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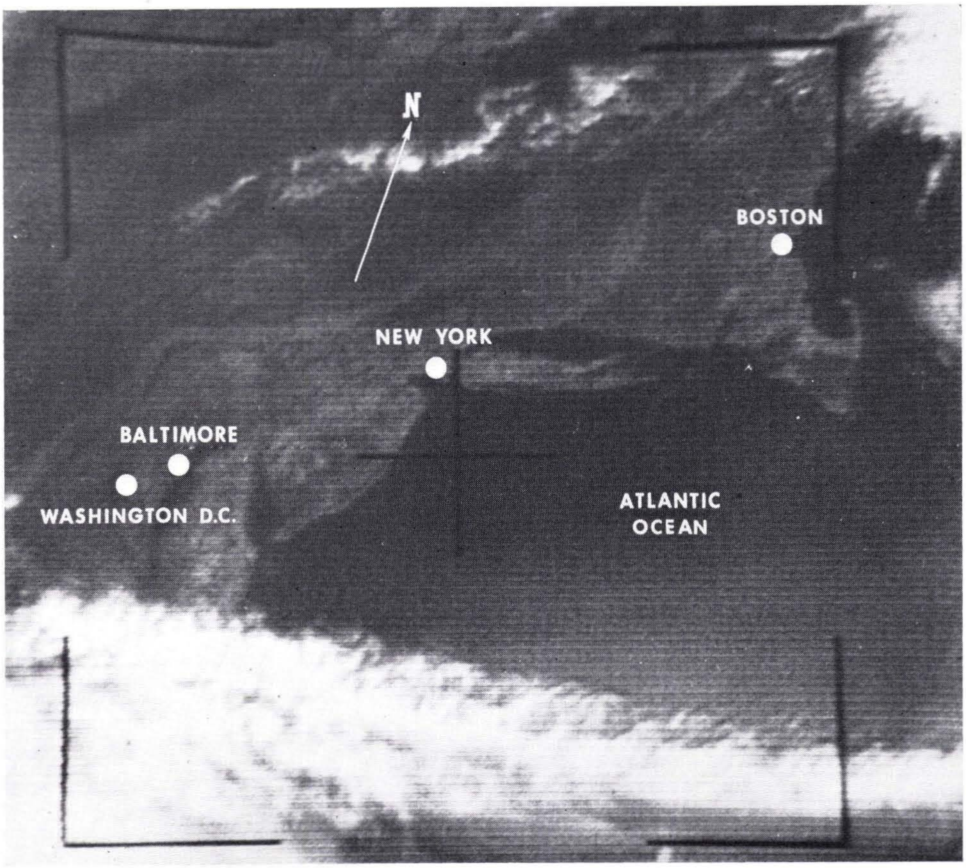
# Planetary Exploration from Orbital Altitudes

**Experience with sensing equipment on Earth and Moon flights will help determine instrument payloads for Mars, Venus, etc.**

## INTRODUCTION

THE PURPOSE of this article is to provide the scientific and technological community with some idea of the National Aeronautics and Space Administration's plans for planetary exploration from orbital altitudes.



FRONTISPIECE. View of the Northeast Coast of the United States from a TIROS satellite. (See text page 256.)

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* Presented at the Annual Convention of the American Society of Photogrammetry in Washington, D. C., March 1965.

The term "planetary" is used here to include any body, except a comet or a meteor, that revolves about the sun of our solar system. Planetary exploration thus includes the study of the earth from space.

This article concentrates mainly on exploration of the earth and the moon using orbital spacecraft, but the reader should realize that the experience acquired on these earlier vehicles is directly applicable to other later planetary missions (Mars, Venus, etc.) also. Orbital vehicles are expected to play a role in planetary exploration analogous to aerial surveys for terrestrial exploration objectives.

The National Aeronautics and Space Administration (NASA) is currently evaluating a number of new and newly refined instruments for use in exploring the earth and planetary surfaces from orbiting spacecraft. Among the instruments which would make up the payloads for orbiting spacecraft are "remote sensors," devices which are sensitive to force fields, such as gravity gradient systems and devices that record the reflection or emission of electromagnetic energy. Both passive (those that rely on natural sources of illumination, such as the sun) and active (those that utilize an artificial source of illumination) electromagnetic sensors are under consideration.

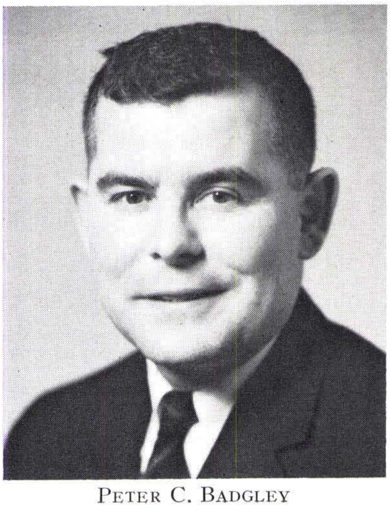
Investigations relating to force field sensors are also being undertaken but are not discussed in this paper.

Each type of surface material (e.g. soils, rocks, vegetation and other forms of life, etc.) absorbs and reflects solar energy in a characteristic manner depending upon its atomic and molecular structure. In addition, a certain amount of internal energy is emitted which is partially independent of the solar flux. The absorbed, reflected and emitted energy can be detected by remote sensing instruments in terms of characteristic spectral signatures and images. These signatures can usually be correlated with known rock, soil, crop, and other conditions. The relationship to specific terrain features can be more closely established by judiciously correlating a group of diverse signatures, obtained simultaneously by different remote sensors.

