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COLLECTION OF *IN SITU* FOREST CANOPY SPECTRA USING A HELICOPTER: A DISCUSSION OF METHODOLOGY AND PRELIMINARY RESULTS

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ABSTRACT

The collection of *in situ* spectral reflectance measurements from earth surface materials is an important part of fundamental research in remote sensing. The availability of such information for forests, which play a vital role in governing many aspects of life on this planet, is lacking due to the difficulty and expense associated with suspending appropriate instruments above these tall canopies. The use of helicopters as a platform to get above these canopies appears to be a logical choice. A "check-out" mission was conducted with a helicopter during the summer of 1983 to assess the utility of this platform for acquiring forest canopy spectra. A helicopter is a good platform, but not ideal. This report documents some of the problems encountered and provides samples of spectral reflectance data acquired during the mission.

I. INTRODUCTION

A. IMPORTANCE OF *IN SITU* MEASUREMENT

The measurement and analysis of spectral reflectance from earth surface materials *in situ* is an important part of fundamental remote sensing research. Studies have shown that different applications of remotely sensed data require spectral measurements from different portions of the electromagnetic spectrum to effectively analyze the target(s) of interest. Intensive field measurement programs using spectrometers and radiometers have been undertaken during the past decade to define appropriate spectral bands and analysis techniques for delineating various cover types, especially agricultural crops and rangeland vegetation.

The specific goals of *in situ* reflectance measurement programs vary widely with each discipline, but there are some common motivations for all disciplines. For example, there is a need to increase the understanding of spectral radiance interactions with surface materials (Miller et al., 1975). From this, an increased knowledge of the information content of spectral reflectance data can be obtained (Tucker, 1979; Cox, 1982). Temporal and spatial variations of spectral reflectance as a function of surface conditions must also be understood if the full potential of the use of multispectral data is to be reached. The acquisition of detailed ground-based measurements is also needed in concert with satellite or aircraft overflights for calibration and evaluation of the performance of existing remote sensing satellite systems (Milton, 1980). Finally, the development and evaluation of new sensor systems for specific tasks requires an in-depth understanding of the specific spectral reflectance characteristics of the target(s) of interest, including information about the potential magnitude of spectral and spatial variability (heterogeneity) within these target(s). Basic research on these parameters is best performed under semi-controlled conditions *in situ*.

B. MEASUREMENT DEVICES

The development and use of devices for *in situ* spectral reflectance measurements have been restricted by the need for special hardware and special manpower requirements (Tucker, 1979). Early devices consisted primarily of modified laboratory instruments, while later devices were designed specifically for field use. The most widely used instruments fall under the category of spectral radiometers (i.e., devices employing a fixed number of discrete spectral bands). Most radiometers have been designed to employ selected spectral bands of the Landsat Multispectral Scanner (MSS) or Thematic Mapper (TM) sensors. A considerable amount of research is presently underway utilizing these devices (NASA, 1981; Dye, 1983).

Spectrometers (i.e., devices capable of measuring continuous spectral reflectance across a wide band of the solar spectrum) have been especially restricted in their use. Many of these devices were conversions or adaptations of rather cumbersome laboratory instruments. These instruments tend to be complicated in their use, calibration, and deployment (Tucker, 1979). The range of field targets that have been measured with these devices is somewhat limited.

Recent developments in solid state sensors and microprocessors have assisted in the production of portable, computer-controlled systems for measuring spectral reflectance. More, and hopefully better, spectral reflectance measurements are now possible for a greater variety of targets. The adaptability of these systems to different platforms has been an important consideration in their design. Two examples of this relatively new breed of instruments are the Barnes Model 12-1000 Modular Multiband Radiometer (MMR) and the Spectron Engineering SE-590 Spectroradiometer[1]. Both of these instruments were used to collect *in situ* spectral reflectance measurements of forest canopies from a helicopter platform during a "check-out" mission conducted in August, 1983 by researchers at NASA's Goddard Space Flight Center in Greenbelt, Maryland. The results of this experiment, primarily conducted to evaluate measurement procedures, have identified a number of factors which must be taken into consideration in helicopter-based acquisition of spectral reflectance measurements.

C. THE NEED FOR *IN SITU* FOREST CANOPY MEASUREMENTS

At present, the detailed spectral reflectance characteristics of forest vegetation are not well understood, particularly in the middle infrared wavelength region. This lack of knowledge is directly related to a paucity of forest canopy spectral reflectance data which has been collected *in situ*. The scarcity of such data stems from the difficulty and expense associated with suspending the appropriate instruments above a forest canopy (as compared to an agricultural crop canopy). Other factors contributing to the lack of forest canopy spectra are: a) remote sensing research during the past decade has emphasized the observation of agricultural phenomena, and b) instruments having the necessary attributes of portability and flexibility for use with a variety of different platforms have only recently become available.

The authors consider the acquisition of *in situ* forest canopy spectra to be important for several reasons. First of all, forests cover approximately 35% of the global land surface area (Matthews, 1983) and they play an important role in governing many facets of life on this planet (Tomlinson, 1983). According to Tomlinson, "they play a significant part in weather control by helping to preserve the hydrological balance between the atmosphere and the earth. Trees absorb, store, and, by transpiration from their foliage, slowly release water to the atmosphere. In the process, they reduce the deleterious effects of heavy rains and help to sustain atmospheric humidity in areas distant from the sea. In addition, forests contribute to the ecological balance between carbon dioxide and oxygen, and store the sun's energy. Through the photosynthetic reaction that converts carbon dioxide and water to organic matter and oxygen, they provide part of the oxygen needed by most living organisms." Secondly, deforestation has accelerated dramatically on a worldwide basis (Woodwell et al., 1983), and widespread declines in the vigor of forests due to acid rain and other environmental factors have been reported recently in North America and Europe (Vogelmann, 1982). In light of these potential impacts on this valuable resource, the close monitoring of the health and extent of our forest resources over time and over widespread geographical regions is paramount.

