NASA Johnson Space Center's
Miniature Autonomous Extravehicular Robotic Camera
(Mini AERCam)

Introduction

Engineers at NASA Johnson Space Center have designed, developed, and tested a nanosatellite-class free-flyer intended for future external inspection and remote viewing of human spaceflight activities. The technology demonstration system, known as the Miniature Autonomous Extravehicular Robotic Camera (Mini AERCam), has been integrated into the approximate form and function of a flight system.

The predecessor to Mini AERCam, called AERCam "Sprint," was flight tested on STS-87 in December 1997. Sprint was released and retrieved in the Space Shuttle Orbiter Payload Bay by astronaut Winston Scott during an extravehicular activity (EVA). Figure 1 shows the retrieval. Astronaut Steve Lindsay controlled the free-flyer using a combination rotational and translational hand controller from inside the Orbiter aft cockpit. Lindsay was able to see Sprint at all times through the Orbiter windows, and also monitored the video on an internal display. The flight test on STS-87 lasted about an hour and fifteen minutes and was highly successful.

Figure 1. AERCam Sprint Retrieval on STS-87

Sprint was approximately fourteen inches in diameter and weighed about thirty-five pounds. The propulsion system consisted of twelve cold gas thrusters with nitrogen as the propellant. Sprint had angular rate gyros for providing angular rate feedback and automatic attitude hold. The video camera could be switched between two focal lengths for a regular or "telephoto" view. A light was available for illumination. Sprint had a soft covering for impact protection.

Following STS-87, a crew evaluation was conducted in JSC's Virtual Reality Laboratory for the purpose of evaluating the suitability of Sprint for use as an operational vehicle outside the International Space Station. The study by nine astronaut participants yielded a set of recommendations for how to improve safety, situational awareness, and handling qualities for a future version of AERCam.

In 2000 Mini AERCam development began with the goal of reducing free-flyer size while simultaneously adding capabilities that would contribute to overall system controllability, reliability, and utility. For situational awareness, it was desired to add an additional camera for an orthogonal view, as well as relative navigation so that crewmembers would know the location of the free-flyer with respect to the very large and complex ISS structure. To improve the handling qualities and reduce crew workload, engineers would incorporate automatic position hold and point-to-point maneuvering. By 2002, a fully functional prototype had been designed, developed, integrated and tested as described below in the following sections.

Figure 2. AERCam Sprint and Mini AERCam

Mini AERCam External Features

The Mini AERCam free-flyer is spherical-shaped and approximately 7.5 inches in diameter. Figure 2 shows a size comparison between AERCam Sprint and Mini AERCam. Mini AERCam achieves its 'nanosatellite' size by a combination of dense packaging and miniaturized components.

Figure 3 highlights some of the external features of the Mini AERCam prototype. Two cameras are aligned with the +X direction of the vehicle. One camera provides NTSC-quality color video, and the other camera can be used for high-resolution still images, when selected. A third color video camera is positioned in the +Y direction for an orthogonal view.

Figure 3. Mini AERCam External Features

The Mini AERCam prototype is designed to have two custom GPS antennas, one on top and one on the bottom. An LED array provides illumination. A communications antenna, not visible in the figure above, is near the top GPS antenna.

Power and Propulsion

As shown in Figure 4, the vehicle is designed with a central ring that houses the power and propulsion system. The batteries are lithium-ion and provide six hours of operational time. The propulsion system is designed for cold-gas xenon, which packs more densely than nitrogen, but is compatible with low-cost nitrogen in the current ground test configuration. Attitude and position control are achieved with the use of twelve thrusters, distributed across four thruster pods around the central ring. The batteries are rechargeable and a port is provided for refueling.
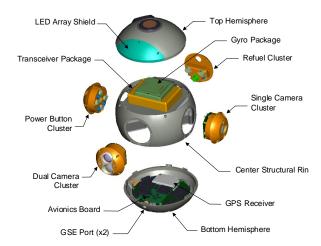

Figure 4. Mini AERCam Exploded View

Navigation

The Mini AERCam navigation system includes a GPS receiver for position and velocity determination, and Draper Micro-Electro-Mechanical System (MEMS) gyros for angular rate sensing. In order to compute precise relative navigation using GPS, the parent vehicle (e.g. the ISS) must also be equipped with a GPS receiver.

The position and velocity are processed in a Kalman filter, and the attitude and attitude rate are processed separately. The navigation system provides data for operator situational awareness, which is important for operations around the complex structure of the ISS. Additionally, precise navigation allows for automated functions such as "Automatic Translation Hold," which is helpful as an operator aid during piloted flight.
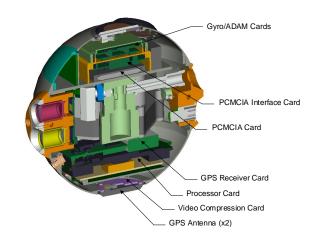

Figure 5. Mini AERCam Cutaway View

Avionics

The Mini AERCam avionics system includes an avionics processor board, a video compression and imaging system, wireless ethernet for communications, and LED illuminators.

