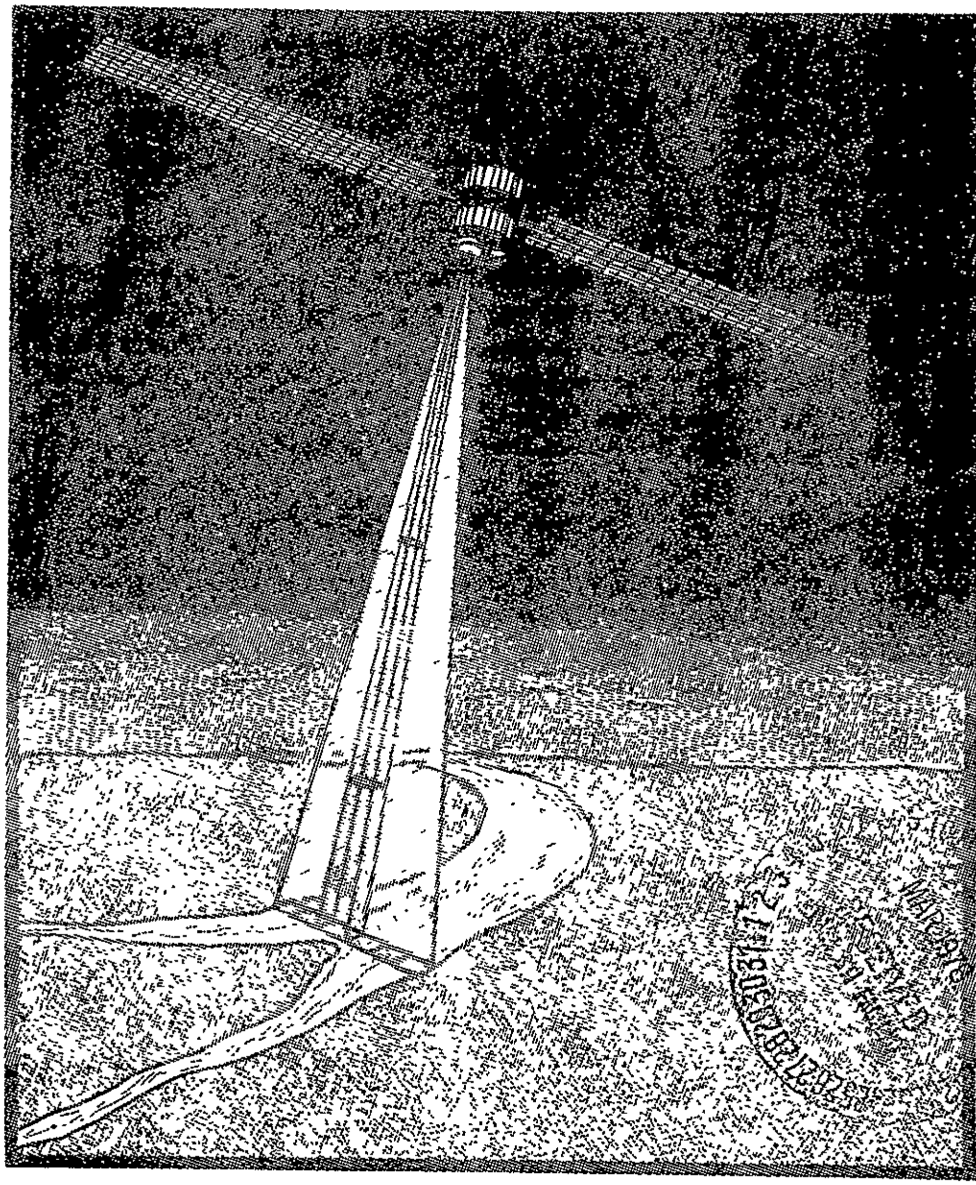
OFFICE OF AERONAUTICS AND
SPACE TECHNOLOGY

SENSORS WORKSHOP SUMMARY REPORT



MAY 11-12, 1977

NASA
National Aeronautics and
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Goddard Space Flight Center
Greenbelt Maryland 20771

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SECTION 1

EXECUTIVE SUMMARY

1 EXECUTIVE SUMMARY

A two-day workshop was held at Goddard Space Flight Center, Greenbelt, Maryland, on 11-12 May 1977 to respond to the results of inventories of NASA and DoD current sensing technologies and to assess the data in terms of future NASA needs. Three working group panels covering the microwave, optical, and high-energy particles and fields sensing areas generated prioritized technologies and estimated development costs for nineteen sensing systems. The need for data processing and reliable cryogenics was common to all three areas.

TECHNOLOGIES/4-YEAR COST RUNOUTS

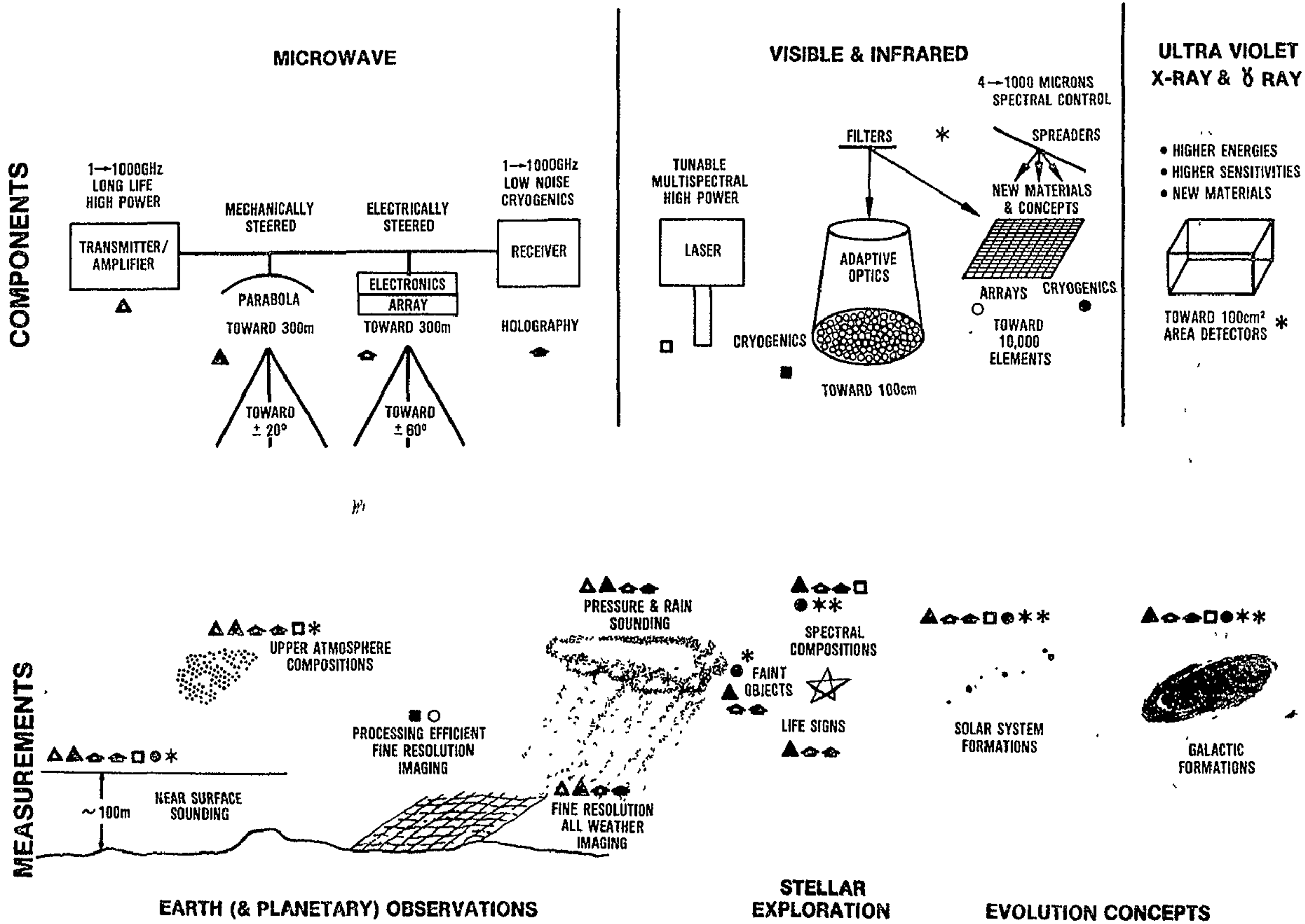
MICROWAVE	ELECTRO-OPTICAL	X-RAY & γ-RAY, PARTICLES & FIELDS
. SUBMILLIMETER WAVE TECHNOLOGY	. IR CCDs (2-30 μm)	. UV TO γ-RAY SENSORS
. PHASED-ARRAY ANTENNAS	. VISIBLE LINEAR ARRAYS	. HIGH-PURITY SILICON
. MICROWAVE MULTISPECTRAL SCANNERS	. VISIBLE IMAGERS	
. MICROWAVE TRANSMITTER COMPONENTS	. VIS & IR SPECTROSCOPY	
. LSI MICROWAVE CIRCUITS	. TUNABLE LASERS	
. LARGE REFLECTOR ANTENNAS	. ADAPTIVE OPTICS	
. MICROWAVE 3-D HOLOGRAPHY	. FAR IR (30-1000 μm) DETECTORS	
$10.5M	$18.2M	$1.3M

No attempt was made to establish priorities among the recommendations of the three panels. The total estimated cost for supporting these technology developments over the next 4 fiscal years is $30M.

CRITICAL MEASUREMENTS AND SENSOR COMPONENT DEVELOPMENT

The relationships between the sensing technologies highlighted during the workshop and their applications to future NASA needs is shown graphically on the facing page. The three spectral regions, starting with the microwave and extending out to the gamma ray regime, are coded to show how the sensing components are related to orbital measurement needs. It can be seen that research and development of these sensing components will have a broad impact on both the exploitation and the exploration of space.

CRITICAL MEASUREMENTS AND SENSOR COMPONENT DEVELOPMENT



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SECTION 2

INTRODUCTION

2 INTRODUCTION

One of NASA's more important functions is to conduct research and technology development programs which will provide more efficient information systems for future missions. The front end of such an information system is the sensor and detector subsystem. Much effort has already been devoted to the optimization of these subsystems. The following section reviews the efforts of three workshops, describes those technology developments that would contribute most to sensor subsystem optimization and improvement of NASA's data acquisition capabilities, and summarizes the recommendations of the sensor technology panels from the most recent workshop.

2.1 BACKGROUND

In March 1977, Mr. Stanley Sadin of the Study, Analysis, and Planning Office and Dr. Bernard Rubin of the Electronics Division of the Office of Aeronautics and Space Technology (OAST) initiated the definition of a workshop on sensing and detection technology. This was to be the third in a series of OAST workshops that had taken place in August 1975 and April 1976. The former was a Space Technology Workshop held at Madison College, Harrisonburg, Virginia, for a two-week period starting 3 August. Its purpose was to derive future technology requirements, major thrusts, and overall goals from the "Outlook for Space" and projected NASA missions and representative user needs. Twelve working group panels were organized by discipline, one of which was the Sensing and Data Acquisition Panel. It consisted of nine NASA members representing six Centers and Headquarters, and included expertise in sensing technology ranging from the microwave region out to high-energy particles and fields.

The major thrusts derived by the Harrisonburg workshop were as follows: (1) provide a ten-fold increase in mission output through improved sensing accuracy, resolution, and spectral range by 1985; (2) reduce information system cost by 1 to 2 orders of magnitude through extensive integration of sensor and on-board processing technology by 1985; and (3) provide the capability for near real-time, low-cost global surveys through multipurpose, all-weather, active/passive microwave systems by 1990. The relevance of these thrusts was demonstrated by identifying various payload experiments and through several examples of payload/major thrusts relationships. The payloads were the primary product of the workshop and were responsive to user inputs as well as possible national space themes contained in the "Outlook for Space."

The second activity was a Space Theme Workshop held at Langley Research Center, Hampton, Virginia, 26-30 April 1976. Nearly 100 of the Agency's top technologists and scientists joined with another 35 theme specialists to produce technology projections for three broad-mission scenarios (themes). The Sensors Working Group consisted of eleven experts from eight Centers and Headquarters; advanced sensing technologies proved to be major drivers for the Space Exploration and Global Services Themes, and it was shown that the sensor program would have to be significantly increased to respond to the needs of these themes.

In order to determine what the status of NASA's sensing activity was and whether any contributions might be derived from the Department of Defense's (DoD) data acquistion program, three studies were initiated with the support of the Office of Studies, Analysis, and Planning. One was to inventory all activities within NASA as well as to assess civilian user needs and derive a list of sensor technology opportunities. This was conducted by Dr. Robert G. Nagler of Jet Propulsion Laboratory, Pasadena, California. The second was to carry out a similar process for DoD, and responsibility for this was given to Mr. David Aviv of Aerospace Corporation, El Segundo, California. The third was a specialized study involving laser systems, conducted by Dr. E. Gerry of W. J. Schafer Associates, Arlington, Virginia. These studies were completed at various periods in early 1977 in the form of written classified and unclassified reports.

In order to apprise the Sensors Working Group of these results, and to derive their evaluation and prioritization of those sensing technologies that would best contribute to NASA's future mission, a meeting was held at Goddard Space Flight Center, Greenbelt, Maryland, on 11-12 May 1977. The 41 attendees represented seven NASA Centers, Headquarters, and DoD, and included leading experts in the various sensing areas. Drs. Nagler and Gerry and Mr. Aviv presented summary talks on their conclusions. On the second day, the Working Group was divided into three panels that were directed to assess the status of microwave, electro-optical, and particles and fields sensing technologies. Each panel was asked to prioritize within each of the disciplines those technologies that were critical to improved capabilities for future missions and to estimate what resources would be required to support such programs. These priorities are summarized in Sec. 2.3 and are detailed in Sec. 3.

2.2 PROBLEMS IN HIGH-BENEFIT SENSING

New understanding of physical processes allows us to project new sensor components which can provide giant strides in our capability to measure the Earth, planetary, stellar, and interstellar environment. These potential steps in sensor technology can be organized around measurement goals which project reasonable steps in increased performance, based on attainment of specific economic, social, or scientific benefits. The sensor technology development goals thus can be used to focus on funding on major voids in measurement capability or on large gaps between existing measurement performance and identified user measurement needs with large economic, social, and/or scientific benefit.

A list of measurement goals with high benefit potential and with developmental status warranting strong research and development investment is provided in Table 1. The Earth observation or living space goals are related to development of large increases in our understanding of atmospheric, ocean, land, and ice dynamics on Earth and the other planets in this solar system, and of the influence of these dynamics on the biological viability of crops and people. The stellar exploration goals look at the new frontiers in knowledge. Exploration is key, whether it be for new objects, new phenomena, or new intelligences. Cosmic evolution goals look at our own origins, both in terms of solar system and galactic evolution. More detailed descriptions of each of the goals follow. The intended level of technology step is also indicated in Table 1. "New" means that no effort of significance along with line exists. "Jump" means that the technology step is large compared to present capability.

TABLE 1

CAST SENSOR TECHNOLOGY DEVELOPMENT GOALS

CAPABILITY STEP	EARTH AND PLANETARY OBSERVATION GOALS (LIVING SPACE)
New	Near-Surface Visible and Infrared Sounding (primarily below 100-m altitude)
Jump	Active Visible and Infrared Sensing of Upper Atmosphere Processes
Jump	Data-Processing-Efficient Visible and Infrared Surface Imaging
Jump	All-Weather Day/Night High-Resolution Imaging
New	Microwave Spectroscopy of Stratospheric and Mesospheric Constituents
New	Active Microwave Sounding
	STELLAR EXPLORATION GOALS (THE NEW FRONTIER)
New	Molecular Astrophysics
Jump	Faint Object Astronomy
Jump	Search for Extraterrestrial Intelligence
Jump	Microwave Astronomy
	COSMIC EVALUATION GOALS (in the beginning)
Jump	Origin of the Solar System
Jump	Galactic Cosmology

2.2.1 Earth (or Planetary) Observation Goals

A. Near-Surface Visible and Infrared Sounding

To provide the new technology which allows satellite-based measurements of temperature, pressure, wind, water, and pollutant profiles in the last 100 m above the Earth's surface. This boundary layer regime is the key to many weather, climate, oceanology, and hydrology processes with economic and hazard avoidance application; yet, present space-based sensors are unable to vertically resolve the detail necessary to achieve the benefits. Critical developments are needed in low-noise detection of narrowband or spectrally scannable signals, in tunable filters, in tunable lasers, in heterodyning and interferometer, and in cryogenics (Electro-Optics Tasks 6, 7, and 9).

B. Active Visible and Infrared Sensing of Upper Atmosphere Processes

To develop the continuous-wave laser technology necessary to allow implementation of multiple line pair measures of upper atomsphere species for pollution and electro-chemical processes studies. Laser techniques have the potential of making downward-looking and limb-scanning techniques for measuring upper atmosphere species obsolete due to their ability to control bandwidth and to achieve fine vertical resolution. Critical developments are needed in compact configurations, in identifying a wider variety of bandwidths, in tunable laser heterodyne receivers, and in cryogenics (Electro-Optics Tasks 7 and 9).

C. Data-Processing-Efficient Visible and Infrared Surface Imaging

To develop the low-noise detectors and detector array concepts which are necessary to interface with practical on-board data processing and information extraction capabilities. Reduction of the potential data glut appears to be an appropriate goal. New high-sensitivity detector systems are needed to provide the unambiguous differentiation necessary to allow information extraction. Large multispectral arrays are needed to provide the fine-resolution capabilities necessary for spatial differentiation. Critical developments are needed in visible and IR CCD and other large-array technologies, in low-noise detector materials, and in cryogenics (Electro-Optics Tasks 1, 3, 4, and 9).

D. All-Weather Day/Night High-Resolution Imaging

To develop microwave receiver sensitivities, antenna sizes, and scan mechanizations which allow all-weather, day/night, high-resolution measurements of temperature, winds, water vapor, clouds, ice extent, precipitation, etc. in resolutions competitive with the spatial resolution capabilities of optical techniques. Most of the world's weather, climate, ocean-motion, ice, etc. are under the cloud cover or night environmental conditions which are not measurable with the visible and infrared techniques. Present microwave detector sensitivities, antenna sizes, and scanning techniques are unable to achieve the resolutions needed for comparative performance. Critical developments are needed in cryogenic detectors, in large deployable reflectors with multiple or electrically scanned feed, and in large deployable electrically scanned phased arrays (Microwave Tasks 2, 3, 4, and 5).

E. Microwave Spectroscopy of Stratospheric and Mesospheric Constituents

To develop receivers which allow the detection of a broad range of microwave absorption spectra related to specific atmospheric and surface constituents. This is a new capability made feasible only through recent technology advances. Microwave absorption bands provide a technique complementary to the visible and infrared techniques allowing improved resolution of some species and a number of new species not separable with visible and infrared. Developments are needed in millimeter and submillimeter detectors with low-noise characteristics; cryogenic support is needed in many applications (Microwave Tasks 1, 2, and 5).

F. Active Microwave Sounding

To develop the active radar techniques necessary to achieve pressure and rain sounding in the atmosphere of Earth or of the heavy atmosphere planets. This is a new capability made feasible only through recent technology advances. For Earth surface, pressure is of key importance to weather forecasting and is not presently measured. Water and other condensates are of key importance to the meteorology and energy exchange processes of Earth, Venus, Jupiter, Saturn, Uranus, and Neptune. Development is needed to produce a wider range of transmitter frequencies, to achieve wide-swath scanning with fine resolution from frequencies below L-band and up, and to provide low-noise, long-life cryogenic detectors (Microwave Tasks 1, 2, 3, 5, and 6).

2.2.2 Stellar Exploration Goals

A. Molecular Astrophysics

To develop the visible and infrared detector sensitivities needed to allow a spectrographic survey of the molecular species present in a wide range of stellar objects. This is a new capability made feasible by recent technology advances. Molecular surveys allow us to assess stellar development, the probability of Earth-like planets, and the potential paths in the development of our galaxy. Developments are needed in tunable laser heterodyne techniques, in large adaptive optics, and in cryogenic support systems (Electro-Optics Tasks 5, 7, and 9).

B. Faint Object Astronomy

To develop the visible and infrared detector sensitivities needed to allow study of faint celestial objects. This capability would allow detection of a wide range of new objects. Developments are needed in visible and infrared detector concepts, in spectral sweep concepts, in large IR telescope design, and in cryogenics for both detectors and optics (Electro-Optics Tasks 2, 4, 6, 8, and 9).

C. Search for Extraterrestrial Intelligence (SETI)

To develop the visible spectrum detectors and collectors necessary to distinguish spectral detail of the type either indicative of life or conducive to life as we know it. This requires high spectral and spatial sensitivities beyond those presently available. Developments are needed in new visible detectors, in large adaptive cryogenic optics and in cryogenics (Electro-Optics Tasks 4, 5, and 9).

D. Microwave Astronomy

To develop the microwave receiver sensitivities and spectral range necessary to provide microwave scanning of the planets and of major celestial objects. The distribution of microwave emission provides critical information on the origin and state of stellar bodies and planetary systems and potentially could be a direct indication of life. Developments are needed in millimeter and submillimeter detectors and in low-noise microwave multispectral scanning components in general (Microwave Tasks 1 and 3).

2.2.3 Cosmic Evolution Goals

A. Origin of the Solar System and Comparative Planetology

To develop sensors with the spectral, or energy, resolution necessary to understand the physical processes by which our solar system evolved and to project those dynamic processes which might affect our continued existence.

