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# MULTI-SENSOR SYSTEM (MUSS)
# FOR AIRBORNE SURVEILLANCE
# OF INSHORE WATERS

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# ABSTRACT

Data were assembled and listed in this report on state-of-the-art aircraft sensors which could be integrated to form a Multi-Sensor System (MUSS) for surveillance of inshore waters. The following sensor categories are included: radars (active, imaging), optical multispectral spectrometers (passive, imaging), infrared scanners (passive, imaging), infrared radiometers/spectrometers (passive, non-imaging), cameras and active laser systems. The MUSS might be required to perform the following missions: 1) collect data on previously uncharted areas; 2) collect data on previously charted areas using different sensors, and 3) collect data for update and/or verification of archival data. The principal beach parameters which must be measured by the MUSS include: length, width, gradient, surf and tidal range and nearshore currents. It is possible that the MUSS would also be able to yield information on the type of sediment and trafficability of the nearshore zone in addition to locating obstacles in the surf zone and mapping the ground cover.

# MULTI-SENSOR SYSTEM (MUSS) FOR AIRBORNE SURVEILLANCE OF INSHORE WATERS

## I. INTRODUCTION

Amphibious warfare is one of the most complicated and sophisticated forms of warfare, combining mobility and flexibility with the element of surprise. Perhaps no other military operation is as concerned with its environment and as vulnerable to the caprices of wind and water.

The principal parameters characterizing beaches, such as - length, width, gradient, approach, material, surf and tidal range, and nearshore current are subject to change of wind, water, and land interactions. The result is that beaches are the most complex and dynamic of land forms.

Adequate beach data must be collected prior to any mission if mobility and flexibility of the mission is to be maintained. The surprise element of the mission is lost unless the collection process remains covert. A complicating factor is that the political turmoil of the mid-twentieth century demands that U.S. military forces be prepared to operate upon a variety of beaches worldwide and within a very narrow time frame. The requirement thus exists not only for maintaining data files on the world beaches, but the capability to rapidly update and incorporate data of specific parameters which are time dependent. Present efforts for maintaining current data have not been satisfactory and conventional methods for near-realtime updating are too time consuming frequently resulting in insufficient and/or incorrect data.

The application of remote surveillance of inshore waters has the combined problems of sensing both the land formations and the inshore waters. The optimum remote sensing system must therefore have sensors which can both detect and identify surface and subsurface conditions as well as sensors which are capable of supplying information on a variety of atmospheric parameters.

A project was initiated in August 1976 by Applied Science Technology, to investigate the design criteria of a Multisensor Surveillance System (MUSS) for survaillance and reconnaissance of the inshore area. The results of Phase I of this project are described in this report. Phase I consisted of a technical assessment of the state-of-the-art aircraft sensors which could possibly be integrated to form an airborne system for inshore surveillance.

Development of the MUSS system concept requires one to consider the operational aspects of the data collection and reduction process. Some, but by no means all, amphibious zones of the world have been charted. The utility of these data to directly support a tactical mission is subject to examination on two accounts.

- accuracy of original sensor data, and
- changes in beach structure in the time period since the original data were acquired.

Such archival data can be useful in developing predictive models of beaches, particularly if measurements are repeated over a period of time. It is possible, therefore, to derive a set of viable beach parameters. The use of either the archival or derived data in a tactical mission requires that such data be verified and updated just prior to the mission.

To summarize; the MUSS will be required to perform the following types of missions:

- collect new data, area previously uncharted,
- collect new data, area previously charted using different sensors, and
- collect data for update and/or verification of archival data.

Three levels of priority for inshore surveillance have been stated by the Office of Naval Research. These priority rankings are shown in Table I. The application of the various sensors considered in this study have been included in this table. Final sensor selection must correlate the state-of-the-art sensors with these requirements.

**Table I - Remote Sensing Requirements for Inshore Surveillance**

| Hydrographic Parameter | Microwave Radiometers (passive; non-imaging) | Radars (active; imaging)* | Optical Multispectral Spectrometers (passive; imaging) | Infrared Scanners (passive; imaging) | Infrared Radiometers/ Spectrometers (passive; non-imaging) | Cameras | Active Laser Systems |
|---|---|---|---|---|---|---|---|
| **LEVEL I** | | | | | | | |
| • waves | X | X | | | | X | X |
| • currents | | | X | X | | X | X |
| • wind field | X | X | | | | | X |
| • bathymetry/modeling | | | X | | | X | X |
| • btm sediment, types, transport | | | | | | | X |
| • tides | | X | X | X | | X | X |
| **LEVEL II** | | | | | | | |
| • beach profile | | X | X | X | | X | X |
| • beach trafficability | X | X | X | X | | | X |
| • water temperature | X | | X | X | X | | X |
| • atmospheric visibility | | | X | | | X | X |
| • barometric pressure | X | | | | | | X |
| • channel geometry | | | X | | | | X |
| • salinity | X | | | | | | |
| **LEVEL III** | | | | | | | |
| • underwater visibility | | | X | | | X | X |
| • internal waves | | | X | | | X | |
| • marine animals | | | | | | | X |
| • vegetation | | X | X | | | X | X |

*all weather

# II. SENSORS

A number of devices, both imaging and non-imaging, known collectively as "remote sensors", have been and are currently being developed to measure electromagnetic radiation emitted or reflected from the earth at various frequencies, angles, polarizations, etc. These instruments are also currently being used aboard many satellites and spacecraft.

The multispectral concept generally states that the level of energy reflected or emitted from objects normally varies with wavelength throughout the electromagnetic spectrum. A unique signature of an object can therefore often be identified if the energy that is being reflected and/or emitted from it is separated into carefully chosen wavelength bands. Many conventional systems with a wide range of sensitivity tend to inhibit object-to-background discrimination, however, discrimination capability can generally be improved by selectively recording energy from within different wavelength bands.

While this multispectral imaging technique may appear to be relatively simple, complications arise owing to uncertainties or variations related to the following factors:

- spectral characteristics of the source emitter,
- the angle of incidence of the emitter with respect to the surface,
- selective transmission, reflection, absorption, emission, and scattering effects of the atmosphere,

- reflectance and emittance characteristics of the surface,
- altitude of the sensor platform,
- data collection, processing, and presentation techniques, and
- data interpretation techniques.

An understanding of these factors and the uncertainties associated with their distribution, measurement, and relative importance is necessary in order to enhance the object-to-background contrast ratio in any remote sensing operation. Voluminous data have been obtained during the past decade in a wide variety of disciplines with numerous types of sensors. The majority of the sensors used are those that produce imagery or photography in the wavelength bands between 0.3 micrometers in the near ultraviolet to approximately 1.3 meters in the microwave portion of the spectrum. Within this relatively broad band, sensing systems may include the use of cameras; optical, infrared and microwave scanners, spectrometers and radiometers; as well as active laser systems. With the exception of radars and lasers, which are active systems providing their own source of illumination, the systems operating in the bands mentioned above are generally passive; that is, they record the natural level of radiation from a given scene.

The following is a list of the sensor categories for which data were assembled during this contract.

- microwave radiometers (passive; non-imaging)

- radars (active; imaging)
- optical multispectral spectrometers (passive, imaging)
- infrared scanners (passive; imaging)
- infrared radiometers/spectrometers (passive; non-imaging)
- cameras
- active laser systems

A brief description of each sensor category is given, along with the salient parameters for the specific sensor systems in that category. Information for this study was assembled from a variety of sources: personal contact with key scientists and marketing managers, NASA centers, Marine Corps and Navy personnel, private companies, conferences, specification sheets, and technical reports and handbooks.

