CIRRIS-1A Space Shuttle Experiment

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This paper describes a Space Shuttle payload designed to measure infrared emissions from upper atmosphere airglow, aurora, and targets of opportunity in support of space defense operations. The payload, Cryogenic Infrared Radiance Instrumentation for Shuttle (CIRRIS-1A), consists of a Michelson interferometer for high-resolution spectral measurements and a dual-focal-plane radiometer with selectable band pass filters for spatial/clutter measurements in the 2.5–25 μm wavelength region. The interferometer and radiometer share the collection optics of a high off-axis-rejection telescope for simultaneous spectral and spatial measurements within the same field of view. The sensor optics and detectors are cooled to liquid helium temperatures to allow measurements of emissions from weak infrared sources in the 60–150 km upper atmosphere. CIRRIS-1A will be launched on STS-39 in early 1991 into a 57-deg inclination circular orbit at an altitude of 260 km.

Introduction

FUTURE space defense systems such as the Space Surveillance and Tracking System (SSTS), Boost Surveillance and Tracking System (BSTS), Space Based Interceptor (SBI), and other weapon systems using infrared sensors must acquire, track, and, if necessary, perform a home-to-kill and kill assessment of threat vehicles. These targets may be in the boost phase, postboost phase, orbiting, or in the re-entry phase of their mission. To be able to detect and track these targets at long ranges and with a cost-effective number of sensor platforms, systems must be able to discriminate the emissions of the targets, i.e., the target signatures, from the emissions produced by atomic and molecular species in the Earth's upper atmosphere. Previous measurements conducted by the U.S. Air Force Geophysics Laboratory,[1] however, have shown that the upper atmosphere is highly dynamic and has spectral and spatial structure that can mask a target signal.

The purpose of CIRRIS-1A (Cryogenic Infrared Radiance Instrumentation for Shuttle) is to duplicate the low-Earth-orbit geometry of a space defense sensor and measure the spectral and spatial infrared characteristics of the 60–150 km altitude atmosphere over a range of latitudes, day/night conditions, and geomagnetic activity (Fig. 1). These data will then be used to update and validate U.S. Air Force atmospheric models, which are used in the design of operational systems.

CIRRIS-1A, along with its shuttle payload support structure and secondary experiments, is designated as AFP-675 on the National Space Transportation System manifest.

This paper describes the CIRRIS-1A mission objectives for airglow, auroral, and target measurements. The design of the interferometer, radiometer, ancillary sensors, pointing system, and a brief overview of on-orbit operations will be given.

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Mission Objectives

The primary objective of the CIRRIS-1A mission is to obtain simultaneous spectral and spatial measurements of atmospheric emissions in the 2.5–25 μm infrared region over an altitude range of 60–150 km. Secondary objectives are to measure targets of opportunity (TOOs), such as low-Earth-orbit satellites passing within the sensor field of view.

Based on the collected data, we hope to address four specific questions related to space defense infrared sensor systems looking at targets in the upper atmosphere[2] (Fig. 2):

1) What are the optimum wavelengths of atmospheric windows for detecting cold body targets, i.e., the system pass bands where the target/background contrasts are maximized?

2) What are the background radiance levels in these window regions, i.e., how far down in the window region can we see the target?

3) What is the spatial structure (clutter) of the background in terms of power spectral densities (PSDs), i.e., frequency distribution of clutter?

4) What are the variabilities of earthlimb emissions as a function of day/night and geomagnetic activity?

In addition, the auroral data will be used to validate and refine nuclear predictive codes that simulate trans- and postnuclear attack effects on operational systems.

