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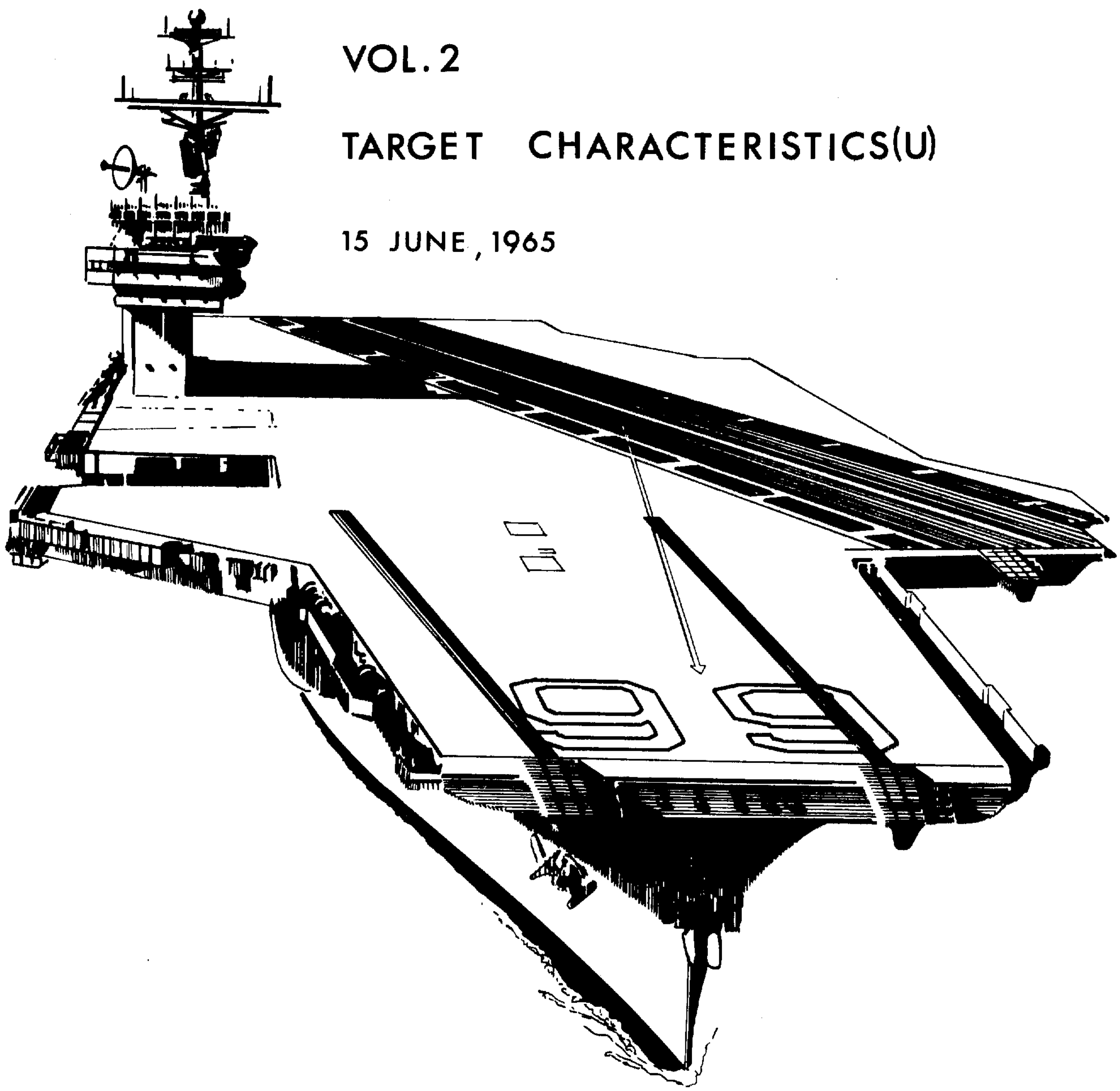
TACTICAL MULTISENSOR RECONNAISSANCE (U)



VOL. 2

TARGET CHARACTERISTICS(U)

15 JUNE, 1965

SPECIAL HANDLING

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1. INTRODUCTION

1.1 THE REASON FOR TACTICAL AERIAL RECONNAISSANCE

Commanders of military units require current intelligence about the enemy forces with which they are, or may become, engaged. To satisfy this need, the unit's intelligence element maintains a data base comprised of basic intelligence information compiled prior to hostilities (frequently by higher headquarters), and current intelligence derived from such sources as prisoner of war interrogation, defectors, surface reconnaissance units, and - most important of all - aerial reconnaissance.

Airborne tactical reconnaissance systems in current usage are capable of collecting large quantities of intelligence information. They employ optical cameras, infrared detectors, radar, electronic intercept equipment, and visual observation in the collection process. They may overfly the enemy's territory, or they may fly along the periphery. The primary function of tactical aerial reconnaissance is to obtain information about changes to the previously known enemy order of battle and an assessment of our offensive actions. The urgency with which this information must be made available to the commander and his battle staff depends upon whether hostilities are possible, imminent, or under way.

Under actual combat conditions, the commander requires current intelligence in real time. Today, tactical reconnaissance systems can provide real time response only through visual observation and radio transmission of the data. Information collected by photographic devices and other sensors is not available until the aircraft has returned to a base at which the film can be developed and the electronic records processed. The records must then be interpreted, and the derived information collated with data from other sources, before the intelligence picture is complete.

A requirement exists to minimize the time between activation of the sensor and delivery of the finished intelligence to the commander. An obvious solution would be to provide the capability to process and interpret the sensor records while the aircraft is airborne, and to relay the required information to the commander by data link. Techniques for inflight processing of some, if not all, of the sensory records are available today. The possibility of inflight interpretation is more remote. This study is concerned primarily with an evaluation of the usefulness of the various sensor records to the interpreter, without regard to the techniques used to process them. The nature of tactical targets and the ability of each sensor to record interpretable data about them are the main subjects of this discussion.

1.2 AN OPTIMUM TACTICAL RECONNAISSANCE SYSTEM

To iterate, the primary function of tactical aerial reconnaissance is to obtain information about changes to a previously compiled data base or order of battle. This function can be satisfied if the collected sensor records enable the interpreter to detect, locate, identify, and describe elements of the enemy's forces quickly and accurately. The information content of such records thus can be much less than would be required for a detailed technical analysis of military equipment, but must be greater than would be required to compile a map or chart of an area.

The tactical commander is essentially concerned with factual answers to questions such as "How many fighters are operating from X airfield?" and "Has the enemy moved a certain tank battalion across the river?" A theoretically ideal reconnaissance sortie would answer these questions with "36" and "No". An actual sortie will return to base with several hundreds of feet of film, several magnetic tapes, pilot traces and observer notes, and perhaps other materials which must be subjected to time-consuming processing and interpretation before the "36" and "No" can be ascertained. The sortie may also have encountered targets not listed on the flight plan, but obviously of military importance; intelligence about these targets must also be produced.

An optimum tactical reconnaissance system should minimize the quantity of sensor records that must be interpreted, and thus achieve a corresponding reduction in the time required to answer the commander's questions. This optimization involves careful planning that considers the intelligence required, the targets to be covered, the routes and altitudes to be flown, the sensors to be used, and the optimum methods of operating the sensors over the targets.

1.3 TARGETS FOR TACTICAL RECONNAISSANCE

In order to define an optimum tactical reconnaissance system, it is necessary first to list the targets the system's sensors will be required to reconnoiter. The list should include those types of weapons, military equipment, installations, support facilities, and terrain features whose presence in an area would be of concern to a tactical commander.

Each type of target has certain characteristics that differentiate it from others. The target system must include a description of these characteristics in order that the ability of various sensors to collect definitive information can be evaluated.

With the possible exception of visual observation, none of the sensors used in tactical aerial reconnaissance is completely selective. Each will acquire and record data on any target whose emissions or reflections fall within the sensitivity range of the sensor. The target list will assist in establishing sensor sensitivity parameters that will result in collecting a minimum of redundant information.

A basic target list has been developed (Table 1-1) and provided to the participating contractors. Each contributor was requested to describe the parameters of each target that permit its recognition or identification by the sensor for which he is responsible, and to prepare a discussion of the optimum conditions under which that sensor should be employed on a tactical reconnaissance mission. The results of this request are contained in Sections 3 through 6 of this report.

Table 1-1. Basic Target List

I AIRFIELDS AND AIR ORDER OF BATTLE (AOB)

1. Types
   - A. 2000 ft and under
   - B. 2000 to 5000 ft
   - C. 5000 to 10,000 ft
   - D. 10,000 ft and over
2. Capabilities
   - A. Runways and Taxiways
     - (1) Surface
     - (2) Number
     - (3) Dimensions
     - (4) Orientation
   - B. Facilities
     - (1) Hangars
     - (2) Repair shops, stores
     - (3) Lighting
     - (4) Dispersal areas
     - (5) Open storage
     - (6) Underground storage
3. Order of Battle
   - A. Number of aircraft
   - B. Types of aircraft
   - C. Names of aircraft
4. Defenses
   - A. Anti-aircraft artillery (AAA)
   - B. Surface-to-air missiles (SAM)
   - C. Other (trenches, searchlights)
5. Electronics
   - A. Ground control approach (GCA)
   - B. Radar (other than GCA)
   - C. Radio

Table 1-1 (contd)

6. Support
   - A. Rail
   - B. Road

II GROUND FORCES AND GROUND ORDER OF BATTLE (GOB)

1. Troop Concentrations
   - A. Type of characteristics
   - B. Size
2. Vehicles including mobile weapons
   - A. Type
     - (1) Transport vehicles
     - (2) Tanks, armored scout cars, etc.
     - (3) Self-propelled guns
     - (4) Rocket launchers
     - (5) Armored personnel carriers
     - (6) Other
   - B. Size
   - C. Number
3. Fixed weapons sites, defensive positions
   - A. Type
     - (1) Field artillery
     - (2) Fixed missile sites
     - (3) Strong points, earthworks, trenches
     - (4) Barbed wire, hedgehogs, tank traps, etc.
   - B. Extent
4. Command posts, headquarters, barracks, hospitals, etc.
5. Support facilities (supply, ammunition or petroleum-oil-lubrication dumps, etc.)

III NAVAL INSTALLATIONS AND NAVAL ORDER OF BATTLE (NOB)

1. Harbors
   - A. Capabilities
     - (1) Size and depth
     - (2) Shipbuilding and repair
     - (3) Berthing facilities
     - (4) Piers (number and kind)
     - (5) Supplies and equipment

Table 1-1 (contd)

(6) Storage (underground and open)
(7) Sub pens
(8) Barracks

B. Order of Battle

(1) Number of ships
(2) Types of ships
(3) Names of ships

C. Defenses

(1) Mines
(2) Submarine nets
(3) Guns
(4) Radar

2. Ships at sea

A. Carriers
B. Cruisers
C. Destroyers, destroyer escorts
D. Elint pickets, patrol-torpedo boats
E. Submarines
F. Other

IV TERRAIN

1. General land forms

A. Ridges, hills, cliffs
B. Valleys
C. Streams (depth, flow, banks, fords)

2. Beaches

A. Type (rocky, sandy)
B. Gradient
C. Hydrographic information
D. Routes of egress and ingress
E. Defenses

V COMMUNICATIONS

1. Radio

2. Land lines

Table 1-1 (contd)

VI TRANSPORTATION ROUTES (SURFACE)

1. Ground
   - A. Rail lines
   - B. Roads and major trails
   - C. Bridges, (rail and road)
   - D. Tunnels (rail and road)
   - E. Marshalling yards, terminals
   - F. Motor pools (with equipment)
2. Inland waterways
   - A. Ports and landing areas
   - B. Locks (lift in feet)
   - C. Basins
   - D. Trans-shipment points
   - E. Bridges

VII SUPPORT FACILITIES

1. Supply dumps
   - A. Petroleum-oil-lubricant (POL)
   - B. Ammunition
   - C. Other
2. Gun Parks
   - A. Type and number of weapons
3. Motor pools
   - A. Type equipment
4. Staging areas
   - A. Size
   - B. Ground force distribution
   - C. Equipment

1.4 TARGET/SENSOR MATRIX

The final section, Section 7, is a matrix that relates sensor capabilities to various types of targets and to various operating conditions that affect these capabilities. An arbitrary numerical scale is used to establish a relative rating for each sensor used alone and for various combinations of sensors.

1.5 THE RECONNAISSANCE CYCLE

The cycle starts with the determination that additional intelligence is required about some aspect of the enemy's forces or capabilities. Frequently, a single target or target area achieves an importance that establishes the need for a sorties. Other targets enroute to or from the prime target are selected at this time.

The flight plan is developed, with consideration being given to such factors as anti-aircraft protection of the target area(s), the extent of the area(s) to be covered (as related to the coverage capabilities of the sensors to be used), aircraft operating characteristics, and penetration and evasion tactics to be employed. A major portion of this step is determining which sensors will be used, and how and when they will be used. This determination is based on the ability of each sensor to acquire the required data under the planned flight conditions. It is affected by weather conditions, time of day, nature of the targets to be covered, and other operational and technical considerations.

The next step in the cycle is the accomplishment of the sortie. The crew is expected to adhere as closely as possible to the flight plan; deviations are permitted to assure the safety of the aircraft and, in rare circumstances, to obtain coverage of targets of opportunity.

At some time after the sensor records its data, the record must be processed. As stated before, techniques are available that permit some, if not all, of the records to be processed while in flight. If these techniques are not used, the aircraft must return to its base, where the records can be converted to human-readable form.

The processed records are delivered to the data reduction team who extract the required information, collate it with corollary information from other sources, and present the finished intelligence to the commander. The requirement to provide the commander with near real time information places constraints on this step. The interpreter must be completely aware of the essential elements of information required in the circumstances at hand. He must limit his interpretations to extracting only immediately useful data.

It should be noted that there is a limit to the amount of information contained in a set of reconnaissance records that is useful in a given situation. This limit is often reached before the limit of interpretability is reached. As soon as all useful information is extracted, any additional information provided by other sensors, additional coverage, increased resolution, or more detailed interpretation, is not significant, and time should be wasted in processing or interpreting it.

The finished intelligence resulting from the sortie is incorporated in the data base, and the cycle is complete. Any further exploitation of the reconnaissance data to extract more detailed information is outside the realm of tactical reconnaissance, regardless of its importance to other aspects of a military operation.

2. RECONNAISSANCE SENSORS AND THEIR CAPABILITIES

2.1 VISUAL OBSERVATION

Visual reconnaissance is simple, direct, and capable of real-time response in the form of voice transmission of observations. The use of visual observation is limited by the speed and altitude of the aircraft, concealment of the target by clouds, vegetation, camouflage, and by other factors that affect the observer's ability to detect and identify objects on the ground.