The use of satellite remote sensing techniques to monitor the areal extent of our global forest resources is feasible with the sensor systems currently in orbit. However, methods for assessment of forest extent and vigor from satellite altitudes are not well developed. This lack of methodology stems from the fact that: a) forests are extremely heterogeneous targets, both spectrally and spatially; b) few *in situ* measurements of these forest canopy radiance attributes are available to support the characterization of expected satellite forest radiance measurements; and c) a majority of the remaining forests occur on fairly rugged terrain which complicates the collection, analysis and interpretation of remotely sensed data.

It will be difficult to successfully develop appropriate instrumentation and

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[1] [NOTE: Use of manufacturer names in this document is for descriptive purposes only and does not imply endorsement by NASA.]

techniques for analysis of forest extent and condition from satellite observations if we are continually forced to make assumptions based on: a) extrapolation of spectral reflectance data acquired over agricultural crops or rangeland vegetation, or b) the use of "forest spectra" obtained by sensing a few tree leaves in a laboratory environment. Thus, the acquisition and analysis of *in situ* forest canopy spectra has become a goal of researchers within NASA/Goddard's Earth Resources Branch, and at other remote sensing institutions. This paper presents a discussion of methodology and preliminary spectra based on an experiment to use a helicopter as an observing platform for *in situ* forest canopy spectra measurement.

II. HELICOPTER COLLECTION OF *IN SITU* FOREST CANOPY SPECTRA

A. HELICOPTERS AS A PLATFORM

Although helicopters seem to be a logical choice for forest observations, they are not an "ideal" platform. For example, there is considerable motion and vibration when a helicopter is in the "hover" mode. The magnitude of these motions is dependent on winds aloft and whether the helicopter is pointed directly into the wind or at some angle to the wind. Also, a helicopter cannot safely hover at any given altitude. There is a prescribed altitudinal zone of avoidance for each model of helicopter called the "dead man's zone". A helicopter should not be placed in a hover mode for any extended period of time within this zone, because there would be insufficient altitude available to recover from a power failure. This stipulation significantly limits the flexibility of data acquisition dependent on sensor attributes and the size of the target to be sensed.

B. MANPOWER CONSIDERATIONS FOR A HELICOPTER MISSION

In the absence of sophisticated data recording equipment, it is usually desirable to have one person in the helicopter for each instrument employed to ensure that the instrument is operating properly for the duration of the mission. In addition, a "mission manager" is needed on board during the flight to take notes describing data acquisition conditions (e.g., helicopter bearing, altitude, and ground cover conditions), to pick out the next target, and to ensure that all aspects of the mission are proceeding as planned.

The large number of recommended support people is largely necessitated by the poor working environment inside a helicopter. It is extremely noisy within the cabin and communications must take place via headsets. Personnel movement (e.g., to check different instruments) is restricted and, in fact, forbidden while in the hover mode, as a sudden shift in weight on either side of the central axis of propeller rotation can cause the helicopter to become dangerously unstable. Vibration makes the taking of notes and the observation of instrument dials very difficult. Therefore, an instrument operator would not have sufficient time or freedom of movement to accomplish other tasks, such as those performed by the mission manager. This results in a requirement for a helicopter of sufficient size to carry the necessary people and equipment.

A Bell UH-1B Iroquois helicopter (popularly referred to as a HUEY), operating out of NASA's Wallops Flight Facility at Wallops Island, Virginia, was available for this study (Figure 1). This helicopter has a payload capacity of approximately 910 kilograms (2000 pounds) and can carry up to seven people. Five people were on-board during our check-out missions: the pilot, a mission manager, and three instrument operators (i.e., radiometer, spectrometer, and film camera). The previously mentioned "dead man's zone" for this helicopter dictated a hovering altitude in excess of 215 meters (≅700 feet) when ground speed was less than 20 knots. Knowing this constraint, we chose a comfortable data acquisition altitude of approximately 300 meters (1000 feet). This altitude above ground, coupled with the 1° IFOV of the two sensing devices yielded a ground sample resolution of approximately 5.5 meters (18 feet) in diameter.

C. INSTRUMENTATION USED IN THIS EXPERIMENT

The instrumentation mounted underneath the helicopter during our check-out mission is shown in Figure 2. The key devices were the optical heads for the Barnes MMR 8-band radiometer and the SE-590 spectrometer, a Hasselblad camera, and a video camera. Each device is described below.

Radiometer. A Barnes Model 12-1000 Modular Multiband Radiometer (MMR), referred to elsewhere in this document as the Barnes MMR 8-band radiometer, was used to acquire radiometric data during the mission. This instrument is a high quality, field-rated multiband radiometer which has been widely used in remote sensing research during the past few years. It is essentially the "standard" against which other instruments are compared. The Barnes MMR simultaneously produces analog voltage responses to the scene radiance in each of eight spectral bands (i.e., the seven TM bands, plus an additional band covering the 1.15 to 1.30 μm region).

