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MC 65-145-R2

THE IMPLICATIONS OF
ELECTRO-OPTICAL TECHNIQUES
FOR GROSS OCEAN SURVEILLANCE
FROM ASTRONAUTIC SYSTEMS
(UNCLASSIFIED TITLE)

BY
ARTHUR C. S. ROBERTS
LAWRENCE D. LORAH

CONTRACT NONR 4829(00)

FINAL REPORT
JANUARY 1966
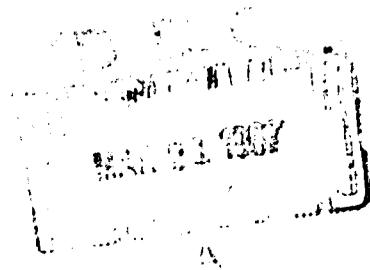
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MITHRAS, INC.

AEROTHERMODYNAMICS — ELECTROMAGNETICS — QUANTUM PHYSICS

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THE IMPLICATIONS OF
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Arthur C. S. Roberts
Lawrence D. Lorah

FINAL REPORT

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FOREWORD

The study reported herein was performed for the Department of the Navy's Office of Naval Research on Contract Nonr 4829(00), Contract Authority NR 277-020/1-18-65, under the cognizance of Mr. Emanual Haynes. The work was carried out at MITHRAS, Inc., in the Electromagnetics Division under the direction of Mr. Don H. Ross.

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ABSTRACT

Research on the implications of using electro-optical techniques for gross ocean surface surveillance from astronautic systems has been carried out. The ranges of radiating temperatures to be expected of typical surface ships and the ocean background have been established. The signal available for detection per degree of temperature contrast between typical surface ships and the ocean was established for orbit altitudes of from one hundred to four hundred nautical miles. In turn, the temperature contrast between typical surface ships and the ocean required to achieve detection was established as a function of scan angle for a specified optical system using a long wavelength detector and operating at 200 nautical mile altitude. Correspondence was maintained between the irradiance at the collector and the scan angle to allow for the effects of atmospheric transmission and range changes.

Included in the overall study were a review of current ocean surveillance methods and an estimate of current and future ocean traffic. Some characteristics of clouds as a background constituent were established. Consideration was also given to the problems of tracking, recognition, classification, resolution requirements and man's role in a satellite.

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IMPLICATIONS OF THE STUDY TOWARD FUTURE
RESEARCH AND DEVELOPMENT

The study presented herein establishes that during a large portion of the day and night the temperature contrast between many of the surface ships of the world and their ocean surroundings is adequate to permit detection and tracking from low satellite orbits using available background-limited detectors operating in the 7.5 to 14 μ spectral region in conjunction with a state-of-the-art optical system of relatively modest dimensions.

Since the anomaly presented by a ship on the sea might be duplicated by the presence of other objects in the field-of-view of an infrared system, the next desirable step to take towards establishing the feasibility of a total system is to formulate the logic which enables the system to recognize that the anomaly it perceives is indeed a ship and not a cloud, an airplane, a piece of land, an iceberg, etc. Characteristics which might be considered in formulating the recognition process are size and shape of the object, the apparent temperature of the object, speed of the object, spectral content of the scene, polarization techniques, etc.

Another pertinent facet of the problem which should be pursued is automatic shape recognition to provide for the classification of ships and possibly their identification. Subsequent to the derivation of logic systems to carry out recognition, classification, and identification, an experimental program should be carried out to substantiate the principles derived and certify the performance of the hardware required. Other programs of importance are: a sensitivity analysis to determine the dependence of the accuracy of ship location to such quantities as errors in ship heading and speed, satellite location and speed, and satellite instrument errors; and an investigation of the trade-of' on data handling requirements for satellites, ground based relay stations, and ground based central processing units.

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Haunting any study dealing with reconnaissance of the earth from airplane or satellite is the degrading effects of clouds. An indication of the true practicality of any reconnaissance system would derive from a consideration of cloud cover statistics and detection probabilities and their limitations on the achievement of the goals of the system. To properly assess the interrelationships of cloud cover and the practical operation of a satellite-based surveillance system using only a particular portion of the electromagnetic spectrum, one must use cloud cover statistics based only on that portion of the spectrum. In view of the results of the study presented herein there is need then to acquire and analyze the statistics on cloud cover, and the emission and reflection characteristics of clouds in the 7.5 to 14 μ region of the spectrum.

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GLOSSARY

AMVER	Automated Merchant Vessel Reporting System. A voluntary system for merchant ship position reporting.
CARDE	Canadian Armament Research and Development Establishment.
CINCLANT	Commander in Chief, Atlantic.
CIRVIS	Civilian reports of visual sightings of airborne objects.
CNO	Chief of Naval Operations.
CONUS	Continental United States
ELINT	Electronic Intelligence.
FISHSIGHT	Naval report of a sighting of a group of fishing ships.
FLAG PLOT	An enclosed tactical and navigational center used by the Flag Officer and Air Staff in exercising tactical command of ships and aircraft.
HF/DF	High frequency direction finding net.
MEREP	Peacetime daily reports of merchant shipping by designated reporting officers.
MERINT	Civilian reports of visual sighting of certain ship movements.
MERSIGHT	Naval report of sighting of merchant ship or a single fishing ship.

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MMDPU	Merchant Marine Data Processing Unit.
MRCC	Movement Report Control Center.
MSTS	Military Sea Transport Service – ocean freight and passenger service for DOD.
NAVCOSSACT	Naval Command Systems Support Activity.
NAVIC	Navy Information Center.
NCSO	Naval Control of Shipping Officer.
NIRM	Naval Intelligence Requirements Memorandum.
OCEAN-SYSLANT	Ocean Systems Atlantic.
ONI	Office of Naval Intelligence.
OPCON-CENTER	Operations Control Center.
SECNAV	Secretary of the Navy.
SECDEF	Secretary of Defense.
SOSS	Sound Search Stations.
SOSUS	Deep water passive sound surveillance system.

1. INTRODUCTION

Ocean surveillance can provide a wide spectrum of information covering both peaceful and military needs. A good example of a peacetime ocean surveillance system is the Automated Merchant Vessel Reporting System (AMVER) operated by the Coast Guard. Its prime reason for being is search and rescue at sea. It is an international maritime mutual aid program in which ships of approximately 60 nations voluntarily radio their sailing reports and periodic positions to AMVER. Should any of the ships encounter an emergency situation while at sea, AMVER, upon becoming aware of the situation, directs its computers to determine the nearest cooperating ships in the area so that they may offer assistance to the ship in danger. On the other hand a system with military utility is the Movement Report System, which monitors reports on all Naval ships and command movements. The system operates on the basis of prefiled planned destination, estimated time of arrival, speed of advance etc. Subsequent large deviations from the original plans are also monitored. Thus reliable information is available for use in operations, search and rescue, and administration.

Ocean surveillance systems have been in operation for many years under the direction of a variety of Navy and Coast Guard agencies. These systems seem to have evolved as a succession of responses to implement specific requirements with subsequent improvements based on operating experience and the incorporation of technological advances. Attempts to organize the individual systems into a single cohesive system have been minimal.

Recently, however, the Navy provided for future efforts to establish an integrated ocean surveillance system by publishing a General Operational Requirement No. 35 on Ocean Surveillance. This GOR pertains to a capability for ocean surveillance derived both from systematic observations of ocean areas and from reporting systems. The objects to be monitored may be on the surface, beneath the surface, or above the surface of the sea. The product of the surveillance system is to be correlated information to support naval operations including intelligence activities and naval and national planning.

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The ocean surveillance capability is to encompass the acquisition and collection of input information pertaining to ocean traffic and ocean environment, the processing of this information, and the dissemination of the appropriately processed information to the proper naval and national authorities.

It is pointed out in GOR No. 35 that one of the high priority studies and development efforts required is one which will provide for increased air and space borne surveillance capabilities for detecting and tracking surface and air ocean traffic.

Unaware of the above official requirements but knowing that potential improvements in electro-optical search, detection, and track techniques coupled with the use of satellite platforms offered the possibility of increased effectiveness in ocean surveillance, MITHRAS, Inc. in December of 1964, submitted a proposal to the Office of Naval Research to study the implications of electro-optical techniques for gross ocean surveillance. Subsequently ONR issued Contract Nonr-4829(00) to MITHRAS on 1 April 1965 to carry out the investigation.

Included in the study are the following considerations:

1. Feasibility of using electro-optical techniques for ocean surveillance.

2. The most promising techniques.

3. A preliminary estimate of performance in terms of system characteristics.

4. The importance of the human operator.

5. Specification of additional data requirements.

6. Subsequent R & D efforts to verify and test the promising system concepts.

The study is to reflect the probable capabilities of the 1970-1980 time period.

A portion of the time allotted to the contract was devoted to a literature survey to establish the current knowledge on ship signatures and background radiation. (The reports acquired in the course of the study are listed

in Appendix A.) On the basis of effective radiating temperatures and emitting and reflecting characteristics of typical ships and probable background constituents it is possible to establish the magnitude of the contrast signal which will be available for detection, tracking, recognizing and classifying ships. Consideration of the spectral distribution of the emitted and reflected energy together with the spectral intervals that permit good atmospheric transmission indicates the types of sensors which might be suitable for use in a successful system. The field of view of interest, the contrast signal available, the characteristics of the detector material to be used, and the resolving capability desired, all combine to determine the basic characteristics of the optical system required to gather the radiation and focus it on the detector.

A review of current systems of ocean surveillance was undertaken to acquire an understanding of their capabilities and their deficiencies. Closely allied with this effort was one devoted to a determination of the number of ships of possible interest in the world today and in the future, and the resulting number of ships which might appear on the oceans at any one time. A consideration of the numbers of ships involved indicates the magnitude of the data handling inherent in the problem.

Also considered in the study was the importance of man in a satellite based surveillance system and a discussion is presented of some of the ways in which a man on board could contribute to a successful ocean surface surveillance mission.

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2. CURRENT AND FUTURE OCEAN SURFACE TRAFFIC

2.1 Current Traffic

The number of ships which must be observed by an ocean surveillance system depends on the use to be made of the data obtained by the observations and relates to what sizes and kinds of ships will constitute sources of information pertinent to the achievement of the goals of the system.

The use for military systems is usually defined in an "Operational Requirement" document which establishes bounds for the particular problem of interest. The Navy has recently published General Operational Requirement No. 35 on Ocean Surveillance in which some of the requirements pertinent to this study are (using their numbers)

1. Maintain current position, track and identity information on all surface naval units.

2. Maintain current position, track and identity information on all submarines.

3. Maintain current position, track and identity information on significant merchant shipping of 1000 gross tons or greater. Similar information on shipping down to 100 tons displacement to be maintained in specified geographical areas.

How many ships there are throughout the world in the above three categories is rather difficult to say. With respect to categories 1 and 2 Reference 1 indicates that there are a total of 12,857 fighting ships in the world of which 856 are submarines. This total includes such small ships as motor torpedo boats, motor gunboats, fast patrol boats, river gunboats, landing craft, etc. It also includes ships in reserve but not those under construction. This number is therefore high in its indication of active ships but should an international emergency develop many or all of the ships in reserve would become active again. In considering category 3, one must be careful of the nomenclature. The term gross tons indicates the cubic capacity of a vessel inclusive of hull, erections, and superstructures, but with exemptions

for wheelhouse, galleys, stairways, etc. (Reference 2). In these terms one ton is 100 cubic feet. Displacement tonnage, on the other hand is "the weight of water displaced by the vessel whether in light or loaded condition and is in fact the actual weight of the vessel and all that is contained therein." (Reference 2). Reference 3 shows that as of 31 December 1964 there were a total of 18, 115 oceangoing steam and motor ships of 1000 gross tons and over. This number excludes ships operating exclusively on the Great Lakes and inland waterways and special types such as channel ships, icebreakers, cable ships, etc. and merchant ships owned by any military force.

Statistics on ships of over 100 ton displacement are not readily available but Reference 4 presents data on merchant vessels of 100 gross tons and over. This latter limit represents a larger ship than the 100 ton displacement ships. In 1963 there were 37, 310 such vessels owned throughout the world. Excluded from this number are sailing ships, nonpropelled craft, and all ships built of wood. This information was obtained from previously unpublished data of Lloyds Register of Shipping, London. Thus the approximately 37, 000 ships of 100 gross tons and over together with the approximately 13, 000 naval ships, agrees with the total of 50, 000 ships in the world suggested in Reference 5.

How many of these ships appear on the oceans of the world at any one time is important because it is indicative of the data handling requirements of the surveillance system. In Reference 6 is shown a typical ship density diagram which was based on data collected in October 1962 and provided by the Office of Naval Intelligence. This diagram shows 8, 658 ships distributed over the world oceans. It is not known what distribution of ship size is involved in these data since the study in which they were used made no attempt to classify ships according to tonnage. MITHRAS recently received from ONI a similar World Shipping Density Chart, dated June 12, 1964. This chart indicated 9, 299 ships on various waterways of the world. Again the types of ships involved in the count are not known but one might infer that ocean surface traffic on the average increased in approximately two years by over 600 ships. This could indicate any of several things, i.e., (1) an increase in ships over a given size on the ocean at one time, (2) during this

period the Navy has included other classes of ships in their field of interest, (3) the Navy has improved its methods for counting ships, or (4) it might be the tolerance for this sort of estimate.

More indicative of the amount of shipping on the worlds oceans at any one time involving ships of 1000 gross tons or greater are the results of the ONI study of 1958 from Reference 7 tabulated below:

Area	No. of Ships
Atlantic	3400
Pacific	929
Indian	575
Mediterranean	560
Baltic	200
Total	5664

Assuming that this number of contacts could be handled uniformly throughout the day by a single surveillance vehicle, there would be 236 contacts in an hour if no duplication occurred. This corresponds to approximately 15 seconds to detect, recognize, classify, and identify each contact. Thus even with this number of ships to consider, the ocean surveillance problem appears quite formidable just from data handling considerations.

2.2   Future Traffic

Reference 3 indicates that as of 31 December 1964 the world merchant fleet of vessels of 1000 gross tons and over showed a net increase of 82 ships and 9,880,000 deadweight tons over the corresponding date in 1963. This net deadweight gain in shipping prevailed in the presence of 403 153 deadweight tons of marine losses and the scrapping of 3,134,160 tons. There was not time to trace this trend back through a few years to permit extrapolation for the future. There is, however, the data from Reference 4 shown in Figure 2.1 which pertains to United States and foreign ships owned and launched over the years 1950 through 1963. It is obvious that foreign ownership has been increasing steadily over the years and that U.S. ownership has been continually decreasing. These conditions derive from the difference in
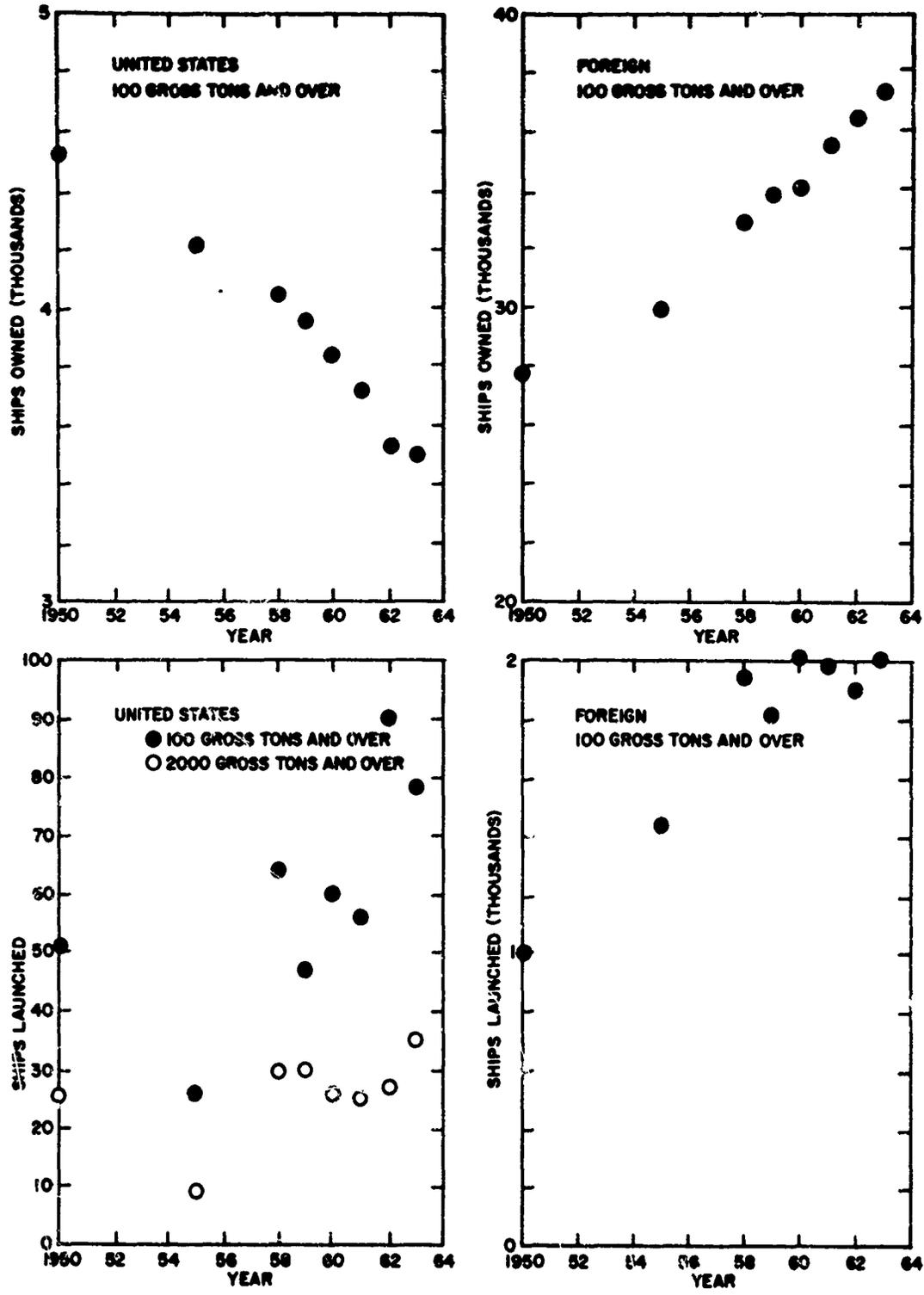
Figure 2.1. Merchant Vessels Owned and Launched

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building and scrapping policies at home and abroad and the trend for transfers of ownership from the U.S. which has prevailed. In the years from 1958 to 1963, foreign countries have launched on the order of 2000 new ships per year and showed an increase in ownership over those years from 32,857 to 37,310. Thus, in numbers of ships over 100 gross tons, foreign countries are building more ships than they are scrapping. On the contrary the U.S. is showing approximately 100 ships per year fewer owned while building fewer than 100 new ships per year. Thus they are scrapping and losing more ships by transfer than they are building.

The overall picture seems to be that in future years there will probably be as many or more ships than there are now to keep track of but a greater percentage of them will be foreign ships with the option of becoming uncooperative towards ocean surveillance. This is important because many of the methods of ocean surveillance used today depend on the cooperation of the ships' crews and owners.

With respect to size there has been a continuing tendency to develop super and mammoth-sized tankers and bulk carriers. Speed increases will not be marked except in the case of special purpose vehicles such as hydrofoil and air-cushion craft which may show a factor of 2 or 3 higher speed. Their size, however, will be small and their operation will not carry them far from land, at least in the near future. In any event their numbers are and will be quite limited for sometime.

The Institute of Naval Studies indicates that in the next few years a good average number for the ships at sea on any given day in the North Atlantic is 4,000 units over 1,000 gross tons. Although they gave no estimate of total traffic to be expected in all areas, they did indicate the number of reports you could expect on a world-wide basis would be approximately 12,000 for a system which was essentially an extension and expansion of the current Navy capability.

3. PRESENT OCEAN SURVEILLANCE TECHNIQUES

There are several obvious uses for an ocean surveillance system and these can be classified in a broad sense as military or peaceful. For example, under the military category are strategic warning, targeting, and command and control. Peaceful uses include search and rescue, location and analysis of potential hazards to shipping traffic, and arms control.

There are three categories of information available which can be used as inputs to an ocean surveillance system. These are:

1. Departure-Arrival Reports which include:

   Port departures
   Intended routes and destinations
   Cargoes
   Port arrivals

2. Ship's position, course, and speed at sea as observed by sightings or sensors, or reported voluntarily.

3. Files of ship's characteristics and registry.

Much of the discussion which follows concerning sources of the above types of information is based on the contents of References 8 and 9.

3.1 Sources of Information

Some sources of departure-arrival reports for merchant and military ships are:

1. The Corporation of Lloyd's
2. Merchant Reporting System (MEREPS)
3. Movement Report System
4. NIRM 2 Reports

Data of this type for merchant ships are produced on a regular basis by two major sources, the Corporation of Lloyd's and the Merchant Reporting System (MEREPS). The Corporation of Lloyd's is a unique private enterprise

and as one of its endeavors they have for two centuries persevered in the collection and distribution of maritime information. Lloyd's agents are established at every seaport of any importance and at many inland towns throughout the world to collect information, give assistance in casualties, and survey and assess damaged cargo. In 1955 there were about 1500 Lloyd's agencies and subagencies.

One use of some of the information collected by Lloyd's agents is in the preparation of Lloyd's Shipping Index and Lloyd's Gazette. The former is a daily compilation listing the current activities of about 15,000 ships. The latter is a daily maritime newspaper carrying current marine news and cataloging departures and arrivals throughout the world. Another interesting feature of the Gazette is a daily listing of charters concluded at the Baltic Exchange, the major chartering center for the world's tramp fleet. Also listed are reports of ship sales and ship repairs and refits.

The Merchant Reporting System is under the cognizance of the Naval Control of Shipping Organization. Daily reports of merchant vessel movements are transmitted from major United States ports and many foreign ports by Navy Control of Shipping Officers (NCSO), Temporary Naval Control of Shipping Officers, or specifically designated United States civilian or military reporting Officers. Both arrival and departure information is transmitted. Arrival reports are supposed to specify a ship's name, its flag and its time of arrival, while departure reports should include ship's name, its flag, port of departure, port of destination, date and time of departure, speed, route, and estimated time of arrival.

Departure and arrival reports on military and some merchant ships are covered by the Movement Report System and NIRM 2 reports. The former system is a product of the Movement Report Control Center (OP-334) in Washington which receives reports on all Naval ships and command movements. The system operates on the basis of prefiled planned destination, estimated time of arrival, speed of advance, etc. Subsequent large deviations from original plans are also reported. Information is gathered on Military personnel movements, Navy ships, Coast and Geodetic Survey Ships, Army Transports, Coast Guard (ocean going), foreign vessels under

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United States operational control and military Sea Transport Service ships.

NIRM 2 reports i.e., Naval Intelligence Requirements Memoranda, Class 2, are the results of ONI requirements. These memoranda cover the arrivals, departures, and movements of all Sino-Soviet Bloc merchant ships and the arrivals, departures and movements of all non-Bloc shipping to and/or from Sino-Soviet Bloc ports.

A variety of sources of observed position, course, and speed of ships at sea are summarized in Table 3.1 and discussed below.

Automated Merchant Vessel Report System (AMVER)

Under the control of the Coast Guard, the AMVER is based on voluntary radio reports from merchant ships of 62 nations. Under the same initials the system was originally described as the Atlantic Merchant Vessel Report System since the first system went into operation in 1945 in the Atlantic Ocean. As of July 1965, however, coverage has been extended to the Pacific.

