

FINAL

# Optomechanical Design of Ten Modular Cameras for the Mars Exploration Rovers

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## ABSTRACT

The 2003 mission to Mars includes two Rovers, which will land on the Martian surface. Each Rover carries 9 cameras of 4 different designs. In addition, one similar camera is mounted to each lander assembly to monitor the descent and provide information for firing the control jets during landing. This paper will discuss the mechanical systems design of the cameras, including fabrication tolerances of the lenses, thermal issues, radiation shielding, planetary protection, detector mounting, electronics, the modularity achieved, and how the 10 different locations were accommodated on the very tight real estate of the Rovers and Landers.

## 1. BACKGROUND

Both rovers are identical with mission plans for landing in different locations on the Martian surface to explore different terrains. The complement of camera types on each lander are: three science cameras - two Panoramic Cameras and one Microscopic Imager; and seven engineering cameras - two Navigation Cameras, four Hazard Cameras, and one Descent Camera - for a total of five types of cameras. The Descent Camera is very similar to the Navigation Camera, differing only in the filtering in the front of the lens. The rover cameras are located as shown in Figure 1. All cameras were to be modular - to have identical housings, detectors and electronics, with five unique lens assemblies for each of the five camera types.

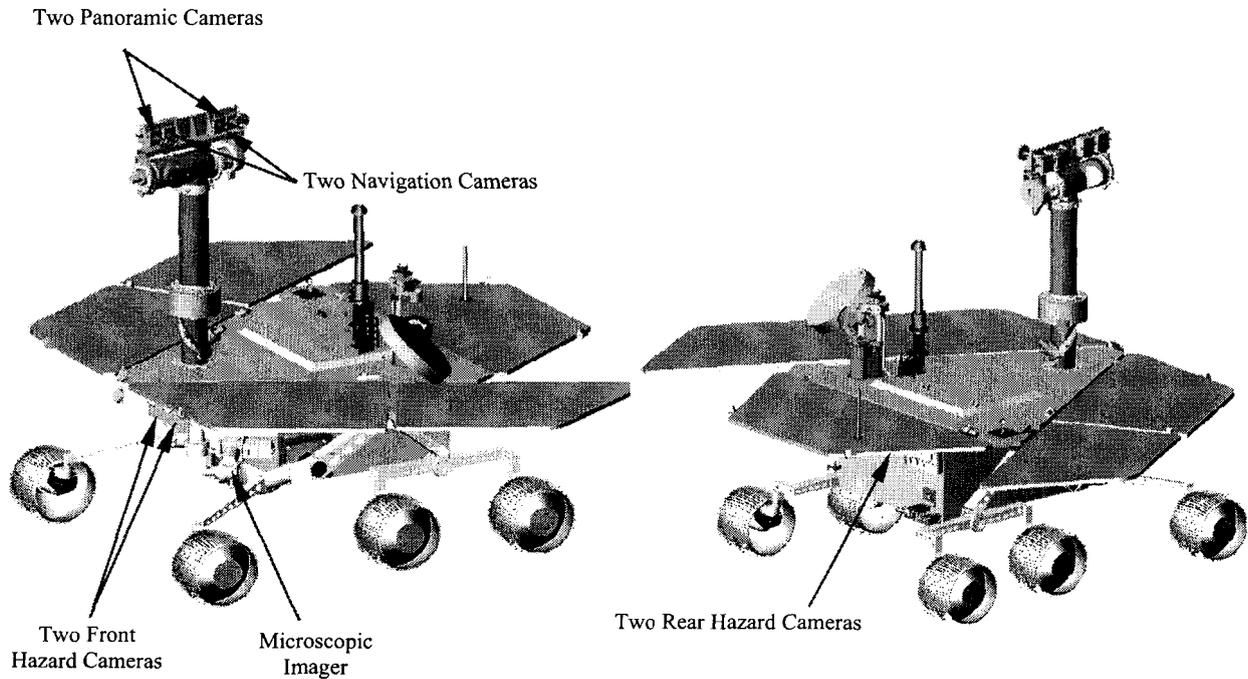


Figure 1. Rover with Cameras

## 2. CAMERA DESIGN

The cameras had to meet some very tight volume constraints as well as some difficult temperature requirements. Figure 2 shows the Rover in its stowed configuration prior to deployment on the Martian surface. There was very little volume available for the cameras. Each camera includes a filtered lens assembly, a detector assembly and an electronics housing for the camera preamplifier. An additional systems configuration challenge was that the detectors need to run fairly cold – less than 10C – to reduce noise, and the preamplifier electronics had to run fairly warm to perform within