The investigation of discrete energy bands, and their broadening in the x-ray and γ-ray regions, are particularly important to establishing the dynamics of planetary evolution. While all regions of the spectrum, from radio frequencies to high-energy γ-rays, particles of all energy levels, and fields of all strengths are important, developments are specifically needed in: CCD arrays operating into the x-ray region; large-area, high-purity silicon detectors; detectors for 10-30 MeV, 1GeV and higher; and in focusing techniques for high-energy quanta.

B. Origin of the Universe and the Galaxies

To develop sensors with the spectral, or energy, resolution necessary to understand the physical processes of galactic and cosmic evolution.

Signals from sources of cosmological interest are so weak that they offer a major challenge to our ability to sense them at all, but also provide opportunities for studying physical processes which are not observable on Earth. In the x-ray and γ-ray regions particularly, the universe is relative transparent with the propagation following "straight" lines. This allows us to investigate processes which occurred billions of years ago, farther back in time than possible in any other spectral region (except perhaps, the energy spectrum of neutrinos).

Again, all regions of the spectrum from radio frequencies to high-energy γ-rays, as well as particles of all energy levels and fields of all strengths, are important. Developments are needed in large-area, high-purity silicon detectors, in detectors for high-energy γ-rays, and in focusing techniques for high-energy quanta.

2.3 CRITICAL SENSOR TECHNOLOGY DEVELOPMENT TASKS

The specific sensor technology tasks which were recommended by the three Sensor Workshop panels and which provide the capability steps delineated in the goals are listed in Table 2. Note that each of these tasks applies to several of the goals, but that several tasks are often needed in parallel before OA or OSS can make use of the technology to produce full sensor systems for particular missions.

The first five recommended microwave tasks were given top and equal priority by the Microwave Panel. The investment estimated to achieve these capabilities over a 4-year period was about $9M. A second priority was given to Microwave Tasks 6 and 7 primarily due to an assumption that they were already being funded in other offices. An investment of about $8M was estimated to be necessary to achieve these capabilities. Microwave holography was given a third priority based on less immediacy of need and on higher developmental risk involved with achievement. An investment of $1M to $2M was estimated to achieve this capability. The total microwave investment recommended over the next 4 years is about $10.5M, excluding supporting technologies.

The Electro-Optical Panel recommended nine technology tasks which are listed in Table 2. The first five tasks relate primarily to Earth observation goals and will require an estimated investment of $12.7M over a 4-year period. The next three tasks relate primarily to astrophysics goals and will require an estimated investment of $5.5M over a 4-year period. The last task is considered supporting technology and no funding estimate was made. The total electro-optical investment over the next 4 years is about $18.2M.

The X- and γ-Rays, Fields and Particles Panel suggested four tasks. The first two, high-energy sensor systems and large-area, high-purity Si detectors, received major emphasis. The last two tasks are considered supporting technology. The total investment estimated for these tasks is about $1.3M.

TABLE 2

CRITICAL SENSOR TECHNOLOGY DEVELOPMENT TASKS

MICROWAVE TASKS

- Millimeter and Submillimeter Detectors (towards 1000 GHz)
- Large, Deployable, Electrically Steerable Phased-Array Antennas
- Low-Noise Microwave Multispectral Scanner Components
- Microwave Transmitter Components
- Integrated Microwave Circuits
- Large, Spaceborne Reflector Antennas
- Long-Life, High-Reliability, Cryogenic Systems
- Microwave Holography

ELECTRO-OPTICAL TASKS

- Infrared (IR) Charged Couple Devices (CCDs) for Earth Observation Imaging in the 2 to 30 μm Regime
- Large Linear (10^4 element) Arrays for Earth Observations in the Visible Regime
- Visbile Imaging for Astronomy and Earth Observations Systems
- Imaging Spectroscopy (0.3 to 30 μm)
- Tunable Laser Technology for High-Specificity Remote Sensing
- Large Adaptive Optics Arrays/Systems
- Large Infrared Cryogenic Telescope
- Far Infrared (30 to 1000 μm) Detectors for Cooled Astronomical Telescopes
- Cryogenic Systems for Detectors and Optics Cooling

X- AND Y-RAYS, PARTICLES AND FIELDS

- High-Energy Sensor System (UV to Ultra-High Energy X-Rays)
- High-Purity Silicon Technology--Materials Proceesing in Space
- Data Processing and System Software Engineering
- Study of Power Supply Technology (find alternatives to RTGs)

SECTION 3

RECOMMENDATIONS OF SENSOR TECHNOLOGY PANELS

3 RECOMMENDATIONS OF THE SENSOR TECHNOLOGY PANELS

Three Sensor Technology panels were convened the second day of the workshop to assess the NASA and DoD activities in sensing and detection that were presented on the first day and to recommend those technologies that they considered to be of the highest priority for support to meet the needs of future NASA missions. One thrust was common to all of the panels' recommendations; namely, the need to develop sensors with the capability of preprocessing data so that the subsequent data handling load would be reduced.

It may be possible to enhance data management efficiency and reduce development costs by considering all potential applications of the prioritized technology requirements. Where a technology offers a capability of serving several applications, planners should address the question of developing multiple rather than single application technologies. For example, microwave radiometry can be used for measuring ocean surface salinity, fresh water influx, ocean heat flux, soil moisture, evaporation rates, surface temperatures, atmospheric water vapor profiles, precipitation rates, and atmospheric temperature profiles. The development of multispectral and frequency scanning capabilities in microwave radiometers, together with multifunction antennas, could lead to new systems capable of satisfying a broad range of application requirements. If these passive capabilities can also be integrated with active capabilities for performing altimetry, scatterometry, and radar imaging, then even more efficient systems could be implemented.

The technology panels covered sensing of microwaves; infrared and optical radiation; x-rays, γ-rays, fields and particles. Their prioritized recommendations are presented in the following subsections.

3.1 MICROWAVE PANEL: TECHNOLOGY DEVELOPMENT SUMMARY

Group I	1.	Submillimeter Wavelength Components to 10^{12} Hz	$1.2M
	2.	Large, Deployable, Electrically Steerable, Phased-Array Antennas	$2.7M
	3.	Microwave Multispectral Scanner Components	$2.4M
	4.	Microwave Transmitter Components	$1.0M
	5.	Integrated Microwave Circuits	$1.8M
Group II	6.	Large, Spaceborne Reflector Antennas	--*
	7.	Long-Life, High-Reliability, Cryogenic Systems	--*
	8.	Microwave Holography	$1.4M
			$10.5M

Group I consists of Primary and Equal Priority Items.
Group II consists of Secondary and Equal Priority Items.

*It is assumed that funding for Items 6 and 7 will be from outside the OAST Sensors Program.

WORK SHEET FOR MICROWAVES

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Submillimeter Wavelength Component Development ($\rightarrow 10^{12}$ Hz)

JUSTIFICATION (RATIONAL):

Submillimeter radiometers can be used for terrestrial atmospheric observations from Earth orbit; astronomical observations from Earth orbit of planets, comets, and interstellar molecules; observation and analysis of planetary atmospheres and cometary gases on orbiting, flyby, and rendezvous missions. The 100-1000 GHz region contains many of the strongest spectral features suitable for analysis of planetary atmospheric composition and processes as well as interstellar molecules and excitation mechanisms.

STRATEGY FOR DEVELOPMENT:

Development of efficient quasi-optical techniques for submillimeter front ends, development of techniques for efficient coupling of submillimeter radiation to nonlinear devices, development of efficient nonlinear devices, development of local oscillator sources. Milestones: June 78 - 300-GHZ receiver; September 79 - 400-GHz receiver; September 80 - 600-GHz receiver; September 81 - 1000-GHz receiver.

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	0.300	0.300	0.300	0.300
NASA Manpower (Man-Years)	2	2	2	2

WORK SHEET FOR MICROWAVES

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Deployable, Large Electrically Steered Phased Arrays

JUSTIFICATION (RATIONAL):

User agencies have needs for high-resolution, wide-swath microwave imagery. Present antennas cannot meet these needs, especially in the L&K_a band region. This technology can be used for both passive and active (radar) imaging systems. Combination of the antenna elements with distributed active devices can provide low-noise passive and high-power active capability. DoD technology transfer may be possible.

STRATEGY FOR DEVELOPMENT:

Phase I: Study complete June 1979.

Phase II: Study feasibility hardware October 1980. Flight feasibility test start September 1981.

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	0.4	1.0	0.9	0.4
NASA Manpower (Man-Years)	2.5	4.0	4.0	1.5

WORK SHEET FOR MICROWAVES

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Microwave Multispectral Scanner

JUSTIFICATION (RATIONAL):

Future applications of multispectral microwave scanners require the design and development of wideband scanning antenna systems and low-cost, integrated circuit receivers to provide the information critical to Earth observations. Both mechanically and electrically scanned high-resolution (1-10 km IFOV) beams are needed to cover the wide range of scan geometries and swath requirements.

STRATEGY FOR DEVELOPMENT:

Phase I: Study of scanning multifrequency systems - complete June 1979.

Phase II: Development of electrically scanning array technology and mechanical scan mechanisms - complete June 1980.

Phase III: Development of microwave multispectral scanner breadboard with integrated receivers - July 1982.

Phase IV: Shuttle flight experiment - July 1983.

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	0.400	0.600	0.800	0.600
NASA Manpower (Man-Years)	2	4	8	4

WORK SHEET FOR MICROWAVES

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Integrated Microwave Circuits

JUSTIFICATION (RATIONAL):

Low-loss, matched front ends are required for improved performance of both active and passive microwave systems. Integrated microwave circuits can achieve this goal by eliminating cables, connectors, matching elements, and discrete components which degrade overall system performance. Integration also implies miniturization, which results in better thermal stability for precision microwave radiometry.

STRATEGY FOR DEVELOPMENT:

Phase I: Study complete (September 1979).

Phase II: Feasibility demonstration of front-end hardware (September 1980). (Example: integrated circuit radiometric front end including isolators, couplers, latching circulators, etc.)

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	0.2	0.4	0.7	0.5
NASA Manpower (Man-Years)				

WORK SHEET FOR MICROWAVES (J. C. Shiue)

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Spaceborne Large Reflector Antennas for Sensors

JUSTIFICATION (RATIONAL):

Large reflectors (5-10 m in diameter) in 60-200 GHz are needed for atmospheric temperature and humidity profiling from geosynchronous orbits and for radio astronomy and upper atmospheric studies from lower Earth orbits. Multibeam reflectors of up to 100 m (1-2 GHz) are needed for soil moisture/coastal water salinity mapping purposes.

STRATEGY FOR DEVELOPMENT:

Phase I: Study for 5-m, 200-GHz graphite epoxy-type reflector antenna is ongoing and will be completed in May 1978. A system study for 1-2 GHz larger reflector should be conduced (1978-79).

Phase II: Develop and lab test a 5-m reflector. Develop a subscale model of 1-2 GHz multibeam reflector. (1979-81).

Phase III: Shuttle flight test (1982).

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	1	2	3	1
NASA Manpower (Man-Years)	2	3	3	2

WORK SHEET FOR MICROWAVES

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Development of Long-Life, High-Reliability Cryogenic System

JUSTIFICATION (RATIONAL):

Cryogenic cooling (2-3 K) is essential to achieve ultra-low noise figures in microwave receivers. Current cooling methods employ expendable cryogenic or complex mechanical refiguration systems which are not suitable for long-term, unattended operation needed for space application.

STRATEGY FOR DEVELOPMENT:

Investigate current state of technology (VM, molecular absorption, Sterling, etc.) and identify most promising technique for further development.

Phase I: Study (December 1979).

Phase II: Feasibility (lab) model (September 1981).

Phase III: Flight demonstration (September 1982).

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	0.100	0.200	0.300	0.200
NASA Manpower (Man-Years)	1	1	2	2

WORK SHEET FOR MICROWAVES

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Microwave Holography

JUSTIFICATION (RATIONAL):

Microwave holography offers the capability of providing three-dimensional imagery with resolution of a few hundred meters when coupled to a large antenna. To perform the system must incorporate a large number of matched, coherent receivers. The development of this system requires improved front-end microwave components and wideband transceivers.

STRATEGY FOR DEVELOPMENT:

Phase I: Feasibility and parametric studies complete (September 1979).

Phase II: Fabrication of subsystem complete (September 1981).

Phase III: Demonstration of laboratory breadboard (September 1982).

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	0.1	0.3	0.6	0.4
NASA Manpower (Man-Years)	0.5	1.0	2.0	1.0

MICROWAVE PANEL PARTICIPANTS

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*Panel Chairman.

3.2 ELECTRO-OPTICS PANEL: TECHNOLOGY DEVELOPMENT SUMMARY

Group I	1.	IRCCD with Signal Correlation Devices for Earth Observation Imaging (2-30 μm)	\$3.0M
	2.	Large (10^4 Element) Linear Arrays of (Visible) Detectors for Advanced Earth Observation	\$1.0M
	3.	Visbile Imaging Techniques for Astronomical, Planetary, and Earth Observations	\$3.5M
	4.	Imaging Spectroscopy (0.3-30 μm)	\$1.2M
	5.	Tunable Laser Technology for High-Specificity Remote Sensing with Inherent Data Compressions (UV-2 μm)	\$4.0M
Group II	6.	Large Adaptive Optical Arrays/Systems	\$3.5M
	7.	Large Cryogenic ($T \leq 10$ K), Adaptive Optics, IR Telescope	--*
	8.	Far IR (30-1000 μm) Detectors for Cooled Astronomical Telescopes	\$2.0M
	9.	Cryogenic Systems for Telescope Optics, Focal Plane Assemblies, etc.	--*
			\$18.2M

Group I consists of top and equal priority items primarily applicable to Earth observation goals.

Group II consists of top and equal priority items primarily applicable to astrophysics goals.

The complete list of goals related to the above numbered development items follows.

Earth Observations	• Imaging (Surface Features) and Data Processing	1, 2, 3, 8, 9
	• Near-Surface Sensing	4, 5, 9
	• Atmospheric Processes	5, 6, 9
Astrophysics	• Molecular Astrophysics	6, 5, 9
	• Faint Astronomical Objects	7, 8, 3, 4, 9
	• Search for Extraterrestrial Intelligence	6, 3, 9

*It is assumed that the funding for Items 7 and 9 will be from outside the OAST Sensors Program.

WORK SHEET FOR ELECTRO-OPTICS

(H. D. Hendricks)

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Infrared Charge Coupled Devices with Signal Correlation Devices for Imaging Applications in Pollution, Environmental, and Earth Resources

JUSTIFICATION (RATIONAL):

NASA mission requirements in pollution, environmental, and Earth resources demand improved resolution (10 m) in combination with improved sensitivity (0.1°) and spectral response (2-30 μm) in addition to increased data requirements. Other applications in the areas of astronomy, geology, and mapping technology will also benefit from this development.

STRATEGY FOR DEVELOPMENT:

(1) Fully develop CCD technology on InSb infrared semiconductor materials (79); (2) demonstrate 100 element linear array imaging capability (80); (3) demonstrate 100 × 16 (TDI) array for thermal imaging (81); (4) demonstrate chip signal cancellation techniques (82); (5) demonstrate pushbroom-TDI array with signal correlation techniques (83). Additional program elements that could be addressed: monolithic InSb, CCD, 1-5 μm, LaRC; monolithic HgCdTe, CID, 5-14 μm, NRL; hybrid HgCdTe, Si CCD, 5-14 μm, GSFC; extrinic Si, Si CCD, 1-30 μm, GSFC, LaRC; hybrid PSSnTe, Si CCD, 5-14 μm, NRL.

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82	FY 83
Costs (Dollars in Millions) (InSb Only)	0.2	0.4	0.6	0.8	1.0
NASA Manpower (Man-Years)	2.0	3.0	3.0	4.0	4.0

WORK SHEET FOR ELECTRO-OPTICS

(H. Ostrow)

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Large (≈10,000 element) Linear Detector Arrays for Advanced Earth Observation Missions

JUSTIFICATION (RATIONAL):

Sensors beyond the Thematic Mapper will require use of pushbroom techniques and arrays of this type will be required, operating in both the visible and near-IR regions.

STRATEGY FOR DEVELOPMENT:

Evaluate various alternatives, e.g., CCD and photodiode arrays. Investigate inclusion of TDI capability to improve sensitivity. Emphasize radiometric accuracy (that is, elimination of spectral response ripples in front surface illuminated CCDs).

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	0.300	0.400	0.300	
NASA Manpower (Man-Years)	1	1	1	

WORK SHEET FOR ELECTRO-OPTICS

(John Rather)

CHECK ONE: IN SITU ( ); SPACE APPLICATION (x)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE): Visible Imaging for Astronomical and Planetary Observations
Need higher resolution, better photometric accuracy, better sensitivity. Ruggedness against saturation and damage. Long-term gain stability. Ease in processing data (pre- or post-processing?).

JUSTIFICATION (RATIONAL):

1 photon/sec--Astronomoy--Need maximum sensitivity with maximum resolution. Need to "remember" previous images and compare changes. Background usually well below detector noise.

10^6 photon/sec--Earth Applications--Limited by background. Need to detect subtle color changes, shading damages, etc. Both moderate and high resolution applications. Need to compare changes from previous images.

Other Planets and Satellites--Similar to Earth Requirements.

STRATEGY FOR DEVELOPMENT:

Which is better: Million-element CCD array? High-resolution vidicon? Return-beam vidicon? Need decision on best approach. Important to key to specific applications. Different approaches may be required for different applications. Need system study to segregate applications and possible solutions.

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	0.3 (Systems Studies)	0.6 (Critical Component R&D)	0.6 (Critical Component R(D)	2 (System Dev.)
NASA Manpower (Man-Years)				

WORK SHEET FOR ELECTRO-OPTICS (J. Wellman)

CHECK ONE: IN SITU (X); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Imaging Spectroscopy from 0.3 to 30 μm

JUSTIFICATION (RATIONAL):

The wealth of information in this spectral region is well known. Combining spectral resolution ($\Delta\lambda/\lambda$ = 1%) and spatial resolution will permit mapping the distributions of materials with characteristic spectral behavior. Applications include planetary atmospheres (spacecraft and space telescope), planetary surfaces (including the earth), and astronomy. Development is needed in two areas:

(1) CCD-type infrared area array sensors with broad spectral response.

(2) Spectral resolvers/dispersers including gratings and tunable acousto-optical filters (TAOF).

STRATEGY FOR DEVELOPMENT:

Year 1: Develop small prototype area array(s).
Develop TAOF for breadboard use.

Year 2: Build breadboard.
Extend spectral range and size of sensor array.
Continue TAOF development.

Year 3: Build and test engineering model with large sensor and TAOF/grating system.
Continue development of area array and TAOF with specific objectives for flight program.

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	$.25M	$0.5M	$0.75M	$1.5M
NASA Manpower (Man-Years)	3	5	8	16

WORK SHEET FOR ELECTRO-OPTICS

(R. Hess, M. Mumma,
E. Gerry)

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Tunable Laser Technology for High-Specificity Remote Sensing with Inherent Data Compression

JUSTIFICATION (RATIONAL):

Tunable laser-based sensor generates specific data needed by user (e.g., concentration of specific pollutants, wind speed, temperature, pressure particles, excitation conditions of species, astronomy, ocean). Greatly compresses data handling required for more general, less specific detectors. Can probably avoid cryogenic cooling requirements.

STRATEGY FOR DEVELOPMENT:

Develop tunable coherent sources: (1) for heterodyne radiometry, $\approx 10^{-2}$ W, 2 µm → 2 mm; (2) for two satellites, ~5 W, 2 µm → 2 mm; (3) ground or cloud reflection differential absorption, ~50 W, 2 µm → 15 µm; (4) LIDAR, ≃1-100 J, UV through 10 µm. Develop low-noise mixers: (1) temperature > 77 K, 2 µm → 2 mm; (2) noise $\lesssim 2h\nu$.

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	1	1	1	1
NASA Manpower (Man-Years)	7	7	7	9

WORK SHEET FOR ELECTRO-OPTICS

(M. Mumma, E. Gerry)

CHECK ONE: IN SITU (X); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Adaptive Optical Systems

JUSTIFICATION (RATIONAL):

Adaptive optics eliminate image degradation due to the optical system or atmospheric turbulence: (1) space telescope systems could be made diffraction limited even if thermally disturbed; (2) satellite-to-satellite laser atmospheric sensing requires optical beam focusing and tracking of the target; (3) ground-based coherent laser experiments require diffraction limited wave fronts for best signal to noise.

STRATEGY FOR DEVELOPMENT:

1. Demonstrate feasibility on large ground-based telescope at 1-kHz bandwidth.

2. Develop techniques for using adaptive optics with lightweight optical structures in space.

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	0.5	1.0	1.0	1.0
NASA Manpower (Man-Years)	3.0	4.0	4.0	4.0

WORK SHEET FOR ELECTRO-OPTICS (John Rather)

CHECK ONE: IN SITU (X); & SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE): *Large Adaptive Optics Arrays.*

Key to very sensitive monitoring of anything in visible or IR range! Large adaptive optical surfaces with many elements ($>10^4$ elements). Need to develop lightweight, cheap, optical elements and monitoring and control system for same. Need 1/20 wavelength precision control.

JUSTIFICATION (RATIONAL):

Development (in space or on surface) of very large diffraction-limited optical aperture. Eliminate need for classical very rigid telescope structures. Compensate for wavefront distortion resulting from atmosphere or from thermal and mechanical vibrations and distortions in the telescope itself. Applications range from astronomy to planetary laser probing to search for extraterrestrial intelligence. Also laser propulsion and power transmission.