The plot center is in New York connected by teletype and radio links to 18 marine-type radio stations ranging from Newfoundland to Balboa. Included are 4 ocean-station vessels. The same communication network connects the AMVER center to 11 permanently organized Rescue Coordination Centers.

Ship Synoptic Weather Messages

Under auspices of the World Meteorological Organization (in this country, the United States Weather Bureau), periodic reports, up to 4 per day, per ship, are forwarded from member ships throughout the world. The items of interest to ocean surveillance which are normally transmitted are ship's call sign, ship's heading, ship's position, and ship's speed.

Movement Report System

Movement Report Control Center is located in Washington, under OP-334. This system handles reports of major deviations from prefiled

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Table 3.1

Sources of Observed Position, Course, and Speed of Ships at Sea

1. Automated Merchant Vessel Report System (AMVER)

2. Ship Synoptic Weather Messages

3. Movement Report System

4. NIRM 16 Reports

5. MERSIGHT

6. FISHSIGHT

7. High Frequency Direction Finding Net (HF/DF)

8. Sound Surveillance System (SOSUS)

9. CIRVIS

10. MERINT

11. International Ice Patrol Reports

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plans concerned with Military Personnel Movements, Navy ships, Coast and Geodetic Survey ships, Army transports, Coast Guard (ocean going), foreign vessels under United States Operational Control, and Military Sea Transport Ships.

NIRM 16 Reports - Naval Intelligence Requirements Memoranda - ONI

These reports contain information concerning the fishing fleets of Sino-Soviet Bloc nations, particularly the U.S.S.R. The following fishing fleet activities should be reported:

1. Sightings of ELINT (electronic intelligence) trawlers including geographic location, course and speed of trawler, details on movements and maneuvers, electronic equipment, and any other pertinent observations.

2. Any unusual movements of fishing ships or activities not covered in (1).

3. Highlights of normal fishing activities in the regular fishing areas are supposed to be reported weekly.

Reports should contain identification and location information on all units sighted.

MERSIGHT

This is a fleet requirement of intelligence reporting of sightings of single merchant or fishing ships.

FISHSIGHT

This in turn is a fleet requirement of intelligence reporting of sightings of groups of fishing ships.

High Frequency Direction Finding Net-HF/DF

HF/DF obtains positions of ships in distress whatever their nationality and is also used to ascertain the location of particular transmitters of strategic interest to the United States.

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Sound Surveillance System (SOSUS)

The prime mission of SOSUS is the detection of submarines. In the Atlantic SOSUS is organized under Commander, Oceanographic System, Atlantic, with headquarters at the U.S. Naval Base, Norfolk, Virginia. The primary mission of the command is long-range acoustic detection, classification and location of enemy submarines. The instrumentation of the system in the Atlantic consists of fifteen deep water hydrophone arrays and one shallow water complex located at various points along the edge of the Eastern Continental Shelf of the United States and Canada, the Caribbean Island chain, and at Bermuda. These arrays are connected by undersea cable and monitored by twelve shore installations known as Sound Search Stations (SOSS). These stations communicate with each other, and the evaluation center at Norfolk by Teletype.

Data on contacts are analyzed in the individual stations, and pertinent information on submarines is forwarded to other stations and the evaluation center. If additional action is warranted, such as continuing surveillance on what appears to be a Soviet submarine, the target information is forwarded to Commander, Anti-Submarine Warfare Force, Atlantic.

CIRVIS/MERINT

These are vital intelligence sightings. Commercial vehicles are requested to report all observations of guided missiles, aircraft, or contrails which appear to be directed against CONUS; also surface warships positively identified as not United States or Canadian, submarines, and unidentified flying objects are to be reported.

International Ice Patrol

The Ice Patrol is conducted by the United States Coast Guard. Headquarters are maintained at Woods Hole, Massachusetts from approximately July to March and then shifted to Argentia for the rest of the year. Radio advisory bulletins are issued twice daily and individual requests for information will be answered.

Ice and water temperature reports were made by approximately 550 ships from 26 nations in 1960. These reports can be helpful in ocean surveillance because they are supposed to contain among other things, the position, course, and speed of the reporting ship.

Sources for ship characteristics and registry information are shown in Table 3.2.

3.2   General Observations of System Performances

How suitable a given kind of data is depends upon what use is to be made of it. If one is concerned with long time period effects such as changes in shipping patterns which might indicate buildup in military installations in certain areas, then accurate and prompt departure and arrival data are required for analysis. However, for real time problems such as targeting or search and rescue, an actual location time history of individual vessels is required. In a complete surveillance system, all of these requirements must be met.

Ideally merchant ships on planned cruises could be located if they departed a certain place at a certain time and maintained a specified course at a specified speed on the way to their destination. Unfortunately things do not occur that simply. Departure times do not get recorded or are not made available immediately, courses deviate and speeds vary. Not all ships, especially military ones of other nations, make their travel plans public. To alleviate these shortcomings, various types of reports of sightings or sensing of ships at sea should be up to date to enable corrections on supposedly known tracks or to establish new contacts.

In their analysis of sources of ocean surveillance data the Institute of Naval Studies found many shortcomings with most of the sources. For example the Corporation of Lloyd's was found to be the most comprehensive source of data on world shipping now in existence. However, the data supplied by Lloyd's concerning a number of ships in the INS analysis showed a wide variety of deficiencies, e.g., wrong destination, data too old, no sailing dates given, no destination given, etc. Similarly many MEREPS reports

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Table 3.2

Sources of Ship Characteristics

and Registry

1.   Lloyd's Register of Shipping

2.   Similar Publications of Other National Ship Registry
      Organizations

3.   The AMVER Directory.

4.   Merchant Vessels of the United States (Bureau of Customs)

5.   ONI Series 35 Listing of Ships' Characteristics (OP 922 N2)

6.   NAVCOSSACT, The Maritime Administration, NATO and
      Oceansyslant

7.   Jane's Fighting Ships

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lacked the destination, estimated time of arrival at next port, and speed, or were one to three or more days late in arriving. The most startling thing about MEREP reports, however, was that only 15 out of 57 stations reported.

In a specific analysis of Boston, Massachusetts MEREP departures, INS found that an average time of 34 hours and 34 minutes elapsed between the actual departure time and the receipt of such notification in Washington. This time lag means a 15 knot ship would be 520 n. miles off the coast before word is received that it had left.

Ship Synoptic Weather Messages were found lacking in many instances in that call signs were missing or unidentifiable in many cases, and the heading and speed values were also omitted in a large portion of cases.

According to Reference 8 the various kinds of data are used by the Navy as shown in Figure 3.1. Note here that no information pertaining to surface ship traffic is passed on from SOSUS centers. It has been determined from personnel of the Bureau of Naval Weapons that lack of manpower is the main reason that the SOSUS net does not forward data on surface ship traffic beyond the detection point within the net or external to the net. Current methods of classifying signatures depend on visual analysis of displays of frequency spectra, and are, therefore, slow. Indications are that the classification process will be automated to some extent.

In any event the systems currently in use which do provide, or have the potential to provide, the most data all have defects of one type or another. It is the goal of this study to show the feasibility of using a satellite system with sensors in the optical wavelengths (i.e., UV to IR) as a source of data for an ocean surveillance system. The obvious use of satellites would be in updating the tracks of ships at sea and discovering ships at sea which had previously been unreported by other means. Also, since many of the systems in use today depend on the voluntary cooperation of foreign ships, a satellite based system would be valuable in the event that foreign ships turn uncooperative for some reason.

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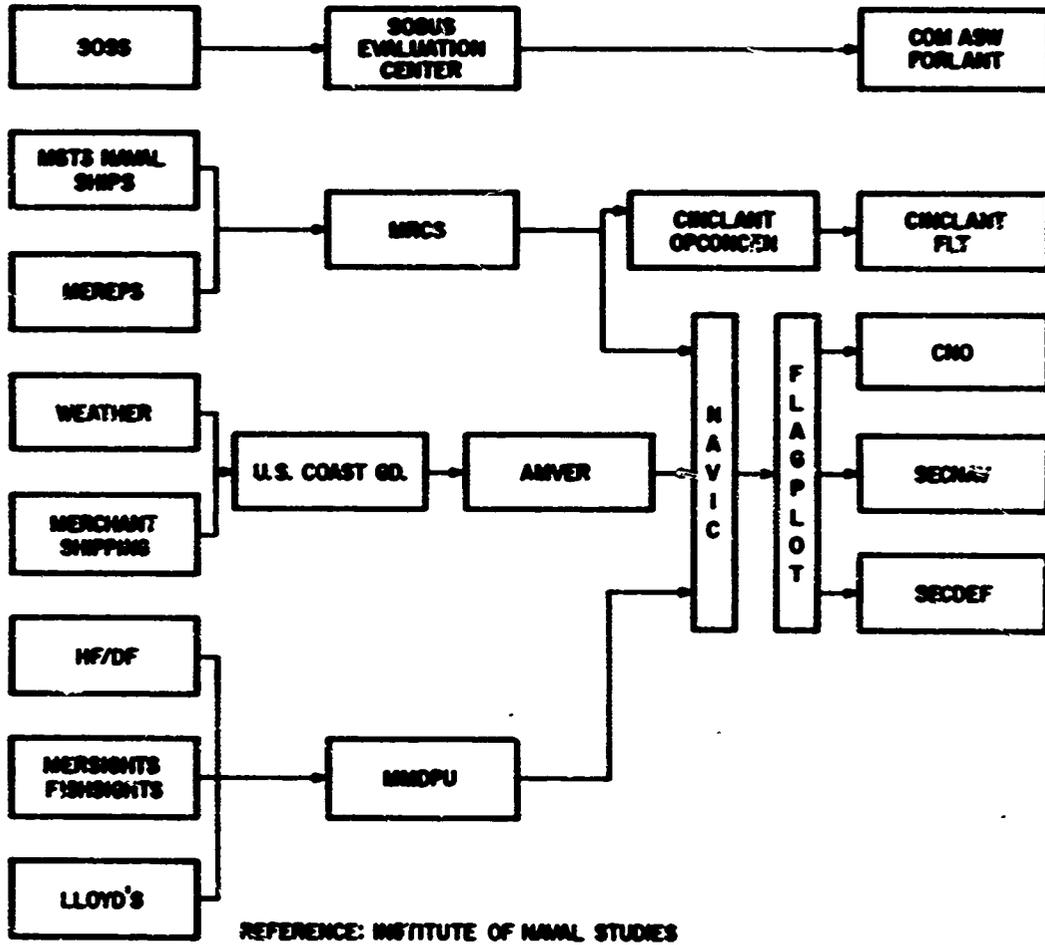
Figure 3.1. Ocean Surveillance Information Flow

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4. ANALYSIS

4.1 The General Problem

Portrayed schematically in Figure 4.1 is the problem of discriminating a ship from its background using satellite based instrumentation operating in the optical portion of the electromagnetic spectrum. Shown here is the radiant energy emitted by the target, E_t, and a portion of the incident energy from the sun which is reflected by the target, R_t, into the field of view of the detector. Also shown in the figure are both emitted and reflected radiation from the ocean, clouds, and the atmosphere itself. Other possible sources of both emitted and reflected radiation not included in the figure are nearby land masses, icebergs, and aircraft.

4.2 The Spectrum of Interest

The current study is restricted to consideration of the optical portion of the electromagnetic spectrum. The bounds of the "optical" portion of the spectrum are, however, somewhat arbitrary. As is pointed out in Reference 10 much depends on man's tools for understanding these radiations, so that the view adopted there is that the region of optics is limited to the range "in which we can control the flow of electromagnetic energy with man-made devices involving reflection, refraction, and diffraction — that is mirrors, lenses and gratings." The short-wavelength limit on the optical spectrum was established at 10 angstroms where useful reflectivities are obtained from metallic surfaces only when the energy is incident at almost grazing angles. A more reasonable lower limit for the current study for cases in which we assume that some optical system will be employed to collect and concentrate the energy is 1000 angstroms ($\overset{\circ}{A}$) since there are few, if any, refractive media which transmit at wavelengths less than this. The upper limit of the optical spectrum was set at 500 microns (μ) which is about 10 times the wavelength at which we lack suitable materials for lenses and prisms. These limits are not far different from those shown in Reference 11 where the upper limit is given as 500μ (in agreement) but the lower limit is shown as

SUN

DETECTOR

E_C R_C TOP OF SENSIBLE ATMOSPHERE E_A R_A

E_T R_T

E_O R_O
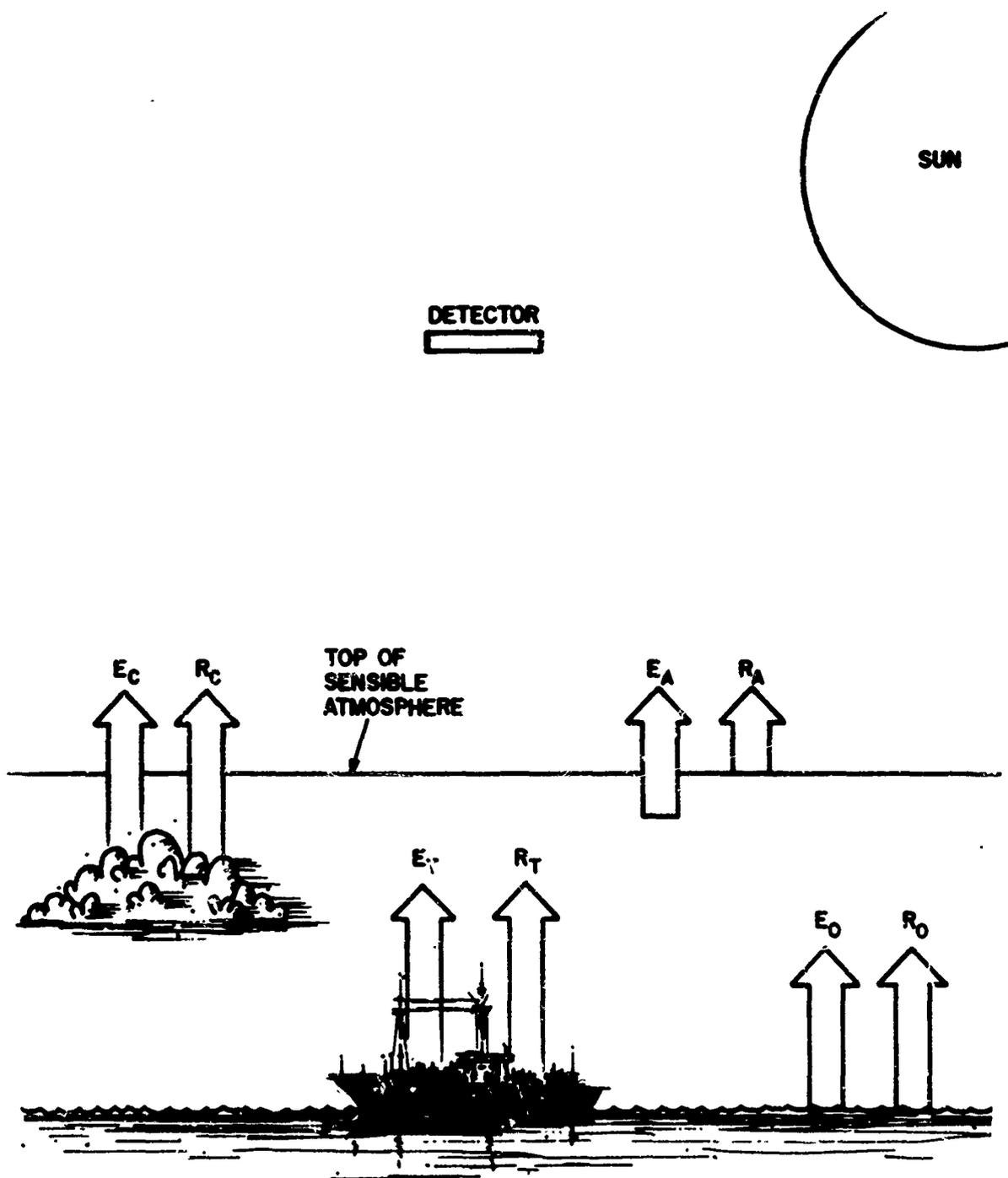
Figure 4.1. Problem Schematic for Detection of Surface Ships

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approximately 60 $\overset{\circ}{A}$ instead of 10. In any event the current study will be restricted to the consideration of that part of the spectrum from 1900 $\overset{\circ}{A}$ to 500 μ.

The portions of the optical spectrum that can be relied on to permit detection, recognition, tracking, etc. depend on the emission and reflection characteristics of the prospective targets and backgrounds and on the absorption and scattering characteristics of the atmosphere. The latter characteristics control the amount and spectral quality of the radiation emitted by the ships, the background, and other objects, which will arrive at the detector system, and they also determine the amount and spectral quality of the solar radiation which will reach the earth's surface and in turn be reflected back outside the atmosphere.

Gross transmission of the atmosphere up to 3.2 μ is shown in terms of incident and transmitted solar energy in the upper portion of Figure 4.2 (taken from Reference 12). The window regions of the spectrum for which large portions of the incident solar radiation are able to reach the earth's surface, are easily discernible. The deep depressions in the sea level curve are caused by absorption of the radiation by the atmospheric constituents indicated on the curve. The difference between the top-of-the-atmosphere curve and the envelope of the sea level curve is due to various scattering processes to which the radiation is subjected. Scattering effects appear most severe in the shorter wavelength regions. The curves shown are based on the sun being at zenith. For off-zenith angles of the sun, the path length for the radiation increases and thus the absorption and scattering effects are more severe.

In the lower portion of Figure 4.2 (Reference 12) is shown gross transmission of solar energy over the wavelength interval from 1 to 15 μ and points up some other window regions at the intervals 3.3 to 4.2 μ, 4.4 to 5.0 μ and 7.5 to 14.0 μ. In the latter interval there is a short absorption band between 9.5 and 10 μ due to the ozone concentrations in the stratosphere. Strong absorption by water vapor occurs at wavelengths beyond 14 μ out to the limit of interest in this study.

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NOTE: SHADED AREAS INDICATE ABSORPTION, AT SEA LEVEL,
DUE TO THE ATMOSPHERIC CONSTITUENTS SHOWN

SOLAR IRRADIATION CURVE OUTSIDE ATMOSPHERE
SOLAR IRRADIATION CURVE AT SEA LEVEL
CURVE FOR BLACKBODY AT 5900 °K
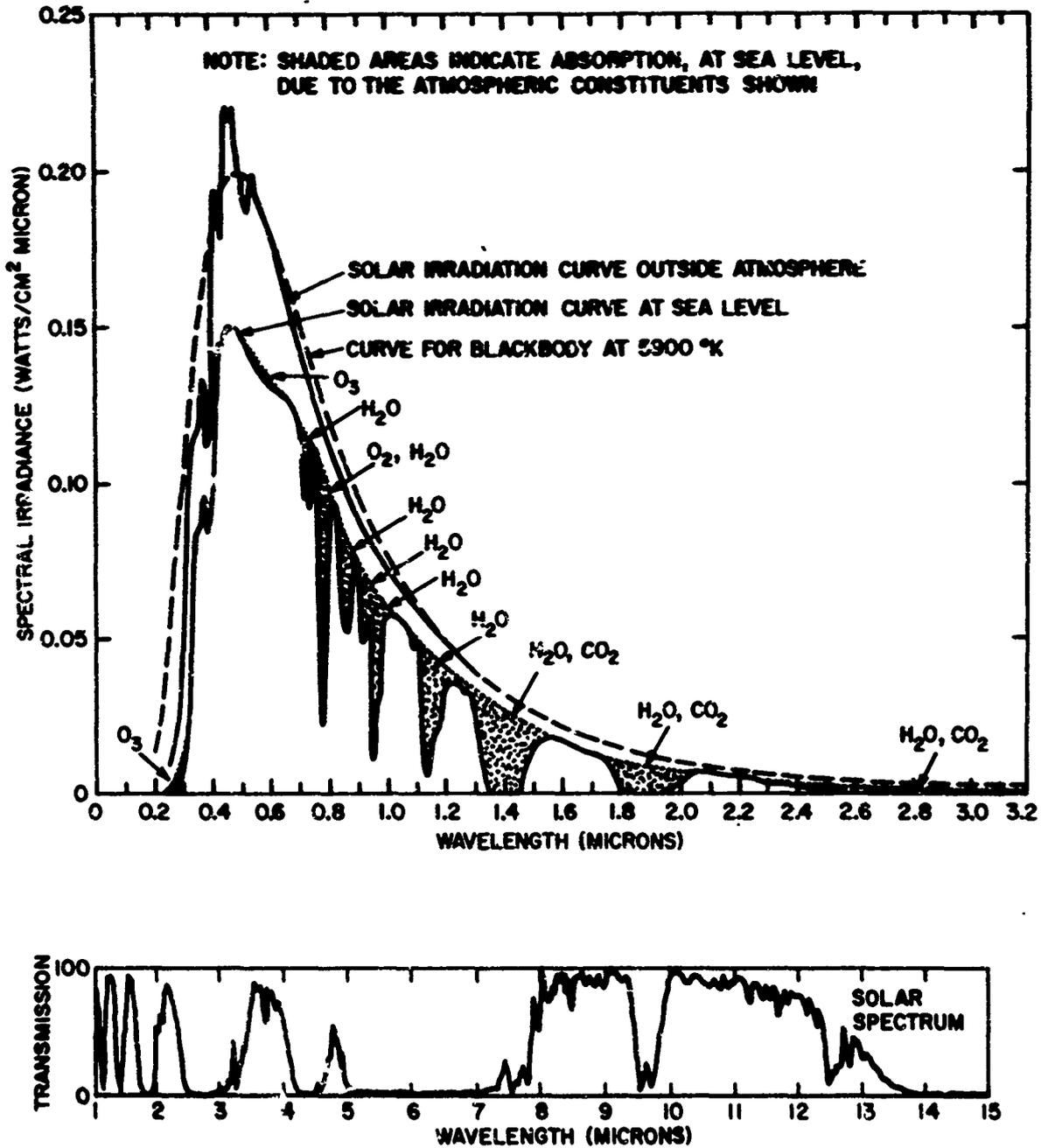
Figure 4.2. Solar Irradiation and Gross Atmospheric Transmission

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4.3 Basic Orbits

We look next at the basic characteristics of some orbits and determine the fields of view which might be required of detector systems to achieve a search mode of operation. We have initially chosen a range of circular polar orbits from 100 to 400 n. miles in height since we are interested in man's capability to enhance the performance of the system. For orbits in excess of 200 to 400 n. miles the shielding required to protect human occupants becomes quite severe (Reference 13). The critical altitude depends on the criterion adopted and the shape of the vehicle, among other things.

Figure 4.3 shows orbital velocity and orbital period as a function of altitude. The orbital period varies from approximately 88 minutes at 100 n. mile altitude to 99 minutes at 400 n. mile orbits. These variations of orbit velocity and period include the effect of g variation with altitude.

Figure 4.4 shows the ground range variation with scan angle in the direction transverse to the orbit plane. The scan angle shown being one-half the lateral field of view. The upper limit of the curve is determined by the horizon (with no atmospheric refraction effects included). To provide for contiguous coverage by subsequent orbits the scan angles need only be as large as those determined by the lower intersecting curve, labeled "adjacent path scan".

Figure 4.5 again shows the scan angle and ground range versus orbit altitude for horizon scans and in addition the slant range to the horizon and the ground area (of the spherical earth) under surveillance. The slant range to the horizon indicates the maximum range from which a signal could be received.