ABSTRACT: *The National Aeronautics and Space Administration is engaged currently in planning scientific payloads for future earth and planetary (Mars, Venus, Moon) orbital spacecraft. These vehicles are expected to play a role in planetary exploration analogous to aerial surveys in the natural resources field. Some of the instruments which would make up the scientific payloads are remote sensors, including detectors to measure infrared, microwave, X-ray and gamma ray emittance; active radar systems, multiband photography; gravity, magnetic, and other sensors. Because the scientific applications of remote sensors are not well understood, the NASA is now engaged in a comprehensive aircraft flight program over known ground sites to test these new and hopefully very useful tools.*

## CHARACTERISTICS OF ELECTROMAGNETIC SPECTRUM

Sensors which respond to energy in the gamma ray, ultraviolet, visible, infrared, and radio parts of the spectrum are being considered for use in the NASA exploration program. Selection of the specific parts of the electromagnetic spectrum to be utilized in these investigations is governed largely by the photon energy, frequency, and atmospheric transmission characteristics of the spectrum (Colwell et al. 1963). The exploration role that sensors will be assigned on terrestrial or



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lunar surveys is similarly dictated by spectrum characteristics, principally atmospheric transmission. Some of the remote sensors responding to various parts of the spectrum and their possible exploration applications are illustrated (Figures 1 and 2).

### Basic Preflight Studies Underway

Chemical composition, surface irregularity, degree of consolidation and moisture content are among the parameters that are known to affect the records obtained by electromagnetic remote sensing devices. Full interpretation of sensor records requires, therefore, that these effects be known and studied quantitatively. A number of fundamental laboratory studies concerned with these effects are underway. Laboratory studies are being supplemented by detailed studies of a number of test sites in the United States and elsewhere. Detailed ground study of these test areas, coupled with preliminary remote sensing surveys from aircraft, are being undertaken by various governmental agencies, universities and commercial organizations in cooperation with NASA. An evaluation of the scientific applications of each type of promising remote sensor is currently underway. These basic studies should serve to:

- ☆ Advance our knowledge of the fundamental effects of various terrain parameters on sensor records.
- ☆ Provide a means of calibrating data returned from earth-orbiting sensors (the areas studied are of sufficient size to be resolved from space).
- ☆ Test the operation of the sensing equipment for earth orbital flights as well as for later planetary missions.
- ☆ Enable us to refine our data handling and interpretation techniques.

### Remote Sensor Aircraft Flights

The use of aircraft flights over known calibrated ground sites is a very important phase of NASA's pre-spaceflight studies (Table 1). A basic requirement of the feasibility test program is the simultaneous sensing of the test sites by as many of the sensor systems as possible. Therefore, it is highly desirable to conduct as many experiments as possible with the same aircraft.

To provide for simultaneous observations in several parts of the spectrum a Convair 240 aircraft has been heavily instrumented by NASA-MSC. This aircraft is now serving as a test bed for a wide variety of electronic and electro-optical experiments. Basically, the

| | APPLICATION<br>EXPERIMENTAL TECHNIQUE | AGRICULTURE/ FORESTRY | GEOLOGY/ PLANETOLOGY | HYDROLOGY | OCEANOGRAPHY | GEOGRAPHY |
|---|---|---|---|---|---|---|
| REMOTE SENSOR INSTRUMENTS | VISUAL PHOTOGRAPHY | SOILS<br>PLANTS<br>VIGOR<br>DISEASE | SURFACE STRUCTURE<br>SURFACE FEATURES | DRAINAGE PATTERNS | SEA STATE—<br>EROSION<br>TURBIDITY<br>HYDEOGRAPHY | CARTOGRAPHY<br>LAND USE<br>TRANSPORTATION<br>TERRAIN & VEGETATION<br>ORGANIZATION |
| | MULTI-SPECTRAL PHOTOGRAPHY | | | SOIL MOISTURE | SEA COLOR<br>PRODUCTIVITY | |
| | I. R. IMAGERY AND SPECTROSCOPY | TERRAIN COMPOSITION<br>PLANT CONDITION | THERMAL ANOMALY<br>MINERALS | AREAS OF COOLING | OCEAN CURRENTS<br>SEA ICE | ENERGY CURRENTS & LAND USE |
| | RADAR IMAGERY & SCATTEROMETRY | SOIL CHARACTERISTICS | SURFACE ROUGHNESS<br>TECTONICS | SOIL MOISTURE<br>RUN-OFF SLOPES | SEA STATE<br>ICE FLOW & ICE<br>TSUNAMI WARNING | LAND/ICE<br>CARTOGRAPHY<br>GEODESY |
| | R. F. REFLECTIVITY | | SUB-SURFACE LAYERING<br>MINERALS | SOIL MOISTURE | ICE THICKNESS<br>SEA STATE | LAND/ICE THICKNESS<br>VEGETATION |
| | PASSIVE MICROWAVE RADIOMETRY & IMAGERY | THERMAL STATE OF TERRAIN | SUB-SURFACE LAYERING | SNOW<br>ICE | | SNOW & ICE |
| | ABSORPTION SPECTROSCOPY (REMOTE GEO-CHEMICAL SENSING) | | MINERAL DEPOSITS<br>TRACE METALS<br>OIL | | SURFACE FLORA | |