STRATEGY FOR DEVELOPMENT:

Decide on wavelength of operation (shorter λ means more elements and finer control). Decide on best control methods--laser sensing, internal or external logic. Build prototype. Optimize for minimum power consumption and lightweight.

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	Conceptual Design. Identify Key Problems.	Develop Needed Control System Etc.	Build Prototype System.	R&D with Prototype System.
	500K	1	4	1
NASA Manpower (Man-Years)				

WORK SHEET FOR ELECTRO-OPTICS (C. McCreight)

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Large Cryogenic Telescopes (possibly cryogenic, large-aperture adaptive optics)

JUSTIFICATION (RATIONAL):

Infrared astronomical requirements for high-quality imaging and low-background telescopes are forthcoming. Cooling and active control (of position and/or figure) must be provided simultaneously. Diffraction-limited performance for large aperture ($\geq$1 m), low background (T $\lesssim$ 10 K) telescopes is a goal to provide high-resolution spatial information about celestial IR structure. Shuttle-based IR interferometry would become possible with adaptive optics for interferometer base-line active control.

STRATEGY FOR DEVELOPMENT:

- Study Phase: Survey of DoD work on control algorithms, useful materials (1979-80).
- Design Phase: Incorporate cooling technology constraints and active control techniques (1980-81).
- Demonstration: Operate in optical calibration chamber (e.g., Tullahoma) or in flight (1982).

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	0.2	0.4	0.4	0.3
NASA Manpower (Man-Years)	3	3	4	4

WORK SHEET FOR ELECTRO-OPTICS

(H. D. Hendricks,
Craig McCreight)

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Far-Infrared Detectors for Cooled Astronomical Telescopes (30-1000 μm)

JUSTIFICATION (RATIONAL):

Future infrared astronomical missions (e.g., SIRTF) will involve cryogenically cooled telescopes to allow zodiacal background-limited operation with very low photon background levels ($\sim 10^8$ photons/cm^2/sec). Substantial DoD-funded work has been carried out for $\lambda < 30$ μm, with NEPs of approximately 10^{16} W/Hz$^{1/2}$. Very little work has been done for low-background 30-1000 μm detectors; 10^{-16} W/Hz$^{1/2}$ in discrete and arrayed detectors would be a sensitivity goal. Extension of DoD work wherever feasible would be stressed.

STRATEGY FOR DEVELOPMENT:

1. Adapt discrete and CCD IR detector technology for astronomical conditions and evaluate (March 1980).
2. Develop and demonstrate improved thermal and photon detectors for 30-1000 μm (March 1981).
3. Flight test an airborne observatory (October 1982).

Hybrid extrinsic Ge-Si CCD; extrinsic Si-Si CCD; bolometer arrays.

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	0.3	0.5	0.7	0.5
NASA Manpower (Man-Years)	2	2	3	3

ELECTRO-OPTICS PANEL PARTICIPANTS

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H. D. Hendricks	LaRC	804/827-3418
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J. B. Wellman	JPL	213/354-5942 FTS 792-5942

*Panel Chairman.

X- & γ-RAYS, FIELDS & PARTICLES PANEL: TECHNOLOGY DEVELOPMENT SUMMARY

1.	High-Energy Sensor System (UV to Ultra-High Energy γ-Rays) for Astronomy, Astrophysics, Solar Physics, and Planetary Science	$1M
2.	Data Processing and System Software Engineering	--*
3.	High-Purity Silicon Technology--Materials Processing in Space	$255K
4.	Study of Power Supply Technology (Find Alternatives to RTGs)	--*
		$1.255M

*It is assumed that funding for Items 2 and 4 will be from outside the OAST Sensors Program.

WORK SHEET FOR X- & γ-RAYS, FIELDS & PARTICLES

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

High-Energy Sensor System for Astronomy, Astrophysics, Solar Physics, and Planetary Science (UV to ultra-high-energy gamma ray)

JUSTIFICATION (RATIONAL):

OSS has developed a 5-year plan for space exploration in these fields. OAST does not have a development plan for technology for the sensors and systems for the disciplines as in past this time frame. The last decade has shown great development in this field using much already developed techniques. Within the better defintions of the field new technologies are required.

STRATEGY FOR DEVELOPMENT:

Areas of specific interest may be: (1) development of CCDs for UV, x-ray, and electronic detection; (2) large area silicon detectors for the x-ray discrete lines; (3) sealed proportional scintillators detection x-ray discrete lines; (4) detectors for 10-30 MeV rays; (5) γ-ray imaging, 1 MeV region with decent spatial resolution; (6) ultra-high energy detectors GeV region and higher; (7) focused energy spectrometers. These are but a few areas of development. As the space Shuttle area opens a whole to family of sensors.

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	~250 K±ε	250±ε	250±ε	250±ε
	(where ε is +250 if positive, -250 if negative)			
NASA Manpower (Man-Years)				

WORK SHEET FOR X- & γ-RAYS, FIELDS & PARTICLES

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Data Processing and System Software Engineering

JUSTIFICATION (RATIONAL):

Projected data noted and total accumulated data for future space flight programs are so great that a detailed end-to-end look systems for such missions are necessary. Such studies will significantly effect detector design, on-board processors, and ground support.

STRATEGY FOR DEVELOPMENT:

A number of models of experiments for space fight programs and end-to-end software engineering studies performed. As a result of studies looks for requirements and use of on-board microprocessors, distributed intelligence, high capacity and high speed memories, ground systems use of ILIAC. (Look systems developed by NRL Dr. Shore, Weiss, etc.)

(Emphasis that application region use quite different in many cases than science area. Thus results are now model dependent.)

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	~50-100 K	~50-100 K	Depends on Requirements Derived	
NASA Manpower (Man-Years)				

WORK SHEET FOR X- & γ-RAYS, FIELDS & PARTICLES

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

High Purity Silicon Technology - Materials Processing

JUSTIFICATION (RATIONAL):

Astronomical and astrophysical sensor system using silicon diode sensors are limited in range and sensitivity now by the limited boule area (~15 cm^2) and the eventual diode depletion depth with accuracy. The latter problem is especially severe for detectors with full depletion depths $2 \leq d \leq 20$ μm.

STRATEGY FOR DEVELOPMENT:

(A) Apparently the Si boule size is limited by gravity considerations. 15 cm^2 is the largest presently available with high purity (~10^5 ohm cm). In zero G (spacelab) it may be possible to grow Si boules of ~100 cm^2 area. Resulting detector systems could have ~30 times to geometrical factor and therefore the sensitivity. Additionally, zone refining of boule could be very efficient at zero G. (B) ERDA (Los Alamos Scientific Lab) has developed the technology for epitaxially grown thin wafers of Si in the range of ~1 to 10's of micrometers. Seed money is needed to transfer this technology to the two detector companies (Ortec and Princeton Gamma-Tech). The potential business is not firm enough to justify the use of company funds.

RESOURCE REQUIREMENTS:	FY 78	FY 79	FY 80	FY 81
Costs (Dollars in Millions)	Task A depends on spacelab facilities--200 K for development. Task B ~50-60 K in any man-year; 15 K - LASL; ~20 K each to Ortec and Princeton Gamma-Tech.			
NASA Manpower (Man-Years)	Task A ~ few man-years. Task B less than 0.2 man-year.			

WORK SHEET FOR X- & γ-RAYS, FIELDS & PARTICLES

CHECK ONE: IN SITU ( ); SPACE APPLICATION (X)

HIGH PAYOFF TECHNOLOGY DEVELOPMENT (SHORT TITLE):

Study of Power Supplies (interference of RTGs)

JUSTIFICATION (RATIONAL):

Presence of RTG interfere with x-ray, γ-ray, particle detectors.

STRATEGY FOR DEVELOPMENT:

RESOURCE REQUIREMENTS:	FY 79	FY 80	FY 81	FY 82
Costs (Dollars in Millions)	50-60 K Preliminary Study			
NASA Manpower (Man-Years)				

X- & γ-RAYS, FIELDS & PARTICLES PANEL PARTICIPANTS

*J. I. Trombka	GSFC/Code 682	301/982-5941
H. B. Niemann	GSFC/Code 623	301/982-4706
J. H. Trainor	GSFC/Code 666	301/982-6282
J. T. Williams	GSFC/Code 673.2	301/982-5095

*Panel Chairman.

SECTION 4

INVITED PRESENTATIONS

4 INVITED PRESENTATIONS

The three invited presentations given on the first day of the workshop were reports of continuing survey efforts supported by various offices (OSF, OA, OAST, OSS) within NASA Headquarters. These reports were intended to acquaint a cross section of NASA scientists and engineers from eight Centers with user measurement needs, especially gaps and voids in sensing capabilities, as well as current and developing capabilities in a wide range of sensor technologies.

R. Nagler of JPL reported on surveys of user measurement needs and unclassified sensor and platform capabilities, with primary emphasis on sensor technology trends. E. Gerry of W. J. Schafer Associates reported on DoD high-energy laser technology. Only an unclassified summary of his report is included in this volume. D. Aviv of Aerospace Corporation reported on extensive surveys of DoD systems and technologies which could be applicable to many aspects of future NASA missions, not just sensing capabilities alone. Only an unclassified abridgement of his report is included in this volume. Classified reports are available on request through proper security channels.

4.1 SENSOR TECHNOLOGY TRENDS

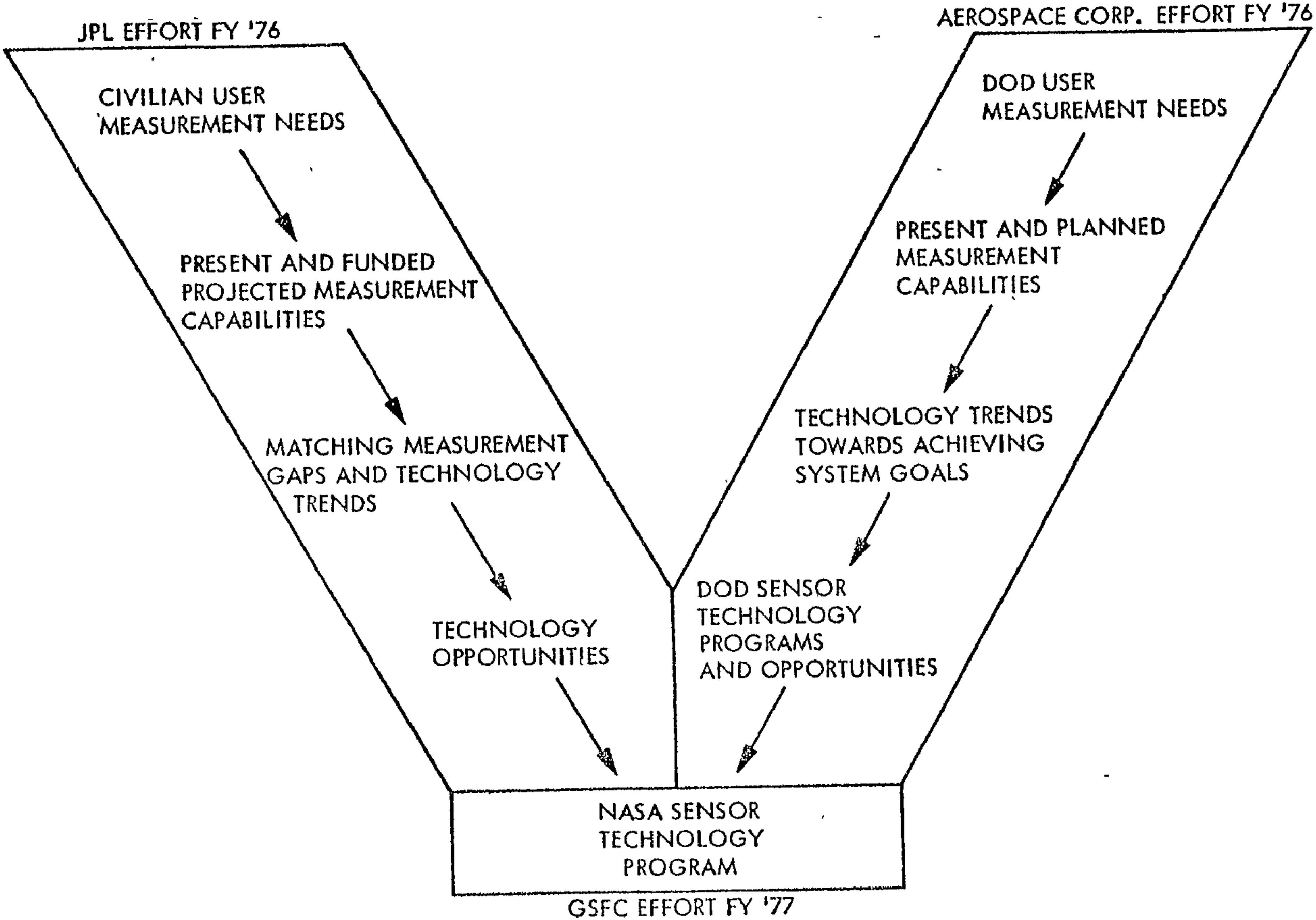
OAST SENSORS WORKSHOP

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

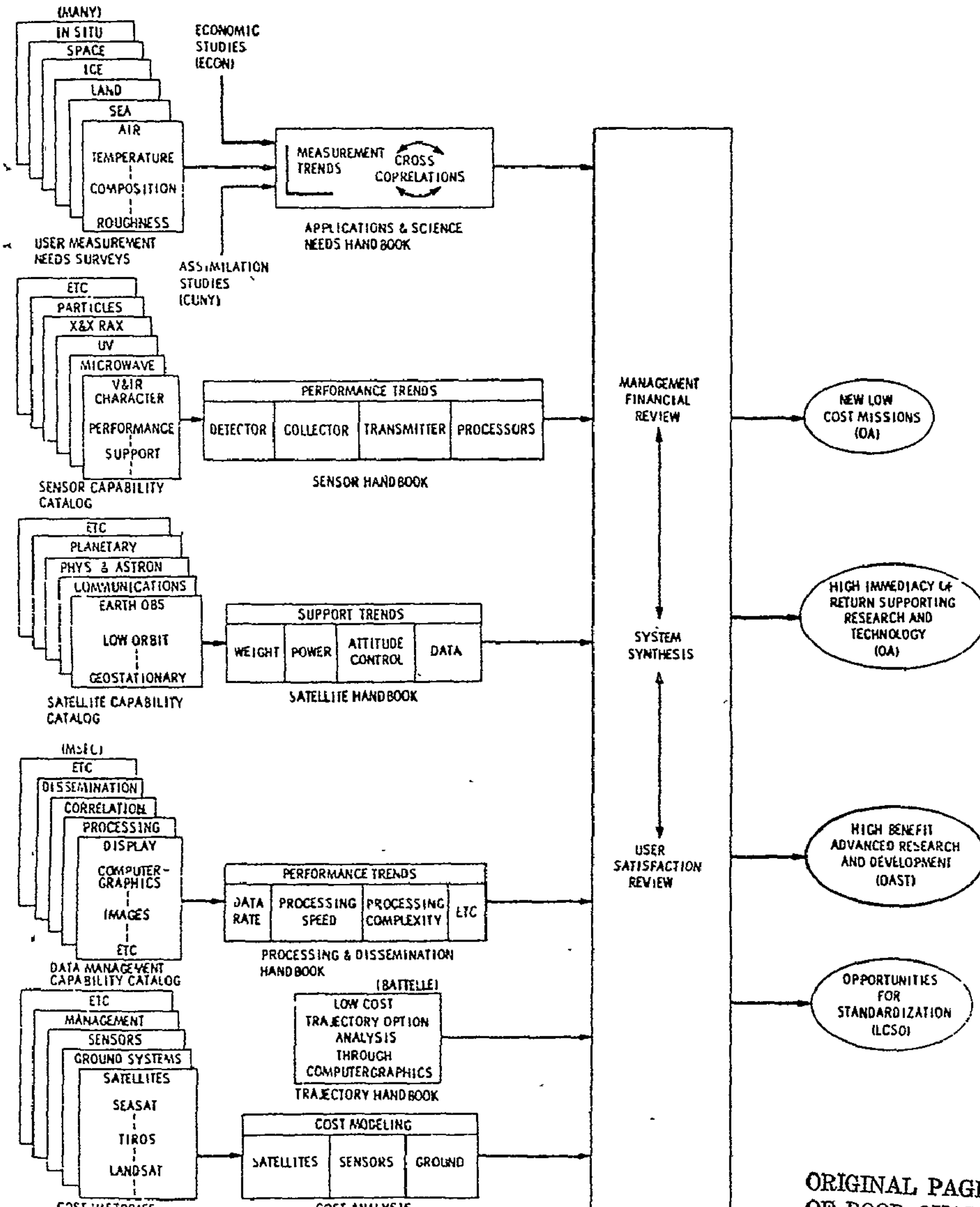
11-12 MAY 1977

ROBERT G. NAGLER
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

SPACE MISSION SENSOR TECHNOLOGY ASSESSMENT STUDIES



NASA/JPL MISSION PLANNING TOOLS EFFORTS



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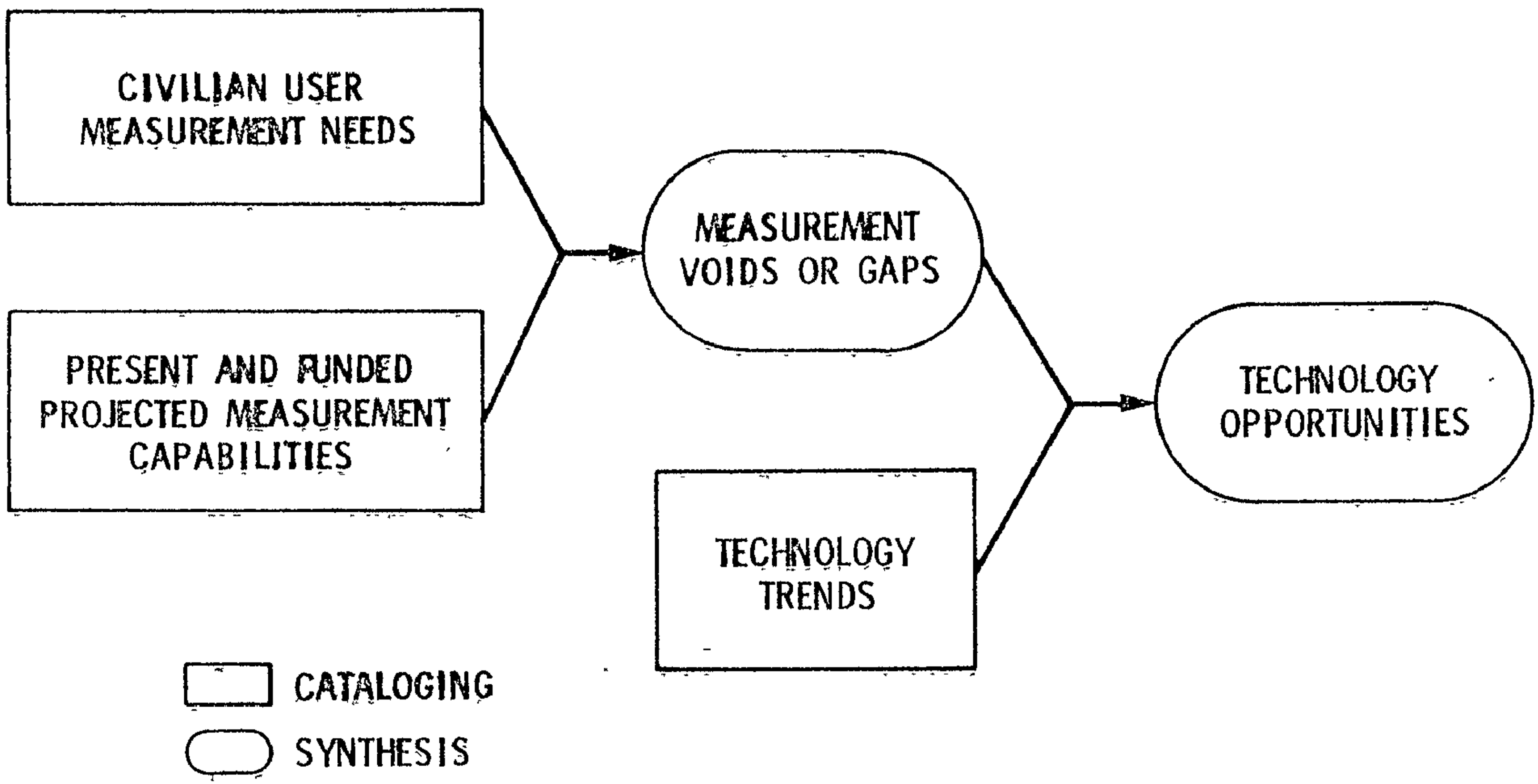
JPL SENSOR TECHNOLOGY ASSESSMENT STUDY SCOPE



JPL SENSOR TECHNOLOGY ASSESSMENT STUDIES
PARTICIPATING ORGANIZATIONS

NASA CONTRIBUTORS

AMES RESEARCH CENTER

GODDARD SPACE FLIGHT CENTER

JET PROPULSION LABORATORY

LANGLEY RESEARCH CENTER

WALLOPS FLIGHT CENTER

CONTRACTED DATA COLLECTION

BALL BROTHERS RESEARCH CORPORATION,
BOULDER, COLORADO

LOCKHEED MISSILES AND SPACE CORPORATI
SUNNYVALE, CALIFORNIA

SYSTEMS PLANNING CORPORATION,
WASHINGTON, D.C.