Another consideration associated with many techniques which we might investigate is detector dwell time on the target. These times are shown in Figure 4.6 as a function of orbit altitude for various target dimensions representative of length and width. Actually these times are for a field of view along the flight path of zero degrees and are the times required for the specified length of image to traverse a reference line on the detector.
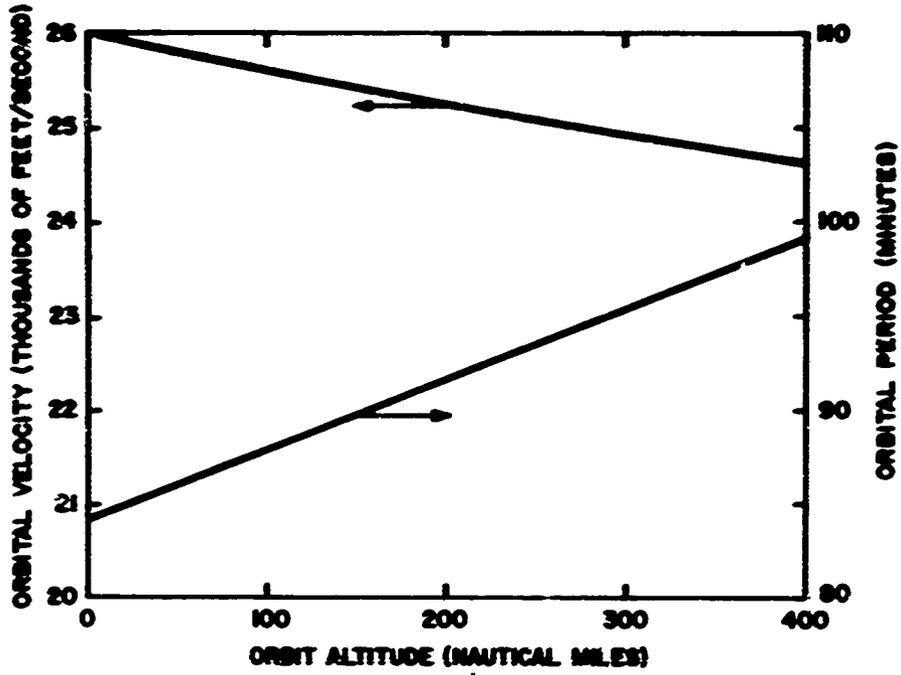
Figure 4.3. Circular Orbit Characteristics

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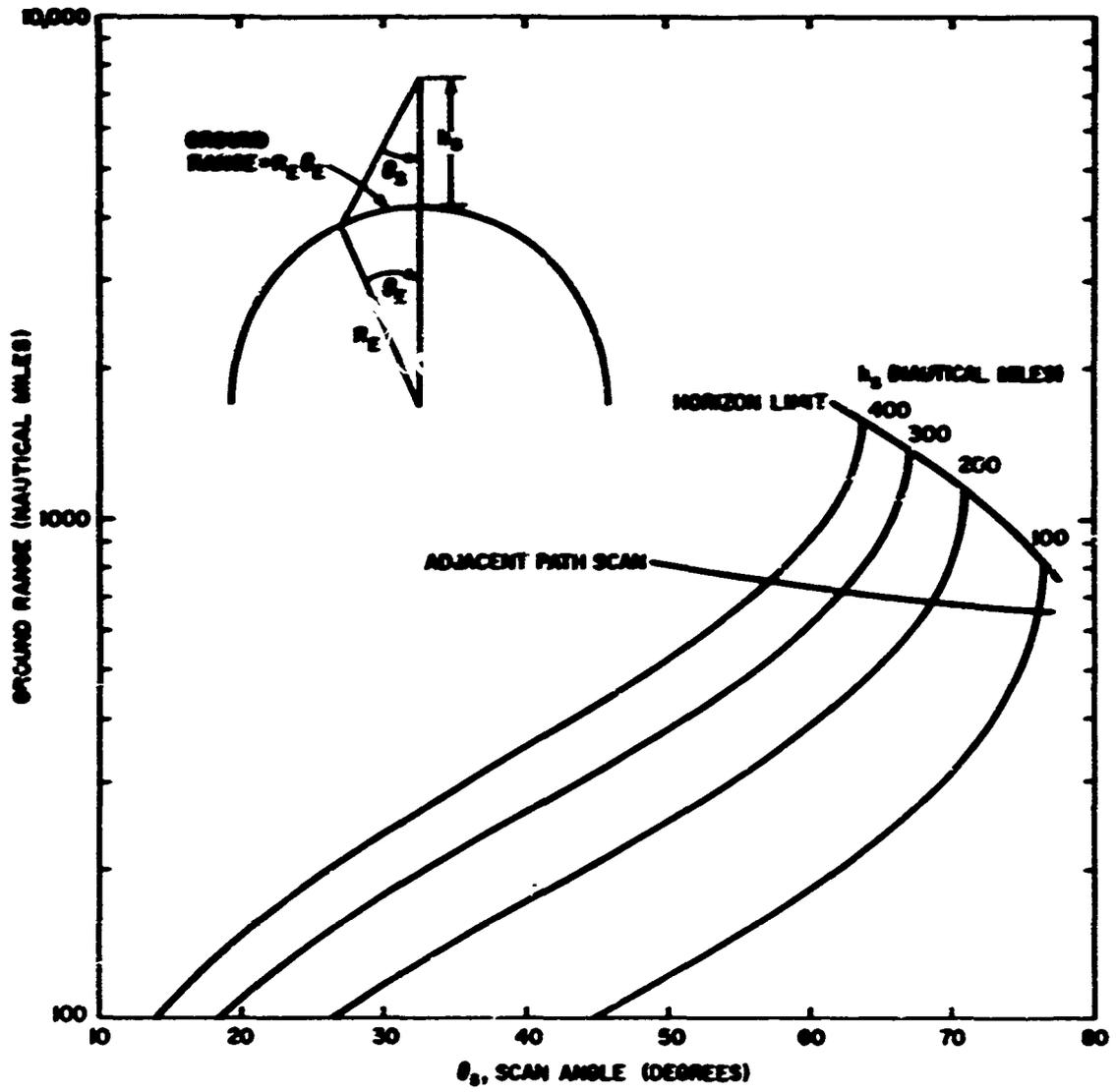
Figure 4.4. Ground Range Variation with Scan Angle

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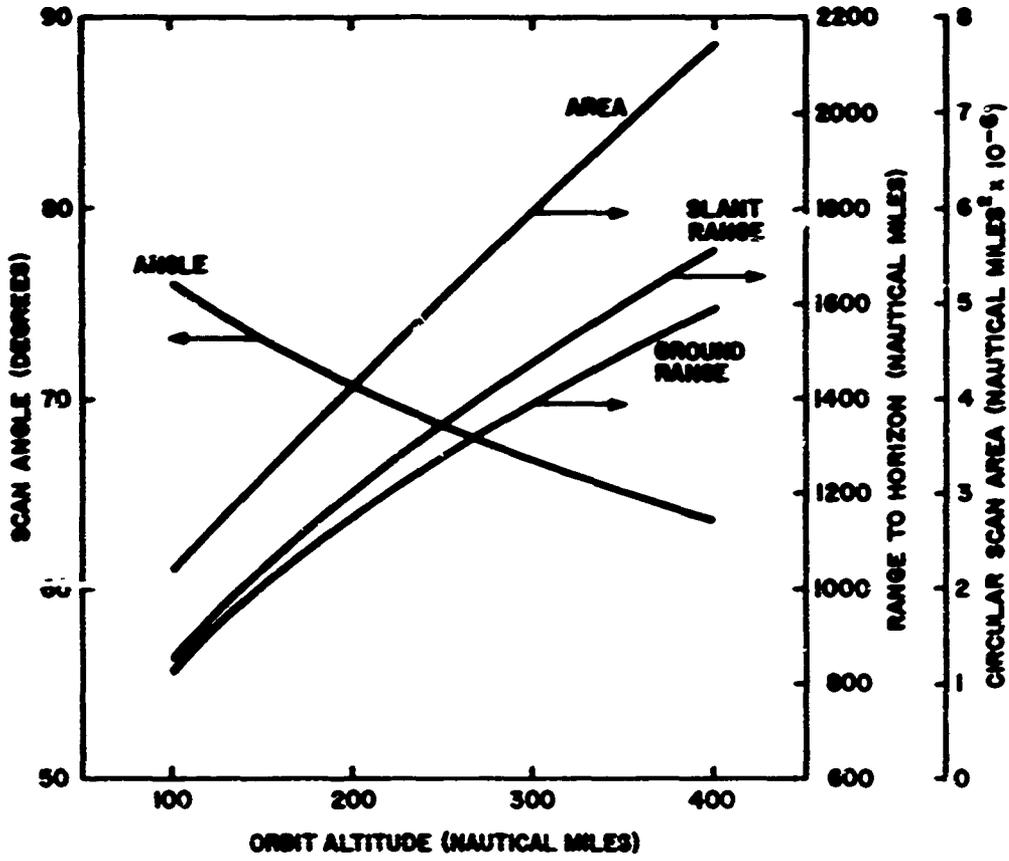
Figure 4.5.   Horizon Scan

MC 65-145-R2
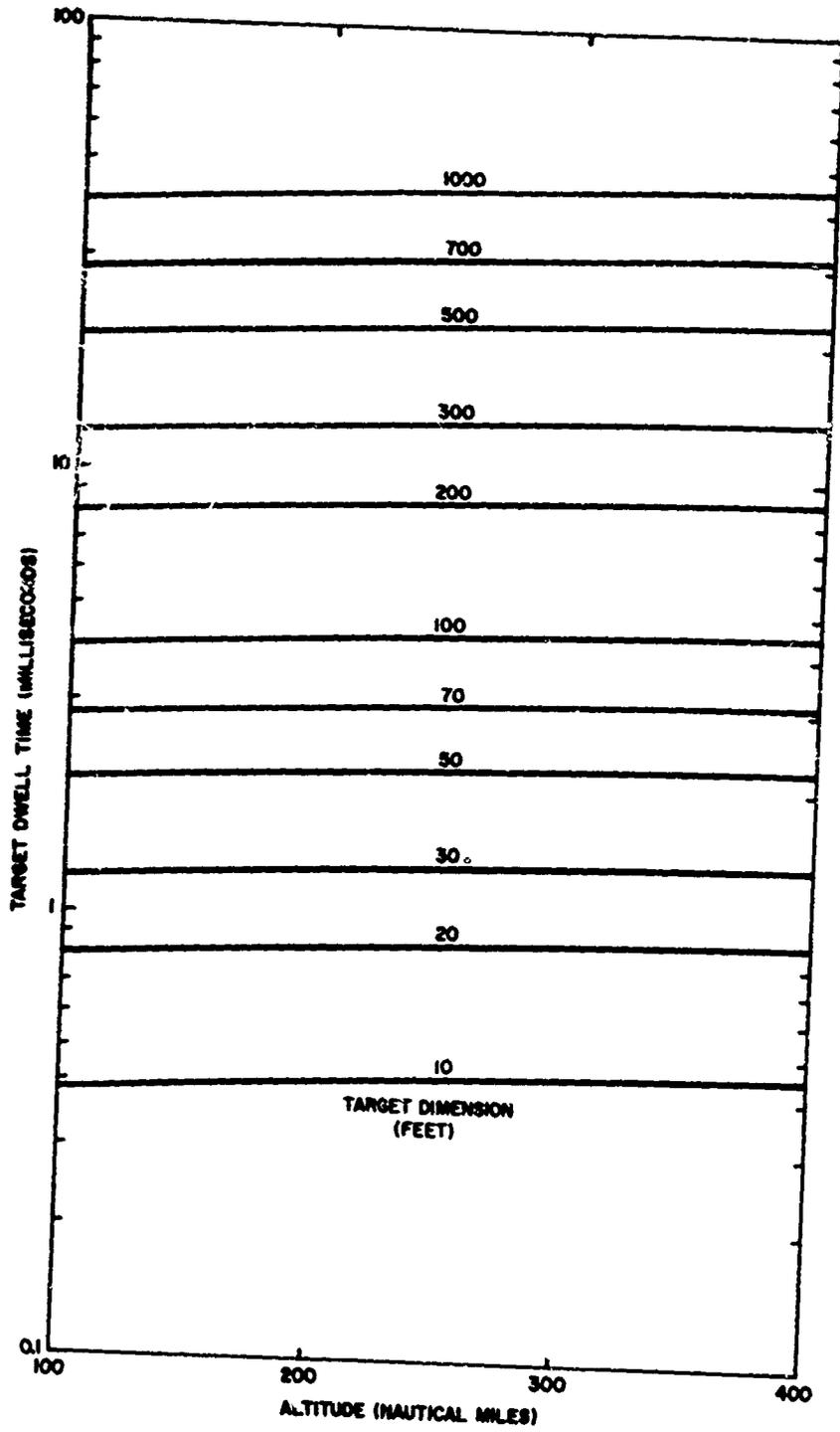
Figure 4.6. Target Dwell Time

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4.4   Target Characteristics

4.4.1 The Physical Dimensions

Surface vessels currently have a maximum length on the order of 1100 feet (e.g., the large nuclear powered aircraft carrier Enterprise) and may have maximum speeds as high as 35 knots. The flight deck of such a vessel as the Enterprise has an area of approximately 4-1/2 acres, or 196,000 square feet. (Reference 1). The huge passenger liner Queen Elizabeth, with dimensions of 987.4 feet length and 118.6 feet wide, has a planform area of approximately 93,600 square feet. The dimensions quoted for the Queen Elizabeth are so-called mol ̄ed dimensions which correspond to the outside of the frame. The area estimate is the product of the length and width and a factor which allows for the bow and stern shapes. A tabulation of some of the characteristics of these and other typical military and commercial ships are presented in Table 4.1. The shape factor used in computing the area ̄is 0.8 for ̤ilitary ships and merchant ships if overall dimensions are used (excepting the nuclear aircraft carrier for which a deck area was known). A factor of 0.85 is more suitable for the Queen Elizabeth. The ships are listed in order of decreasing size. The planform area in square centimeters is listed for use in radiant power calculations but it is also handy for relative size considerations.

4.4.2 Target Signature

In recent years several government sponsored programs have been carried out to obtain information concerning the characteristics of the electromagnetic energy emanating from ocean surface ships. Since these investigations were primarily involved with the surface vessel as a prospective target for missiles and were concerned with the homing phase, the data were obtained from relatively low flying aircraft, i.e., on the order of 2000 to 3000 feet. The infrared portion of the spectrum was of primary interest.

In general it has been found in these investigations that ships may present either a positive or a negative contrast to the ocean background, i.e.,

Table 4.1

Dimensions of Representative Surface Ships

Ship Type	Length (ft)	Width (ft)	Planform Area (ft²)	Planform Area (cm²) × 10⁻⁸	Ref. No.
Nuclear Powered Attack Aircraft Carrier (CVAN), Enterprise	1102	133 (hull) 252 (flt deck)	196,000	1.83	1
Liner Queen Elizabeth	987.4(m)	118.6	99,500	.93	14
Liner S. S. United States	990	101.6	80,400	.75	14
Battleship (BB), Iowa Class	861	108	74,400	.69	1
Large Cruiser (CB), Alaska	808	91	58,800	.55	1
Liner Independence	683	89	48,600	.45	15
Heavy Cruiser (CA), Salem Class	716	75	43,000	.40	1
Nuclear Powered Guided Missile Cruiser (CGN) Long Beach	700	75	42,000	.39	1
Light Cruiser (CL), Cleveland Class	610	66	32,200	.30	1
Standard American Tanker, 2-SE-A1	524	68	28,500	.27	15
Standard American Merchant, C-3	492	70	27,600	.26	15
Standard American Merchant, C-2	459	63	23,200	.22	15
Standard American Merchant, C-1	418	60	20,100	.19	15
Destroyer (DD), Forest Sherman Class	418	45	15,000	.14	1
Destroyer Escort (DE), John C. Butler	306	37	9,050	.084	1

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they may appear either hotter or colder than the ocean. Whichever situation exists depends on a number of variables which include local air and sea temperatures, time of day, and current and prior meteorological conditions experienced by the ships. With respect to a surfaced submarine, its contrast condition depends to some extent on whether or not it has just been submerged and the temperature of the water in which the submarine was submerged. Obviously a decks-awash condition of the submarine would reduce the contrast of the deck considerably.

Prediction of the contrast for a particular case may not always be possible but generally after a ship has been exposed to the sun for a considerable time it will become hotter than the surrounding ocean, but some time after the sun has set, the ship may become cooler than its surroundings.

A summary of results found in these recent studies is presented in Table 4.2. The maximum ship temperature recorded was 41°C (314°K) and the minimum recorded was 13°C (286°K). In Reference 16, which summarizes an extensive study of stresses induced by temperature distributions in ships, are tabulated a number of observed maximum temperatures in a variety of ships under various operating conditions. The highest temperature listed is 130°F which corresponds to 55°C (328°K). This temperature was on the deck of a 305 foot LST during a time when the weather was described as clear and the air temperature was 71°F (22°C). The hull temperature below the water line (which is indicative of the water temperature) was 57°F (14°C). Thus the contrast between the deck and water in this case could have been on the order of 41°C. Another extreme case recorded was that of a 515 foot tanker with a deck temperature of 127°F (53°C) and the below-waterline hull temperature of 66°F (19°C) for a possible deck-water contrast of approximately 34°C. The air temperature in this case was 92°F (33°C) and the weather was clear. Both of these deck temperatures are higher than the maximums listed in Table 4.2. The effects of color upon the temperature of horizontal surfaces subjected to insolation are also shown in Reference 16. Test panels of various colors were exposed for a day to the sun. With the maximum air temperature on the order of 90°F (32°C) white and aluminum panels reached a maximum of approximately 100°F (38°C), red

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Table 4.2

Summary of Ships' Temperatures and Background Contrast

Name of Ship	Dimensions of Ship Length (ft)	Beam (ft)	Propulsion Type	Number of Stacks	Location of Experiment	Date of Experiment	Time of Experiment	Air Temperature (°C)	Water Temperature (°C)	Ship Temperature (°C)	Stack Temperature (°C)	Ship-To-Ocean Contrast (°C)	Reference
USS Abbott (DD629)	376	39	Steam Turbine	2	Newport-Quonset Point	10/7/63	14:48	16.5	15.5	27 (Sun) 23 (Shade)		11.5 7.5 34.5(vent)	17
							19:49	16.5	15.			-1 to +1 10.5(vent)	17
USS Gyatt (DDG712)	390	41	Steam Turbine	2	Norfolk, Virginia	10/9/63	14:15 19:08	17.0	19. 19.			Positive -1	17
							13:52 19:41		15.6 16.2	16 to 22 13		to 6 -3	18
USS Longbeach (CG(N)9)	721	73	Nuclear-Steam Turbine	None	Wilmington, Delaware	6/15/63	Day	19.	22.	27 to 37		5 to 15	17
USS Salinan (ATF161)	205	39	Diesel-Electric	None	Key West, Florida	10/11/63	13:19	28.5	29.	41		12(Sun) 1(Shade)	17
							19:14	25.5	28.	30		-1.5	17
HMCS Chaudiere	366	42	Steam Turbine	1	Halifax, Nova Scotia	9/19-26/60					200 to 315		
HMCS Restigouche			Steam Turbine	1		6/5-14/61							19

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reached 130°F (55°C) and black attained 145°F (63°C). Since black results
in the highest temperatures, it would probably not be used as a deck color.
In view of this consideration and the measured deck temperatures cited above,
a reasonable maximum temperature to expect for a ship deck is 130°F or
328°K. Assumed for a lower limit is 0°C (273°K). In polar regions and in
winter conditions in the northern and southern hemispheres ships' exteriors
can become laden with ice which might attain temperatures lower than
freezing. However, it is presumed that the hull with its higher internal
temperatures, particularly in the powerplant and inhabited areas, will have
a moderating effect on subfreezing exterior ice to produce an effective
average 0°C.

As a source of electromagnetic radiation it will be assumed for the
purposes of this study that a ship may have a range of effective radiating
temperature from 0°C (273°K) to 55°C (328°K). In Figure 4.7 we see that
these values correspond, according to Wien's displacement law, to regions
of wavelength of maximum radiation of 8.8μ to 10.6μ. The range of ocean
temperatures is discussed in Section 4.5.1.

In some of the observations made in the experiments discussed in
References 17 and 19 it was noted that the radiation emanating from the
stacks of the steam turbine powered ships, such as the U.S.S. Abbott or
HMCS Chaudiere for example, was very intense. Reference 19 indicated
that the probable temperature for gases escaping the funnel of the HMCS
Chaudiere should be on the order of 200°C to 315°C (473°K to 588°K). This
would correspond to wavelengths of maximum radiation of 6.1 and 4.9 μ as
shown in Figure 4.7. In the course of the investigation it was shown that
the intensity of the radiation emanating from the stacks increased with in-
creasing speed of the ship. The increased intensity of the stack radiation
was related to increased radiating temperatures, which agreed fairly well
with the theoretical values for the class of ship under consideration.

With respect to the exhaust from diesel powered craft no data was
found. The U.S.S. Salinan which participated in the experiments of
Reference 17, although diesel powered, lacked a funnel, so that no high
temperature sources indicative of exhaust were observed. It is noted in
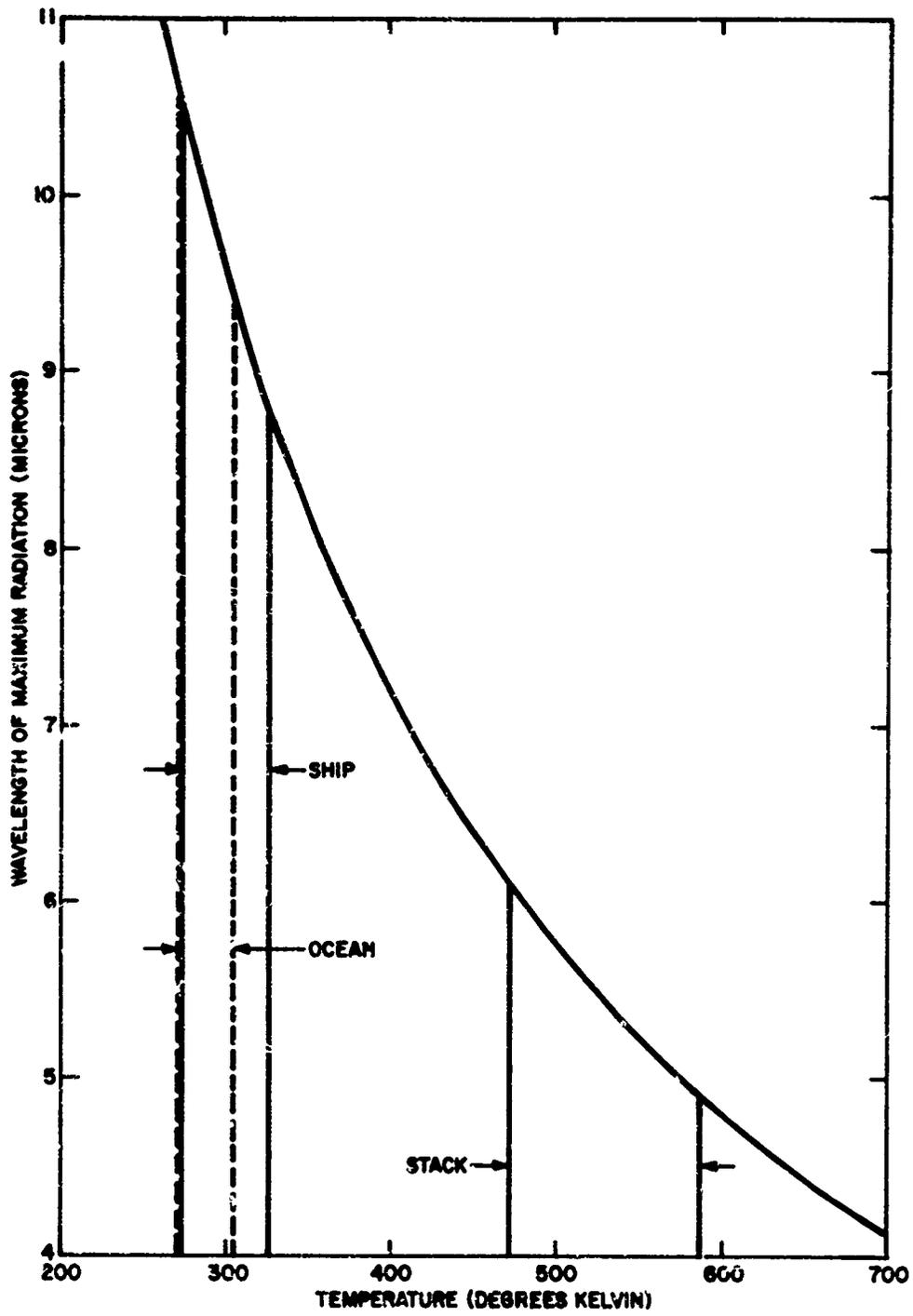
Figure 4. 7. Wavelengths of Maximum Radiant Emittance

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Reference 20 that diesel engines in general, operating at full load, will have exhaust gases at temperatures from 500-700°F (533°K-644°K). At fractional load conditions the temperatures are less. These values are not far different from the temperatures attributable to the flue gases of the Chaudiere class of steam turbine propelled destroyers. Hence the temperature of exhaust gases to be observed on a diesel powered ship having a funnel (and using it to exhaust the combustion products) might be as high as 644°K although lower temperatures could prevail due to losses occurring in the uptakes.

