer for inspection
  - 35 pound, 14 inch diameter cushioned sphere
  - Automatic attitude hold capability
  - Single string system with impact energy controls



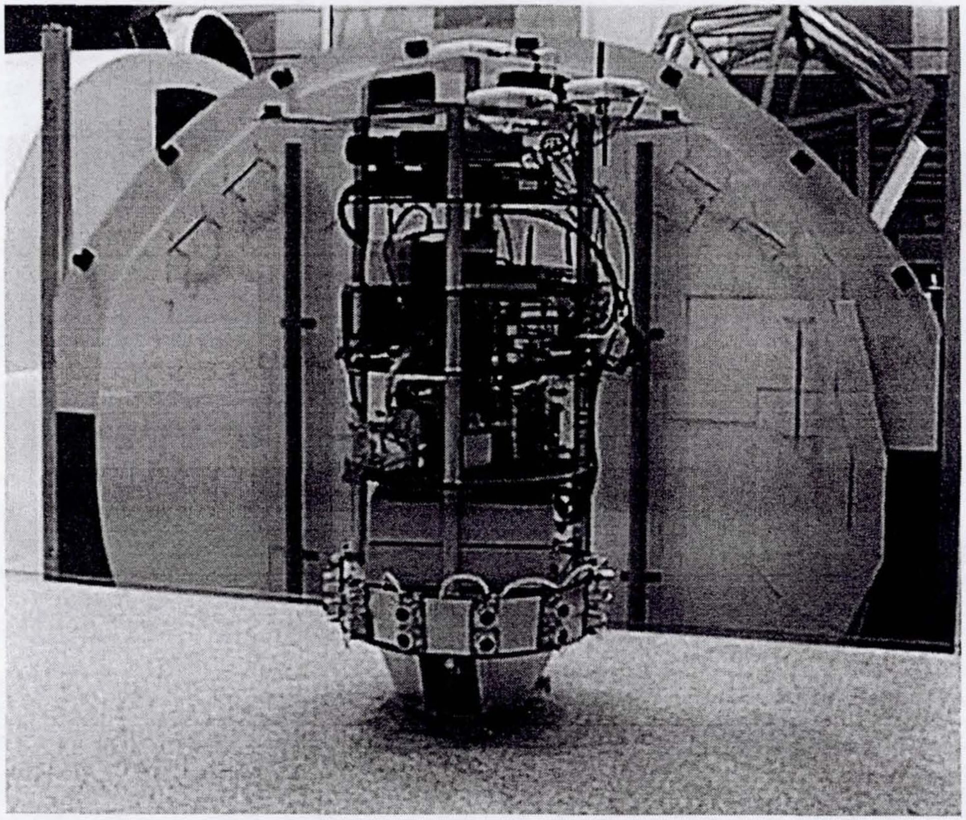
AERCam Sprint





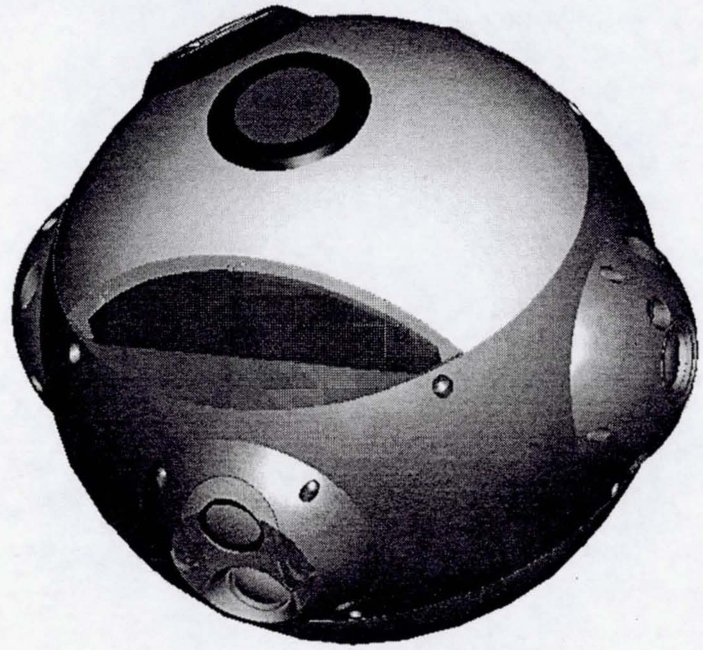
AERCam Integrated Ground Demonstration

- **Configuration**
  - Untethered robot on a granite air bearing table
  - Indoor GPS pseudo-satellites
  - Mockups of Shuttle bulkheads, payload bay obstacles, and space suit
- **Demonstration results**
  - Autonomous point-to-point maneuvering accomplished using differential carrier phase Global Positioning System (GPS) navigation
  - Obstacle avoidance achieved using proximity sensors and a path planner
  - Dynamic object tracking performed using stereo machine vision
  - Advanced inspection techniques demonstrated using an image mosaicking system



