REMOTE SENSING APPLICATIONS IN FORESTRY

THE DEVELOPMENT OF SPECTRO-SIGNATURE INDICATORS OF ROOT DISEASE IMPACTS ON FOREST STANDS

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Pacific Southwest Forest and Range Experiment Station
Forest Service, U. S. Department of Agriculture

Annual Progress Report

30 September, 1968

A report of research performed under the auspices of the

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Frontispiece.--A merchantable stand of 50 year old Douglas-fir "rot-thrown" by _Poria weirii_ root rot disease. Tree roots disintegrated by this disease can no longer sustain or support affected trees.

ABSTRACT

Investigations of several remote sensing techniques were continued in 1968 to discriminate between healthy Douglas-fir trees in the Pacific Northwest and those affected by *Poria weirii* root rot disease. This one disease causes more damage to Douglas-fir timber than is caused by either fire or insects. Both aerial and ground operations were conducted to ascertain the type of airborne sensor best suited to collecting data from trees under stress caused by root disease infection.

One of the most significant features of this year's investigations was the development of a reconnaissance device consisting of a thermal infrared radiometer and, collated with it, an instant replay video-scan system for use in survey operations from a helicopter or fixed wing aircraft. This system shows promise of providing thermal profiles of the forest canopy from which the incidence of forest diseases can be determined. Aerial photography is obtained simultaneously to facilitate the location, on the ground, of points along the thermal profile.

In August, 1968 a reconnaissance mission was flown of our test sites in the Pacific Northwest by the P3A Lockheed Electra aircraft which is based at NASA's Manned Spacecraft Center near Houston, Texas. An analysis of the multispectral imagery from that mission is pending. It is anticipated that data obtained by the sophisticated sensors

operated from this aircraft will indicate the most definitive part of the electromagnetic spectrum for use in detecting trees under stress from root rot disease. New research in conjunction with the NASA flyby has been started on the physiological parameters of healthy and root rot infected Douglas-fir trees.

ACKNOWLEDGMENTS

This research was performed under the sponsorship and financial assistance of the National Aeronautics and Space Administration for the Manned Earth-Orbital Experiment Program in Agriculture/Forestry (Contract Number R-09-038-002).

The cooperation and assistance of various members of the following organizations have facilitated implementation of this remote sensing project during the past year:

Pacific Northwest Regional Office, U. S. Forest Service, Portland, Oregon.

Pacific Southwest Forest and Range Experiment Station, U. S. Forest Service, Berkeley, California.

Pacific Northwest Forest and Range Experiment Station, U. S. Forest Service, Portland, Oregon.

Wind River Forest Nursery, Carson, Washington.

Bonneville Power Administration, U. S. Department of Interior, Vancouver, Washington.

NASA - USDA Forestry Remote Sensing Laboratory, University of California, Berkeley, California.

Barnes Engineering Company, Stamford, Connecticut.

Weyerhaeuser Company, Aberdeen, Washington

Port Blakeley Mill Company, Elma, Washington.

Oregon Audio Video Systems, Portland, Oregon.

The time and experience of many technical and professional scientists from these organizations were willingly provided at no cost to NASA in the development of techniques and methods to solve the root rot disease problem that so vitally affects one of our major natural resources. Their contributions to this research study are gratefully acknowledged.

TABLE OF CONTENTS

THE DEVELOPMENT OF SPECTRO-SIGNATURE INDICATORS OF ROOT DISEASE ON LARGE FOREST AREAS

by

John F. Wear

INTRODUCTION

Multispectral remote sensing techniques continue to be tested and exploited in an effort to evaluate certain forestry problems. These problems are of economic and physical importance in relation to the total supply of our earth resources. Forest diseases cause reduction of growth and extensive loss of the timber resource each year. The research program conducted this year and described herein is a continuation and expansion of research started under NASA contract R-09-038-002 and reported under NASA-CR-78-781.

Spectral signature indicators of tree killing diseases such as Poria weirii, (Murro) may help to detect and locate centers of distressed timber that would otherwise be unsalvaged and from which the disease would continue to spread. With adequate remote sensing survey techniques forest managers will be able to protect forest resources more effectively and maximize the use of diseased timber. The serious impact of forest diseases on our world timber supply could thus be greatly reduced.

More than half of all disease-induced timber losses suffered in the United States each year (170 million board feet of timber) are caused by Poria weirii root rot disease. These heavy losses occur in extensive stands of Douglas-fir, Pseudotsuga menziesii (Mirb. Franco), a major commercial timber species of the Pacific Northwest. Trees weakened by the disintegration of their root systems are highly subject to "wind throw." (Frontispiece)

Root rot infection centers are distributed erratically in forest stands, are relatively inaccessible, and in their initial stages are of insufficient volume to warrant economic salvage. However, if the forest manager knew the location of these many centers, he frequently would be able to develop a logging plan whereby the economic removal of diseased timber could be accomplished.

The inefficiency of ground survey methods to locate and appraise infection centers of Poria weirii root rot is well known. Present research seeks to develop more efficient survey methods for locating and evaluating the incidence of root rot disease centers (Figure 1) in forested areas by exploiting new remote sensing techniques.

Remote sensing research on Poria weirii root rot disease was continued during the period covered by this report in the visible, reflective infrared, and thermal infrared spectral zones of the electromagnetic spectrum. Major consideration was given to the development of an integrated video scan-infrared hear sensing system to provide temperature profiles of forest areas and to program the collection of "ground truth" for the NASA P3A (Electra) aircraft "flyby" which covered the research study plots in late August, 1968.