The Barnes MMR 8-band radiometer is a stand-alone device suitable for operation from 0° to 60° C, and can be mounted on a tripod, truck boom, helicopter, or small airplane. Key features of the radiometer relative to its use from a helicopter platform are:

- it is compact in size, with dimensions of 26.4 x 20.5 x 22.2 cm (10.3 x 8.07 x 8.74 in), and weighs only 6.4 kg ($\cong$ 14 pounds),
- it may be powered by any 12-volt battery and is protected for vehicular operation; a sealed lead acid battery (12-volt, 5 amp hour) weighing approximately 2.3 kg ($\cong$5 pounds) will operate the radiometer for more than 10 hours,
- the eight spectral bands covered by the instrument are equivalent to those of the Landsat TM, and provide information in each of the four major optical regions of the electromagnetic spectrum (i.e., visible, near IR, middle IR, and thermal IR),
- scene radiance is simultaneously recorded in all eight bands in a fraction of a second, so that minor motion by the helicopter platform does not "blur" the signal,
- the coaligned fields of view of the eight detectors can be altered to 1° or 15° by simply changing lenses, and thus offers a degree of flexibility in specifying the actual size of the ground footprint.

Spectral data are recorded on an Omnidata International, Inc., Model 516 Polycorder. This unit provides 12 bit accuracy with an acquisition interval of about 20 milliseconds per band. Thus, for the eight radiometric channels, about 0.16 seconds are required to record the data. About 350 observations may be stored on the unit at any one time.

For a more in-depth discussion of the Barnes MMR 8-band radiometer see Robinson et al. (1981).

Spectrometer. The Spectron Engineering SE-590 Spectrometer, referred to elsewhere in this paper as the SE-590, is a moderately priced, field-portable instrument which can be used for various spectral radiation measurement applications. The device is composed of two major components: the optical scan head, and the controller unit (Figure 3). Like the Barnes MMR 8-band radiometer, it is compact (9 x 23 x 23 cm), lightweight (3 kg), and operates as a stand alone unit by drawing power from a small 12-volt battery. The visible/near infrared (0.4 to 1.0 μm) optical scan head used during our mission contains a 256 element linear photodiode array sensor. Exposure of the linear array to scene irradiance is controlled by a shutter which is operated by the controller unit. A diffraction grating is used as a dispersive element, with each element of the array simultaneously integrating a separate spectral wavelength. The nominal spectral resolution of the device is 2.34 nm (i.e., 600 nm divided into 256 regions).

The total observation time for one spectrum is dependent upon the shutter speed and on the mode selected for setting the shutter speed. The shutter speed can be manually set or selected automatically by the controller unit based on at least two sample scans of the scene irradiance prior to recording the actual measurement. Use of a manual setting usually results in an observation time of a fraction of a second, whereas the automatic approach will slow down the process by the amount of time required to make the two or more additional scans. Either method results in an observation time which is much faster than that which can be achieved by spectrometers that do not use linear array technology. This is a key attribute of this particular spectrometer which makes it ideal for use from a less than stable platform such as a helicopter (i.e., it is much easier to maintain platform stability during a measurement taking a few seconds, than it is to maintain stability for one spectrum measurement taking up to a minute or more). Additional flexibility in the use of the SE-590 is provided by the availability of interchangeable 1° and 20° FOV lenses for the optical scan head. During the check-out mission we equipped the SE-590 with the 1° FOV lens to make it compatible in viewing angle with the Barnes radiometer described above[2]. We also elected to use the automatic shutter setting feature because: (a) we had no prior experience in using the device from

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[2] [NOTE: We have requested Spectron Engineering to manufacture a 15° FOV lens to provide additional compatibility with the Barnes instrument.]

an aerial platform and, therefore, we did not know how the intervening atmosphere might effect the settings normally used on the ground, and (b) we planned to acquire measurements over a variety of cover types which varied greatly in reflectance properties, therefore, one preselected manual setting would have been inadequate. A disadvantage associated with the use of the automatic shutter setting mode was that the Barnes and SE-590 could not be triggered simultaneously. There is as much as a 1.5 second indeterminacy of when the measurement spectrum is acquired due to the procedures used to automatically set the shutter speed.

The SE-590's controller unit contains a 12 bit microprocessor which is used to control operation of the optical scan head, all internal controller functions, and the operation of the external peripheral devices. A 16 key hexidecimal keypad for operator control is located on the front panel next to a four digit LED window. The top of the controller unit has a built-in data logging and playback micro-cassette player/recorder. It takes approximately two seconds to write an observation onto tape[3], and each of the micro-cassettes holds approximately 40 observations (i.e., complete spectral scans) per side. Outputs from the controller unit include oscilloscope data and synchronization signals, digital printer/plotter information, X-Y plotter information, a 35 mm camera signal, and RS-232 compatible signals for data transfer to an external general purpose computer. An oscilloscope was mounted inside the helicopter during the mission so that we could view sample data at any time to verify proper instrument performance.

Film camera. A photographic record of ground cover conditions was desired for each individual set of spectral data acquired during the mission. A boresighted Hasselblad 70mm camera was used. It was equipped with an 80mm lens and loaded with Kodak 2443 color infrared film. This set up provided a useful picture of a large area surrounding the actual sample point (i.e., ≅210 meters^2; see Figure 6), but it was inadequate for pinpointing the exact location and/or analyzing the cover conditions within the actual sample area. For future missions, we plan to use the Hasselblad to obtain the big picture, plus a 35mm research camera equipped with a long enough lens to photograph only the sample area.