Mini AERCam Overview

- **Goal: Develop an enhanced-capability "nanosatellite" AERCam**
  - Miniaturized AERCam Sprint-like free-flying camera system with advanced capabilities on path to operational system
  - ~7.5 inch diameter sphere
    - » ~20% of AERCam Sprint volume



- **Plan: Develop and integrate lab demonstration unit in approximate form, fit, and function of a miniaturized flight configuration**
  - Free-flyer hardware will be demonstrated on an airbearing table
  - On-orbit operational simulation with hardware-in-the-loop testing will complement airbearing table demonstration

Mini AERCam Technologies

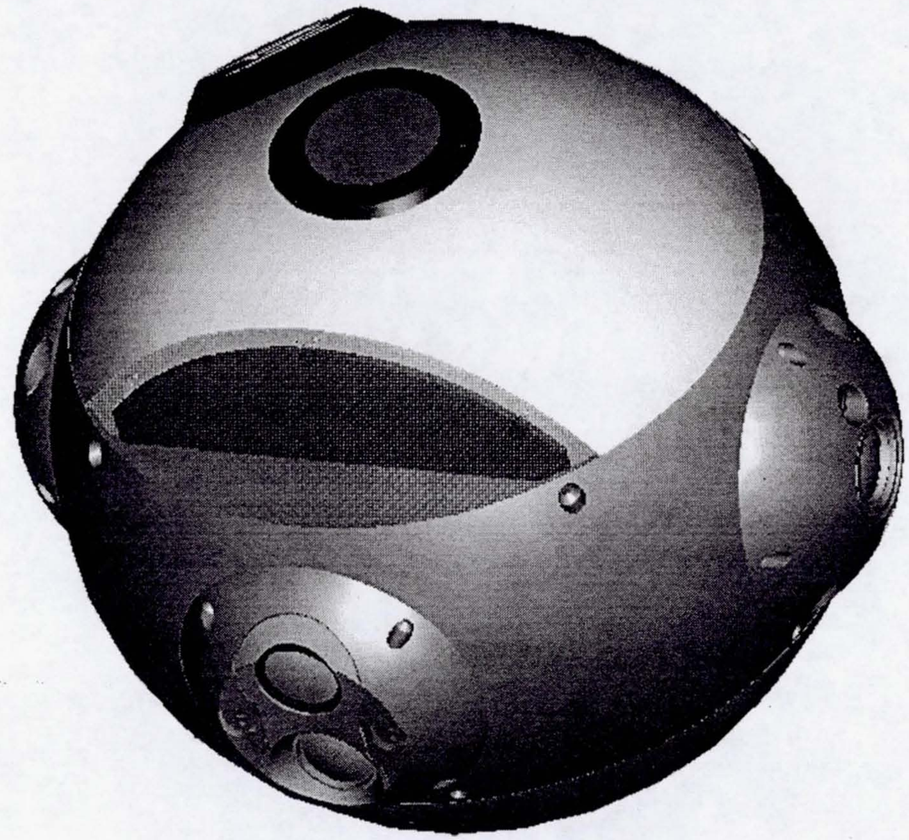
- Rechargeable pressurized xenon gas propulsion system
  - 6 DOF thrusting capability (12 thruster configuration)
  - Compatible with nitrogen for ground operations
- Rechargeable batteries (Li-Ion chemistry)
- CMOS cameras ("Camera on a chip" technology)
- Solid state illumination (LEDs)
- Avionics
  - PowerPC 740 based design
  - High Density Interconnect (HDI) technology
  - MOSIS silicon foundry for further size reduction
  - IIC digital sensor network

Mini AERCam Technical Concept Overview (continued)