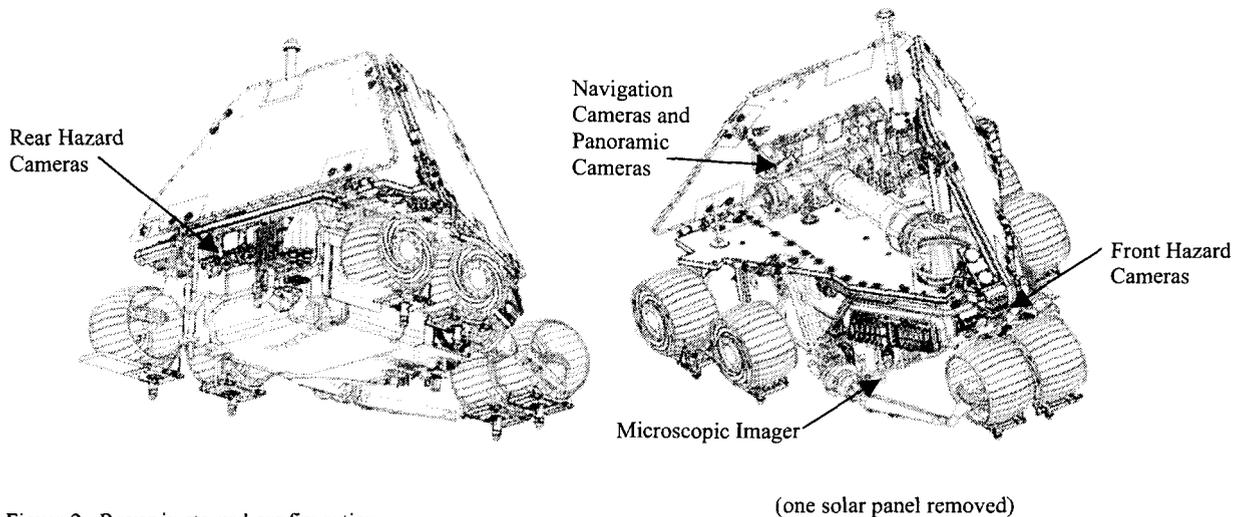


Figure 2. Rover in stowed configuration

specifications. To solve the tight packaging constraint and the conflicting thermal requirements, the cameras were split into two parts – a lens and detector assembly and an electronics assembly. The two halves are connected only by a flex cable to allow flexibility of the angular relationship of both parts of the camera as needed to fit each camera into its designated location. By splitting the camera into two parts, each side could be designed to better serve the thermal requirements. The lens and detector assembly is insensitive to Martian temperatures and could be designed to be as cold as possible. The detector operates better when cold than when warm. The electronics components are sensitive to cold