To obtain the data, the CIRRIS-1A on-orbit operations include vertical, horizontal, and stare scans of the earthlimb us-

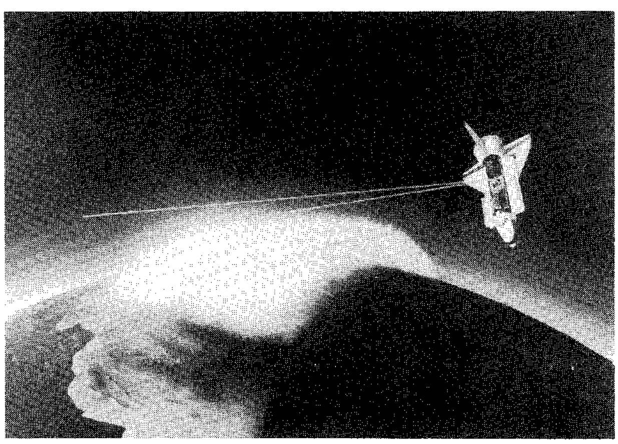

Fig. 1 Artist's concept of CIRRIS-1A measuring upper atmosphere emissions in a Space Shuttle nose down gravity gradient attitude.

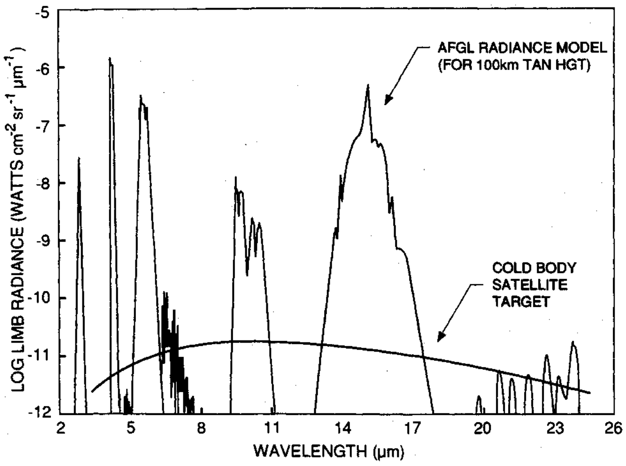

Fig. 2 U.S. Air Force earthlimb model of atmospheric infrared emissions[2] compared with a theoretical 300 K blackbody target.

ing various interferometer, radiometer, filter, and scan pattern combinations. A midlatitude earthlimb scan, for example, may be entirely preprogrammed where the sensor will step through a sequence of look altitudes to provide a vertical atmospheric profile. On the other hand, for transitory observations the shuttle crew will track events such as aurora and TOOs using the CIRRIS-1A manual pointing controller (joystick) while guided by imagery from the low-light-level televisions (coaligned to the CIRRIS-1A telescope) that will be displayed on the aft flight deck closed circuit television system. At the present time, 35 measurement modes are selectable and should provide a tailored capability for each type of phenomenon we expect to measure.

Sensor Design

The CIRRIS-1A payload includes several sensors and subsystems.[3] The primary sensors are a high-resolution Michelson interferometer and a dual channel radiometer that share the common collecting optics of a high off-axis-rejection 0.3-m telescope. The optics, detectors, and preamplifiers are cooled with helium to temperatures of 12 K to maximize the instrument sensitivity to faint infrared sources. Coaligned on the outside of the telescope heat exchanger are two photometers, two low-light level television (LLLTV) cameras, a 16-mm film camera celestial aspect sensor, and an infrared horizon sensor. The entire assembly is mounted on a two-axis-gimbal system to provide pointing and scanning capability. All the sensor and housekeeping data are redundantly recorded on tape recorders for postflight reduction and analysis. The entire payload mass is 2045 kg. Figure 3 is an artist's drawing of the system.