Visual observation can be enhanced by the use of devices that assist the observer in detecting targets; moving-target-indicating-radar is an example.

Recording devices can be used to provide a permanent record of the observer's report; these may be on the aircraft, at the home base, or both. Radio transmission of oral reports can be speeded up through the use of an airborne recorder and a high-speed transmission device.

Visual observation is usually employed against specific targets to obtain specific information. Typical examples are the use of visual observation to adjust artillery fire, to locate a convoy en route to the combat area, or to search for troop concentrations in an area.

2.2 PHOTOGRAPHY

Aerial photographs that meet certain operational and technical specifications can be the most valuable source of tactical intelligence. It is occasionally difficult, and sometimes impossible, to meet these specifications. When this is the case, other sensors must be used to acquire the data, or to acquire data that will be useful in interpreting less-than-optimum photography. Additionally, the time required to return the film to the photo lab, to process it, and to interpret it reduces the effectiveness of photography to provide intelligence under rigid real-time conditions. However, technology advances in the future could improve the transmission of near real-time photographic information.

The processing and interpretation time can be minimized if the characteristics of the cameras to be operated over the target are carefully matched to the sortie's requirements. Duplicate coverage of a target by more than one camera may be desirable under some circumstances, but the need should be weighed against the added workload in the photo lab and the additional imagery that must be interpreted. Selection of the cameras and their mode of operation should be governed by the types of target, the aircraft altitude, weather, and related factors.

The imagery obtained on a photographic sortie will be used for one of two purposes: to recognize a target, or to identify a target. "Recognition" implies the ability to detect the presence of a target whose characteristics are known, and to determine its geographic location. "Identification" implies the ability to determine to some degree of detail the characteristics and military significance of a target about which this information is not available. As an example of the first purpose, it may be sufficient to establish that a tank battalion is operating in a given sector; other intelligence is available as to the battalion's strength and capabilities. As an example of the second purpose, it may be necessary to determine whether a group of vehicles is comprised of tanks or of personnel carriers, and, if they are tanks, to establish their type or model. It is obvious that the latter case requires better resolution and detail in the sensor record than does the former. The ability of a photographic system (camera, lens, filter, film, exposure, and processing) to record fine detail as it applies to the utility of the system to provide interpretable intelligence information about specified types of targets is discussed elsewhere in this study.

To help assure survivability, tactical reconnaissance sorties will usually be flown at altitudes less than 1000 feet or greater than 30,000 feet. It is probable that a single sortie will include legs flown at high altitude and others at low altitude. Two different sets of cameras will be required to meet the intelligence requirements at these different altitudes. Cameras designed for low altitude work are generally equipped with lenses of short focal length

(6 inches or less); they will produce vertical or oblique frame photos or strip or panoramic photos; and they will be capable of producing high resolution imagery at high velocity/ height ratios. Cameras intended for high altitude work will use lenses of long focal length to obtain medium to large scale vertical or panoramic photos of extremely high resolution.

Records produced by other sensors are often of value during the interpretation of the photographs. For example, targets not readily visible on the photo may be "pointed" by radar or infrared records; doppler radar can indicate that a target is moving, thus modifying positional information derived from the photo. Conversely, photography is almost essential in the interpretation of infrared and radar imagery. When lighting conditions preclude the use of cameras concurrently with other sensors, photography obtained on previous sorties may be used.

2.3 RADAR

High-resolution side-looking radar uses a much longer wavelength than does optical photography. For this reason, radar images can never equal optical images in resolution. However, recent developments in such components and technology as synthetic array antennas, aperture focusing, and coherency produce imagery that can be extremely useful in a tactical situation. Radar provides its own "illumination" and can thus be used when optical cameras cannot; radar energy can penetrate most atmospheric obscuration, foliage, and some other natural or man-made conditions or materials. As noted earlier, doppler radar can be used to detect targets in motion. A disadvantage to radar is, of course, its "active" nature which permits the aircraft to be detected and tracked.

Radar returns may be recorded in the air for delivery to the processing facility upon return to base; they may be transmitted by a data link to a ground processing station, or they may be converted in the air to an image that can be displayed to the aircrew for various purposes. Radar thus has a real-time capability to provide intelligence information, either to the crew or to the command post. The interpretation of this information will be enhanced if photographs of the area being covered are available.

The radar may be operated to provide "cueing" signals to an airborne observer, or to provide an input to a device that will create, on photographic film being exposed simultaneously, a record of the location of radar-detected targets. Moving target indicator (doppler) signals can be used to generate azimuth and range position data that will cause an area to be covered by high-resolution or by other sensors aboard the aircraft.

Radar is primarily useful in the recognition phase of tactical reconnaissance, rather than in the description phase. In general, radar lacks the ability to produce images that depict the true size and shape of the target, or that depict texture and tone. Other deficiencies include the absence of returns from a strip immediately under the aircraft, and obscuration of some elements of a target by radar shadows.

2.4 INFRARED

Infrared detection equipment can be used to produce low-resolution photographic images, or electronic signals, that permit the detection and recognition of thermal differences. Infrared sensors detect emitted or reflected invisible radiations, rather than reflected actinic light; they may thus be used when lighting is inadequate for photography. Thick clouds will interfere seriously with all infrared operations; haze and turbid atmosphere adversely affect detection of radiation in the 1 to 8 micron range, while in the 8 to 13 micron range haze and ground fog have little or no adverse effect.

Infrared imagery has sufficient resolution to permit the determination of the shapes and sizes of objects as large as aircraft wings and fuselages. Smaller objects can be detected, but probably cannot be recognized by virtue of their size or shape. The availability of corollary intelligence information is probably more essential in the interpretation of infrared imagery than in the interpretation of any other sensor record.

As is the case with radar, infrared can be used to cue the aircrew by calling their attention to thermal anomalies in the scene. The range and azimuth to an emitter may be recorded on the photograph, thus serving as a pointer to the photointerpreter. Many photographically invisible targets can be detected by infrared; cooking fires under a tree canopy are but one example. Similarly, infrared provides such indications of activity as differentiating between vehicles with engines in operation and those whose engines have been inoperative for a period of time.

2.5 ELECTRONIC RECONNAISSANCE (ELINT)

Electronic reconnaissance (ELINT) is used to collect information on the enemy's electronic order of battle. This information is useful to ground, naval, and air forces because of the wide range of electronic emitters that can be detected and located, and whose operating parameters disclose their purpose.

Airborne ELINT systems can intercept signals over very long ranges, and weather conditions have a negligible effect on this interception. ELINT information is usually recorded in flight and returned to a data reduction facility on the ground for processing. However, the data can be transmitted to the ground over relatively narrow-bandwidth data links. Some processed signal information can be displayed in the cockpit for use by the pilot or observer as navigation aids, as cues to the location of significant targets, or for the selection of electronic countermeasures.

When correlated with data from other sensors, ELINT data is useful in helping to detect and identify such targets as radar-controlled guns or missiles, aircraft control centers, and other targets whose function can be deduced from the parameters of their associated electronic emitters. Other sensors may produce data that will assist in refining the location of an emitter, thus facilitating its destruction or neutralization by friendly forces.

2.6 CAPABILITIES AND LIMITATIONS OF REMOTE SENSORS

An excellent general discussion, entitled as above, appears in the November 1964 issue of "Photogrammetric Engineering" (Vol. XXX, No. 6, Pp. 1005 - 1010). Table 2-1, taken from this article, summarizes the advantages and disadvantages of remote sensors.

Table 2-1. Remote Sensor Comparison

	Camera	Infrared	Radar
Day/Night	5	10	10
Haze-Fog Penetration	3	6	10
Cloud Penetration	1	2	9
Temperature Discrimination	2	10	1
Sub-Surface Detection	4	6	3
Stereo Capability	10	2	3
Accurate Image Representation	9	6	5
Long-Range Capability	7	4	8
Resolution	9	7	5
Interpretability of Imagery	9	6	6
Availability of Equipment	10	4	4

Poor = 0 Good = 10

3. PHOTOGRAPHIC RECONNAISSANCE

3.1 GENERAL COMMENTS

Aerial photography is the most useful all-around tactical reconnaissance sensor. One or more cameras will be carried in any reconnaissance aircraft that operates in daylight, or that carries artificial illumination for night photography. The ability of a particular camera (or more correctly, photographic system) to collect usable information about a target depends on a number of variables that are discussed in subsequent paragraphs.

As stated earlier, it is probable that a reconnaissance sortie will include both high-altitude and low-altitude portions. Photographic equipment capable of producing usable information from both of these altitude ranges is necessary. The main limiting factors at low altitudes are the ability of the camera to cycle rapidly enough to provide overlapping photography, its ability to compensate for image motion, and the area it can cover. These are functions of focal length, aircraft speed, camera mechanics and film format dimensions. The major limiting factor at high altitudes is scale; this also is a function of focal length and altitude.

The ability of a photographic system to resolve fine detail is perhaps the overriding consideration in determining whether a certain class of information can be recorded and interpreted. This ability can be affected by any or all of the components of the system. These components include the lens, filter, film, camera, exposure conditions, lighting, processing techniques, and interpretation techniques. The system's resolving power is also a function of the contrast between the detail to be recorded and its background.

The balance of this section of the report is devoted to a discussion of the factors mentioned above, and to conclusions regarding the effectiveness of photographic systems as an intelligence collection medium under tactical conditions.

3.2 PHOTOGRAPHIC SCALE

The scale of a photograph is simply stated as the ratio between the focal length of the lens and the altitude of the cameras above the terrain. Scales as small as 1:300,000 are useful for some types of tactical reconnaissance; for example, map-type photography of a large area can be obtained with a minimum number of exposures using a 1.5-inch lens at altitudes of 35,000 or 40,000 feet. A limited amount of tactical intelligence can be extracted from photography at a scale of 1:20,000 to 1:40,000 (24- and 12-inch lenses, respectively, at a 40,000 foot altitude). Large scale photography (1:5000 or larger) is required for detailed interpretation.

Scale per se is no longer a major consideration in evaluating a photographic system. The components of a modern photographic system have so advanced that scales previously unusable are now completely satisfactory. There are, however, limits on the minimum scale allowable for specific types of interpretation. These result from mechanical and optical characteristics of the image and from characteristics of the photographic emulsion.

The photographic image is made up of individual and clumped grains of metallic silver of a certain size range. Compensation for small scale by magnification is limited by this grain size. Similarly, the ability of the system to image detail is limited; detail whose image would be smaller than the size of the largest grains cannot be recorded discretely.

The contrast between small details and their background is generally less than between larger details and their background; this factor is discussed further in subsequent paragraphs.

Although not strictly a matter of scale, the areal coverage capability of a system also depends on the focal length of the lens and the altitude — and on the additional factor of negative dimensions. Areal coverage capability determines whether a given system can obtain the necessary coverage of a given target at a given altitude.

This study is based on the fact that photography will be obtained at altitudes between 200 and 1000 feet and between 30,000 and 40,000 feet. Cameras will have focal lengths ranging between 1.5 to 24-inches. The various combinations of focal length and altitude produce three general scale ranges. These are:

Small scale	(1:200,000 - 1:300,000)
Medium scale	(1:20,000 - 1:40,000)
Large scale	(1:500 - 1:2000)

3.3 PHOTOGRAPHIC RESOLUTION

The resolving power of a photographic system is indicative of its ability to record fine detail. In a general sense, resolving power is the reciprocal of the smallest dimension that can just be seen in a photograph; it is stated in terms of the number of line pairs per millimeter that the system can image as discernible lines.

The resolving power can be used to predict the ability of the system to produce a readable image of various objects on the ground. The formula for this prediction is

$$GR = S/300L,$$

where GR is the ground distance resolved, S is the reciprocal of the photographic scale, and L is the resolving power in lines per millimeter. The factor "300" (actually 304.8) converts GR to feet. This formula must be used with caution for the reasons described below.

3.3.1 Computation of L

The numerical value of L is usually determined by examining the image of a standard Air Force three-bar resolution target photographed by the system being calibrated. This target is illustrated by Fig. 3-1. The smallest three-bar group that can be discerned as separate bars on the image determines the value of L. However, this value refers only to the ability of the system to resolve regularly repetitive detail at a specific object contrast (discussed shortly) and aspect ratio. Further, the quoted value is actually only an indication of the central tendency of the values derived during a series of replicate tests. This is illustrated by Fig. 3-2, which is a plot of 163 values obtained from a test of a specific emulsion under closely controlled replicate conditions. The standard method of reporting L is to quote the arithmetic mean — in this case, 316 lines per millimeter. It can be seen from the figure that many values greater or less than this are present.

USAF Resolution Chart

Group	-2	-1	0	1
Step	lines/mm	lines/mm	lines/mm	lines/mm
1	25.0	50.0	100	200
2	28.1	56.1	112	225
3	31.7	63.5	126	254
4	35.6	71.2	141	285
5	39.9	79.9	159	320
6	44.5	89.1	178	356

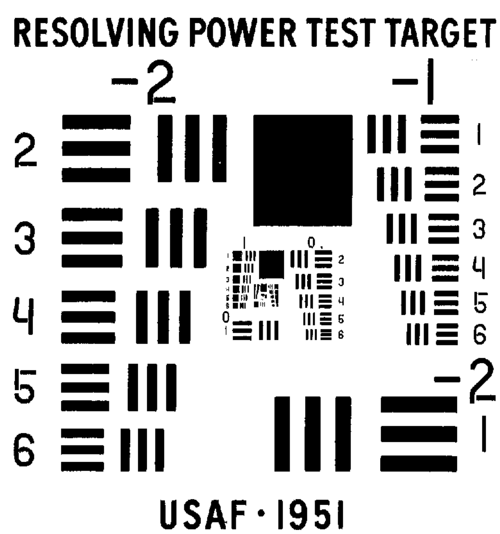

Fig. 3-1 — Three-bar resolution target.