Video camera. A video camera was also mounted in a boresighted fashion beside the equipment described above. This provided real-time black and white video output which could be viewed by the instrument operators in the rear of the helicopter. This proved to be an invaluable tool for ensuring that we were obtaining data over the desired cover type. Without such a device, the instrument operators would have no way of seeing or verifying what was beneath them. The camera lens used during our mission was of fixed focal length. It would be ideal if one could make arrangements for zoom capabilities such that small targets (e.g., a balloon marking the center of a forest plot of interest) could be more easily detected from higher altitudes.

III. INSTRUMENT CALIBRATION CONSIDERATIONS

Calibration of the scanning devices used during our helicopter mission was required, but proved to be a difficult problem. Ideally, a reference standard, such as a barium sulfate panel, should be observed after each spectrum is acquired. This feat is difficult during ground data collection and it proved to be, for all practical purposes, impossible to do during a helicopter flight.

Having the optical scanning heads rigidly mounted underneath the helicopter presented a major problem in obtaining reference panel readings before and after our check-out mission. We attempted to hover over a barium sulfate reference panel shortly after take-off (Figure 1), but the target was too small and we had to hover so low that the helicopter itself was cutting off a portion of the incoming solar radiation. As a back-up, we had staked out a 6 x 6 meter white canvas panel and we obtained several reference scans of this canvas panel at the beginning and end of the two hour mission. During the mission, we kept a pyranometer operating at the airport to provide a record of any fluctuations in solar radiation which should be accounted for in processing the data.

After the mission was completed, we mounted the Barnes MMR 8-band radiometer and the SE-590 spectrometer on a truck boom to characterize the reflectance characteristics of the canvas panel relative to a barium sulfate reference panel. Analyses of these data revealed

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[3] [NOTE: As discussed, the observation time can vary between a fraction of a second, up to perhaps two seconds. Therefore, the total time between two successive observations will be about four or five seconds.]

that the canvas panel was not an ideal reflector. It provided approximately 85% reflectance over the 0.4 - 1.0 μm range covered by the SE-590 and the first four bands of the Barnes instrument, and 50% reflectance or less in the three shortwave IR bands of the Barnes instrument.

If duplicate instruments are available, one could use an alternate approach to that described above. One instrument could be kept on the ground viewing a reference panel during the entire mission. These data could be used to calibrate the data acquired by the duplicate instrument mounted in the helicopter. The reliability of this technique necessarily drops off if the helicopter strays significantly (i.e., greater than 10 to 15 km) from the geographic location of the ground-based calibration instrument. Also, it would be necessary to make simultaneous readings over a common reference panel with both instruments immediately before and after the mission to facilitate interinstrument calibration. Researchers working out of the NASA/Johnson Space Center utilized this technique with apparent success during the summer of 1983 (Pitts, personal communication).

An additional problem in the calibration procedures which has not yet been resolved, is the effect of atmospheric attenuation differences between target measurements taken at 300 meters and the calibration panel measurements acquired at no more than 20 meters above the panel. The optical depth of the atmosphere is greatest in the lowest portions of the atmosphere. Even at relatively low altitudes above the ground, such as the 300 meter acquisition altitude employed during our mission, significant scattering and absorption of the surface reflected radiance may be encountered. To characterize this effect may require the use of calibration targets of sufficient size to be readily observed from 300 meters (e.g., the concrete aprons of airport runways). Evaluation of this problem is still under investigation.

IV. SAMPLE SPECTRA

The primary goal of our check-out mission was to obtain first hand experience in collecting spectral data from a helicopter before initiating a major data collection effort based on using such a platform. A secondary goal of this initial mission was the acquisition of representative, high-quality spectral data of a variety of cover types for the purpose of evaluating instrumentation performance. To keep the overall expense of the mission at a minimum, while fulfilling our pre-mission goals, we decided to: (a) operate out of the Wallops Island facility where the helicopter is based and to collect measurements of targets within approximately 15 km of the Wallops facility in order to minimize non-acquisition flying time, and (b) acquire an average of six observations for any given target to provide enough information to minimally assess target or instrument variability.

The mission was conducted on August 24, 1983[4]. This date was driven by the limited, simultaneous availability of the helicopter *and* the remote sensing instruments, and on a 24-hour prediction for clear skies. A few thin cirrus clouds drifted over the site during the mission and atmospheric turbidity was relatively high, but we did not feel that the prevailing weather conditions would significantly impact our mission objectives. In addition, either the helicopter and/or the Barnes instrument were reserved for use by others for several days into the future, such that rescheduling the mission would have been very difficult.

We collected a total of 183 spectral measurements over twelve different cover types. We have selected 58 spectra of eight different cover types (Table 1) for presentation in this paper based upon a post-mission analysis of the pyranometer data and the aerial photography acquired with each spectral measurement. The pyranometer data verified that solar irradiance was minimally effected by atomospheric variability during the time of acquisition of the selected spectra (i.e., minimal cloud cover overhead at the time of acquisition) and the aerial photography verified that these measurements were collected well within the boundaries of a specific cover type.

Due to the various calibration problems already discussed, the accuracy of the calibrated reflectance measurements presented here is uncertain. However, calibrated measurements are presented in this paper for two primary reasons: (a) to compare measurements recorded in equivalent portions of the spectrum by the two instruments (i.e., a check of the performance of the SE-590 spectrometer against the widely accepted Barnes radiometer) and (b) to evaluate the relative differences in reflectance characteristics of different cover types.

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[4] [NOTE: July and August, 1983, were extremely dry months in the general location of the study area, and the vegetative canopies for corn and grass were poorly developed and stressed.]