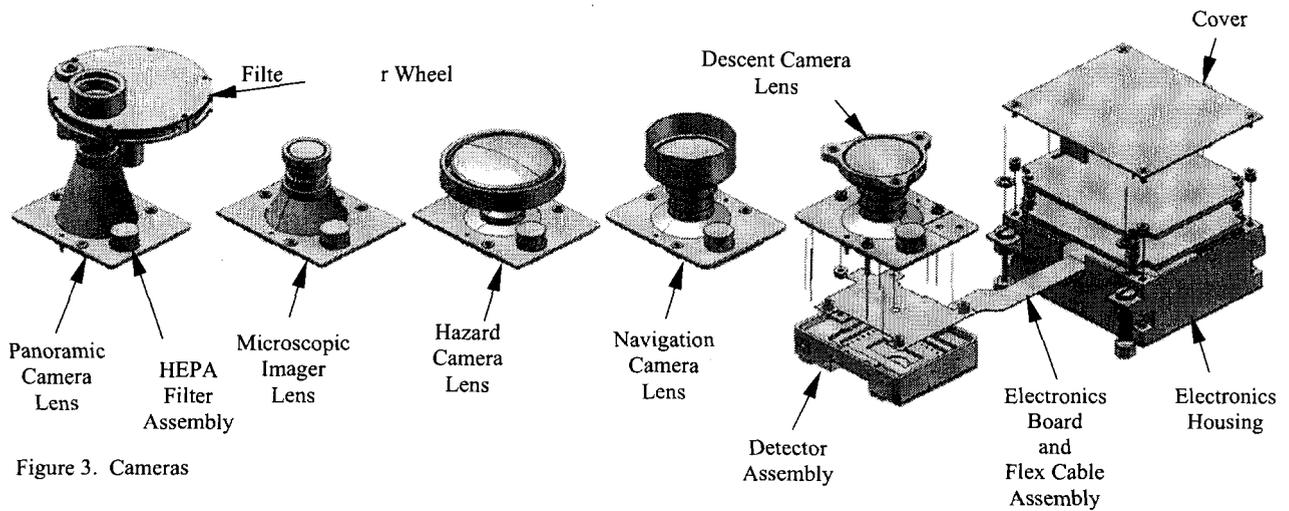


Figure 3. Cameras

temperatures and could not operate at temperatures encountered during the Martian night or morning. The separate electronics box could be optimized to prevent heat loss with heaters incorporated to increase the duration of when cameras could collect data. Each camera mounts to a bracket that arranges both parts of the camera to fit compactly into its volume. The parts of each camera are a lens assembly, a detector assembly, an electronics housing, and the electronics board and flex cable assembly. The lens assembly consists of a lens housing which mates to the modular detector housing. The lens housing includes a lens barrel, lenses, baffles and a HEPA filter that is required for venting the lens to the Martian atmosphere while keeping Mars dust outside and any Earth-born microbes inside the lens. The lens assemblies for each camera type are unique, but mount to the detector assembly with an identical interface. Figure 3 shows the parts of a camera. The lens assemblies are interchangeable on the detector assemblies. Also, the electronics box and electronics board and flex cable assembly are common to all the cameras.

### 2.1 Lens Assembly Description

Figure 4 shows five lens designs for the Mars Cameras. The optomechanical packaging approach was the same for all five lenses. The lenses all sit on ledges of the lens housings that are machined within tight enough tolerances to locate the lenses within the axial position requirements. Radially, the lenses were located using precision machined bores in the lens housing, with precision pins that located the outside diameter of the lenses to within the centering specification. The lenses were bonded in place with RTV through injection holes. Once the RTV cured, the precision pins were removed. The outside element of each lens is bonded all the way around with RTV to seal the assembly. The RTV thicknesses around the outer elements are calculated to compensate the thermal expansion of the aluminum housing to the thermal expansion of this element. The rest of the elements are not so carefully compensated. The inner lens elements are bonded to the lens barrels using RTV pads in six places for each element. Since only pads are used, the RTV can stretch and compress so that imperfect thermal compensation does not build up large stresses in the elements. Stray light baffles are sandwiched between the lenses and ledges on the barrels and were held under pressure while the RTV was setting up. Analysis of tolerances and stresses in the lenses showed that thermally induced stresses and motions were insignificant with lens and housing assemblies of this style and size. The thickness of the centering pins determines the thickness of the RTV pads. Only one size precision pin was chosen based on the average radial thermal compensation required by all the lens elements in all the cameras except the outer elements. The resulting RTV thickness created only moderately stressed conditions that would not affect lens performance. The spaces between the lenses are vented through holes parallel to the lens axis. The stray light baffles cover the holes from passing light, but were not fully successful – this will be discussed later. The lens assembly and detector package vent out to the Martian atmosphere through a HEPA filter assembly that prevents Martian dust from entering the assembly as well as protecting Mars from any microbes that may be captured inside the cameras. The panoramic camera has a filter wheel that bolts to the front of its lens barrel. The Navigation Camera has a light baffle shielding it from stray light and is bonded to the outside of its lens barrel.