Table 1 CIRRIS-1A sensor specifications

Parameter	Specification
	Interferometer
Spectral sensitivity range	4000–400 cm^{-1}
Detectors	Si:As, five-element array. Detector package includes preamplifiers.
Noise equivalent spectral radiance (NESR) Det 2	2×10^{-13} W cm^{-2} sr^{-1} cm^{-1} at 625 cm^{-1} (8×10^{-12} W cm^{-2} sr^{-1} μm at 16 μm)
Dynamic range	Eight orders considering entire array; Two bias levels; Three electronic gain levels
Focal plane optics	Ritchey-Cretien f/1.6
	Radiometer
Aperture	182 cm^{-2}
Field of view	Focal plane 1 overall: 22.0×3.0 mr; Focal plane 2 overall: 8.5×3.0 mr
Dynamic range	
D/A conversion	6×10^6
Preamplifier	1×10^5 (dual channel gain)
System	1×10^7
Chopper	Tuned fork at 84.6 Hz
	Telescope
Aperture	30.48-cm diam, D-shaped
Image quality	0.5 mr on axis
Throughput	60%
OFV rejection	1×10^{-10} at 2.5 deg

Interferometer

The Michelson interferometer is a flex pivot design with three selectable scan lengths that provide spectral resolutions of 1, 4, and 8 cm^{-1} with moving mirror scan times of 9.7, 2.7, and 1.5 s, respectively. The focal plane is an impurity band conduction (IBC) type silicon doped arsenic (Si:As) with five detector elements designed for various measurement scenarios and resolutions (Fig. 4). An eight-element filter wheel is used to reduce photon noise in selected band passes (Fig. 5) by minimizing out-of-band radiation. Built into the interferometer is an auto-alignment mechanism that allows on-orbit alignment of the interferometer optics should they become misaligned from forces encountered during launch. The interferometer is shown in Fig. 6.

Radiometer

The second primary sensor is a two-channel radiometer with a dichroic beamsplitter. One focal plane contains nine detec-

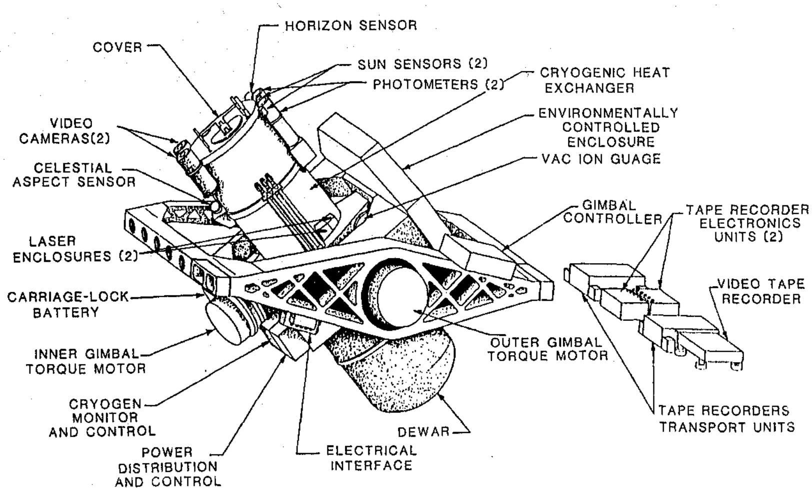

Fig. 3 CIRRIS-1A payload.

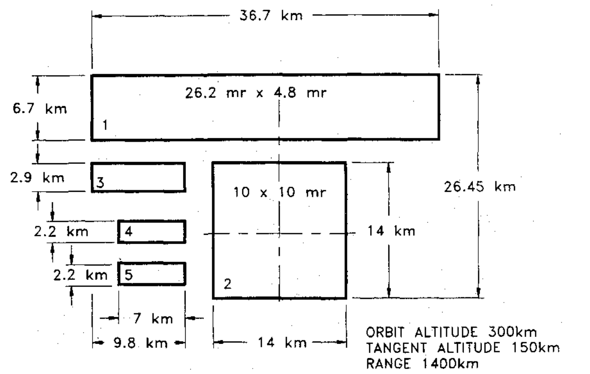

Fig. 4 Interferometer focal plane configuration showing angular subtense and tangent point spatial extent.

