G 301: THE FLYING FALCON GEOLOGICAL REMOTE SENSING EXPERIMENT

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ABSTRACT

Get-Away Special (GAS) G-301, named the Flying Falcon and scheduled for launch on the STS-77 Space Shuttle in April, 1996, is being prepared to perform an experiment designed by the Department of Geology, Bowling Green State University (BGSU). The experiment will employ a new type of infrared imager designed and built by a consortium of Teltron Technologies Inc., Hudson Research Inc., and BGSU that is an uncooled, quantum ferroelectric, infrared return beam vidicon (IRBV) camera capable of detecting thermal infrared radiation throughout the 2.0-50.0 μm wavelength region, and to which an integral, tunable Fabry-Perot filter and a telescopic lens have been added. The primary objectives in the experiment include the mapping of methane plumes from solid waste landfills and wetlands in the midwestern U.S., the mapping of methane plumes offshore in the Gulf of Mexico and in the Middle East, brief monitoring for precursors of volcanoes or earthquakes in the South China Sea and the East Pacific Rise (about 300 km west of Easter Island), and the mapping of silica content in exposed outcrops and residual soils of the southwestern U.S. and Middle East.

The IRBV camera will be operated as a framing camera with a 512 x 512 pixel frame, due to GAS constraints. It is capable of collecting one frame each 1/30th of a second. The integrated tunable filter will switch spectral bands faster than the framing speed of the camera, and images of two consecutive spectral bands will be co-registered during ground-based image processing by

dropping an appropriate number of lines off the beginning of one image (band 1) and the end of the next image (band 2). The zoomed spatial resolution of the sensor will be 20 m, with a non-zoomed resolution of 200 m. The limitation on number of spectral bands that can be co-registered is limited by the speed of the Space Shuttle and the acceptable size of the resulting multispectrally co-registered image. For the imaging of methane plumes over land or water, three spectral bands in the 3.0-4.0 μm wavelength region are sufficient. A different three spectral bands (in the 8-14 μm wavelength region) will be used for mapping silica content in exposed rocks. Approximately 127 data collection opportunities (DCO) will be collected, each covering 1,356 x 512 pixels of non-overlapped area in three spectral bands, with about 2.36 megabytes per DCO. A computer program called FALCEYE, operating on a personal computer board, will use input from an on-board global positioning satellite (GPS) receiver and from a GIS data base to automatically tell the camera when to collect data, with which trio of spectral bands. A clone of the zoom version of the camera described below, aboard a geostationary platform, may be well suited for mapping precursors to earthquakes and volcanic eruptions.

INTRODUCTION

Carbon dioxide and methane are both Greenhouse gases, because they are transparent in the visible wavelength region (passes visible sunlight) and opaque in parts of the thermal infrared wavelength region. A Greenhouse gas absorbs heat radiated by the Earth's surface and re-radiates it back down to the surface, thereby heating the surface. The global atmospheric concentration of carbon dioxide has increased from 280 parts per million by volume (ppm) to 353 ppm since 1800 AD, the beginning of the Industrial Revolution, and methane has increased from 0.8 ppm to 1.72 ppm in that same time period (ref. 1). Thus, methane has increased at almost twice the rate of carbon dioxide over the last 200 years. Most natural methane is thought to come from vegetative decay in wetlands, particularly tundra regions, though some comes from natural gas seeps and volcanic eruptions. Recent work (ref. 2, 3, and 4) has implicated methane as a precursor of earthquakes and volcanic eruptions, and thermal anomalies associated with the outflow of methane and charged particles from stressed rocks have reportedly been mapped from weather satellite images. Man-made sources of methane include pipeline/well leaks, solid waste landfills, sewage treatment plants, and livestock feedlots. Methane imaging has been proposed (ref. 5) by the use of three narrow spectral bands in the 3.0-4.0 μm wavelength region, which could be performed on data collected during night-time or day-time.