LIAISON INTERFACES

NOAA, NATIONAL ENVIRONMENTAL SATELLITE SERVICE

DOD, AF SPACE TEST PROGRAM

DOD, NAVAL RESEARCH LABORATORY

ENVIRONMENTAL PARAMETERS

	TEMPERATURE	
	PRESSURE DENSITY	
AIR	COMPOSITION	ICE
	SURFACE ROUGHNESS	
	CONVECTIVE MOTIONS	
SEA	WATER CYCLE	LAND
	BIOLOGICAL STATUS	
	LOCATION/EXTENT	

TABLE I. USER SUBCOMMUNITIES USING REMOTE SENSING DATA

BENEFIT \ ENVIRONMENT	AIR	SEA	ICE	LAND
VIABILITY OF LIFE	CLIMATE FORECASTS			
	POLLUTION MONITORING			
OPERATIONS EFFICIENCIES	WEATHER FORECASTS	SEA STATE FORECASTS	ICE FORECASTS	LAND MOTION FORECASTS
	PLANE SURVEILLANCE	SHIP SURVEILLANCE	LEAD SURVEILLANCE	
HAZARD AVOIDANCE/ ACCOMMODATION	RAIN, WIND & DUST STORM FORECASTS	FREAK WAVE FORECASTS	ICEBERG & FREEZE ONSET FORECASTS	ICING, EARTHQUAKE, & ERUPTION FORECASTS
	SEARCH & RESCUE			
MINERAL RESOURCE MANAGEMENT		MINERAL LOCATION		MINERAL LOCATION
		UTILIZATION MONITORING		UTILIZATION MONITORING
BIOLOGICAL RESOURCE MANAGEMENT (ANIMAL & VEGETABLE)		LOCATION & GROWTH STATUS MONITORING		LOCATION & GROWTH STATUS MONITORING
		YIELD FORECASTS		YIELD FORECASTS
		UTILIZATION MONITORING		UTILIZATION MONITORING
RESEARCH	INTERNAL MACRO/MICROPROCESSES			
	INTERFACE EXCHANGE PROCESSES			

TABLE II. COMPARISON OF ATMOSPHERE MEASUREMENT NEEDS AND FUNDED CAPABILITIES

Environmental Parameter	Differentiation Sensitivities Needed (Goal/Minimum-Useful)					Applicable Sensors					Funded Space Capability						Remarks
	Measurement Accuracy	Measurement Precision	Vertical Resolution	Horizontal Resolution	Temporal Repeat	Microwave		Visible and Infrared		Other	Satellite	Energy Precision	Spectral Channels	Horizontal Resolution	Vertical Resolution	Effective Swath	
						Active	Passive	Active	Passive								
Thermal Balance																	
Surface Air Temperature	0 5/1°C	0 1/0,25°C	--	10/500 km	3/24 hr			•	•		--	--	--	--	--	--	6m Reference
Vertical Temperature Profile	0 5/2°C	0 1/0 25°C	1 km/5 km	1 km/25 km	3/12 hr		••		••		TIROS-N	1 5°C	20 V&IR 2μw	25 km	2 km	1500 km	Combined necessary
Atmospheric/Cloud Albedo	0 2/4%	0 2/4%	--	10/500 km	3/12 hr				••		NIMBUS-G	1%	12(0.2-50μm)	--	--	--	
Atmospheric Heat Flux	0 2/1%	0 2/1%	--	10/500 km	3/12 hr				••		NIMBUS-G	1%	12(0 2-50μm)	--	--	--	
Solar Input Heat Flux	10/25 w/m^2	10/25 w/m^2	--	500 km	3/24 hr				••	UV	NIMBUS-G	0 02/0 8 w/m^2	10(0 2-4μm)	--	--	--	
Convective Balance																	
Sea Surface Pressure	1/3 mb	1/3 mb	--	1/500 km	3/12 hr	•		•			--	--	--	--	--	--	
Vertical Pressure Profile	1/3 mb	1/3 mb	1 km/5 km	1/25 km	3/12 hr	•		•			--	--	--	--	--	--	
Sea Surface Wind-Velocity/Direction	1/4 m/s, 10/25°	0 5 m/s/20%, 2/10°	--	5/500 km	3/12 hr	••	•				SEASAT-A	2 m/s or 10%, 20°	Ku-Band	50 km	--	1100 km	19 m Reference
Vertical Wind Profile-Velocity/Direction	1/4 m/s, 10/25°	0 5 m/s/20%, 2/10°	1 km/5 km	5/500 km	2/12 hr	•	•		••		GOES-1,2	2 m/s	Visible	25 km	--	--	
Vertical Convective Ducts	10%	10%	10 levels	10/50 km	3/12 hr						--	--	--	--	--	--	
Atmospheric Stability					3/12 hr						--	--	--	--	--	--	
Water Balance																	
Vertical Water Profile	7/30%	7/30%	1/5 km	1/500 km	3/12 hr		••		••		TIROS-N	20%	20 V&IR, 2μw	25 km	2 km	1500 km	Combined
Cloud Extent	5/20%	5/20%	--	1/50 km	3/12 hr				••		TIROS-N	1 km	2V, 3 IR	1 km	--	1500 km	
Cloud Level/Thickness	1/5 km	1/5 km	1/5 km	1/50 km	3/12 hr	•	•	•	•		--	--	--	--	--	--	
Precipitable Water	10/50 mg/cm^2	10/50 mg/cm^2	1/5 km	5/500 km	3/24 hr	•	•	•	•		--	--	--	--	--	--	
Precipitation Rate	0 1/2 cm/hr	0 1/1 cm/hr	--	5/500 km	3/24 hr	•	•	•			--	--	--	--	--	--	
Fog/Mist Visibility	10/4 levels		--	1/10 km	3/12 hr		•		•		--	--	--	--	--	--	Combined
Composition																	
CO_2	0 5/10 ppm	0 5/10 ppm	1/5 km	5/500 km	12 hr/30 days			•	••		NIMBUS-G	0 006 w/m^2 str	13-17 μm	--	1 5 km	Umb	
Ozone	0 01/0 02 cm	0 01/0 02 cm	1/5 km	5/500 km	12 hr/30 days			•	••		SAGE	0 001 sun	0 4-0 8 μm	200 km	0 1 km	Umb	
CFMs	0 1/0 3 ppb	0 1/0 3 ppb	1/5 km	5/500 km	12 hr/30 days			•	•		--	--	2 4,3 4 μm	--	--	--	
N_2O, NO_x	0 01/0 03 ppm	0 01/0 03 ppm	1/5 km	5/500 km	3 hr/30 days			•	•		SAGE	0 001 sun	0 4-0 8 μm	200 km	0 1 km	Umb	
CH_4	0 05/0 15 ppm	0 05/0 15 ppm	1/5 km	5/500 km	3 hr/30 days			•	••		NIMBUS-G	0 003 w/m^2 str	3 4, 8 6-9 1 μm	--	4 km	Umb	
NH_3	2×10^{-4}/ 10^{-3} mm	2×10^{-4}/ 10^{-3} pnm	1/5 km	5/500 km	3 hr/30 days			•	•		--	--	3,10 6, 11 4 μm	--	--	--	
HNO_3	0 5/2 ppb	0.5/2 ppb	1/5 km	5/500 km	3 hr/30 days			•	••		NIMBUS-G	0 003 w/m^2 str	11 5 μm	--	1 5 km	Umb	
Aerosols	0 002/0 02 ppm	0 002/0 02 ppm	1/5 km	5/500 km	3 hr/30 days			•	•		SAGE	0.001 sun	0 4-0 8 μm	200 km	0 1 km	Umb	
SO_2, H_2S	0.001/0 01 ppm	0 001/0 01 ppm	1/5 km	5/500 km	3 hr/30 days			•	•		--	--	4,7 4 μm	--	--	--	
C_xH_x	0 001/0 01 ppm	0 001/0 01 ppm	1/5 km	5/500 km	3 hr/30 days			•	•		--	--	3 3,9 5-11 μm	--	--	--	
CO	0 001/0 1 ppm	0 001/0 1 ppm	1/5 km	5/500 km	3 hr/30 days			•	••		--	--	4 8 μm	--	--	--	
Monitor																	
Airplane/Balloon/Flock/Swarm Location/Identification	5/100 m	5/100 m	--	0 1/1 km	1/3 hr	•					--	--	--	--	--	--	

TABLE III. COMPARISON OF OCEAN MEASUREMENT NEEDS AND FUNDED CAPABILITIES

Environmental Parameter	Differentiation Sensitivities Needed (Goal/Minimum Useful)					Applicable Sensors					Funded Space Capability						Remarks
						Microwave		Visible and Infrared									
	Measurement Accuracy	Measurement Precision	Vertical Resolution	Horizontal Resolution	Temporal Repeat	Active	Passive	Active	Passive	Other	Satellite	Energy Precision	Spectral Channels	Vertical Resolution	Horizontal Reso-lution	Effec-tive Swath	
Thermal Balance																	
Sea Surface Temperature-Global	0 2/1°C	0 1/0 25°C	--	50/500 km	3 hr/4 days		••		•		SEASAT-A	0 5°C	5 w	--	121 km	638 km	All weather
Sea Surface Temperature-Local	0 5/1°C	0 1/0 5°C	--	0 25/25km	3 hr/4 days		•		••		TIROS-N+	0 25°C	2V, 3 IR	--	10 km	1500 km	Clear weather
Ocean Temperature In Depth	0 2/2°C	0 1/1°C	2/10 m	10/100km	12 hr/3 days	•		•			--	--	--	--	--	--	
Ocean Albedo	0 2/1%	0 2/1%	--	25/500km	3 hr/30 days		•		•		NIMBUS-G	1%	12(0 2-50µm)	--	--	--	
Ocean Heat Flux	0 25/4 w/m^2	0 25/4 w/m^2	--	25/500km	3 hr/30 days		•		•		NIMBUS-G	1%	12(0 2-50µm)	--	--	--	
Evaporation Rate	0 5/2 mm/deg	0 5/2 mm/deg	--	25/500km	3 hr/4 days						--	--	--	--	--	--	
Convective Balance																	
Wind Shear	0 1/0 3dyne/cm^2	0 1/0 3 dyne/cm^2	--	5/200 km	3/12 hr	••	•				SEASAT-A	0 2dyn/cm^2	Ka-Band	--	50 km	1100 km	
Gravity Waves-Height	0.3/0 7m or 10%	0.3/0 7 m or 10%	0 3/0 7m or 10%	1/100 km	3/12 hr	••		•			SEASAT-A	0 5m or 10%	Ka-Band	0 5m or 10%	2-12km	Nadir	
Gravity Waves-Length	5/15%, 10/45°	5/15%, 5/30°	--	1/100km	3/12 hr	••		•			SEASAT-A	10%, 15°	L-Band	--	25 m	100 km	
Wind-Surge/Surface-Transport	1/10cm, 0.2/1cm/s	1/10cm, 0 2/1cm/s	1/10 cm	500m/100 km	3/1 month	••		•			SEASAT-A	10 cm	Ka-Band	--	2-12km	Nadir	
Upwelling Location/Extent	100m/10 km	100m/10 km	--	100m/10 km		••			•		SEASAT-A	25m	L-Band	--	25m	100 km	
Ocean Current-Velocity	2/50 cm/s	1/5 cm/s	--	500m/10 km	3 hr/1 month	••				Buoy Relay	SEASAT-A	10 cm bulge	Ka-Band	--	2-12km	Nadir	
Ocean Current-Extent/Direction	500m/10 km, 10°	500m/10km, 5/10°	--	500m/10 km	3 hr/5 days	••			•		SEASAT-A	25m	L-Band	--	25m	100km	
Estuary Circulation-Velocity/Direction	1/5 cm/s, 10°	1/5 cm/s, 5/10°	--	100m/1 km	3 hr/1 day	••			•		--	--	--	--	--	--	
Fresh Water Influx-Extent/Direction	500m/10km, 10°	500m/10km, 5/10°	--	500m/10km	12h4/30days	•	•		••		NIMBUS-G	--	Glitter	--	825 m	1500 km	
Sediment Transport-Extent/Direction	10m/1km, 10°	10m/1km, 5/10°	--	10m/1 km	3 hr/5 days				••		NIMBUS-G	0 4%	Yellow	--	825m	1500 km	
Iceberg Location/Sizing	5/25m	5/25m	--	0 3/2 km	12/24 hr	••					SEASAT-A	25m	L-Band	--	25m	100 km	
Astronomical Tides	1/10 cm	1/10 cm	1 10 cm	500m/100km	3/6 hr	••		•			SEASAT-A	10 cm	Ka-Band	10 cm	2-12km	Nadir	
Coastal Depth	15 cm/10m	15 cm/10m	15 cm/10m		1/30 days	•		•	•		--	--	--	--	--	--	
Shoal/Shoreline Movements	2/25m	1/10m	--	1/10m	1/7 days	•			•		--	--	--	--	--	--	
Marine Geoid	1/10 cm	1/10 cm	1 10 cm	500m/100km	3/6 hr	••		•			SEASAT-A	10 cm	Ka-Band	10 cm	2-12km	Nadir	
Biological Balance																	
Surface Salinity	0 01/1 ppt	0 005/1 ppt	-	1/200 km	12hr/30days		•		••		NIMBUS-G	0 4%	0 55µ (yellow)	--	825 m	1500 km	
Turbidity	0 01	0 01	--	100m/1km	6/12 hr			•	•		--	--	--	--	--	--	
Nutrient Availability			--	100m/1km	12hr/3 days			•	•		--	--	--	--	--	--	
Chlorophyl Extent/Concentration	0 3µg/ℓ or 10%	0 3µg/ℓ or 10%	--	100m/1 km	12hr/3 days			•	••		NIMBUS-G	0.4%	0 44, 0.52 0 67 µm	--	825m	1500 km	
Vegetation Extent/Type			--	100m/1km	12hr/			•	••		NIMBUS-G	0 4%	0.75 µm	--	825m	1500 km	
Disease Vectors (e g Red Tide, etc)			--	100m/1km	12hr/			•	••		--	--	--	--	--	--	
Fish/Mammal Location/Extent			--			•					--	--	--	--	--	--	
Fish Oil/Biproducts			--			•	•	•			--	--	--	--	--	--	
Human Impact																	
Pollutant Extent/Identification			--			•		•	••		NIMBUS-G	0 4%	V&IR	--	825 km	1500 km	
Ship Location/Identification	1m/100m	1m/100m	--	30m/2km	3/12 hr	••					SEASAT-A	25m	L-Band	--	25m	100 km	

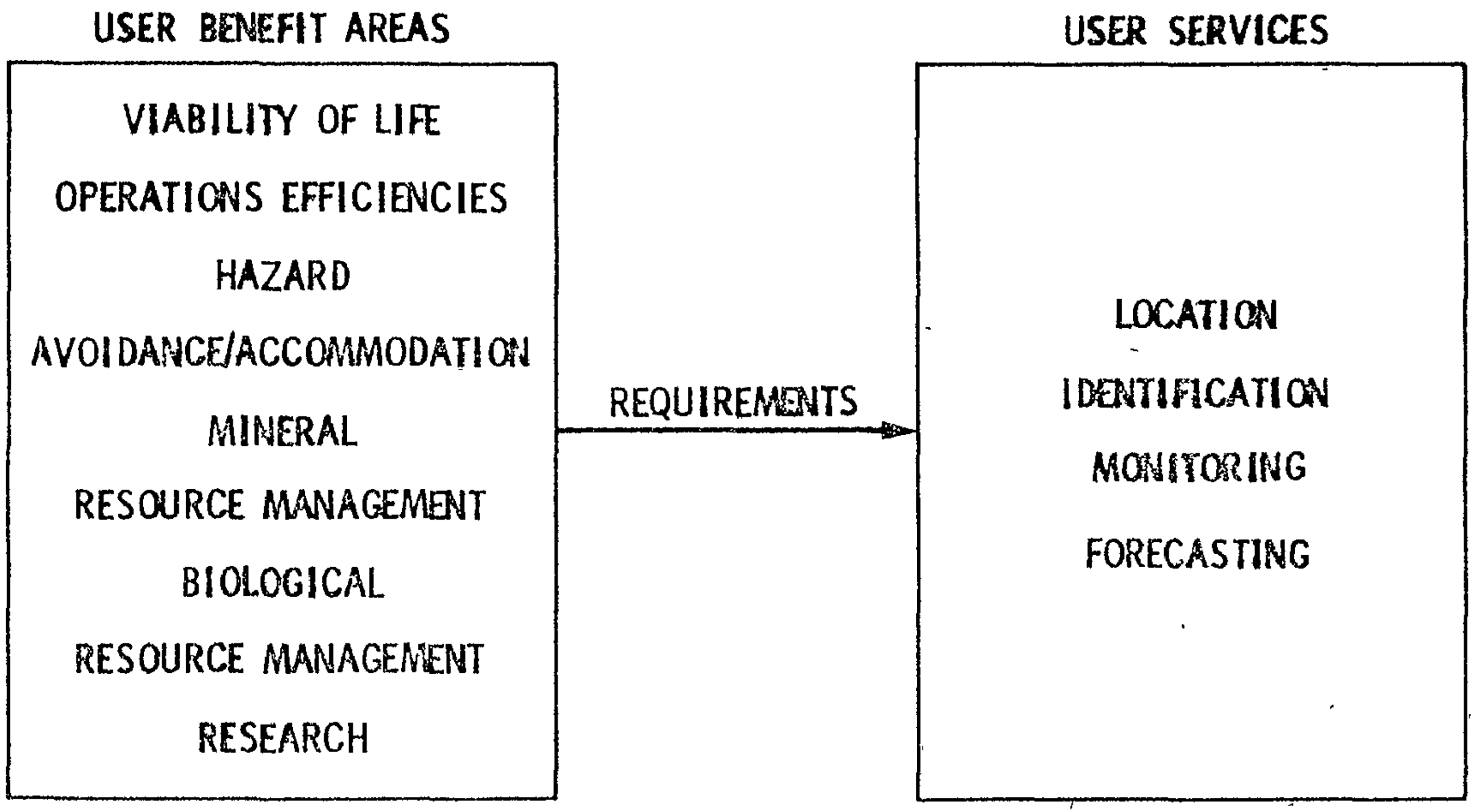
TABLE IV. COMPARISON OF CRYOSPHERE MEASUREMENT NEEDS AND FUNDED CAPABILITIES

Environmental Parameter	Differentiation Sensitivities Needed (Goal/Minimum-Useful)					Applicable Sensors					Funded Space Capability						Remarks
						Microwave		Visible and Infrared									
	Measurement Accuracy	Measurement Precision	Vertical Resolution	Horizontal Resolution	Temporal Report	Active	Passive	Active	Passive	Other	Satellite	Energy Precision	Spectral Channels	Horizontal Resolution	Vertical Resolution	Effective Swath	
Thermal Balance																	
Surface Temperature	0 5/1°C	0 1/0 25°C	--	5m/500km	3 hr/4 days		•		••		TIROS-N	0 25°C	2V, 3 IR	10km	--	1500km	
Temperature in Depth	0 5/1°C	0 1/0 25°C	--	5m/25km	12hr/30 days						--	--	--	--	--	--	
Surface Heat Flux	0 25/4 w/m²	0 25/4 w/m²	2/10m	100m/500km	3 hr/30 days				••		NIMBUS-G	1%	12(0 2-50μm)	--	--	--	
Surface Albedo	0.2/1%	0 2/1%	--	100m/500km	3 hr/30 days				••		NIMBUS-G	1%	12(0 2-50μm)	--	--	--	
Sublimation Rate	0 5/2 mm/deg	0 5/2 mm/deg	--	25/500km	3hr/4 days						--	--	--	--	--	--	
Convective Balance																	
Ice/Snow Extent	5m/25km,3%	5m/25km,3%		5m/25km	12/24 hr	••	•		•		SEASAT-A	25m	L-Band	25m	--	100km	
% Open Ocean	3/30%	1/25%	--	0 5/100 km	12hr/7 days	••	•		•		SEASAT-A	25m	L-Band	25m	--	100km	
% Snow Cover	5/20%	2/20%				••	•		•		SEASAT-A	25m	L-Band	25m	--	100km	
Ice/Snow Thickness	10 cm/5m	10 cm/5m	10 cm/2m	2/50m	12hr/3 days	•					--	--	--	--	--	--	
Ice/Snow Surface Roughness	10 cm/1m	10 cm/1m	10 cm/1m	1/10m		•	•	•			--	--	--	--	--	--	
Ice Drift	5m/25km	5m/25km	--	5m/25km		••					SEASAT-A	25m	L-Band	25m	--	100km	
Ice Deformation	50/100m/yr, 0 1%	50/100m/yr, 0 1%				••			•		SEASAT-A	25m	L-Band	25m	--	100km	
Age	1, 2, mult	1, 2, mult	--	2/20km	12hr/3 days		••				SEASAT-A	1,2 yr	37 GHz	21km	--	638km	
Berg Formation Rate											--	--	--	--	--	--	
Ice Lead/Crevasse Location/Sizing	5/100m	5/100m	--	5/100m	1/6 hr	••			•		SEASAT-A	25m	L-Band	25m	--	100km	
Human Impact																	
Search & Rescue			--	30m/1km	3/12 hr					Relay							