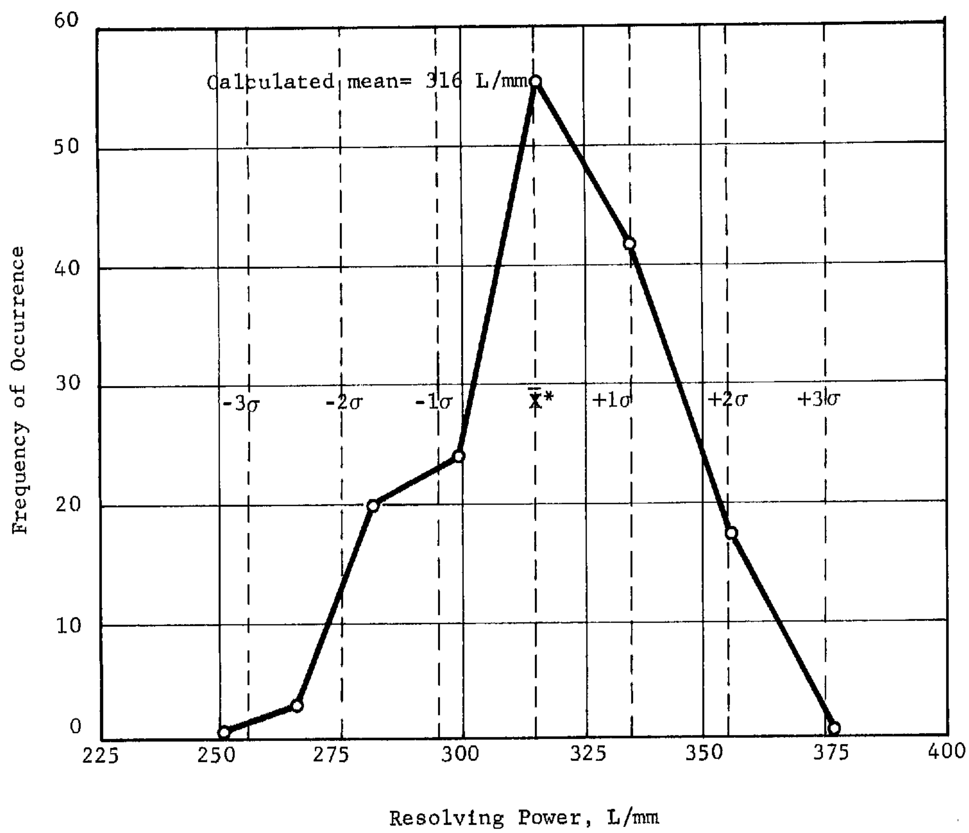

Fig.3-2 — Frequency of occurrence vs resolving power for film type 4404 data at 2:1 object target contrast

A value for L obtained under controlled conditions will seldom be valid under field conditions. Even minor variations in any of the parameters of the photographic system will have an effect on this value. It is possible, however, to establish a value for L that can be consistently achieved in the field under standard conditions. It is essential that all the conditions in existence when L is derived be known and stated, in order that they may be duplicated or, if this is impossible, compensated for. For the purposes of this study, the values of L used in various tables are attainable under actual field conditions, as determined by examination of operational photography. It is convenient to refer to such field-derived resolution values as "operational resolving power".

3.3.2 Object Contrast

Any value for L is theoretically valid for only one object contrast. Object contrast is the ratio between the brightness of the object and the brightness of its background. Note that the object may be an aircraft on a runway, or a rifle on a tank; the contrast between the things that actually comprise the target must be considered in any computation of ground resolving power of a system. This factor is discussed in some detail in the following subparagraphs.

Contrast is affected by color or tonal differences, by the intensity of the illumination, by the sun angle, by the size of the components of the object to be imaged, and by scale and altitude. The Air Force bar target referred to above is made at two contrasts — 1000:1 and 1.6:1. The resolving power of the system varies for these two contrasts, and the quotation of L must be accompanied by a statement of the contrast of the target used. See Fig. 3-3 and Table 3-1.

It may be assumed that the enemy will make every effort to reduce the visibility of his equipment and forces by using protective coloring or camouflage. Thus, most tactical targets can be expected to have relatively low contrast with their backgrounds. Note that this implies that the components of a target will often all be of the same color or tone, and that the color or tone of the target will match its background. There are obvious exceptions; dark-colored vehicles may operate against a background or of snow or concrete, or unpainted aircraft may be parked on a Macadam hardstand.

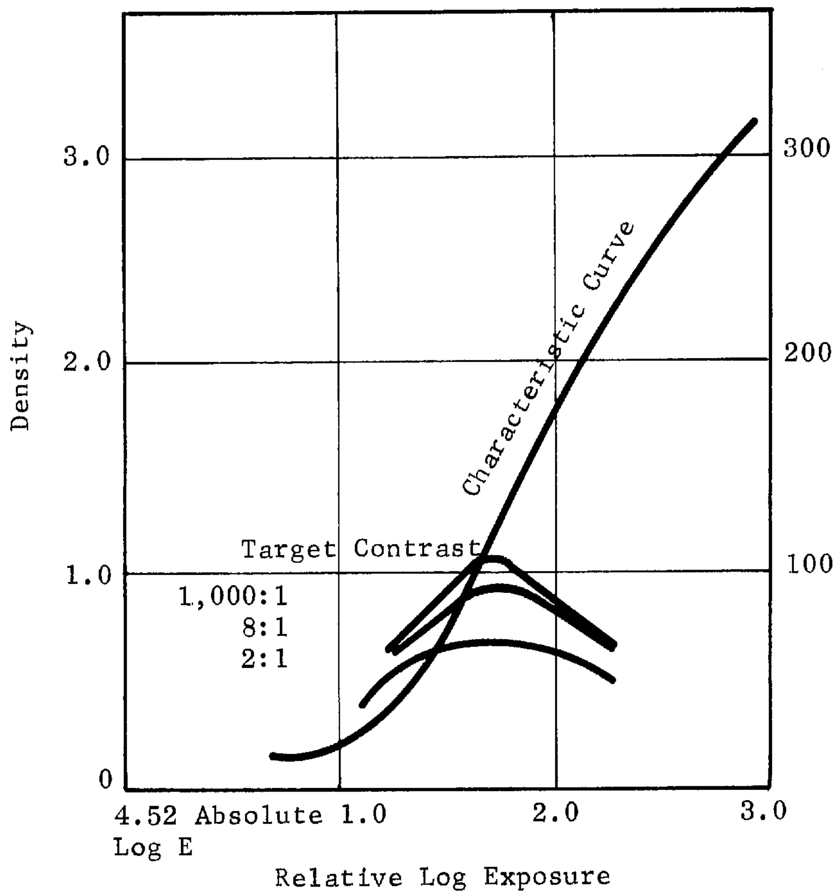

Fig. 3-3 — Resolving power vs log exposure for SO-102 film, D-19 development, 6 minutes at 68°F.

Table 3-1. Resolving Power Values for Representative Aerial Emulsions, L/mm

Film	Target Luminance Ratio 1000:1	6.3:1	2:1
3 ~~4~~404 (SO-132)	840	550	280
SO-243	540	440	260
SO-206	380	270	160
SO-226	340	260	160
SO-190	240	180	120
SO-136	180	150	100
3 ~~4~~400 (SO-130)	170	150	100
3 ~~4~~401 (SO-102)	120	100	65
8401	110	90	50

Object contrast is reduced when the intensity of illumination is reduced. This reduction is nonlinear; dark objects are affected much more than are bright objects, even though their contrast ratios are the same. Most objects of importance in tactical reconnaissance will be dark in color; the intensity of illumination is therefore an important consideration in assessing the effectiveness of a photographic system. Intensity is a function of the time of day, time of year, latitude, and atmospheric conditions. Illumination also affects the intensity of shadows, which provide a valuable form of object contrast.

A decrease in the size of the detail to be resolved results in a decrease in contrast between the detail and its background. According to Macdonald (Photogrammetric Engineering, March 1958, p. 50), " . . . more resolution lines per object are required to detect the image, the smaller the scale of the image. A corollary to this statement is that high resolution systems require more resolution lines per object in order to detect the image at the limit of the system than do low resolution systems".

Photometric data compiled by P. D. Carman and R. A. F. Carruthers (Journal of the Optical Society of America, 41:305-310) indicate that targets typical of those of concern in tactical reconnaissance (man-made complexes of cities and towns) have a contrast range that rarely exceeds 10:1 (a comparatively low value) from an altitude of 4000 feet. At "hyper-altitudes", a much lower contrast will be obtained; a ratio of 2:1 or even lower should not be unexpected.

The meaning of values for GR obtained from the given formula must be understood. If the formula produces a value for GR of 2 feet, this means that an object with a minimum linear ground dimension of one foot should appear as a just discernible blob on the film, if it is surrounded by a contrasting area with a minimum dimension of at least one foot. Thus the values of GR determined in this manner refer only to the <u>detection</u> step of the photointerpretation process. The <u>recognition</u> of an object requires a resolution some five times finer than the computed value of GR. <u>Identification</u> may be possible at this finer resolution if the interpreter is highly skilled and has additional information on the target, but it is probable that still finer resolution will be required in many tactical reconnaissance situations.

Although any number of scale and resolution values will produce the same computed GR, scale and resolution are not interchangeable at parity. If scale and resolution are to be traded, the trade should be in favor of larger scale and lower resolution to obtain the most information from the image. Stating this principle differently, as the scale of the object decreases (i.e., as its image becomes smaller), the number of lines required to detect it becomes larger. — this may be the effect of exploitation equipment deficiencies

3.4 TARGET CHARACTERISTICS

Each target has certain characteristics or sensor signature that differentiate it from other targets. The term "target" in this sense refers to the thing or place about which information is desired. It may be major installation, a vehicle or weapon, a mine field, or a component of a vehicle necessary to the identification of the vehicle. The level of interpretation that can be achieved from a photograph depends on how many, or which, of the target's characteristics must be recognizable and perhaps measurable, and on how well these characteristics are imaged.

It is convenient to refer to these characteristics in terms of the three categories of detail that must be recognizable to permit the positive identification of the target. Table 3-2 describes general treatment of this categorization. It groups under three headings — "Gross," "Medium," and "Fine" — examples of the kinds of things or places that can be identified from imagery at these levels of detail.

3.4.1 Gross Detail

The level of detail denoted as "gross" includes targets or target components 10 feet or more in minimum dimension. This level will enable an interpreter to recognize large targets such as airfields, port facilities, garrisons, depots, etc. It will not always permit the functions of such installations to be clearly identified. For example, an airfield could be located and identified as an airfield but the type or function; i.e., military, heavy bomber, fighter, or civilian, could not be established at the gross level of detail.

Table 3-2. Targets Categorized by Detail Level

GROSS DETAIL — Targets in this group can be identified from imagery with ground resolution of not better than 10 feet.

- Airfields (paved runways)
- Ports and harbors
- Military installations
- Industrial installations
- General terrain information
- Large vessels
- Large buildings (hangars, etc.)
- Large open storage areas
- Tank farms
- Railyards and facilities
- Transportation network
- Towns and villages
- ICBM/MRBM sites
- Large dams

MEDIUM DETAIL — Targets in this group can be identified at ground resolutions of 2 to 10 feet.

- Operational details on targets in preceding group
- Types of vehicles, railroad cars, aircraft, smaller vessels
- Types of materiel in open stores
- Underground bunkers; revetments
- Large radar antennas
- Large weapon emplacements, guns
- Sodded airfields, helicopter pads
- Minor roads, trails
- Passive defenses (trenches, wire, tank obstacles, etc.)
- Trafficability of sectors of transportation network
- Field command posts, bivouacs, camps
- Beach gradients, trafficability, exits
- Vehicular activity
- River ports
- Agriculture, vegetation (general information)
- Surface-to-air missiles

FINE DETAIL — Targets in this group can be identified at ground resolutions better than 2 feet. This group includes components of larger targets; identification of these components permits a more detailed or exact determination of the identity and military significance of the "parent" target.

- Operational details on the preceding groups of targets
- Individual personnel, personnel shelters, foxholes
- Beasts of burden; porter trains
- Detailed designation by type and model of vehicles, weapons, aircraft, vessels, etc.
- Details on crops
- Detection of military use of civilian vehicles, river boats, etc.
- Ambush and surveillance sites
- Anti-helicopter landing stakes
- Cooking fires, campfires
- Trails, small streams, fords
- Mine fields
- Automatic weapon emplacements

3.4.2 Medium Detail

"Medium" detail includes targets or components from 2 to 10 feet in size. It will permit identification of the function of an installation, or identification of smaller objects. Buildings could be measured and identified as to function; vehicles and other targets of similar size could be identified by generic name. The airfield located under the gross level of detail could, under the medium level, be identified as to type and function, and the aircraft could generally be identified as to types and classes.

3.4.3 Fine Detail

The "fine" level of detail includes targets or components 2 feet or less in minimum dimension. With this level of detail all installations may be fully described, with the status of occupation and operation defined in detail. Types and models of aircraft, ships, vehicles, radar, etc., can be determined. Personal equipment and other very small detail may be identifiable.

3.5 EVALUATION OF PHOTOGRAPHY AS A RECONNAISSANCE SENSOR

The various cameras that are, or will be, available for tactical reconnaissance were analyzed in terms of their ground resolution, areal coverage, and cycling rate. Table 3-3 is a compilation of these data on vertical cameras with five different focal lengths and with various image dimensions. The data in this table may be taken as typical of the performance of tactical cameras.

The values for ground resolution indicate the dimension of the smallest object that can be identified (at least as "probable") from its image. The values were established by computing GR for each of the L values, using the formula previously given, and multiplying this result by 3 for large scale, 5 for medium scale, and 10 for small scale. The values for S were taken as the approximate midpoints of the ranges produced by the various combinations of focal length and altitude. These values are 1000 for large scale, 30,000 for medium scale, and 250,000 for small scale.

The multiplying factors (3, 5, and 10) used in compiling Table 3-3, are empirical approximations. The table indicates that detail as small as 2-inches in its minimum dimension can be identified from large scale imagery produced by

Table 3-3 — General Camera Information for Flight Altitudes of 1000 and 30,000 feet at Flight Speed of 1000 Knots

Focal Length	Ground Resolution In Feet			Film Size	Swath Width In Feet		Cycle at 1000 fps for 55% FWD Overlap	
	L/mm	1000'	30,000'		1000'	30,000'	1000'	30,000'
1 1/2"	150	0.197	5.25	2"x2"	1,333	40,000	0.47	14.13
	100	0.262	7.87	5"x5"	3,325	116,666	1.16	35.32
	50	0.524	15.75	9"x9"	6,000	180,000	2.12	63.64
	25	1.05	31.50	9"x18"				
3"	150	0.098	2.62	2"x2"	666	20,000	0.23	7.07
	100	0.131	5.24	5"x5"	1,651	50,000	0.59	17.66
	50	0.262	10.48	9"x9"	2,999	90,000	1.06	31.97
	25	0.524	20.96	9"x18"				
6"	150	0.048	1.48	2"x2"	333	11,250	0.12	3.53
	100	0.065	1.97	5"x5"	833	25,000	0.29	8.82
	50	0.131	3.83	9"x9"	1,500	45,000	0.52	15.89
	25	0.262	7.67	9"x18"				
12"	150		0.74	2"x2"		5,600	0.06	1.76
	100		0.98	5"x5"		12,500	0.14	4.42
	50		1.97	9"x9"		22,500	0.26	7.94
	25		3.94	9"x18"				
24"	150		0.37	2"x2"		2,800	0.05	0.88
	100		0.49	5"x5"		6,150	0.07	2.21
	50		0.98	9"x9"		11,250	0.13	4.06
	25		1.97	9"x18"		22,500	0.13	4.06

5,600 Computed but not considered practical a 1.5-inch lens at 150 lines per millimeter. Since the formula, by definition, gives the width of a resolved line pair (i.e., the image of a line that contrasts against a surrounding background of equal or greater width), the tabulated values may be halved with reasonable assurance that objects with the smaller dimension can be identified, at least at the "possible" level.