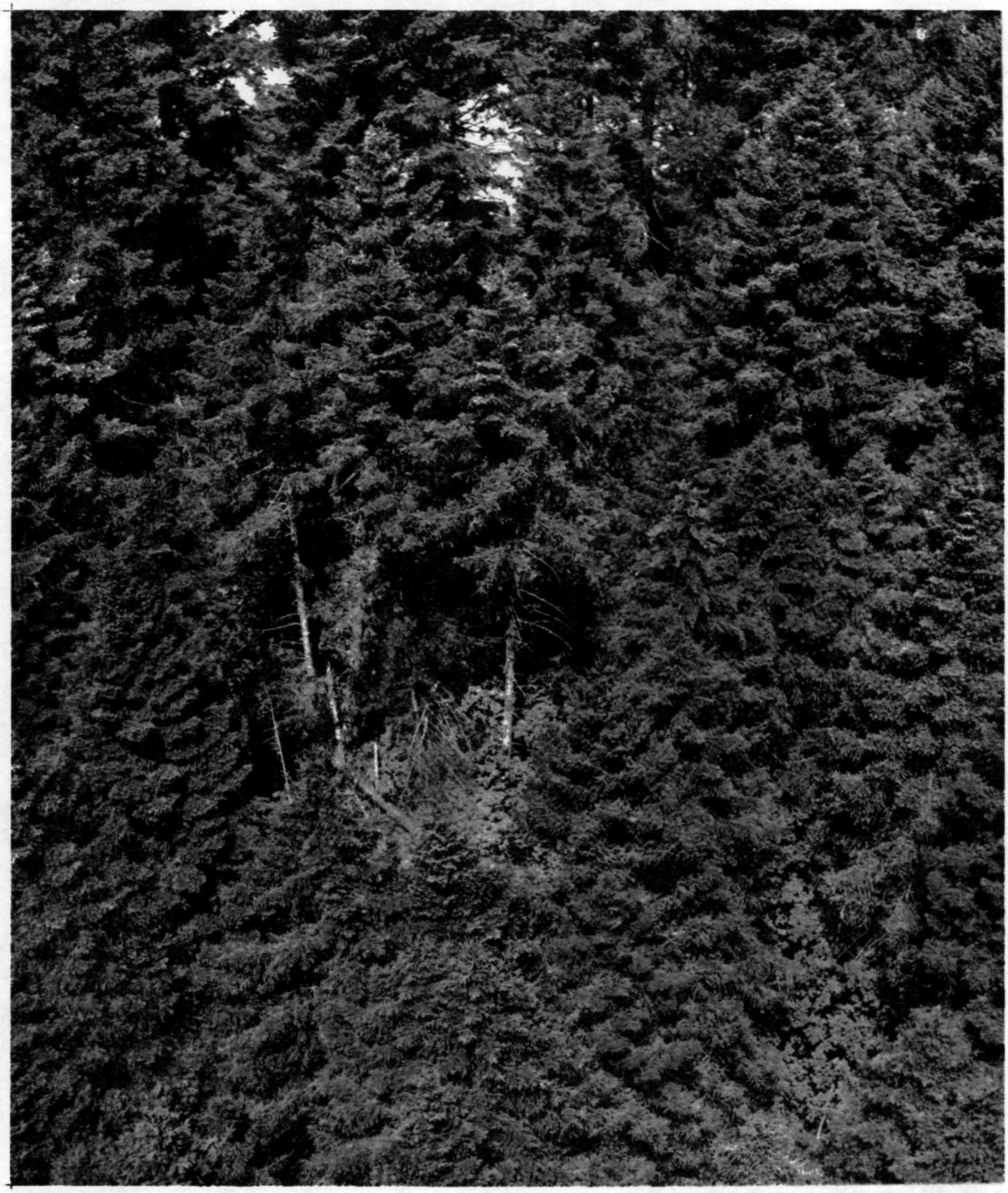

Figure 1.--Aerial oblique view of typical root rot disease center in a 60 year old stand of Douglas-fir in Washington. Distressed trees will continue to fall into opening. Single patches are uneconomic to salvage, but forest managers can develop profitable salvage operations when the locations of many disease centers are known.

LITERATURE REVIEW

In an effort to update literature reviews that were included in our previous annual reports a search was made for new publications--which might advance our knowledge regarding Poria weirii. No new publications of this type were found, however. References listed previously by the principal investigator are therefore considered as representing current published experimentation and research on this root rot problem. Literature on other root rot diseases and on various remote sensing techniques was studied for systems improvement and application to the Poria weirii root rot problem.

JUSTIFICATION

Forest diseases continue to destroy more forest resources than either fire or insects. Forty-five percent of the growth loss in forested areas of the United States is caused by tree diseases. In one recent year 300 million board feet of sawtimber was lost to root diseases alone in the United States. Losses of this magnitude create a serious impact on our decreasing supply of timber and are of great concern to forest managers and earth resource analysts.

Poria weirii root rot is by far the most destructive disease attacking Douglas-fir in Washington and Oregon. Douglas-fir represents 57 percent of the total sawtimber volume in the Pacific Northwest and a substantial portion of the United States forest resource. Therefore, an efficient root rot disease survey technique would provide tangible benefits to the forest economy of the United States. Land managers and foresters need adequate disease detection systems to reduce the impact of forest diseases on this valuable resource.

Ground survey methods to locate and appraise infection centers of Poria weirii root rot are laborious, time consuming, and costly. Forty days of effort by a two-man crew is required to obtain "ground truth" on a single section (640 acres) of timbered land. Present research seeks to develop more efficient survey methods for locating and evaluating the incidence of root rot disease centers in forested areas by exploiting new remote sensing techniques.

METHODS AND PROCEDURES

The remote sensing research covered in this progress report concerns the testing and development of airborne sensors that might be effective in discriminating root rot infected trees from healthy trees. This is a continuation of previous experimentation in three parts of the electromagnetic spectrum; the visible, reflectance infrared, and thermal infrared. In this report brief description of the "state of the art" understanding in each of these areas of aerial research, the new remote sensing system designed for highly definitive "ground truth" and aerial survey operations, and the NASA flyby are considered separately with appropriate illustrations.

A. Ground Truth

Before an orbiting satellite survey program for assessing root rot infection centers in forest areas can be implemented, considerable basic research in applying remote sensing techniques at lower flight altitudes is required. Trees infected with root rot do not show visual symptoms that would normally discriminate healthy from diseased trees. Only in the most advanced stage of decline do infected trees exhibit slight changes in crown structure and foliage complement and color. Therefore, successful estimations of Douglas-fir characteristics will require testing of various remote sensors at several wavelengths and with adequate "ground truth". The physiological parameters of healthy and diseased trees (foliar temperature, soil moisture tension and availability, solar energy input and output, transpiration rate, leaf moisture tension, spectral reflectance, and others) need to be evaluated for a comprehensive understanding of the Douglas-fir disease problem.

The research study reported herein was conducted on 90 trees on six 10-acre plots located in three stand-age classes on two different site conditions. Fifteen Douglas-fir trees in each of three stand-age classes, young growth (40 to 80 ft. tall), second growth (90 to 120 ft. tall), and old growth (130 to 225 ft. tall) were selected from the ground on test sites near Wind River and Elma, Washington. Five trees were picked in each age class to represent three tree condition classes; healthy, root rot infected with no visible crown symptoms, and infected with visible crown symptoms. Trees were marked on the ground with painted numbers and in the tree tops with highly fluorescent cloth streamers; yellow for healthy trees, orange for infected without symptoms, and hot pink for diseased with symptoms. (Figure 2) Presence or absence of root rot disease was determined by increment core samples taken about six inches above ground