Figure 4 is a plot of the percent reflectance recorded by the Barnes MMR and SE-590 instruments during a single, representative acquisition over a hardwood forest canopy. Inspection of this plot affords a qualitative comparison of the performance of the two instruments over that portion of the spectrum covered by both instruments (0.4 to 1.0 μm). They appear to agree with one another quite well. In addition, notice that the SE-590 curve for this hardwood forest canopy is representative of a typical green vegetation reflectance curve. For example, chlorophyll absorption bands centered at approximately 0.45 and 0.68 μm are readily detectable, as is the sharp rise in near IR reflectance beginning at approximately 0.70 μm, followed by a flattening off of reflectance between approximately 0.75 and 0.90 μm. A water absorption band centered at approximately 0.94 μm is responsible for the sharp reduction in reflectance in this region.

A more quantitative comparison of the two instruments is provided in Figures 5a and 5b. These figures represent scatter plots of the measurements acquired by both instruments over the eight cover types summarized in Table 1. Figure 5a is a plot of Barnes band 3 (0.63 - 0.69 μm; the red band) reflectance values against SE-590 reflectance values averaged over the equivalent wavelength interval. Note that three distinct clusters of reflectance values (low values for forests and soybeans; medium values for grass and corn; and high values for soil, concrete and sand) are readily apparent and that they have a strong linear relationship to one another. The correlation coefficient for these points is 0.99.

Figure 5b is similar to Figure 5a, but it represents a plot of Barnes band 4 (0.76 - 0.90 μm; the near IR band) reflectance values against SE-590 reflectance values averaged over the same wavelength interval. This plot indicates that there is also a linear relationship between the near IR reflectance values derived from the two instruments. However, the near IR data are more scattered in appearance than the red band data and there are no obvious clusters within the data set. The correlation coefficient for the Barnes/SE-590 near IR data is 0.88, as compared to 0.99 for the red band. Thus, the two instruments appear to be in good agreement with one another in both the red and near IR regions, but there is greater variability in the near IR reflectance values derived from the two instruments. This variability may be a function of: (a) differences in the timing of the acquisitions for each instrument such that both instruments may not have been looking at exactly the same portion of a target, or (b) the fact that the reflectance values in the near IR are considerably higher than those in the red band and, therefore, there would be greater inherent variability in the data. Variability due to the acquisition timing problem would be expected to be greatest for those targets which have the greatest inherent spatial variability, such as forests. This supposition was substantiated by the fact that when the 27 reflectance values for the forests were deleted from the near IR data set, the correlation coefficient rose from 0.88 to 0.97.

Representative SE-590 spectra from each of the nine cover types illustrated in Figure 6 (i.e., the eight cover types summarized in Table 1, plus water) are plotted in Figure 7. Each of the images in Figure 6 represents the aerial photograph taken simultaneously with the spectral data plotted in Figure 7. The actual area sampled by the sensors is located at the center of each of these photographs and is very small (i.e., 5.5 meters in diameter) in comparison to the entire area covered by each photograph (i.e., ≅210 meters^2). Close inspection of Figure 7 will reveal that the reflectance curves derived from the SE-590 data for the various cover types are comparable to published reflectance curves for major earth surface materials (i.e., vegetation, soil, and water; Swain and Davis, 1978).

A preliminary evaluation of atmospheric water vapor absorption effects can be made by comparing the magnitude of the dip in the reflectance curve for sand in the 0.94 μm region, against that for a similar target, such as concrete, which was observed from the ground and from an altitude of 300 meters (Figure 8). The sand measurement was acquired from an altitude of approximately 25 meters, as opposed to 300 meters for the other cover types, because the strip of sand along the beach at Wallops Island was too narrow to ensure the acquisition of pure target signals from 300 meters. Thus, if atmospheric water vapor were the primary cause of the decrease in reflectance in the 0.94 μm region, the magnitude of the decrease for the sand target would be less than that for the other targets because of the significantly lower observation altitude for sand (i.e., less intervening atmosphere). Note that the magnitude of the 0.94 μm water absorption phenomenon in the ground-based concrete spectra is similar in magnitude to the dip in the reflectance of the sand target, and the depression in both curves is less than that for the concrete spectra acquired from 300 meters. Thus, the amount of absorption associated with atmospheric water vapor, as opposed to the water content of the target itself, may be derivable from the difference in the magnitude of the reflectance depression between the sand and concrete spectra acquired from the helicopter.

Figure 9 permits a closer comparison of the visible and near IR reflectance characteristics of a pine stand versus a hardwood stand. The curve plotted for each cover type represents a mean response curve calculated from five individual spectra. A one standard deviation error region is plotted about each curve and serves to illustrate the relative variability and overlap of each set of data.

An anomaly associated with Figure 9 is that the averaged pine spectra is higher in reflectance in the near IR region than the averaged hardwood spectra. This is contrary to the widely accepted fact that hardwood foliage is a better reflector in the near IR region than coniferous foliage. Also, conifers always appear to be darker than hardwoods in color IR aerial photography. The reverse trend illustrated in Figure 9 is largely due to the fact that: (a) the reflectance curves are based upon an insufficient sample size (i.e., five observations for each cover type) given the inherent variability of forest stands, and (b) for this set of data, the pine canopy was more closed and homogeneous than the hardwood canopy, and, therefore, there were fewer shaded portions within the pine canopy that might cause reduced reflectance.