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FIG. 1. Remote sensor instruments being studied by NASA and some of their expected applications.

|  | $\gamma$-RAYS | HARD X-RAYS | SOFT X-RAYS | VACUUM ULTRA-VIOLET | NEAR U.V. | VISIBLE |  |  | INFRARED |  |  | MICROWAVE | RADAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | PHOTOG U.V. | SPECTRAL VIS. | PHOTOG IR | NEAR INFRARED | MED. INFRARED | FAR INFRARED |  |  |
| FREQUENCY | $10^{14}$ MC | $10^{13}$ MC | $10^{12}$ MC | $3 \times 10^{10}$ TO $10^9$ MC | $8 \times 10^8$ MC | AROUND $5 \times 10^8$ MC |  |  | ABOUT $10^8$ MC | ABOUT $10^7$ MC | ABOUT $10^6$ MC | — | 20 KMC TO 0.3 KMC |
| WAVE LENGTH | 0.03 A | 0.3 A | 3 TO 100 A | 100 to 3000 A | NEAR 4000 A | 4000 TO 5000 A | 5000 TO 7000A | 7000 A TO 10,000 A | 0.7 TO 4 MICRONS | 4 TO 15 MICRONS | 15 TO 800 MICRONS | 1MM TO 100 CM | K-BAND 1.5 CM TO P-BAND 100 CM |
| ENERGY | $1 \times 10^6$ EV | $5 \times 10^4$ EV | $1 \times 10^3$ EV | 12 EV TO 4 EV | 3 EV | 2.7 TO 1.75 EV |  | 1.75 TO 1.25 EV | 1.75 TO 0.3 EV | 0.3 TO 0.08 EV | VERY LOW | VERY LOW |  |
| OPERATIONAL MODE | PASSIVE-SCINTILLATION COUNTERS |  |  | ACTIVE (2000 TO 3900 A) | PASSIVE | GENERALLY PASSIVE |  |  | REFLECTANCE (SOLAR - ACTIVE) | EMISSION (PASSIVE) | EMISSION (PASSIVE) | PASSIVE, OPERATED TUNED TO ONE WAVELENGTH | ACTIVE, CW OR PULSED, TUNED TO ONE WAVELENGTH |
| ATMOSPHERE ATTENUATION | EXTREME ATTENUATION |  |  | 2200 TO 2700 A RALEIGH SCATTERING<br>2400 TO 3100 A OZONE STRONGLY ABSORBS | LIMITED ATTENTUATION | LIMITED ATTENUATION | GOOD VISIBILITY | BETTER VISIBILITY | EXTREME IN BANDS AT 0.9, 1.13, 1.38 1.9, 2.7 MICRONS | EXTREME IN BANDS AT 4.3, 6.0, 15.0 MICRONS | EXTREME IN BANDS AT 25 THROUGH 1000 MICRONS | LOW EXCEPT FOR SOME SPECIFIC BANDS | VERY SLIGHT |
| DATA TYPE | ANALOG SIGNAL PULSE HEIGHT ANALYSIS |  |  | PHOTOMULTIPLIER SIGNALS | IMAGE ORTHICONS & FILM | PHOTOGRAPHIC FILM (IMAGING) SPECTRAL SERIES |  |  | IMAGE & TAPE | RADIOMETER OUTPUT- (TAPE) | RADIOMETER OUTPUT (TAPE) | RADIOMETER RESPONSE (TAPE) | ANALOG SIGNAL, CAN BE CONVERTED TO IMAGING SYSTEM |
| STORAGE FORMAT | FILMS OR DIGITAL TAPE (NON-IMAGING) |  |  | FILM OR TAPE (POSSIBLY IMAGING) | FILM OR TAPE | FILMS- WHICH MAY BE READ BY A FLYING SPOT SCANNER-CONVERTED INTO DIGITAL TAPE |  |  | FILMS AFTER AN IMAGING SYSTEM | TAPE-ANALOG SIGNAL | TAPE-ANALOG SIGNAL | OSCILLOSCOPE OR TAPE & FILM FOR STORAGE | OSCILLOGRAPH OR TAPE & FILM FOR STORAGE |
| EFFECTIVE SOURCE DEPTH OF INFORMATION IN RECEIVED SIGNAL | "PENETRATES 20 CMS OF ROCKS" | ONE TO SEVERAL MICRONS |  | ANGSTROMS TO MILLIMETERS | ANGSTROMS TO MILLIMETERS | ONLY ANGSTROMS DEEP IN SOLIDS - TO TENS OF METERS DEEP IN WATER ABSORPTION COEFFICIENTS BEST KNOWN OF ANY PART OF THE EM SPECTRUM |  |  | SOURCE DEPTHS ARE MEASURED IN MICRONS (EVEN FOR WATER), SOME ABSORPTION COEFFICIENTS ARE KNOWN - ATTENUATION IS COMPLETE WITHIN 10 TO 100 MICRONS. |  |  | UNCERTAIN, SEVERAL CENTIMETERS ONLY | SANDY-SOIL LOAM<br>K-BAND — —<br>X-BAND 2" 1"<br>C-BAND 8" 2"<br>P-BAND 315" 10" |
| PHENOMENA DETECTED | ATOMIC TRANSITIONS AND INNER ELECTRON SHIFTS |  |  | OUTER ELECTRON SHIFTS | OUTER ELECTRON SHIFTS | REFLECTION OF VISIBLE LIGHT INCREASED CONTRAST, INCREASED HAZE PENETRATION |  |  | REFLECTANCE OF SOLAR INFRARED- PRINCIPALLY SURFACE EFFECTS, ROUGHNESS | THERMAL MOTION OF ATOMS MODIFIED BY THE VIBRATIONS OF THE MOLECULES & CRYSTAL LATTICES. |  | MOLECULAR ROTATIONS IN ATMOSPHERE, SURFACE & SUB-SURFACE. EMITTANCE IS A FUNCTION OF REFLECTANCE ABSORPTION & TEMPERATURE | BACKSCATTERING BY THE SURFACE: DIELECTRIC CONSTANT, ROUGHNESS, DEPOLARIZATION ARE SIGNIFICANT PARAMETERS. |