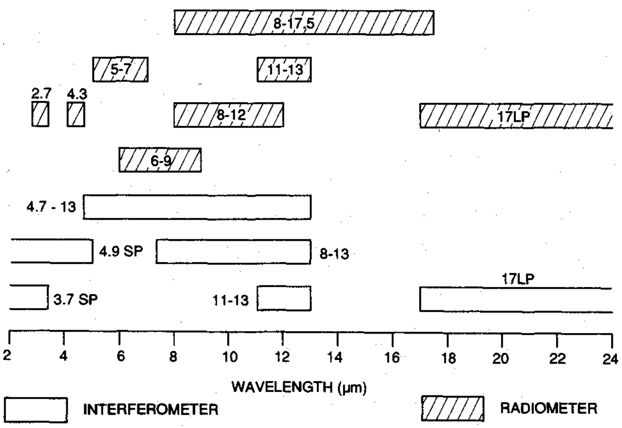

Fig. 5 Interferometer and radiometer filter band passes.

tors, Si:As, behind an eight-position filter wheel. The second focal plane has five detectors, Bi:As, which are geometrically identical to a subset of the nine detectors on the first focal plane, as shown in Fig. 7.

Radiation reaching the second focal plane passes through a fixed wavelength 2.7-μm band pass filter that acts as a constant reference channel for comparison with the eight selectable band pass filters used for the nine-element focal plane. This two-channel design allows simultaneous radiometric measurements in two wavelength regions, i.e., auroral emissions at 2.7 μm. The radiometer filter wavelengths are shown in Fig. 5. Both of the focal planes are coaligned with the interferometer focal plane. A combination of detector sizes, bias levels, and signal conditioning electronics makes the radiometer sensitive over a wide dynamic range; it is capable of measuring zodiacal light, earthlimb emissions, and hard Earth emissions.

Figure 8 shows the interferometer and radiometer responsivities in terms of noise equivalent spectral response (NESR) relative to the signal intensities from atmospheric radiation. Table 1 gives the sensor specifications. A system schematic of the radiometer, interferometer, and telescope is shown in Fig. 9.

Photometers

The externally mounted photometers are band pass filtered to detect visible and ultraviolet radiation at 5577 and 3914 Å. The 5577-Å photometer acts as both an auroral and airglow monitor for atomic oxygen ^1S-^1D emission while the 3914-Å channel monitors the nitrogen ion, N_2^+ (0-0) band that serves as a monitor for electron deposition into the upper atmosphere, such as in an auroral event. In addition, both photometers have sun sensors to warn the crew that the sun is approaching a restricted field of view for the infrared telescope.

Low-Light-Level Televisions

The low-light-level television cameras allow the shuttle crew to point the CIRRIS-1A at aurora and other targets of interest. One camera has a wide-angle field of view and the other has a narrow field of view slightly larger than the total field of view of the interferometer and radiometer. During operations the crew selects one of the camera outputs for display on the orbiter aft flight deck closed circuit television screens and can use that display to point the sensor using a joystick controller.

Celestial Aspect Sensor

The celestial aspect sensor is a 16-mm film camera mounted such that its field of view is 45 deg from that of the telescope. In this orientation, it records the star field while the CIRRIS-

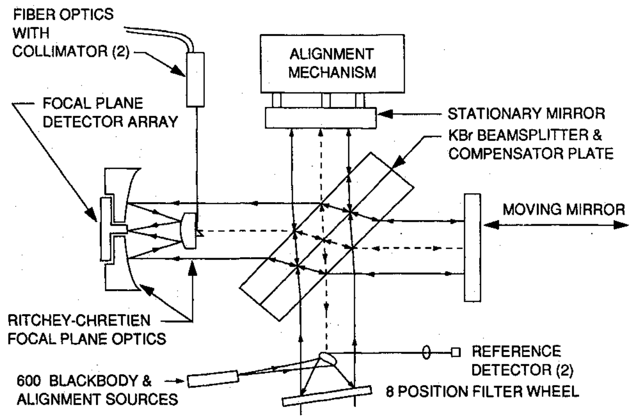

Fig. 6 Interferometer configuration.