The GR values in Table 3-3 are based on the assumption that the photos are made under bright sunlight and that the targets have an object contrast in the 10:1 range. The increase in the multiplying factor is intended to compensate only for the effects of reduced object contrast caused by reduced scale. Identification of targets with less than a 10:1 inherent object contrast will require better resolution than that stated in the table. Similarly, reduction in object contrast caused by reduction in the illumination must also be compensated for. These two factors are additive.

The implication that can be derived from Table 3-3 is that almost any target of concern in tactical reconnaissance can be imaged with adequate scale and resolution by one or more of the cameras aboard the aircraft at either high or low altitude if the 150 lines per millimeter resolution can be achieved.

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4. RADAR RECONNAISSANCE

4.1 GENERAL

The usefulness of radar in the detection and recognition of different targets depends upon several particulars. The basic outputs of a radar system are imagery and moving target indications (MTI). The factors which influence the system's performance are summarized below.

4.2 IMAGERY FACTORS

Targets can be identified from radar imagery because of variations in radar cross-section or radar reflection coefficient. Either high or low radar return is discernible. Targets can be recognized by the size and shape of their images. Radar imagery differs from photographic imagery in several particulars which now will be discussed.

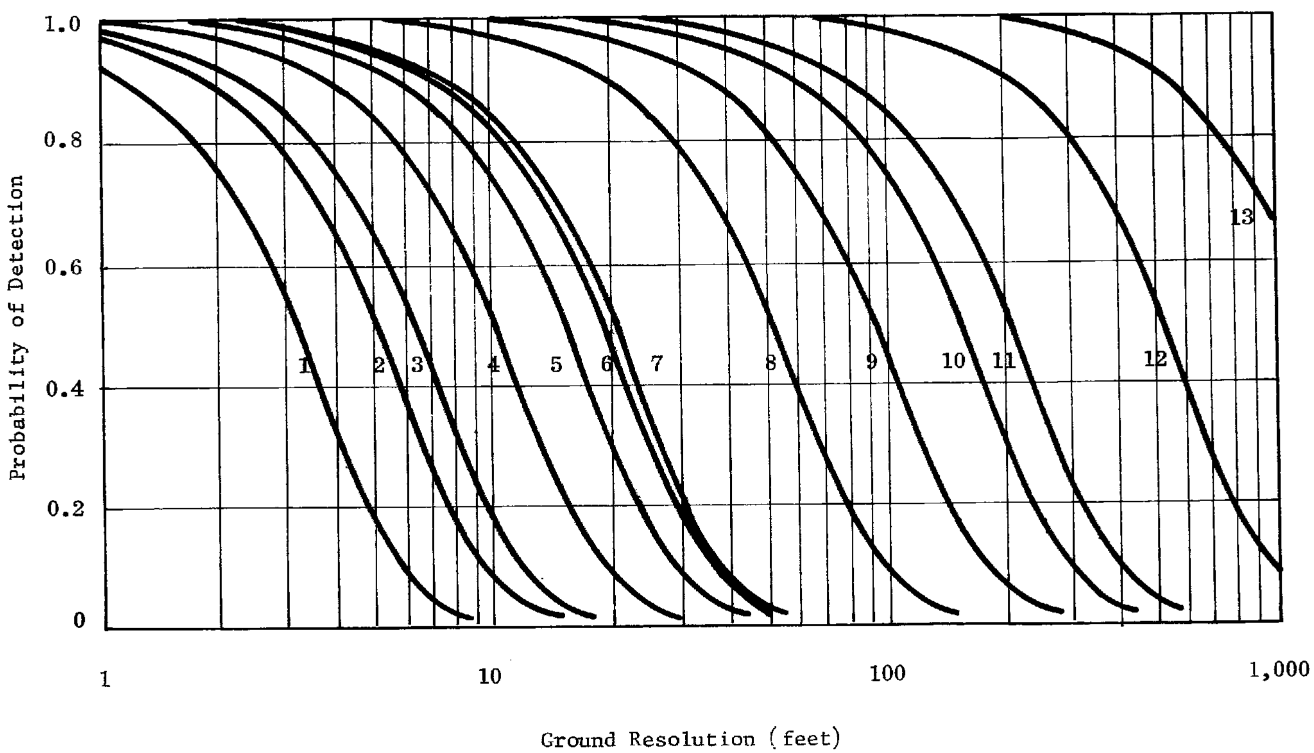
Radar provides its own illumination; therefore the target is always illuminated from the same direction as it is viewed. Radar shadows thus fall in a predetermined direction regardless of time, weather, or day-night condition. The amount of shadowing can be controlled by setting the incidence angle to the earth. This shadowing is helpful in recognizing terrain features and contours, but it can hide targets of interest. Past experience with high resolution radar imagery has shown that acceptable performance over average terrain can be obtained down to incidence angles of three degrees.

The radar reflectivity of an object usually bears little correspondence to its optical reflectivity. The radar cross-section of a resolved ground patch can vary from a few hundredths of a square foot to one thousand square feet for a vehicle. Man-made objects, especially metallic ones, tend to have many specular reflection points. This, in turn, produces a large average cross-section;

therefore large radar returns are important cues to the existence of military vehicles, weapons, supplies and structures. On the other hand, it is difficult to identify objects by examining radar imagery alone. However, the location of a large radar signal return can be a cue for the reconnaissance analyst to inspect corresponding portions of the photo and infrared records.

The resolution and contrast required to recognize size and shape on a radar image differ from those required by an optical photographic system. In general, finer resolution is required for synthetic-array radar than for photography. This is due both to the coherence of the radar energy, and to the fact that the principal return from many objects is actually a composite of reflections from specular points. The fact that a synthetic-array radar is coherent means that at any given aspect angle the diffraction pattern from a reflector can be at a peak or a null depending upon the incidental reinforcement or cancellation of the reflected electromagnetic waves. Unless some averaging is applied to the aspect angles, coherence can lead to "spotty" returns. Returns from specular points may not correspond to the outline of the target, making it more difficult to recognize size and shape. These factors mean that finer resolution is sometimes required for radar than for photography to achieve the same level of target recognition.

For synthetic-array radar, resolution is usually defined as the 4db distance width of the point reflector response function after signal correlation. When two point reflectors, such as corner reflectors, are separated by this distance, then 50 percent of the time the correlated images will have at least 20 percent contrast (peak to maximum ratio). Resolution is useful for battlefield surveillance and target recognition down to values of 1 or 2 feet. However, the present radar state-of-the-art does not allow such fine resolution. Shown in Fig. 4-1 are probabilities based on radar sensor resolution in feet of recognizing various military targets. It can be seen that several high-value targets require resolutions of the order of 1 to 5 feet to achieve a high probability of detection. Fine-resolution synthetic-aperture radar has the potential to achieve at least the upper region of this capability.



1. VTOL, STO Atomic Artillery, Honest John
2. Matador
3. Small Aircraft off Airfields
4. Fighter, Fighter Bomber on Airfields
   Long Range Ballistic Missile
5. Suspicious Clearings
6. Farms, Military Units Having Large Vehicles
7. Light Bombers on Airfields
8. Airbase Occupied
9. Roads and Streams
10. Airbase
11. Large Industrial Complex
12. Town
13. City

Fig. 4-1 — Radar recognition probability versus ground resolution.

For a high-resolution side-looking radar, the minimum high accuracy range is set at a depression angle of approximately 60 degrees, since at greater angles the range resolution deteriorates rapidly. The maximum range at high altitude is limited by average power capability, while that at low altitude is limited by the necessity of keeping the depression angle above some minimum level, approximately 3 degrees. Because of the depression angle restriction, a ground strip centered on the flight path is not covered. The central 10 degrees below the aircraft is essentially a blind area for this reason.

Fig. 4-2 illustrates the radar range coverage that can be expected at low altitudes. Note that a good mapping capability does not extend to the radar horizon at 500 feet altitude, the unmapped region below the flight path is reduced to about 50 feet and good mapping capability is assured only out to a 3 degree grazing angle or about two nautical miles. Some mapping performance can be expected out to five nautical miles with more serious shadowing effects.

4.3 FOLIAGE PENETRATION

Long wavelength radar can be employed to "see" targets beneath heavy foliage or camouflage. Measurement programs are currently being conducted by Conductron Corporation to determine the optimal radar frequency and target detectability using various frequencies. The optimal wavelength for foliage penetration is not the optimal or even a good frequency for normal high definition terrain mapping or MTI operation. Therefore, a multifrequency radar needs to be considered and the trade offs between complexity and increased operational usefulness must be determined.

4.4 LONG TERM ACTIVITY DETECTION

Long term activity detection refers to a system configuration which allows a comparison of two pieces of imagery, made on independent aircraft flights, and detect any position changes in reflections. These changes can be detected automatically, or by visual interpretation aided by data processing. Successful results are being obtained on several research and development programs in this area.

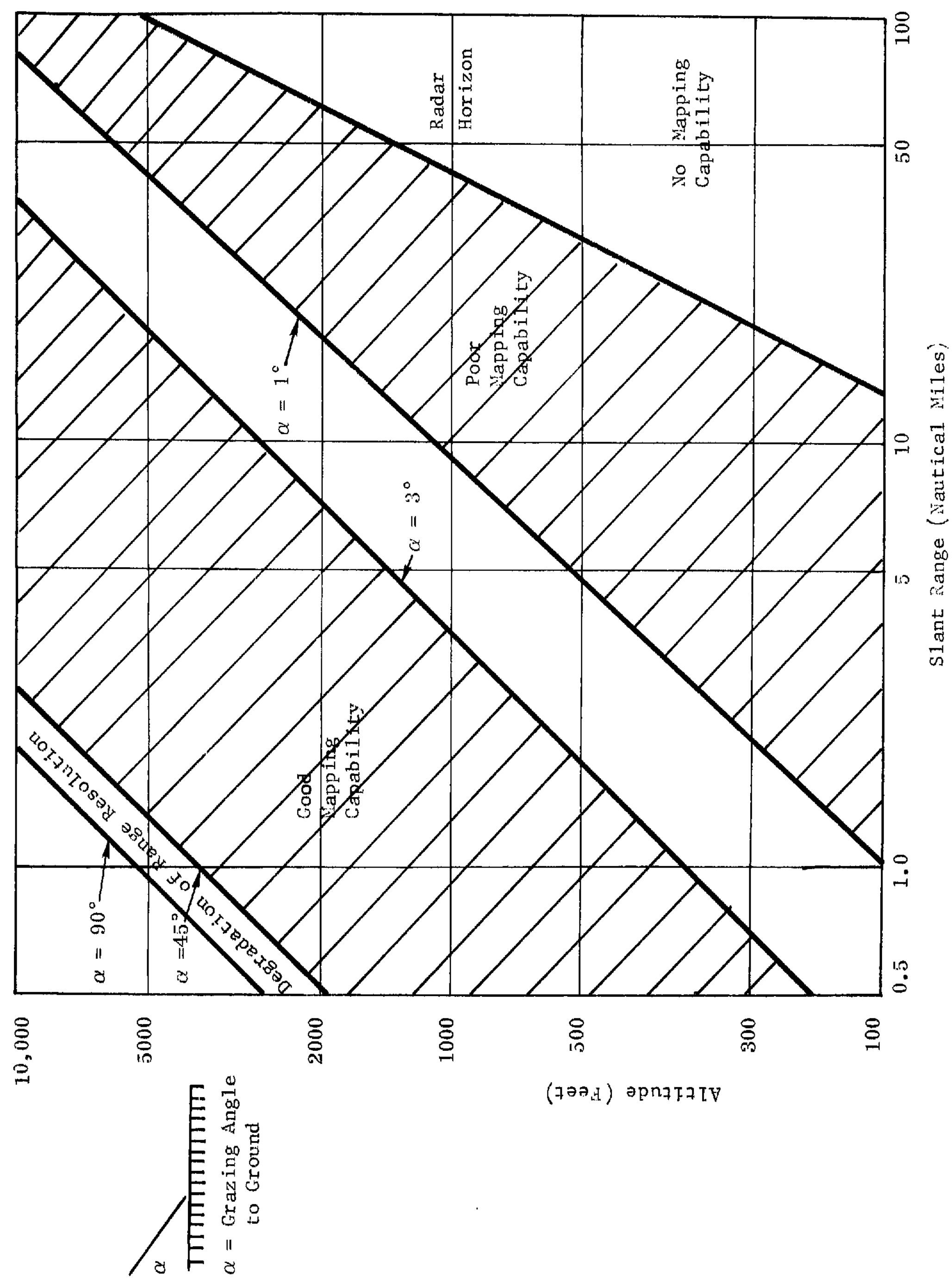


Fig. 4-2 — Radar mapping capability at low altitude (grazing angle effects only).

4.5 MOVING TARGET INDICATOR (MTI) FACTORS

The doppler shift due to target motion can be used to differentiate moving from fixed targets. For relatively slow-moving ground targets, the doppler spread of the ground clutter return causes confusion between the moving and the fixed reflector returns. One method of separating these returns is to use displaced phase center MTI processing, the performance of which is described in detail in the discussion on HRSLR in the Survey Document. MTI is very useful as an alerting device since a large percentage of moving targets in a tactical battle are "interesting" targets. The presence of multiple moving objects is an important clue in the recognition of target complexes and in determining fluid military situations. It is therefore desirable to have a short-time airborne processor for MTI so that it can serve this alerting function, and can aid in selecting sensors for limited spot coverage.

MTI alerting signals can be generated with azimuth and range position data so that the area of interest can be mapped (by photography, radar, or infrared) with fine resolution. The accuracy of location in range of the moving target is approximately the range resolution (8 to 25 feet). The azimuth placement accuracy of the moving target depends upon the radial velocity uncertainty. The maximum angular uncertainty, however, will never be larger than the beamwidth of the physical antenna.