## A. Microwave Radiometers (passive; non-imaging)

Microwave radiometry holds promise as a passive all-weather technique; it may have improved capabilities over shorter wavelength sensing in detection of: ground moisture, ocean-wave heights, and near surface temperatures. Generally, the wavelengths longer than 10cm are surface penetrating and provide good measurements of subsurface phenomena, soil moisture and salinity. Wavelengths between 4 and 6cm provide the best window through the atmosphere to the surface. Wavelengths between 0.75 and 6cm are utilized to distinguish between temperature and emittance effects in the energy source such as wind induced surface roughness and foam, the atmospheric water vapor column, and precipitation levels. Wavelengths below about 0.6 cm (750GHz) are most useful in providing indication of storms over land and of sea ice boundaries because of their finer resolutions for a given antenna size or in providing temperature, humidity and pressure sounding due to differential effects on specific absorption lines.

Table II lists the various microwave radiometers that were identified by this study while figure 1 shows these same systems superimposed on the various atmospheric bands. The majority of the passive microwave systems are large and weigh in access of 400 lbs. The only exceptions to this are 1) the S-Band radiometer of North American Rockwell, 2) the swept frequency microwave radiometer of North American Rockwell, and 3) the electrically scanning (imaging) microwave radiometer of Aerojet General.

### B. Radars (active; imaging)

Radars exist in many different configurations, each designed to perform specific measurements on an illuminated scene. The type of radar which appears to offer the most potential for airborne remote sensing applications is designated as the Side Looking Airborne Radar (SLAR) systems. SLAR systems can be divided into two basic classes; a) real-aperture or non-coherent radar and b) Synthetic Aperture Radar (SAR) or coherent radar.

Radar provides a specular reflection from smooth objects.

Table II - MICROWAVE RADIOMETERS
(passive; non-imaging)

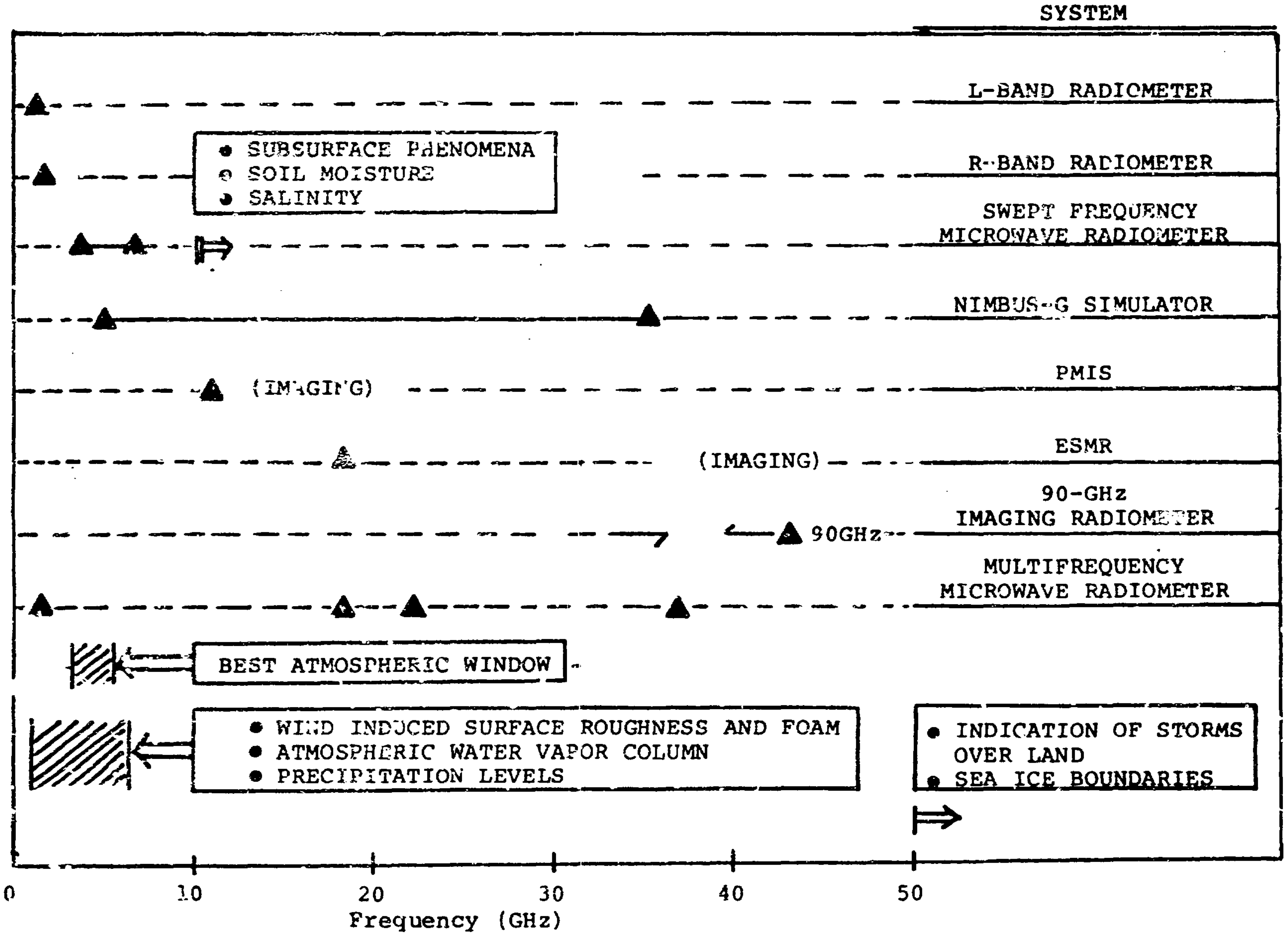
| | SYSTEM<br>L-BAND RADIOMETER | SYSTEM<br>S-BAND RADIOMETER | SYSTEM<br>SWEPT FREQUENCY MICROWAVE RADIOMETER | SYSTEM<br>NIMBUS-G SMMR SIMULATOR |
|---|---|---|---|---|
| DEVELOPER (YEAR) | NASA/LRC (1975) | North American Rockwell (1972) | NASA/LRC; North American Rockwell (1976) | NASA (1976) |
| APPLICATION | Water salinity ~1% | Water temperature ~ ±0.1K° | • Ocean temperature<br>• Salinity<br>• Pollution<br>• Ice | • Sea temperature o Sea ice<br>• Wind speed<br>• Water vapor<br>• Precipitation |
| OPERATING FREQUENCY (WAVELENGTH) | 1.43 GHz (20.98cm) | 2.65 GHz (11.32cm) | 4.5 GHz (6.67cm) to<br>7.2 GHz (4.17cm) | 5,6.6,10.7,18,19.3,21,37GHz (6,4.54,2.80,1.67,1.55,1.43, 0.81cm) |
| SYSTEM FIELD OF VIEW (INSTANTANEOUS) | 20° | 20° | 20° | 6° |
| SYSTEM FIELD OF VIEW (TOTAL) | 20° | 20° | 20° | 6° |
| RESOLUTION ELEMENT ON GROUND | 0.36 x Aircraft altitude | 0.36 x Aircraft Altitude | 0.36 x Aircraft Altitude | 0.10 x Aircraft Altitude |
| SCAN CAPABILITY | No | No | No | No |
| AIRCRAFT DISPLAYS AND SIGNAL PROCESSOR(S) | • Strip chart<br>• Data recorded on digital tape onboard A/C<br>• Processed off-line on CDC 6600 | • Strip chart<br>• Data recorded on digital tape onboard A/C<br>• Processed off-line on CDC 6600 | • Strip chart<br>• Data recorded on digital tape onboard A/C<br>• Processed off-line CDC 6600 | • Data recorded on digital tape onboard A/C - ADIS, System<br>• Processed off-line on ground computer |
| SIZE/WEIGHT/POWER REQUIREMENTS | • 5 ft$^3$ receiver & antenna<br>• 1 relay rack processing<br>• 350 lbs.<br>• 110V, 12A | • 3 ft$^3$ receiver & antenna<br>• 1/2 rack processing<br>• 200 lbs.<br>• 110V, 12A | • 5-10 ft$^3$ receiver & antenna<br>• 1 relay rack processing<br>• 200 lbs.<br>• 110V, 12A | • 8-10 ft$^3$ receiver & antenna<br>• 2 relay racks processing<br>• 500 lbs; excl of rec equip.<br>• <2KVA |
| AIRCRAFT | C-54 | C-54<br>C-130 | C-54<br>CV-990 | CV-990 |
| STATUS | • MESA 1975<br>• Chesapeake Bay 1975 | • Acceptance test 1972<br>• Jonswap II 1973<br>• WISEX 1975<br>• MESA 1975 | • Prelim. flight tests only<br>• System test scheduled for 1977 | • Several missions flown between 1974-1977. |
| REFERENCE | • James H. Schrader NASA/LRC<br>• NASA Sensor Handbook Special Prgms Office-1977 | • James H. Schrader NASA/LRC<br>• NASA Sensor Handbook | • James H. Schrader NASA/LRC<br>• NASA Sensor Handbook | • Thomas T. Wilheit NASA/Goddard<br>• NASA Sensor Handbook |