Even if the temperatures of the waste products of the power plant are known, it is not feasible to predict the expected funnel signature of various types of ships without knowing considerable detail concerning the power plant and its exhaust system. It is not adequate to know just the cross section of the funnel at the exit to the atmosphere, in particular with respect to newer ships since only a fraction of the funnel cross section is being used to evacuate the waste gases.

In the earlier steam powered ships, the funnel was used only to guide the waste products of the furnace safely to the atmosphere, and its full inside dimensions were used to do the job. As the steam powerplants have been refined through the years and as new types of powerplants, such as diesel, gas turbine, and nuclear have evolved, the uptakes from the main and auxiliary machinery in a ship have come to require less and less cross-section area. Funnels, however, still persist, for appearance sake as much as anything, although their shape has changed from circular to teardrop to reduce wind resistance. The steam powered ship still probably requires the greatest active funnel area but even in this case the prediction of the actual radiating area is not straightforward because of the presence of deflectors or spark arrestors of various kinds designed to prevent soot, ash, and exhaust gases from blowing down on the deck. In Reference 19 the presence of a spark arrestor on the ships being observed was blamed in part for the discrepancy between the expected and observed stack temperatures.

Some ten years ago the so-called "Clinker Effect" was first observed by Harry Clark of NRL. This effect is the infrared radiometric observation of the wake associated with a fully submerged submarine. Although other

observations of the effect have been made over the years, it is not yet known to be a reliable method for detecting a submerged submarine. Since infrared instrumentation has been used to observe the wake, one or all of such effects as change in surface temperature of the sea, change in surface emissivity of the sea, or change in reflected radiation could be responsible for any anomalies which appear. Surface ships also generate wakes which leave obvious scars lingering on the surface of the water.

In the course of the experiments reported in Reference 19 measurements were made of the wake radiance from an altitude of 250 feet. The aircraft was flown across the wake and the radiometer employed was operated at sensitivities higher than used when observing the ship since the wake signals were relatively feeble. The wake measurements were carried out during June 1961.

The infrared properties of the wake were found to fluctuate considerably from trial to trial. In general it was found that the wake became wider at increasing distances behind the ship, but that the infrared radiance relative to the surrounding ocean seemed to be independent of distance behind the ship to the point where the wake broke up and the radiance structure across the wake became irregular. For the restricted range of conditions under which observations were made, the breakup distance extended to values somewhat in excess of 3000 feet. An example of a particularly well defined wake is shown in Figure 4.8. Shown herein are variations of radiance across the wake at different distances behind the ship, not including the distance at which break-up of the wake occurs. The contrast radiance between the wake and the surrounding ocean was usually found to be of smaller magnitude than shown here. It is interesting to note that the wake radiance relative to the surrounding ocean is negative indicating that the wake is the colder of the two. This might indicate that decreases in emissivity and/or reflectivity of the ocean surface or exposure of colder subsurface water more than offset any increase in temperature of the water which might be associated with kinetic energy dissipation of the ship and its propellers in the water.

With respect to wakes it is also worth noting that in the infrared pictures in Reference 21 wakes behind surfaced ships are quite prominent in
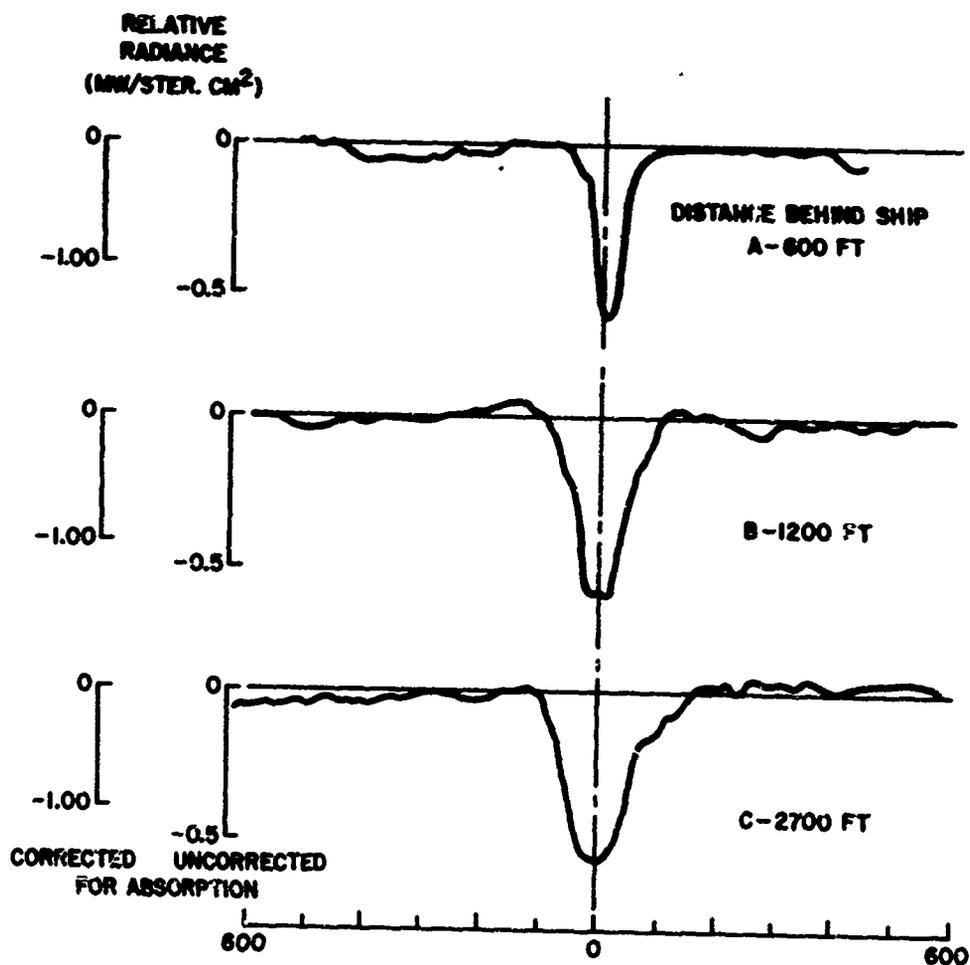
Figure 4. 8.   Radiation Profiles Across A Ship's Wake

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some instances but seemingly more prominent behind snorkels and surfaced submarines.

A current investigation is concerned with the application of laser beams and spatial frequency filtering techniques to the amplification of ship wake signatures (Reference 22). It is indicated in Reference 22 that if the state of the sea, as observed photographically by radar or infrared for example, could be displayed without excessive delay in the path of a laser beam, then spatial frequency filtering techniques could be used in the detection of vehicles moving on or under the sea.

One other possibility for target detection might be the observation and analysis of the exhaust products of the ships' power plants. No specific results were found on this subject but it was noted in Reference 19 that although the authors had originally planned to detect 4.3 micron carbon dioxide radiation in the exhaust gases, equipment failures and problems in the procurement of a suitable filter prevented their obtaining conclusive results.

4.5   Background

4.5.1 The Ocean

Ocean surface temperatures are reported in Reference 23 to vary throughout the world between approximately $-2^\circ C$ ($271^\circ K$) and $32^\circ C$ ($305^\circ K$). The distribution of these temperatures depends on such factors as the latitude, the season, and the character of ocean currents at the area under consideration. Extremes of ocean surface temperatures occur in most areas during the months of February and August. The largest annual variations in temperature occur in the mid-latitudes and along the coasts of continents in the Northern Hemisphere; for example the annual range of ocean surface temperature off the east coast of Japan is over $22^\circ C$. On the contrary in regions where upwelling occurs, such as off the California coast, the annual range is only 3 or $4^\circ C$. Over large tropical areas and in the polar regions, the annual temperature range is even more restricted, being only about $2^\circ C$. Charts of the mean ocean surface temperatures throughout the world for the months of February and August are shown in Reference 23.

The wave lengths of maximum spectral radiant emittance correspond-
ing to the temperature extremes of $-2^{\circ}C$ and $32^{\circ}C$, are $10.7\,\mu$ and $9.5\,\mu$
respectively. From Figure 4.7 it is apparent that a considerable overlap of
possible ocean and ship hull temperatures occurs indicating that zero or
negative contrast between the ship and the ocean could occur.

Note that the range of wavelengths of maximum spectral radiant
emittance for a black body corresponding to the ocean and ship hull tempera-
tures is within the 7.5 to $14\,\mu$ interval defining an atmospheric window.

Reference 24 states that in the infrared region from 4 to $12.5\,\mu$, the
emissivity of the ocean surface is 0.98 for radiation normal to the surface.
The reflection for normal radiation is 2 percent and increases to 4 percent
for radiation incident at 60° from the normal. Since the range of wavelengths
of maximum spectral radiant emittance corresponding to ocean temperatures
is 9.5 to $10.7\,\mu$, it is reasonable to consider the ocean as a black body
emitter in the interval from 4 to $12.5\,\mu$.

Consider now the relative magnitude of the energy emitted by the
ocean and that of the sun reflected by the ocean in the 7.5 to $14\,\mu$ band. First
assume that the ocean is radiating as a $300^{\circ}K$ black body so that a total of
4.5×10^{-2} watts/cm^2 are emitted. However, only 46 percent of this amount
is in the 7.5 to $14\,\mu$ interval corresponding to 2.1×10^{-2} watts/cm^2. In turn
Reference 12 shows that the solar spectral irradiance just outside the earth's
atmosphere in the interval from 7 to $30\,\mu$ is 2.48 watts/meter^2 (2.48×10^{-4}
watts/cm^2). This represents 0.18 percent of the total energy arriving from
the sun. Calculations indicate that approximately 60 percent of the energy in
the wavelength interval from 7.5 to $14\,\mu$ will pass outward from sea level
vertically through the atmosphere. If we assume that the same percentage
will be transmitted in through the atmosphere to sea level and in turn that
2 percent is reflected by the water, then $0.6 \times .02 \times 2.48 \times 10^{-4} = 3.0 \times 10^{-6}$
watts/cm^2 reflects back from the surface of the water. Thus the ratio of
emitted to reflected radiation is $2.1 \times 10^{-2}/3.0 \times 10^{-6} = 7 \times 10^3$. Thus even
if 100 percent of the solar energy in this interval were reflected, the emitted
radiation would still be 140 times greater than the reflected energy. Since
ships have approximately the same temperature and their emissivity is only

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slightly less, the same considerations apply. For the same reasons reflected radiation from clouds will not be of the same magnitude as that emitted by ships or the ocean in the wavelength interval from 7.5 to 14 μ.

Below about 4 μ, most of the radiation from the earth observed from a space platform will be scattered or diffusely reflected sunlight. The observed values of the radiance vary greatly with the position of the sun and the observer and the nature of the surface of the water.

In Reference 25 are shown the results of the measurement of radiation reflected by various types of terrain and clouds in the wavelength interval from 0.35 to 2.6 μ. Measurements were taken from an aircraft flying in the region of 8000 to 20,000 feet. Measurements were made of the radiation reflected from the water of Great Salt Lake, Lake Pontchartrain, Gulf of Mexico, Mobile Bay, and the Atlantic Ocean. The range of values of spectral radiance of water measured in the course of the experiment are shown in Figure 4.9. The range of values measured is indicated by a vertical line at the specific wavelength and the dot indicates the mean of the range of values at each wavelength.

It is interesting to compare the results obtained for clouds as portrayed in Figure 4.10. At all wavelengths the spectral radiance of clouds is much higher than for water. The cloud types on which measurements were made were stratus and stratocumulus clouds. In some instances the clouds were thin enough that the terrain below could be seen. This result seems reasonable in view of the fact that Hanel points out in Reference 26 that Nordberg using TIROS data found, apparently in the 0.2 to 7.0 μ band, that the reflectivity of the ocean would correspond to an albedo of a few percent and the brightest part of a cloud would be of the order of 60%.

It is also to be noted from results in Reference 25 that at several of the lower wavelengths snow exhibited a spectral radiance as high as, or higher than, that of clouds. At the higher wavelengths, 1.62 and 2.-2.6 microns, snow had a lower spectral radiance than clouds, but was still higher than that of water.
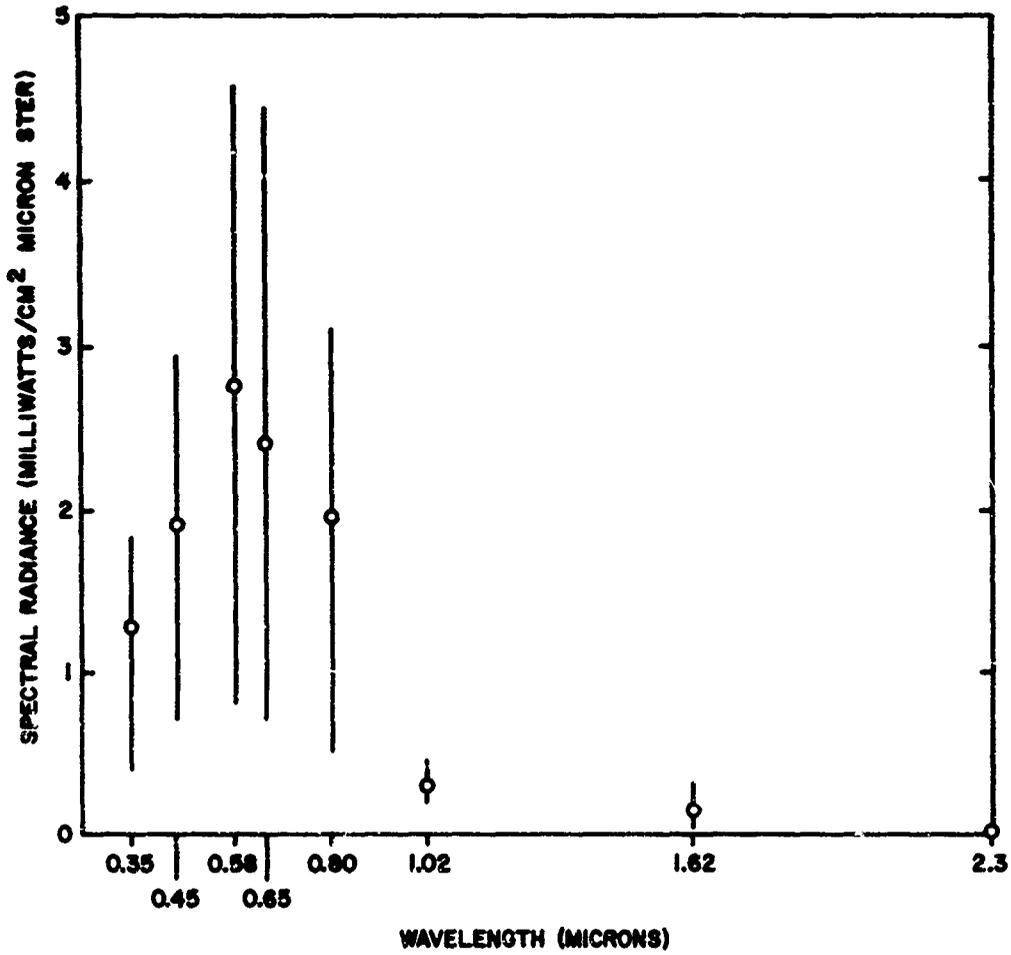
Figure 4.9. Spectral Radiance of Water

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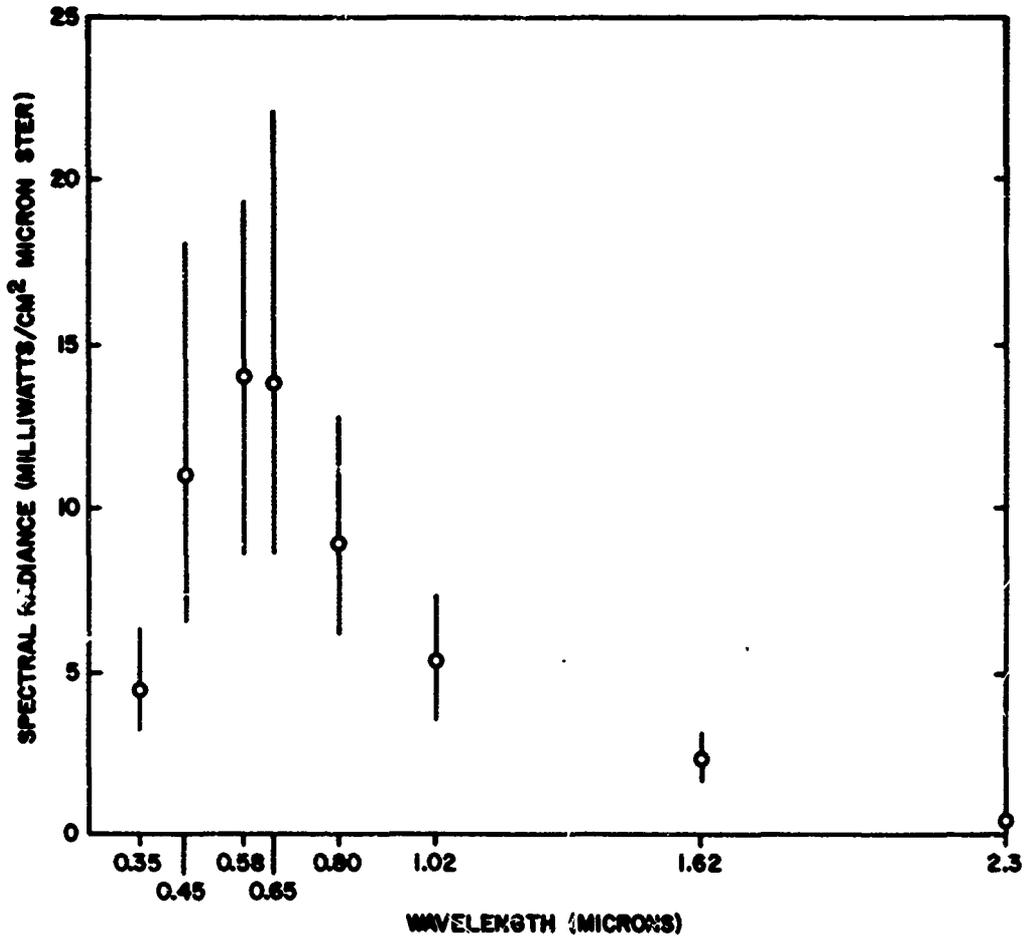
Figure 4.10. Spectral Radiance of Clouds

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4.5.2 Clouds

Clouds present a variety of problems to any system using the optical
wave lengths under consideration to detect, locate, track, classify and
identify ships on the ocean. Large expanses of clouds act as a barrier to
radiation emanating from a surface ship, preventing its reaching the detector
system by reflection and absorption. In turn, clouds reflect much of the
sun's incident energy during the day and the sky and atmospheric emissions
at night. Small clouds may thus appear as potential targets in some portions
of the spectrum. Another consideration of importance with respect to the
longer wavelengths is the energy emitted by the clouds.

4.5.2.1 Cloud Cover — A good indication of world cloud cover is
shown in Reference 27 in which TIROS results covering a period from March
1962 through February 1963 are compared with results obtained by H. Lands-
berg for available surface cloud observations covering many years (Reference
28). Results based on Landsberg's work are shown for regions around the
world between $\pm 60°$ latitude. From the appearance of the plots of cloud
frequency shown one can see that the major portion of the ocean areas are
covered with clouds more than 50 percent of the time. A strip of the Atlantic
between Cuba and the coast of Africa is relatively open (i.e. less than 50 per-
cent coverage) throughout the year. Central sections of the Pacific enjoy
similar conditions.

Some interesting observations on cloud cover have come from the
Mercury program and these are summarized in Reference 29. The only areas
that were consistently clear in the first four orbital missions were the western
African desert and the southwestern United States. Efforts to observe ground
signal lights from the spacecraft were frustrated on three of the four missions
by overcast conditions. Although astronaut Cooper enjoyed the best visibility
conditions of any of the astronauts, he estimated the cloud cover to average
about 50 percent for his flight.

4.5.2.2 Cloud Characteristics — At wavelengths greater than ap-
proximately 3μ self emission is the predominant source of cloud radiation,

while below $3\,\mu$ reflection of solar radiation predominates. In Reference 30 it is demonstrated with both theory and experimental results that relatively little reflectivity variation occurs over a wide range of wavelength from the visible to $4\,\mu$. The correlation of the data available at the time was accomplished by normalizing the radiance at a given scattering angle to that at a scattering angle of 40°. The 40° scattering angle is unique in that at this angle scattered intensity is insensitive to particle size. The results of the correlation can be expressed as

$$\frac{N_{\theta}}{N_{40}} = 0.084\, e^{(0.004\,\theta)^{-1/2}}$$

where

N is cloud radiance

θ is the scattering angle - the angle between the ray from the observer to the cloud and the extension of the ray from the sun to the cloud.

Figure 4.11 is a plot of the relative radiation as a function of scattering angle. It is pointed out in Reference 30 that no dependence on wavelength was found in the available data. This particular correlation is also presented in the current edition of the Handbook of Geophysics and Space Environments (Reference 12). The correlation obtained was for ice cloud data. No data was located resulting from continuous angular measurements on clouds substantiated as water clouds.