The silica content of exposed silicate rock types can be mapped with two or more spectral bands in the 8.0-14.0 μm (ref. 6). A hyperspectral thermal infrared sensor with narrow spectral bands in both the 3.0-4.0 μm and the 8.0-14.0 μm wavelength regions would be able to perform both of these tasks. In the past, this would have required two different detector systems, one with a Hg:Cd: Te sensor and the other with an InSb sensor. The sensor that will be used in the Flying Falcon experiment is uniquely qualified for imaging differences in both methane content of the atmosphere and silica content of exposed rocks and soils on the ground.

The anomalies and areas selected for study include methane escape from solid waste landfills in the midwestern U.S., known methane seeps in the Gulf of Mexico (at the edge of the continental shelf), methane flares in the Middle East, methane anomalies associated with earthquake and volcanic eruptions in the South China Sea and the East Pacific Rise (about 300 km west of Easter Island), and exposed rocks in the southwestern U.S., the Middle East, and Australia.

THE CAMERA

A new type of infrared sensor, called an infrared return beam vidicon (IRBV) camera, will be employed for the experiment. Fig. 1 shows a cross-sectional drawing of the camera. The IRBV camera is very similar to a return beam vidicon (RBV) camera that works in visible wavelength regions and has been employed on early satellites of the LANDSAT series, except that the electron "target" (photocathode) inside the video tube is a quantum ferro-electric (QFE) material that is sensitive to thermal infrared photons, instead of visible photons, and the IRBV camera lens is reflective instead of transmissive. Fig. 2 shows a cross-sectional drawing of the QFE video tube.

The camera was designed and build by a consortium of Teltron Technologies Inc, which supplied the unique QFE video tube; Hudson Research Inc., which supplied lens, optical and electro-optical design, tunable filter, low noise power supply, video electronics, and system integration; and the departments of geology and physics at Bowling Green State University, which supplied the multispectral design, custom circuit boards, and custom machined parts. The IRBV which has variable framing, but the constraints of a GAS experiment resulted in our choice of 512 pixel x 512 pixel frames, each collected in 1/30th of a second. The IRBV is uncooled and can detect single photons, owing to its noiseless signal amplification by a negative electron affinity dynode amplifier (ref. 7). A photon hits the QFE material inside the tube, kicking out several electrons, which are then multiplied 10^{15} times by the photomultiplier tube, with no Johnson noise. The video tube integrates all incoming photons except during readout. The electrons are then counted in a scan sweep across the back of the QFE photocathode, which is converted to 512 pixels during the on-board analog to digital conversion. Except for the QFE photocathode, the telescope, and the tunable filter, other parts of this sensor package are almost identical to visible RBV cameras that have been flown in space on several occasions. The noiseless amplification feature is one of the principal ways of achieving low-light-level vision in the visible wavelength region. With the new quantum ferro-electric coating, this same feature yields low-heat-level thermal vision in the thermal infrared wavelength region.

A tunable Fabry-Perot filter, which is integrated with the QFE video tube, is capable of restricting the input infrared radiation to selectable, narrow spectral bands anywhere in the 2.0-50.0 μm wavelength region. The switching rate of the tunable filter is faster than the framing rate of the IRBV camera, which permits three spectral bands to be selected as three consecutive frames of data. To provide multispectral co-registration of the spectral bands, images of two consecutive spectral bands will be co-registered during ground-based image processing by dropping an appropriate number of lines off the beginning of one image (band 1) and the end of the next image (band 2). Currently, the spatial resolution of the sensor will be 20 meters in the zoom mode, which means that the Space Shuttle's velocity will cause approximately 15 lines to be dropped on each image of a two-band pair, for a total of 30 lines for the pair. If a third band is co-registered with the first two bands, a total of 60 lines must be dropped of the total of 512 lines per frame, leaving a 452 x 512 pixel image with all three bands co-registered, yielding an area covered per frame of 9.0 km x 10.2 km in the zoom mode. In the non-zoom mode, the pixel size will be 200 m on a side, which will yield a total area covered per frame of 90.4 km x 102.4 km.