# Table II - MICROWAVE RADIOMETERS
(passive; non-imaging)

(continued)

|  | SYSTEM | SYSTEM | SYSTEM | SYSTEM |
|---|---|---|---|---|
|  | 90-GHz IMAGING RADIOMETER | ELECTRICALLY SCANNING (IMAGING) MICROWAVE RADIOMETER - ESMR | PASSIVE MICROWAVE IMAGING SYSTEM (PMIS) | MULTIFREQUENCY MICROWAVE RADIOMETER (MFMR) |
| DEVELOPER (YEAR) | NRL (1975) | NASA/Aerojet Electro-Systems Company (1970) | NASA/Goddard (1971) | Texas A&M Univ. (1973);<br>Aerojet General (1969) |
| APPLICATION | • High spatial resolution radiometric images of Earth's surface and atmosphere | • Meterological features<br>• Ground truth for Nimbus 5<br>o Used in conjunction with SMMR Simulator | • Moisture content of soils and snow packs<br>• Ice thickness } Brightness temp at two polarizations<br>• Sea state } | • brightness temperature of surface & atmosphere for different angles of incidence & polarization |
| OPERATING FREQUENCY (WAVELENGTH) | 90GHz (0.33cm) | 19GHz | 10.69GHz (2.81cm)<br>X-band | L-Band Ka-Band<br>K-Band Ku-Band |
| SYSTEM FIELD OF VIEW (INSTANTANEOUS) | 2° | 2.8° | 1.6° x 2.6° | L-Band (17°); K-Band (4°)<br>Ka-Band (4°); Ku-Band (4°) |
| SYSTEM FIELD OF VIEW (TOTAL) | 64° | ±50° | ±34.5° | Same as Above |
| RESOLUTION ELEMENT ON GROUND | 0.03 x Aircraft Altitude | 0.05 x Aircraft Altitude | 0.03 x Aircraft Altitude | 17° / 0.3xA/C Alt.<br>4° / 0.07xA/C Alt. |
| SCAN CAPABILITY | 640°/sec | • Electronically scanned phased array<br>• 0.187 scans/sec | • Variable electronic scan | No |
| AIRCRAFT DISPLAYS AND SIGNAL PROCESSOR(S) | • Format-decimal 12 bit | • CRT | • TV display<br>• Realtime image and/or corrected brightness temperature | • 10-bit digital<br>• Realtime analog and digital uncorrected brightness temperature |
| SIZE/WEIGHT/POWER REQUIREMENTS | • 5 ft³<br>• 1 relay rack<br>• 570 lbs. | • 5 ft³<br>• 97.5 lbs. | • 12 ft³<br>• 650 lbs. | • 650 lbs. |
| AIRCRAFT | C-54 | CV-990 | NP3A | NP3A |
| STATUS | • 15 missions (1975)<br>• 10 missions (1976) | • several missions | • 6 or 7 missions/year | • 6 or 7 missions/year |
| REFERENCE | • J. P. Hollinger NRL<br>• NASA Sensor Handbook | • Thomas T. Wilheit NASA/Goddard<br>• NASA Sensor Handbook | • NASA Sensor Handbook | • NASA Sensor Handbook |

Figure 1: MICROWAVE RADIOMETERS
(passive; non-imaging)



Hence, it proves to be an especially good sensor not only for identifying calm water bodies (and therefore their shorelines), but also for identifying rough water areas. Applications include the identification of oil slicks on water and estimation of the strength of winds near the sea's surface. Additionally, radar has been used to measure soil moisture and in identifying both sea and lake ice.

The most important characteristic of radar is its ability to penetrate clouds (i.e., to be an "all-weather" sensor) and map terrain and water features over a broad area of coverage. The active microwave sensors are displayed in Table III. The majority of these systems fall into the category of developmental systems which have been built mainly to demonstrate feasibility of a particular design. These systems have been flown in support of numerous research programs and, in general, have yielded good to excellent results. The three production systems available are 1) the AN/APS-94D (Motorola), 2) the UPD-4 (APD-10) reconnaissance system (Goodyear), and 3) the WX-50 (Westinghouse). These vary in weight from 140 lbs. for the WX-50 system to 650 lbs. for the Goodyear system. The highest resolution system is the APD-10, which is currently installed in the Navy Marine Corps RF-4B reconnaissance aircraft. This system is, however, fairly large and relatively expensive. One must ascertain that the missions demanded of MUSS require the use of the APD-10. Perhaps, a less sophisticated system would suffice.

# Table III - RADARS
(active-imaging)

|  | SYSTEM<br>X-L BAND DUAL POLARIZATION RADAR | SYSTEM<br>AN/APS-94D | SYSTEM<br>AAFE L-BAND SYNTHETIC APERTURE RADAR | SYSTEM<br>UPD-4 (APD-10) RECONNAISSANCE RADAR SYSTEM |
|---|---|---|---|---|
| DEVELOPER (YEAR) | ERIM<br>(1973) | Motorola:/U.S. Army Electronic Command - Ft. Monmouth | Jet Propulsion Lab/NASA<br>(1977) | Goodyear Aerospace (NASA/JSC) - 1971 |
| APPLICATION | "All Weather" Sensor - penetrates clouds, map terrain and water features - reconnaissance and surveillance |  |  |  |
| APERTURE |  | Real; can convert to synthetic aperture on receive | Synthetic | Synthetic |
| OPERATING FREQUENCY (WAVELENGTH) | X-Band (3cm)<br>L-Band (23cm) | X-Band | L-Band | 10,000 MHz |
| SYSTEM FIELD OF VIEW (INSTANTANEOUS=TOTAL) | Nadir to 80° | Maps 60-100 miles on each side of A/C | 45° - optimum swath 14km | 10NM swath to 30NM Max. Range |
| RESOLUTION ELEMENT ON GROUND | 3m x 3m; Independent of wavelength or altitude | Azimuth res: = range x sin0.45°<br>range res: = 30m | Azimuth res: 30mrad | 10ft. |
| SCAN CAPABILITY | No | No | No | No |
| AIRCRAFT DISPLAYS AND SIGNAL PROCESSOR(S) | • A scope display<br>• Chart recorder<br>• Data recorded on "signal film" in A/C | • On board display: recorder and viewer - dry film processing | • Both optical and digital recording<br>• all processing performed on ground | • Optical processor<br>• Digital processor, CRT<br>• Off-line digital processing |
| SIZE/WEIGHT/POWER REQUIREMENTS | • 4000 lbs.<br>• 115V @ 400Hz - 5kw<br>• 28 VDC - 30 Amps | • 9 units ( $0.4m^3$)<br>• 500 lbs; excl. antenna<br>• 115V @ 400Hz<br>• 28VDC - 20 Amps | • 100 lbs<br>• 20W/110V @ 400Hz | • 625 lbs<br>• 2700 watts 400 Hz |
| AIRCRAFT | C-46 | Army's OV-1D Mohawk<br>Lockheed Electria & P-3<br>McDonnell Douglas B-26 | CV-990 | RF-4C RF-4E<br>RF-4B |
| STATUS | • Good | • Good: Modular Approach | • Several flights in 1977 | • Can be data linked to ground<br>120MHz W/B data |
| REFERENCE | • Frederick J. Thomson<br>ERIM | • Motorola Spec Sheets | • NASA Sensor Handbook | • Goodyear |