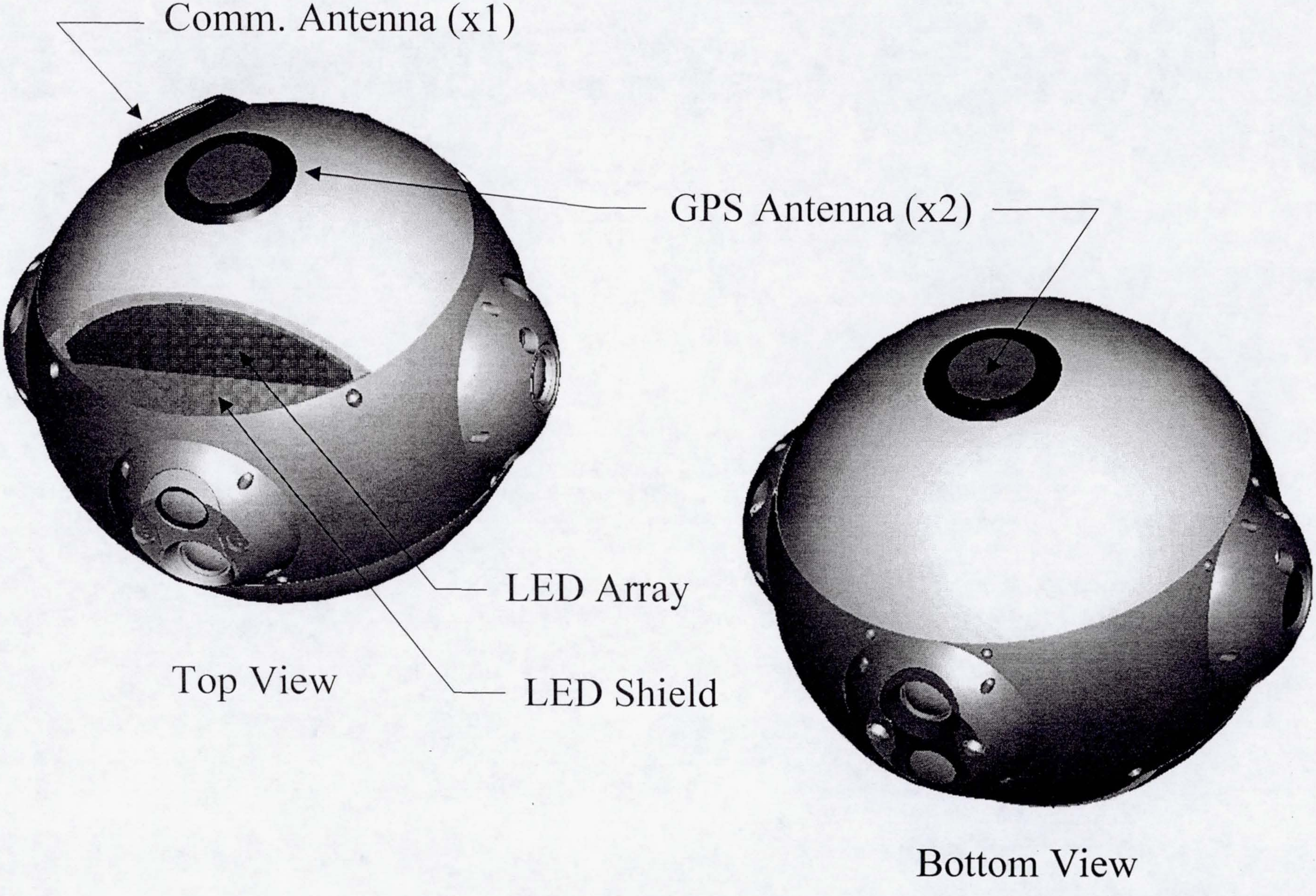
- Communications
  - Digital transceiver for video, commands, and telemetry
  - Integrated RF tracking transmitter for supplemental relative navigation
  - Micro-patch antennas on free-flyer surface for communications and GPS navigation
- GN&C
  - MEMS angular rate gyros for propagated relative attitude
  - Relative navigation via GPS mini-receiver
  - Supplemental relative navigation with RF tracking
  - Pilot aids: AAH, LVLH hold, attitude maneuvers, translation hold, point-to-point guidance

Mini AERCam Packaging Design

- 7.5" Diameter Sphere
- "Central Ring" As Structure Approach
  - Center Ring and Shelf Provide All Structural Strength
  - Two Hemispheres Are Close-out and Protection With Limited Mounting
  - All Propulsion and Power Located on Center Ring and Shelf
- Four Thruster Clusters (12 Thrusters)
- Three Cameras As Payload