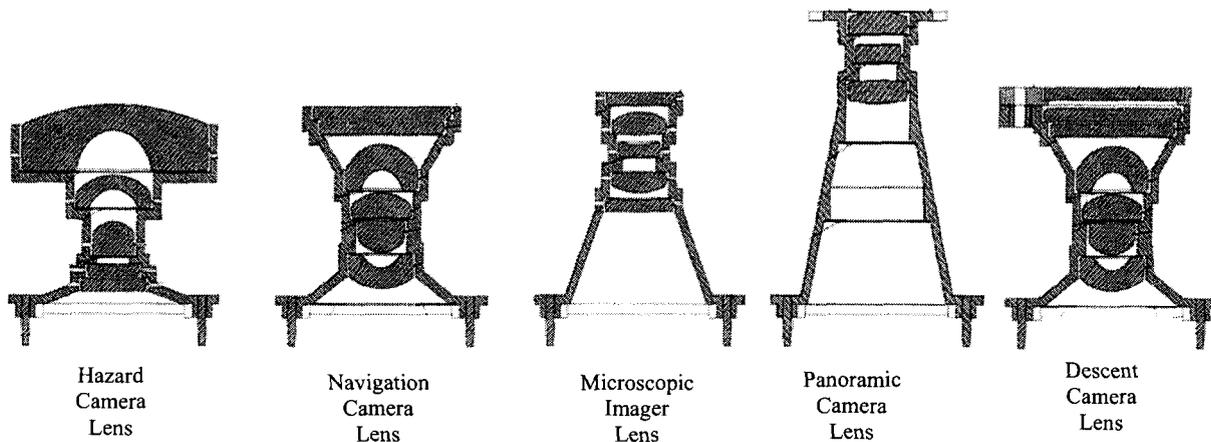


Figure 4. Five Mars Camera Lenses

All the lenses have the same interface with the detector assembly. Three pads form a reference plane that the lens pointing alignment is measured from. The lens barrel is centered with machining precision between two pins that perform the lens decenter placement control. The three pads align with three precision pads on the detector housing which are the reference pads for the detector axial location. The detector is located with machining precision to a slot and hole that engage the lens assembly pins. The tolerances sum together to provide acceptable errors between the two assemblies. The only adjustment is in the focus of the lens on the detector. When each lens is assembled, the focal distance is measured with respect to the three planar pads. This information is supplied along with the lens. When the lens is assembled to a detector assembly, shims are placed on the pads between the lens and the detector assembly to adjust the position of the detector to the lens focus. The detector housing has an overhanging ledge that overlaps a low wall around the lens interface. After the lens and the detector assemblies are shimmed together, the gap between the edge of the detector housing and the lens flange is filled with RTV to seal the assembly. Figure 5 shows the lens interface and Figure 6 shows the detector interface.

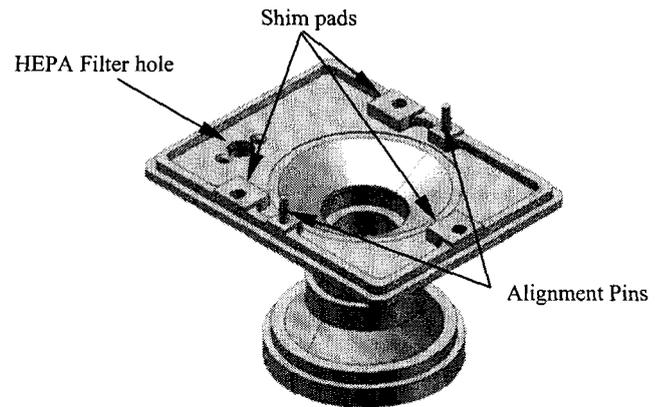


Figure 5. Lens Assembly Interface

## 2.2 Detector Assembly Description

The detector assembly is shown in Figure 6. It includes a CCD detector chip bonded to a Kovar package. The package is bonded to an aluminum detector housing. The CCD detector chips are bonded into a Kovar detector packages using fixturing to locate them within specified tolerances. The packages are bonded into the detector base plate using locating pins that register to areas on the Kovar packages that are also used to position the detectors. The packages are bonded using a complete surround of RTV to prevent any contaminants from traveling into or out of the assembly. The thickness of the RTV bond line is calculated to compensate for the difference in the thermal expansion of the aluminum housing and the Kovar detector package. The pins of the detector package are hermetically sealed using fused glass through the detector package. The pins engage the interface board of the flex cable that connects the lens and detector assembly to the electronics box. A cover mounts above the board interface and has a slot where the flex cable exits. The slot is filled with RTV that compresses around the exiting flex cable to prevent dust from entering the back detector cavity. The cover contains a HEPA filter assembly to allow venting of the cavity. On the outside of the Detector Housing are raised precision machined pads – three on the