## Table III - RADARS
## (active-imaging)

(continued)

| | SYSTEM | SYSTEM | SYSTEM | SYSTEM |
|---|---|---|---|---|
| | JPL - X-BAND IMAGING RADAR | KANSAS UNIVERSITY SLAR | JPL VHF IMAGING RADAR | JPL - L-BAND IMAGING RADAR |
| DEVELOPER (YEAR) | Jet Propulsion Lab Modified APQ-102A (1976) | University of Kansas/NASA (1973) | Jet Propulsion Lab (1973) | Jet Propulsion Lab (1969) |
| APPLICATION | "All Weather" Sensor - penetrates clouds, map terrain and water features - reconnaissance and surveillance | | | |
| APERTURE | Synthetic | Real | Synthetic | Synthetic |
| OPERATING FREQUENCY (WAVELENGTH) | X-Band | 9.4 GHz | 150 MHz | L-Band |
| SYSTEM FIELD OF VIEW (INSTANTANEOUS-TOTAL) | • 45°<br>• Optimum swath 14km | • Beam width 0.46°x 20° | • Beamwidth 30°x90°<br>• Optimum Swath: 14km | • Beam width 18°x 90°<br>• Optimum Swath: 14km |
| RESOLUTION ELEMENT ON GROUND | • Azimuth: 10m<br>• Range: 30m | • Azimuth: 6 mrad | • Azimuth: 10m<br>• Range: 30m | • Azimuth: 10m<br>• Range: 30m |
| SCAN CAPABILITY | No | No | No | No |
| AIRCRAFT DISPLAYS AND SIGNAL PROCESSOR(S) | • Optical recorder on board<br>• Processing performed on ground | • TV Display<br>• Store on scan converter & photographed<br>• Uses serial analog mem. to record video on tape | • Optical Recorder<br>• Processing done on ground on Optical Correlator | • Optical Recorder<br>• Processing done on ground on Optical Correlator |
| SIZE/WEIGHT/POWER REQUIREMENTS | • $0.1m^3$<br>• 125 lbs<br>• 100W/28V<br>• 2300W/115V @ 400Hz | • $0.35m^3$<br>• 550 lbs<br>• 400W/110Vac @ 60Hz | • 75lbs + 150 lbs for optical recorder<br>• 180W/28V<br>• 100W/110V @ 400Hz | • $0.4m^3$<br>• 212 lbs + 150 lbs for optical recorder<br>• 400Hz |
| AIRCRAFT | CV-990 | | CV-990 | CV-990 |
| STATUS | • Two missions in 1976 | | • Numerous Flights | • Numerous Flights |
| REFERENCE | • NASA Sensor Handbook | • NASA Sensor Handbook | • NASA Sensor Handbook | • NASA Sensor Handbook |

## Table III - RADARS (active-imaging)

(continued)

|  | SYSTEM | SYSTEM | SYSTEM | SYSTEM |
|---|---|---|---|---|
|  | WX-50 |  |  |  |
| DEVELOPER (YEAR) | Westinghouse (1975) |  |  |  |
| APPLICATION | ● mapping<br>● letdown terrain clearance mode |  |  |  |
| APERTURE | Real |  |  |  |
| OPERATING FREQUENCY (WAVELENGTH) | K-Band (35 GHz) |  |  |  |
| SYSTEM FIELD OF VIEW (INSTANTANEOUS-TOTAL) | ● Beam Width: 1.5°<br>● Scan Angle: ±35° |  |  |  |
| RESOLUTION ELEMENT ON GROUND | ● 50 ft. |  |  |  |
| SCAN CAPABILITY | ● 60°/sec |  |  |  |
| AIRCRAFT DISPLAYS AND SIGNAL PROCESSOR(S) | 70° forward sector scan PPI presentation |  |  |  |
| SIZE/WEIGHT/POWER REQUIREMENTS | ● $2.5 ft^3$<br>● 140 lbs (less pod)<br>● 1000 Watts |  |  |  |
| AIRCRAFT | ● TA-4 ● AV-8<br>● OV-10 ● F-5 |  |  |  |
| STATUS | ● 162 flight hours<br>● 75 ground hours |  |  |  |
| REFERENCE | ● Westinghouse Spec Sheets |  |  |  |

## C. Optical Multispectral Spectrometers (passive; imaging)

The class of multispectral imaging spectrometers must be considered for possible inclusion in any multisensor reconnaissance system. These systems simultaneously register data on magnetic tape from several spectral bands, from the visible through the infrared region. These data are then analyzed on ground-based computers to extract classes of features having similar spectral characteristics. Examples of several applications of this new technique to various aspects of the inshore environment include (1) mapping of aquatic vegetation, (2) bathymetry, (3) thermal effuents and associated mass movements, (4) detection of industrial discharge, (5) mapping oil slicks and (6) chlorophyll distribution. Table IV lists the current state-of-the-art multispectral imaging spectrometers. All of these spectrometers are similar, having 5-10 bands in the visible, with some systems having a band in the thermal IR. The field of view of these instruments is very small; in the order of a few milliradians. Except for the prototype systems being developed by ERIM and NASA the systems are generally small and weigh less than 200 lbs. The two production units that are possible choices for inclusion in the MUSS are 1) the DS-1200 series, passive line scan systems (Daedalus) and 2) the modular multispectral scanner - $M^2S$ (Bendix).

## D. Infrared Scanners (passive; imaging)

The thermal infrared scanner (see Table V) normally has

# Table IV - OPTICAL MULTISPECTRAL SPECTROMETERS (passive; imaging)

SPECTROMETERS (Imaging)

| | SYSTEM | SYSTEM | SYSTEM | SYSTEM |
|---|---|---|---|---|
| | M-7 MULTISPECTRAL SCANNER | M-8 ACTIVE - PASSIVE MULTISPECTRAL SCANNER | RS-18 MULTISPECTRAL SCANNER (THERMAL) | MODULAR MULTISPECTRAL SCANNER ($M^2S$) |
| DEVELOPER (YEAR) | ERIM/NASA (1970-1971) | ERIM/NASA (1976/1977) | • Texas Instr-Scanner (1975)<br>• MacDonald-Dettwiler-Digitizer (1975) | Bendix (1974) |
| APPLICATION | • Mapping Aquatic Vegation<br>• Bathymetry<br>• Thermal Effuents and Associated Water Mass Movements | | • Industrial Discharges<br>• Mapping Oil Slicks<br>• Detection of Certain Spectral Characteristics Related to Chlorochyll Concentrations | |
| OPERATING FREQUENCY (WAVELENGTH) | Up to 13 bands from 0.32 - 14μm | Passive: (10 bands) 0.4-14μm<br>Active: 1.06μm | 5 bands similar to LANDSAT C 0.5-12.5μm | 10 bands visible & reflec. IR (0.38-13.5μm)<br>1 thermal band(3-5 or 8-12μm) |
| SYSTEM FIELD OF VIEW (INSTANTANEOUS) | 2 mrad | 3 mrad | 1 mrad | 2.5 mrad |
| SYSTEM FIELD OF VIEW (TOTAL) | 90° | 90° | 80° ±15° Roll Compensation | 103° |
| RESOLUTION ELEMENT ON GROUND | 2 mrad x A/C altitude | 3 mrad x A/C altitude | 1 mrad x A/C altitude | 2.5 mrad x A/C altitude |
| SCAN CAPABILITY | • Linear Scan - 60°/sec | • Linear Scan - 60°/sec<br>• Limited by Performance Specs to 1-2kft altitude | 80° scan angle | • Dig Scan Motor, 0-199 scans/sec<br>• Single Sided 45° Rot mirror |
| AIRCRAFT DISPLAYS AND SIGNAL PROCESSOR(S) | • A Scope<br>• High Density Digital Tape in A/C (1000 bpi)<br>• Data Rate 20.8 megabits/sec | • A Scope<br>• High Density Digital Tape in A/C (1000 bpi)<br>• Data Rate - 25 megabits/sec | | • Honeywell visicorder moving window CRT display<br>• Video signal recorded on FM-14 track tape |
| SIZE/WEIGHT/POWER REQUIREMENTS | • Total System - 400 lbs.<br>• Scanner - 85 lbs.<br>• 5 kva 115V @ 400 cps | • Total System - 1500 lbs<br>• Scanner - 700 lbs.<br>• 30 kva | | • 7 units - 280 lbs, not incl racks and recording equip.<br>• less than 30A @ 30 VDC. |
| AIRCRAFT | • C-46<br>• C-47 | C-47 | WB 57F | • Lockheed P-3; NF 3A Light Twin Engine, HS-125, KC-135 C-130 |
| STATUS | • Over 80 Missions Flown<br>• Developmental<br>• Extremely Reliable | • Active System Installed & Flight Tested - 1977<br>• Developmental<br>• Good Results | • In Process of being Evaluated | • Good (Modular & Easily Repaired)<br>• In Production |
| REFERENCE | • Frederick J. Thomson<br>• ERIM | • Frederick J. Thomson<br>• ERIM | • NASA Earth Resources Prgm: JSC Earth Resources A/C Plan (1975) | • Bendix Spec Sheets |