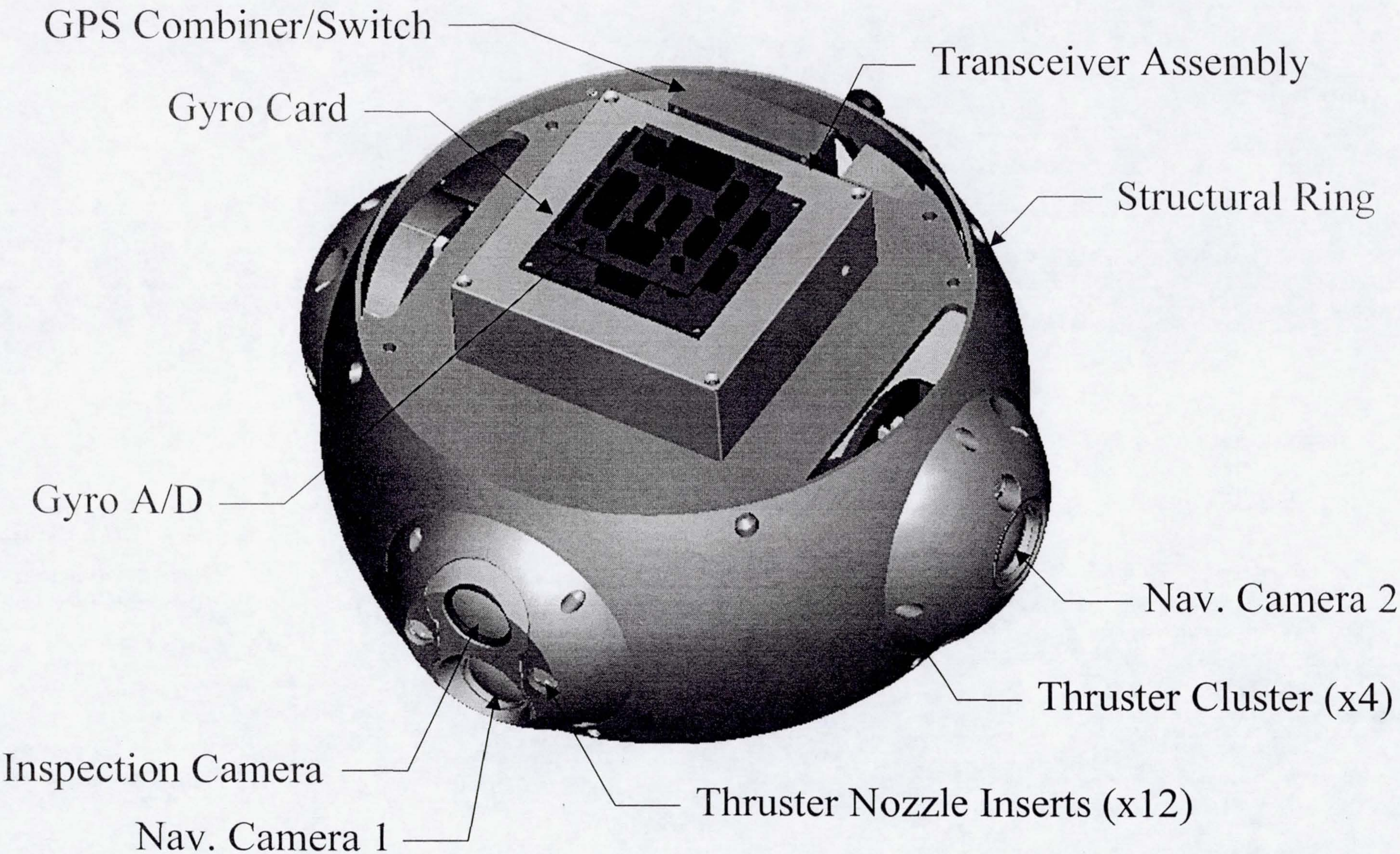


Exterior Component Layout