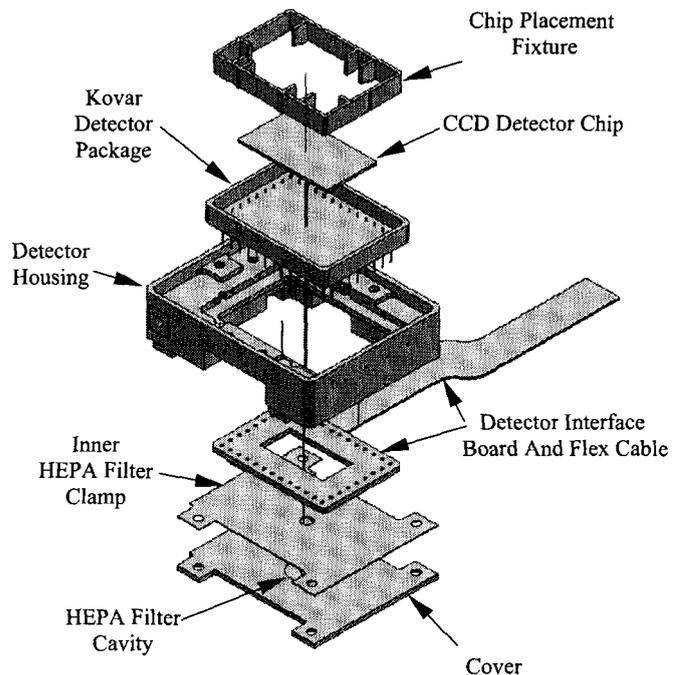


Figure 6. Detector Assembly with Assembly Fixture

side away from the lens, two on one of the short sides, and one pad on each of the long sides. These pads are machined precisely with respect to the lens mounting surfaces so that the cameras with tight pointing requirements could be registered kinematically against these pads and meet pointing specification.

### 2.3 Electronics Boards and Flex Cables

All the flex cables and electronics boards in the cameras are a single unit. Figure 7 shows pictures of the assembly from

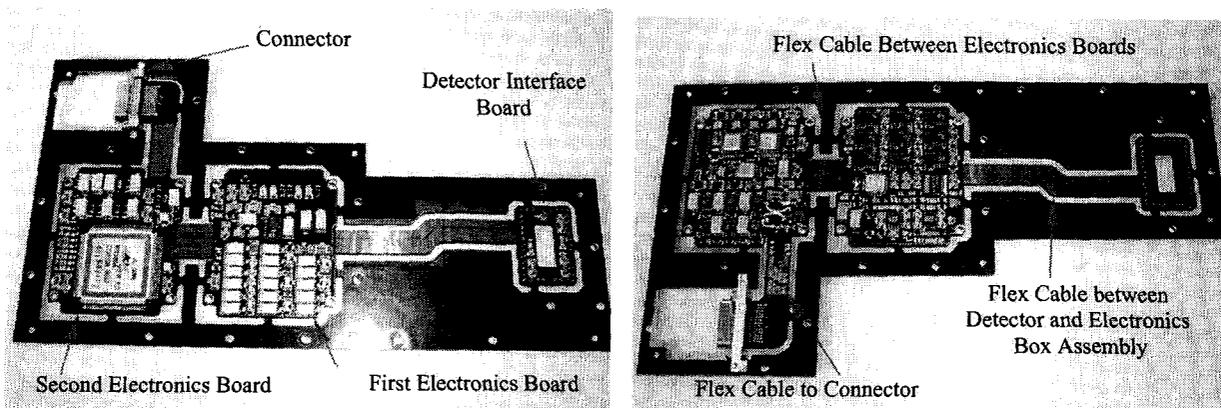


Figure 7. Electronics Boards and Flex Cable Assembly

both sides. From the detector interface board, a flex cable exits the back of the lens and detector assembly, travels to the electronics box, enters the box through an RTV-coated slit, then merges into the first electronics board. From the other side of the board, a short flex cable connects it to the second electronics board. On the side of the second board, a flex cable emerges that exits the box through another RTV-coated slit and folds over to end in a connector that mounts to a bracket on the outside of the electronics box. The connector is the electrical attachment to the rover. By integrating the flex cable and the boards into one unit, no internal connectors were used. This saves space and mass, and provides cleaner signals, but adds risk. Any flex cable failures require replacement of the entire electronics board assembly. Each electronics board is mounted to the electronics housing on sets of thermally-insulating fiberglass stand-offs. The boards are copper-centered, double-sided PWBs with components on both sides. Heaters are included in the board design, with the heater circuitry integrated along with the pre-amplifier design. The heaters enable the boards to be heated directly. This, along with the fiberglass insulators, minimizes the power needed for warming the components.