## Table IV - OPTICAL MULTISPECTRAL SPECTROMETERS
(passive; imaging)

(continued)

| | SYSTEM | SYSTEM | SYSTEM | SYSTEM |
|---|---|---|---|---|
| | DS-1200 SERIES PASSIVE LINE SCAN SYSTEMS | OCEAN COLOR SCANNER (OCS) | MULTICHANNEL OCEAN COLOR SENSOR (MOCS) | |
| DEVELOPER (YEAR) | • Daedalus Enterprises, Inc. (1968 - Present) | • NASA Goddard | • TRW Defense & Space Stations (1972) | |
| APPLICATION | • Same as on previous page | • Prototype for Coastal Zone Color Scanner (Nimbus G)<br>• Map regions of high prod.<br>• Upwelling Regions<br>• Red Tide | • Map subtle differences in Ocean Color to Determine Seawater Constituents | |
| OPERATING FREQUENCY (WAVELENGTH) | • 0.32 m - 14.0μm<br>10 channels visible<br>1 channel IR (8-14μm) | • 10 channels visible<br>.427 - .774μm | • 400 to 700μm | |
| SYSTEM FIELD OF VIEW (INSTANTANEOUS) | 1-2 mrad | 3-5 mrad | 0.11 x 0.23° | |
| SYSTEM FIELD OF VIEW (TOTAL) | 88° | 90° | 17.1 x 0.23° | |
| RESOLUTION ELEMENT ON GROUND | (1-2 mrad) x A/C altitude | (3-5 mrad) x A/C altitude | (2x4 mrad) x A/C altitude | |
| SCAN CAPABILITY | • line Scan<br>12.5-100 scans/sec digital<br>80-160 scans/sec analog | Yes | • Raster Scan: 285ms<br>150 Spatial x 20 Spectral Elements: 3.5 frames/sec | |
| AIRCRAFT DISPLAYS AND SIGNAL PROCESSOR(S) | • Storage CRT<br>• 5-in paper printout (dry process<br>• High density digital tape | • Data Recorded on 14 track Mag tape in analog<br>• Also Recorded in PCM digital format | o Video | |
| SIZE/WEIGHT/POWER REQUIREMENTS | • 150 lbs.<br>• 28VDC<br>• 8-50 Amps depending on Ancillary Equipment | • 128 lbs.<br>• 120 watts @ 117 VAC | • 22 lbs<br>• 47.5 x 17.5 x 16.9cm<br>• power less than OCS system | |
| AIRCRAFT | Various: Single engine piston to high altitude jet. | U-2 | CV-990 | |
| STATUS | Good - In Production | Good - 3 Systems Built | Approximately 20 flights flown from 1972 - 1975 | |
| REFERENCE | • Daedalus Spec Sheets<br>• Carl D. Miller | • U-2 Investigators' Handbook-NASA Ames<br>• William Barns/NASA Goddard | • NASA Sensor Handbook<br>• (NASA/Langley) | |

# Table V - INFRARED
(passive; imaging)

| | SYSTEM | SYSTEM | SYSTEM | SYSTEM |
|---|---|---|---|---|
| | AN-AAD-5 | LIGHT WEIGHT FORWARD LOOKING INFRARED (FLIR) | RS-18 THERMAL SCANNER | THERMAL INFRA-RED SCANNER (TIRS) |
| **DEVELOPER (YEAR)** | Honeywell Radiation Center (1971) | Honeywell Radiation Center/ U.S. Army Night Vision Lab (1977) | Texas Instruments (1973) | NASA Ames |
| **APPLICATION** | • Down Looking Infrared Strip Mapper | • Remotely Piloted Vehicle, Surveillance & Fire Control Helicopter Navigation | • Water pollution<br>• Thermal Mapping<br>• Ocean Surveys<br>• Geothermal | • Soil Moisture<br>• Snow Packs<br>• Fire Reconnaissance<br>• Geologic Studies<br>• Thermal Pollution |
| **OPERATING FREQUENCY (WAVELENGTH)** | 7-14μm | 8-12μm | 8-14μm | • one channel 3-5μm<br>• one channel 8-14μm |
| **SYSTEM FIELD OF VIEW (INSTANTANEOUS)** | CLASSIFIED | Narrow: 2.6°x3.5°<br>Wide: 9°x12° | 1mrad | 1mrad |
| **SYSTEM FIELD OF VIEW (TOTAL)** | CLASSIFIED | 12° | 80° ( 40° from Nadir) | 90° |
| **RESOLUTION ELEMENT ON GROUND** | CLASSIFIED | CLASSIFIED | 1mrad x A/C altitude | 1mrad x A/C altitude |
| **SCAN CAPABILITY** | • Line Scanner<br>• Max. 4800 scans/sec | ○ Line Scanner<br>• Frame rate - 30Hz<br>• Width - 12° | Yes | 10RPS |
| **AIRCRAFT DISPLAYS AND SIGNAL PROCESSOR(S)** | • 5 in Film Format<br>• Data link from A/C to Ground<br>• Signal Compression | • TV Compatible | | • Data is PCM encoded on to a digital tape recorder |
| **SIZE/WEIGHT/POWER REQUIREMENTS** | • 283 lbs.<br>• 210 watts - 28 volts [illegible] - 400Hz, 3Ø | • 11 lbs.<br>• 8.6 in x 9.0 in x 48 in<br>• 25 watts | | |
| **AIRCRAFT** | RF-4 | Qualified to MIL-STD 810 | WB57F | |
| **STATUS** | • In Production | • Building One Unit | • Good Performance<br>• Operational 4/1974 | |
| **REFERENCE** | • Honeywell Radiation Center<br>• Jerry C. Bates | • Honeywell Radiation Center<br>• Jerry C. Bates | • NASA Earth Resources Prgm.<br>• JSC Earth Resources Aircraft Plan Revised 11/1975 | • U-2 Investigators' Hndbk - NASA Ames<br>• John Arvesen |

one channel in the infrared. located some place between 7-14μm. The NASA TIRS system has an additional channel to detect the 3-5μm radiation. The systems are so designed that the forward motion of the aircraft is used to generate an image of the radiation pattern. The IR scanners are useful in detecting and mapping thermal anomalies in both the water and on land. The most advanced production system appears to be the AN-AAD5 (Honeywell). The AN-AAD5 has been installed in the Navy/Marine Corps RF-4B reconnaissance aircraft. This system is relatively light (283 lbs.) and should be considered as a candidate for the MUSS.