The avionics processor board, shown in Figure 6, is a 22-layer board. The board houses a PowerPC 740 which runs at 266 MHz, with 64 Mbytes of RAM. The board includes a field programmable gate array (FPGA) which implements most of the hardware interface functions. Data buses include RS-232, I^{2}C for instrumentation, RS-422, and LVDS.

Figure 6. Avionics Processor Board

The vision subsystem consists of three complementary metal oxide semiconductor (CMOS) imagers, an onboard video compression system, and an off-board video decompression and display system. The video compression system performs wavelet compression in both hardware and custom software. The video is transmitted as part of a single multiplexed data stream.

Operational Interfaces

The vehicle is designed for either remotely piloted operations or supervised autonomous operations. A set of rotational and translational hand controllers are used to operate the vehicle manually. The operator may also input commands through the Control Station, which also displays system status and engineering data. Multiple Mini AERCam camera views are available to the operator. For the ISS application, a Situational Awareness display provides a high fidelity graphical representation of the Mini AERCam location with respect to the ISS. Figure 7 shows the hand controllers and selected displays.

Figure 7. Operator Controls and Displays

Air Bearing Table Test Facility

An air-bearing table test facility is used for hardware and avionics testing. A special sled, illustrated in Figure 8, produces a cushion of air to float the free-flyer on an air-bearing table, which simulates microgravity. The vehicle is then able to translate in two directions and rotate about one axis.
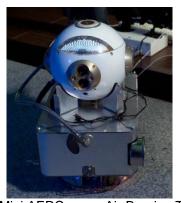

Figure 8. Mini AERCam on Air-Bearing Table Sled

The free-flyer is controlled on the air-bearing table using separate rotational and translational hand controllers and a control station. Live video and images from the free-flyer are provided on two video displays. Engineering data and state information are displayed on the control station. On the air-bearing table, the free-flyer can perform rotational and translational maneuvers, including automatic attitude hold, automatic translation hold, and point-to-point maneuvering. Since GPS is not available inside the laboratory, a commercial-off-the-shelf (COTS) image-based navigation system called Visualeyez is used for position determination.

Orbital Simulation Test Facility

The orbital simulation testbed is designed for testing guidance, navigation, and control capabilities in a high fidelity simulation with much of the Mini AERCam avionics in the loop. The MEMS gyros and thrusters are emulated in hardware, and a high-fidelity GPS signal generator provides realistic Radio Frequency (RF) signals to the GPS receivers.

As on the air-bearing table, the free-flyer is controlled in the orbital simulation using separate rotational and translational hand controllers and a control station. In place of live video, the images as seen from the free-flyer are simulated with high-fidelity graphics. Engineering data and state information are displayed on the control station. In addition, a "God's Eye View" is generated for the Situational Awareness display, which provides the operator with a graphical view of the Mini AERCam location with respect to ISS structure. Figure 9 shows an example scene from the high-fidelity graphics that are used for the orbital simulation.
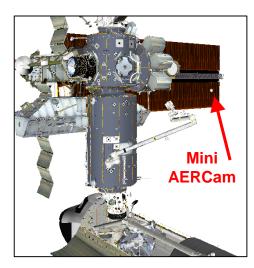

Figure 9. "God's Eye View" for the Orbital Simulation

In the orbital simulation, the free-flyer can perform rotational and translational maneuvers, including automatic attitude hold, automatic translation hold, and point-to-point maneuvering.

Applications

The current Mini AERCam prototype has demonstrated capabilities that can be of significant benefit to NASA's human spaceflight program for external visual inspections of space vehicles. In addition, Mini AERCam can serve as a test platform for evaluating algorithms and

relative navigation for autonomous proximity operations and docking around the Space Shuttle Orbiter or the ISS, or for evaluating candidate sensors and technologies.

In the future, small free-flyers like Mini AERCam may serve many functions around the ISS, such as visual or non-visual inspections, communications relay, or viewing for human and robotic extravehicular activities, both in low earth orbit and during exploration missions.

Quick Facts

A summary of Mini AERCam specifications is provided below.

Size	7.5 inch diameter sphere
Mass	5 kg
Power (avg)	15 Watts (6 hours run time)
Attitude and position control	12 thrusters mounted around central ring
Propellant	Xenon gas (about 40 ft/s delta-V) (nitrogen for ground test vehicle)
Attitude rate sensors	MEMS gyros
Relative position sensors	Precise relative GPS
Avionics processor	Custom built board with PowerPC 740
Instrumentation	I^2C network
Communications	Wireless Ethernet
Lighting	LED array
Video	2 NTSC-quality video cameras (+X and +Y) and a 1 megapixel inspection camera for still images

Table 1. Mini AERCam Fact Sheet

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Last revised: 2/24/02