TABLE V. COMPARISON OF LAND MEASUREMENT NEEDS AND FUNDED CAPABILITIES

Environmental Parameter	Differentiation Sensitivities Needed (Goal/Minimum Useful): Measurement Accuracy	Measurement Precision	Vertical Resolution	Horizontal Resolution	Temporal Repeat	Applicable Sensors: Microwave Active	Microwave Passive	Visible and Infrared Active	Visible and Infrared Passive	Other	Funded Space Capability: Satellite	Energy Precision	Spectral Channels	Horizontal Resolution	Vertical Resolution	Effective Swath	Remarks
Thermal Balance																	
Surface Temperature	0 2/1°C	0 1/0 5°C	--	2/100m			•		•		LANDSAT-D	1°C	IR	30m	--	185km	
Temperature In Depth	0 2/1°C	0 1/0 5°C	10cm/1m	2/100m							--	--	--	--	--	--	
Surface Heat Flux	0 25/4 w/m^2	0 25/4 w/m^2	--	25/500km					•		NIMBUS-G	1%	12(0 2-50μm)	--	--	--	
Surface Albedo	0 2/1%	0 2/1%	--	25/500km					•		NIMBUS-G	1%	12(0 2-50μm)	--	--	--	
Evaporation Rate	0 5/2mm/deg	0 5/2mm/deg	--	25/500km		•	•				--	--	--	--	--	--	
Convective Balance																	
Crustal Shifts			--			••					SEASAT-A	25m	L-Band	25m	--	100km	
Crustal Bulges	1/10 cm	1/10 cm	--			••		•			SEASAT-A	10cm	Ka-Band	2-12km	10 cm	Nadir	
Topsoil Transport			--		1mo/1yr	•		•	•		--	--	--	--	--	--	
Volcanic Activity			--			•			•		LANDSAT-D	30m	V&IR	30m	--	185km	
Thermal Sources	0 2°C	0 2°C	--	10/100m					•		LANDSAT-D	30m	V&IR	30m	--	185km	
Magma Convection			--			•				Gravimeter	--	--	--	--	--	--	
Water Balance																	
Lake/Reservoir/River/Extent	1/25m	1/25m	--	1/25m		•			••		LANDSAT-D	30m	V&IR	30m	--	185km	
Lake/Reservoir Depth	10cm/1m	10cm/1m	10cm/1m	1/25m		•		•			--	--	--	--	--	--	
Wetlands Extent	2/100m	2/100m	--	2/100m		•			••		LANDSAT-D	30m	V&IR	30m	--	185km	
Soil-Moisture/Irrigation	0 01/0 05cc/cc	0 01/0 05cc/cc	--	10m/500km	3hr/1mo	•	•		•		--	--	--	--	--	--	
Mineral Resources																	
Geological Formation Mapping	2/100m	2/100m	--	2/100m		•			••		LANDSAT-D	30m	V&IR	30m	--	185km	
Surface Character/Roughness	2/100m	2/100m	--	2/100m		•			••		LANDSAT-D	30m	V&IR	30m	--	185km	
Mineral Identification/Location	2/100m	2/100m	--	2/100m		•			••		LANDSAT-D	30m	V&IR	30m	--	185km	
Mining/Drilling Land Use	2/100m	2/100m	--			•			••		LANDSAT-D	30m	V&IR	30m	--	185km	
Biological Resources																	
Acid/Base Balance			--								--	--	--	--	--	--	
Nutrient Availability			--						•		LANDSAT-D	?	V&IR	30m	--	185km	
Chlorophyl			--						•		LANDSAT-D	?	V&IR	30m	--	185km	
Vegetation Extent/Type/Growth-Status	2/5%	2/5	--	2m/500km	1/7 days	•			•		LANDSAT-D	30m	V&IR	30m	--	185km	
Plant Water Stress			--	10m/500km	12hr/1wk	•			•		LANDSAT-D	30m	V&IR	30m	--	185km	
Disease Vector Extent	2/5%	2/5	--	10m/500km	1/7 days	•			•		LANDSAT-D	?	V&IR	30m	--	185km	
Grazing/Range-Herd Effects	2/5%	2/5	--	10m/500km	1/7 days	•			•		LANDSAT-D	?	V&IR	30m	--	185km	
Human Impact																	
Water Quality	?	-	--	5/50m					•		LANDSAT-D	?	V&IR	30m	--	185km	
Urban/Power/Transport Land Use			--	5/50m		•			•		LANDSAT-D	30m	V&IR	30m	--	185km	
Search and Rescue			--			•				Relay	--	--	--	--	--	--	
Space Effects																	
Magnetic Field	0 01/100Y	0 01/100Y	--	0 1/0 7deg	Monthly					Magnetometer	MAGSAT						
Trapped Particle Field		$10/10^4/cm^2$s str kev		-	Monthly					Particle Detector							
Gravity Field	0 3/0 1 EU	0 3/0 1 EU	--	--	Yearly					Gradiometer	--	--	--	--	--	--	

USER NEEDS


USER BENEFIT AREAS
VIABILITY OF LIFE
OPERATIONS EFFICIENCIES
HAZARD
AVOIDANCE/ACCOMMODATION
MINERAL
RESOURCE MANAGEMENT
BIOLOGICAL
RESOURCE MANAGEMENT
RESEARCH
REQUIREMENTS
USER SERVICES
LOCATION
IDENTIFICATION
MONITORING
FORECASTING

MEASUREMENT NEEDS/CAPABILITY COMPARISON

<u>SENSITIVITIES NEEDED</u>

MEASUREMENT ACCURACY

MEASUREMENT PRECISION

VERTICAL RESOLUTION

HORIZONTAL RESOLUTION

TEMPORAL REPEAT

<u>FUNDED SPACE CAPABILITY</u>

SATELLITE

ENERGY PRECISION

SPECTRAL CHANNELS

VERTICAL RESOLUTION
HORIZONTAL RESOLUTION

EFFECTIVE SWATH

AIR - SEA - ICE - LAND - SPACE - IN SITU

MEASUREMENT GOAL

MINIMUM USEFUL MEASUREMENT

MEASUREMENT VOIDS

AIR

MEASUREMENT	IMPORTANCE
SURFACE AIR TEMPERATURE	WEATHER AND CLIMATE MODELING
ATMOSPHERIC PRESSURE	WEATHER MODELING
PRECIPITATION RATES	WEATHER MODELING
VERTICAL ATMOSPHERIC MOTIONS	WEATHER MODELING
FOG/MIST VISIBILITY	HAZARD MONITOR

MEASUREMENT VOIDS

SEA

MEASUREMENT	IMPORTANCE
TEMPERATURE IN DEPTH	FISHERIES VIABILITY
EVAPORATION RATES	WEATHER AND CLIMATE MODELING
SURFACE LAYER TRANSPORT	FISHERIES VIABILITY
SALINITY	FISHERIES VIABILITY AND CLIMATE
CURRENT VELOCITIES	SHIP ROUTING, FISHERIES VIABILITY, POLLUTION DISSIPATION, AND CLIMATE MODELING
TURBIDITY AND NUTRIENT AVAILABILITY	FISHERIES VIABILITY
SHOAL MOVEMENTS	COASTAL HAZARDS
TSUNAMIS AND FREAK WAVES	HAZARD AVOIDANCE

MEASUREMENT VOIDS

ICE

MEASUREMENT	IMPORTANCE
TEMPERATURE IN DEPTH	DYNAMICS
SUBLIMATION RATES	WEATHER AND CLIMATE MODELING
THICKNESS/ROUGHNESS	NAVIGATION AND CLIMATE MODELING

MEASUREMENT VOIDS
LAND

MEASUREMENT	IMPORTANCE
TEMPERATURE IN DEPTH	BIOLOGICAL GROWTH AND CLIMATE MODELING
EVAPORATION RATE	WEATHER AND CLIMATE MODELING
SOIL MOISTURE	BIOLOGICAL GROWTH
LAKE/RESERVOIR DEPTH	WATER AVAILABILITY/FLOOD HAZARD
SURFACE MOVEMENTS	EARTHQUAKE PRECURSERS

MEASUREMENT VOIDS
SPACE AND IN SITU

MEASUREMENT NEEDS APPEAR TO BE TIED TO

'Lets Look and See'

Rather Than

'This Accuracy is necessary to distinguish between theories'

SENSOR CLASSES COVERED IN JPL STUDY

- MICROWAVE RADIOMETERS
- ACTIVE MICROWAVE RADAR
- VISIBLE & INFRARED RADIOMETERS
- ACTIVE VISIBLE & INFRARED LIDAR
- ULTRAVIOLET RADIOMETERS
- X-RAY
- γ-RAY
- LOW ENERGY PARTICLES
- HIGH ENERGY PARTICLES
- MAGNETOMETERS
- MASS SPECTROMETER/GAS CHROMATOGRAPHS
- MISCELLANEOUS

ACTIVE SENSOR TYPES

RADAR		LASER
√	ALTIMETRY	√
√	SCATTEROMETRY	
√	PRESSURE SOUNDING	√
√	RAIN SOUNDING	
√	SURFACE COMPOSITION	√
√	FEATURE IDENTIFICATION	

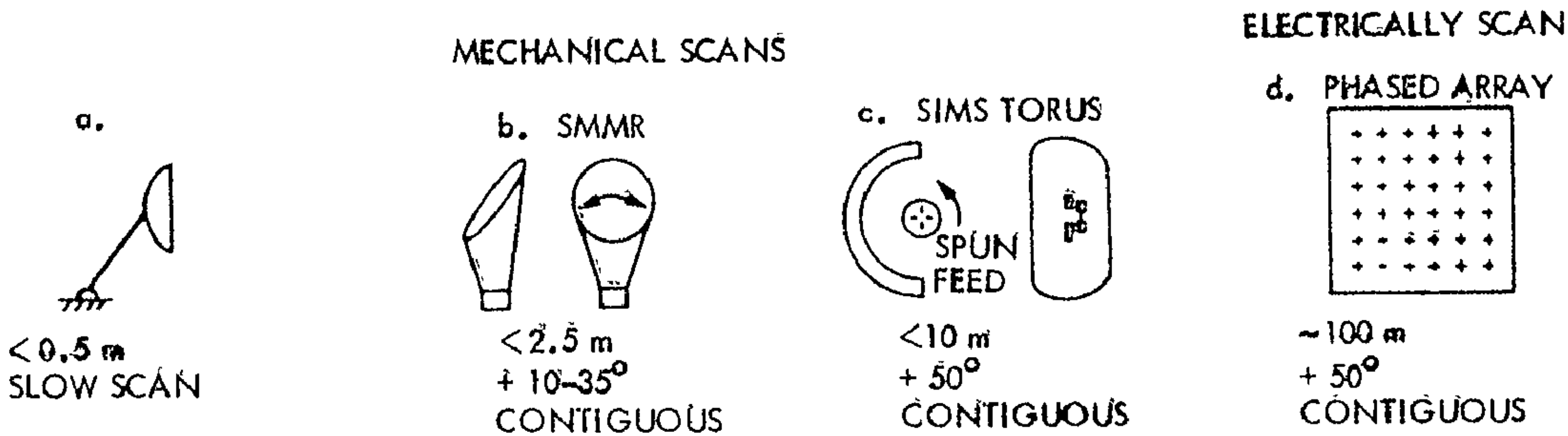
PASSIVE SENSOR TYPES

MICROWAVE		VISIBLE AND INFRARED
√	THERMAL MAPPING	√
√	ATMOSPHERIC SOUNDING	√
	ATMOSPHERIC COMPOSITION	√
	SURFACE COLORIMETRY	√
	FEATURE IDENTIFICATION	√

SENSOR DEVELOPMENT NEEDS
MICROWAVE RADIOMETER

	SRT	AST
1. Improved Accuracy (→0.1 ^{0}C, → /m/s wind, →1 mg H_2O/cm^2 →0.1 cm/hr precipitation, →0.01 ppt salinity, →1 m ice thickness)		
Wider Range of Frequencies (→0.1 GHz, →1000 GHz)	*	*
Low Noise Detectors (→maser & josephson junctions at cryogenic temperatures)	*	*
Cryogenic Detectors (→ 4 ^{0}K)	*	*
Frequency Scanning	*	*
2. Improved Resolution (→5 km at C and L-Bands)		
Larger Antennas (→100 m aperture)		*
3. Improved Swath (→1500 km)		
Multibeam Scanning (allows continguous coverage at 1 to 5 km resolutions)		*
Large Phased Arrays with Low Noise		*
Large Torus with Spun Feed (→10 m)	*	*
4. Real Time Processing		
Onboard Location, Bias Calibration and Conversion to Geophysical Meaning	*	

PASSIVE MICROWAVE ANTENNA SCANNING TRENDS



SENSOR DEVELOPMENT NEEDS
RADAR ALTIMETER

	SRT	AST
1. Improved Accuracy (→ ± 1 cm)		
Shorter Effective Pulse Length (→ 1 ns)		*
Higher-Energy/Longer Life Transmitters (→ 10 kw, 6 yr)		*
2. Improved Surface Resolution (→ 1 km)		
Beam Limited Footprint (→ 10 m antenna)		*
(→ higher frequencies)		*
3. Surface Profiling (Lateral and Nadir Measurements)		
Multibeam Implementation (→ 10 m antenna with ≥ 3 feeds)		*
Cross Track Scanning (→ higher frequencies)		*
4. Ice and Snow Thickness (second surface reflection)		
Multifrequency Implementation (adding S or L band)	*	*
5. Real Time Altimetry Processing (complex support algorithms)		
High Accuracy Geoid (multiple error source corrections)	*	
Current & Tidal Fluctuations (altimetry comparison with best Geoid)	*	
Wave Height Distribution (return signal shape comparison)	*	

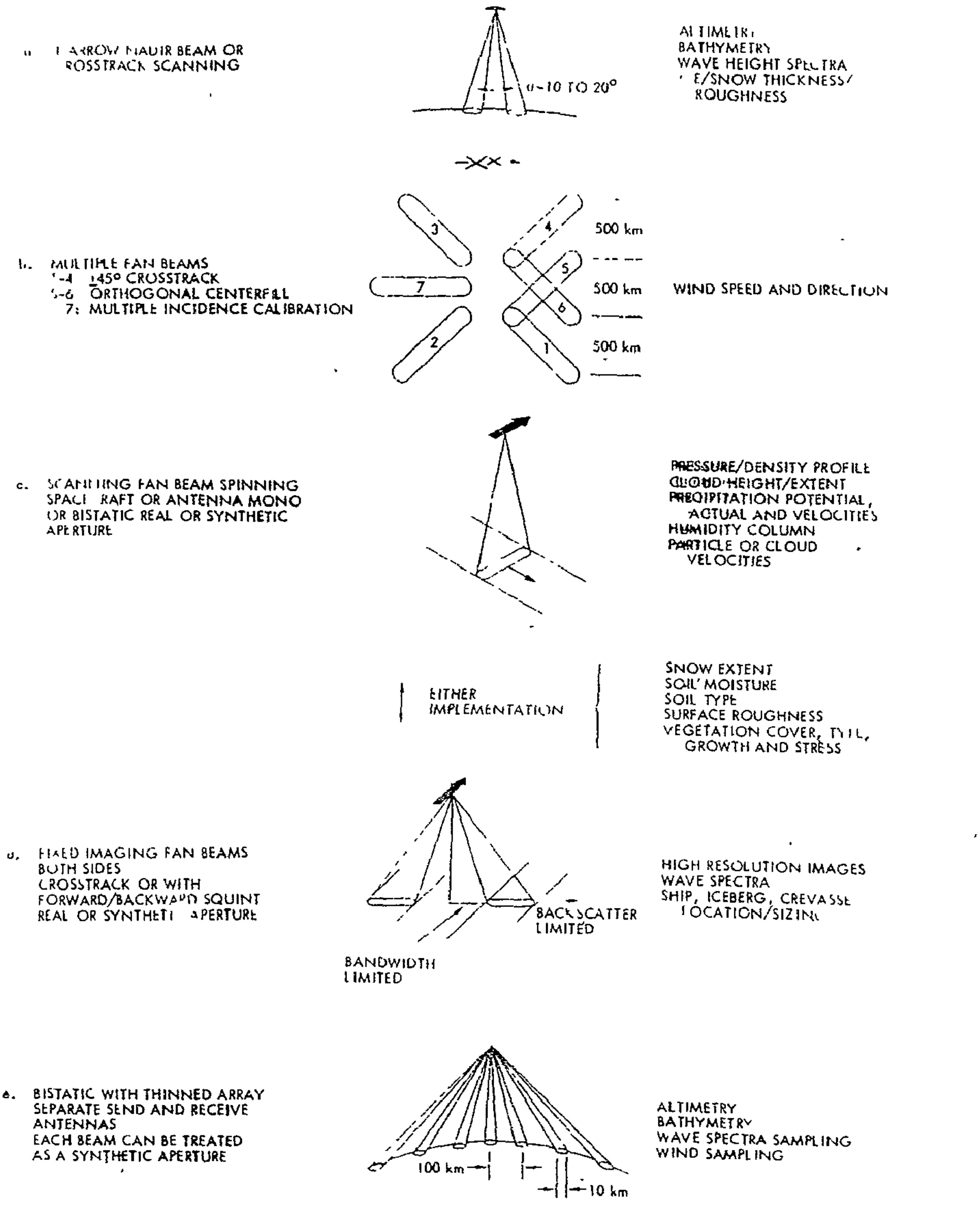


FIGURE 3. SAMPLE ILLUMINATION POSSIBILITIES

SENSOR DEVELOPMENT NEEDS
RADAR SCATTEROMETER

	SRT	AST
1. Improved Accuracy (→ ± 0.1 db)		
Improve Attitude and Boresite (→ 0.01 deg)	*	
Receiver Noise & System Errors (→ 1%)	*	*
2. Reduced Interpretation Ambiguities		
Third Measurement Angle (90^0 or)	*	
Variable Filters (earth rotation correction)	*	
3. Improved Surface Resolution (→ 5 km)		
Beam Limited Direction (→ 10 m stick arrays)	*	
(→ 1 kw power)	*	
Range & Doppler Differentiation (imaging radar like implementation)		*
4. Swath Improvement		
Center Fill-in (Special center antenna)	*	
5. Real Time Interpolation (complex support algorithms)		
Wind-Shear/Surface-Wind-Velocity Conversion	*	

SENSOR DISCUSSION OUTLINE

- List of Sensors
- Spectral Bands of Sensors
- Spectral Band Trends
- Transmitter Power Trends
  - Pulse Trends
- Collector Scanning Trends
  - Size Trends
  - Resolution Trends
  - Swath Trends
- Detector Noise Trends
  - Dynamic Range Trends
- Support Cooling Trends
  - Power Trends
  - Attitude Trends
  - Data Trends

SENSOR DEVELOPMENT NEEDS
ATMOSPHERIC RADARS

	SRT	AST
1. Improved Accuracy (→<0.5 mb pressure, →<0.5 m/s wind, →0.1 cm/hr precipitation)		
Multifrequency Implementation (6 channels between 20→80 GHz for Pressure)	*	*
(3, 14, & 37 GHz for Precipitation and wind Doppler)	*	*
Higher-Energy, Longer-Life Transmitters (→10 kw for Pressure, 6 yrs)		*
(→1 Mw for precipitation, 6 yrs)		*
Doppler sensitivity (→0.01)		*
2. Improved Resolution (→1 km horizontal, 1 km vertical)		
Large Phased Array Antennas (→200 m and scanning)		*
3. Real Time Processing (complex support algorithms)		
Direct readout of pressure, rain rate, or wind velocity/direction		

SENSOR DEVELOPMENT NEEDS
SYNTHETIC APERTURE RADAR

	SRT	AST
1. Improved Accuracy		
Multifrequency Implementation (L, S, C, X, Ke, Ka, Ku, & Vc bands)	*	*
Higher-Energy Longer-Life Transmitters (e.g. 10 kw at L, 20 kw at X, 30 kw at Vc, 6 yr life)		*
Narrower-Bandwidth/Shorter-Length Pulses (→20 nm, →1 μs)		*
Digital Chirp and Jittered PRF	*	
2. Improved Resolution (→5 m)		
Large Antennas (→50 m low earth, →200 m geostationary)		*
3. Larger Swath (→1500 km)		
Step Scan Phased Array		*
Wide Band Receivers (→100 MHz)		*
4. Special Applications		
Multibeam Sampling (→fifteen 10 km samples each 100 km apart)	*	
Stacked Receiver Beams		*
Forward/Backward Squint (reduces location ambiguities)		*
5. Real Time Processing (complex support algorithm and processing architecture)		
Direct Conversion to Wave Spectra without Image	*	
Real Time Onboard Correlation	*	*
Real Time Information Extraction (ship/iceberg location/identification, vegetation extent, typing, etc.)	*	*

SENSOR DEVELOPMENT NEEDS
INFRARED SOUNDERS

	SRT	AST
1. Improved Accuracy		
Extension of Spectral Range ($\rightarrow$1 mm)	*	*
Increase in Number of Channels ($\rightarrow$100)	*	*
Improved Spectral Resolving Power ($\rightarrow 10^{7}$)	*	
Simultaneous Measure of All Spectral Channels	*	*
Lower Noise ($\rightarrow 10^{-13}$ w/cm^{2}st NER, $\rightarrow 5^{0}$K)	*	*
2. Improved Resolution ($\rightarrow$5 km from geostationary)		
Larger Optics ($\rightarrow$2 m)	*	
Larger Focal Lengths ($\rightarrow$10 m)	*	

INFRARED SURFACE THERMAL MAPPERS

	SRT	AST
1. Improved Accuracy		
Increase in Number of Channels ($\rightarrow$10)	*	
Lower Noise ($\rightarrow 10^{-13}$w/cm^{2}st NER, $\rightarrow 5^{0}$K)	*	*
2. Improved Resolution ($\rightarrow$10 m)		
Larger Optics ($\rightarrow$50 cm)	*	