## E. Infrared Radiometers/Spectrometers (passive; non-imaging)

This category (shown in Table VI) is reserved for non-imaging radiometers that are used to detect thermal radiation in the spectral region ranging between 6 and 14μm. One system, the S191 Field Spectrometer System (FSS) has a second channel to detect radiation between 0.4-2.4μm. In some cases, spectral filter wheels are used to obtain radiation values for various spectral bands. Infrared radiometers have been used for various ocean and meterological studies to detect temperatures to ±0.1°C. These systems are generally small and could easily be used as part of the MUSS. All systems listed are possible candidates for the MUSS.

## F. Cameras

Four basic types of aerial cameras are currently being deployed. These cameras are listed under the following categories:

## Table VI - INFRARED
(passive; non-imaging)

| | SYSTEM | SYSTEM | SYSTEM | SYSTEM |
|---|---|---|---|---|
| | S191 Field Spectrometer System (FSS) | Filter Wheel Spectrometer Airborne Rapid Scan Spectrometer | Precision Radiation Thermometer (PRT-5) | Infrared Radiometer |
| DEVELOPER (YEAR) | Block Engineering (1972) | Lockheed Missile & Space Co. (1966-1967) | Barnes Engineering Co. (1966-1972) | Block Associates (1966-1967) |
| APPLICATION | • Measures energy reflected/ emitted from surface.<br>• Same as Skylab spectrometer; modified for A/C | • Ocean & met. studies<br>• Water pollution surveys<br>• Geology/minerals<br>• Resolution (2% of wavelength) | • Thermal IR to ±0.1°C | • Thermal IR to 0.1°C<br>• Ocean & Meteorological Stdys<br>• Water pollution studies<br>• Geology/minerals |
| OPERATING FREQUENCY (WAVELENGTH) | 0.4-2.4μm<br>6.2-15.5μm } 2 channels | 6.7 to 13.3μm | 8-14μm | 10.4-12.1μm |
| SYSTEM FIELD OF VIEW (INSTANTANEOUS) | 2° and 22° | 7 mrad | 2° | 7 mrad |
| SYSTEM FIELD OF VIEW (TOTAL) | -9° (Rear-Ward) to +22° (Forward) from Vertical | 7 mrad | 2° | 7 mrad |
| RESOLUTION ELEMENT ON GROUND | | 7ft: A/C alt. of 1000ft. | 350ft: A/C alt. of 10,000ft. | 7ft: A/C alt. of 1000ft |
| SCAN CAPABILITY | Spectral scan Filter Wheel | Scans 7 times/sec (Circular variable filter) | No | |
| AIRCRAFT DISPLAYS AND SIGNAL PROCESSOR(S) | • Ampex 700 tape recorder | | | |
| SIZE/WEIGHT/POWER REQUIREMENTS | | | • Lightweight, portable, battery powered | |
| AIRCRAFT | Bell 206B<br>Bell H47G<br>& Huey } Helicopters | NP3A or WB57 | NP3A, NC130B | NP3A, WB57F |
| STATUS | Excellent | Good | Fair to Good | Good |
| REFERENCE | • NASA Earth Resources Prgm JSC Earth Resources A/C Plan revised 11/1975 | • NASA Earth Resources Prgm JSC Earth Resources A/C Plan revised 11/1975 | • NASA Earth Resources Prgm JSC Earth Resources A/C Pla revised 11/1975 | • NASA Earth Resources Prgm. JSC Earth Resources A/C Plan revised 11/1975 |

- Mapping frame camera
- frame reconnaissance camera
- panoramic camera
- strip camera

A brief description of each category is given along with a few examples of commonly used cameras. Additionally, a fifth category designated, "hybrid camera" has been introduced to cover cameras that do not exactly fit one of the basic generic categories. No attempt is made to list the more than 100 different aerial camera models that are in current use. The reader is referred to the following references* which give listings of aerial cameras.

### 1. Mapping Frame Camera (Metric Camera)

Mapping cameras are all of the same basic design and their distinctive feature is its high degree of distortion correction. The mapping camera can be characterized as having a wide field of view, in addition to being restricted to aircraft usage of low v/h values.

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*Cimerman, V.J., and Z. Tomasegovic, 1970, Atlas of Photogrammetrics Instruments: New York, Elsevier Publishing Co.

Data Corporation, 1965, Airborne Photographic Equipment, Vols. I, II, and III: Report RC013200 for Recon Central, WPAFB (and supplements, Report RC076575).

Data Corporation, 1967, Aerial Camera Lenses: Contract AF33C65D-14443 for Recon Central, WPAFB.

McDonnell Douglas Corporation, 1973, Reconnaissance Reference Manual: Prepared for Naval Air Systems Command by McDonnell Douglas Reconnaissance Laboratory, St. Louis, Missouri.

One mapping camera which is widely used by NASA, is the Wild Heerbrugg RC-10 system. This camera is described below.

### RC-10 Metric Camera

| | |
|---|---|
| Film | |
| Format | 9-inch x 9-inch |
| Roll Size | 400 feet |
| No. of exposures/roll | 450 |
| Lens | Wild-Heerbrugg Universal Aviogon II 6-inch f4, with an angular field of view of 73°45', or an interchangeable 12-inch Aviogon f4, with an angular field of view of 41°. |
| Weight (System) | Approximately 75kg |
| Resoluting power | 70 cycles/mm |
| Ground coverage | From an altitude of 60,000 feet:<br>16 x 16 nautical miles - 6-inch lens<br>8 x 8 nautical miles - 12-inch lens |
| Ground Resolution | 15 to 25 ft - 6-inch lens;<br>4 to 15 ft - 12-inch lens |

## 2. Frame Reconnaissance Camera

Frame reconnaissance cameras, in contrast to the mapping cameras, can not be characterized by a single physical configuration. There are, however, several important parameters that are common among this type of camera. These features are listed below:

- high resolving power and low f-number,
- highly corrected distortion is not a requirement,
- narrow fields of view (10° to 40°),
- film widths range from 70 to 240nm,

- focal lengths range from a few cm to more than a meter - common focal lengths are 6-inch. 12-inch and 18-inch,
- focal plane shutters, and
- used in high-performance aircraft and high v/h ratios.

One commonly used frame reconnaissance camera by the military is the KS-87 built by Chicago-Aerial Industries. The KS-87 camera is currently installed in the Marine Corp's Marine Tactical Reconnaissance Squadron Three (VMFP-3) RF-4B. Specifications for the KS-87 camera are given below.

### KS-87 Camera

| | |
|---|---|
| Film | |
| Format | 4 1/2 inch x 4 1/2 inch |
| Roll Size | 500 feet |
| No. of exposures/roll | 1300 |
| Lens | Dayphoto<br>3,6,12 or 18-inch focal length<br>Nightphoto<br>3 or 6 inch focal length |
| Weight | Approximately 30-40kg |
| Ground coverage (lateral) | |
| Focal Length Lens | Coverage |
| 3-inch | 1.5 x A/C altitude |
| 6-inch | 0.75 x A/C altitude |
| 12-inch | 0.375 x A/C altitude |
| 18-inch | 0.25 x A/C altitude |

## 3. Panoramic Camera

The panoramic camera is characterized by its small instantaneous field of view which yields a resolving power of over 100 cycles/mm. The large resolving power of the panoramic camera makes it popular in photo reconnaissance. Listed below are some of the characteristics which are common among the various types of panoramic cameras:

- the film surface is cylindrical and the width of the film is parallel to the axis of the cylinder,
- the instantaneous field of view is small because the image falls onto a narrow slit immediately in front of the film,
- the slit length equals the width of the picture format, and
- the slit width is usually variable to control the exposure time.

A few panoramic cameras presently being used are give in Table VII.