| ANALYTICAL END RESULTS | ELEMENTAL ANALYSIS:<br>TOTAL $\gamma$-RAY FLUX SPECTRAL $\gamma$-RAY FLUX: $40^K$ U, TH SERIES RADIONUCLIDES.<br>GEOCHEMICAL DATA |  |  | ELEMENTAL ANALYSIS: ELECTRON TRANSITION FROM GROUND STATE | VALENCE & OXIDATION, ELEMENTAL ANALYSIS, SOME GAS ANALYSIS | REFLECTANCE VALUES (EITHER POLYCHROMATIC - BROAD BANDPASS, OR SPECTRALLY FILTERED-NARROW BANDPASS). STRUCTURAL STYLE, TEXTURAL DATA, MORPHOLOGIC DATA |  |  | MOLECULAR COMPOSITIONS. THIN GAS LAYERS EMIT AS NARROW SHARP LINES. SOLIDS SHOW BROAD STRUCTURELESS BANDS. TEXTURAL DATA, AND PERHAPS SOME THERMAL RESULTS |  |  | THERMAL, TEXTURAL AND COMPOSITIONAL DATA, EMITTANCE OR APPARENT TEMPERATURES DIFFERENCES, GEOLOGICAL VALUE UNDEFINED. | SURFACE ROUGHNESS: CONDUCTIVITY AND DIELECTRIC CONSTANT, STRUCTURAL STYLE, TEXTURAL DATA |
| GEOLOGIC MAPPING APPLICATIONS — EARTH ORBIT | ← NO APPLICATION DOWNWARD → |  |  | NO APPLICATION DOWNWARD |  | EXTRAPOLATIONS FROM KNOWN AREAS WILL EXPLAIN DIFFERENCES IN REFLECTIVITY (SHAPE, SIZE & ASSOCIATONS FORM THE BASIS OF PHOTO INTERPRETATION). |  |  | MARKEDLY ATTENUATED BY ATMOSPHERE OTHERWISE ONE OBTAINS REFLECTIVITY OF SOLAR RADIATION, ROUGHNESS CRITERIA | ONLY SOME WINDOWS AVAILABLE (8 - 12 $\mu$) RESTRICTS COMPOSITIONS OF SURFICIAL MATERIALS WHICH MAY BE DETERMINED. | NO APPLICATION DOWNWARD | RELATIVELY UNEXPLORED. ROCK DIAGNOSIS BY DIFFERENCE IN APPARENT TEMPERATURE-FUNCTION BOTH OF EMITTANCE & TRUE TEMPERATURE DIFFERENCE | SAME AS FOR LUNAR ORBIT-LITTLE OR NO ATMOSPHERE EFFECT. |
| GEOLOGIC MAPPING APPLICATIONS — LUNAR ORBIT | $\gamma$-RAY DISTRIBUTION OF NUCLEAR SPECIES U, TH, $K^{40}$ DISTINGUISHING SURFACE ROCK TYPES BY $K^{40}$ CONTENT. $AL^{26}$ $BE^{10}$ MAY BE PRESENT IF SURFACE HAS BEEN SPUTTERED<br>X-RAY ANALYSIS OF A FEW STABLE ELEMENTS |  |  | ELEMENTAL ANALYSIS OF SURFACE ROCKS & DUST LAYERS |  | PHOTOGRAPHY (VISIBLE) CANNOT GIVE AN UNIQUE ANSWER TO FINE-SCALE PHYSICAL OR CHEMICAL COMPOSITIONS UNLESS CALIBRATED AREAS ARE USED. ONE CAN ONLY INFER COMPOSITIONS OF LAYERS AND DISTRIBUTIONS OF SHAPES LARGER THAN THE LIMIT OF RESOLUTION |  |  | SENSITIVITY TO SOLAR REFLECTIVITIES INCREASED BECAUSE OF ABSENCE OF ATMOSPHERE. | SURFACE ROCK & DUST, CHEMICAL COMPOSITION OR PHYSICAL CHARACTERISTICS, APPARENT TEMPERATURE RANGE AND COMPOSITIONS NOT LIMITED BY ATMOSPHERE | REGION UNEXPLORED FOR GEOSCIENCE VALUE. | NEAR-SURFACE AND SUB-SURFACE TEMPERATURE, TEMPERATURE GRADIENT. | ROUGHNESS CRITERIA, PERHAPS LAYERING IN DEPTH (10-1000 CM), COMPOSITION, DIELECTRIC CONSTANT, & PARTICLE SIZE DIFFERENCES. |
| CONTRIBUTION TO MAJOR LUNAR PROBLEMS | ← COMPOSITIONS OF LUNAR SURFACE, CONTENT OF RADIOACTIVE ELEMENTS, SURVEY OF LUNAR RESOURCES, CRATER FORMATION: e.g. VOLCANIC ACTION VS. METEORITE IMPACTS, EXTENT OF LUNAR RAYS, DUST LAYER DEPTH, BRIGHTNESS VS. NUMBER OF SECONDARY CORPUSCULAR CRATERS, DENSITY OF SMALL CRATERS. → |  |  |  |  |  |  |  | ← THERMAL STATE OF LUNAR SURFACE, THERMAL MAPPING DATA, NATURE OF DARK SPOTS, e.g. LAVA LAKEBEDS. → |  |  |  |  |
| IMPORTANT TERRESTRIAL APPLICATIONS | NO DATA POSSIBLE |  |  | ← DATA RETURNS FOR STUDY OF METROPOLITAN GROWTH →<br>← STUDY OF AIR POLLUTION →<br>← STUDY OF WATER RESOURCES; RELATIONSHIP TO INDUSTRIAL GROWTH AND GENERAL AVAILABILITY: OTHER PREDICTIONS IN HYDROLOGY, e.g. PRECIPITATION, STREAM-FLOW, AND GROUND-WATER LEVELS →<br>← OPTIMUM USE OF HABITABLE LAND →<br>← DATA SYSTEM FOR AGRICULTURAL RESOURCE SURVEYS AND CROP PREDICTIONS →<br>← SPACE DERIVED EARTH DATA FOR USE IN INDUSTRIAL REGIONS AND UNDERDEVELOPED COUNTRIES →<br>← SYNOPTIC ANALYSIS OF SEA STATE, AIR-SEA INTERACTION, ETC. →<br>← WEATHER FORECASTING AND AIR - MASS FLOWS → |  |  |  |  |  |  |  |  |  |