The number of spectral bands that can be co-registered is limited by the speed of the Space Shuttle and the acceptable size of the resulting multispectrally co-registered image. There will be two sets of three spectral filters used for this experiment, one trio for imaging methane plumes over land or water, and a second trio for imaging silica differences in exposed rocks and soil on land. Methane imaging will be performed with a trio of 0.032-μm-wide spectral bands, one (called band 2) centered at 3.314 μm, where methane absorption is greatest, and two bands centered near wavelengths of 3.116 μm (band 1) and 3.516 μm (band 3), respectively (ref. 5). Fig. 3 shows a three-band spectral ratio (the average of bands 1 and 3 divided by band 2) versus ppm of methane in a 10-m-thick plume of methane, as seen from space (ref. 5). Such a plume would be equivalent to one-thousandth as much methane concentration (in ppm by volume) for a 10-km-thick "plume" (ref. 5). The minimum difference in methane concentration for a 10-m-thick plume that is detectable from space by normal infrared sensors has been estimated by signal-to-noise calculations to be 16,000 ppm, which is considerably less than the lower explosive limit of methane in air (ref. 5). This is equivalent to saying that a 10-km-thick plume would have a minimum detectable methane concentration limit of 16 ppm. The proposed sensor will likely be substantially (more than a factor of 2) better. The trio of spectral bands for mapping silica content in exposed rocks will be approximately 0.10 μm wide, centered at 8.95 μm, 11.40, and 10.60 μm, (labeled bands 4, 5, and 6), respectively.

The camera design is based on experience gained from a number of space and military applications. Teltron built the video imaging system on the Apollo landers, so their expertise in producing highly reliable hardware is well established. The camera contains the necessary support electronics. These include deflection circuitry, various high voltage DC power supplies (including those for the Fabry- Perot filter), synchronization circuitry, and signal amplifiers associated with the photocathode. The camera also has circuitry to support the anti-blooming, dynode amplifiers, self-adjusting pedestal, and electronic zoom and centering features. The self-adjusting pedestal, which effectively neutralizes the charge on the electron target when the shutter is closed, eliminates the need for an external chopper or shutter.

SUPPORT ELECTRONICS EXTERIOR TO THE CAMERA

The camera analog output will be digitized with 10 bits per pixel and stored on a solid state memory device capable of holding approximately 300 megabytes of 10-bit digital data. Nine frames of data will be recorded for each data collection opportunity (DCO), overlapping just enough such that the total area covered by each DCO will be 1,356 x 512 pixels, with 3 spectral bands of data. A DCO will be mapped either for methane or for silica content, but not both. Because of the along-track overlap, there will be 3x512x512x3=2.36 megabytes of data stored for each DCO. Therefore, there will be enough data storage for approximately 127 DCOs.

An on-board GPS (Global Positioning Satellite) receiver and on-board computer will be used to determine the position of the Space Shuttle and to automatically tell the camera when it is time for a DCO. Study areas are being selected and digitized with a GIS system to determine the polygon outline of each study area. A study area will typically be much greater in size than a DCO. A computer program (FALCEYE) on a solid-state ROM, created at BGSU, will determine when the camera should start a DCO by automatically comparing the Shuttle's GPS position with the stored study area polygons. Any DCO within a study area will be deemed acceptable, day or night (this is a thermal infrared sensor). Rather than automatically detecting clouds, we will accept cloud cover as-is and spend most of the post-processing time on the cloud-free DCOs.

The final piece of support electronics is the Shuttle Motorized Door Assembly (MDA), which will be activated when the Shuttle bay is finally opened and pointed at Earth, and just before the Shuttle bay is closed.

POST PROCESSING

The stored data will be brought to the BGSU Geology Department for downloading and image processing in our GIS/Remote Sensing computer lab, which contains 5 Silicon Graphics Indigo computers and 3 Sun Microsystems (SPARC 10, SPARC 1000, and 470) workstations. KHOROS, ERMAPPER, and other image software will be used to spectrally co-register the images of each DCO. Spectral ratio images and other types of processed images will then be produced. Field work will be conducted, as travel support for graduate students becomes available in the post mission phase.