### 2.3 Electronics Housing Design

The Electronics Housing was designed to keep the electronics boards isolated so that they can be heated using low power during the Martian night and morning. The housing parts are shown in Figure 8. The housing is aluminum and will be coated with silver-teflon tape aluminized Mylar on the outside surfaces to provide a low solar absorptivity, high

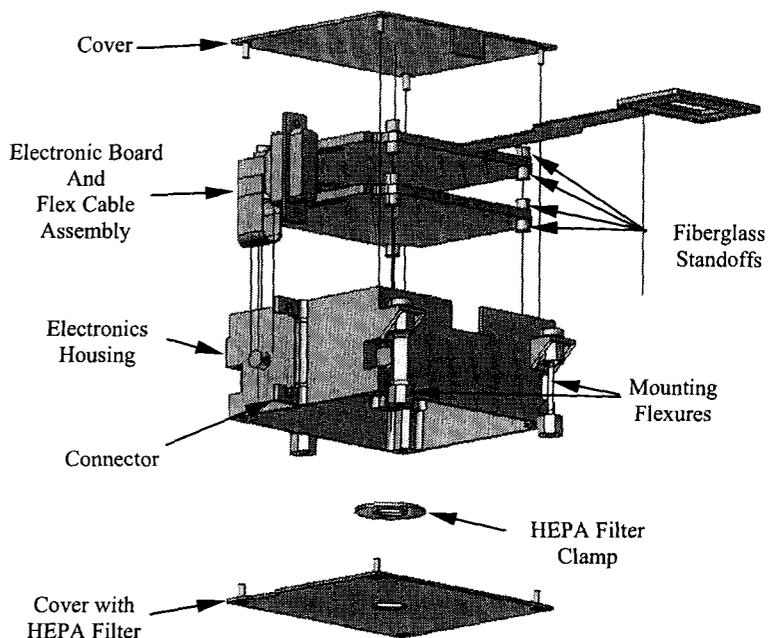


Figure 8. Electronics Housing Assembly

emissivity surface. The housing is mounted on three titanium flexure posts to provide thermal insulation to the surface of the rover and to provide accommodation to the difference in temperature between the housing and the surface to which it mounts. Both sides of the housing have covers, one of the covers contains a HEPA filter assembly for contamination control. Removing the covers provides access to the screws that hold the electronics boards in the housing. The boards are thermally isolated from the housing by fiberglass stand-offs between the boards and the housing and screws.

#### 2.4 Radiation

Radiation is a concern because it can damage the electronics, the detector and can degrade the transmission of the glass of the lenses. There are two main sources of radiation for the Mars Cameras: particles encountered in the space environment while cruising to Mars, and radiation created by other components on the rovers. Each radiation source on the Rovers blocks its own radiation in the direction of other sensitive components. Analysis showed that the electronics and detectors could be protected by the thickness of aluminum around them during cruise. The lenses receive protection from the outer shells of the Lander, the spacecraft and by orienting the lenses to point toward protected directions during cruise.

#### 2.5 Contamination Control

To prevent outgassing, materials were selected that have low volatile properties. All parts of the lenses were precision-cleaned prior to assembly. After the bonding processes, the assemblies were heated in a vacuum chamber to fully remove any volatiles. To prevent contaminating Mars with Earth microbes, the exteriors of the cameras will be cleaned with an alcohol wipe after integration and test onto the rovers. HEPA filters prevent any microbes inside the cameras from escaping onto Mars as well as preventing Martian dust from entering the cameras.