SENSOR DEVELOPMENT NEEDS
VISIBLE AND INFRARED COMPOSITIONAL MAPPERS

	SRT	AST
1. Improved Accuracy		
Extension of Spectral Range ($\rightarrow$1 mm)	*	*
Increase in Number of Channels ($\rightarrow$100)	*	*
Improved Spectral Resolving Power ($\rightarrow 10^7$ with laser heterodyne or interferometers)	*	*
Low Noise ($\rightarrow 10^{-13}$ w/cm^2 str NER, $\rightarrow 5^0$K)	*	*
2. Improved Resolution ($\rightarrow$5 km horizontal from geostationary, $\rightarrow$1 km vertical along Limb)		
Larger Optics ($\rightarrow$2 m)	*	
Larger Focal Lengths ($\rightarrow$10 m)	*	
Adaptive Cryogenic Optics		*
3. Real Time Processing (complex support algorithms)		
Information Extraction ($\rightarrow$10 mbps)	*	

SENSOR DEVELOPMENT NEEDS

VISIBLE COLORIMETRY

	SRT	AST
1. Improved Accuracy		
Improved Spectral Resolving Power (→10 mm using laser heterodyne or interferometry)	*	*
Increase in Number of Channels (→20)	*	*
Lower Noise Levels (→10^{-13} w/cm^2 str NER, →5^{0}K)	*	*
2. Improved Resolution (→10 m from low altitudes, →100 m from geostationary)		
Larger Optics (→2 m diameter, →10 m focal lengths)	*	*
3. Real Time Processing (complex support algorithms)		
Information extraction (→10 mbps)	*	

VISIBLE AND INFRARED FEATURE MAPPING

	SRT	AST
1. Improved Accuracy		
Increase in Number of Channels (→20)	*	*
Lower Noise Levels (→10^{-13} w/cm^2 str NER, → 5^{0}K)	*	*
2. Improved Resolution (→5 m)		
Monolith Detectors (→1000 elements)	*	*
Improved Angular Resolution (→10^{-5} deg)	*	*
3. Real Time Processing		
High Data Rate Processing (→2 Gb/s)	*	*

SENSOR DEVELOPMENT NEEDS
LASER AND LIDAR SENSORS

	SRT	AST
1. Improved Accuracy (→1 cm altitude accuracy, → <10 nm bandwidth sensitivity		
Wider Range of Wavelengths (10^{-3} to 10 mm)		*
More Frequencies (→100 line pairs for composition)		*
Higher-Power Longer-Life Transmitters (→10 Mw & 1 ns pulse length, 6 yrs)		*
(→10 kw continuous wave, 6 yrs)		*
Better Detector Sensitivity (→10^{-5} cm^{-1})		*
Improved Frequency Tuning (tuned laser heterodying or interferometry)	*	*
2. Improved Resolution (→5 km horizontal, 1 km vertical)		
Large Optics (→50 cm apertures)		
Adaptive Cryogenic Optics		
3. Improved Swath		
Horizontal Profiling (→multibeam or cross track scanning)		*
Wide Swath Compositional Mapping (→1500 km)		*
4. Real Time Processing		
Onboard Compositional Determinations	*	

SENSOR DEVELOPMENT NEEDS

ULTRAVIOLET RADIOMETERS

	SRT	AST
1. Improved Sensitivity (→1 Å)		
Lower wavelengths (→100 Å)	*	*
Narrower Bandwidths (→Interfermetric or tuned filters)	*	*
Larger Detectors (→100 x 100 arrays)	*	*
2. Improved Resolution		
Holographic Methods of Dispersion		*

X RAY & γ RAY SENSORS

	SRT	AST
1. Improved Sensitivity		
Larger Detectors (→1 m^2 area)	*	*
Cryogenic Cooling (→5^0 K)		*
2. Improved Resolution		
Attitude Knowledge (→0.001 arcsec)	*	

IN SITU SENSORS

Primarily Sample Preparation Oriented

SENSOR DEVELOPMENT NEEDS

CHARGED PARTICLE SENSOR

	SRT	AST
1. Improved Sensitivity		
Larger Detectors (→ 1 m^2)	*	*
Increased Magnetic Field Strength (→ 50 kg -m)		*
Elimination of Induced Charge Buildup	*	

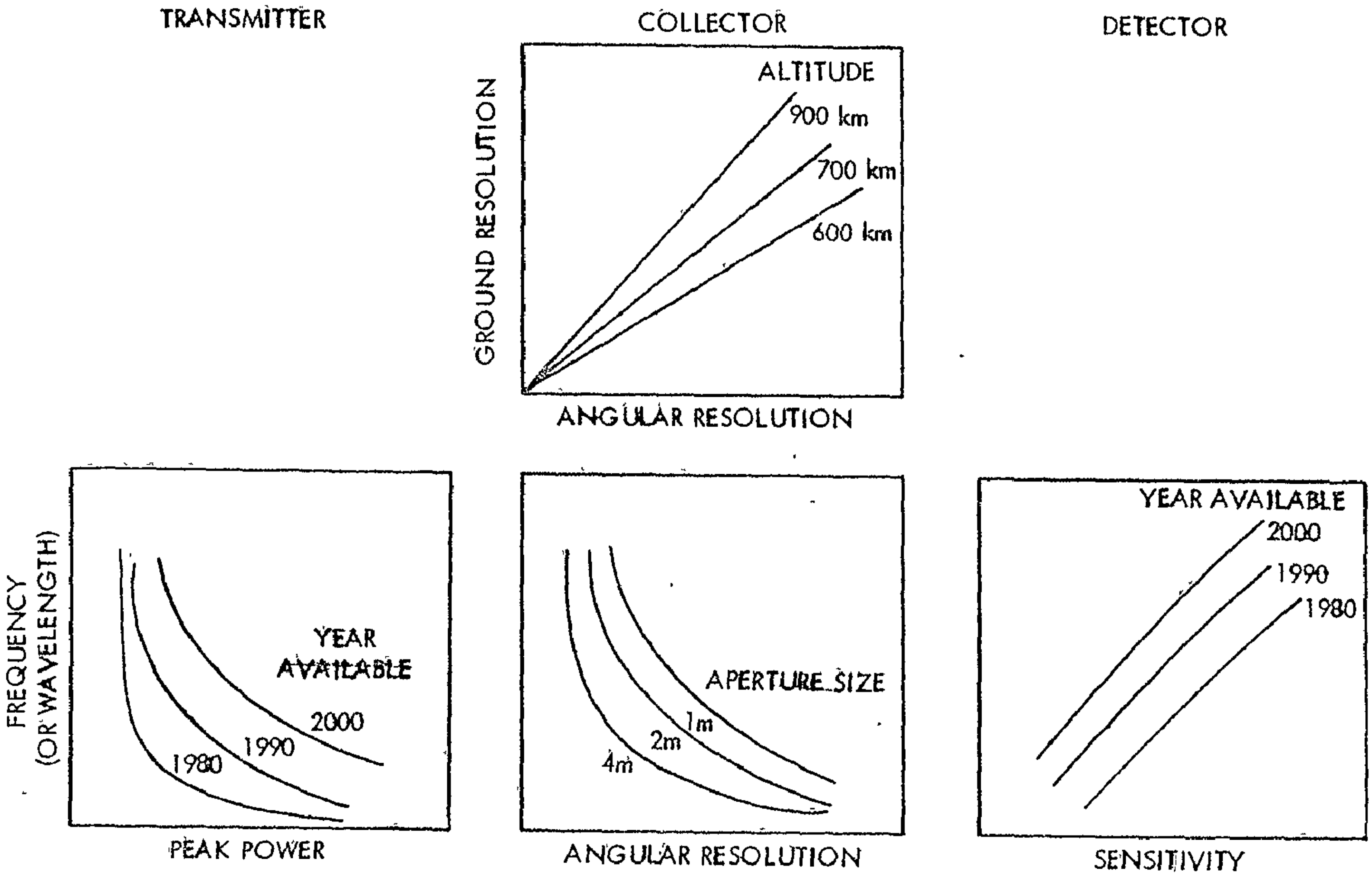
MAGNETOMETERS

Needed Sensitivities and Resolutions Obtainable

GRAVITY GRADIOMETRY

	SRT	AST
1. Improved Sensitivity (→ < 0.001 E.U.)		
Longer Rotor Arms (→ 5m)		*
Reduced System Distortions		*

GENERALIZED SENSOR DESIGN



SENSOR TECHNOLOGY RESEARCH OPPORTUNITIES

VISIBLE INFRARED SENSORS

RADIOMETER TECHNOLOGY

- LARGER AND COOLED OPTICS
- ADAPTIVE OPTICS (TOWARD 30m)
- MORE SENSITIVE AND CRYOGENICALLY COOLED SOLID STATE DETECTORS
- MULTIPLEXED SPECTROMETER/INTERFEROMETERS
- TUNABLE LASER HETERODYNE SPECTROMETER
- LARGE FRAME CCD (etc.) MONOLITH CAMERAS (TOWARD 10^7 ELEMENTS)
- LOW COST IMAGE INFORMATION EXTRACTION

LASER RADAR TECHNOLOGY

- TUNABLE CW SPACE LASERS
- EXTENSION INTO FAR INFRARED AND EVEN MILLIMETER WAVE REGIMES
- HIGH PEAK POWER PULSED SPACE LASER

SENSOR TECHNOLOGY RESEARCH OPPORTUNITIES
MICROWAVE SENSORS

RADIOMETER TECHNOLOGY

- CRYOGENIC LOW NOISE DETECTORS (MASARS, JOSEPHSON JUNCTIONS)
- LARGE ELECTRICALLY SCANNED PHASED ARRAYS
- FREQUENCY SCANNING CAPABILITIES (ABSORPTION BAND IDENTIFICATION, PRESSURE SENSITIVITES, etc.)

RADAR TECHNOLOGY

- MULTIFREQUENCY MULTIPURPOSE SPACE IMAGING RADAR
- LONG LIFE HIGH POWER TRANSMITTERS (SOLID STATE, etc.)
- LARGE ELECTRICALLY SCANNED/STEPPED PHASED ARRAYS
- MULTIPLE FREQUENCY ANTENNAS (30 dB DOWN SIDELOBES)
- LOW COST IMAGE PROCESSING
- SPECIALITY RADARS (WAVE SPECTRA, RAIN, etc.)

4.2

(UNCLASSIFIED SUMMARY)

DOD HIGH ENERGY LASER TECHNOLOGY

OAST SENSORS WORKSHOP

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

11-12 MAY 1977

EDWARD T. GERRY
W. J. SCHAFER ASSOCIATES, INC.

This talk provided an overview at the Secret level of the major technology development programs being carried out by the DoD in the high-energy laser technology area. The use of high-speed flow common to all high-average power lasers was discussed, and the three major types of high-energy lasers now under development under DoD were reviewed. These are the gas dynamic laser, the chemical laser, and the electrical laser. In the gas dynamic laser the population inversion is created as a direct result of gas dynamic processes, i.e., expansion of an initially equilibrium hot gas through a supersonic nozzle with the inversion created as a result of vibrational nonequilibrium in the expanded flow. In contrast, the chemical laser creates a population inversion as a direct result of chemical reactions. Finally, the electrically excited laser uses discharge excitation or electron beam/discharge excitation in the laser cavity to create the inversion under high-speed flow conditions. The fundamentals of each of these types of lasers were reviewed and the achievements to date and near-term plans comprising the current DoD program were discussed. In addition, recent developments in short-wavelength lasers, specifically the excimers, were also reviewed. The excimer lasers offer the potential of compact, efficient, scalable high-power electrically excited lasers in the visible and ultraviolet portions of the spectrum. This type in particular may have very significant impact in remote sensing applications.

4.3 UNCLASSIFIED OUTLINE AND TABLE OF CONTENTS FOR

TECHNOLOGY ASSESSMENT AND NEW OPPORTUNITIES STUDY 2.3

DAVID G. AVIV
THE AEROSPACE CORPORATION

FOREWORD

This report documents The Aerospace Corporation effort on Study 2.3, Technology Assessment and New Opportunities, which was performed under NASA Contract NASW-2884 during fiscal year 1976. The study direction at NASA Headquarters was under Mr. S. R. Sadin of the Office of Aeronautics and Space Technology.

This volume is one of two volumes of the final report for Study 2.3. The volumes are:

Volume I	Executive Summary
Volume II	Technology Assessment and New Opportunities

Volume I summarizes the overall study in brief form and includes the relationship of this study to other NASA efforts, significant results, study limitations, suggested research, and recommended additional effort.

Volume II consists of more than 1200 pages in three separately published parts as follows:

Part 1	Strategic and Tactical Systems and Near-Term Technology Programs
Part 2	Technological Assessment for DoD Space Programs (1980-2000)
Part 3	Technological Assessment for DoD Space Programs (continued) and Appendix on New Technological Opportunities

Volume II, Part 1, Section 1, describes strategic and tactical DoD space systems associated with earth, near-Earth, and space surveillance systems; navigation systems; and other space system

C-2

configurations planned through the year 2000. Section 2 discusses near-term (1976-1981) technology development program plans including schedules and costs.

Volume II, Parts 2 and 3, give the long term (1980-2000) technology assessment for DoD space systems (Section 3) and discuss new technological opportunities (Appendix).

1 INTRODUCTION

1.1 STUDY OBJECTIVES

The objective of this study is to survey and assess DoD-supported technology programs through the year 2000, covering the fields of strategic and tactical surveillance, navigation, meteorology, communications, and various special-purpose space applications. The purpose of this assessment, evaluation, and, to some degree, forecasting effort is to enable NASA to review its own future programs in the light of the information provided by this study. Their future programs then may be modified and enhanced, as required.

An additional purpose of the study is to avoid, as far as possible, duplication of effort between military and civilian agencies. These data, in no way, represent or imply a specific DoD poisition. They are intended to present an exhaustive collection of technology initiatives which may or may not be exercised in the future.

The scope and depth of the effort are indicated by the Appendix to this volume which reproduces the Table of Contents of the three accompanying technical volumes.

1.2 STUDY APPROACH

The approach used was first to describe appropriate DoD space missions (both ongoing and planned) for the next 25 years and then to identify the kind of DoD technology needed to support these and similar programs. Some 27 separate missions are described, 45 near-term technology programs are summarized, and 23 far-term technology programs are discussed in detail. The material presented may provide new mission opportunities and space systems initiatives for NASA.

1.3 ASSESSMENT OF STUDY RESULTS

Several major trends become evident from the results of this study. For instance, the need for higher optical resolution implies the development of focal planes containing several hundred million detector elements in the sensor focal plane with sensitivity in a number of wavelength bands. The resulting very high data rates of more than 10 gigabits/sec necessitate the development of on-board adaptive data processing and compaction to enable effective management of downlink data. Also, the opening up of the region between 10.6 μm and millimeter wavelengths by means of CO_2 laser pumping of assorted symmetric topped organic molecules together with the use of sensitive receivers of the Schottky barrier group supports the requirements for all-weather imaging and communication systems.

Towards the end of this century, satellite-deployed radar whose RF components, large structures, and high power requirements may mandate deployment by the Space Shuttle, will become viable. Preliminary design numbers for a radar concept are presented which substantiate the feasibility of a number of other conceptual space systems. Adaptive optics is also addressed.

A solid-state satellite solar power station is described wherein a novel power distribution system, identified by the acronym LITOMIC (light-to-microwave converse), is introduced. This power distribution concept has applications to several large space systems other than the satellite solar power station.

A list of space initiatives which are outside the scope of the planned DoD systems and technology for the 1980-2000 time frame but which, nevertheless, are of great interest, is also given. They include the following categories:

1. Lasers
2. Large Structures
3. Observation Technology
4. Quantum State Engineering

In general, NASA's year 2000 goals in communication systems and in obtaining qualitative and quantitative measurements in space and on Earth, including land, water, and underwater physical characteristics, as they pertain to expressed civilian applications are indicated by the various technology activities and trends discussed in the accompanying technical volumes.

1.4 MAJOR STUDY QUALIFICATIONS

A major objective of this study was to determine technology needs that DoD and NASA have in common and avoud a duplication of effort between military and civilian agencies. However, it must be recognized that continued coordination between these agencies is required to fully achieve this objective. In addition, NASA's expressed need to improve viewing resolution in a number of wavebands when surveying certain areas of the world[1] dictates a technology which can also be used to view areas not within the scope of civilian agencies or interests. Thus, if NASA is to utilize such technology, specialized networking control techniques would have to be implemented including on-board processing, specialized coding, and confined cross and downlink secure ground network optimization and controls.

Although many major space systems are described in this study, some are system concepts which have received only preliminary examination by DoD agencies. It is not the desire or intent of this study to indicate any specific DoD, ARPA, Air Force, Army, or Navy position on either

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[1] For example, the mid-continent of Africa, to detect locust breeding grounds and be able to instigate control action before agricultural devastation takes place.

programs, systems, or technology. This report is a collection of technology initiatives which may or may not be exercised in the future, and, as special trends are developed in the collection, they are indicative of the author's viewpoint rather than of any government agency.

VOLUME II, PART 1

CONTENTS

CONTENTS (Cont.)

CONTENTS (Cont.)

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VOLUME II, PART 2

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VOLUME II, PART 3

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4.4 ADVANCED DOD SENSOR SYSTEMS AND TECHNOLOGY APPLICABLE TO NASA MISSIONS

OAST SENSORS WORKSHOP

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

11-12 MAY 1977

DAVID G. AVIV
THE AEROSPACE CORPORATION

OUTLINE

- DOD SPACE ACTIVITIES THROUGH CY 2000
- NEAR-TERM (1975-85) SUPPORTING TECHNOLOGY PROGRAMS
- FAR-TERM (THROUGH CY 2000) TECHNOLOGY PROJECTIONS
- PASSIVE SENSOR SUBSYSTEMS AND ASSOCIATED TECHNOLOGY
- ACTIVE SENSOR SUBSYSTEMS AND ASSOCIATED TECHNOLOGY
- LWIR AND FIR IMAGING SYSTEMS REQUIREMENTS
- ATTITUDE REFERENCE SYSTEMS REQUIREMENTS
- MULTIFUNCTIONAL SPACE-BASED RADAR

DOD SPACE SYSTEMS OVERVIEW INDICATING TECHNOLOGY TRENDS

SURVEILLANCE:

STRATEGIC (EARTH AND SPACE ORIENTED)

DSP, Advanced DSP, HALO, TEAL RUBY, SIRE (Space IR Experiment), DS^3 (Deep Space Surveillance) and TEAL AMBER

Also, conceptual system plans demonstrating various technology trends: MINISAT System, ABPSS (Advanced Boost Phase Surveillance System), SMASS (Synchronous Missile Attack Assessment), MASS (Mid-Altitude Surveillance System), LASS (Low Altitude Surveillance System), CBPSS (Conus-Based Probe Surveillance System), RMASS (Radar Missile Attack Assessment Satellite System), PASS (Powered Airship Surveillance System), AS^3 (Airborne Space Surveillance System), SAS-I (Spacetrack Augmentation System using LWIR), and SAS-II (Spacetrack Aug mentation System Using Visible Sensor).

TACTICAL

Extension of DSP for tactical applications, SOSS (Satellite Ocean Surveillance System, Bi-Static Space-Based Radar, Air Defense via Spaceborne Radar, and XOS-19.