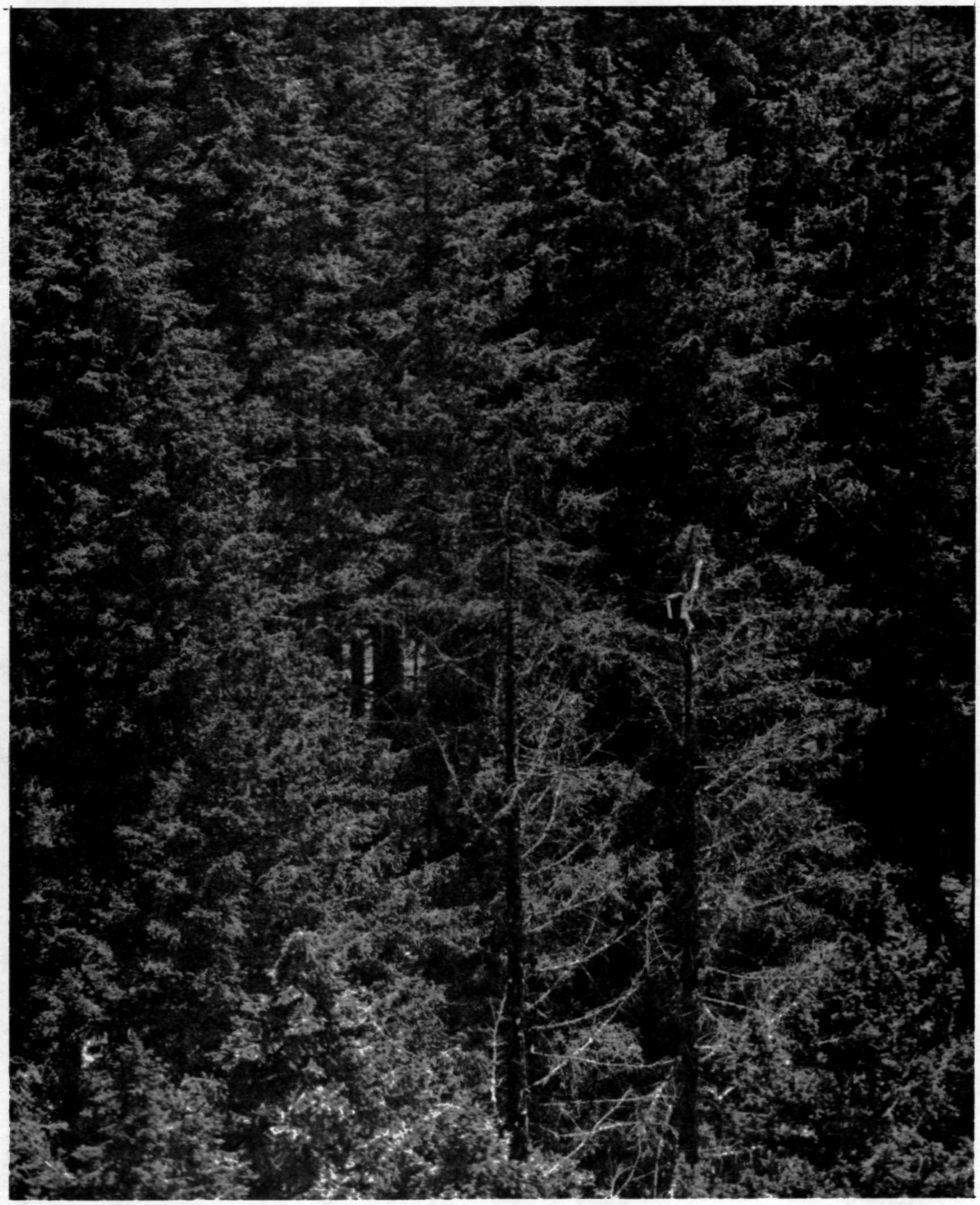

Figure 2.--Streamer-type tree markers flung into the tree crowns from a helicopter identify individual trees by color code for each condition class. Markers are visible for more than a mile.

level (exhuming root structures is not feasible under forest conditions to determine the early penetration of the root rot).

B. Aerial Photography

The making of a spectrometric analysis of Douglas-fir foliage from the tops of healthy and infected trees was considered essential to ascertain the best film-filter combination for an aerial photo survey of root disease impact over large forest areas. To collect many treetop foliage samples in a very short time for the spectrometric analysis, a special pole pruner was designed and an efficient helicopter sampling procedure developed by the principal investigator. Foliage collections were made during the first field season at three different periods corresponding to three different tree moisture conditions (i.e., those prevailing during overwintering, full new growth, and late-summer hardening) to determine any significance in season of the year for discriminating healthy from diseased trees.

Foliage samples of all study plot trees were processed immediately after each collection, flown to California under refrigeration, and spectrally analyzed in a G. E. spectrophotometer at the University of California in Berkeley. The foliar reflectance curves were programmed in the second year with four black-and-white photographic films and 23 Eastman filter curves using a SANTAD, IBM 7094 Fortran IV computer program. We predicted the likeliest film-filter combinations to identify tree crown condition from the SANTAD program by interrelating: (1) the spectral sensitivities of film (2) the spectral transmissivities of filters, and (3) the spectral reflectivities of the foliage samples. Results of this analysis showed that no consistent film-filter combination is applicable to all three moisture periods of the year. The most promising and realistic combinations for aerial photographic testing at the three seasonal periods are: (1) IR film with no filter for over wintering foliage, (2) Plus X film with WR61 filter for foliage with new spring growth and (3) Super XX with WR 47B for summer hardened foliage.

Photography was scheduled in 1968 for the three periods of foliar condition. Ektachrome and Ektachrome IR films were included in the tests. The broad spectrum of colors provided by such films and the possible advantages of multispectral interpretation with various combinations of black-and-white photography offered important possibilities for discriminating healthy from diseased trees. The taking of photography on the Elma and Wind River areas, scheduled for the first two weeks of May, proved unfeasible this year because of an extended period of adverse weather conditions. The new Maurer KS 67A 70mm camera purchased by the U.S. Forest Service for use from a Cessna 180 failed during the first run (across the Elma plot #6) on an excellent day in early July. Magazine and camera were returned to the factory for overhaul. The NASA P3A flyby in late August was counted on to provide the photographic imagery for the third sampling period of the year. Details of the NASA flight are considered in a separate section.

Vertical photogra phy of ponderosa pine trees under stress from disease and from insect attacks and from various unknown causes was obtained of timber stands in eastern Oregon in mid-June. A 12-inch focal length K-17 aerial camera was used in a U. S. Forest Service Cessna 180 airplane to obtain 1/4000, 1/8000 and 1/16,000 scale photography of a group of selected trees. In September of 1967, after a prolonged drought, trees under stress had been identifiable on "off-color" Ekta IR film at a scale of 1/15,840. The Ekta IR photography was flown commercially in an attempt to locate stress trees that should be harvested within the next two years to maximize timber values. The excessively blue cast to the film was helpful in delineating such trees. Replication of this result would benefit remote sensing research on Poria weirii root rot and would help forest managers maintain healthy stands and minimize timber mortality.

It was not possible to duplicate the "off-color" Ekta IR in June and trees under stress were not discerned on any scale or filter combination. Further aerial photographic tests will be made in October, 1968 in an attempt to replicate the 1967 previsual indications of trees under stress.

C. Infrared Heat Sensing Techniques

Sensing beyond the visible and near infrared regions of the electromangetic spectrum (i.e., in the middle infrared) has been investigated since 1966 with some promising results. Trees under severe moisture stress may not be able to transpire as readily and stay as cool as healthy trees. A tree of declining vigor caused by drought, partial destruction of root systems (root rot disease), or insect attack may be unable to absorb and transport moisture through roots and stem to the tree crown. Tree vigor and the availability of moisture in the tree crown are two important factors governing the temperature of a tree. Root rot infection appears to affect tree temperature at certain times of the day and seasons of the year. The physiological changes that cause this temperature difference are not precisely understood by tree physiologists. Thus, tree physiological research is needed for forest types in the Pacific Northwest. As part of the Poria weirii study, Douglas-fir physiological parameters of healthy and diseased trees will be investigated in an effort to determine reasons for temperature differences.

Energy emitted from tree crowns in the thermal infrared part of the spectrum can be collected through either an imaging or non-imaging infrared radiometer. NASA provided IR imagery in the 8 to 14 micron band through use of the Reconofax IV in 1967 and the RS-7 in 1968. The latter data are to be analyzed this winter. No significant tonal differences between healthy and diseased trees were evident on the Reconofax IV thermal imagery.