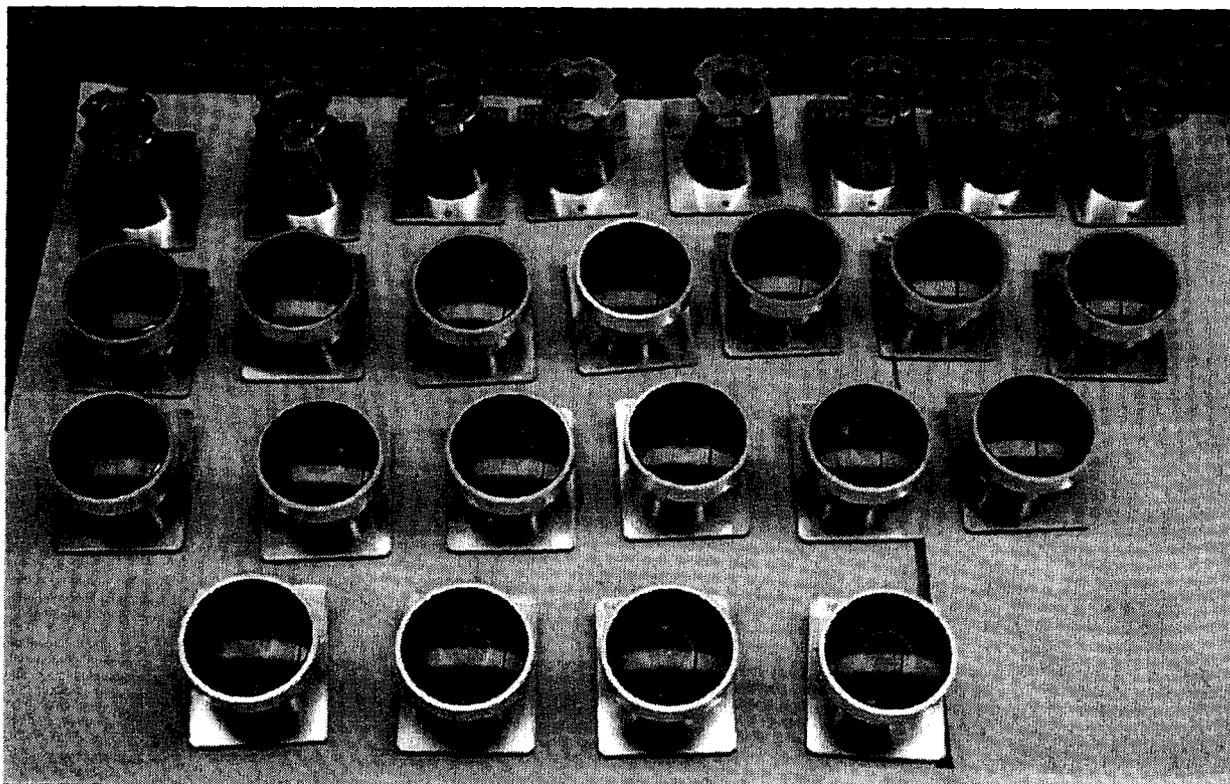


Figure 9. An Array of Completed Panoramic Camera Lenses and Hazard Camera Lenses

### 3. Current Status

All of the lens assembly was done at Kaiser Electro-Optics, Inc. along with qualification vibration and optical testing to ensure performance of each lens both before and after vibration. The focus of the lens was measured with respect to the pads that interface with the detector housing. Currently, images have been taken by at least one of each camera configuration. A Landing Descent camera was flown on a helicopter to test the ability to implement the jet control