4.6 USEFULNESS OF FINE RESOLUTION RADAR

Fig. 4-3 gives an independent assessment of the cumulative percent of battlefield targets identified as a function of resolution required for identification. Shown, for correlation purposes, are horizontal bars giving the range of resolution required for 90 percent probability of detection of several typical targets as taken from Fig. 4-1. Reasonable agreement exists between these independently derived curves considering subjective factors which must enter in. Again, it is seen that the payoff in number of military targets identified begins when resolution is reduced below 5 to 7 feet. Fig. 4-3 was taken from Ref. 2 in Section 4.8.

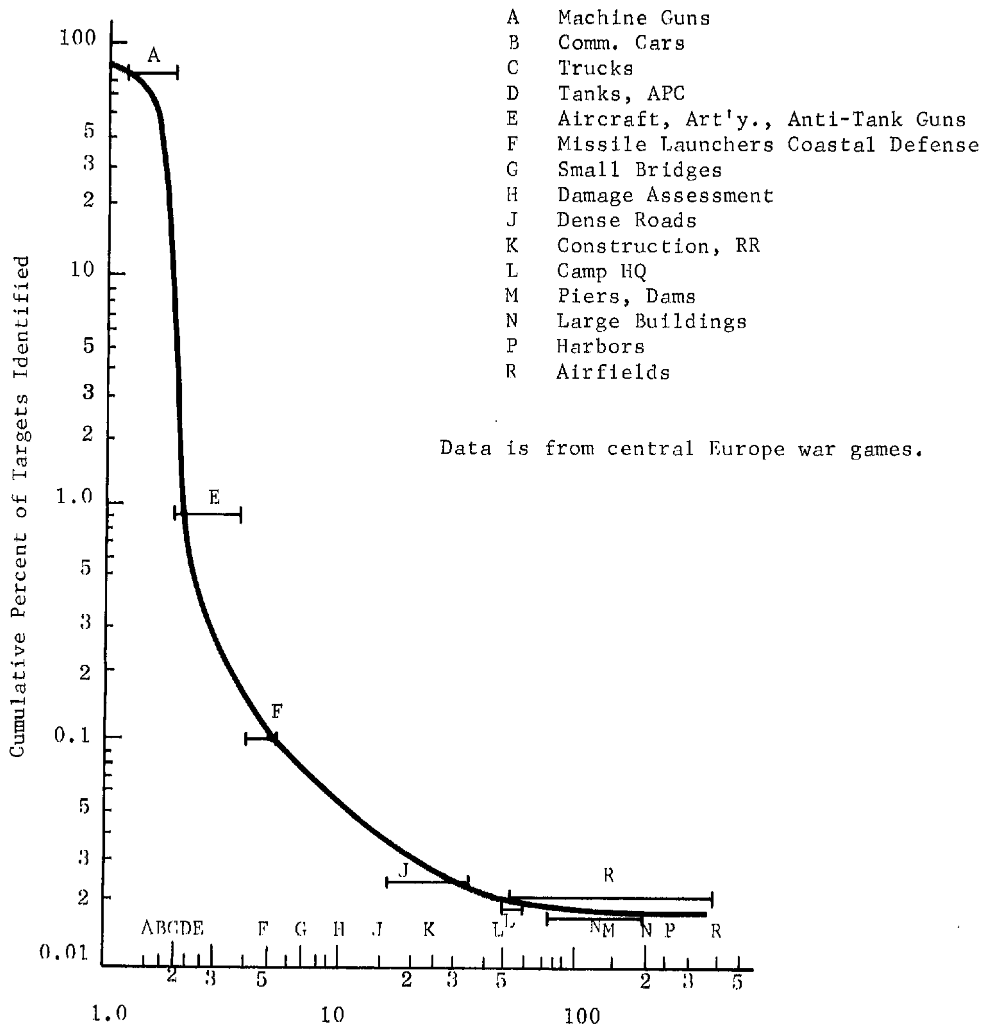


Fig. 4-3 — Resolution Required for Target Identification (ft)

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4.7 EVALUATION OF RADAR AS A SENSOR

Radar has a high probability of detecting man-made objects. Such objects usually contain surfaces or reflectors which have a high radar cross-section. The "pointing" or "indicating" ability of the radar record can be used to locate the corresponding portions of photographic records which should be analyzed on a priority basis or given a detailed analysis in order to interpret the object causing the reflection.

Another unique feature of a high-resolution SLR that can be utilized during reconnaissance system design is the MTI capability. This capability can be used for surveillance of road and rail traffic in all types of weather.

Camouflage of objects to avoide radar detection is much more difficult than is photographic camouflage. Again, concealed man-made objects will have high radar cross-sections which can be used to call attention to photographic imagery which should be subjected to intensive analysis and integration to determine the identity of the concealed object.

For the above reasons, passive defenses are especially easy to detect. Tank traps and barbed wire emplacements will be very apparent. In addition, wire fences around munitions dumps, weapons sites, or special installations will be very noticeable in a high resolution SLR picture and again can be used as a pointer by photo analysts to determine what are being fenced off.

4.8 REFERENCES

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5. INFRARED RECONNAISSANCE

5.1 GENERAL

The characteristics of infrared targets, as documented in the literature, fall into two categories. In one category, infrared image scans or thermal patterns of large scale features are a thermal analog of the field of view. The noise equivalent temperature of the associated systems varies from 0.1 to 0.25°C. Detection or identification of the individual targets generally has been accomplished by visual inspection of the record. These systems use the 8 to 13-micron region or the 4.5 to 5.5-micron window. IR systems provide maximum detection of the operational status of targets, that is, it readily furnishes information concerning the activity associated with a target such as movement of vehicles, personnel activity, etc.

The other type of target data is associated with individual high temperature sources of infrared radiation.

Data are not readily obtained on target complexes whose identification or detection is based on <u>automatic</u> pattern recognition techniques employing the joint spatial, spectral, or infrared power characteristics of the complex. Therefore, the inclusion of targets in this category is based, in part, on the characteristics of related targets specified in the literature, or on an understanding of the physical basis underlying the target signature, or on the inspection of infrared image scans of many types.

Figure 5-1 is a diagrammatic outline of the radiative regime associated with an infrared target. It is seen that the infrared target contrast results from a complex interaction of many processes. The relative weights of these processes are spectrally dependent.

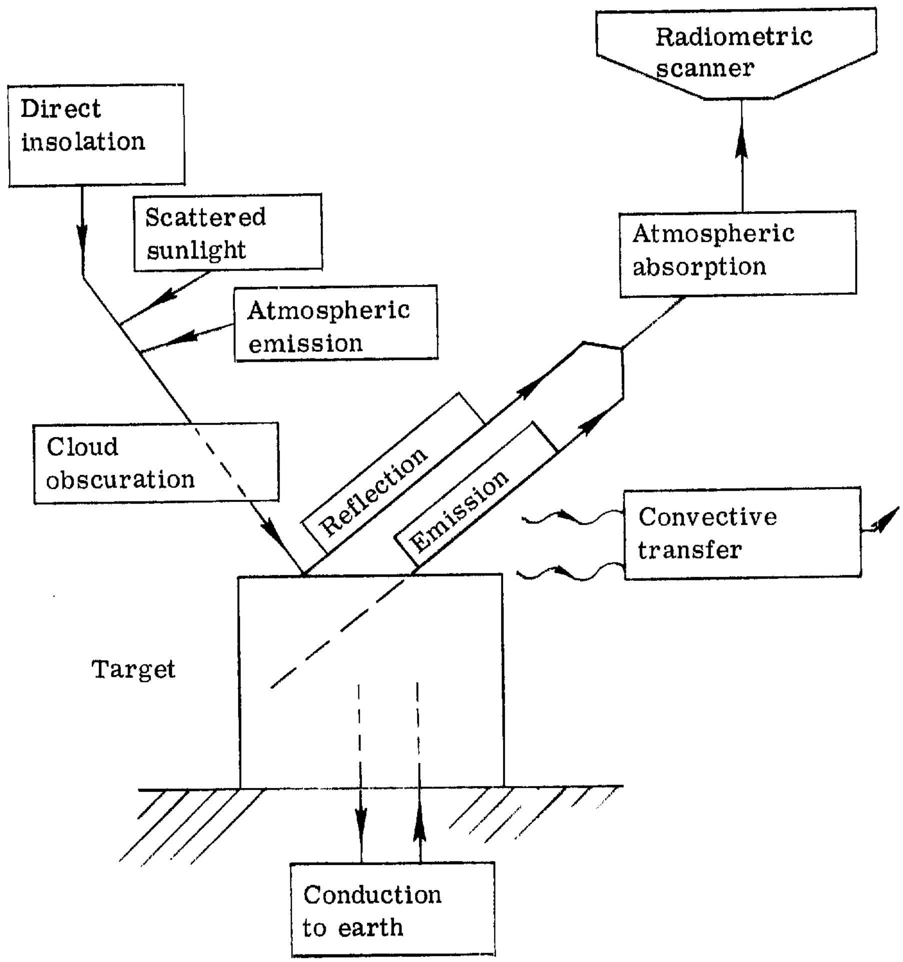

Fig.5-1 — Diagram of the Thermal Processes Associated with the Radiance of an Infrared Target.

Figure 5-2, the infrared transmittance through the whole cloudless atmosphere, is presented for the convenience of the reader.

Figure 5-3, the downwelling infrared spectral radiance, is an infrared analog to the incident illumination in the visible region. Beyond five microns, the downwelling atmospheric emission exceeds the solar input, and system operation is independent of daylight hour. Contrast differences of terrain features are determined by their temperatures and emissivities, as well as by the reflection of the downwelling flux. The contrast differences in terrestrial features may be considered as background noise, when the target is a high-temperature radiation-emitting source.

The following are categorical statements concerning the use of an infrared sensor at night or in inclement weather.

1. Thick clouds will interfere seriously with all infrared operations.

2. The 8 to 13-micron window region has been shown to be virtually unaffected by haze and even ground fog in some cases.

3. Although the region from 1 to 8 microns will be adversely affected by haze and turbid atmosphere, there will be some improvement over the visible region.

4. Operation of a system in the 8 to 13-micron region is not dependent on the daylight hour, except as the temperature of terrestrial features may be dependent on the solar forcing function.

Figure 5-4 shows the wavelength distribution and the magnitude of the emitted radiation for certain targets. The radiating area, highly variable from one curve to the other, is not shown on this graph.

5.2 TARGET CHARACTERISTICS

Table 5-1 provides data on radiating areas and temperature of certain targets.