NAVIGATION: GPS (Global Positioning System)

METEOROLOGY: DMSP Block-5D-I, II, and METSAT

COMMUNICATION: SCS (Satellite Control Satellite)

SPECIAL PURPOSE: High Energy Space-Based RF and Laser Systems

DOD SPACE ACTIVITIES THROUGH CY 2000

- STRATEGIC SURVEILLANCE
  - / EARTH AND SPACE ORIENTED STRATEGIC SURVEILLANCE
  - / DEVELOPMENT AND DEMONSTRATION OF ADVANCED TECHNOLOGY
- TACTICAL SURVEILLANCE
  - / TACTICAL APPLICATION OF DSP
  - / SPACEBORNE RADAR SURVEILLANCE SYSTEMS
- NAVIGATION
  - / GLOBAL POSITIONING SYSTEM (GPS)
- METEOROLOGY
  - / DMSP, BLOCK 5D-I, II
  - / METSAT
- COMMUNICATION
  - / SATELLITE CONTROL SATELLITE (SCS)
- SPECIAL PURPOSE
  - / HIGH ENERGY RF AND LASER SYSTEMS

LISTING OF TECHNOLOGY PROGRAMS IN SUPPORT OF NEAR-TERM (1975-1985)

SPACE MISSIONS

SURVEILLANCE

- Follow-on to DSP
- Optical System Development
- Focal Plane Development
- Sensor Concept and Component Development

SPACE SYSTEM SURVIVABILITY

- Optical Warning Sensor
- Radiation Sensor
- Countermeasures
- Hardened Electronics
- Laser Vulnerability and Hardening
- Survivability Satellite Airborne Control Facility
- Satellite Observable Control

SPACECRAFT SUPPORT AND SYSTEMS

- Improved Solar Cells
- Secondary Battery
- Fuel Cell
- Spacecraft Charging (Scatha)

LWIR

- CCD at LWIR
- Low Noise Detector/Amplifier
- Multi-Band Technology
- Sensor Out-of-FOV Rejection

S/C GUIDANCE, PROPULSION, CONTROL

- Autonomous Navigation Technology for Low/High Altitude
- UV Radiometer
- Precision Attitude Gyro
- Electrostatically Suspended Accelerometer

COMMUNICATION

- Laser Communication
- EHF Communication
- Narrow Beamwidth
- Multibeam Antenna
- Variable Beamwidth Antenna
- Solid-State Amplifiers and Oscillators

SPACE SURVEILLANCE AND DEFENSE

- Solid-State Detector
- Cryocooler
- Satellite Attack Warning
- System Development
- Phenomenology and Advanced Technology

METEOROLOGICAL SATELLITE TECHNOLOGY

- Cloud Composition Analyzer
- Ionosonde Antenna
- Microwave Technology
- Sea-State Monitor
- Ionosonde Data Processing
- Nuclear Survivability

INFORMATION PROCESSING AND TRANSFER

- High Speed Data Buffer and processor
- Fault Tolerant Spacecraft Computer
- Computer Program Verification and validation
- Improved Magnetic Bubble Storage
- Tape Recorders

NEAR-TERM (1975-1985) SUPPORTING TECHNOLOGY PROGRAMS

- SURVEILLANCE
- LONG WAVE INFRARED (LWIR) TECHNOLOGY
- SPACE SURVEILLANCE AND DEFENSE
- SPACE SYSTEM SURVIVABILITY
- SPACECRAFT GUIDANCE, PROPULSION, AND CONTROL
- METEOROLOGICAL SATELLITE TECHNOLOGY
- SPACECRAFT SUPPORT AND SYSTEMS
- COMMUNICATION
- INFORMATION PROCESSING AND TRANSFER

FAR-TERM (THROUGH CY 2000) TECHNOLOGY PROJECTIONS - I

- DATA RATE PROJECTIONS AND ASSOCIATED SIGNAL PROCESSING/COMPRESSION TECHNIQUES*
- COMPUTER TECHNOLOGY*
- SOFTWARE*
- VISIBLE, NWIR, MWIR, LWIR, FIR SENSOR TECHNOLOGY*
- CRYOGENIC COOLING*
- ADAPTIVE OPTICS*
- MICROWAVE SENSOR SYSTEMS AND COMPONENTS*
- GUIDANCE, ATTITUDE DETERMINATION AND CONTROL*
- MATERIAL TECHNOLOGY (CONTAMINATION CONTROL, HEAT SHIELDS, ABLATION SENSORS)*
- SOLID-STATE RF DEVICES (ALL SOLID-STATE RADAR)*
- HIGH POWER MICROWAVE DEVICES (INTENSE RELATIVISTIC ELECTRON BEAM)*
- MULTIFUNCTIONAL SPACE-BASED RADAR*

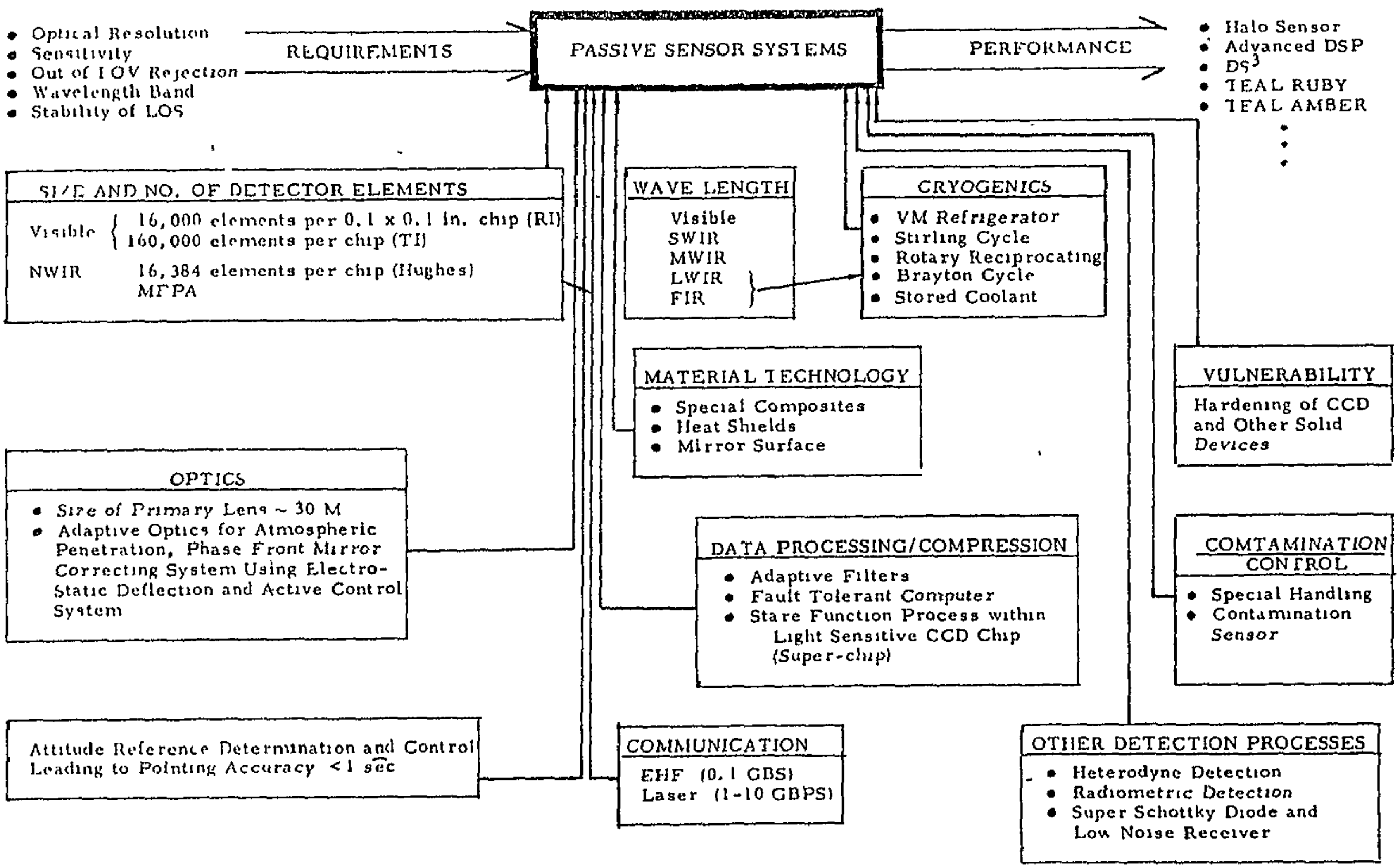
*Techniques are Applicable to Sensor Design and its Deployment

FAR-TERM (THROUGH CY 2000) TECHNOLOGY PROJECTIONS - II

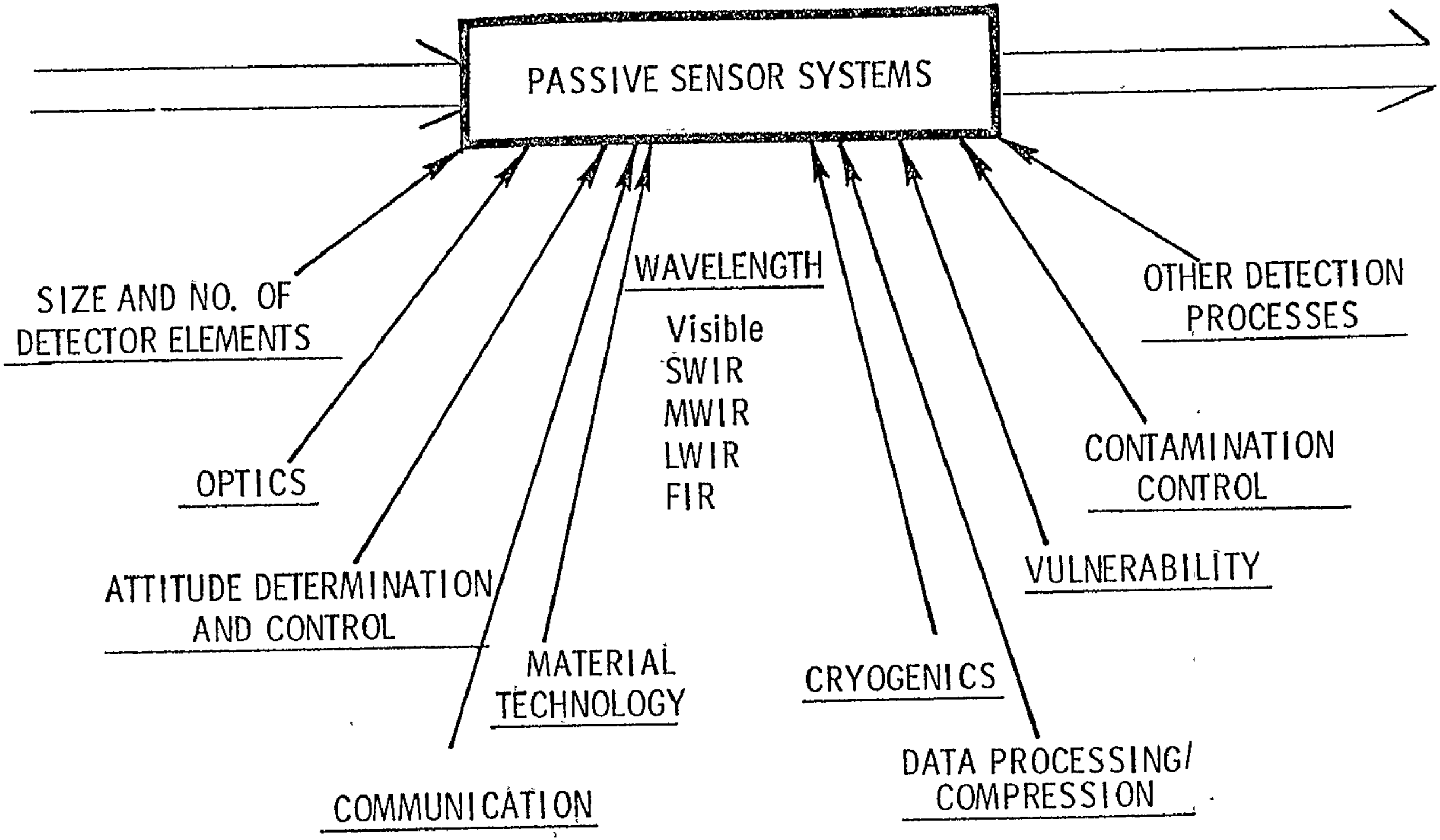
- SUPER-SCHOTTKY DIODE AND LOW NOISE 10-60 GHz RECEIVER.
- FAR INFRARED HETERODYNE RADIOMETER*
- FAR INFRARED LASERS
- SINGLE AND MULTIPLE RESONANT DISTRIBUTED FEEDBACK SEMICONDUCTOR LASER*
- SOLID-STATE SPACE-BASED LASERS*
- TRACE GAS DETERMINATION
- VISIBLE CHEMICAL LASERS*
- EFFICIENT UV LASERS*
- MILLIMETER WAVE RADIOMETRIC IMAGING*
- MODE LOCKED LASERS (LASER FUSION, LASER PLASMA DIAGNOSTICS, X-RAY LASER)
- GPS TECHNOLOGY (ATOMIC CLOCKS, SURFACE ACOUSTIC WAVE DEVICES, NULL STEERING ANTENNAS)

*Techniques are Applicable to Sensor Design and its Deployment

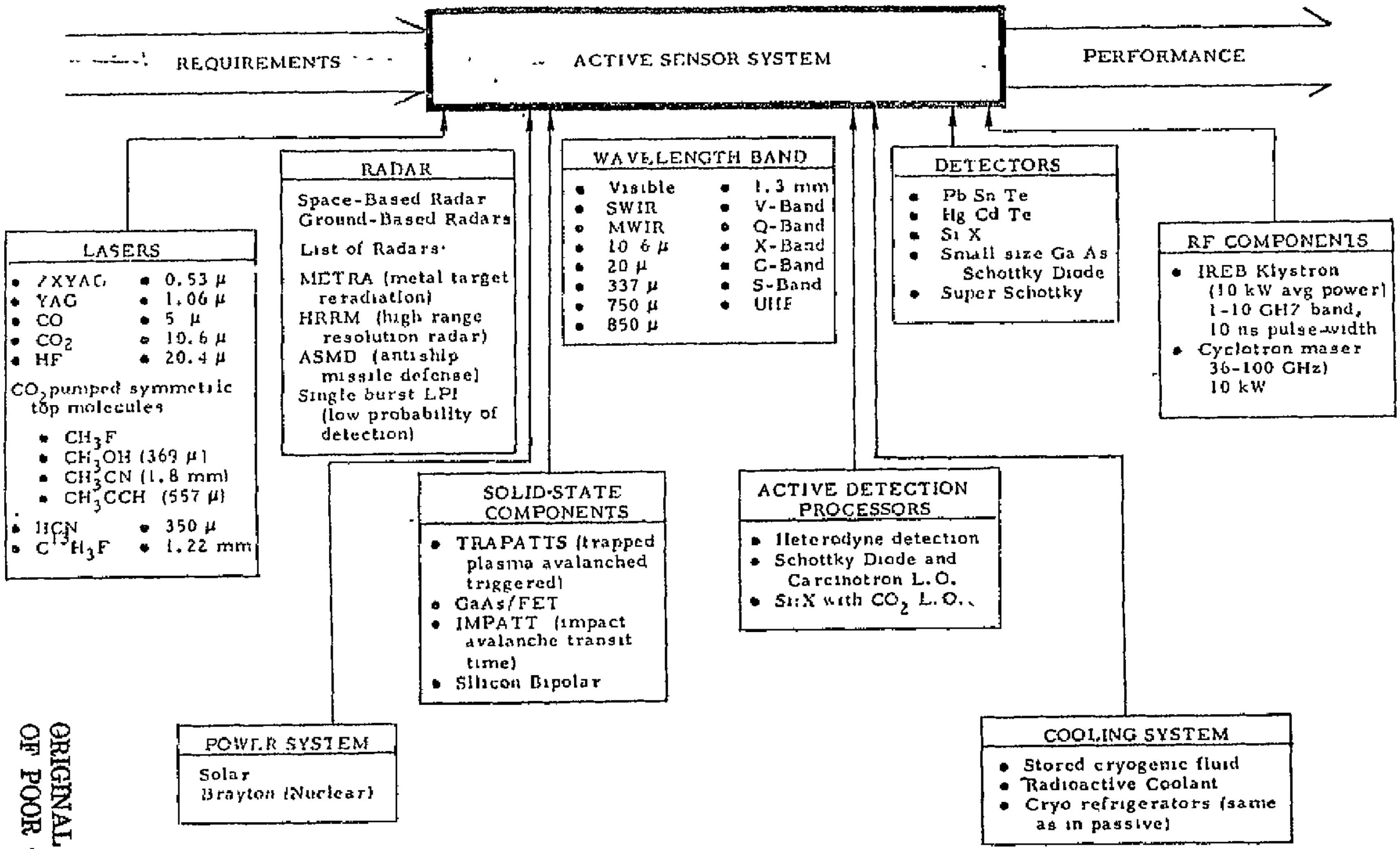
PASSIVE SENSOR SYSTEMS AND ASSOCIATED TECHNOLOGY



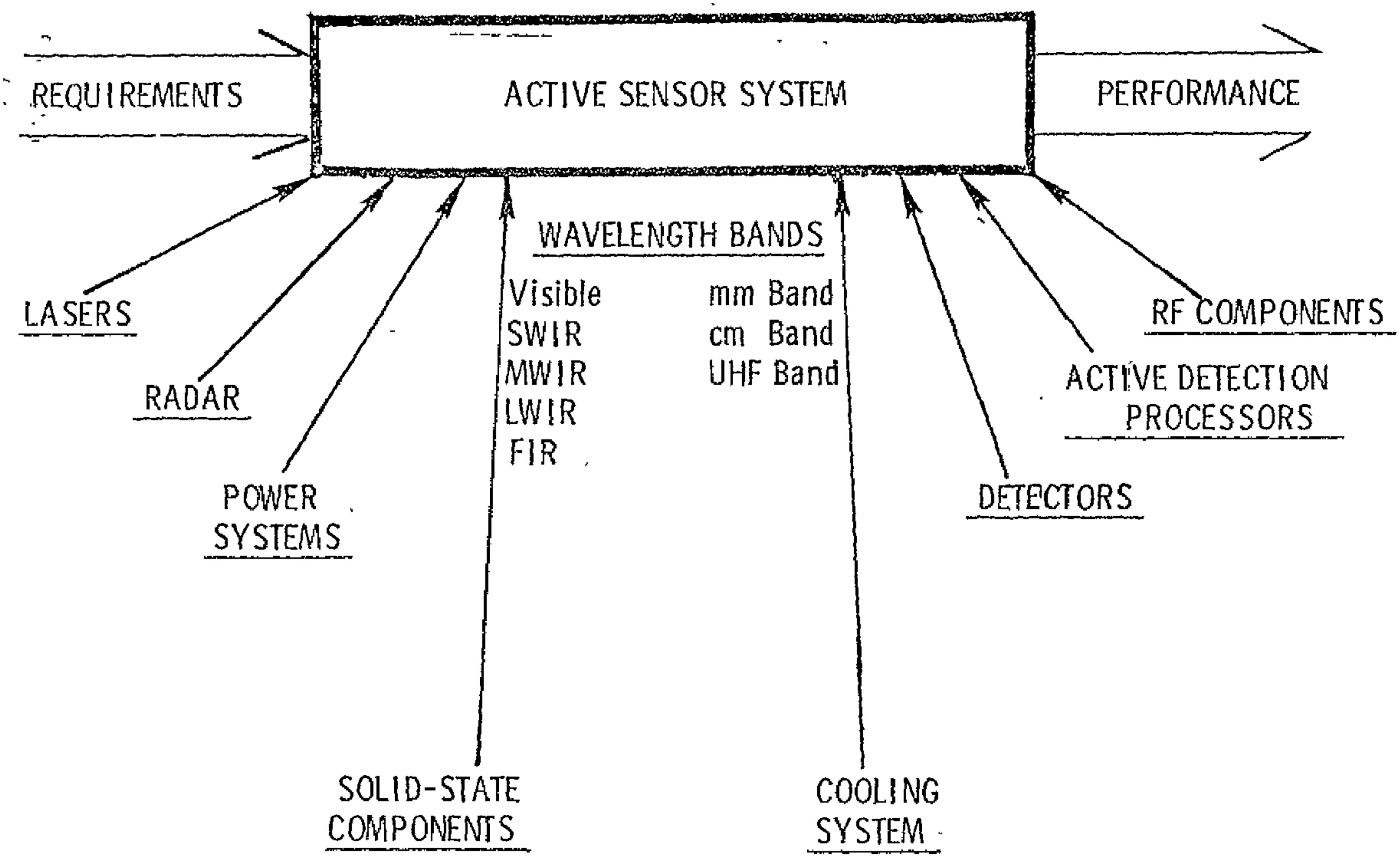
PASSIVE SENSOR SYSTEMS AND ASSOCIATED TECHNOLOGY



ACTIVE SENSOR SUBSYSTEMS AND ASSOCIATED TECHNOLOGY



ACTIVE SENSOR SYSTEM AND ASSOCIATED TECHNOLOGY



LWIR AND FAR INFRARED IMAGING PERFORMANCE

THROUGH CLEAR AND INCLEMENT WEATHER ATMOSPHERIC LINK

LWIR AND FIR RADIATION EMITTED IN NARROW BEAM SCANNING SCENE IN TWO DIMENSIONAL RASTER: REFLECTED RADIATION IMPRESSED UPON IMAGING DISPLAY

10.6 μ : Efficient CO_2 and HgCdTe detectors available 77 °k; atmospheric turbulence will limit maximum aperture to about 15 cm; effective in rain (5 dB/mile 25 mm/hr/1.0 Gm/M^3). However in fog range is under 1 km for median fog droplets of ~ 5μ (0.1 Gm/M^3 density of H_2O) (50 db per mile)

20 μ : HF laser with $Hg_{0.82}$ $Cd_{0.18}$ Te detector; less satisfactory than the 10.6 μ because of increased attenuation in clear weather; slightly better ability to penetrate fog but range still unsatisfactory

337 μ : HCN laser with small area GaAs Schottky diode at room temperature; least desirable system because of large atmospheric attenuation; the range even in clear weather is < 1 KM

750 μ : CH_3CCH laser and small area Schottky diode; attenuation in clear weather and fog improves dramatically over 337 μ in rain same as 10.6 μ

850 μ : $C_2H_2F_2$ laser and Schottky diode mixer with carcinotron L.O. can operate in the six bands

1.3 mm: Penetration through clear weather and fog exceedingly good; penetration through rain slightly better than 850 μ $C^{13}H_3F$ laser and small area in Sb electron bolometer or small area Schottky

CONCLUSION: USE MULTIBAND SYSTEM; FOR RAIN AND SNOW, THE SIX BANDS ARE NEARLY INDEPENDENT OF λ. THE 1.3 mm SYSTEM BEST FOR FOG.