Data derived from the Barnes Engineering PRT-5 non-imaging radiometer indicated significant temperature differences at certain times of the day between healthy and diseased trees in 1966 and 1967. Radiometer readings were taken from a semi-hovering helicopter while it was slowly orbiting around individual trees at about 150 feet above the forest canopy (Figure 3). Sightings were concentrated within the upper 30 percent of the tree crown but more than 10 feet down from the tree top. Thus, chances of including other trees or openings in the two degree cone of PRT-5 coverage were minimized. Output readings of the PRT-5 are in terms of irradiance or equivalent black body temperatures. A Mark VII Cole-Parmer chart recorder with a speed of four inches per minute

Figure 3.--Infrared heat emissions from individual trees are recorded with Barnes PRT-5 radiometer and a Cole-Parmer recorder. Helicopter is orbiting above the trees in a flat circular pattern about 150 feet above the treetops.

was collated with the electronic output of the PRT-5 (Figure 4). The first sampling period in May for the 90 test trees was cancelled because of poor weather conditions throughout the two weeks period. The second sampling period for new foliage condition was implemented in early July. Data on 45 trees of the three Elma areas and 45 trees of the Wind River areas were taken on July 2 and July 8 respectively. Readings were taken separately on the sunlit and shaded sides of the tree crown rather than taking the average for each tree. This was done because of strong indications by Gates and Weber that more significant temperature differences between stressed and healthy trees occur on the sunlit side. A third sampling of test trees with the non-imaging PRT-5 is now scheduled for early October, 1968, to supplement those taken in conjunction with the NASA Mission 78 flyby with the Lockheed P3A on August 30. Data from the RS-7 IR scanner on August 30 will be analyzed for detecting Poria root rot stressed Douglas-fir. In addition the readout from the PRT-5 aboard the P3A will be synchronized with whichever camera has been boresighted with the non-imaging radiometer for detecting the presence of large centers of trees exhibiting higher than normal temperatures.

D. PRT-5 radiometer/Video-scan system

The two successive years of promising results with a non-imaging IR radiometer indicated the need to develop an aerial scanning system for surveying large forest areas. The principal investigator conceived the idea of collating an instant replay video scan system with the PRT-5 so that the highest possible accuracy and efficiency in an aerial survey operation might be achieved. After extensive discussions with

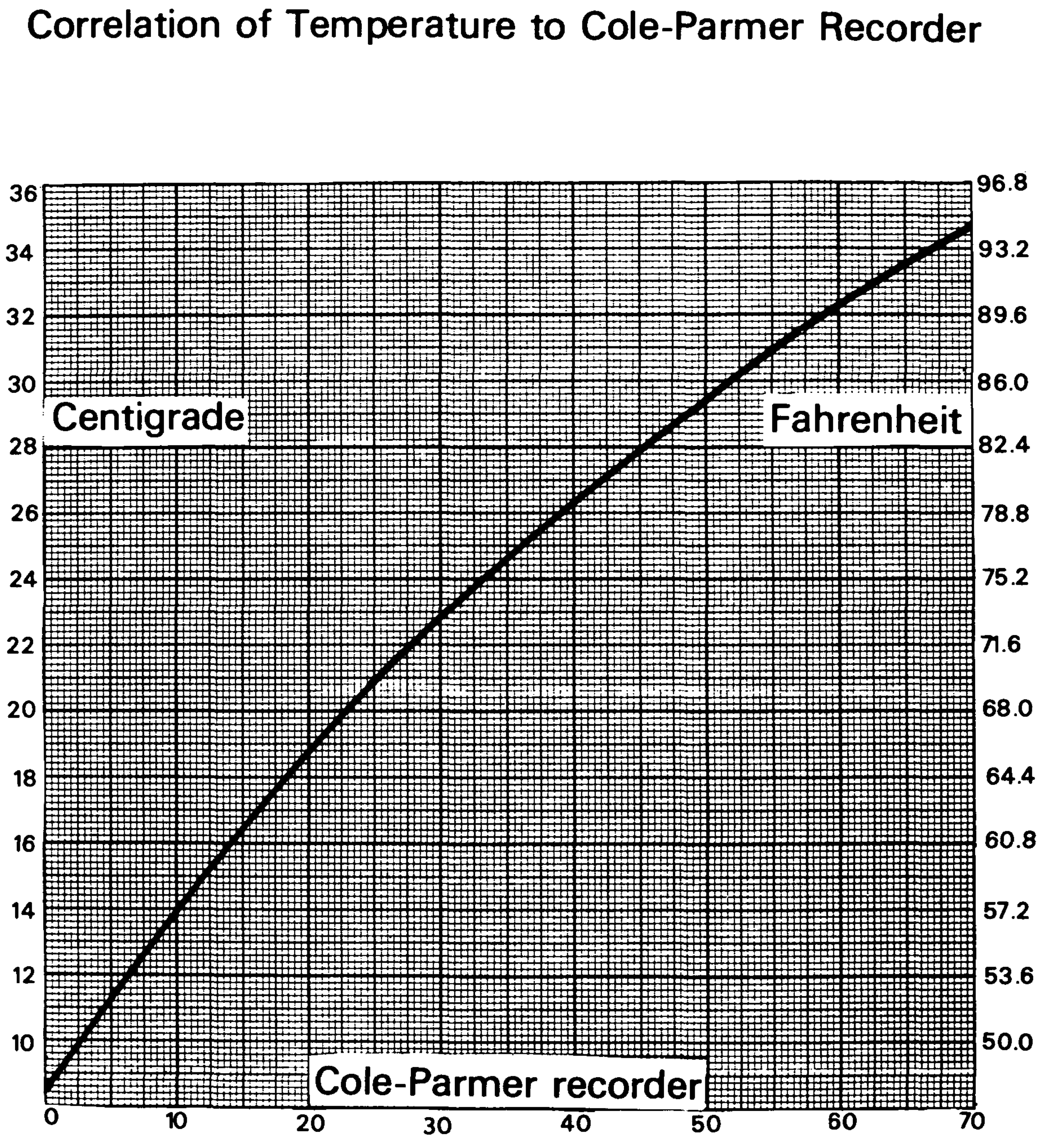

Figure 4.--Temperature conversion chart for Barnes PRT-5 radiometer and Cole-Parmer chart recorder.

Barnes Engineering personnel, TV electronic engineers, and instrument specialists of Bonneville Power Administration, a bid proposal was formulated to provide an integrated system for operation from a helicopter. Rental bids based on the purchase price were issued for the design and fabrication of the integrated scanning system. Oregon Audio Video Systems Co. was the successful bidder.

The basic objectives for the electronic video-scan equipment consisted of (1) boresighting and mounting a vidicon camera and the optical head of the PRT-5 radiometer in a vertically oriented enclosure, (2) inscribing on the lens of the vidicon camera an area-indicator for the nominal two degree coverage of the PRT-5 so that it would appear on the center of each frame of the video tape, and (3) transcribing the thermal output in digitized form from the PRT-5 to each frame of the video tape. The electronic components and engineering design needed to meet the above objectives were quite complicated and required considerable experimentation and equipment testing. Numerous delays in obtaining specific equipment prevented operational testing until the NASA flyby of August 30, the third sampling period.