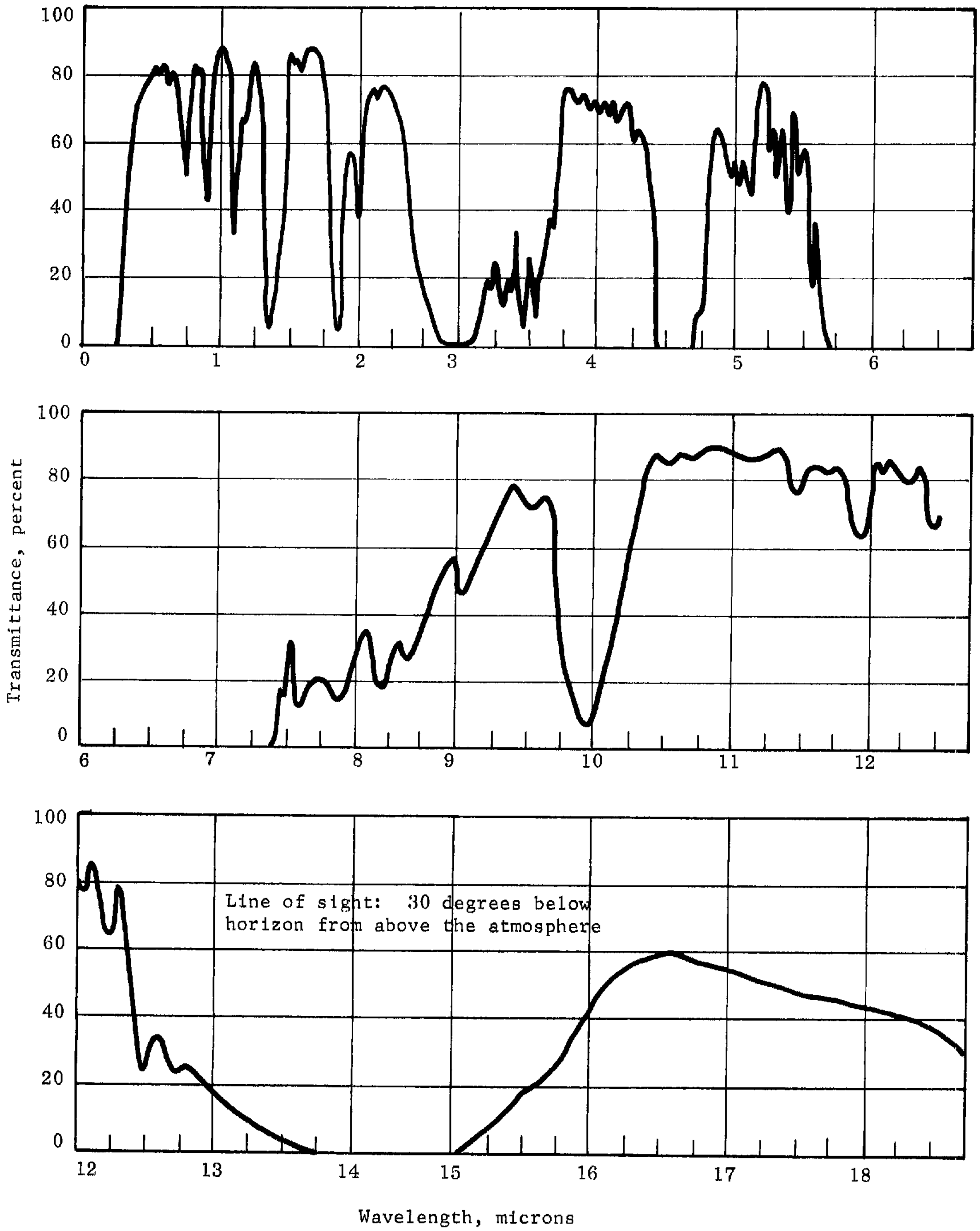

Fig. 5-2 — Transmittance through the Cloudless Atmosphere versus Wavelength

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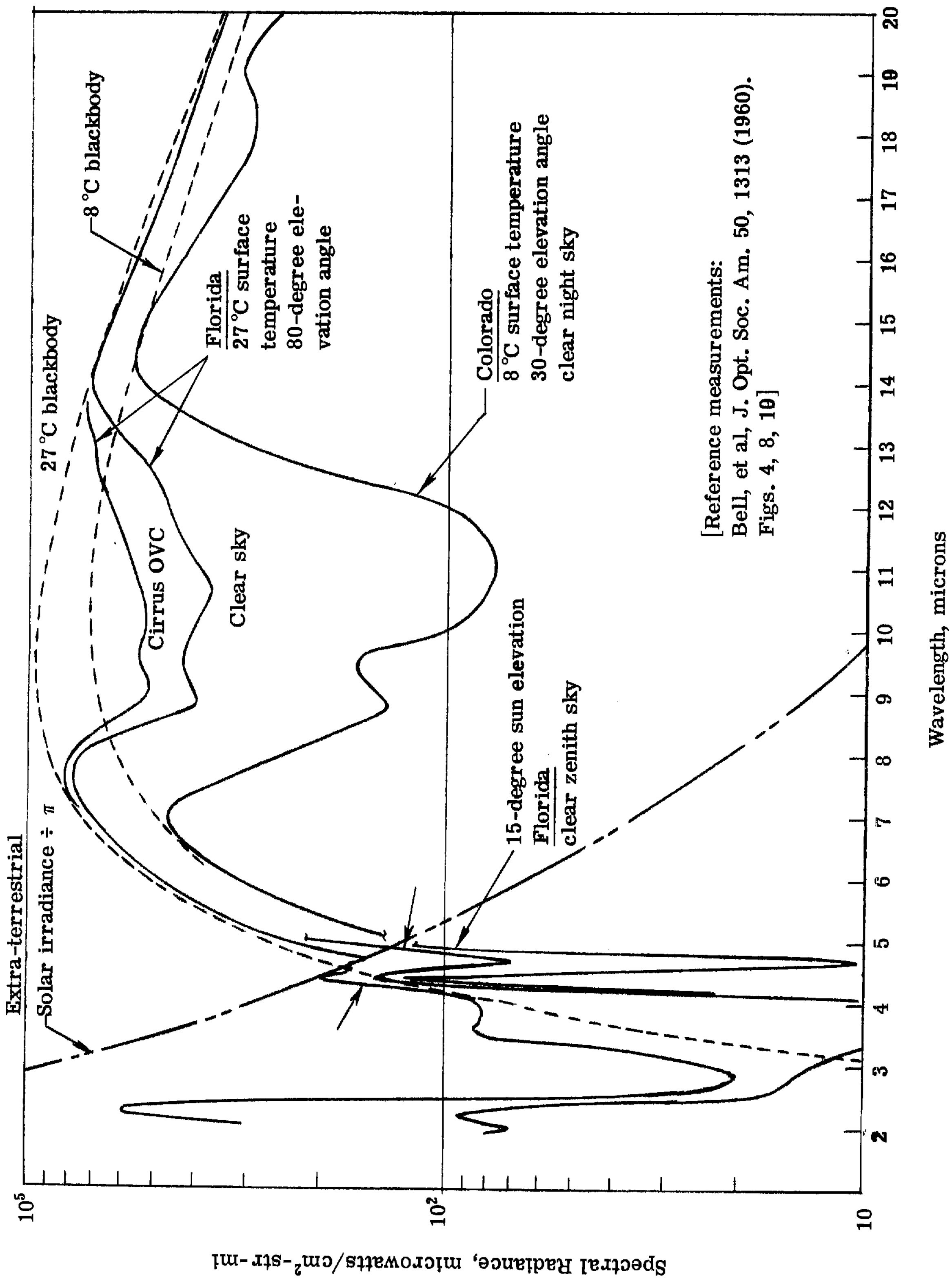

Fig. 5-3 — Downdwelling IR spectral radiance.

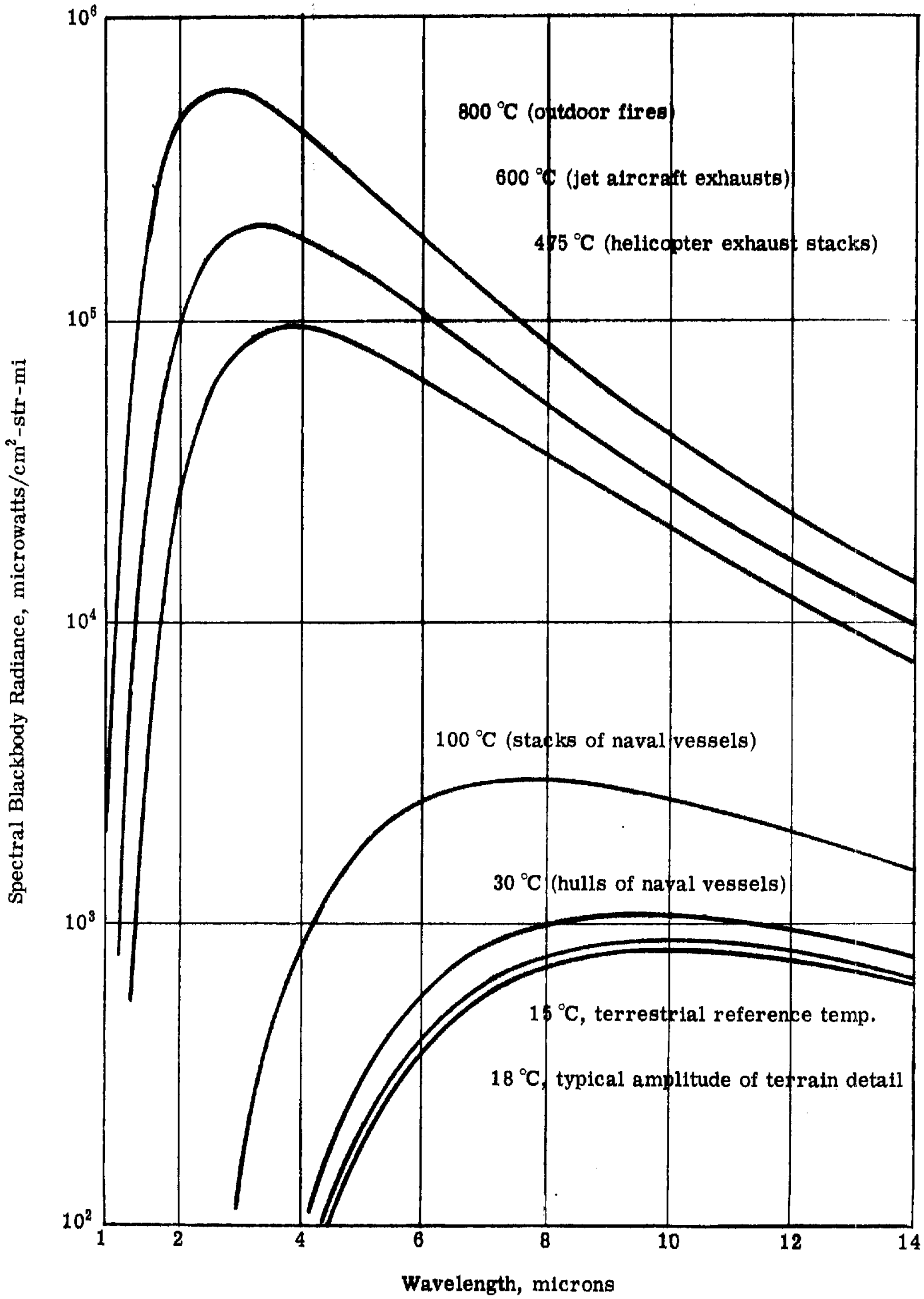

Fig. 5-4 — Wavelength distribution and magnitude of emitted radiation for certain targets.

Table 5-1. Characteristics of Certain Targets

Target	Radiating Area (sq ft)	Temperature Differences (^{o}C)
Hull, aircraft carrier	5×10^4	15^o
Hull, destroyer	10^4	13^o
Hull, destroyer escort	10^4	10^o
Hull, submarine	5×10^3	6^o
Ship exhaust stack	60	100^o
Outdoor cooking fire	1	800^o
Road	10^3	3^o
Parked aircraft	5×10^2	-2^o
Helicopter exhaust	0.25	475
Footpath	10	2

5.3 EVALUATION OF INFRARED AS A SENSOR

5.3.1 Airfields

Airfields usually appear in bold relief on an infrared image. Airstrips and approaches are characteristically warm areas; parked aircraft, hangars, and nearby terrain are comparatively cold. When the infrared image is recorded in the 4.7 micron window, contrast is high with little detail in the "shadows;" in the 8 to 13 micron region, the range of radiance values is higher with more detail apparent. In both, visual determination of runway lengths and classification of the airfield type can be made readily. It is estimated that the associated temperature differences are in the vicinity of $3^{o}C$.

Runways and taxiways, irrespective of size, can be readily detected by visual inspection of data derived in the emission region of from 4 to 13 microns by virtue of their temperature contrast with respect to the adjacent terrain. The dark surface layer absorbs the solar infrared incident by day and the low thermal conductivity of the subsurface retards the downward dissipation of heat. Adjacent terrain is usually more moist and is cooled by evaporation. At night, the airstrip again appears warmer because of the low cooling rates associated with the low thermal conductivity.

The straight edges or borders of permanent airstrips are easily resolved with the 1/2 to 1 milliradian resolution of infrared scanners. Temporary or unfinished approaches may be characterized both by the irregularity of the edges or by detail structure within the periphery. This is caused by the relation of the thermal properties of the surface to the physical structure - such as compactness due to the burden of traffic.

Taxiways in use are detectable in several ways. Jet plumes of slowly taxiing aircraft appear as bright individually-resolved trails. Aircraft ghost images on the ground, which are cooler images formed where a parked aircraft used to be, are discernible.

Airfield hangars and other buildings with metallic roof tops are typically cooler at night, due probably to the lowered emissivities of metals in the emission region and to convective cooling enhanced by the increased thermal conductivity of metals. Temperature contrasts of buildings with respect to the adjacent terrain may be reversed due to internal heat sources associated with repair facilities or other manifestations of human activity.

Light sources and chimney stacks can be expected to be good emitters of infrared in the 4 to 13 micron region.

The number, size, and shape of aircraft may be determined from infrared line-scan images in either the 4.7 micron or 8 to 13 micron windows. Especially at night, they produce black (cold) images, appearing in silhouette, and where the detail in the shape of the edges is consistent with the 1 milliradian resolution. The shapes and sizes of wings and fuselages, and the number of engines, can be determined.

5.3.2 Defense Installations

Defense installations such as anti-aircraft artillery, surface-to-air missiles, trenches, etc., are expected to be characterized by hard-surface covering surrounding the installation, a metallic superstructure, and access paths for associated personnel. Differential cooling and heating processes allow infrared detection in the 4 to 13 micron region. Parts of the installation heated by active use, missile at the time of launch, and searchlights, are especially vulnerable to detection. Trenches are characteristically colder.

5.3.3 Electronic Equipment

Local heat sources associated with the operation of electronic gear will be sensed in the emission region. The shape of colder metallic structures may be detected.

5.3.4 Bridges

Railroad bridges and trestles of metallic structure have a high thermal conductivity that promotes differential cooling. Also, metals have a lowered emissivity in the main atmospheric window (10 microns) dependent in magnitude on surface characteristics such as the amount of protective paint. It is reasonable to expect that such structures will be a few degrees cooler than the background, and that detection can be made by virtue of the differential emission in the 8 to 13 micron window.

5.3.5 Roads and Paths

Roads and footpaths have been well resolved by the 1 to 3 milliradian resolution with image scanning systems operating in either the 4.7 micron or 10 micron window. Hard-surface roads, intended to be such by standard construction procedures, are similar with respect to their infrared characteristics to the airfield runways and taxiways discussed above. Footpaths, however, similar in composition to the adjacent terrain, but differing in surface texture or compactness as a result of the traffic burden, exhibit an anomalous behavior dependent on the daylight hour. Although emissivity differences may have some role in the prediction of contrast, the principal mechanism is the temperature difference resulting from variations in the thermal admittance of the ground. Compacted road surfaces have a higher heat conductivity than adjacent porous soil. They appear colder by day due to the conduction of heat into the lower levels, and they appear warmer by night since more heat is conducted from lower levels as compared to the adjacent porous terrain.

5.3.6 Personnel

Although personnel have been detected with an infrared image scanner with a 2 milliradian resolution in the 4.5 to 5.5 micron region, individual personnel from 300 feet appear as mere pinpoints. Troop concentrations are probably better detected indirectly because they alter or disrupt the normal scene. This includes temporary housing facilities, stacks of dead vegetation, and cooking fires. Outdoor charcoal fires (800°C), have been detected even under a dense forest canopy, by day in the 4.5 to 5.5 micron region and by night in the 1.5 micron region.

5.3.7 Vehicles

Vehicles are characterized by infrared radiation in the emission region from 4 to 13 microns as associated with engine exhaust stacks, internal heat sources, and hot gun muzzles when in active use. The strength of the emitting sources is variable, depending on the viewing aspect and the extent of shielding. At night and over hard surfaced roads, vehicles in motion would have a negative temperature contrast thus exhibiting their silhouettes with warm spots superimposed.

5.3.8 Missile Sites

Fixed missile sites with service roads, concrete aprons, and earth-works are readily detected, day and night, in the 4 to 13 micron emission region with image scanners. The physical basis that causes the radiance contrast follows along lines discussed previously.

5.3.9 Harbors and Coastal Areas

Harbors and coastal areas lend themselves readily to infrared image reconnaissance because of the marked temperature contrast of the harbor installations with reference to the sea. Port facilities, buildings, docking areas, ship traffic, thermal sea contours, and infrared detail associated with both onshore and offshore activity are readily discerned.

5.3.10 Ships

The infrared radiation from ships at sea that is generated from within, transmitted through the hulls, and observed from a distance, produces an effective temperature difference (with respect to the sea) which can be as high as 15°C. It is a function of the ambient air temperature through the cooling effects of the air stream, and of the type of ship. The temperature differences can be expressed in terms of radiant intensity. They give values of from 1 to 40 kilowatts per steradian in the 8 to 13 micron region. These values apply to aircraft carriers, destroyers, destroyer escorts, and submarines, with carriers providing the maximum signal. The others follow in order.

Naval vessel exhaust stacks are especially vulnerable to detection in the emission region from 4 to 13 microns.

Infrared image scans of ship decks have shown them to be of variable contrast with respect to the sea. They are usually colder than the sea at night, and often warmer by day, with local heat sources or areas of differential temperature apparent. The detail and structure are sufficient for purposes of classification.