Engineering approximations were also presented in Reference 30 for the absolute radiance of thick cirrus (ice particle) clouds and thick cumulus (water particle) clouds. These results were presented as preliminary in view of the limited data that were available for analysis. Thus for thick cirrus clouds

$$N_{\lambda,\,\theta} = 10^{-2} H_{\lambda} e^{(0.004\,\theta)^{-1/2}}\ watts/cm^2\text{-ster-micron}$$

where H_{λ} is the incident spectral solar flux, $watts/cm^2$-micron. This expression applies to wavelengths between 0.6 and $3.5\,\mu$. It is pointed out in Reference 30 that the reflecting ability of the clouds portrayed by this expression

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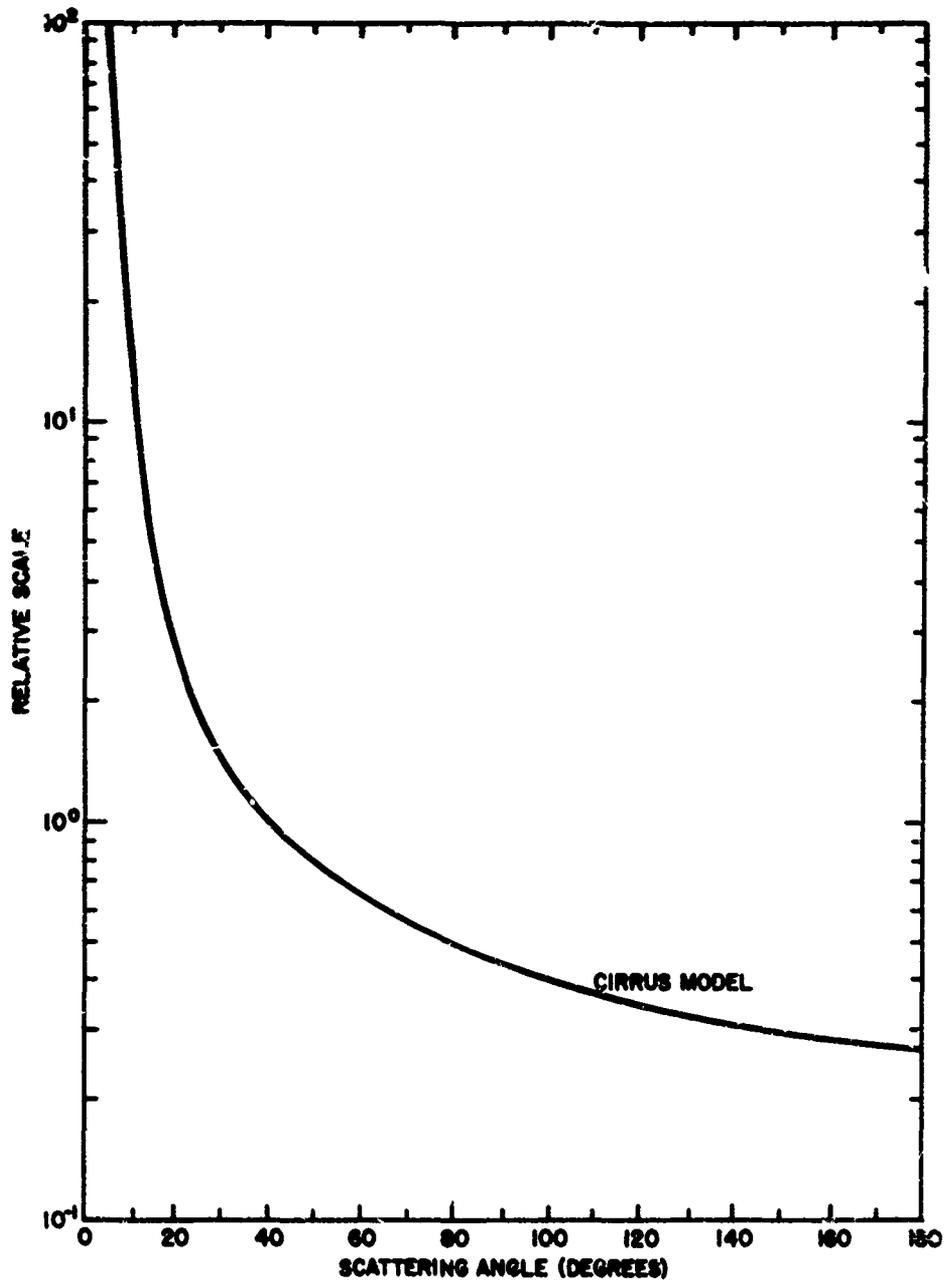
Figure 4.11. Cirrus Scattering Function
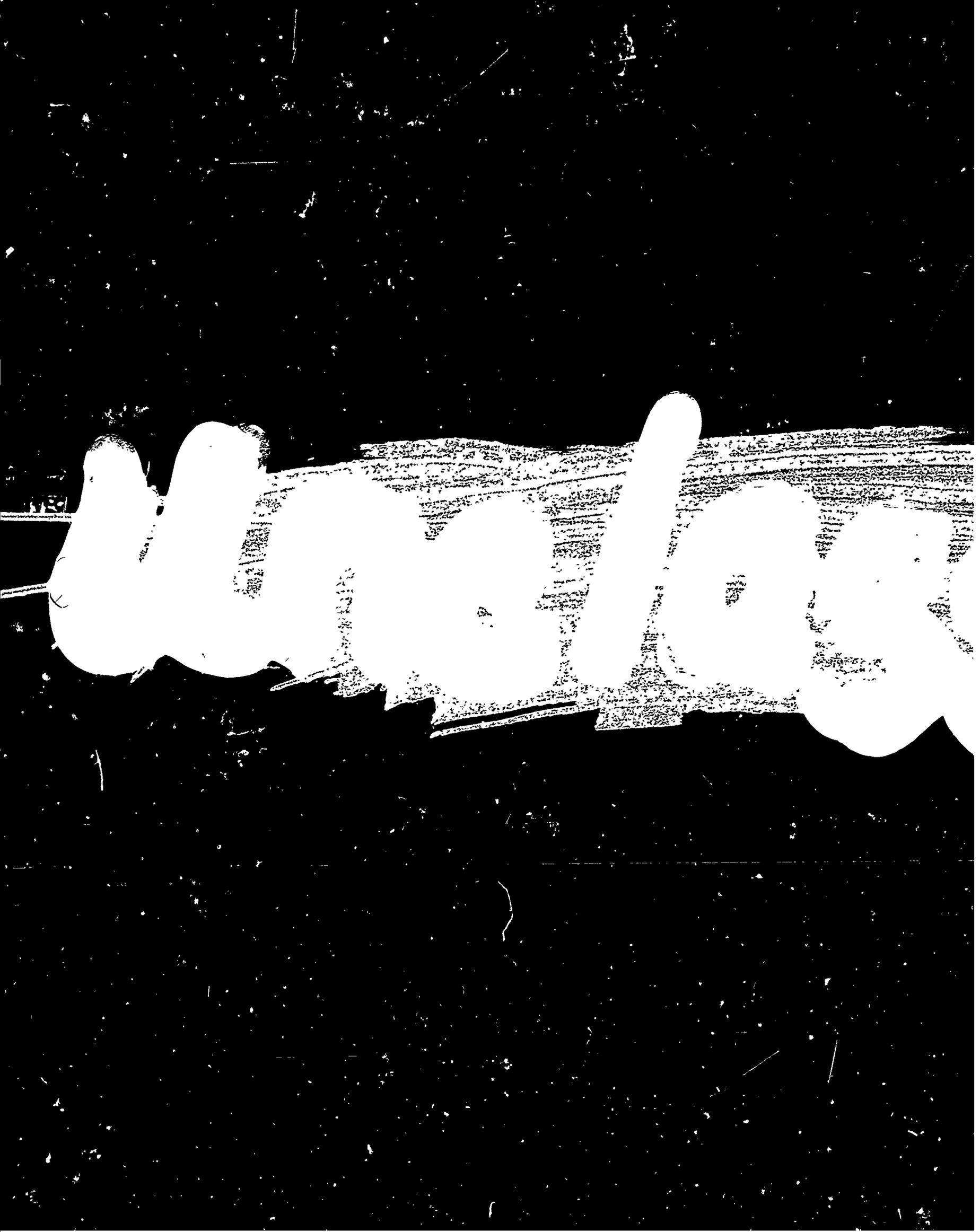
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Figure 4.12. Target and Background Spectral Radiation

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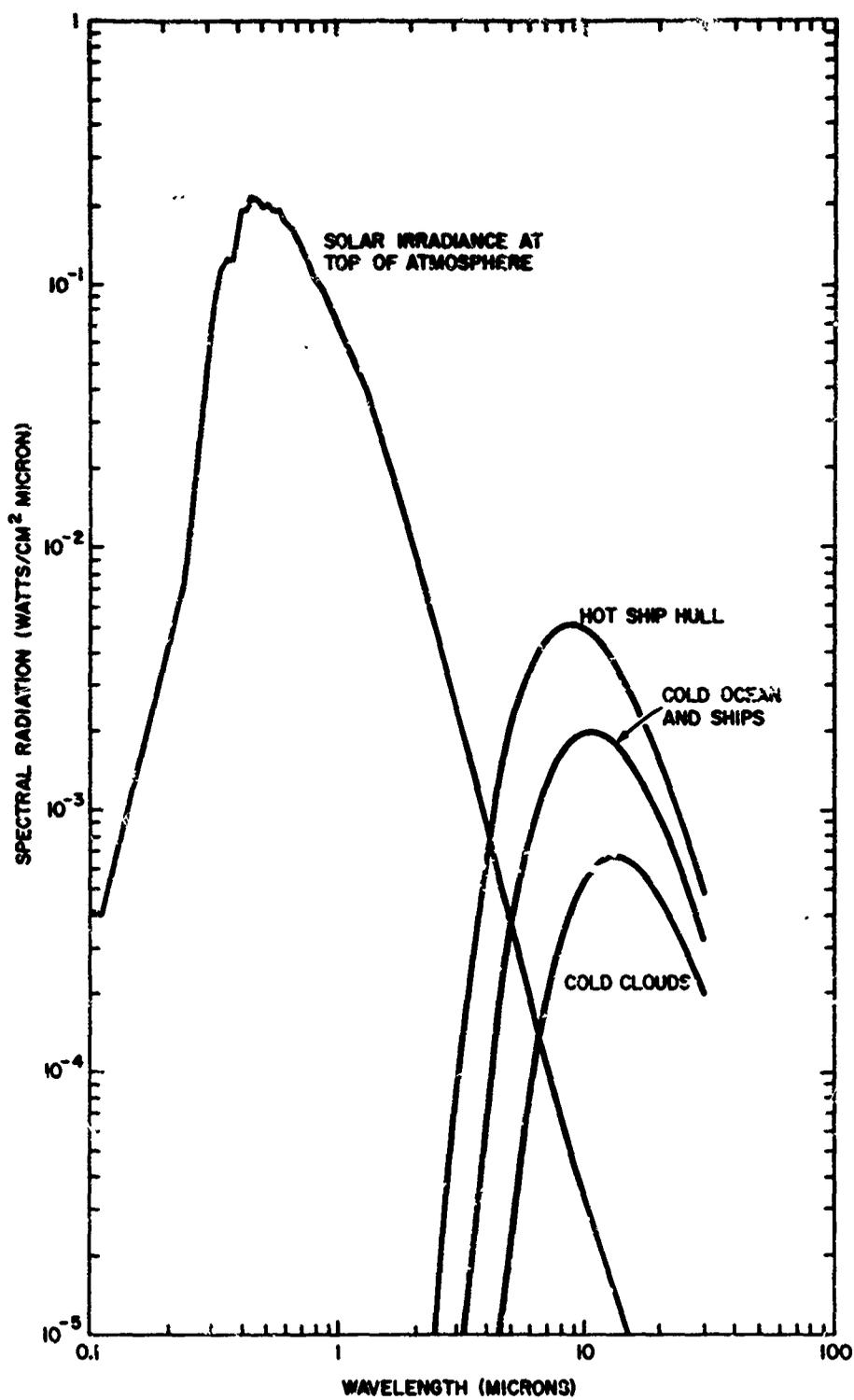
Channel 1 covers the band in which water vapor absorbs much of the radiation trying to traverse the atmosphere. Channel 2 is an atmospheric window which permits high transmission of energy. Channel 3 covers the major portion of solar radiation, since 99.8% is emitted at wavelengths up to $7\,\mu$. In turn about 80 percent of the thermal emission from the earth occurs in the band from 7 to $30\,\mu$ covered by Channel 4. Channel 5 was employed to gather data to compare with the television pictures obtained.

One of the more important results of the TIROS experiments as far as the ocean surveillance problem is concerned is that the presence of clouds could be discerned from examination of more than one channel of the radiometer (Reference 26). For example when high clouds are scanned, Channels 1 and 3 indicate peak values while Channels 2 and 4 form dips on the traces, the latter indicating the low temperature associated with high clouds. It thus may be possible to derive a logic circuit for cloud recognition and discrimination based on these considerations.

4.5.3 Summary

At this point it is appropriate to present Figure 4.12 which shows the spectral irradiance of the top of the atmosphere by the sun and also the range of spectral emittance associated with ship hulls, the ocean, and cold clouds. The sun irradiance derives from Reference 12. This plot again emphasizes that target emission is the important source of target information in the 7.5 to $14\,\mu$ atmospheric window. At shorter wavelengths and in daytime operations, the solar irradiance becomes increasingly important and the relative reflecting properties of the ship, ocean, and clouds become the predominant considerations. These properties will vary with such things as the zenith angle of the sun, the viewing angle of the sensors, the types of clouds in view, and the sea state.

Figure 4.12. Target and Background Spectral Radiation

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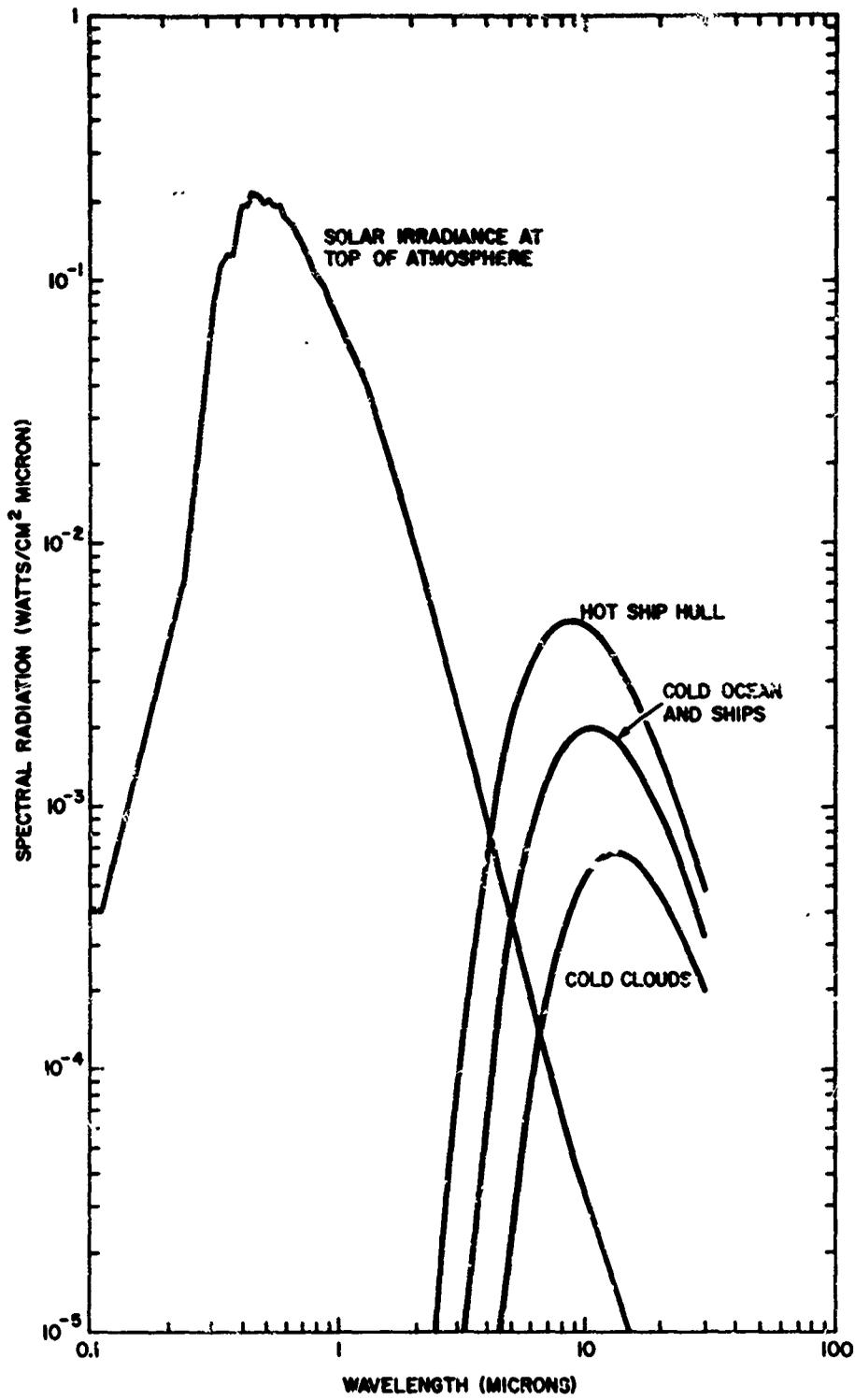
5. SYSTEM PERFORMANCE

The ultimate performance of an ocean surface traffic surveillance system would be to provide the identity (name and flag) of each ship on the ocean and determine its position, heading, and speed periodically from the time it leaves its initial port until it reaches its destination, so that its location at any time can be specified within a few nautical miles. Probably the first requirement of such a system is that complete, accurate, and timely departure-arrival reports are made available to an analysis center. Subsequently periodic enroute location reports, either self-reported or observed, are required to maintain an accurate track. Assuming now that enroute sightings are to be made from satellites, a series of events of increasing difficulty can be associated with the performance of the system. First, perception of an anomaly with respect to the normal background must occur. The anomaly must then be studied in order that it be recognized either as a ship, an iceberg, an airplane, etc. If the anomaly be recognized as a ship, it should then be classified as to a certain kind of ship, e.g. destroyer, tanker, passenger ship, etc. Ideally it should then be identified as a specific ship, say the nuclear powered ship Savannah.

Implementation of the search mode might involve a push broom technique in which an array of sensors looks straight down with a wide lateral view angle and scans on the basis of the motion of the satellite along its orbit. To relax the requirements of the wide lateral angle of view it is possible to achieve lateral scan by rotating or oscillating the sensors about an axis in the plane of the orbit. A variety of other scanning techniques are possible. It is not expected that man using a telescope would be capable of efficient scanning since the human visual system has a poor quantum efficiency at daylight levels (10^{-3}) and has a slow perceptual system time constant, i.e. > 0.1 sec. (Ref. 31).

The recognition phase of the process might be carried out electronically or it might rely, at least in part, on a human on board the satellite. Electrical discrimination processes might involve signal strength due to the

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anomaly, apparent size of the target, its apparent temperature, and speed, or some sort of spectral analysis could be resorted to.

The classification process might conceivably be worked out automatically either in the satellite or in an analysis center, using a catalogue of stored information on size-shape characteristics, stack or no stack, wake size and shape, speed, etc. Again a human on board the satellite might help the process.

The ultimate job of identifying the target might not take place in the satellite but would be performed in a ground based analysis center which correlates the sighting information with departure-arrival information and the prevailing track information of all of the ships at sea.

These latter tasks would be achieved with the data acquired by a supplementary set of instruments, directed by the search mode, to inspect more closely those regions of the gross scan pattern which contain anomalies. This phase might also be carried out by a scanning process, but one of finer resolution, which ultimately would create an image of the source of the radiation and permit recognition, classification, and perhaps identification of the target. Accomplishment of these tasks requires vast amounts of stored information and the proper division of this information between the satellite and the ground station constitutes one of the important considerations of the study of satellite surveillance systems. If some of the discrimination processes cannot be carried out in the satellite and all of the data on anomalies must be transmitted to the ground (with a resultant loss in resolution) then a limitation on information handling arises. The presence of man on board the satellite would undoubtedly help ease some of the data handling problems associated with the recognition and classification aspects of the task.

The subsequent subsections will be devoted primarily to an analysis of the process of detection using infrared sensors. The fundamental detection equations employed are presented as are properties of the present and future detectors applicable to the problem. Also presented are the signal levels to be expected for indication of the contrast between typical ships and the ocean for the orbit altitudes assumed. These factors are combined to determine the contrast temperature required for detection of typical ships by a selected size

of optical system operating from a satellite platform at 200 n. miles. Some discussion of tracking capability as well as recognition, classification, and identification is presented but an extensive analysis with respect to these subjects is beyond the scope of the current contract.

5.1   Detection Equations

It is necessary to express the detection capability of the automatic optical systems in terms of the target and system parameters. In this way the performance envelope of possible systems can be drawn using the practical technological and mission constraints. When considering only the detection of a target the systems can be divided into two categories – (1) detector noise limited systems and (2) background noise limited systems. (It is assumed that the system design is sophisticated enough so that the electronic signal processing does not limit the system performance.) The following paragraphs present briefly the development of the performance equations for these two types of automatic detection systems – performance is in terms of the minimum detectable signal.

5.1.1   Detector Noise Limited Systems

The sensitivity of most optical systems is determined by the noise inherent in the photosensitive detector element. There are several noise mechanisms which are important in the practical cases; current noise, thermal noise, generation-recombination noise, etc. Absolute noise level is not, by itself, a significant parameter, but must be considered in conjunction with the expected output signal levels with given amounts of radiation. For the purposes of engineering calculations the detector figure of merit, D^*, has been developed. Using this parameter, the ratio of output signal to noise level can be written

$$\frac{S}{N} = \frac{\int_o^\infty D_\lambda^* P_\lambda \, d\lambda}{(A_{det})^{1/2} (\Delta f)^{1/2}} \qquad (5.1)$$

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where

$\dfrac{S}{N}$ = signal-to-noise ratio at the detector

P_λ = target spectral power falling on the detector (watts/micron)

λ = wavelength (microns)

A_{det} = area of the detector (cm^2)

Δf = noise equivalent bandwidth (cps)

D_λ^* = spectral detectivity ($cm(cps)^{1/2}$/watt)

This spectral detectivity is essentially a property of the detector material and is available as a "catalogue" parameter. Some care must be exercised in using the D_λ^*'s in the literature, the detectivity being somewhat dependent on signal modulation frequency and very dependent on detector temperature.

It is convenient to define the target energy in terms of an equivalent irradiance at the aperture of the optical system. The effective equivalent irradiance, $\overline{H}$ is defined

$$\overline{H} = \frac{\int_0^\infty D_\lambda^* \ H_\lambda \ K_\lambda \ d\lambda}{(D_\lambda^* \ K_\lambda)_{max}} \qquad (5.2)$$

where:

K_λ = relative spectral transmission of the optical system

H_λ = target spectral irradiance at the system aperture, watts/cm^2 micron

$\overline{H}$ = effective equivalent irradiance, watts/cm^2

Defined this way $\overline{H}$ can be considered a monochromatic source at the wavelength of peak system sensitivity (i.e., where $D_\lambda^* \ K_\lambda$ is a maximum). Of

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course, the target irradiance being considered here is always the irradiance due to the <u>contrast</u> between the target and its background.

Using Equation (5.2) in Equation (5.1) yields

$$\frac{S}{N} = \frac{D_p^* \; \overline{H} \; A_{coll} \eta_t}{(A_{det})^{1/2} \; (\Delta f)^{1/2}} \tag{5.3}$$

where:

A_{coll} = collector area, cm^2

η_t = overall optical efficiency

D_p^* = (D_λ^*) max

Now the detector area is roughly determined by the focal length of the optical system and the required instantaneous field of view. Considering the detector itself as the field stop, the area is

$$A_{det} = F^2 \; \Omega$$

or

$$A_{det}^{1/2} = (\frac{F}{D_{coll}}) \; D_{coll} \; \Omega^{1/2} \tag{5.4}$$

where

F = effective focal length, cm

Ω = field of view, steradians

D_{coll} = diameter of collector, cm

The ratio F/D_{coll} is the effective "f-number" of the optical system. It will be seen that small values of this ratio are desirable -- the telescope optical system itself is restricted for engineering reasons, to $F/D_{coll} \gtrsim 1$. However, relay optics and immersed detector techniques can reduce the effective ratio to values near the theoretical minimum of 0.25.