The initial problem was to obtain an adequate power source for operating all electronic units within minimum electrical tolerances when using either helicopter or airplane battery power. Tests were made of gasoline generators as well as various dc to ac converters. A Topaz transistorized converter (12 volt dc to 110 volt ac) was found to provide sufficient power at 4.5 amps and 60 cycles (plus or minus .5 cycles) to operate the following: two vidicon cameras, an Ampex VR-7000 tape recorder, a Concord electronic video synchronizer, a Hickok digital voltmeter, and a Sony nine inch TV monitor. The two Ampex CC-6007 vidicon cameras were equipped with a 25mm and a 12.5mm focal length lens respectively. The 25mm focal length camera is mounted vertically with the PRT-5 optical head to cover about 80 feet horizontally from 150 feet above terrain. The 12.5 mm camera is mounted horizontally in a metal box about 18 inches from the digital output signals of the Hickok voltmeter. The Concord special effects generator or synchronizer (Figure 5) phases "in or out" either camera for optimal data fed to the tape recorder. The Ampex VR 7000 (e) is a portable videotape recorder capable of recording and reproducing both black-and-white and color (modified). It uses a single-head helical scan, has 3.5 MHz bandwidth with 350 lines horizontal resolution and a 42 db signal-to-noise ratio. It also has stop-action to permit single frame examination. It provides one hour recording time on one inch tape, and may be used with any television receiver or video monitor. The nine-inch Sony TV monitor (g) requires sun shielding for optimum use by helicopter pilot and video-scan operator.

Vibration is a major problem with any photographic or imaging system mounted to a helicopter frame. Considerable experimentation was needed to determine the least expensive but effective system of providing vidicon imagery from a helicopter that would be clearly resolvable and with sufficient detail to identify individual tree crown characteristics. Various shock mounting devices and positions on the helicopter were tried before finalizing the vertical pod (Figure 6). The basic support frame is attached rigidly to the helicopter. The helicopter vibration is

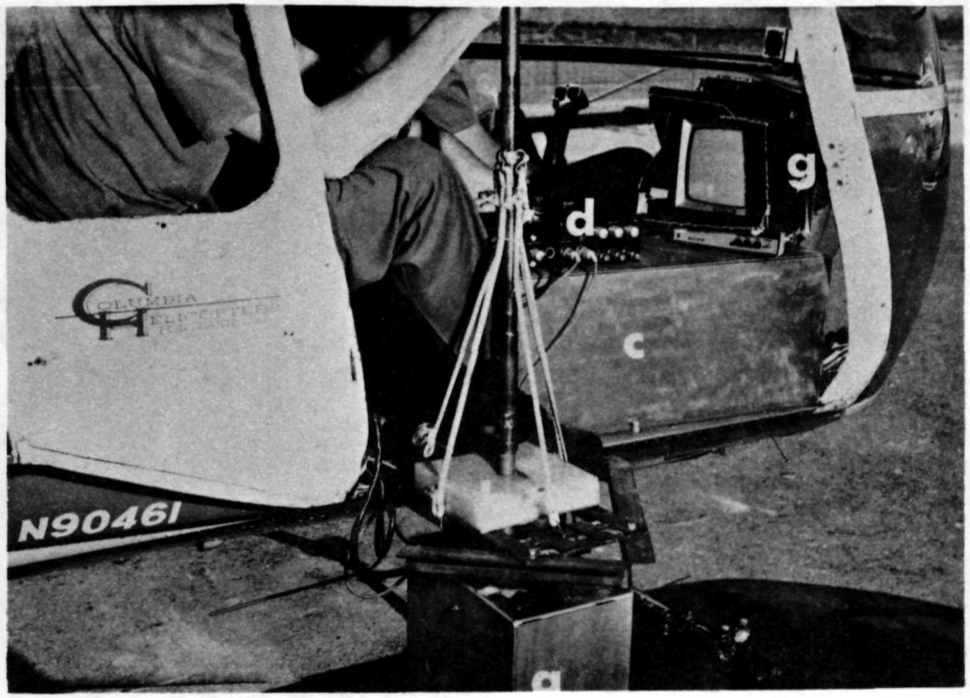

Figure 5 and 6.--IR radiometer and video scan tape recording system collated for use from slow flying helicopter. (a) Vertical pod contains #1 vidicon camera and Barnes PRT-5 radiometer boresighted for vertical coverage. (b) Special mount attached to helicopter supports vertical pod. Two-inch polyurethane block molded around pipe (manual leveling) minimizes helicopter vibration. (c) Floor mounted metal box has #2 vidicon camera that takes continuous video picture of Hickok voltmeter (electronic transfer of picture to tape recorder). (d) Concord electronic integrating mixer that crown references picture inputs from the two vidicon cameras to the Ampex VR 7500 recorder. (e) Electronics section of Barnes PRT-5 nonimaging radiometer in the 8 to 14 micron band. (f) Ampex VR 7500 tape recorder uses a Topaz converter (12 volt d.c. to 110 volt a.c.) to give 60 minutes of audio and picture recording. (Topaz is on floor to left of pilot). (g) Nine inch Sony TV monitor with sun shade for pilot and observer orientation.

dampened to within usable limits by a two inch thick block of polyurethane plastic, (11" x 11") that was molded around the vertical supporting pipe. The metal box containing the #1 video camera and optical head of the PRT-5 is attached to the end of the pipe with a threaded flange. A hinged half-door on the bottom of the metal box is opened while taking readings (Figure 7) but is closed for landing and takeoff to prevent small rocks from scratching the lens or dust from entering the optical head of the PRT-5. All electronic units of the video scan system attached to the helicopter floor are shock-mounted with aviation type Lord suspension. The padded seat provides adequate shock mounting for the PRT-5 radiometer electronics and Ampex video tape recorder.

Two steps were taken to accurately boresight the #1 camera with the optical head of the PRT-5. A 3.64 inch diameter circle that represents the two degree angle of the PRT-5 coverage was attached in the center of the back lens. This diameter of the circle was computed to represent 7.5 feet at a distance of 150 feet. Large circles were drawn on white paper, photographed, and then photographically reduced on clear film to the desired size. The second step was to boresight the vertical instrument pod. This phase was accomplished on the ground and checked in the air. A three foot diameter high-intensity heat reflector was placed on the ground 150 feet from the #1 camera and the PRT-5 optical head mounted on a tripod. The circle in the center of the camera lens was aimed at the heat reflector, (as projected to the TV monitor), and the PRT-5 was thermally centered on the heat reflector. The two units were then bolted