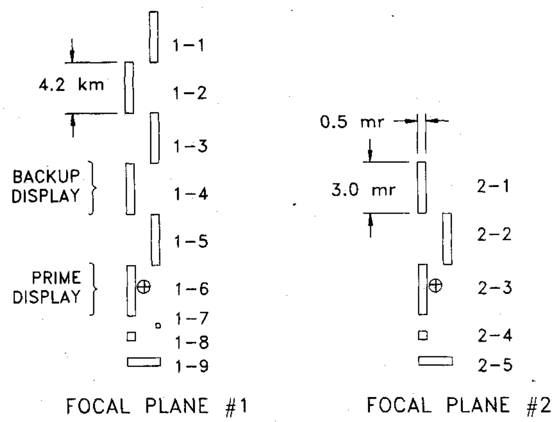

Fig. 7 Radiometer focal plane 1 and 2 configuration.

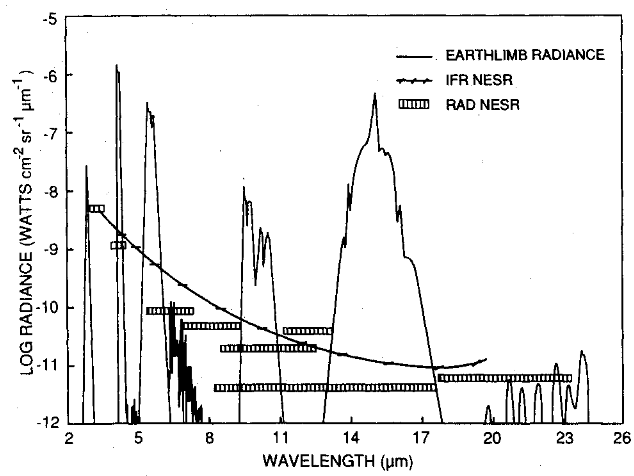

Fig. 8 Interferometer and radiometer responsivities relative to earthlimb emissions.