FIG. 2. Chart showing some characteristics of parts of the electromagnetic spectrum, some operational characteristics of devices sensitive to radiation in various parts of the spectrum, and some potential applications of data to be gathered by these sensors.

TABLE 1

SEQUENTIAL RELATIONSHIP OF REMOTE SENSOR EQUIPPED AIRCRAFT FLIGHTS TO SUBSEQUENT ORBITAL FLIGHTS

| Current–1968 | 1968–1969 | 1968–1970 |
|---|---|---|
| Remote sensor geologic mapping capability:<br>Aerial overflight of Terrestrial and oceanic sites to determine scientific significance of multispectral responses<br>—plus—<br>Associated "ground truth" calibration in laboratory and field. | Earth orbital overflight of same geological test sites:<br>Will permit additional calibration of sensors from orbital altitudes. | Manned lunar orbital scientific survey carrying many of same sensors used in earth orbit. A.E.S. ground traverses proadditional "ground truth" calibration. |

aircraft instrumentation provides highly controlled power for the experiments and full inflight monitoring and data recording of all events. All flight parameters are continuously displayed and recorded at one-second intervals by the data-recording camera system. All data from the various sensors are indexed together by a time signal and frame number of the master survey camera for ease of retrieval. Conventional photography for indexing and control of all sensor events with ground-position information and general terrain features is obtained with the master survey camera on all daylight flights. Although the NASA Convair 240A is well suited for the initial phases of this remote sensor program, a NASA Electra P3A is expected to be brought into the program in 1966 for higher altitude and overseas work.

Eventually the jump to spacecraft must occur because aircraft platforms will not be available in orbit about the Moon and other planets. There is of course great merit in viewing the Earth itself from orbital altitudes. Many terrestrial features such as crops, water resources, coastlines and oceanic phenomena are transient in nature and therefore require repeated observations. These may be more readily available in the future via operational spacecraft than by repeated aircraft coverage. Most aerial surveys are one-time flights and do not provide periodic or continuous coverage of transient features. The entire battery of remote sensors designed for terrestrial and planetary surface study constitutes a vast data-gathering system. The applications of this information present an exciting challenge to all branches of earth science.

## USE OF CALIBRATED TEST SITES

The use of calibrated ground test sites is an important phase of the remote sensor evaluation program being conducted by NASA. Two types of test sites are being studied: (1) fundamental sites and (2) extended sites. Fundamental sites are commonly applicable to a single user discipline, small in size, and located in areas that have been previously studied and mapped in detail. Fundamental sites have been selected for studies in the fields of geography, agriculture, forestry, oceanography, and geology. Areas, thought to be lunar analogs, are included in the geologic sites. The extended sites are larger in size, also quite well known insofar as ground data is concerned, and contain a number of fundamental sites for various user disciplines. Special guidelines were used for selection of fundamental, extended, and lunar analog sites. These are summarized in Table 2. Some of the test sites already under study are shown in Figure 3.