### 4. Strip Camera

The continuous strip camera works on the simple principle of moving the film behind a slit in the focal plane of the camera at exactly the same velocity that the image is moving past the slit. Only limited developments have been made on this camera type during the past 30 years. The lone survival in this field is the KA-18A manufactured by Chicago Aerial Industries. Although this camera is not widely used, many of its features make it well-suited for multiband use. Additional characteristics

## Table VII - Panoramic Cameras

| | SYSTEM | SYSTEM | SYSTEM |
|---|---|---|---|
| | OPTICAL BAR | HP-307 | KA-56<br>(low altitude) |
| DEVELOPER | Itek Corporation | Hycon Corporation | Fairchild |
| USER AGENCY<br>STATUS | NASA - Earth Resources<br>U-2 | NASA - Earth Resources<br>U-2 | Installed in Marine Corps/Navy<br>RF-4B |
| FORMAT (FILM) | 4 1/2 x 50 inches | 2 1/4 x 7.2 inches | 4 1/2 x 9 1/4 inches |
| LENS | 1 KA-80A<br>Focal length-24 inches<br>Field of View-120° | Focal length-80mm | Focal length-3 inches<br>Field of View-180° |
| WEIGHT/POWER REQ'S | 255 lbs, used in Apollo flights-1972 | 9.9 lbs | 105 lbs |
| RESOLVING POWER | | 100 cycles/mm | |
| GROUND COVERAGE/ RESOLUTION | A/C altitude-65,000 ft 37 N. miles x 2.3 N. miles. Res. - 2 ft. | | |
| COMMENTS | | | Day VFR System Only |
| REFERENCE | U-2 Investigators' Handbook-Vol II-Sensors NASA Ames | U-2 Investigators' Handbook-Vol II-Sensors NASA Ames | Marine Tactical Recon. Squadron Three's User Manual |

## Table VII - Panoramic Cameras
(Continued)

| | SYSTEM | SYSTEM | SYSTEM |
|---|---|---|---|
| | KA-82<br>(medium altitude) | KA-99<br>(low/medium altitude) | KA-93<br>(medium/high altidue) |
| DEVELOPER | Fairchild | Fairchild (1974) | CAI/Bourns, Inc. |
| USER AGENCY<br>STATUS | Installed in Marine Corps/Navy<br>RF-4B | Navy-Flight tested in POD by NADC<br>Developmental | Developmental |
| FORMAT (FILM) | 4 1/2 x 29.3 inches | 4 1/2 x 28.3 inches | 20° 95°<br>8.4x4 1/2 in 39.6x4 1/2 in |
| LENS | Focal Length-12 inches<br>140° scan | Focal Length-9 inches<br>180° scan | Focal Length-24 inches<br>min: 20°;max: 90° (scan) |
| WEIGHT/POWER REQ'S | 190 lbs | 243 lbs<br>28VDC, 50 watts | 210 lbs |
| RESOLVING POWER | | 80lp/mm | 90lp/mm |
| GROUND COVERAGE/ RESOLUTION | 1.08H x 5.5H<br>(H=A/C altitude) | 28° coverage along flight path/frame exposure | |
| COMMENTS | | Altitudes-500-12000 ft.<br>v/h range-<br>0.05-1.06 knots/ft. | v/h depends on scan angle<br>20° 95°<br>0.097 [illegible] s/ft 0.[illegible]8knts/ft |
| REFERENCE | Marine Tactical Recon. Squadron Three's User Manual | Aerial Recon. Systems Vol 79, Pro. Soc. of Photo-optical Inst. Engineers 1976 | Aerial Recon. Systems Vol 79, Pro. Soc. of Photo-optical Inst. Engineers 1976 |

of the strip camera are:

- it has few moving parts, and these are continuous rather than intermittant as in other camera types,
- very reliable,
- an array of cameras can be readily synchronized by driving them from a single shaft. The film rates in each camera are therefore identical, and photography of an area (with perfect boresighting) is simultaneous, and
- the photography is continuous, so that no film is wasted as in other forms of photography where a safety margin of overlap is introduced.

## 5. Hybrid Cameras

### a. Multiband Cameras

A number of different types of multiband cameras have been built, however, they all operate on the same principal - that of recording images of a scene simultaneously through a variety of spectral filters. Excellent reviews of multiband cameras are given in the following references* and will not be repeated here. A list of some of the more widely used multiband cameras is given below.

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*Slater, P.N., 1972, Multiband Cameras; Photogram. Eng., vol 38, p. 543-555.

*Manual of Remote Sensing, 1975, Robert G. Reeves (Editor), American Society of Photogrammetry, Falls Church, VA, vol I, p. 286-323.

- Nine lens (Itek)
- Model 10 (Spectral Data)
- Mark I ($I^2S$)
- Aero I (Dot Products, Inc.)
- MPF (Itek)

These cameras all weigh in the order of 100 lbs. or less and have shown to have good operational characteristics. Spectral Data reports that U.S. Army tests comparing the Model 10 with the KA-76 Frame Camera showed superior performance for target detection using the multispectral camera.

### b. Day/Night Laser Camera System

KA-98 Realtime reconnaissance system
(Perkin-Elmer Corporation)*

This camera is developed around a CW gallium arsenide laser. The system was designed to be compatible with the RF-4 and the RPV environment and mission profiles. The KA-98 system has been flight tested and imagery collected. The salient characteristics of using gallium arsenide as the illuminator are:

- spectral covertness (850nm),
- compactness,
- efficiency, and
- inherent contrast environment

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*Toles, Marvin, KA-98 Realtime Reconnaissance System, Proceedings: SPIE, vol 101, Airborne Reconnaissance (1977), p. 6-9.

The KA-98 system consists of the gallium arsenide laser line scanner, video tape recorder, a TV display console and a laser diode film recording console. The TV display console consists of two 2000 line TV monitors, one for the moving map display and one for freeze frame viewing and enlargement, three scan converter tubes, and associated electronics. The total weight of the system is under 90 lbs. A similar type of system could be built for mini-RPV's having a size of less than 0.2ft$^3$ and weigh less than 10 lbs.

The KA-98 system has been flight tested in the RF-4 aircraft and the BGM-34B RPV. During the RPV flight test, the KA-98 was used in a realtime reconnaissance mode. Imagery taken by the sensor was data linked to a ground TV display console for realtime readout of the data.

### c. ESSWACS - Solid State Camera System

(RCA Automated Systems/Air force)

A new type lightweight ( 64 lbs.) camera system has been designed and constructed for realtime wide angle reconnaissance from low flying, high performance aircraft*. This system is composed of a multiple lens-linear CCD array airborne sensor head, an air to ground data link; and a ground based, dry silver film, laser beam recording system that produces hard copy imagery on the ground within 30 seconds of

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*Barton, G.T., Electronic Solid State Wide Angle Camera System - ESSWACS, SPIE vol. 101 Airborne Reconnaissance (1977), p.10-19.

data acquisition. Flight tests of the ESSWACS system is scheduled for early 1978. The current silicon CCD sensors limit the system to daytime, fair weather reconnaissance. Substitution of an IR sensor or active illumination could extend the sensitivity range, permitting nighttime and all weather operation. The salient characteristics of the ESSWACS system are given in Table VIII.

Table VIII - ESSWACS System Characteristics

| | |
|---|---|
| Number of lenses | 5 |
| Focal lengths | 18mm(1), 53mm(2), 101mm(2) |
| Scanning mode | Line Scan/Push Broom |
| FOV | 140° |
| PhotoSensor | |
| number-type | 5-Fairchild CCD-121H |
| elements/sensor | 1724 (active) |
| data rate | 10.5 megasamples/sec |
| Video processing | AGC, band limiting, ABLC |
| Video bandwidth | |
| array sample rate | 10.5 megasamples/sec |
| Recorder | laser beam film recorder |
| Film width | 4.55 inches active |
| Film | Dry silver (3M type 7869) |
| Ground coverage | 5210ft (from A/C altitude of 1000ft) |
| Resolution | 1.5ft/lp central 80% @ 100,000lm/m$^2$<br>2.0ft/lp central 80% @ 3,000lm/m$^2$ |

## G. Active Laser Systems

The airborne laser sensor is the newest of the remote sensors described in this report. Laser systems have been built to measure various parameters of both the atmosphere, the hydrosphere, including the following:

- water depth
- water temperature

- water salinity
- pollutants (water and atmosphere)
- wave heights
- atmospheric pressure and temperature

In spite of the research that has taken place in this field during the past few years, such systems have not advanced to the point where they can be considered off-the-shelf items. As such they probably should not be considered as prime sensors for inclusion into the MUSS. The laser profilometer is the most advanced type of laser system that has been built and tested over the past few years. Wavelengths in the order of a few centimeters have been measured with such laser systems.