Combining Equations (5.4) and (5.3) yields the basic performance equation for a detector noise limited detection system

$$\frac{S}{N} = \frac{\pi}{4} \; \frac{D_p^* \; H \; D_{coll} \; \eta_t}{(\frac{F}{D}) \; \Omega^{1/2} (\Delta f)^{1/2}} \tag{5.5}$$

5.1.2 Background Photon Noise Limited Systems

Many of the detection systems which should be considered for ocean surveillance are not limited by the internal noise of the system but by the noise produced by the uniform background. Specifically, the long wavelength systems (operating at about 7μ and more) are subject to this background limitation. This noise arises from the random emission of photons from the background. The resulting fluctuations are detected by the system and show up as the limiting noise in the output.

To determine the variation in photon noise with variations in system parameters, it has been shown that Bose-Einstein statistics give the mean square deviation in the rate of photon arrival as

$$\overline{N^2} = \overline{N} \left[\frac{\exp \left(\frac{h\nu}{kT_2} \right)}{\exp \left(\frac{h\nu}{KT_2} \right) - 1} \right] \tag{5.6}$$

where:

$\overline{N^2}$ = mean square fluctuation in rate of photon arrival

$\overline{N}$ = average rate of photon arrival

T_2 = background temperature

ν = radiation frequency

h = Planck's constant

k = Boltzmann's constant

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The bracketed term is approximately equal to 1 for the situations of interest here.

Now it is known that the average rate of arrival of photons at a particular radiation frequency is

$$\overline{N} = M(\nu, T_2) \frac{d\nu}{h\nu} \tag{5.7}$$

where $M(\nu, T_2)$ is the total power per unit area per unit frequency interval emitted by a blackbody at temperature T_2. From Equations (5.6) and (5.7) it is seen that the mean square photon fluctuation (and thus the resulting mean square noise from the photon detector) is proportional to the radiated power from the background which falls on the detector. Armed with this fact, one can determine the variation of photon noise with variations in system parameters by scaling measured noise values by the square root of the incident background radiation. [*]

It is convenient to characterize the measured performance of a background limited detector in terms of a spectral detectivity under specified background conditions. This detectivity, denoted as D_λ^{**} is given for a specific background temperature, T_2, and a specific detector field of view equal to 2π steradians. The functional relationship of this detectivity to S/N, Δf, and A_{det} is the same as shown in Equation (5.1). Conventionally the D^{**} is given for a background temperature of 295°K and, rigorously, some adjustment in D^{**} should be made accordingly. However, an error of less tha...

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[*] For this simple systems analysis a straightforward scaling procedure is satisfactory. However, a more rigorous treatment is possible. Photon noise can be determined analytically from the basic quantum physics of the radiators and the basic mechanisms of the photon detector. This more complete approach would account for a much wider variation in background temperature than is of interest here and would also determine the ultimate capabilities of photon noise limited systems. This analysis has been carried out in several publications, typically in Reference 32.

$\pm 20\%$ in D^{**} is incurred if the ocean temperature is assumed constant at $295^{\circ}K$ (see Reference 32 and Section 4.5.1). Therefore, in the following discussion it is assumed that the D_p^{**} is given for the background temperature of interest in the detection problem, and only the changes in background power incident on the detector due to geometrical factors need to be corrected for. If the background brightness is $B(T_2)$ in watts/cm^2 sterad, the effective background power falling on the detector, is

$$P(T_2, 2\pi) = \pi \ B(T_2) \ A_{det} \tag{5.8}$$

for a 2π sterad field of view and

$$P(T_2, \Omega) = \Omega \eta_t \ B(T_2) \ A_{coll} \tag{5.9}$$

for an optical system where

Ω = field of view of optical system, sterad

A_{coll} = collector area of optical system, cm^2

η_t = efficiency of optical system

This approximation assumes

(1) small Ω

(2) small $A_{coll}/(\text{Focal Length})^2$

(3) Negligible emission from optical elements

(4) Cold stops to shield the detector from the radiation emitted by the interior of the telescope.

The power in Equation (5.8) is that measured with the standard background viewing angle (2π steradians). Now the relative mean square photon noise in the actual system can be determined by simply taking the ratio of Equation (5.9) and (5.8). Going back to Equation (5.3) and using the relationships of Equations (5.6), (5.7), (5.8), (5.9) we can write the S/N for a photon noise limited system

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$$\frac{S}{N} = \frac{\overline{H} \ L_p^{**} \ A_{coll} \ \eta_t}{(A_{det})^{1/2} (\Delta f)^{1/2}} \left[\frac{P(T_2, \ 2\pi)}{P(T_2, \ \Omega)} \right]^{1/2}$$

or

$$\frac{S}{N} = \frac{\overline{H} \ D_p^{**} \ D_{coll}}{2} \left[\frac{\eta_t}{\Omega (\Delta f)} \right]^{1/2} \hspace{3cm} (5.10)$$

Equation (5.10) is the basic detection equation for the photon noise limited system.

5.2   Detectors

The critical component in the design and construction of any of these detection systems is clearly the photo-detector. There are available a great variety of detector materials which can be used for ocean surveillance and it is the purpose of this short section to present the capabilities of the most common ones and comment on their suitability for the problem at hand.

In this discussion the detectors of interest can be broken down into three loosely defined groups based on the portion of the spectrum in which they are sensitive:

Long Wavelength Infrared Detectors – This group includes the detectors sensitive in the wavelength region from about 7μ to about 14μ. This wavelength interval corresponds to a major atmospheric window (see Section 4.2) and can be used for the primary detection of hull radiation of a ship (See Section 4.4). Extrinsic germanium photoconductive detectors have been the most successful in this region and the D_λ^{**} versus λ curves for three of the best doped germanium detectors are shown in Figure 5.1. When operated in an optimum manner these detectors are all characterized by:

1. photon noise limited operation
2. very short time constants ($\approx 1 \mu$ sec)
3. extreme cooling requirements (operating temperatures well below that of liquid nitrogen).
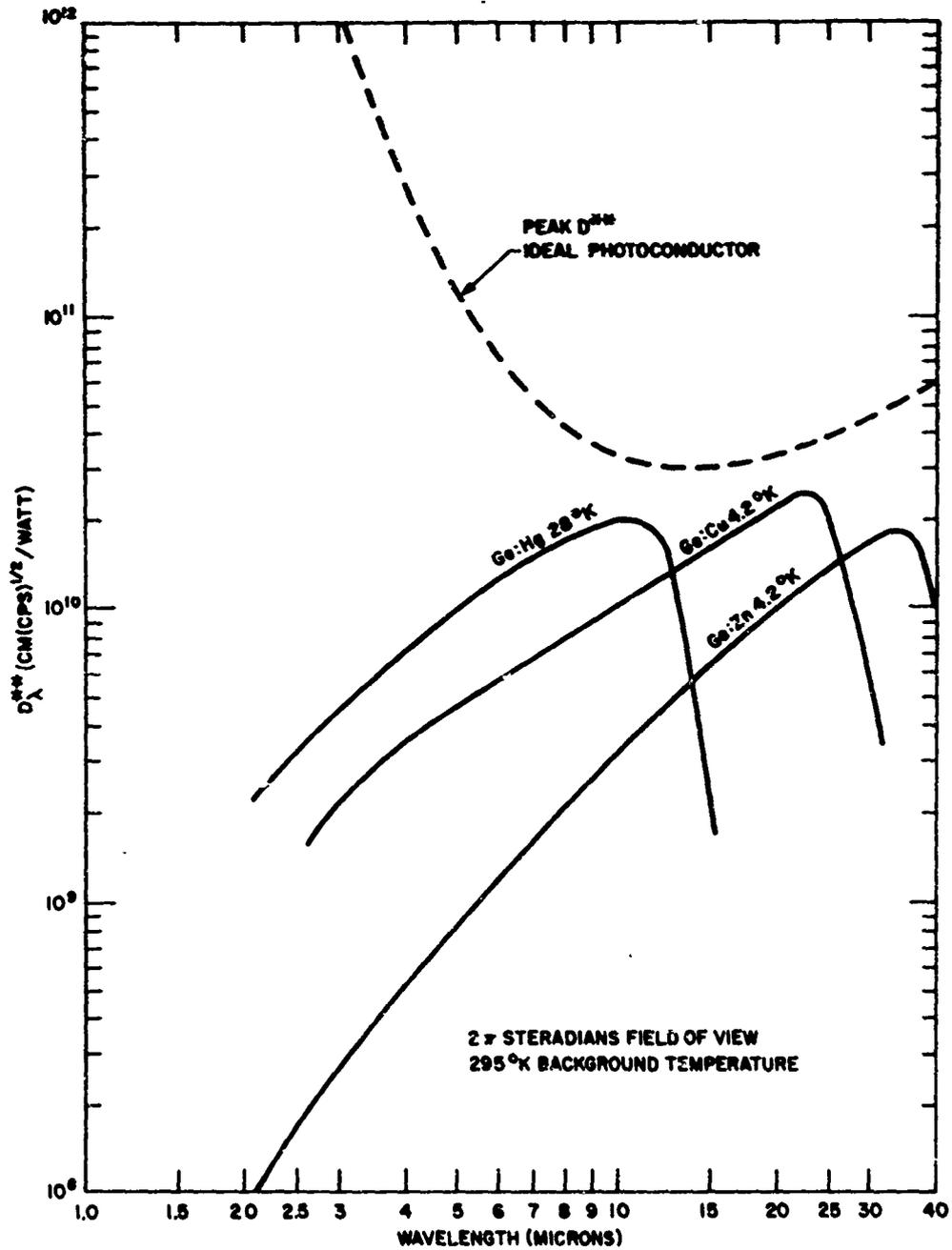
Figure 5.1. Long Wavelength Infrared Detectors

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It is of interest and importance to note that the peak D^{**}'s of these detectors are within about a factor of two of the theoretical maximum obtainable. An approximate upper limit of D^{**} is shown in Figure 5.1 as the curve labeled "Ideal Photoconductor". (Reference 32 gives a derivation of this theoretical curve.) The obvious conclusion is that there is little left to be gained in long wavelength detector technology as far as sensitivity is concerned. In principle long wavelength systems designed today will be as sensitive as those of the future.

Other types of long wavelength detectors such as thermistors, bolometers and thermocouples are not considered because they are considerably less sensitive than the photoconductors and have, in general, unacceptably long time constants. The theoretical ultimate sensitivity of these thermal detectors is also inferior to that of the photoconductors.

Short and Intermediate Wavelength Infrared Detectors — This group includes detectors sensitive in the wavelength region from about $2\,\mu$ to about $5\,\mu$. Several atmospheric windows occur in this region - notably the $3.2\,\mu$ to $4.2\,\mu$ window. This spectral region lies between that containing the major thermal emission of the ships' hulls and the spectral region containing the reflected sunlight from the target. Detection systems in this wavelength region will find most use as aids in discrimination against false targets but probably will not be used as a primary detection system.

A variety of photoconductive and photovoltaic detectors is available for application in this spectral region. Figure 5.2 presents D_λ^{**} for some of the most interesting. The technology of making some of these detector materials is quite empirical and there is generally some small variation in quoted properties — Figure 5.2 represents superior, or selected detectors for each type. In practical operation most of the detectors are limited by internal noise. As indicated in Figure 5.2 considerable control of the peak detectivity and the long wavelength cutoff is achieved through variation of the detector operating temperature.

Again it can be seen that the best detectors available today are very nearly at the ultimate of their sensitivity. The best detectors theoretically
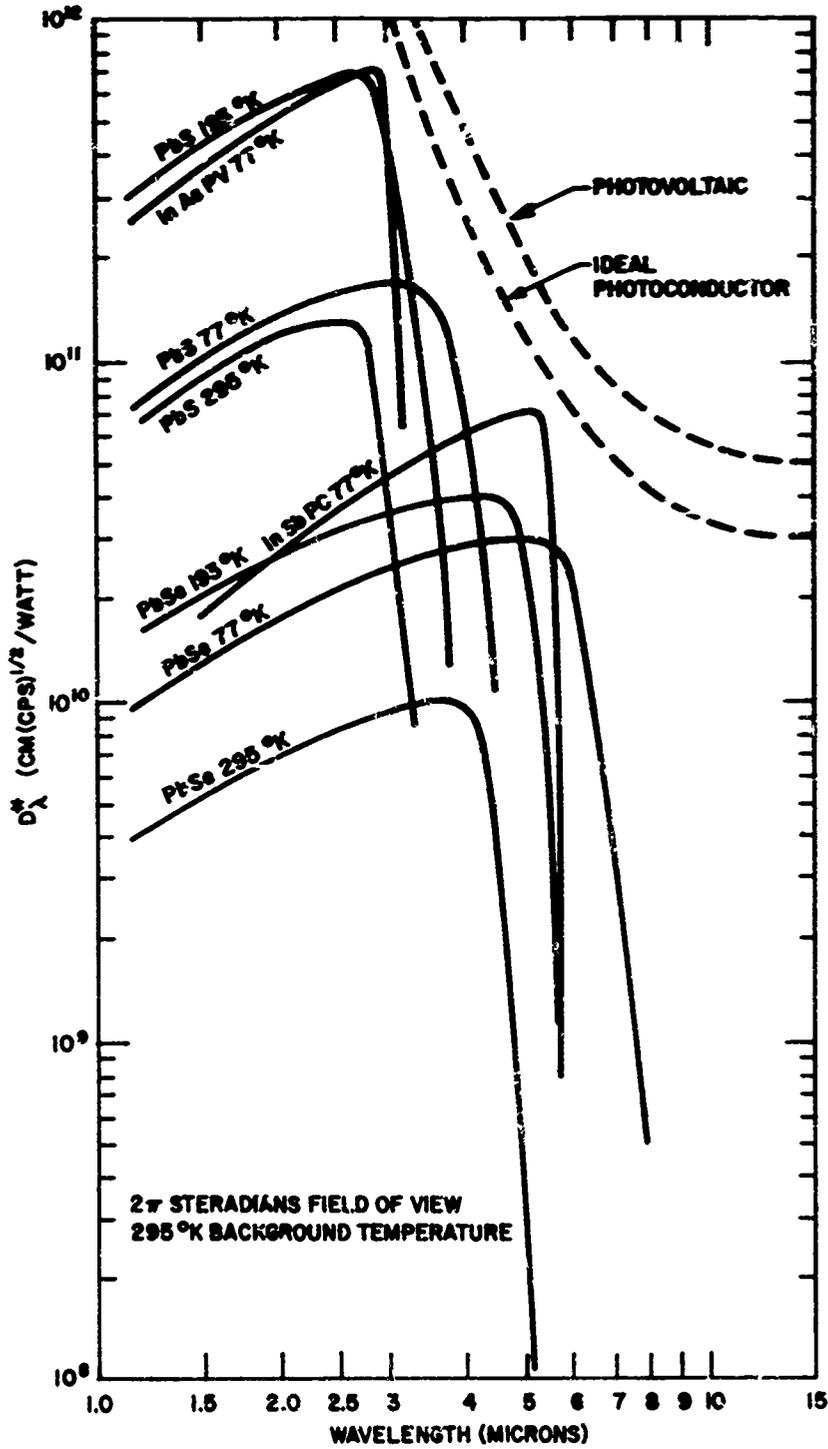
Figure 5.2. Short and Intermediate Wavelength Infrared Detectors

possible would not offer as much as an order of magnitude increase in sensitivity over current detectors.

Visible Wavelength Detectors – The atmosphere is relatively transparent between the ozone absorption band at about $0.3\,\mu$ and the first CO_2 absorption band at $1.4\,\mu$. Any system operating on reflected sunlight (or moonlight) would operate in this region. It is possible that some discrimination systems would rely on operation in this spectral region. Even though these detectors operate far from the theoretical maximum detectivities they are severely limited by background generated false alarms during daytime operation. A few representative detectors are shown in Figure 5.3. Low light television systems and image intensifier systems are not shown.

5.3 Theoretical Signal Strength

It is pertinent at this point to look at the magnitude of the infrared energy emanating from the target which arrives at the detection system in space. The irradiance on the collector is

$$H_c = \frac{P_c}{A_c} = \eta_{ET}\,\epsilon_t\,A_t\,\frac{\sigma T_t^4}{\pi}\,\frac{1}{r^2} \qquad (5.11)$$

where

P_c = the radiant power arriving at the collector

H_c = the radiant power per unit area incident on the collector

ϵ_t = the emissivity of the target

A_t = the planform area of the target

σ = the Stephan-Boltzmann constant

T_t = the effective radiating temperature of the target

A_c = the area of the collector of the detection system

r = the range between the target and the collector

η_{ET} = the fraction of the total energy emitted by the target and transmitted by the atmosphere in a particular wave length interval.

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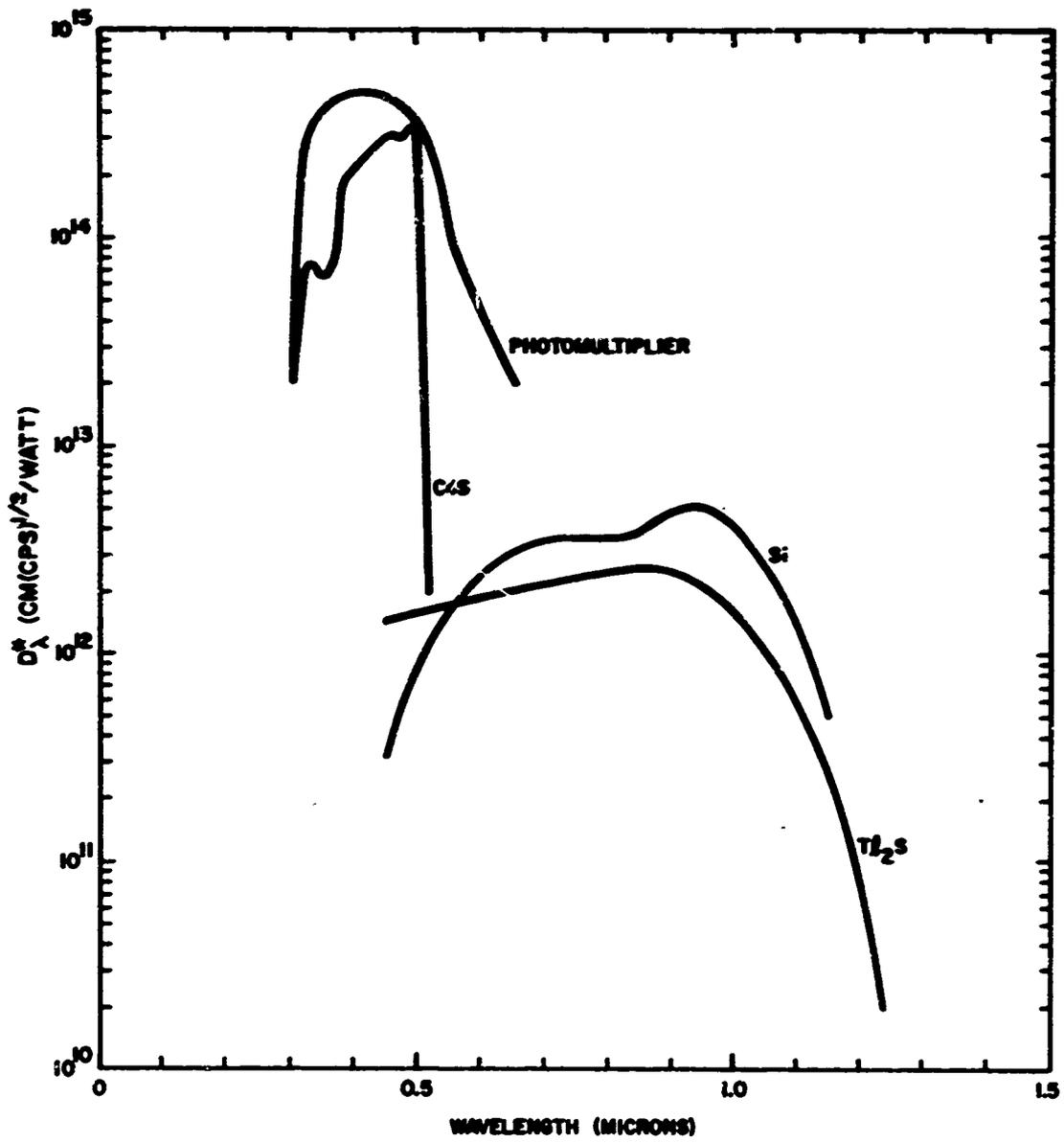
Figure 5.3. Visible Wavelength Detectors

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The latter quantity has a value of approximately 0.24 for a 300° K(27°C) target and the energy transmitted straight up through the atmosphere. Emissivity of the surface of the ships was taken as 0.9. Thus for the case of the detector looking straight down on the target the irradiance is as shown in Figure 5.4 as a function of orbit altitude for various representative military and commercial ships. These magnitudes currently offer no problem in the way of being detectable.