Figures 10a and 10b are plots of the five individual spectra for the pine and hardwood cover types, respectively. Notice that the average pine reflectance curve in Figure 9 was dominated by three observations of high reflectance, as opposed to one observation of intermediate reflectance, and one of lower reflectance (see Figure 10a). The average hardwood reflectance curve was dominated by three observations of intermediate reflectance, with additional, single observations of high and low reflectance (see Figure 10b). The low observations for both cover types were undoubtedly areas of dense shadow, whereas the high observations were probably acquired from fully illuminated portions of the canopies. The intermediate observations probably occurred when both illuminated and shaded portions of the canopies fell within the sensor's IFOV.

Similar analyses of the spectral reflectance data for the non-forest cover types indicated that the forest canopies were by far the most variable. There is nothing particularly new about such an observation, but it bears repeating because it implies that in order to adequately characterize forest spectral properties one must acquire numerous measurements (i.e., on the order of 20 to 40 acquisitions) while hovering over a given parcel of forest canopy.

V. SUMMARY

The collection of forest canopy spectra from helicopter platforms is perhaps the most logical and attractive approach for bridging the gap in our understanding of this spectrally and spatially complex cover type. However, a number of potential obstacles to helicopter use must be overcome, and the learning experience can be expensive. Some of the key factors discussed in this paper are summarized below.

The remote sensing instruments to be used should be rugged, portable (i.e., small and lightweight with an independent power supply), easy to operate, capable of rapid-fire acquisition and storage of data, and offer interchangeable lenses of varying FOV. If more than one instrument will be used, precautions should be taken to ensure that the instruments have the same IFOV, can be activated at the same time, and that they have nearly equivalent scan or observation times.

The methodolgy to be used in calibrating the selected remote sensing devices before, during and after the mission should receive major attention. Calibration is an absolute requirement, but it is perhaps the most challenging obstacle associated with using a helicopter as a remote sensing platform. In addition to the difficulties associated with obtaining reference panel readings before and after a mission, there is the problem of potential atmospheric effects in the data which are not adequately accounted for by observing a reference target from lower altitudes than the targets of interest.

The amount and kind of sophisticated equipment and skilled personnel needed to support the mission, both in the air and on the ground, should be carefully considered. The poor working environment within a helicopter, as well as difficulties associated with ensuring that the helicopter is indeed hovering over the target of interest, often results in the need for more people or equipment than one would normally expect.

Care should be taken to ensure that an adequate number of samples will be taken over any given cover type to properly characterize the target's reflectance properties. The actual number of samples that are needed will depend on the inherent variability of the target and the eventual application of the derived information.

Finally, it is highly recommended that anyone planning to use a helicopter for the first time should always plan a check-out mission before attempting to acquire data of research quality.

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TABLE AND FIGURES

Table 1. Summary of the eight cover types for which sample data are plotted in Figures 5a and 5b. Photographs of these cover types are shown in Figure 6.

hardwood	bare soil
pine	concrete
soybeans	sand
corn	grass

Figure 1. Photograph of the Bell UH-1B Iroquois (HUEY) helicopter used as a data acquisition platform. This photograph was taken as the pilot attempted to hover over a barium sulfate reference panel (weighted down with sand bags) at the beginning of our check-out mission.

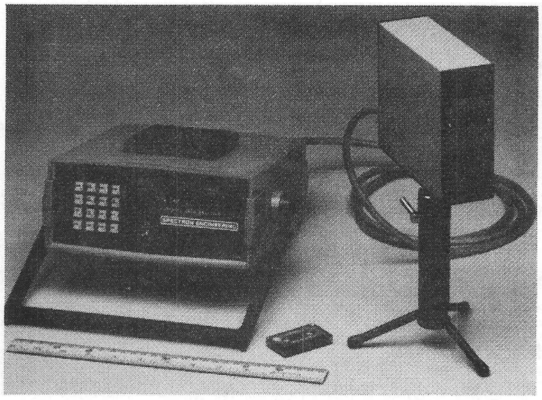

Figure 3. Photograph of the Spectron Engineering SE-590 spectrometer. Major components are the optical head and the microprocessor-based controller unit.

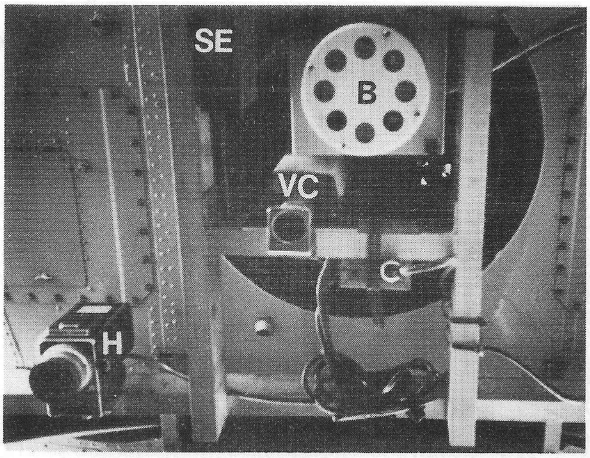

Figure 2. Photograph of the instrumentation package mounted underneath the helicopter. Key devices were the optical heads for the Barnes MMR 8-band radiometer (B) and the SE-590 spectrometer (SE), as well as a Hasselblad 70mm camera (H) and a video camera (VC).