## INITIAL RESULTS OF THE REMOTE SENSOR PROGRAM

Initial surveys utilizing the NASA remote sensing aircraft were undertaken in February 1965 by the U. S. Geological Survey at Pisgah Crater, San Bernardino County, California (Figure 4). Sensors aboard the aircraft utilized in these surveys included a Reconofax 4 infrared scanner, operating in the 8–13$\mu$ part of the spectrum, and a AAS-5 scanner, filtered so as to record energy in the 4.5–5$\mu$ part of the spectrum. The principal objectives of the initial surveys were testing the air-borne and related field monitoring equipment under operational conditions and developing field methods for describing the surface of various rock units in a statistically valid manner and in terms meaningful to the interpretation of the infrared records. Field measurements of surface temperatures, microrelief, and laboratory measurements of reflectance were con-

TABLE 2

GUIDELINES USED BY NASA FOR SELECTING TEST SITES

| *Fundamental test sites should be:* | *Extended test sites should be:* | *Lunar analog sites should:* |
|---|---|---|
| 1. Well known through detailed conventional (ground and/or aerial) studies/mapping | 1. Reasonably well known, extensive ground work is not necessary | 1. Include several lunar rock types |
| 2. Uniform with respect to features being studied and resolution of instruments | 2. Large enough for broad scale test of remote sensors over wide range of features or conditions, yet small enough to be conveniently studied | 2. Include segments of the terrain that are uniform chemically and physically |
| 3. Amenable to study by all or most remote sensors | 3. Of interest to all or most user areas | 3. Be free from vegetation |
| 4. Readily accessible | 4. Accessible so that necessary ground checks can easily be made | 4. Be relatively flat, uniform elevations |
| 5. Small in area | | 5. Be at lower altitudes, favorable climate for all year study purposes |
| | | 6. Represent lunar analog geologic situations (volcanic cones, lava flows, large impact areas, ejecta blankets, etc.) |

| STATUS | CATEGORY | TYPE |
|---|---|---|
| UNDER STUDY | | |
| 1. PISGAH CRATERS | LUNAR ANALOGUE-GEOLOGIC | FUNDAMENTAL |
| 2. MONO CRATERS | LUNAR ANALOGUE-GEOLOGIC | FUNDAMENTAL |
| 3. SCRIPPS BEACH | OCEANOGRAPHIC | FUNDAMENTAL |
| 4. PURDUE FARMS | AGRICULTURAL | FUNDAMENTAL |
| 5. WILLCOX PLAYA | RADAR | SPECIAL PURPOSE |
| 6. WESTERN KANSAS | AGRICULTURAL-GEOGRAPHIC | EXTENDED |

FIG. 3. Index map showing location of Pisgah Crater Area and of Willcox Dry Lake.

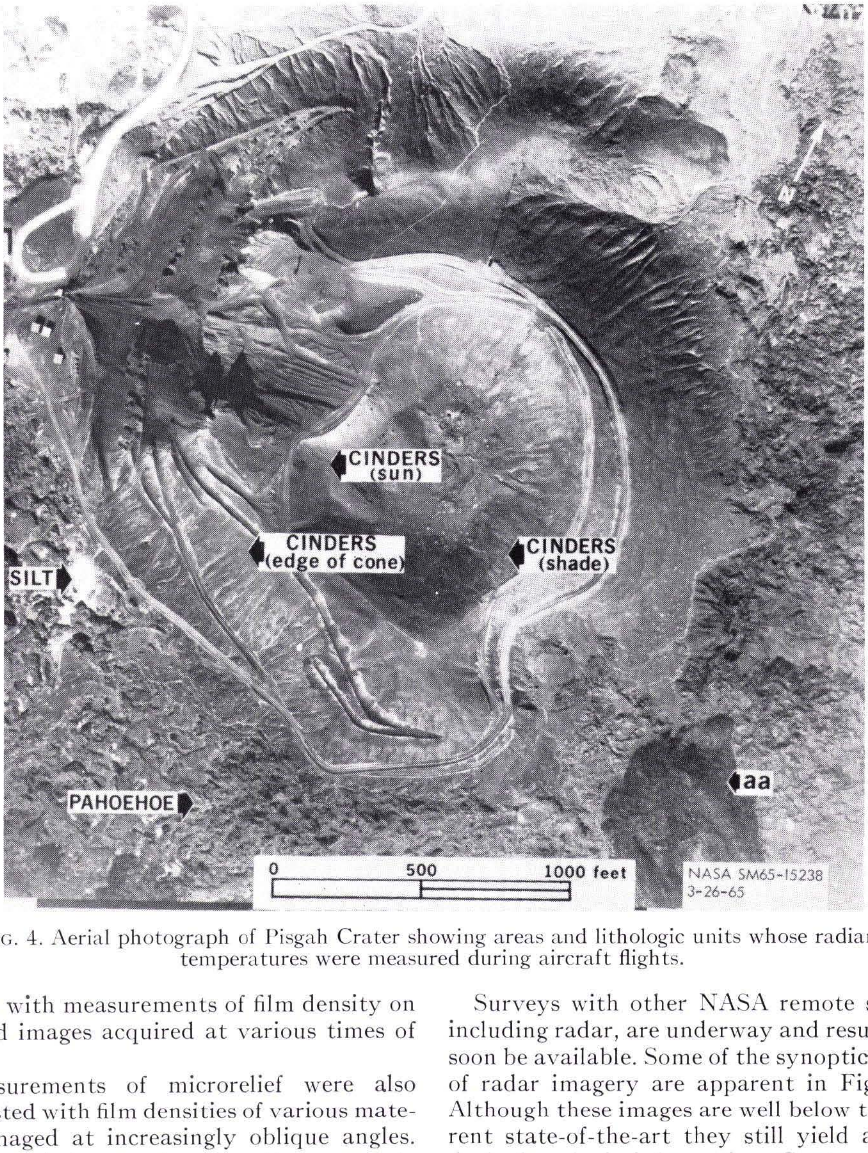

FIG. 4. Aerial photograph of Pisgah Crater showing areas and lithologic units whose radiant temperatures were measured during aircraft flights.

trasted with measurements of film density on infrared images acquired at various times of day.