CONCLUSION

The following "firsts" are expected, among others, to occur as the result of the Flying Falcon GAS experiment:

1. The first imaging attempt for a GAS experment.
2. The highest spatial resolution of any civilian thermal infrared imaging system ever orbited.
3. The first space test for an IRBV camera.
4. The first attempt at imaging methane from space in the thermal IR.
5. The first attempt at imaging silica differences in exposed rocks and soils from space.

If this experiment is able to conclusively image methane, the IRBV camera would make an excellent addition to a geostationary platform, where the zoom capability would yield pixels of about 4.5 km spatial resolution and would cover an area about 2,300 km x 2,300 km, with a virtually unlimited number of narrow spectral bands available for use. Any gas with an infrared absorption band in an atmospheric window region could be imaged with such a system. If large-area methane anomalies are a precursor of earthquakes and volcanic eruptions, as some have claimed (ref. 2 and 3), this capability would be excellent for monitoring such precursors.

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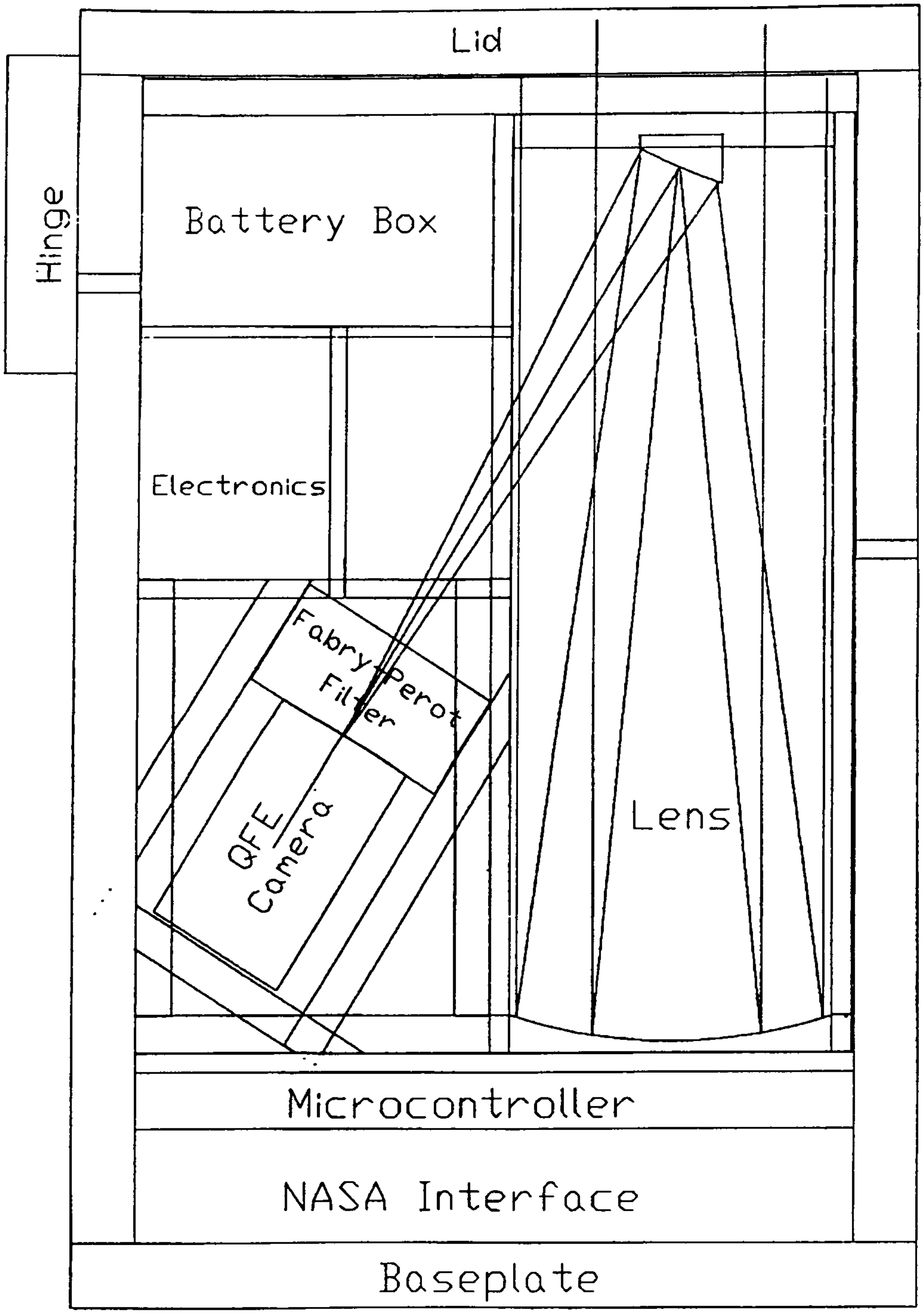