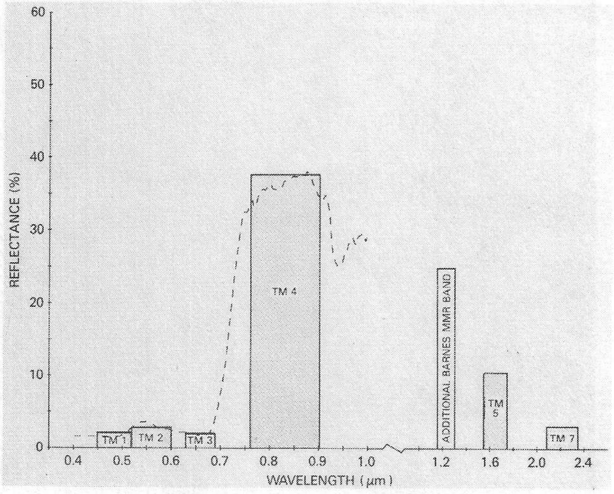

Figure 4. Plot of the spectral reflectance characteristics of a mixed hardwood stand as recorded by the Barnes MMR 8-band radiometer and the SE-590.

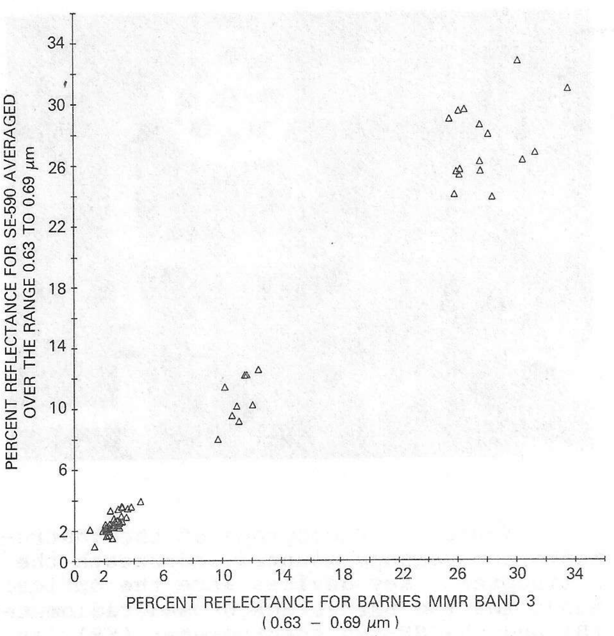

Figure 5a. Scatter plot of Barnes band 3 (0.63 - 0.69 μm) reflectance values versus SE-590 reflectance values (averaged over the equivalent wavelength interval) for 58 observations acquired over eight different cover types.

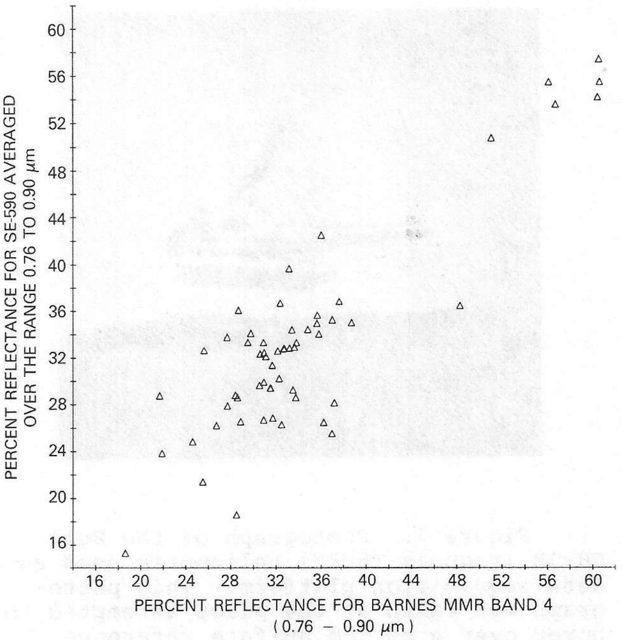

Figure 5b. Scatter plot of Barnes band 4 (0.76 - 0.90 μm) reflectance values versus SE-590 reflectance values (averaged over the equivalent wavelength interval) for 58 observations acquired over eight different cover types.

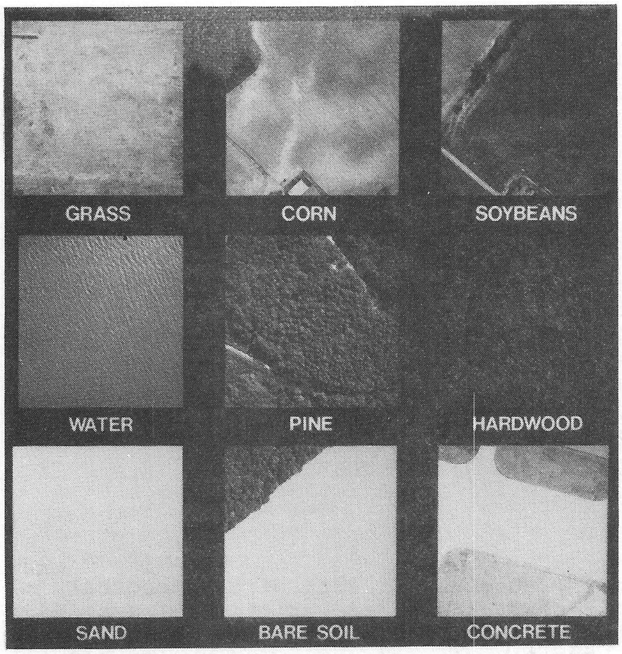

Figure 6. Black and white rendition of the color IR aerial photography acquired from the helicopter. Each photograph was taken simultaneously with the SE-590 spectral reflectance data plotted in Figure 7.