Measurements of microrelief were also contrasted with film densities of various materials imaged at increasingly oblique angles. Contrast of these various functions suggests that unconsolidated materials possess a lower thermal inertia than consolidated materials (Figure 5); that unconsolidated materials emit larger quantities of infrared energy (greater film density) than consolidated materials when both are subjected to similar quantities of solar radiation (Figure 6); and that the film densities with which objects are recorded on infrared imagery differ with angle of view; commonly the differences are greater for rough surface than for smooth. These studies also suggest that these relative quantities and changes in relative quantities of radiation may be observed from airborne platforms.

Surveys with other NASA remote sensors including radar, are underway and results will soon be available. Some of the synoptic values of radar imagery are apparent in Figure 7. Although these images are well below the current state-of-the-art they still yield a great deal of geologic information. Contrast these pictures with those taken from TIROS (Frontispiece) whose prime objective was to recover data for the meteorologist. Some of the advantages of radar data returns are shown in Table 3. Those scientists who have studied photographs from TIROS, NIMBUS, MERCURY and GEMINI will be particularly appreciative of the all-weather capability of radar.

The simultaneous sensing of planetary surfaces with a variety of remote sensor instruments, at resolutions sufficient to provide useful data for the earth scientist and planetologist, requires the availability of heavy payload orbiting spacecraft. Some of the space-

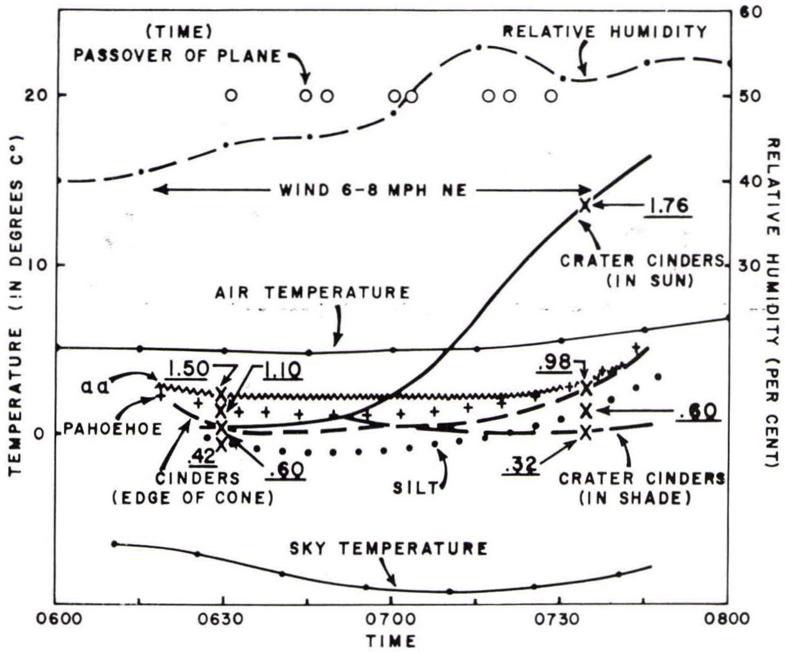

FIG. 5. Chart showing radiant temperatures of various materials during the period 0600 to 0800, February 13, 1965, together with the temperatures of the air and sky and other meteorological parameters. Underscored numerals indicate film density values of infrared images of various materials. The materials to which they refer and the time the images were produced are shown with '*x*'s. Density values not to scale. Based on preliminary interpretation of data (courtesy of Wm. A. Fischer).

TABLE 3

RELATIONSHIP OF REMOTE SENSOR DEVELOPMENTS TO POTENTIAL MANNED SCIENTIFIC MISSIONS OF THE FUTURE

- Side-looking nature of radar permits detection of structural fabric and morphological detail not possible on conventional photographs of same scale.
- Range resolution is not necessarily a function of orbital altitude. Broad area imagery of high resolution can be obtained with the power sources (1 kw ±) available for radar on heavy payload (5000 lb. ±) orbiters.
- Radar is self-illuminating and can therefore produce imagery on dark side of moon for inflight display system.
- Radar has an all-weather capability in earth orbit. In a similar way it will be suitable for Venus missions.
- Radar altimetry and surface profile information is accurate enough for sea-slope, sea-state and planetary roughness measurements.
- New radar and radio frequency measurements may permit depth penetrations of tens of feet.

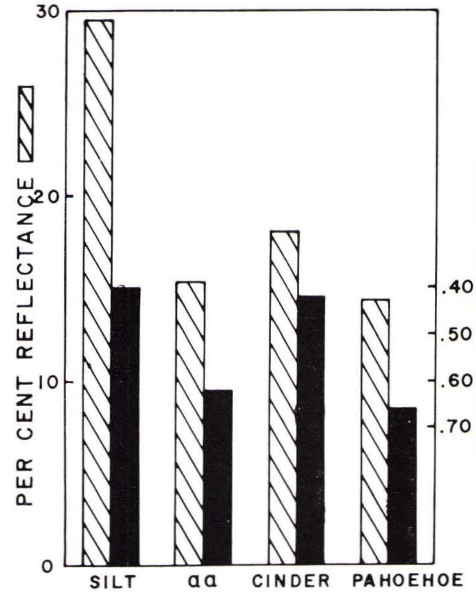

FIG. 6. Relationship of the reflectance of various materials, as determined by colorimeter measurement, to relative infrared emission, measured and expressed as film density as recorded on infrared image produced at 14:10, February 13, 1965 (courtesy of Wm. A. Fischer).