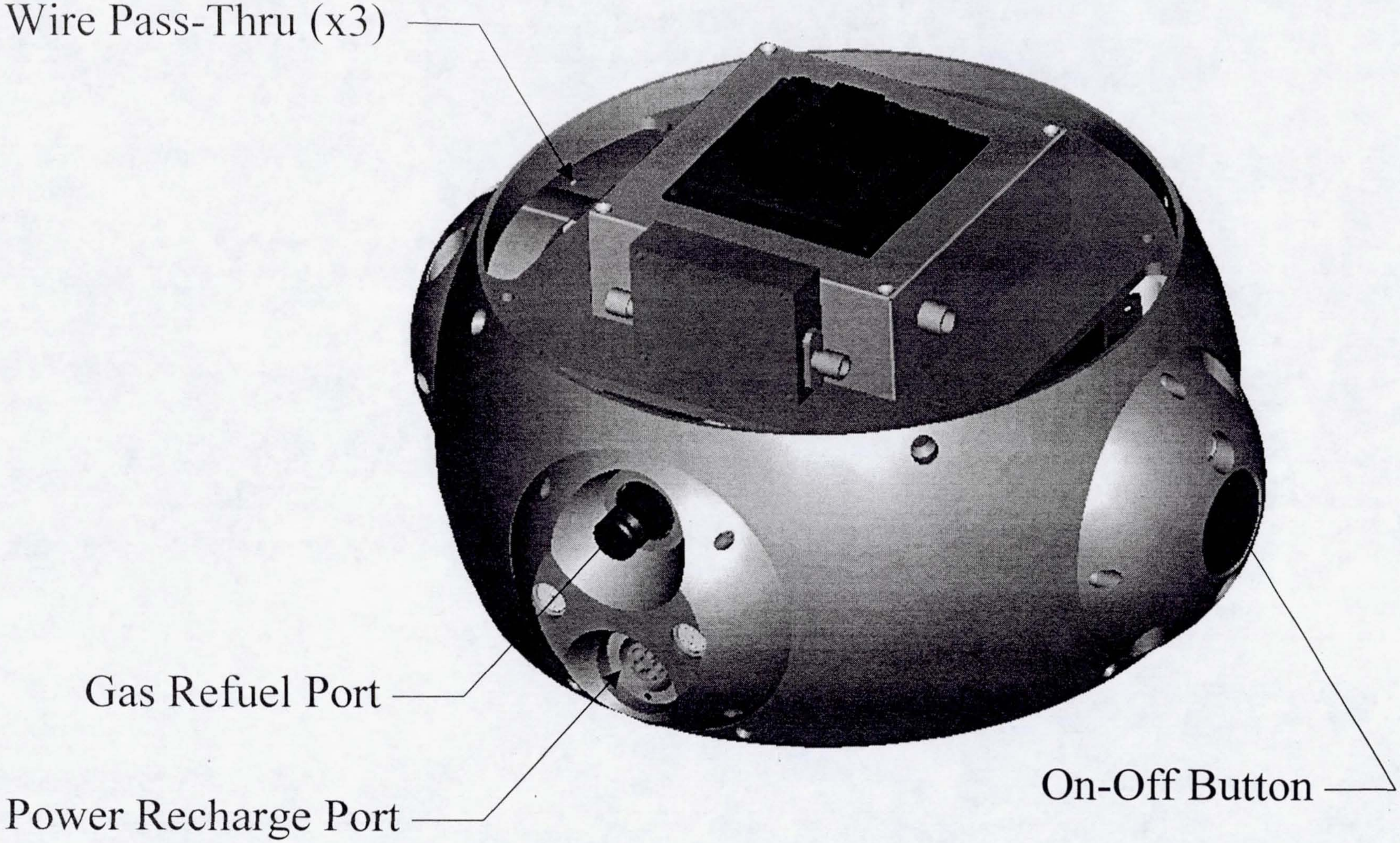
Top Shelf Component Layout

(Front View)