Fig. 1. Drawing of the Flying Falcon experiment, showing the quantum ferro-electric (QFE) infrared return beam vidicon (IRBV) camera, to be flown as the Get-Away-Special G-301 package with the STS 77 Shuttle mission in April, 1996.

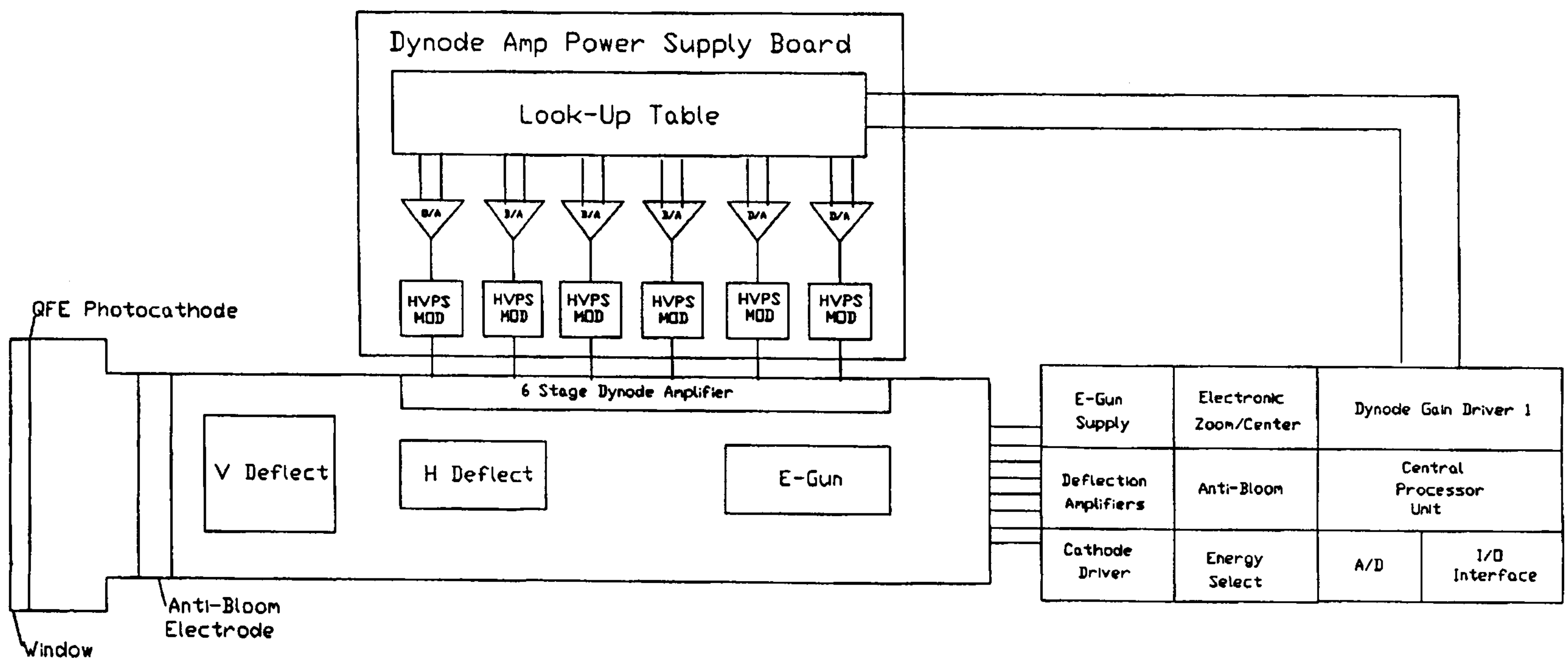

Fig. 2. Cross-sectional drawing of the quantum ferro-electric (QFE) video tube, which is the heart of the G-301 Flying Falcon infrared imaging experiment.