FIG. 7. Sample of radar imagery from aircraft. This imagery is several years behind the current state-of-the-art. Radar imagery reveals many earth and planetary surface features not detected by conventional photography. This radar imagery is of the Appalachian disturbed belt in Virginia. Note the position of the Burkes Garden Dome near the center of the picture.

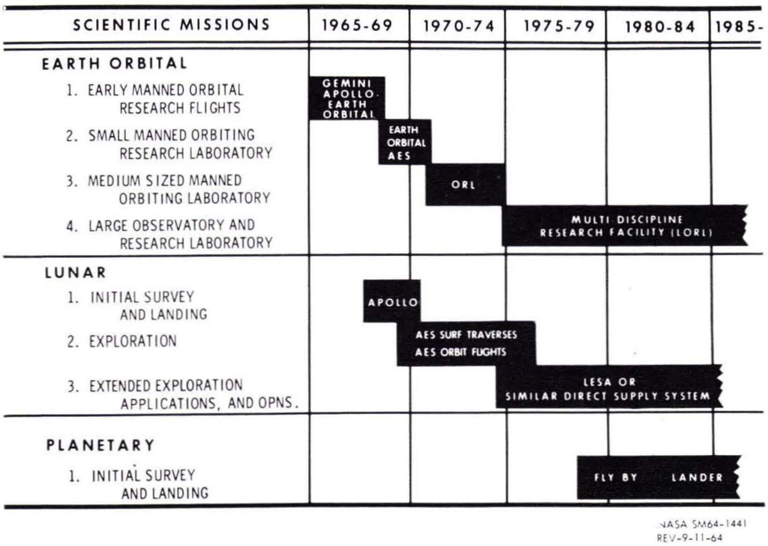

FIG. 8. Relationship of remote sensor developments to potential manned scientific missions of the future.

| REGION OF SPACE | UNMANNED | MANNED | |
|---|---|---|---|
| | | DEVELOPMENTAL | OPERATIONAL |
| EARTH ORBIT | **1. SCIENTIFIC SATELLITES:**<br>EXPLORERS<br>OBSERVATIONS (OGO, OAO, OSO ETC.)<br>APPLICATION:<br>COMMUNICATION (TELSTAR, SYNCOM)<br>METEOROLOGY (TIROS, NIMBUS)<br>NAVIGATION<br>ENGINEERING RESEARCH | **4. SATELLITES:**<br>MERCURY<br>GEMINI<br>APOLLO EARTH-ORB. SAT. 1B + SAT. V QUAL FLIGHTS<br>35-60 DAY ORBITAL FLIGHTS (A.E.S.)<br>ORBITAL RES. LAB. (ORL) | **7. LABORATORIES:**<br>FERRY VEHICLES<br>RECOVERABLE BOOSTERS<br>ENGINEERING<br>EXPERIMENTS<br>DEVELOPMENT |
| LUNAR | **2. LUNAR PROBES:**<br>RANGER<br>SURVEYOR<br>LUNAR ORBITER | **5. LUNAR EXPLORATION:**<br>INITIAL APOLLO LANDINGS<br>2-4 DAY SURFACE TRAVERSES<br>ORBITAL SCIENTIFIC SURVEYS<br>14 DAY SURFACE TRAVERSES | **8. LUNAR STATION:**<br>EXPLORATIONS<br>SCIENTIFIC OBSERVATIONS |
| PLANETARY | **3. DEEP-SPACE PROBES:**<br>MARINER<br>INTERPLANETARY MONITOR<br>SATELLITES<br>VOYAGER<br>SOLAR PROBE<br>OUTER PLANETS & SATELLITES<br>BIOSATELLITE | **6. EXPEDITIONS:**<br>MARS FLY - BY<br>VENUS RECONNAISSANCE<br>SEARCH FOR LIFE ON PLANETS | **9. PLANETARY OPERATIONS:**<br>MARS STATION<br>ADVANCED EXPEDITIONS<br>VENUS<br>JUPITER SATELLITES<br>MERCURY<br>ASTEROIDS |

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FIG. 9. Relationship of manned earth and lunar orbital spacecraft to other NASA missions.

craft being studied by NASA which do have adequate payloads, and their possible schedules, are shown in Figure 8. The relationship of such flights to other NASA missions is shown in Figure 9.

### CONCLUSIONS AND ACKNOWLEDGEMENTS

The final results of this NASA program will not be available for a number of years so that it is difficult to predict the outcome at this time. Many elements of the scientific community have already shown great interest, however, and a significant exchange of ideas is underway. The writer wishes to commend all of those involved for the high degree of cooperation which they have exhibited.

### REFERENCE

Colwell et al., Basic Matter and Energy Relationships Involved in Remote Reconnaissance; PHOTOGRAMMETRIC ENGINEERING, Vol. XXIX, No. 5, Sept. 1963, p. 761–799.