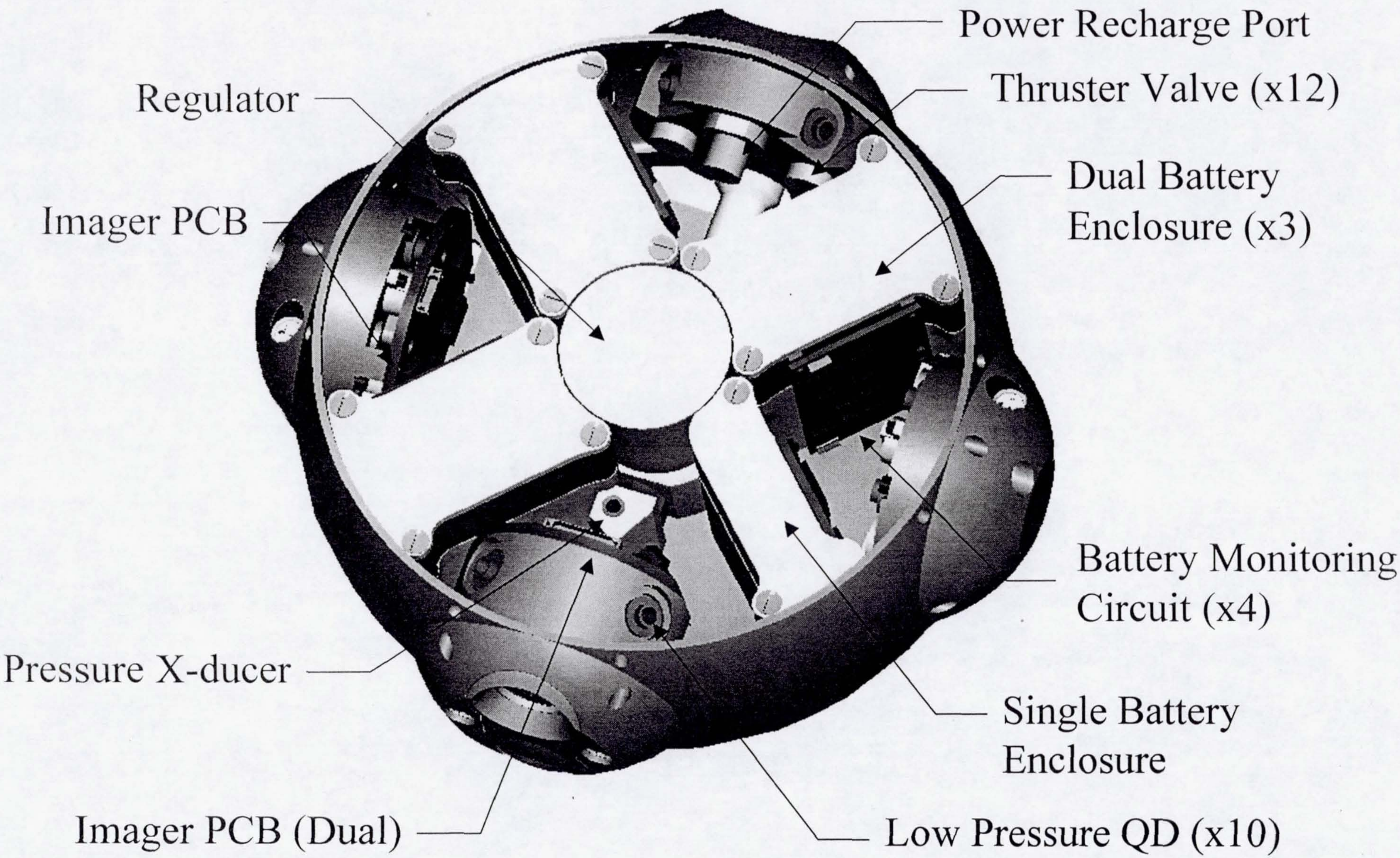


Top Shelf Component Layout

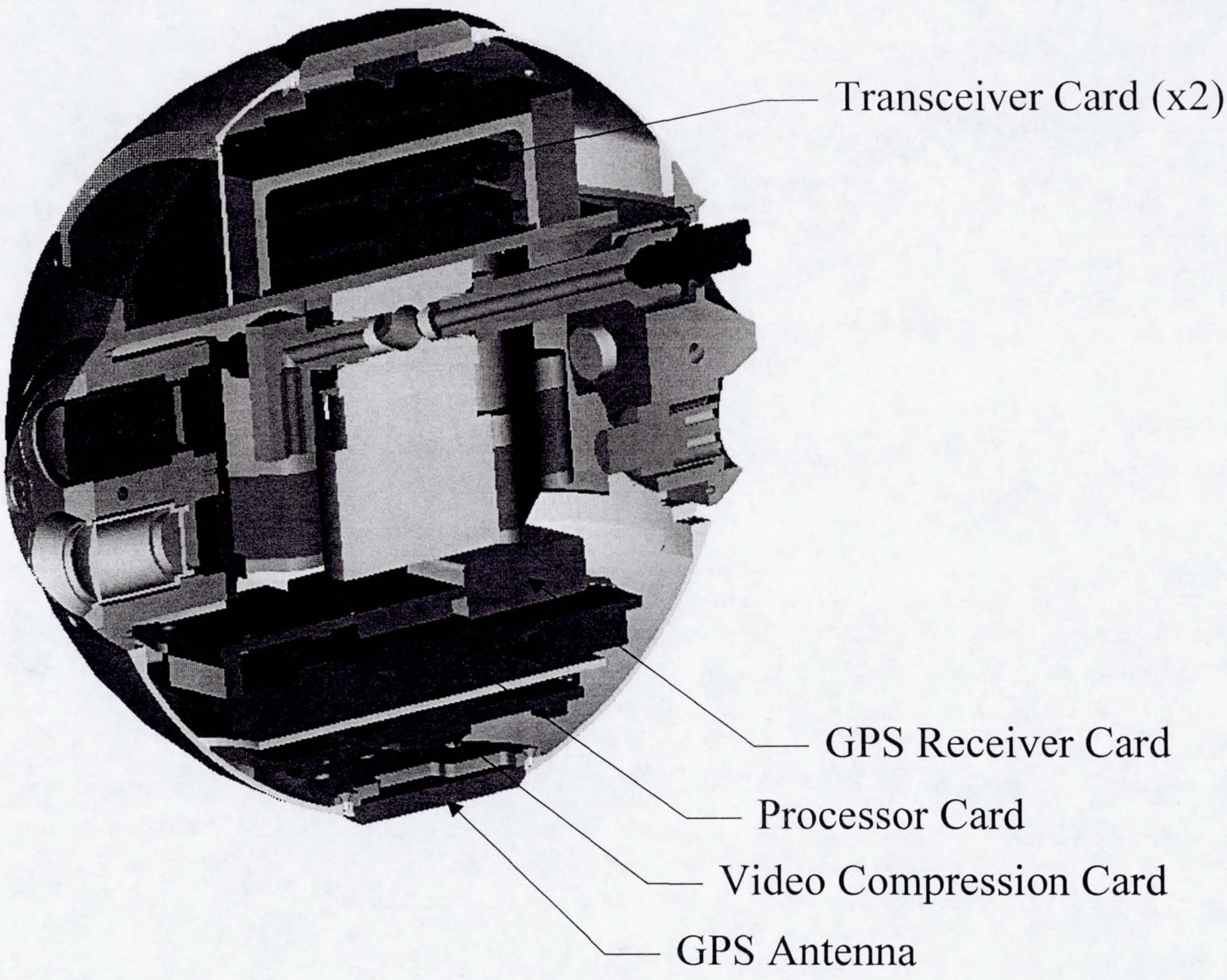
(Reverse View)