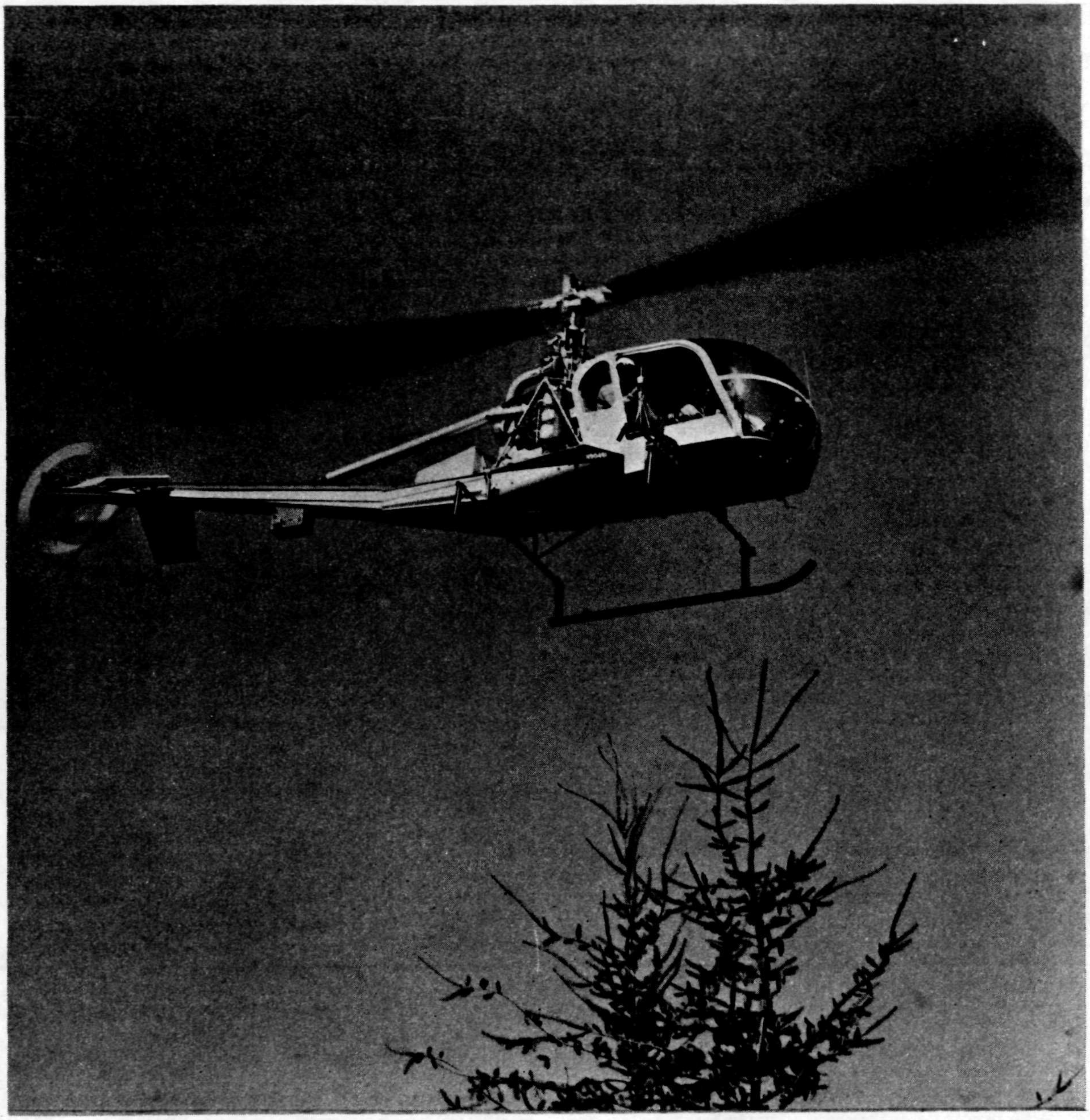

Figure 7.--Upward view of vertical pod showing half-door open for operational heat sensing and recording on video tape.

securely to a metal plate that was attached inside the vertical metal pod. The video scan system was mounted in the helicopter and boresighted again over a six foot wading pool (figure 8). An attempt was made to calibrate the PRT-5 with the surface temperatures of the six foot pool at a later date. This effort was unsuccessful, however, because of erratic radiometer readings. A major breakdown which occurred in the PRT-5 radiometer electronics section is attributed to rough handling in cross country shipment early in the spring.

The digital voltmeter readout through #2 vidicon camera was adjusted in the lab to appear on the videotape just to the right of the black circle (center of each video scan frame). The electrical output of the PRT-5 is transmitted to the Hickok voltmeter instantaneously to the tape recorder for future playback and study. Voltmeter readout is in electrical response and is converted to thermal response with the temperature conversion chart (Figure 9).

This new system provides an accurate vertical picture of the natural vegetation and geographical features as well as a continuous thermal profile of specific strip areas that can be readily checked on the ground. "Ground truth" is derived by transferring details from the videotape, as viewed on a TV monitor, to good quality aerial photographs. The "stop action" feature of the tape recorder permits studying each video frame in depth to delineate positions of suspect trees that exhibit significant temperature differences (Figure 10). The actual area covered by the IR radiometer (within the circled area) is accurately depicted on each frame.

Technique for Calibrating and Boresighting Video scan PRT-5 Radiometer System

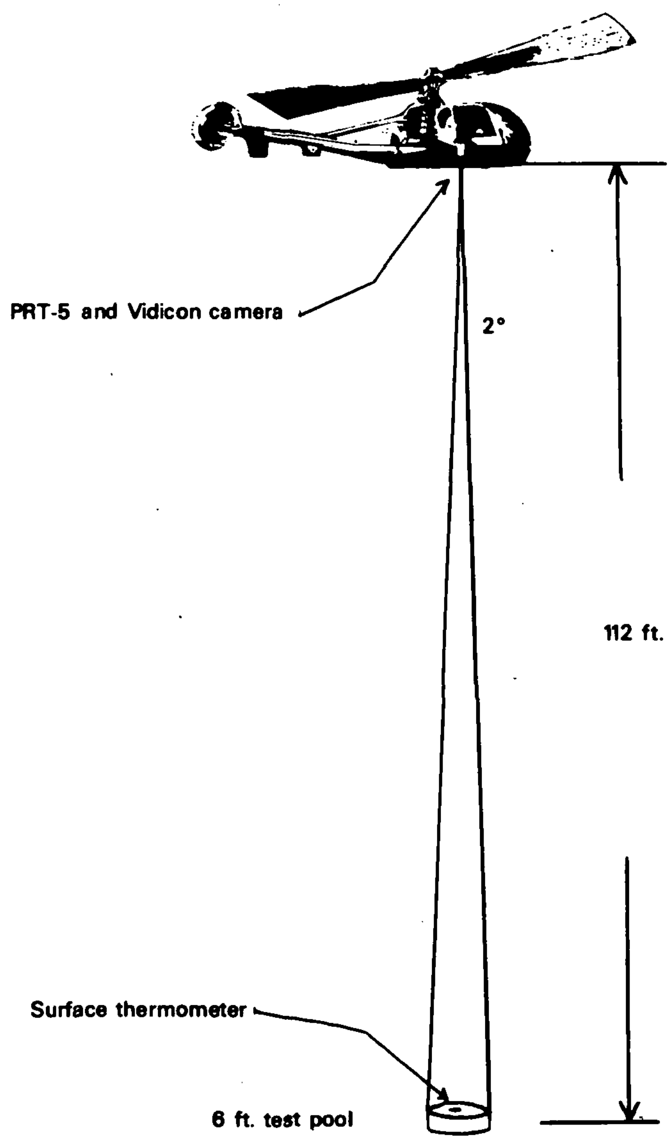

Figure 8.--Diagram shows technique devised for boresighting and calibrating the PRT-5 radiometer with the #1 vidicon camera.