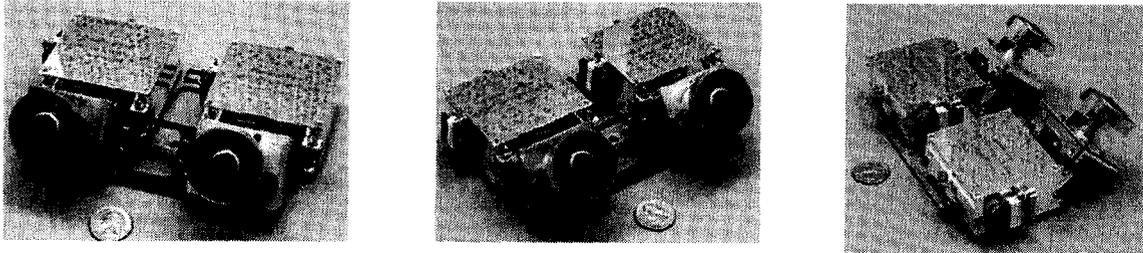


Figure 10. The Rear Hazard Cameras Assembled on the Rear Bracket

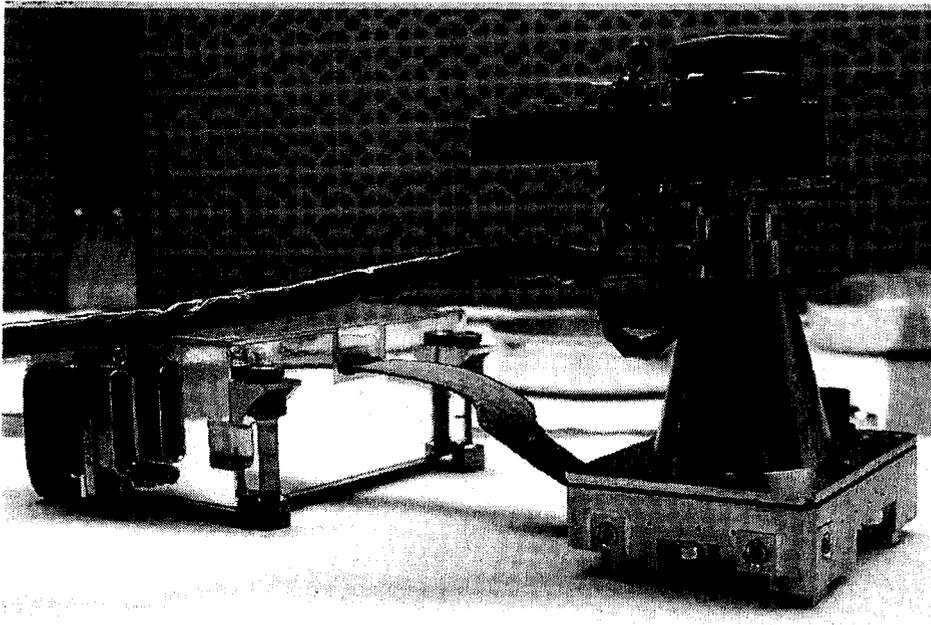


Figure 11. The Panoramic Camera Assembly with Filter Wheel

algorithms using the camera images. Figure 9 shows a photograph of an array of completed Hazard Camera lenses and Panoramic Camera lenses. Figure 10 shows three views of the completed Rear Hazard Camera assembly. Figure 11 shows a Panoramic Camera being tested with its filter wheel mounted to the front of the lens.

#### 3.1 Test Results

At least one of each camera has been tested by imaging on grid and resolution targets. So far, the grid images have been falling on the detector pixels exactly where the ray trace models predict. Also, the resolution target images are in best focus at the object distances predicted by the ray trace models. None of the shim thicknesses between the lenses and detector assemblies have needed adjustment. The Panoramic Camera Qualification unit with the filter wheel has successfully passed 3-axis random vibration, landing loads, pyro-shock and Rover-drilling-induced vibration tests.

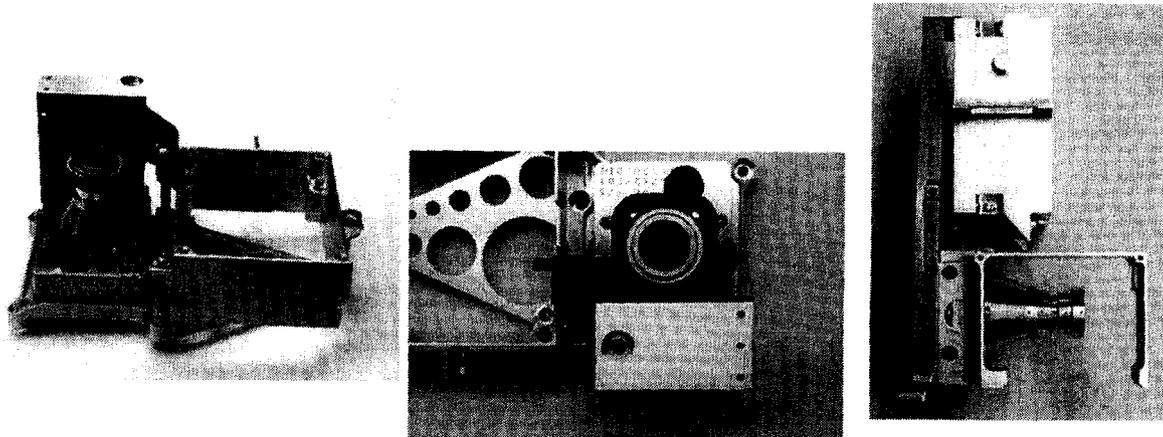


Figure 12. Partially assembled Microscopic Imager on bracket with no electronics.

### 3.2 Lessons Learned

The method developed for venting the lenses was to use holes drilled axially through the edge of the lens barrel that would break into the lens cavities, but not through the lens barrel. This method has been used on many other lens assemblies with no problems. But with no retaining rings in this design, and with out fully surrounding the lens elements with RTV, the axial hole created an unacceptable light leak in one area of the Hazard Camera. This problem was corrected by modifying the stray light baffles in that area to cover the axial hole and block light, but still allow venting.

Another unexpected problem was that the HEPA filters were transparent. This allowed light to leak into the detector cavity. The HEPA filter assembly on each lens was modified to add a light baffle to block the light path.

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