5.3.11 Terrain

Infrared image scans in the 8 to 13 micron region of terrain have been particularly useful for the day or night analysis of land features, streams, forestation, snow and ice mapping, shores, keys, and ocean currents. The technique has been effective in detecting structure and detail corresponding to small values of temperature differences often not seen in the visible.

5.3.12 Communication Paths

It is doubtful whether details of radio or land-line communications can be detected with a resolution of 1 milliradian.

6. ELECTRONIC INTELLIGENCE (ELINT) RECONNAISSANCE

6.1 GENERAL

The electromagnetic spectrum useful for "radio" type communications (not thermal or visual) extends from approximately 3 kilocycle to 3000 gigacycles, as shown on the bar chart of Fig. 6-1. This spectrum has been divided conveniently into nine decade bands, and are identified as follows:

Band Number	Frequency Range	Frequency Subdivision
4	3 - 30 kc	VLF (very-low frequency)
5	30 - 300 kc	LF (low frequency)
6	300 - 3000 kc	MF (medium frequency)
7	3 - 30 mc	HF (high frequency)
8	30 - 300 mc	VHF (very-high frequency)
9	300 - 3000 mc	UHF (ultra-high frequency)
10	3 - 30 gc	SHF (super-high frequency)
11	30 - 300 gc	EHF (extremely-high frequency)
12	300 - 3000 gc	—— ——

From the scale of wavelength at the bottom of Fig. 6-1, it should be noted that the wavelength at the high-frequency end of the radio spectrum is only 100 microns long, and corresponds to the wavelength of low-frequency radiation within the infrared spectrum. At this portion of the spectrum, therefore, the functions of radio and IR equipments can and do overlap.

Targets of tactical concern in battlefield surveillance are listed in Table 1-1 in Section 1. Many of these targets incorporate systems that radiate electromagnetic energy within the above spectrum which may be detected and analyzed

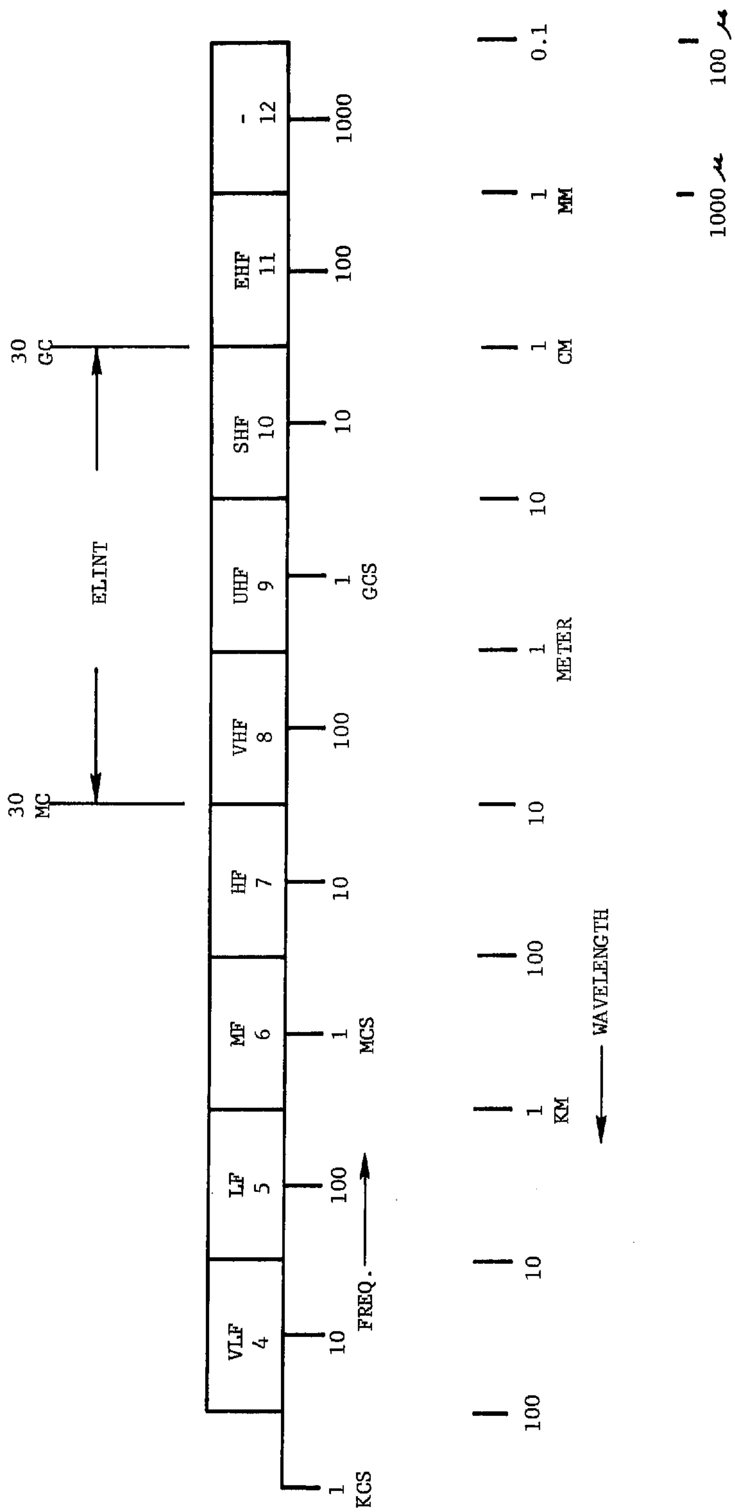

Fig. 6-1 — Radio Electromagnetic Spectrum by Electronic Intelligence (ELINT-SIGINT) receivers to provide valuable information concerning the Electronic Order of Battle (EOB). Although used for many purposes from installations on the ground and vehicles in the air or on water or land, these radiating systems may be categorized in five generic classes according to their fundamental use. These classes are:

Radar Systems
Navigation Systems
Control Systems
Communication Systems
Electronic Countermeasure (ECM Systems)

A sixth class — Industrial, Scientific and Medical Systems — includes radiating systems of doubtful concern to a tactical commander, but which may be of importance in long-term strategic reconnaissance. Included in this class are such systems as radio frequency furnaces for metallurgical use, laboratory cyclotrons, medical diathermy equipment, and similar systems.

Information concerning the use of any or all of these radiating systems by aggressor forces is of value in the overall reconnaissance plan. However, the most valuable information, by far, will be that obtained from the interception and analysis of radar system emissions. Design of the majority of ELINT systems has concentrated on interception of these signals. The radiations from radar emitters are usually characterized by repetitive pulse transmissions of low duty cycle which are very amenable to detailed analysis by intercept equipment. Some of the radars, however, radiate a CW (continuous-wave) signal. The frequency range employed by radar systems extends from 30 megacycles to 30 gigacycles (Bands 8, 9, and 10 in Fig. 6-1), but the systems are usually clustered in small bands throughout the total range.

Over the years various code letters have been used to designate the most prominent of these radar frequency bands. Since they are frequently referred to when discussing radar equipments, a list is given below of the frequency band codes as generally used today with their corresponding frequency limits. Although this is a convenient form of nomenclature, the codes have no official status, and there is not always general agreement as to the limits associated with each band.

Band Code Letter	Frequency Range
HF	3 - 30 Mcs
VHF	30 - 300 Mcs
UHF	300 - 1000 Mcs
L	1000 - 2000 Mcs
S	2000 - 4000 Mcs
C	4000 - 8000 Mcs
X	8000 - 12,500 Mcs
K_u	12.5 - 18.0 Gcs
K	18.0 - 26.5 Gcs
K_a	26.5 - 40.0 Gcs
Millimeter	> - 40 Gcs

Radar systems are normally employed for specific functions and have recognizable characteristics which distinguish one type of emitter from another. The radar systems to be found in a typical battlefield situation consist of a combination of strategic and tactical emitters which may be classified according to function as shown in Table 6-1. The abbreviations given for each class in the table are quite standard and will be used in the remainder of this report.

Many radar systems are capable of performing combinations of the functions shown in the table. For example, an early-warning radar may also be used as a surveillance radar. Also, when operating with a radar having a height-finder capability, the combination can be utilized as a ground-control intercept (GCI) radar.

6.2 TARGET RECOGNITION CHARACTERISTICS

Because battlefield radars and communications equipment are designed for specific functions, there is usually a significant difference in their signal characteristics which enables them to be easily identified by ELINT processing equipment. Early-warning radars, for example, generally use low frequencies, high powers, and long pulse widths to achieve maximum range against small aircraft targets. Fire-control radars, on the other hand, generally use higher frequencies, medium power, and short pulses to accomplish precision tracking of

Table 6-1. Radar Classification by Function

Designation	Radar Function
AAFC	Anti-Aircraft Fire Control
ACQ	Acquisition
AI	Airborne Interceptor
BS	Battlefield Surveillance
CS	Coastal Surveillance
DT	Data Transmission
EW	Early Warning
FC	Fire Control
GCA	Ground Control Approach
GCI	Ground Control Intercept
HF	Height Finder
IFF	Identification Friend or Foe
MC	Missile Control
NAV	Navigation
RS	Radio Sonde
ST	Shell Tracking
SURV	Surveillance
TT	Target Tracking

aircraft targets already acquired by acquisition radars. Some radar equipments use simple pulse modulation while others use more exotic modulation methods. Since each functional type has been designed to accomplish its particular task, its design parameters can be related to function when the intercepted signal is analyzed.

Emitter signal characteristics which can be utilized to identify the source of an emission pertain to the frequency, modulation characteristics, and antenna patterns of the radiator. A tabulation of the parameters which can be used is contained in the following list. The direction-of-arrival and time-of-arrival parameters are not characteristics which normally could be used to identify an emitter, but are included to make the list complete.

Emitter Signal Parameters

Radio Frequency (RF)
Pulse Repetition Interval (PRI)
Pulse Repetition Rate
Pulse Width
Pulse Amplitude (Signal Strength)
Modulation Characteristics (Non-Pulse)
Duty Factor
Antenna Scan Rate and Pattern
Antenna Beamwidth
Polarization
Side Lobe Level
Within Pulse Modulation
Direction-of-Arrival
Time-of-Arrival

ELINT systems used for strategic reconnaissance attempt to evaluate many of these signal characteristics, especially when new or different emissions are intercepted, so that a complete evaluation of the enemy's tactical capabilities can be maintained. However, for purposes of tactical reconnaissance, it is necessary to measure those parameters which are required to insure a high probability of identifying the target. Technical Intelligence is not a tactical reconnaissance function.

A study of the emitter signal parameters given above has shown that the measurements of frequency and pulse repetition interval (or its reciprocal, pulse repetition rate) are usually sufficient to provide a rapid and positive identification of most radar types. Pulse width and emitter antenna scan rate can be useful in resolving the few remaining ambiguous radar identifications. To identify a communications type emitter positively, it is necessary to measure the basic modulation characteristic of the emitter. Such modulation characteristics as single sideband suppressed carrier, frequency modulation (FM), pulse code modulation-FM, and others, can be recognized by the ELINT processing logic.

6.3 TARGET LOCATION CAPABILITY

The location of a radiation emitter by an ELINT system involves the solution of a triangulation problem, using the relative bearing angles of the emitter from the reconnaissance aircraft, and a base line established by the movement of the aircraft. This technique is a requirement because there is no known method of determining the range to a source of radiation when using a single passive receiving system.

The accuracy of triangulation is primarily a function of the accuracy with which the angles of arrival of an intercepted signal can be determined, and the length of the base line between the angles measured. The longer the base line (within limits), the more accurate the "fix" which can be made, since the acuteness of the arrival angles contributes to the uncertainty of the location measurement.

Airborne ELINT systems generate the base line of the mensuration triangle by "flying by" the emitter source for as long a period of time as is feasible. Obtaining many measurements of emitter-bearing angles during the fly-by makes the triangulation more accurate because of the more favorable angular relationship. It also provides a large statistical improvement in the accuracy of emitter location. The statistical improvement is a function of the square root of the number of bearing measurements made, and is quite significant when a large number of "cuts" can be taken. In fact, because of the statistical improvement which can be attained, it is not necessary to use a high resolution approach in the design of the ELINT angle measuring components.

There is also a solution to the location problem which uses the altitude of the reconnaissance aircraft above the earth's surface, in conjunction with measurements of the vertical depression angle from the aircraft, to provide the triangulation. However, this system is only accurate at high altitudes of flight because, as the altitude is decreased, the vertical angles become grazing angles which cannot be measured accurately.

In currently programmed ELINT systems using the fly-by technique, emitter locations can be determined within an accuracy of approximately ±3 percent of the range. The range is the range of the emitter "abeam" the reconnaissance aircraft (perpendicular to the flight path at the point of minimum range). Accuracies of approximately ±5 percent of range can be attained by using only a few fixes, without flying by the target.

The emitter location systems using the radio altitude and vertical depression angles can achieve location accuracies of approximately ±3 percent of range at ranges where the vertical angles remain larger than approximately 10 degrees.

6.4 SIGNAL ENVIRONMENT CONSIDERATIONS

In order to define the problems involved in identifying and locating radiating targets by means of ELINT systems, and to obtain preliminary solutions to them, it has been found helpful to examine in detail existing and postulated radar signal environments. Radar Order of Battle (ROB) and emitter signal characteristics are available for most of the world, and from these such signal environments can be derived. By means of these environmental models the actual frequency distribution, signal densities, pulse repetition interval limits and other factors can be ascertained.

Two environmental models have been constructed for this study, and it is from these that the final conclusions are drawn. The first environment postulates a carrier task force operation in the Baltic Sea near the Soviet mainland during the 1967-70 period of time. The advantage in using the Soviet Radar Order of Battle is that the equipment characteristics will be identical to what will be found in any of the Sino-Soviet nations or their satellites, since classes of Russian equipment are being distributed throughout these areas. By using the Soviet mainland, where both strategic and tactical emitters will exist, a very dense signal environment will be present.

The second environmental model constructed for this evaluation is also for the 1967-70 time period and postulates a carrier task force operation near North Vietnam. Although this is representative of a sparse signal environment, the classes of equipments are similar to those that exist in the denser environment.

6.4.1 Soviet Mainland in Baltic Sea Area

The area chosen for this analysis, although possibly not realistic from the standpoint of an actual carrier task force operation, is representative of tactical reconnaissance in an extremely dense emitter environment. Therefore, any analyses made within the framework of this environment can be very useful in defining the types, probable disposition, and maximum number of enemy emitters in a very dense battlefield situation. Such information is of vital concern to the designer of ELINT systems because it enables him to estimate the maximum signal pulse density, the degree of pulse interleaving likely to occur, the type of signal sorting to be employed, and other important factors.

The area under consideration is approximately 8000 square miles and contains, in addition to the strategic emitters, the tactical emitters associated with a Soviet Combined Arms Army (CAA).