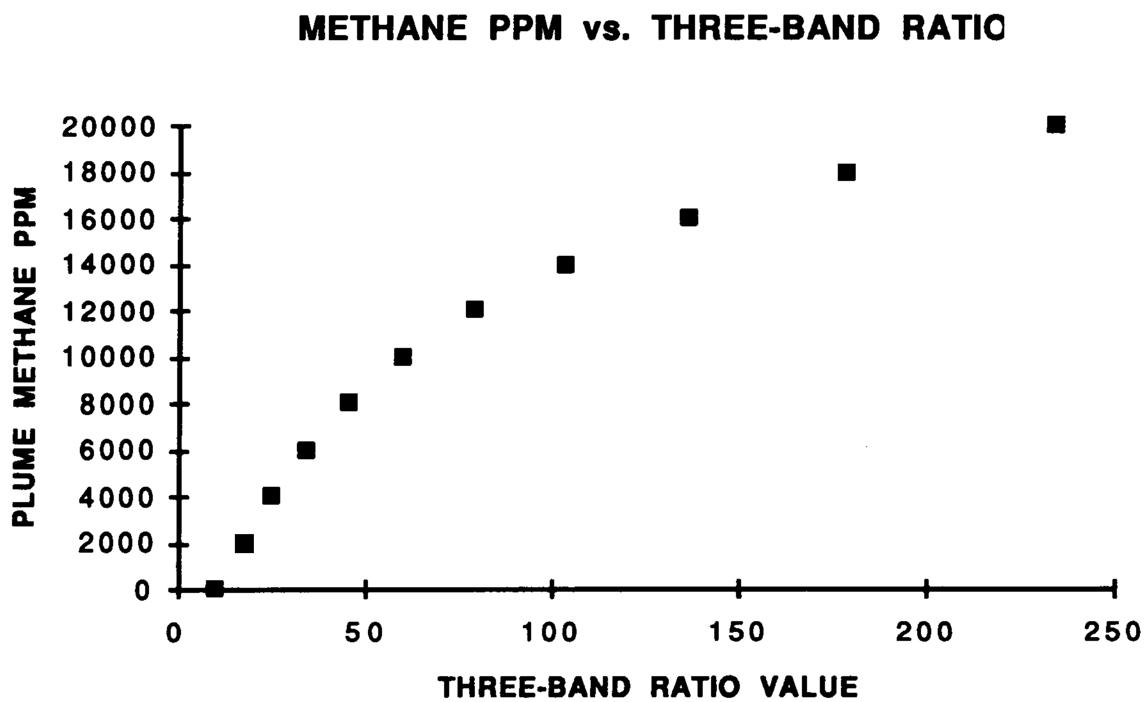

Fig. 3. Concentration of methane (in ppm by volume) in a methane/air plume of 10-meter thickness versus a three-band ratio ($R_{1+3,2}$) as observed over the ocean by a three-band (3.100-3.132 µm, 3.298-3.330 µm, and 3.500-3.532 µm) thermal infrared sensor from space, under conditions of the ocean surface temperature at 25°C and temperature of the plume (and sea-level atmosphere) at 5°C or less.