Correlation of Temperature to Voltmeter Readings

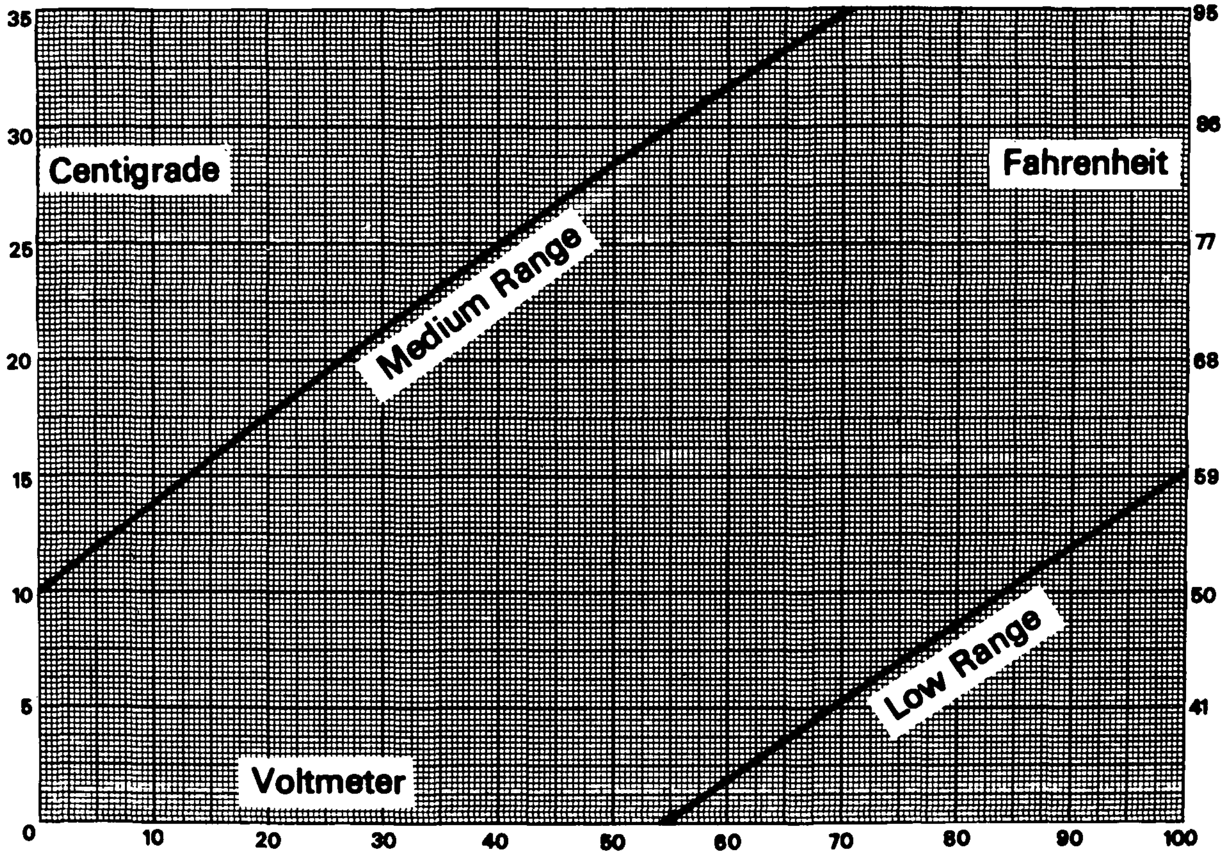

Figure 9.--Chart shows conversion of Hickok voltmeter readings as recorded on video tape to actual temperatures in degrees Centigrade or Fahrenheit.

Figure 10.--Photograph of a single frame of the Ampex VR 7500 tape recording (on a TV monitor). Black circle represents area covered by 2° scan of PRT-5. Digital readout is electronic output of PRT-5 from target tree pictured by the #2 vidicon camera and fed to the tape recorder. This electronic readout is then converted to degrees Centigrade or Fahrenheit using chart from Figure 9.

E. NASA Flybys

NASA aircraft are providing overflights of specific target areas in an attempt to develop spectro-signature indicators of root disease on large forest areas in the Pacific Northwest. Ground truth data have been collected on these specific forest areas in which trees are or are becoming diseased.

Several remote sensing flights have been made to secure imagery at nonorbiting altitudes on several test sites in various spectral zones of the electromagnetic spectrum. Problems of many types have been experienced which have precluded the satisfactory completion of a single complete NASA overflight of Test Site 156. The first NASA flyby on August 15, 1967, with the Convair 240 instrumentation was largely unsatisfactory because of mechanical problems with the equipment, improper film exposure, and inadequate photo coverage. The second attempt on October 19, 1967, was fraught with adverse weather factors and inadequate coverage of the multispectral photography. The "make up" flight provided satisfactory photographic imagery with EK IR film on three plots of the Wind River area (no coverage on the three plots of the Elma area), but not in the .4 to .9 micron band with the 9-lens Itek camera system. Scheduling constraints were so precise as to miss good weather on all target areas the day before and the day after the scheduled operating day for the NASA aircraft. Results of the Reconofax IV (IR scanner in the 8 to 14 micron band) are discussed previously.

NASA Mission 78 with the P3A Lockheed Electra was flown on the

Site 156 plots for discriminating Poria weirii root rot on August 30, 1968. Ideal clear weather for all remote sensing strips at the morning and noon sampling periods was available to maximize the use of specific remote sensors. The multispectral capabilities of the NASA P3A that were utilized included: two RC-9 aerial cameras (Ektachrome and Ektachrome IR films), a four camera 70mm Hasselblad pod (one IR and three panchromatic films), and RS-7 infrared imager (8 to 14 micron band), and a PRT-5 infrared radiometer (10 to 12 micron band) with tape readout.

Sixty percent overlap was requested for all photographic imagery at the noon period only. The originally scheduled 1:4000 scale photography was changed because of the lack of image motion compensation in the RC-8 cameras and the possibilities of not getting the desired overlap at the NASA P3A slowest airspeed of 160 knots. The noon flight consequently was flown at 3,000 feet above terrain for 1:6000 scale imagery. However, a cursory inspection of the film at MSC Houston reveals that this flight altitude is too close to the terrain to provide satisfactory imagery for stereo interpretation.

Other imagery from this flight is being processed. No detailed interpretation or analysis has been possible since the NASA flight. Prior to the NASA flyby, an 8' x 36' resolution target was constructed and installed on Line 1, Wind River test site, to determine the spatial resolution of the various sensors assigned to the Site 156 program. Evaluation of the imagery at the resolution target would help to clarify the need for particular sensors and for modifying subsequent technical procedures for NASA flights (film, filters, scales, etc.) to procure the desired measurements.

Measurements of some physiological parameters between healthy and diseased trees (leaf moisture tension, xylem moisture flow, and various temperature readings) were made during the over-flight period. This is the first attempt to analyze some of the factors in Douglas-fir trees that contribute to the loss of tree vigor caused by Poria weirii root rot.

Data were collected from nine trees (three in each condition class) in the second growth stand in the Wind River area with two primary instruments; the Scholander bomb to record needle moisture tension, and a newly designed portable microvoltmeter (Weber) to measure sap flow through the trunk of the tree at various periods of time during the over-flight. A detailed description of these instruments and an analysis of the data will be given in a later report. Three years of research have been conducted by Heller et al. in studying the physiological changes in ponderosa pine trees attacked by the Black Hills beetle in which these instruments have been used extensively. Data on their research are referenced in the NASA annual progress reports. Comprehensive information on meteorological, ecological, and physiological factors and interactions will be gathered in subsequent years to help determine the best means of evaluating Douglas-fir trees under stress from Poria weirii root rot disease.

INTERPRETATION OF AERIAL IMAGERY

A. Aerial Photography

Imagery obtained in the visible and photographic infrared portions of the electromagnetic spectrum (.4 to .9 micron band) for the six *Poria weirii* root rot study plots on Site 156 has been quite limited during the 1968 field season because of numerous problems and constraints. Weather factors in the Pacific Northwest during the first sampling period in May, and mechanical problems with a new aerial camera at the second sampling period in July precluded procurement of photo imagery by the Forest Service on these plots. Preliminary examination of the NASA imagery from the flyby on August 30, 1968, indicates deficiencies that will make interpretation extremely difficult if not largely unusable. Usually, every other frame is out of focus and occasionally, there are as many as four or five successively bad frames. Apparently, the problem is in the RC-8 camera systems and inability to seat the film at the instant of exposure at the P3A flying speeds. Scale of photography was desired at 1:6000 using EK and EK IR films. The 70mm Hasselblad pod of four cameras exposing black and white film provided imagery of usable quality from three cameras. This imagery will be interpreted and analyzed shortly. One film roll was fouled in processing. The NASA Hasselblad 4 camera pod will soon be phased out and replaced by improved equipment.