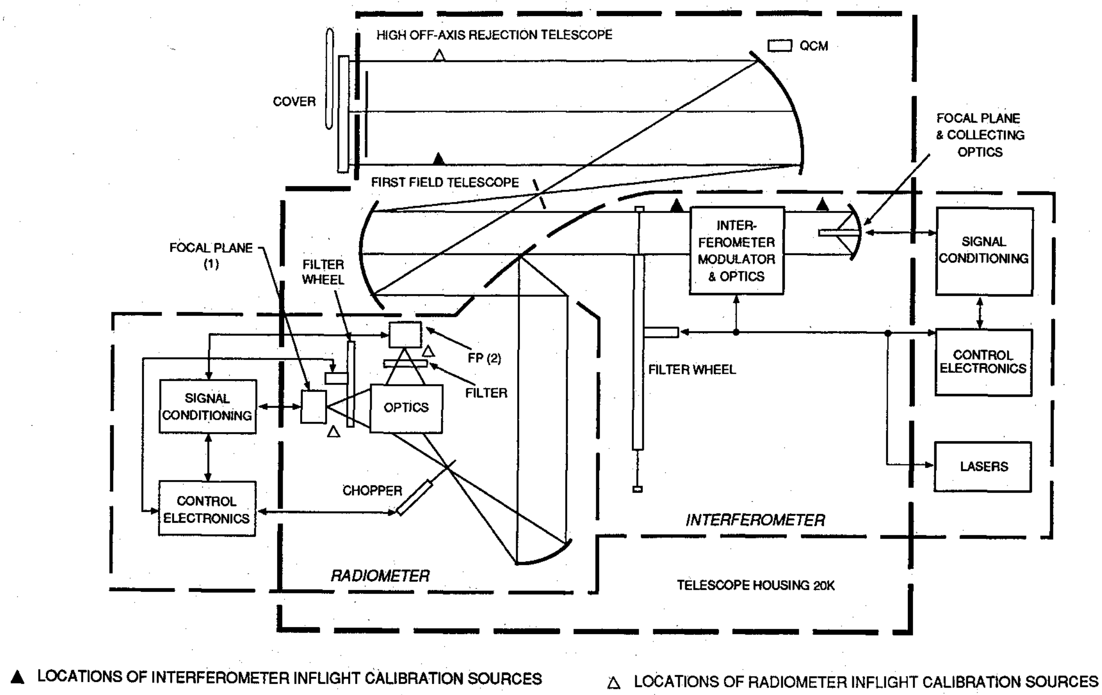

Fig. 9 Telescope, interferometer, and radiometer configuration.

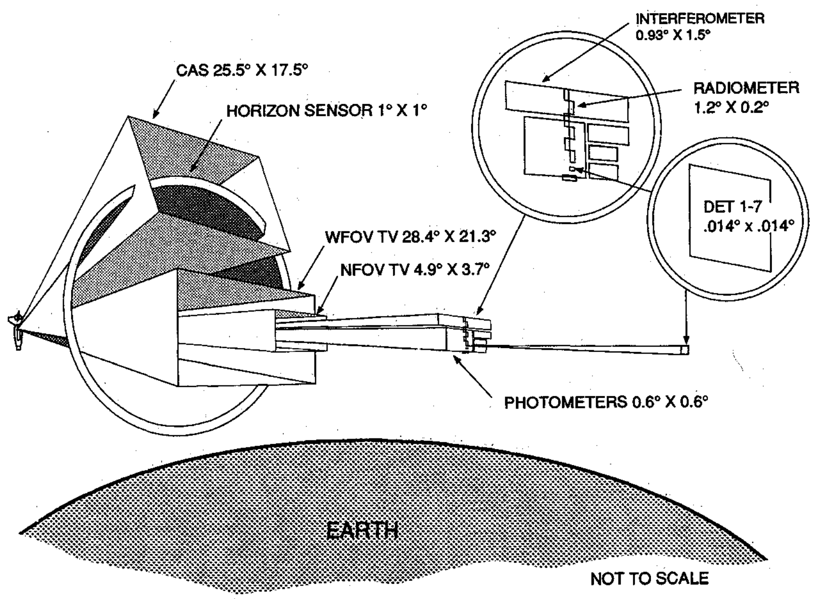

Fig. 10 Field of views for infrared and ancillary sensors.

1A collects earthlimb data. Postflight data reduction of the film in conjunction with the orbiter ephemeris information will determine where the instrument was pointing at a given time. The camera will also play a role in contamination analysis by photographing sunlit particles in the vicinity of the shuttle cargo bay.

Horizon Sensor

The horizon sensor operates at a wavelength of 15 μm and detects CO_2 at an altitude of 40 km. By sensing pitch and yaw angles relative to this emission source, the horizon sensor provides real time data on sensor pitch and yaw to the crew. The gimbal controller also receives this data in certain scan modes, where it is important to maintain a constant pitch angle with respect to the horizon, i.e., tangent altitude.

The combined field of views of all the sensors are shown in Fig. 10.

Pointing System

The pointing system is a two-axis system that rotates the CIRRIS-1A sensor in the orbiter pitch and roll planes in response to commands from either the CIRRIS-1A avionics, the orbiter aft flight deck command and monitor panel, or the crew-held joystick as various mission modes require. Main system elements include the gimbal frames proper, drive and brake elements, and control electronics. Table 2 lists the gimbal specifications.