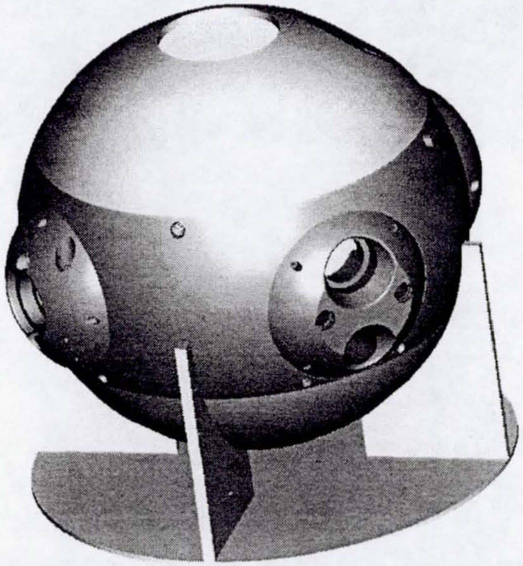
Bottom Shelf Component Layout

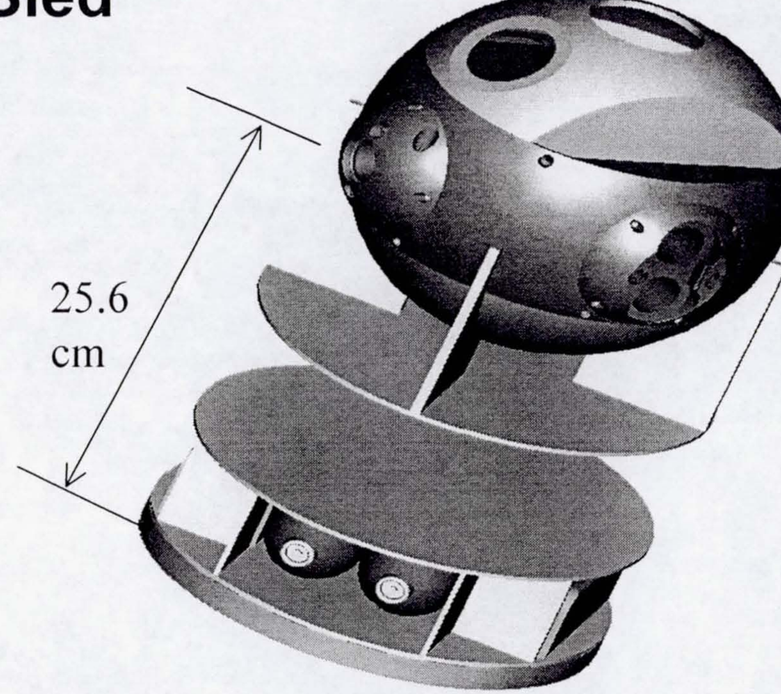


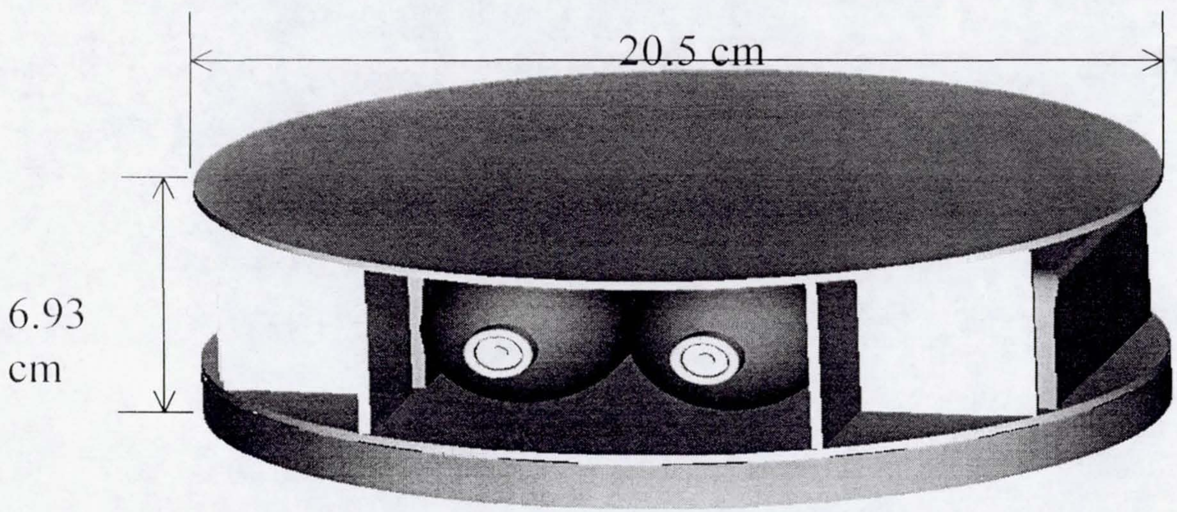
Internal Cross Section

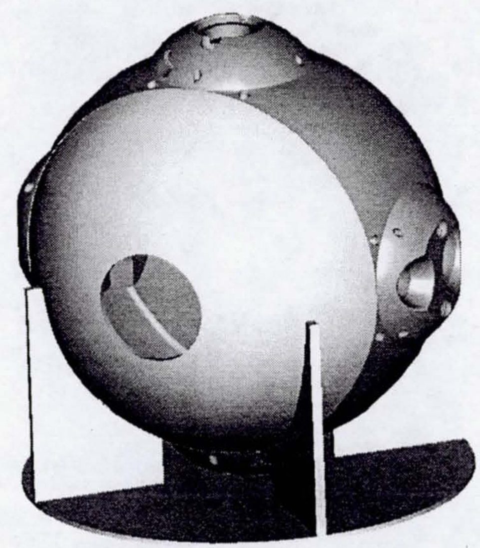


Airbearing Sled

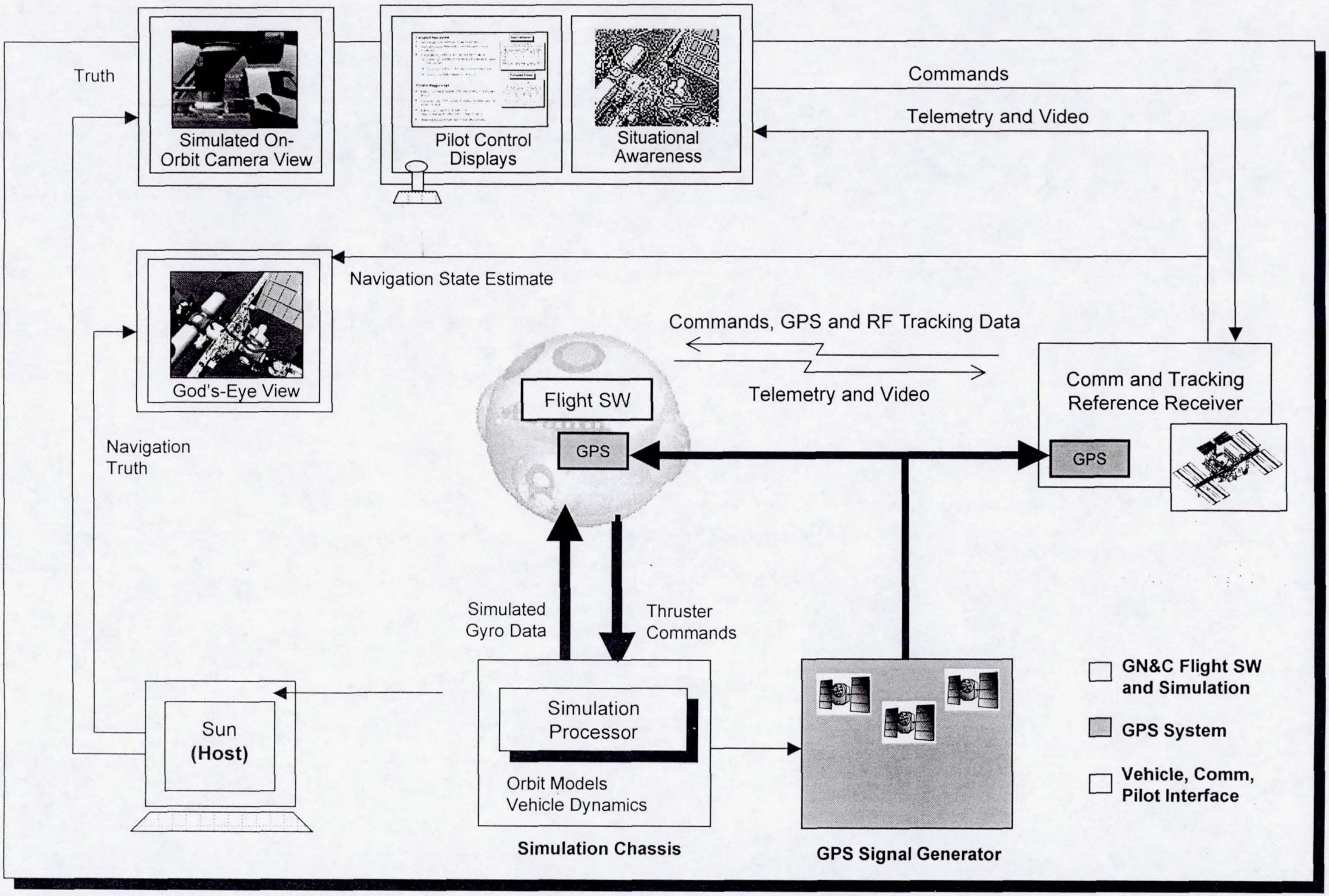








On-Orbit Closed-Loop Simulation with Mini-AERCam Avionics



Conclusion

- AERCam project is making significant progress toward a free-flying inspection capability to assist human space explorers
  - AERCam Sprint ISS Risk Mitigation Experiment proved the viability of a free-flying camera platform
  - VR crew evaluation identified additional pilot aids recommended for an operational AERCam system
  - AERCam Integrated Ground Demonstration developed autonomous capabilities for increasing operator productivity
  - Mini AERCam is miniaturizing free-flyer hardware and implementing enhanced capabilities