Although numerous problems have been encountered this year by both the U. S. Forest Service and NASA in securing good aerial photography of our test sites, progress can be made by greater cooperative effort and more comprehensive understanding of the photographic parameters relating to each Site, by better coordination with the principal investigators as to photographic capabilities and limitations of cameras (or IR sensors), and by better quality control at various stages in the photographic process from the taking of pictures to the finished product.

B. Optical-mechanical Scanner Imagery

Thermal imagery in the 8 to 14 micron band that was provided by the Reconofax IV in the Convair 240 has been monscopically studied on an illuminated table using an 8-power hand lens. An attempt was made on study plots (where trees of three conditions were known to be present) to identify individual tree crown or groups of trees that exhibited tone differences and could be recognized from "ground truth" data. General information about geographical features, drainage patterns, and topographic characteristics are readily discernible on the thermal IR imagery. However, the resolution quality of the Reconofax IV is inadequate to delineate crown characteristics of individual trees or small groups of trees. Thus, there is insufficient detail and tonal contrast on this quality of imagery to discriminate trees under stress. Mission 78 provided IR imagery with the RS-7 scanner on August 30, 1968. Mechanical problems with the scanner in the morning preclude the obtaining of imagery at this most promising time. However, an analysis of the IR imagery taken at noon may reveal some interesting signatures of trees under stress from root rot disease.

C. Nonimaging IR Radiometer Readings

The tree orbiting radiometer readings with the PRT-5 were performed from a Hughes 300 helicopter in July, 1968. Statistical analysis of the data taken on the sunlit and shaded sides of the 90 trees indicated significant temperature differences between the two exposures, but did not indicate significant temperature differences between any of the three condition classes at any of the sampling periods of the day. (Tables 1 and 2). Experience from data of two previous years clearly indicated distinct temperature differences for different condition classes and periods of the day. The analysis of the July data from the PRT-5 and from the Cole-Parmer recorder came too late to repeat the experiment. It was at the time of the August 30 NASA flyby that the first operational test of the PRT-5 videoscan system was being made when it was discovered that the PRT-5 radiometer provided inconsistent and erratic readings. The PRT-5 was bench checked by the electronic technicians of the Instrument Laboratory of the Bonneville Power Administration. The internal electronics of the PRT-5 radiometer were found to be badly misaligned, and the temperature indicator post broken off and "shorting out." Thus, the reliability of any readings taken at the July period (Table 1) are highly suspect.

D. PRT-5 Radiometer Video-scan system

Video-scan data were collected from individual trees on the three Wind River area plots between 7:30 and 1:30 a.m. and again between 11:30 a.m. and 12:30 p.m. Additional strips were flown between known points identifiable on the ground to include as many individual test trees as possible. However, data from the PRT-5 video-scan system taken at the time of the NASA flyby are not considered usable from this first operational test because of the above radiometer conditions. The response time from the PRT-5 to the tape recorder should be almost instantaneous.

Table 1. AVERAGE TEMPERATURES IN DEGREES FAHRENHEIT OF FIVE HEALTHY AND TEN PORIA WEIRII INFECTED TREE CROWNS SCANNED BY A BARNES PRT-5 RADIOMETER, WIND RIVER TEST AREA. TREES HAD TOTAL NEW FOLIAGE GROWTH FOR 1968. DATA COLLECTED JULY 8, 1968.

	Healthy		Diseased Without Symptoms		Diseased With Symptoms	
A.M. Readings	Sun	Shade	Sun	Shade	Sun	Shade
Young Growth (9:00)	74.4	69.3	72.0	70.3	71.6	70.3
Second Growth (8:15)	67.0	65.5	69.5	65.6	69.1	66.2
Old Growth (8:30)	74.1	67.6	74.7	69.5	74.5	69.2
P.M. Readings						
Young Growth (12:00)	81.0	81.5	82.3	81.3	82.1	81.9
Second Growth (12:15)	82.3	81.8	82.1	82.6	82.8	81.3
Old Growth (12:30)	81.9	78.7	81.3	80.5	83.1	81.3

Table 2. AVERAGE TEMPERATURES IN DEGREES FAHRENHEIT OF FIVE HEALTHY AND TEN PORIA WEIRII INFECTED TREE CROWNS SCANNED BY A BARNES PRT-5 RADIOMETER, ELMA TEST AREA. TREES HAD TOTAL NEW FOLIAGE GROWTH FOR 1968. DATA COLLECTED JULY 2, 1968.

	Healthy		Diseased Without Symptoms		Diseased With Symptoms	
A.M. Readings	Sun	Shade	Sun	Shade	Sun	Shade
Young Growth (8:00)	66.2	65.26	66.3	65.6	66.6	66.0
Second Growth (8:30)	67.7	66.81	67.5	66.6	68.5	67.5
Old Growth (9:15)	69.8	68.55	69.9	68.6	70.1	68.6
P.M. Readings						
Young Growth (2:00)	75.0	73.62	74.9	73.7	75.2	73.6
Second Growth (1:30)	74.3	73.63	73.8	73.5	74.2	73.4
Old Growth (12:15)	73.8	72.80	74.3	73.0	74.3	73.2

The one to two second lag between the IR optical input from individual trees and the video tape recording of electrical voltmeter output was the first clue indicating a major malfunction in the video-scan system. The PRT-5 deficiencies have now been corrected and a further test under operating conditions from a helicopter will be attempted this fall. Use of the basic radiometer video-scan system is a feasible approach to scanning large forest areas with an excellent opportunity to collate ground truth with the TV temperature profile. Other scanning systems tested so far do not provide sufficient resolution to identify crown characteristics of individual trees, or to provide true temperature values of specific ground features.

SUMMARY AND CONCLUSIONS

During the period covered by this report considerable progress has been made in the testing and developing of remote sensing techniques for efficient disease detection surveys. Promising results have been obtained in the infrared portion of the electromagnetic spectrum in the 8 to 14 micron band. A nonimaging infrared radiometer has been collated with an instant replay video scan system to provide an active survey technique for scanning across extensive forest areas.

Several remote sensing flights have been made to the Pacific Northwest by NASA aircraft in an effort to secure imagery at nonorbiting altitudes that will differentiate healthy from diseased Douglas-fir trees. Operational problems of many types have been experienced which have precluded the satisfactory completion of a single NASA overflight on the six plots of Test Site 156. Imagery from the NASA P3A flyby on August 30 is now being studied. Visible, reflectance infrared, and thermal infrared spectral zones are included in the NASA imagery.

The continuing losses to the forest resource because of forest diseases such as *Poria weirii* root rot in the Pacific Northwest emphasize the need for developing remote sensing techniques to collect disease impact data rapidly from aircraft and/or orbiting platforms. In order to better analyze this important forest resource problem, expanded research is also needed on the spectral emission and spectral reflectance of specific forest types in the Pacific Northwest, and on the physiological parameters of healthy and root rot infected trees.

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APPENDIX

The following is a list of U.S. Department of Agriculture personnel who have made contributions to this research study and represent a major salary contribution to it:

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