The gimbal proper consists of two nested structural frames. The outer frame is rigidly attached to the shuttle experiment support system (ESS) at four points. Suspended from the fore and aft beams of this outer frame is an inner frame that rotates about an axis parallel to the orbiter's roll axis, enabling the instrument to sweep through an angle of ± 38 deg from top dead center in the roll plane. The CIRRIS-1A instrument itself is suspended in turn from the inner frame about an axis

Table 2 CIRRIS-1A gimbal system specifications

Parameter	Specification
	General
Capacity	715-kg_m instrument
Design goal positional accuracy	±0.167 deg
Excursion limits	
Inner gimbal	+6 deg (aft) to −24.5 deg (forward)
Outer gimbal	±38 deg (roll)
Slew rate limits	0.07 deg/s to 5.0 deg/s
Operating temperatures	253–333 K
Power drive requirements	
Maximum	852 W (Joystick mode)
Minimum	61 W
Average	75 W
Total gimbal mass	930 kg
	Mechanical
Frame assembly structure	Nested frames
Construction type	Box beam and truss
Material	6061-T6 aluminum alloy
Joint type	Threaded fasteners; no rivets
Drive/brake modules	
Drive type	Direct drive, DC torque motors
Brake type	Direct drive, fail safe
Position reference	16-bit optical shaft recorder
Rate reference	Low-ripple/friction tachometer
	Controller board configuration
CPU board	Z8002 Microprocessor 8K word EPROM Clock driver (2.4576 MHz)

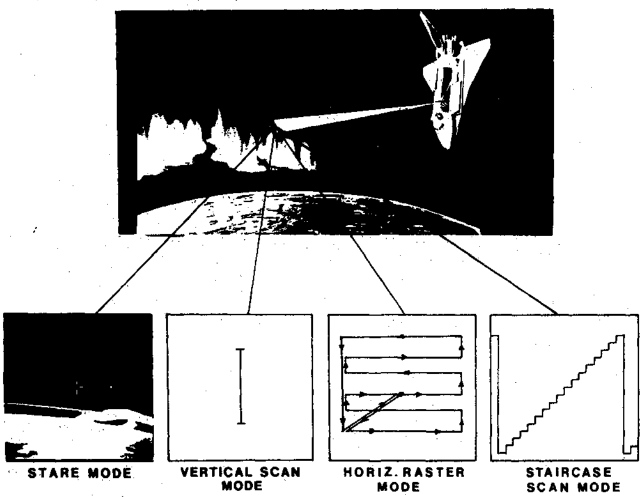

Fig. 11 Typical scan patterns.

parallel to the orbiter's pitch axis through a sweep of +6 deg (aft) to −24.5 deg (forward) from top dead center in the pitch plane.

Two identical drive brake modules, responding to commands from the gimbal system controller, move the sensor through various scan patterns. Each module contains, in addition to the driving torque motor, a 16-bit optical shaft encoder to provide position information, a tachometer to measure rotation rate, and a fail-safe brake.

The final element of the gimbal system is the controller that directs and monitors all gimbal operations in response from the CIRRIS-1A avionics or to commands from the aft flight deck.

Flight Operations

CIRRIS-1A will be launched from Kennedy Space Center (KSC) on board STS-39 (OV-103) into a 260-km circular orbit at an inclination of 57 deg. The mission is scheduled for eight days. To prevent contamination of the telescope's cryogenic surfaces, especially the primary mirror, cover-open measurements will not start until after approximately 24 h on orbit. This should allow the gaseous and particulate contamination inherent with the Space Shuttle to outgas and disperse down to acceptable levels. The crew, using a command and monitor panel in the aft flight deck, will initiate all measurement sequences. After performing initial health and status checks, and realignment of the interferometer mirror, if necessary, the crew will start the auroral, airglow, targets, and calibration measurements. The CIRRIS-1A tape recorders can hold 32 h of data and there is no down-link telemetry to the ground. Typical measurement scenarios are shown in Fig. 11, and a complete list of the measurement modes is given in Table 3. Most of the modes require the orbiter to maintain a nose-down gravity gradient attitude that provides a fairly stable pointing platform without the use of attitude control thrusters. In fact, it is critical that all thruster, flash evaporators, water dumps, purges, etc., be inhibited to prevent irrecoverable damage to the sensor from deposition of contaminants onto the primary mirror.