It is more informative to consider signal levels indicating the contrast between the target and the background. Let us now refer to an expression for the combined target and background power from the ocean arriving at the collector optics.

$$P_{(t+b)} = \left[\frac{\epsilon_t \, \sigma T_t^4 A_t}{\pi} \, \frac{A_c}{r^2} + \frac{\epsilon_b \, \sigma T_b^4 (A_b - A_t)}{\pi} \, \frac{A_c}{r^2} \right] \eta_{ET} \tag{5.12}$$

If we subtract out the signal which would be received if there were no target we have the magnitude of the anomaly due to the presence of the target, i.e.,

$$\Delta H_c = \frac{\Delta P_t}{A_c} = \frac{\epsilon \, \sigma A_t}{\pi} \, \frac{1}{r^2} \, (T_t^4 - T_b^4) \, \eta_{ET} \tag{5.13}$$

wherein ϵ for target and background is considered equal for the purposes of this discussion. If ΔH_c is expanded and rewritten with $T_t = T_b + \Delta T_1$ it becomes

$$\Delta H_c = \frac{\epsilon \, \sigma A_t}{\pi} \, \frac{4}{r^2} \, T_b^3 \, \Delta T \, \eta_{ET} \tag{5.14}$$

This form treats $\Delta T / T_b$ as very small with respect to unity. The contrast signal ΔH_c is now expressed in terms of the background temperature and the difference between the target and background temperature. A plot of this quantity per degree of temperature difference as it varies with orbit altitude for various military and commercial ships is shown in Figure 5.5.
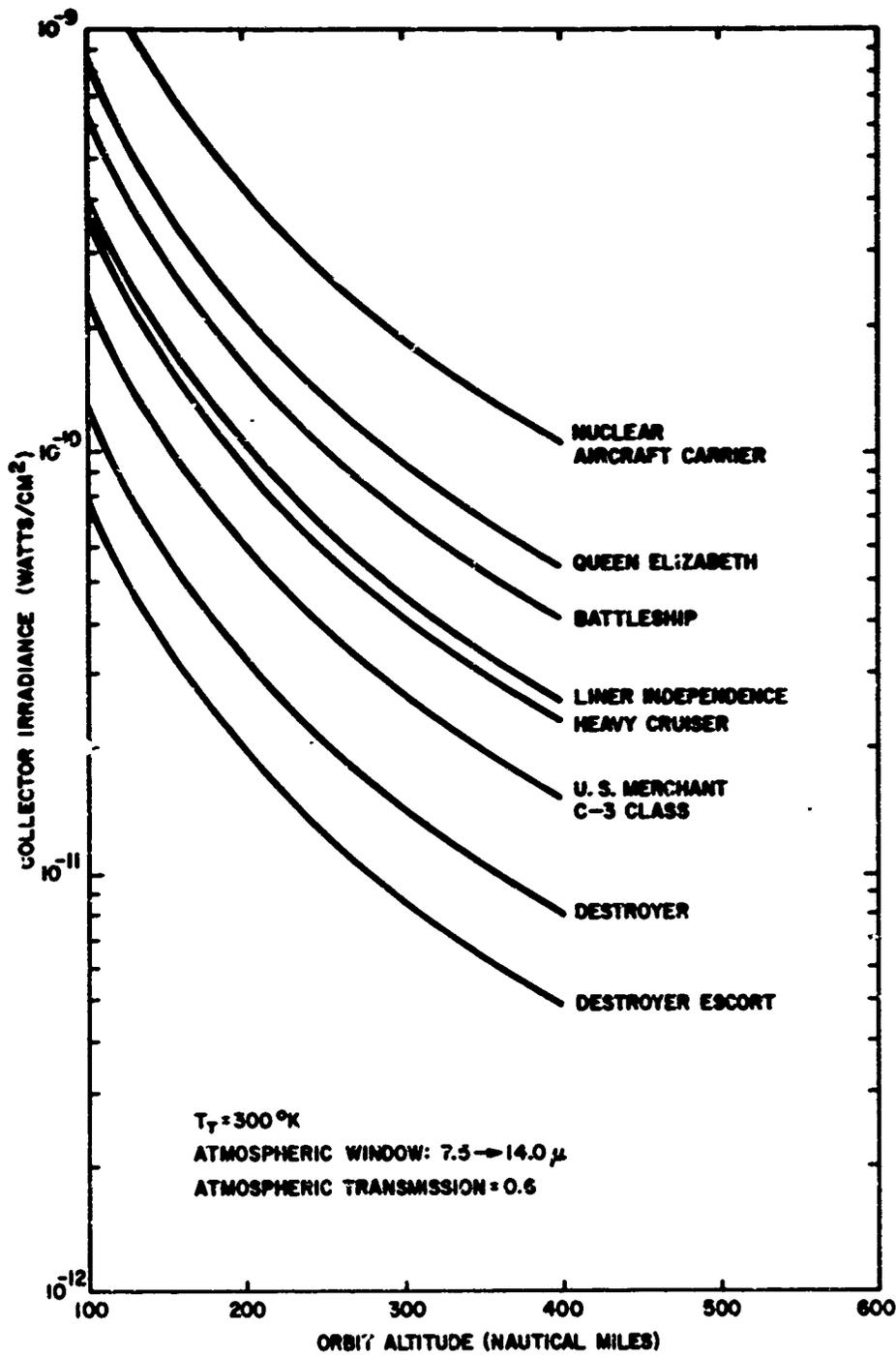
Figure 5.4. Collector Irradiance by Target

63   MC 65-145-R2
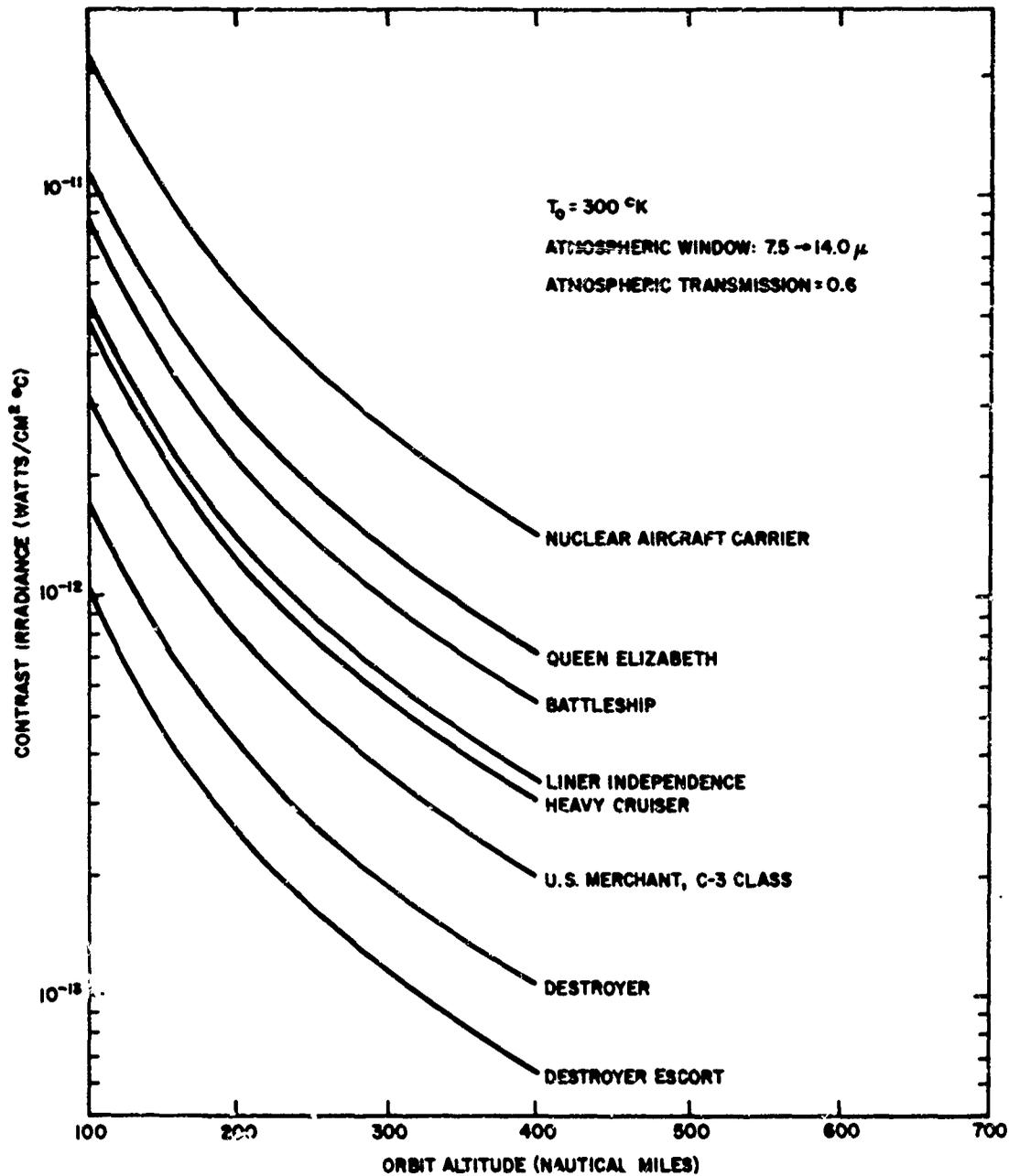
Figure 5.5 Contrast Irradiance on Collector per °C Contrast Between
Target and Background

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Note also that for similar temperatures and emissivities the relationship between H_c and $\Delta H_c / \Delta T$ is approximately

$$\frac{H_c}{\Delta H_c / \Delta T} \approx \frac{T}{4}$$

which for temperatures on the order of $300°K$ is 75.

Consider now the situation which exists if a cold cloud appears in the field of view of the detection system. If we consider the ocean background as our reference level again, the contrast between it and the cloud will then be negative (again using Equation 5.14 and treating the cloud as the target with a negative ΔT). Thus, it is not inconceivable that for the case of a hot ship and a cold cloud or portion of a cloud, in view at the same time, that the resultant signal contrast remains at or near zero, and no detection is made.

The appearance of the cold cloud at night is probably even more important since after sunset, ships cool off and usually become cooler than the surrounding ocean and so can be detected only as negative contrast. But a portion of a cold cloud would also generate negative contrast. The implications are that it will be desirable and probably necessary to implement the system to recognize the presence of clouds.

5.4   Typical System Performance

To demonstrate the feasibility of detecting individual ships against the ocean background a typical system is considered and its performance estimated. The problem assumed is that of detecting in the 7.5μ to 14μ region, all of the ships which are visible to a satellite-borne system. The problems of cloud cover and false alarms are not considered right here, just the problem of detecting the ships' radiation.

The simplest type of scheme to visualize is a pushbroom type of scanner in which an array of detectors is placed in an optical system so that the field of view forms a line perpendicular to the line of flight of the satellite. The optical elements are fixed and the scanning action is provided by the

motion of the vehicle. Along the line of flight the size of the field of view is determined by the resolution o. the optical system and the allowable system electronic bandwidth. Perpendicular to the line of flight the field of view extends to the horizon or to the edge of the ocean region not covered by the previous or next pass of the satellite system.

Starting with Equation 5.10 for a background limited system,

$$\frac{S}{N} = \frac{A \, D_p^{**} \, D_{coll}}{2} \left[\frac{\eta_t}{\Omega (\Delta f)} \right]^{1/2} \tag{5.10}$$

If the peak signal is to be detected the field of view parallel to the flight path should be at least large enough so that the target is on a detector about three system time constants (i.e., 3τ). If rectangular fields of view are used, each element can be represented,

$$\Omega = \ell_\Omega \, w_\Omega \tag{5.15}$$

where the length, ℓ_Ω is perpendicular to the line of flight and the width w_Ω is along the line of flight. Satisfying the dwell time constraint means

$$w_\Omega = 3 V \tau$$

where V is the apparent angular velocity of the target (the size of the target being neglected). Conventionally

$$\Delta f \simeq \frac{1}{2\pi\tau} \tag{5.16}$$

Thus,

$$\Omega (\Delta f) = \frac{3}{2} \frac{\ell_\Omega V}{\pi} \tag{5.17}$$

and the detection equation becomes

$$\frac{S}{N} = \frac{\overline{H}D_p^{**} D_{coll}}{2} \left[\frac{2\pi \eta_t}{3 \ell_\Omega V}\right]^{1/2}$$

(5.18)

Reasonable and achievable system values can be assumed for our typical system. A large peak signal-to-rms noise ratio is assumed to effectively eliminate false alarms due to internal system noise.

$$\frac{S}{N} = 10$$

Detector = Ge:Hg (see Figure 5.1)

$$D_p^{**} = 2 \times 10^{10} \text{ cm cps}^{1,2}/\text{watt}$$

$$D_{coll} = 50 \text{ cm}$$

$$\eta_t = .8$$

$$V = 2 \times 10^{-2} \text{ rad/sec (for h} = 200 \text{ nm)}$$

Rearranging Equation 5.18 and using the above values yield,

$$H/(\ell_\Omega)^{1/2} = 2.2 \times 10^{-12} \text{ watts/rad}^{1/2}\text{cm}^2$$

(5.19)

which is the detectable target effective contrast irradiance per square root of angular length of each pushbroom element. For example a 1 radian field of view perpendicular to the flight path would allow detection (i.e., S/N = 10) of 2.8×10^{-12} watts/cm^2 at the system aperture.

A more meaningful result can be gained by making use of the target contrast irradiance information developed in Section 5.3. In Figure 5.5 the total contrast irradiance from 7.5 to 14μ at the system aperture is given as a function of orbital altitude and for several typical ship types. If a nominal sea temperature of 300°K is assumed an effective irradiance can be computed for the Ge:Hg detector in terms of the contrast temperature between the ship and the ocean, i.e.,

$$\frac{\Delta H}{\Delta T} = \int_{7.5}^{14} \frac{D_\lambda^{**}}{D_p^{**}} \frac{\Delta H_\lambda}{\Delta T} \, d\lambda \qquad\qquad (5.20)$$

(It can be shown that this linearization of H with respect to T is still a reasonable approximation when the integration is made over this spectral region.)

Furthermore, if a specific altitude is selected – say 200 nm – this effective irradiance can be computed as a function of angle from the nadir. This has been done, accounting not only for the change in range between the system and the target, but also the increase in absorption due to the increased atmospheric path length as the horizon is approached. The results are shown in Figure 5.6 as effective contrast irradiance per degree temperature difference between ship and ocean. It is assumed in the figure that the projected area of the ship seen by the system is constant with vertical aspect angle and the irradiance is given for a collector perpendicular to the line of sight.

Using this data, Equation (5.19) can be rewritten

$$\Delta T = \frac{2.2 \times 10^{-12}}{\frac{\Delta H}{\Delta T}(\text{type}, \theta)} \, (\ell_\Omega)^{1/2} \qquad\qquad (5.21)$$

which gives the minimum detectable temperature difference as a function of field of view length for a given ship type and scan angle.

Clearly the values of ℓ_Ω should decrease toward the ends of the detector array (i.e., at larger scan angles) because the effective contrast irradiance is smaller, for a fixed temperature difference, as the horizon is approached. Values of ℓ_Ω have been selected, more or less arbitrarily, starting with $\ell_\Omega = 0.5$ radians, centered at $\theta = 0$, and progressing outward with $\ell_\Omega = 0.25$, .15, .10, and for $.75 \leq \theta \leq 1.20$ a series of elements with $\ell_\Omega = .05$ rad. With these values, the previously cited system parameters, and the data from Figure 5.6, the minimum detectable (S/N = 10) temperature difference has been computed for four ship types and is shown in Figure 5.7 as a function of scan angle.
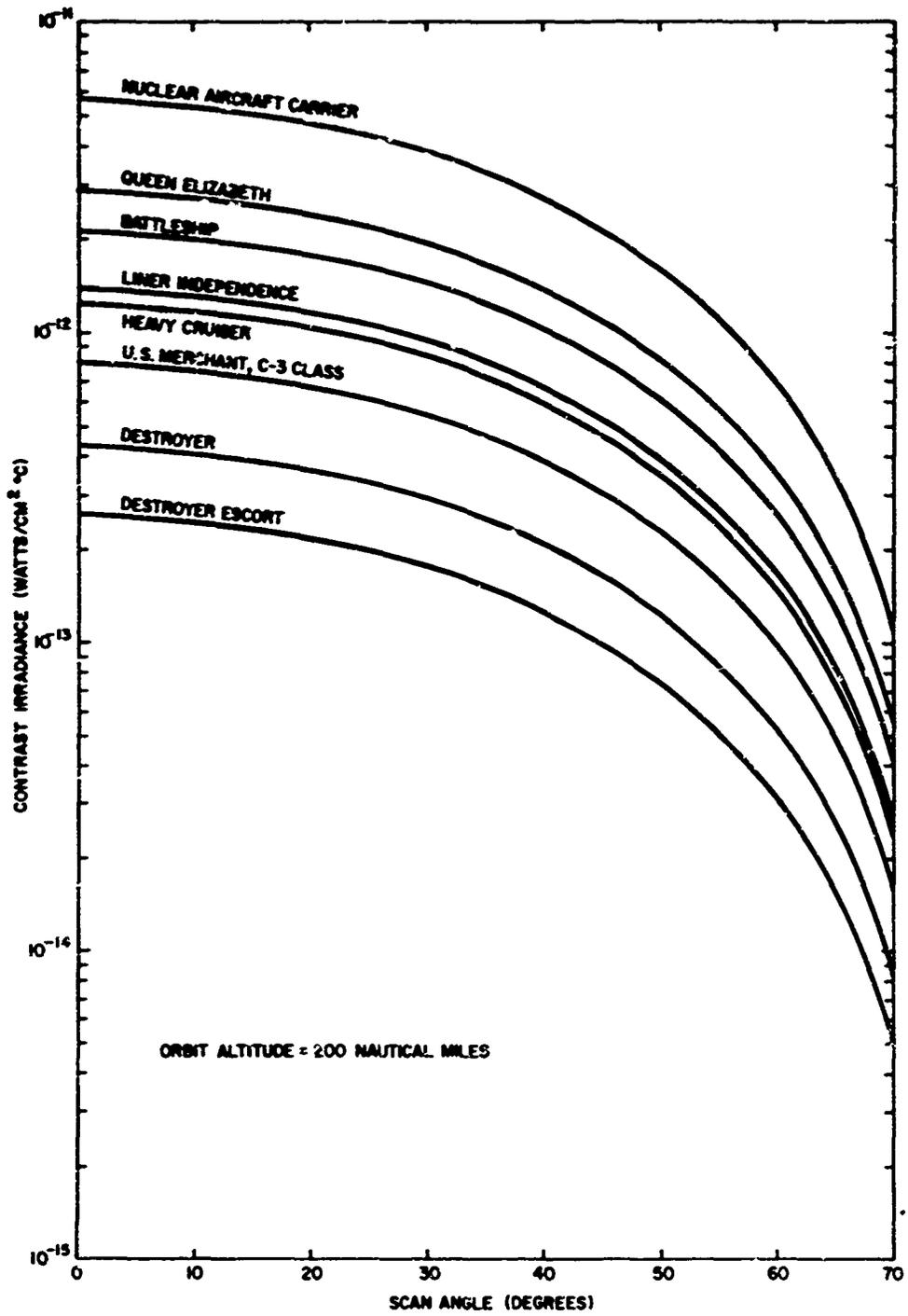
Figure 5.6.   Effective Contrast Irradiance on a Ge:Hg Detector
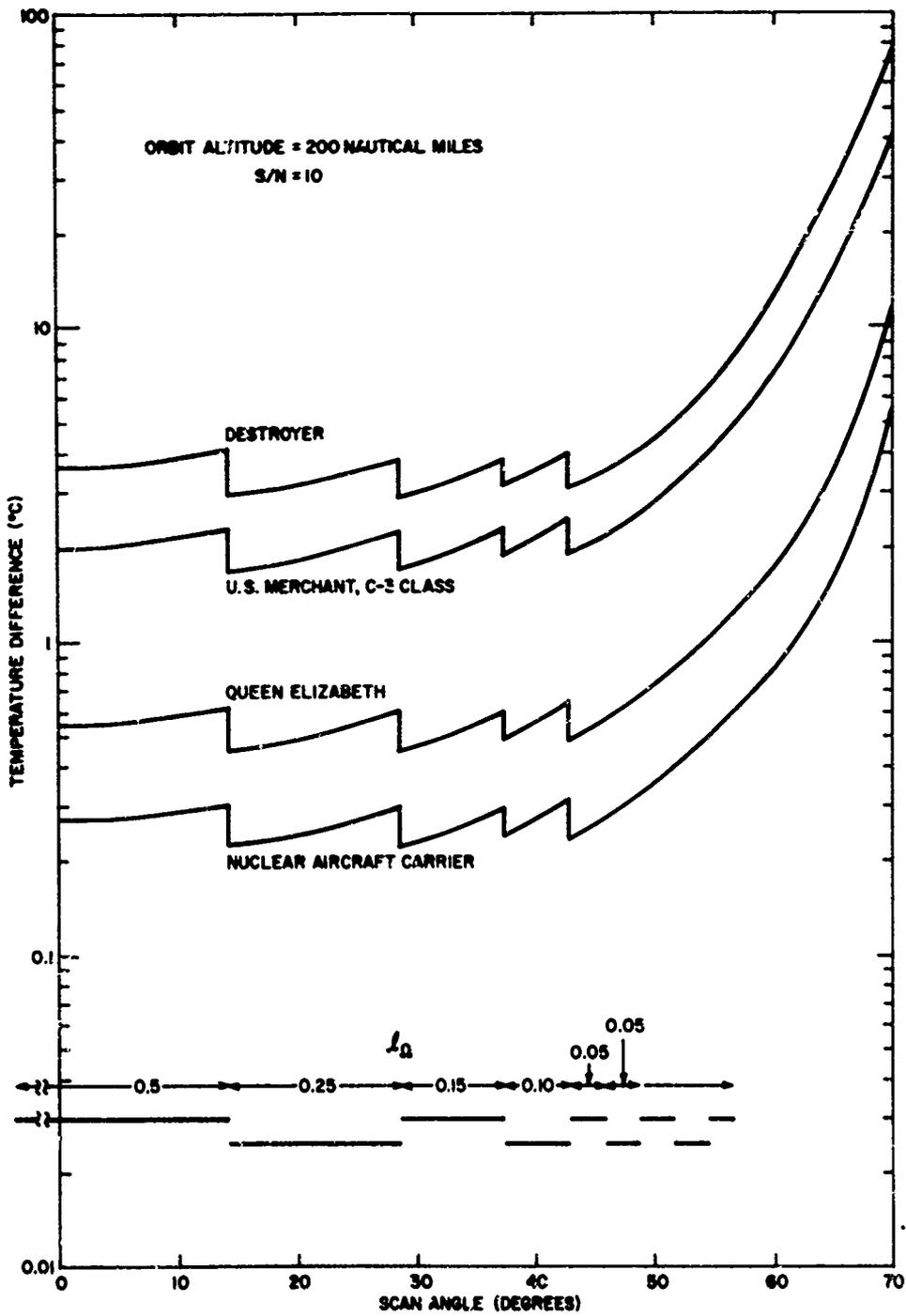
Figure 5. 7.   Temperature Contrast Required for Detection

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The system parameters chosen for this example have been optimized for no particular mission or operational requirement. It is of importance to note some of the trade-offs that might be made to improve performance for a particular requirement. Referring to Equations (5.18) and (5.19), the following parameters can be modified to advantage:

<u>Collector Diameter</u> – 50 cm was chosen arbitrarily, a 100 cm diameter system certainly is within the current state of the art and would lower the required ΔT by a factor of two.

<u>Field of view</u> – smaller fields of view (ℓ_Ω) can be used to gain sensitivity. This superior sensitivity would be bought with increased system complexity. The system used for the above calculation is certainly a modest one in terms of the quantity of electronics and the detector technology required.

<u>Signal-to-noise-Ratio</u> – as in any noise limited system the effective sensitivity can be improved by lowering the detection threshold, however, the false alarm rate would increase. The mission requirements would set the compromise between sensitivity and false alarm rate.

Figure 5.7 represents typical system performance and a general conclusion can be drawn. It is clear that ship detection in the $7.5\,\mu$ to $14\,\mu$ region can be done over vast segments of the ocean by a single satellite-borne system. The optical system required to achieve this has reasonable parameters in terms of today's state-of-the-art, and the minimum detectable contrast is low enough so that meaningful census data can be obtained. It should be noted, that the required temperature difference increases dramatically near the horizon. To bring the required ΔT of $\vartheta = 70^\circ$ down to levels shown in Figure 5.7 for $\theta = 0$ would require unrealistically small ℓ_Ω, unrealistic in terms of the number of detector elements and signal processing channels required to obtain complete coverage.

To achieve contiguous coverage with one satellite it is necessary with a 200 n. mile orbit to use a scan angle of approximately 68 degrees. (See Figure 4.4). From Figure 5.7 this is obviously in the region in which

unrealistically small ℓ_η values are required to achieve reasonable values of required temperature contrast. Thus to insure contiguous coverage with practical instrumentation of a push broom system it would be necessary to employ two satellites.

Another point of interest concerns the implications of the required temperature contrast. Since the contrast between the ship and the ocean can vary from positive to negative during the course of a day, the length of time during a day when a ship can be detected depends on the magnitude of the contrast temperature required. In Table 4.2 for example, there are several instances of post-sunset measurements which indicated temperature contrasts of 3 degrees or less. From Figure 5.7 it is apparent that from a 200 n. mile orbit for the system under consideration, a ship would have to be larger than a destroyer to be detected with a $3^{\circ}C$ contrast. For detection of $1^{\circ}C$ contrast the ship has to be larger than a C-3 class merchant vessel. Also throughout any given day a ship will spend considerably less time at contrast greater than three degrees then it will at contrast greater than one degree.

It would be interesting and pertinent to determine the temperature contrast for typical ships as it varied with time throughout days (and nights) with differing amounts of insolation. It then might be possible to show how available detection time during a day varied with system required temperature contrast and amount of solar insolation.

5.5 Tracking

During the ocean surveillance mission it undoubtedly will be required that individual targets be tracked with rather high precision. This precise tracking would serve one or both of the following purposes

a. obtain accurate target position information

b. direct and stabilize other optical sensors so that visual examination and/or automatic discrimination, classification and identification can be carried out.