Two developmental airborne pulsed laser systems to measure water depths have been built to date in the U.S. One laser system is part of ERIM's M-8 active passive system. This system was flight tested in the summer of 1977, with reportedly good results. The second system, designed and assembled at NASA Wallops Flight Center is in the process of being flight tested. Salient characteristics of this laser system are given in the following table.

Table IX - Characteristics of NASA's Airborne Oceanographic LIDAR (AOL) System

Laser Transmitter (Neon)

| | |
|---|---|
| wavelength | 5401Å |
| bandwidth | 1Å |
| PRF | 400pps |
| beam divergence | 3-20mrad variable with beam expander |
| peak output power | 10kw |

| | |
|---|---|
| Receiver | |
| spectral resolution | $5401 \pm 2$Å |
| FOV | 1-20mrad, variable |
| temporal resolution | 2.5nsec |
| polarization | available for both transmitter and receiver |
| Weight | 1000 lbs. |
| Power Requirements | 50 amps |
| Performance | |
| altitude (max) | 600m |
| area coverage | designed to produce one data point/ $20m^2$, ±5 degree from NADIR; capability to ±15 degree - 280km/hr. |
| measurement depth | 6m with $\alpha$ (attenuation coefficient of the water)$=2m^{-1}$; 10m with $\alpha = 1m^{-1}$. |
| minimum measurement depth | 0.5m |

## III. Summary of Results

The results of the state-of-the-art study of the various aircraft remote sensors have revealed that a number of good aircraft sensors systems (in each sensor category) have been successfully flown. However, this list is rapidly narrowed when production or near production systems are considered. Table X is a compilation of these off-the-shelf systems, which should at least be given prime consideration for inclusion into the MUSS concept. However, one should not completely limit the MUSS sensors to those found in Table X. Several of the sensor systems listed in this study, and perhaps there are others, need only to be reduced in size and weight in order to become a prime MUSS candidate.

Table X - Prime Sensor Candidates for MUSS

<u>MICROWAVE RADIOMETERS</u> (passive; non-imaging)

- S-Band radiometer - North American Rockwell
- Swept frequency microwave radiometer - North American Rockwell
- Electrically scanning (imaging) microwave radiometer - Aerojet General

<u>RADARS</u> (active; imaging)

- AN/APS-94D - Motorola
- UPD-4 (APD-10) reconnaissance system - Goodyear

- WX-50 - Westinghouse

OPTICAL MULTISPECTRAL SPECTROMETERS (passive; imaging)

- DS-1200 series - Daedalus
- $M^2S$ - Bendix

INFRARED SCANNERS (passive; imaging)

- AN/AAD-5 - Honeywell

INFRARED RADIOMETERS SPECTROMETERS (passive; non-imaging)

- S191 FSS - Block Engineering
- Filter Wheel Airborne Rapid Scan Spectrometer - Lockheed
- PRT-5 - Barnes
- Infrared radiometer - Block Engineering

CAMERAS

- A wide choice of frame and panoramic cameras are available.
- A variety of multiband cameras are available - attention should be given Spectral Data's Model 10.
- A new laser camera system (KA-98).
- ESSWACS - A solid state camera system.

## IV. CONCLUSIONS/RECOMMENDATIONS

A number of various types of sensors were listed in section III as prime sensors to be considered for inclusion into the MUSS. A number of reasons went into this final selection, but in general these systems are the most advanced, relatively small, both in size and weight, and require minimum power to operate. These systems have been operated with good success and the majority are in production.

Substantial information must be supplied by the user agency (Navy/Marine Corps) prior to arriving at a final set of recommendations for the MUSS sensors. Some of the information which must be supplied includes.

- detailed specifications of the various missions required for MUSS,
- ascertain the environmental parameters that are deemed requirements - along with associated measurements such as frequency, tolerance, and coverage.

This detailed assessment is required to determine the altitude and type of aircraft. For instance, it may be determined that a single MUSS configuration will not suffice. If such is the case, it may be possible to consider a modular approach, in which specific sensors for a certain type of mission will be chosen - while one or more of the sensors are replaced for another type mission.

The type of aircraft to be deployed is the driving force in designing the MUSS since the aircraft determines the available sensor weight, the altitude and the area coverage of the system. Some of the sensors identified in this report have either been flown successfully on RPV's or could be fairly easily adaptable to the RPV environment. The RPV's should therefore be considered as a possible MUSS platform.

Two other considerations that play an important role in arriving at a final set of recommendations for the MUSS are 1) onboard realtime displays and operator interaction, and 2) telemetry and data link requirements.

Data link requirements evolve from either of two needs. The first need is that of the tactical commander for near realtime update of highly perishable information relayed from the airborne reconnaissance capability to his ground command post. The commander may also wish to re-direct the mission flight plan or re-target an objective based on needs for relevant data or complementary information.

The second need derives when a beneficial trade-off can be made for tactical aircraft configurations between large onboard processors and minimal preprocessors with RF link to ground processing and display equipment.

The output data rate for the sensor systems which have been described varies over a considerable range depending on the information density and the required readout rate. A single unique imaging sensor may output data at millions of bits per second. The transmittal of such high data rates in realtime would require substantial bandwidth in the data link channel whereas selected data or frames could be relayed over a longer period in a narrower bandwidth channel and complete data could be recorded for detailed analysis upon landing.

Other types of sensors, e.g., laser depth finders, provide relatively few data points with simple information.

The multiplicity of these sensors, their type, the scanning or acquisition data rate, the internally processed output data format and rate, and the required update rate required by the ground terminal are all basic factors which are to be coordinated into a compatible data link.

The following recommendations (tasks) are, therefore, made with regard to completing the concept phase of MUSS.

I. Ascertain the exact reconnaissance mission(s) for a MUSS system, including the parameters to be measured, their tolerance and coverage (temporal and spatial),

II. determine the A/C platforms that will be deployed in a MUSS system,

III. determine the exact remote sensors to be assembled to form a MUSS - determine alternative systems if more than one type of mission and/or one type platform are deemed practical,

IV. the final MUSS sensors will be based on the results of both phase I (this report) and the above mentioned tasks (I-III),

V. detail investigations of the A/C displays and telemetry requirements of the MUSS.

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12. SPONSORING MILITARY ACTIVITY
Geography Programs
Office of Naval Research
Arlington, Virginia 22217

13. ABSTRACT

Data were assembled and listed in this report on state-of-the-art aircraft sensors which could be integrated to form a Multi-Sensor System (MUSS) for surveillance of inshore waters. The following sensor categories are included: radars (active, imaging), optical multispectral spectrometers (passive, imaging), infrared scanners (passive, imaging), infrared radiometers/spectrometers (passive, non-imaging), cameras and active laser systems. The MUSS might be required to perform the following missions: (1) collect data on previously uncharted areas; (2) collect data on previously charted areas using different sensors, and (3) collect data for update and/or verification of archival data. The principal beach parameters which must be measured by the MUSS include: length, width, gradient, surf and tidal range and nearshore currents. It is possible that the MUSS would also be able to yield information on the type of sediment and trafficability of the nearshore zone in addition to locating obstacles in the surf zone and mapping the ground cover.

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| 14 KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Remote Sensing | | | | | | |
| Aircraft Sensors | | | | | | |
| Inshore Surveillance | | | | | | |
| Beach Reconnaissance | | | | | | |

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