Because auroral measurements are a high priority, the crew will maintain an auroral watch, and when a bright auroral event is within sensor range, they will initiate an auroral measurement mode. They will use the LLLTVs and joystick controller to center the CIRRIS-1A on the aurora and then start one of the stare, vertical, raster, horizontal, or staircase scans. An auroral and TOO watch will be maintained by ground personnel at various facilities around the world. A voice link with the crew will alert them to measurement events of interest.

During nonauroral and TOO times, preprogrammed earth-limb and calibration measurements will be conducted, as well as operations of other payloads on board this mission.

Table 3 CIRRIS-1A measurement modes

Mode number	Mode title	Run time, min
0	Sequencer idle	0.00
1-1A	Auroral stare	2.89
2-2A	Auroral staircase 1–3	3.90
3-3A	Auroral staircase 4–7	3.90
4	Auroral vertical scan	3.20
5	Auroral horizontal raster 1–2	4.80
6	Auroral horizontal raster 3–4	4.77
7	Auroral horizontal raster 5–7	3.97
8	Auroral staircase scan 1	16.10
9	Auroral staircase scan 2	16.10
10	Auroral staircase scan 3	16.10
11	Auroral staircase scan 4	16.10
12	Auroral staircase scan 5	16.10
13	Auroral staircase scan 6	16.10
14	Auroral staircase scan 7	16.10
15	Fast staircase scan	17.90
16	Low-altitude staircase scan	10.48
17	Airglow vertical scan	7.08
18	Terminator vertical scan	2.65
19	True vertical staircase	17.22
20	True vertical scan	16.35
21	Horizontal stare	100.48
22	Horizontal stare with feedback	100.48
23	Cover open	0.45
23A	Cover closed	0.45
24	Terminator stare	14.00
25	Celestial calibration IFR (high)	2.17
26	Celestial calibration IFR (low)	4.25
27	Celestial calibration RAD	4.20
28-28A	Auroral moving target	2.85
29	Ground target	4.50
30	Internal calibration	11.03
31-31A	Mini-calibration	3.18
32	Auto-alignment	6.00
33	Target dither	0.95
34-34A	Airglow staircase 1–3	12.90
35-35A	Airglow staircase 4–7	12.90

Summary

CIRRIS-1A is an atmospheric measurement experiment designed to obtain simultaneous spectral and spatial infrared measurements on a variety of upper atmospheric phenomena. A state-of-the-art cryogenic infrared telescope/interferometer/radiometer and ancillary sensors will gather 32 h of data on aurora, airglow, and targets from a high-inclination Space Shuttle orbit. These data will provide a comprehensive update and validation of upper atmospheric models for both the scientific and military community. Results will contribute to the understanding of atmospheric infrared radiative mechanisms and to the design and operation of space defense systems.

Acknowledgments

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References

[1]Jursa, A. S., "Handbook of Geophysics and the Space Environment," Air Force Geophysics Lab., Air Force Systems Command, U.S. Air Force, Hanscom AFB, MA, 1985, pp. 18-1–18-80.

[2]Degges, T. C., and Smith, H. J. P., "A High Altitude Infrared Radiance Model," AFGL-TR-0271, Air Force Geophysics Lab., Air Force Systems Command, U.S. Air Force, Hanscom AFB, MA, 1977.

[3]Burt, D. A., and Gordon, T. J., "CIRRIS-1A Critical Design Review: April 1983," AFGL-TR-84-0067, Air Force Geophysics Lab., Air Force Systems Command, U.S. Air Force, Hanscom AFB, MA, 1984.

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