LWIR AND FIR IMAGING SYSTEMS REQUIREMENTS

- TECHNIQUE
  - LONG WAVE OR FAR INFRARED RADIATION EMITTED IN NARROW BEAM SCANNING SCENE IN 2-DIMENSIONAL RASTER
  - REFLECTED RADIATION IMPRESSED UPON IMAGING DISPLAY
- PROBLEM
  - EFFICIENT PERFORMANCE UNDER VARYING ENVIRONMENTAL CONDITIONS
- WAVEBANDS OF INTEREST
  - 10.6μ ; $20\ \mu$; 337μ ; $750\ \mu$; $850\ \mu$; 1.3 mm
- CONCLUSION
  - 1.3 mm SYSTEM BEST IN FOG
  - NO DISTINCTION FOR RAIN OR SNOW
  - UTILIZE MULTIBAND SYSTEM

TECHNOLOGY PROGRAMS TO ACHIEVE HIGH ATTITUDE REFERENCE REQUIREMENTS

(Necessary for Determination and Control of Line-of-Sight
of On-Board Sensor)

MISSION	ORBIT	REFERENCE ACCURACY	TIME PERIOD
S-A	Sync. Equatorial	5-8 $\widehat{sec}$	1980-1985
S-B	Sync. Equatorial	0.4-0.6 $\widehat{sec}$	1980-1985
S-C	Sync. Equatorial	0.5-1.5 $\widehat{sec}$	1980
S-E	1 K nmi	7-11 $\widehat{sec}$	1980-1985
S-F	Sync. Equatorial	0.2-0.4 $\widehat{sec}$	1980-1985
S-G	Sync. Equatorial	80-100 $\widehat{sec}$	1980-1985
S-H	Sync. Equatorial	5-7 $\widehat{sec}$	1985-1990
C-B	5 X Sync. Equatorial	50-60 $\widehat{sec}$	1985-1990
C-D	Sync. 30 deg Inclined	20-28 $\widehat{sec}$	1980-1985
C-E	Sync. Equatorial	18-20 $\widehat{sec}$	1980-1985
C-F	Sync. Equatorial	2-3 $\widehat{sec}$	1985-1990
M-C	Sync. Equatorial	60-90 $\widehat{sec}$	1980
M-E	Sync. Equatorial	1-2 $\widehat{sec}$	1985-1990
M-G	Sync. Equatorial	0.02-0.04 $\widehat{sec}$	1990-1995

Space sextant high altitude navigation and attitude reference system

ADVANCED COMPONENTS

- Precision attitude gyros
- Electrostatically suspended accelerometer
- UV Radiometer
- Magnetically suspended reaction wheel

- On-Board computer capable of processing multiple of navigation associated subsystems and sensors

ATTITUDE REFERENCE SYSTEMS REQUIREMENTS

- PERFORMANCE REQUIREMENTS
  - ACCURATE ATTITUDE REFERENCE
  - DETERMINATION AND CONTROL OF LINE-OF-SIGHT OF ON-BOARD SENSOR

- SYSTEM REQUIREMENTS
  - SPACE SEXTANT HIGH ALTITUDE NAVIGATION AND ATTITUDE REFERENCE SYSTEM
  - ON-BOARD COMPUTER
  - ADVANCED COMPONENTS
    - PRECISION ATTITUDE GYROS
    - ELECTROSTATICALLY SUSPENDED ACCELEROMETER
    - UV RADIOMETER
    - MAGNETICALLY SUSPENDED REACTION WHEEL

MULTIFUNCTIONAL SBR (SPACE-BASED RADAR)*
AT 11,170 KM ALTITUDE (1985-1995)

TRANSMITTER

- Type: Solid-State Module
- Average Power: 8,490 W
- Peak Power: 387 kW
- Frequency: 2 GHZ
- No. of XMTR Modules: 69,645
- Average Power/Module: 0.123 W
- Size of Module: 5 x 7 x 0.127 cm
- Weight of Modules: 0.03 lb
- Prime Power Required: 21,225 W

ANTENNA

- Type: Planar Phase Array with Scanning Lens Cap
- Beamwidth: 1 mrad
- Dimension: 174.5 M Array Diameter; 218 M Lens Cap Diameter
- Coverage: 4 π Sterad
- Directive Gain: 71 dB, Power Gain: 65 dB at maximum scan angle
- No. of Dipoles in Array: 1.74×10^6
- Dipole Spacing: 0.586 λ
- No. of Modules: 6.9×10^6, Module Spacing: 0.52 λ (Phase Delay Modules)

RECEIVER

- Type: *All Solid State* with Varactor phase shifter
- Coherent Integration Gain: 23 dB
- Bandwidth: 454.4 KHz
- System Temperature: 400 deg K
- Dynamic Range: 45 dB *(min)*
- No. Modules and Weight are Same as Tx

WAVEFORM

- Type: Coherent Burst of Pulses
- No. of Pulses per Burst = 200
- Burst Length: 880 μ/sec
- No. of Bursts: 100/sec
- Data Rate: 1/sec/target
- Duty Cycle: 50 Percent
- Range Rate: 11,310 M/sec
- Min. Range: 132 kM
- Range Resolution: 330 m

WEIGHT ESTIMATE

- (Excluding Attitude Control Propulsion Weight)
- Planer Array: 2,390 lb
- Lens Cap: 14,930 lb
- Tx, Rx Modules: 2,090 lb each
- Other Electronics: 250 lb
- Structure: 1,170 lb
- Prime Power (Nuclear): 3,770 lb

Total: 26,914 lb

*The system concept and its associated engineering numbers represent a personal point of view; it should not be interpreted as reflecting the views of The Aerospace Corporation or the official opinion or policy of SAMSO or any other governmental or private research sponsors.

MULTIFUNCTIONAL SBR (SPACE-BASED RADAR) IN THE 1985-1995 TIME FRAME*

- NOVEL RADAR ANTENNA CONCEPT PROVIDING 4π STERADIANS OF COVERAGE
  - COMBINATION OF TWO SIDED ACTIVE SOLID-STATE PLANAR ARRAY WITH ~175 METER DIAMETER AND A 220 METER DIAMETER LENS CAP CONTAINING FIXED PHASE DELAY
- TRANSMITTER COMPOSED OF ~70,000 SOLID-STATE MODULES SUPPLYING RF POWER OF ~8500 WATTS
- INTEGRATED S/N OF 15 DB ON 0 DBSM TARGET AT ~16,000 KM
- WEIGHT - ~23,000 LB
- PRIME POWER SUPPLY, BRAYTON TYPE WEIGHING ~4,000 LB

*The system concept and its associated engineering numbers represent a personal point of view; it should not be interpreted as reflecting the views of The Aerospace Corporation or the official opinion or policy of SAMSO or any other governmental or private research sponsors.

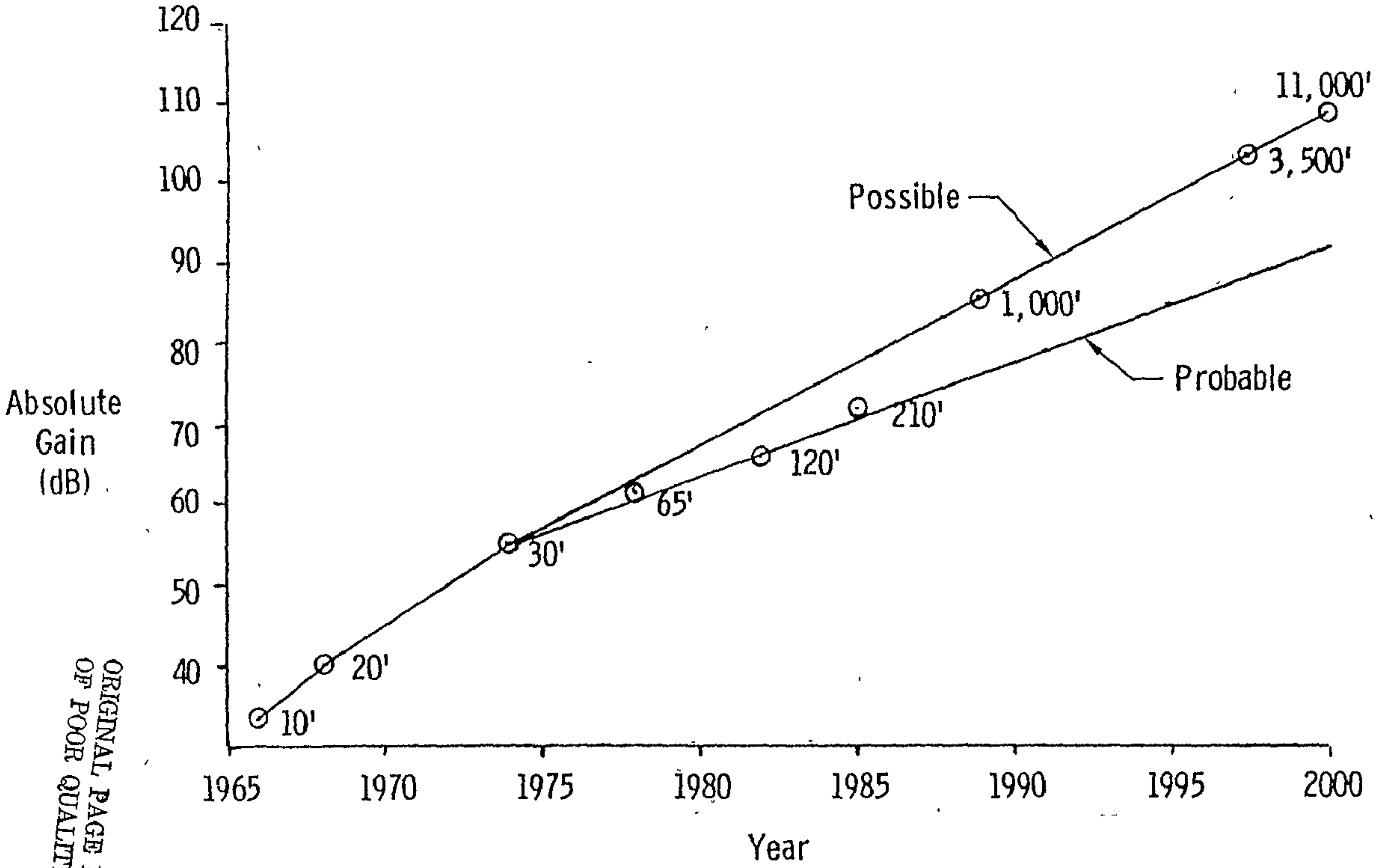
BACKUP CHARTS

TECHNOLOGY TRENDS APPLICABLE

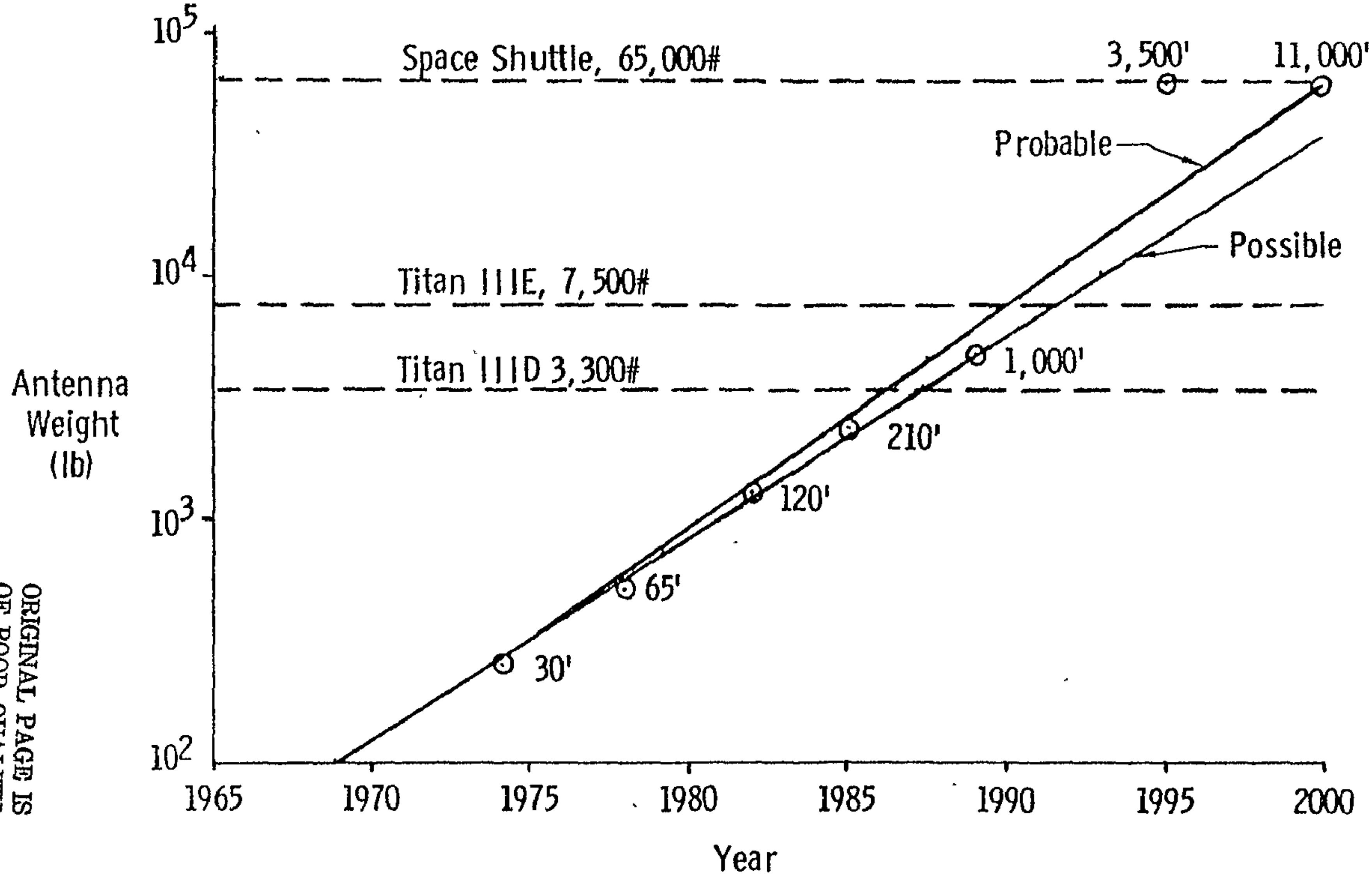
TO SPACE-BASED RADAR

DEPLOYABLE ANTENNA GAIN FORECAST

SYNCHRONOUS EARTH ORBIT - ADJUSTABLE SURFACE

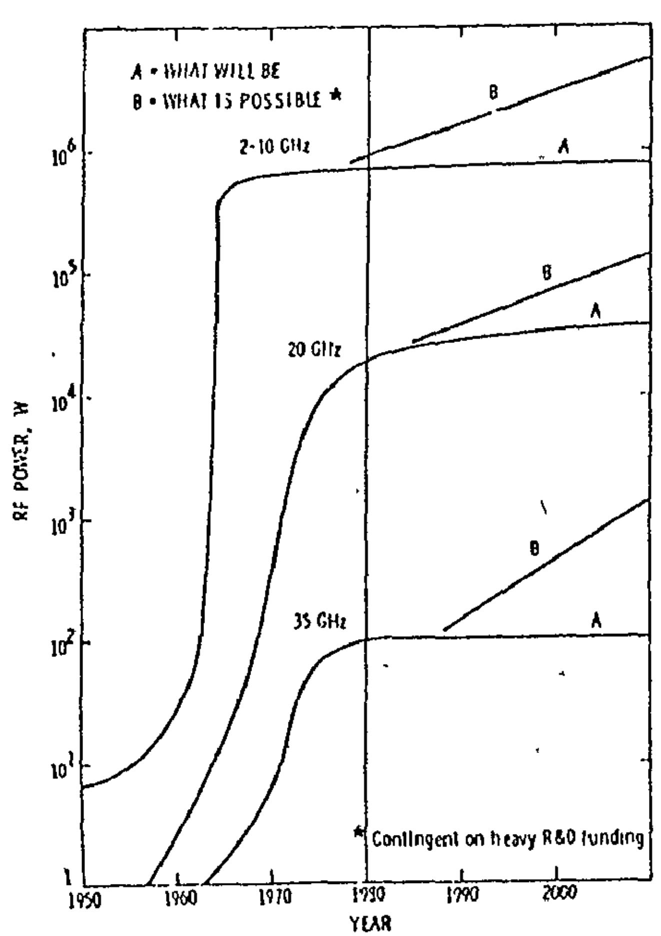


DEPLOYABLE ANTENNA WEIGHT FORECAST
SYNCHRONOUS EARTH ORBIT ADJUSTABLE SURFACE

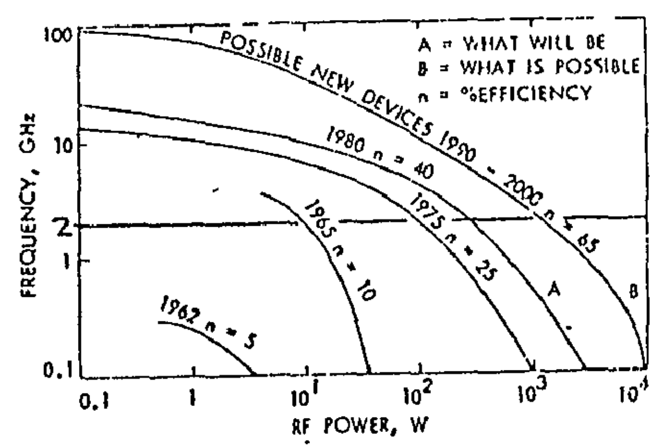


MICROWAVE TRANSMITTER
TECHNOLOGY TRENDS

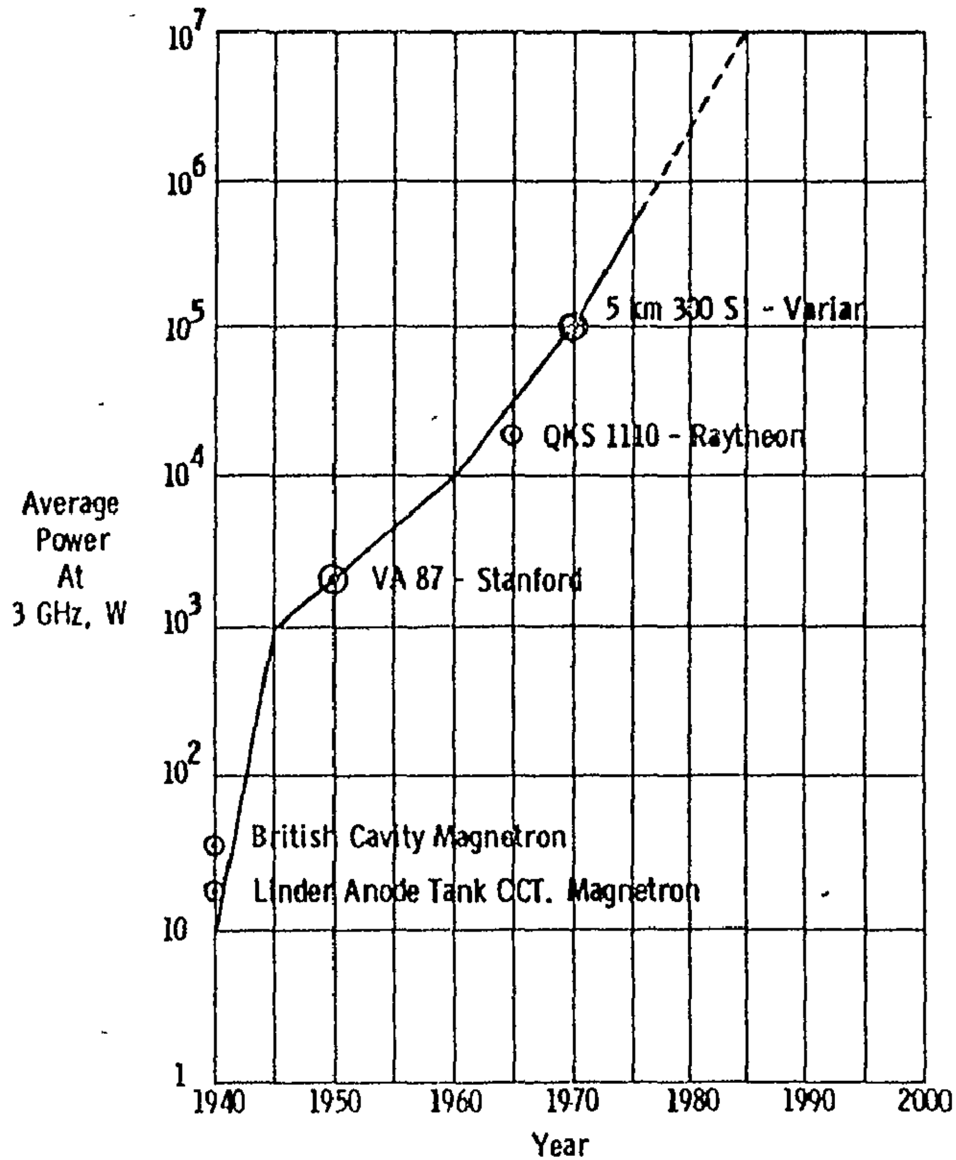
FC 3-26. Klystron RF Power



FC 3-28. Solid-State Power-Frequency Characteristics



TREND IN AVERAGE TRANSMITTER POWER AT 3 GHz



NEW CONDUCTOR TECHNOLOGY

- UNIVERSITY OF PENNSYLVANIA RESEARCH ON GRAPHITE INTERCALATED WITH SUPERACID FLUORIDES IN AN INERT ATMOSPHERE
- GRAPHITE INTERCALATED WITH ANTIMONY PENTAFLUORIDE
- CONDUCTIVITY 1.7 TIMES PURE COPPER
- DENSITY 2.7 GRAMS PER CC
- POTENTIAL WEIGHT REDUCTION BY FACTOR OF 2.7
- REFERENCES:

(a) F. Lincoln Vogel, Univ. of Pennsylvania Moore School, 215 - 243-5000, Ext. 8386

(b) Patent Application SN 499.834, dated 23 August 1974, "Graphite Intercalation Compounds"

(c) Paper Submitted for Publication in Journal of Material Science, "The Electrical Conductivity of Graphite Intercalated with Superacid Fluorides: Experiments with Antimony Pentafluoride"

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