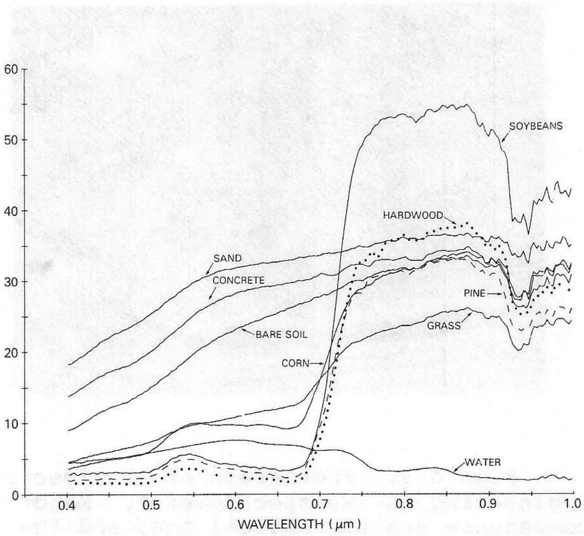

Figure 7. Representative plots of the spectral reflectance data acquired over nine different cover types, from an altitude of 300 meters (25 meters for sand), using the SE-590 spectrometer.

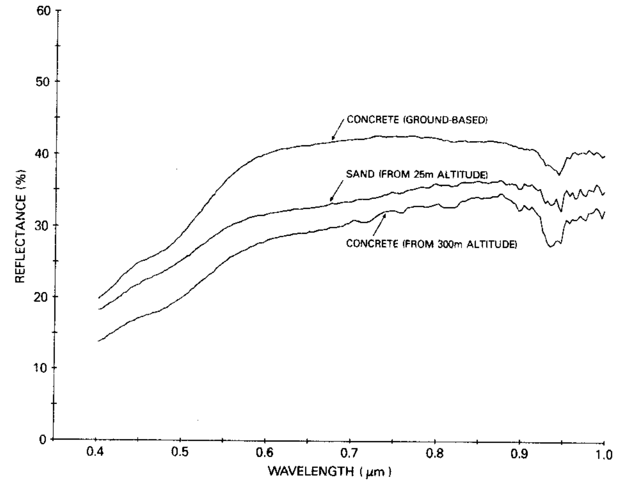

Figure 8. Plot of the sand and concrete reflectance curves shown in Figure 7, plus a concrete reflectance curve acquired on the ground (i.e., no intervening atmosphere between target and sensor).

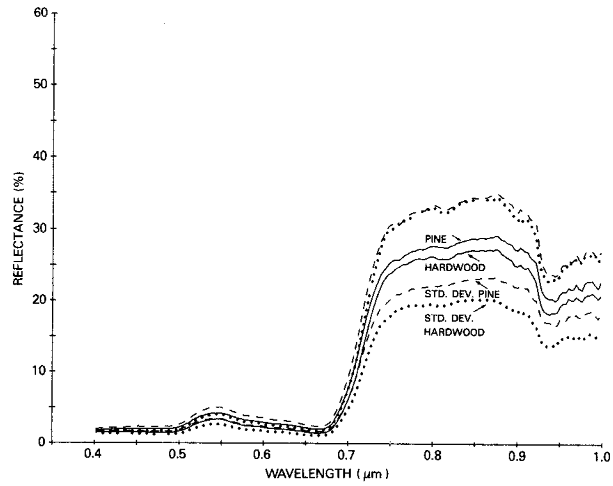

Figure 9. Plot of average reflectance, plus or minus one standard deviation, derived from five observations of a pine stand and five observations of a hardwood stand.

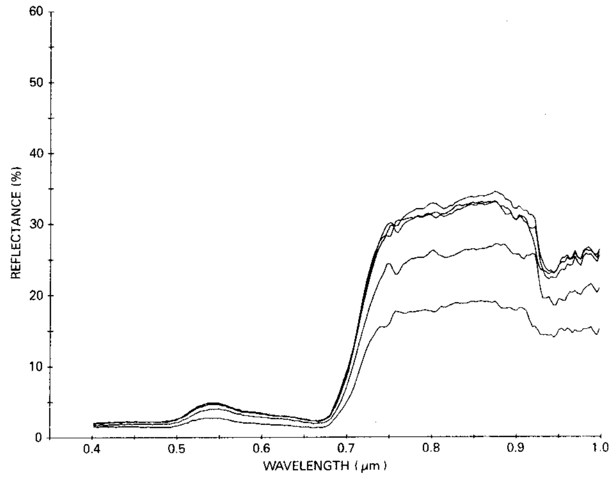

Figure 10a. Plot of the five individual observations of a pine stand which were averaged to obtain the spectral reflectance data shown in Figure 9.

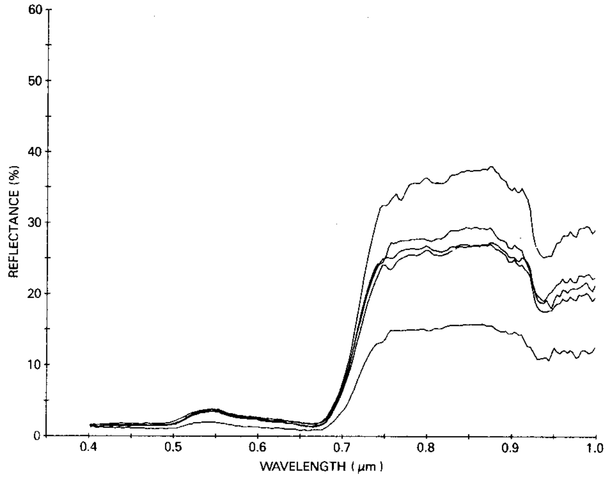

Figure 10b. Plot of the five individual observations of a hardwood stand which were averaged to obtain the spectral reflectance data shown in Figure 9.

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