The most efficient type of operation would be one in which a detection system would initially pick up a target, do some preliminary discrimination and then designate the approximate location of targets of interest. Then the tracking system would automatically search the area indicated by the detection system and lock onto the target. It is assumed that tracking accuracies on the order of a few seconds of arc will be required.

The details of the tracking problem - details such as track accuracy, allowable acquisition time, type of output required, bandwidth, etc. - enormously effect the character of the final tracking system. Few specific statements can be made until these requirements are established. However, a few general observations can be made.

Basically, there is no difference in the S/N calculations between detection and tracking systems, and Equations (5.5) and (5.10) could be used to determine the signal-to-noise ratio of the detector. It should be noted that S/N is inversely proportional to $(\Omega \Delta f)^{1/2}$. Ultimately the allowable acquisition time and the accuracy of the initial designation (i.e., the area which must be searched by the track system) set the value of $\Delta f\, \Omega$.

A simple example is cited in order to show the capabilities of a typical tracking system. The detection system of the previous section is assumed. If w_Ω is set equal to .005 radians (thus requiring a 1.9×10^3 cps bandwidth in the detection system) a convenient tracking system would have the following parameters

$$\Omega \;=\; (5 \times 10^{-3}) \times (5 \times 10^{-3}) \text{ radians}^2$$

$$\Delta f \;=\; 20 \text{ cps (nominal)}$$

$$D_{co_{..}} \;=\; 50 \text{ cm}$$

$$\eta_t \;=\; .8$$

$$D_p^{**} \;=\; 2 \times 10^{10} \text{ cm cps}^{1/2}/\text{watt}$$

Further if the tracker gave error signals proportional to target position over the center 100 sec of arc ($\approx 5 \times 10^{-4}$ radians) of the field of view and constant amplitude signals outside of that region, a $(S/N)_{max} = .00$ would give a random uncertainty in target position of 1 sec of arc at boresight. Since the

instantaneous field of view of the tracking system has the same width as the detection system, the search function is reduced to a single sweep of the tracking field of view along the field of view designated by the detection system. The nominal bandwidth (20 cps) would allow the sweep of the center detection field of view in about 15 seconds. The tracking system bandwidth can be made inversely proportional to the length of scan required thereby increasing the tracker sensitivity. By this simple method the tracker's sensitivity to temperature difference follows exactly that of the detection system of Section 5.4. The reduction in bandwidth requires a slower scan rate, but the shorter l_Ω of the detection system means better initial designation and thus a smaller scan. The acquisition time remains constant.

Thus Figure 5.7 shows also the minimum temperature difference required to track to an rms uncertainty of 1 sec of arc for the tracker parameters assumed.

5.6   Recognition, Classification, and Identification

Once an anomaly has been detected by the surveillance system, it must be recognized by the system and accepted as a ship to be classified and identified, or rejected as some uninteresting object such as an iceberg, a cloud, an aircraft of some kind, etc.

In view of the fact that there will be a large number of ships to observe in addition to signals from other sources to analyze, one cannot rely on a human operator alone to process all of the anomalies in the search. It is necessary, therefore, to evolve electronic and/or other methods to execute all or most of the steps in the recognition procedure. Similarly portions of the classification and identification phases of the problem must be automated.

The process of recognition would evolve from a systematic analysis of the characteristics of the radiation arriving from the target and the background, including all objects other than the target which might be in view. A system of logic circuits should be derived to ascertain the presence or absence of known characteristics of the target and the spurious objects. Consideration must be given to the fact that the contrast between a ship and the ocean can be

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either positive or negative. The presence of cold clouds might be derived by sensing short wavelength radiation indicative of reflected radiation from the sun. But this reflected radiation might also be indicative of snow since the spectral radiances of clouds and snow were qualitatively similar in the results shown in Reference 25. There was an indication there that high clouds might be indicated by higher readings in the 2 to 2.6 μ region. Other considerations which might permit recognition are the effective temperature observed, the magnitude of the measured values, apparent size and shape of the target, polarization of signals, target speed, and possibly stereo effects to indicate height and/or speed.

The processes of classification and identification require increasingly greater resolution capabilities on the part of the sensing systems. The need arises for catalogues of stored information pertaining to hull size and shape wake size and shape, the presence or absence of a stack, speed, etc. Automatic pattern recognition is desirable to achieve classification. If the ultimate task of identifying an individual ship is to be successful, reliance will probably have to be placed on an association procedure with accurate departure-arrival information or prevailing track information.

With respect to the greater resolution requirements associated with classification and identification it is important to point out the advantage of the inherently higher resolving power of optical systems over other types of sensors which might be used for space-based ocean surveillance. Not only does this higher resolving power aid in obtaining more exact position information, but it also opens up the possibility of gaining more information about the target in terms of its shape, size and other geometrical features. The feasibility of certain types of discrimination and target identification follows directly from an analysis of possible imaging capability.

To establish the general magnitude of the resolving power of the optical system it is convenient to consider the Rayleigh diffraction limit. A perfect optical system is limited by the diffraction of the energy through the entrance aperture, and the half-angle subtended by the image of a point source at infinity can be no smaller than

$$\gamma = 1.22 \frac{\lambda}{D}$$

where

$$\lambda \quad = \quad \text{wavelength of radiation}$$

$$D \quad = \quad \text{diameter of entrance aperture}$$

Practical optical systems can approach this performance, particularly at the longer wavelengths.

A second resolution limit which is also important is that due to the earth's atmosphere. Because of atmospheric turbulence, scattering, etc. there is a loss in image quality when an object is viewed through a large mass of air. Earth based astronomical observations, under the very best conditions, are limited to 0.5 to 2 arc seconds in resolution due to image blurring and image dancing. When objects on the earth are viewed from space the atmospheric degradation of image quality will be less since the disturbances are much closer to the object than to the observer. Although empirical studies of earth-based observations are available, no comprehensive study of the space-based problem is available. For the purposes of discussion a 1 arc sec resolution limit imposed by the atmosphere is <u>assumed.</u>

Figure 5.8 shows the diffraction limit of resolution as a function of wavelength for three aperture diameters. A 100 cm diameter aperture is assumed to represent the largest reasonable system. Also shown is the 1 arc sec limit assumed for the atmosphere. For purposes of comparison the typical length of an aircraft carrier (1000 feet) and the typical width of a destroyer (40 feet) are shown in terms of angle subtended at typical orbital altitudes. It should be noted again that the Rayleigh limit describes the performance of the optical elements only, and that any automatic equipment operating in the image plane of the optical system will result in some further degradation at the system output.

From Figure 5.8 it can be seen that the sizes of ships can be determined to within 30 or 40 feet even when operating at the long wavelengths if an aperture diameter of approximately 100 cm is used. Certainly objects larger than a ship can be automatically rejected as a false target since the largest ship dimensions are easily resolvable. In principle a long wavelength system could automatically determine that a ship-sized object was longer than it was
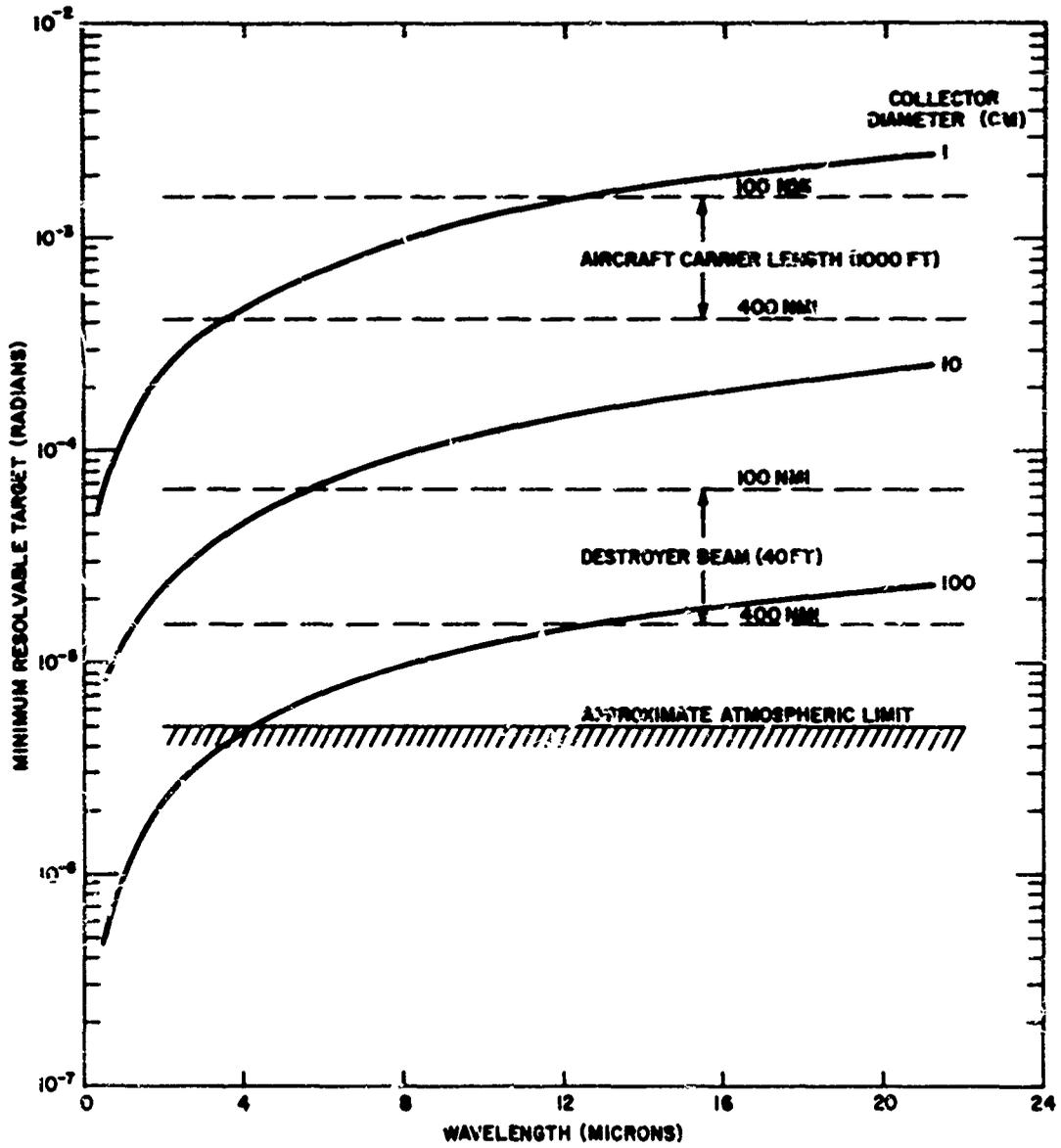
Figure 5.8. Minimum Resolvable Target

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wide and establish the orientation of the long axis. At wavelengths beyond about 7 μ automatic discrimination against some false targets can be accomplished on the basis of a resolved image. However, classification and identification of the image at these wavelengths must be restricted to criteria based on approximate size and aspect ratio.

At wavelengths shorter than about 7 μ more detail is resolvable, particularly in the visible portion of the spectrum wherein details of a ship's configuration can be resolved. The image degradation due to the atmosphere appears to be the ultimate limit here. However, the 1 arc sec limit assumed in Figure 5.8 still allows resolution of about 3 feet at a range of 100 nm. Direct observation of sunlit targets by a human operator, and analysis of low-light-level TV outputs seem to be the obvious approaches for target identification and classification by image analysis.

The ultimate product of a useful ocean surveillance system has to be the accurate prediction of the location of any ship of interest as a function of time. The accuracy of the prediction depends on a variety of things, e.g., variations in ship's heading and speed during an interval of time, knowledge of ship's position at the beginning of an interval, accuracy of the reported position of a ship at any time. With respect to the latter consideration as derived from a satellite surveillance system, the accuracy of a given location will depend on the pointing accuracy of the instruments used on the satellite as well as the accuracy with which the location of the satellite is known. A sensitivity analysis involving the location error of a ship as a function of instrument errors and errors in the satellite location at the same time the ship is reported is vital in establishing the true worth and feasibility of the satellite surveillance system. Also of interest are errors due to refraction effects in the atmosphere and image shifting due to turbulence in the atmosphere. A sensitivity analysis would help determine the kind of instrumentation which would be required to attain a specified accuracy in locating a ship.

The tasks of recognition, classification, and identification require the processing of large amounts of data. Much of the data is gathered by the sensors but another large amount of reference data has to be retained in storage to facilitate the classification and identification procedures. The

configuration of the whole surveillance system depends on the division of the discrimination processes between satellite and ground.

To carry out an analysis of this problem it is necessary to establish the magnitude of the data handling problem associated with transmission of various kinds of data from the satellite to ground based stations. For example how many bits of information are required to transmit the location, heading, speed, length, or width of a ship? More important is how many bits are required to transmit a complete image of a ship while maintaining a certain resolution in the reconstructed image at a central processing point? Also pertinent is how much storage is required on board the satellite if much of the classification procedure is carried out on board?

Extension of this approach would lead to a consideration of trade-off on data handling requirements for satellites, ground based relay stations, and ground based central processing units.

Aside from these more detailed considerations of the investigation, there is a broad aspect of the problem which should not be overlooked, i.e., what is the overall ability of a satellite-based ocean surveillance system using the optical spectrum to recognize, classify, and identify ships at sea. Logical to consider in this viewpoint are such items as probability that a particular section of ocean is under loud cover, probability that a ship will be in an un-obscured section of the ocean, probability of detection of a ship which is on an unobscured section of ocean, overall probability to recognize, classify, and identify a ship. Pursuit of this approach should establish the number of ships about which useful information can be gathered by a satellite based ocean surveillance system. Comparison of this number with the total number of ships at sea at any time will give some indication of the capability of the system to augment or supplant current sources of shipping traffic data. Representative values of the first two items could be established by studies of extensive cloud cover data and ship traffic patterns. With respect to the cloud cover data, it is important to determine the cloud cover statistics for the applicable portion of the electromagnetic spectrum. For example, most of the cloud cover statistics gathered prior to the advant of operational satellites was based on visual observations. These statistics do not necessarily

apply outside the visible portion of the spectrum. There is evidence accumulating that even in the visible region discrepancies can occur. It has been found that an airplane pilot observed a clear sky below him in flight, yet photos taken from his airplane showed clouds which were also observed from the ground. Appropriate statistics for the proper wavelength interval may be available from the TIROS or other satellites or high flying aircraft. Proper values of the detection probability of a ship in an unobscured situation will eventually derive from experimental programs. Ultimately this overall detection probability analysis must be performed to justify the practicality of providing ocean surface traffic data gathered by satellite based observations in the optical portion of the electromagnetic spectrum.

The current study has been concerned with the traffic on the oceans, but the negative information that certain ships were not on the ocean but were in port might also help in the classification and identification problem. This type of information could be helpful in situations wherein cooperative reports were late or inaccurate or the source had turned uncooperative; or wherein the ships in port were "bloc" ships in foreign ports. This problem involves different background conditions which would have to be investigated but the classification-identification aspects of the problem should be improved since there are probably more chances to observe the targets in a given background situation, and the comparison of several nearby targets among themselves and with their surroundings should yield more information about them all.

6. THE ROLE OF MAN IN A SATELLITE

There are many times during the development and operation of satellite systems in which the presence of a human on board the satellite would materially increase the yield of the experiments or missions involved. Some of the ways in which a human on board would help are:

1. Provide vernier orientation control of the satellite when necessary.

2. Check the initial alignment and calibration of instrumentation.

3. Monitor the progress of experiments and refine them if necessary and possible.

4. Capitalize on unusual and unforseen events.

5. Select proper sensors.

6. Recognize, classify, identify observations.

7. Analyze and edit data and relay it to ground stations.

8. Carry out special requests of high priority.

9. Maintain and repair the experimental and vehicle equipment.

Many of these considerations are particularly pertinent in the case of surveillance satellites, e.g., data handling. When an anomaly is detected by the search system it must then be inspected with a high resolution system to try to recognize and/or classify it. In the absence of a recognition-classification system in the satellite, a picture or digitized description of every anomaly discovered by the search system will have to be sent back to earth and relayed to an analysis center. To maintain high quality of the picture ultimately produced at the analysis center, much information must be transmitted. A cumbersome network of relay stations would be required to be able to handle all of the data. If some of the recognition and classification could be carried out in the satellite, requirements on data transmission could be alleviated. A man on board would help considerably in this area. Using a high quality telescope, perhaps one which is motion compensated, or by

viewing a high resolution IR picture, the man could decide that the anomaly discovered by the search system was indeed a ship of interest, or was a small cloud, an iceberg, a small piece of land, or some other unimportant object.

Man's ability to see from a satellite when "seeing" conditions are good, has exceeded expectations. A rule of thumb for the practical limit of human vision has often been taken as one minute of arc. Some work of Blackwell (Reference 33) however, illustrates that the smallness of an object that can be detected is a function of size, contrast, and illumination, so that for many combinations of illumination and contrast the smallest object which can just be seen subtends 10 minutes of arc, while for other conditions objects of approximately 1/2 minute of arc can be seen. The minimum visible white square on a black background has been found to correspond to 10 seconds of arc. This in turn is 30 feet at 100 n. miles. Observations by the astronauts and the study of pictures substantiate that the extended length of long ribbon-like features reduces the necessary width for detection to one-sixth or less of the minimum diameter of a circular object. Thus, roads, rivers, and railroads have been observed from satellites under good seeing conditions. In some instances the astronauts have been able to recognize vehicles. (Ref. 29).

Much of man's ability to see and discriminate relates to his experience with, and knowledge of, the kind of a scene he is viewing. It is in this surveillance type of situation in which man processes the stimuli and compares them with a vast amount of information stored in his mind and decides that he is viewing a certain type of object or natural feature. For example, Cooper in MA-9 was able to discern the wake of a boat in a large river in the Burma-India area.

In spite of the many advantageous facets of man's presence on board a satellite, there are some drawbacks. His presence demands increased systems weight and possibly increased reliability requirements. Some of the increased weight is shielding required to protect the passenger from dangerous radiations. The amount of protection used in conjunction with the exposure criterion adopted also fixes the duration of the flight and restricts the height of the orbits which can be traversed with a reasonably configured satellite.

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7. CONCLUSIONS

1. The study presented herein establishes that during a large portion of the day and night the temperature contrast between many of the surface ships of the world and their ocean surroundings is adequate to permit detection and tracking from low satellite orbits using available background-limited detectors operating in the 7.5 to 14μ spectral region in conjunction with a state-of-the-art optical system of relatively modest dimensions.

2. The temperature contrast between a ship and the ocean might be either positive or negative depending on the time of day and prior meteorological history of the ship.

3. It is possible during the course of a day that the contrast between a ship and the ocean may be so small as to preclude detection. This situation is dependent on the relative cooling and heating rates of the ship and ocean, recent insolation history, the time of day, and the capability of the detection system.

4. Dominant parameters in determining the detectability of ships on the ocean surface are the ship's size and its effective temperature contrast with the ocean. For example, it appears feasible to detect a 492 foot long Class C-3, Standard American Merchant Ship from a satellite in a 200 nautical mile orbit using an optical system collector of 50 centimeters and mercury-doped germanium detector operating against a ship-to-ocean temperature contrast of 2°C or greater. Larger ships such as the approximately 1000 foot long liner Queen Elizabeth need only have a temperature contrast of approximately 0.5°C to be detected with the same equipment.

5. Currently, the sensitivity of long wavelength infrared detectors are within a factor of two of the theoretical maximum obtainable so that little gain in system performance is available through trying to

increase detector sensitivity. In principle long wavelength detection and tracking systems designed today will be nearly as sensitive as those of the future.

6. Clouds present a formidable background to a satellite-based ocean surveillance system operating in only the optical region of the electromagnetic spectrum. The true practicality of such a system would relate to the statistics of the available area of "clear-view-over-the-ocean" and the corresponding probability of ship detection and would depend on how these statistics affect the accomplishment of the tasks to be carried out by the system.

7. To obtain the resolution required for detailed classification of ships it is necessary to operate in the visible or UV regions of the spectrum.

8. RECOMMENDATIONS

There are several areas in which additional efforts should be made to establish the overall feasibility and basic instrument design for the surveillance of ocean surface traffic from satellite platforms using the optical portion of the electromagnetic spectrum.

1. The next necessary step in the investigation is to establish the logic required to solve the recognition problem and control the false alarm rate. Where necessary to augment the logic derivation, continue to investigate the characteristics of target and background radiation. Point out any possibilities wherein the surveillance satellite might easily acquire supplementary information especially with respect to ocean environment.

2. A study is in order to determine if automatic shape recognition can be derived to accomplish the classification of ships. Classification requires fine resolution and therefore implies the use of short wave lengths such as visible and ultraviolet. Within this wavelength regime the degrading effects on the image of the variability and transmission of the earth's atmosphere are significant and they should be established for conditions representative of the ocean surveillance problem.

3. The natural complement of the foregoing tasks is the formulation of an experimental program designed to substantiate the principles derived and certify the performance of the hardware which will eventually evolve.

4. Determine the fractional part of a day during which the contrast temperature between the ship and the ocean is adequate for detection. This would depend on such things as ship size, insolation history, and contrast temperature required for detection.

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5. Carry out a sensitivity analysis to determine the dependence of
    the accuracy of ship location to such quantities as errors in ship
    heading and speed, satellite location and speed, and satellite
    instrument errors.

6. Investigate the trade-off on data handling requirements for
    satellite, ground based relay stations, and ground based central
    processing units.

7. Study the implications of data gathering on ships in port.

8. An investigation of cloud cover statistics as related to the 7.5 to
    14 μ wavelength interval should be carried out.

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APPENDIX A

LIST OF REPORTS PERTINENT TO OCEAN SURVEILLANCE

The initial effort on this contract was devoted to a literature search agreed upon by the contract sponsors designed to acquire information on surface ship signatures and background characteristics. The reports acquired, most of them from the Defense Documentation Center, are listed in appropriate categories below. Included in the bibliography section are two request report bibliographies (Item 1.6 and 1.7) produced by DDC for this project.

As the project progressed various other reports were acquired and these also are listed below in appropriate categories. A few of the unclassified reports listed may have been acquired outside the contract but are listed because they may have bearing on the overall problem. Included where it is known is the DDC AD number.

In order that this Appendix has the potential for wider distribution, it contains no classified titles.

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1.0 Bibliographies

Item No.

1.1 <u>Bibliography of Bibliographies (U)</u> - A Report Bibliography, Defense Documentation Center, AD-281900, Reprint January 1964.

1.2 <u>A Bibliography of Bibliographies (Supplement) - A Report Bibliography (U)</u>, Defense Documentation Center, AD-338580, Reprint February 1965. (Secret)

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13. ABSTRACT

    Research on the implications of using electro-optical techniques for gross ocean surface surveillance from astronautic systems has been carried out. The ranges of radiating temperatures to be expected of typical surface ships and the ocean background have been established. The signal available for detection per degree of temperature contrast between typical surface ships and the ocean was established for orbit altitudes of from one hundred to four hundred nautical miles. In turn, the temperature contrast between typical surface ships and the ocean required to achieve detection was established as a function of scan angle for a specified optical system using a long wavelength detector and operating at 200 nautical mile altitude. Correspondence was maintained between the irradiance at the collector and the scan angle to allow for the effects of atmospheric transmission and range changes.

    Included in the overall study were a review of current ocean surveillance methods and an estimate of current and future ocean traffic. Some characteristics of clouds as a background constituent were established. Consideration was also given to the problems of tracking, recognition, classification, resolution requirements and man's role in a satellite.

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