The total electromagnetic environment within this area between 30 megacycles and 30 gigacycles originates from four separate types of sources:

a. Strategic Emitters
b. Tactical Emitters
c. Airborne and Shipboard Emitters
d. Communications Equipment

Table 6-2 contains a list of the Soviet strategic emitters found within this area. This environment was obtained from the latest available Radar Order of Battle (ROB). Since the time period of interest is 1967-70, the strategic environment has been increased by 5 percent to account for estimated growth. Included in this table are the functions and signal characteristics of each emitter, including the total number of each type to be found in the area of interest. A similar breakdown of the Soviet tactical emitters to be found within this area is given in Table 6-3. The total number of tactical emitters is based on densities previously established for a Soviet CAA. The densities used in this study are as follows.

Table 6-2. Postulated Soviet Strategic Radar Environment for Baltic Sea Area (1967-1970 Period)

Emitter	Function	Frequency	PRF	PW	(KW) Peak Power	Total	Number of Sets On
Bar Lock	EW	2690-3135	360- 380	2-3.1	5 MW	7	4
		555- 570					
Big Bar	GCI	2700-3130	370- 380	2.2-3.0	2 MW	1	1
		555- 570					
Big Mesh	GCI	2700-3130	370- 380	2.2-3.0	1 MW	12	7
Cross Fork	ACQ	204- 215	350- 450	1.5-2.5	200	1	1
Dry Rack	DT	570- 625	374- 380	0.8-1.3	2	2	-
		2953-3009	1172-1293	0.4-1.0			
Fan Song A,B,D	TT, MC	3012-3064	2395-2553	0.1-0.8	1-2 MW	11	3
		4924-4966	917-1043	0.3-0.7			
Fan Song C,E	TT, MC	4989-5099	1730-2151	0.7-1.0	2 MW	4	1
Fish Net	IFF	157- 187	50- 175	4-5	1-2	19	2
			340- 500				
Fire Wheel	FC	2598-3040	677-1182	0.1-1.2	400	7	2
		822- 836					
Flat Face	ACQ	880- 900	365- 800	1.7-2.5	500	9	5
Home Talk	GCA	9300-9388	2000	0.3-0.5	25	2	1
Knife Rest-A	EW	70- 75	50	3-12	100	11	7
Knife Rest-B	EW	80- 88	100	5-12	100	9	5
Knife Rest-C	EW	80- 88	100	5-12	100	1	1
			320- 340				
Rock Cake	HF	2600-2650	365- 450	2.0-3.5	1 MW	7	3
			200- 250				
Slant Mesh	GCI	2680-3255	330- 350	1.0-1.5	350	2	1
Spoon Rest-A	ACQ	153- 157	240- 400	4.3-6.1	350	8	5
Strike Out	EW	2705-2720	330- 350	0.9-1.2	1 MW	1	1
			320- 340				

Table 6-2. (Continued)

Emitter	Function	Frequency	PRF	PW	(KW) Peak Power	Total	Number of Sets On
Stone Cake	HF	2600-2650	360- 390	2.0-3.5	1 MW	3	1
			410- 440				
			520- 660				
Sheet Bend	CS, ACQ	8960-9450	1025-1300	0.2-0.7	Unknown	4	2
Tall King	EW	162- 175	190- 200	1-15	1 MW	4	2
Token	GCI	2700-3120	330- 350	0.8-1.5	750	12	7
			860-1025				
Whiff	FC	2653-2923	1121-1385	0.4-1.0	300	2	1
Witch-4	IFF	650- 685	340- 375	0.7-1.4	2	4	
Witch-5	IFF	650- 685	50- 100	0.7-1.4	2	1	1
Score Board	IFF	650- 685	50- 100	0.8-1.2	2	3	

Table 6-3. Tactical Emitters Associated with a Soviet Combined Arms Army

Emitter	Function	Frequency	PRF	PW	(KW) Peak Power	Total	Number of Sets On
Fan Song C,E	TT, MC	4924-4966	917-1043	0.3-0.7	2 MW	53	16
		4989-5077	1730-2151	0.7-1.0			
Fire Can	FC	2685-2855	1850-1870	0.2-0.8	250	151	45
		822- 836					
Flat Face	ACQ	880- 900	365- 800	1.7-2.5	500	37	22
Long Trough	BS	9300-9500	1500-8000	0.1-1.0	65	72	29
			2700				
Low Blow	TT, MC	6550-6700	2200-2300			18	5
Pork Trough	ST	9220-9520	1500-9000	0.8	250	34	7
Score Board	IFF	650- 685	50- 100	0.8-1.2	2	53	5
Small Yawn	BS	9400-9600	2180-2220	0.4-0.6	250	34	14
Spoon Rest-A	ACQ	153- 157	240- 400	4.3-6.1	350	53	32
Track Dish	FC	2726-2842	2419-2563	0.1-0.9	300	22	4
			250- 500	20-45			
Wave Kite	RS	81- 82	2000-3500	2.0-3.0		3	-

Emitter	Density (No. per square mi.)
Fan Song	0.0066
Fire Can	0.0189
Flat Face	0.0046
Long Trough	0.0090
Low Blow	0.0022
Pork Trough	0.0042
Score Board	0.0066
Small Yawn	0.0042
Spoon Rest A	0.0066
Track Dish	0.0028
Wave Kite	0.0004

In Tables 6-2 and 6-3, a final column has been added which gives the number of sets expected to be operating, or "on", at any given time. These numbers are determined by the "on times" of the specific emitter functions which have been assumed as follows:

Emitter Function	On Time
EW/GCI/ACQ/CS	0.6
BS/HF	0.4
FC/TT/MC/GCA	0.3
ST	0.2
IFF/RS/DT	0.1

Information on the types, number and disposition of emitters associated with Soviet aircraft and ship targets is available, and is of considerable importance for some aspects of military reconnaissance. For purposes of this analysis, however, only small harbor craft, patrol boats, and anti-invasion boats will be considered. It is assumed that the identification and location of inflight aircraft and the identification and location of capital ships will not be a normal requirement for the multisensor reconnaissance aircraft. These functions will be performed by surveillance aircraft, such as the E2A.

The emitters associated with Soviet harbor craft are for the most part low-powered navigation and surface-search radars operating in the vicinity of 3000 and 9000 megacycles, with pulse repetition rates of 400 to 1200 pulses per second, and antenna scan rates of approximately 12 revolutions per minute. The number of such craft is small, so that the effect on densities and traffic is minor.

The fourth source of electromagnetic emissions considered in this analysis is the communications equipment used by the Soviets. Table 6-4 is a list of Soviet ground communication equipments used at both tactical and strategic installations. A remarks column has been included in the table to indicate the most likely usage of this equipment.

Of the four sources of electromagnetic radiation present in this battlefield example, the location and identification of signals from communications equipment would probably be the least useful to the Air Intelligence Officer aboard an aircraft carrier, since communication equipment is widely distributed throughout the area of interest, and is not necessarily associated with particular targets or threats. However, when such signals are intercepted, the ELINT system will in many cases be able to provide Signal Intelligence (SIGINT) by locating and identifying the emitter through the analysis of its technical modulation characteristics. Communications Intelligence (COMINT), involving the analysis of the semantic content of intercepted communications signals, has not been considered in this evaluation.

6.4.2 North Vietnam

The second geographical area used in this analysis of tactical ELINT target recognition is North Vietnam. Because of the limited-war activity now taking place in this country, evaluation of signal radiation present in this battlefield area is particularly timely and is a true representation of the conditions which can exist. Also, since the electromagnetic signals emanating from this area are from only a single source, namely a small population of fixed emitters located throughout the country, the situation is typical of a very light ELINT environment which, in conjunction with the dense environment of the previous example, can provide upper and lower limits of battlefield electromagnetic target densities.

Table 6-4. Soviet Ground Communication Equipment

Emitter	Frequency	Modulation	Power (W)	Remarks
Mercury Grass	60-69.975	FM ± 7 Kc	2.5	Mobile Radio Relay Used at SAM Installations Installed in a GAZ-63 Van
R-821, RSK	100-150	AM	200	
R-800,RSIU-3M	100-150	AM	8	Ground to Ground or Ground to Air Communication
R-801,RSIU-4	100-150	AM	10	
RVG 902	1200-1470	FM ± 75 Kc	8-10	Ground to Ground Communication at Both Mobile and Fixed Installations
RVG 903B	1200-1470	FM ±400 Kc	8	
DSE 8/1	500-555	FM ± 8 Kc	0.6	Ground to Ground Communication Located at Airfields and Air Force Installations
R-400	1580-1760	PPM	80	Mobile Radio Relay Installed in a Z1S-151 Van
R-600 VESNA	3700-4200	FM	3	Ground to Ground High Capacity System
R-105	36.0-46.1	AM	1.2	
R-106	46.1-48.8	AM	0.8	
R-108	27.8-36.35	AM	1.0	Battlefield Communication
R-112	20-40	AM	10-20	
R-116	47-51	AM	0.1-0.5	
	51.0-52.9			
FU 0.25	53.0-54.9	FM	0.3	

Table 6-5 contains an estimate of the radar emitter population for the North Vietnam area extrapolated to the year 1967. It is based on present Radar Order of Battle (ROB) figures, increased by 40 percent to cover some escalation of activity in the area. It is, of course, impossible to predict what actually will occur in the complex situation now existing in this area.

6.5 TARGET MATRIX PARAMETERS

By using the information presented in this study, particularly the postulated signal environments, it is possible to draw conclusions concerning the capability of a tactical ELINT system to identify and locate radiating emitters. Frequency-pulse repetition frequency plots covering the complete frequency range of interest are given to indicate how the use of these signal parameters will be sufficient to identify target emitters with a high order of probability.

Many of the targets listed in Table 1-1 can be recognized by analysis of the signal radiation pattern of associated emitters. These targets fall in the groups listed in Table 6-6; the associated radars are listed for each group.

Radars carried by aircraft will normally be active, and thus interceptable, when the aircraft is airborne.

The usefulness of the ELINT sensor in providing recognition and identification data is primarily in the area of activity detection. Large airfields will be recognized from intercepted GCI and GCA radars associated with them. It is assumed that this equipment will not be used on small, temporary airfields.

Target detail larger than approximately 3 percent of the target range abeam the reconnaissance aircraft is resolved.

The accuracy of directional and locational data will be between 1 and 5 percent of the range to target, depending on the system used and the time permitted to make the measurement.

The cueing potential of the ELINT sensor is extremely high against targets with associated radar and emitting communications equipment.

To determine whether an intercepted emitter signal can be correctly identified it is first necessary to ascertain whether particular set functions can be confused with one another. Since frequency and pulse repetition frequency

Table 6-5. Predicted 1967 Radar Environment for North Vietnam

Emitter	Function	Frequency	PRF	PW	(KW) Peak Power	Total	Number of Sets On
Cross Slot	EW	2970-3040	331- 450	0.8-2.0	250	2	1
Fire Can	FC	2685-2855	1850-1870	0.2-0.8	250	12	4
Knife Rest-A	EW,ACQ	70- 75	50	3-12	100	2	1
Knife Rest-B	EW,ACQ	80- 88	100	5-12	100	4	2
RUS	EW	70- 75	45- 60	5-10	75	5	3
SCR-270	EW	104- 112	200- 400 860-1025	10-30	500	6	4
Whiff	FC	2653-2923	1121-1385	0.4-1.0	300	2	1

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Table 6-6. Target-Associated Radar Complexes

Target/Threat	Function	Associated Radar
Airfields	GCI	Big Bar, Big Mesh, Slant Mesh, Token
	GCA	Home Talk
	HF	Rock, Cake, Stone Cake
	IFF	Witch 4, Witch 5, Fish Net
SAM's (SA-2)	TT, MC	Fan Song (S and C band)
	ACQ	Spoon Rest A
	IFF	Score Board
SAM's (SA-3)	TT, MC	Low Blow
	ACQ	Flat Face
	IFF	Score Board
Seaports	CS	Sheet Bend
Artillery (AA)	AAFC	Fire Can, Whiff
	ACQ	Cross Fork
	IFF	Fish Net, Score Board, Witch 4 & 5
Artillery (Ground)	FC	Track Dish
	BS	Long Trough, Small Yawn
	ST	Pork Trough
Aircraft (Fighters)	AI	High Fix, Scan Fix, Scan Can, Scan Odd, Scan Odd (Mod), Scan Three, Spin Scan
(Bombers)	MC	Komet 3
	ACQ	Puff Ball
	FC	Bee Hind
	Bombing & Nav	Mushroom, Kobalt

(PRF) are two of the more important parameters measured for each signal interception, plots were made of frequency versus PRF for the emitters listed in Tables 6-4, 6-5, and 6-6, to determine whether any overlapping areas exist. These plots are presented in Figs. 6-2, 6-3, 6-4, and 6-5.

It may be seen in Fig. 6-2 that, with the exception of radiosonde emitters, only EW type radars are found below 150 megacycles, three types of emitters are found, namely EW, ACQ, and IFF. However, for the frequency range indicated on this plot, there is no overlapping of any of the emitter functions.

Figure 6-3 covers the frequency range from 550 to 900 megacycles, and here it may be noted that presently no emitters are found between 215 and 550 megacycles. On this plot there are four distinct emitter functions. The GCI function appearing on this plot is from the single L-band beam of the BIG BAR and BIG MESH radars. For this frequency range there are also no ambiguities among the emitter functions.

In Fig. 6-4 some ambiguities are found in the S-band region. This region has the highest density of Soviet emitters; therefore, it is expected that some overlapping will exist in this band. A significant overlapping occurs in the fire control function region, where it may be noted that an airborne emitter (Scan Fix) is present. This is the only airborne emitter used by airborne intercepters (AI) to be found in the S-band region. A second area of overlap is in the GCI, EW area. This overlapping is expected since EW emitters are very similar to GCI emitters. As previously mentioned, any EW emitter can perform a GCI function when operating in combination with a height-finder radar. The remaining emitter functions appearing on the plot lie in separate areas and have no ambiguities with other emitter functions. It may be noted from Fig. 6-4 that a large gap appears in the region from about 3300 to 4900 megacycles.

Figure 6-5, the final plot of this group, covers the frequency range from 6500 to 10,000 megacycles. In this plot there exists considerable overlapping of functions within the X-band region from about 9250 to 9500 megacycles. The major ambiguities in this frequency range are between the tactical emitters associated with the Soviet CAA and the airborne emitters associated with Soviet fighter and bomber aircraft. Two other emitter functions also appear in this region, namely GCI (HOME TALK), and CS (SHEET BEND). The remaining emitter

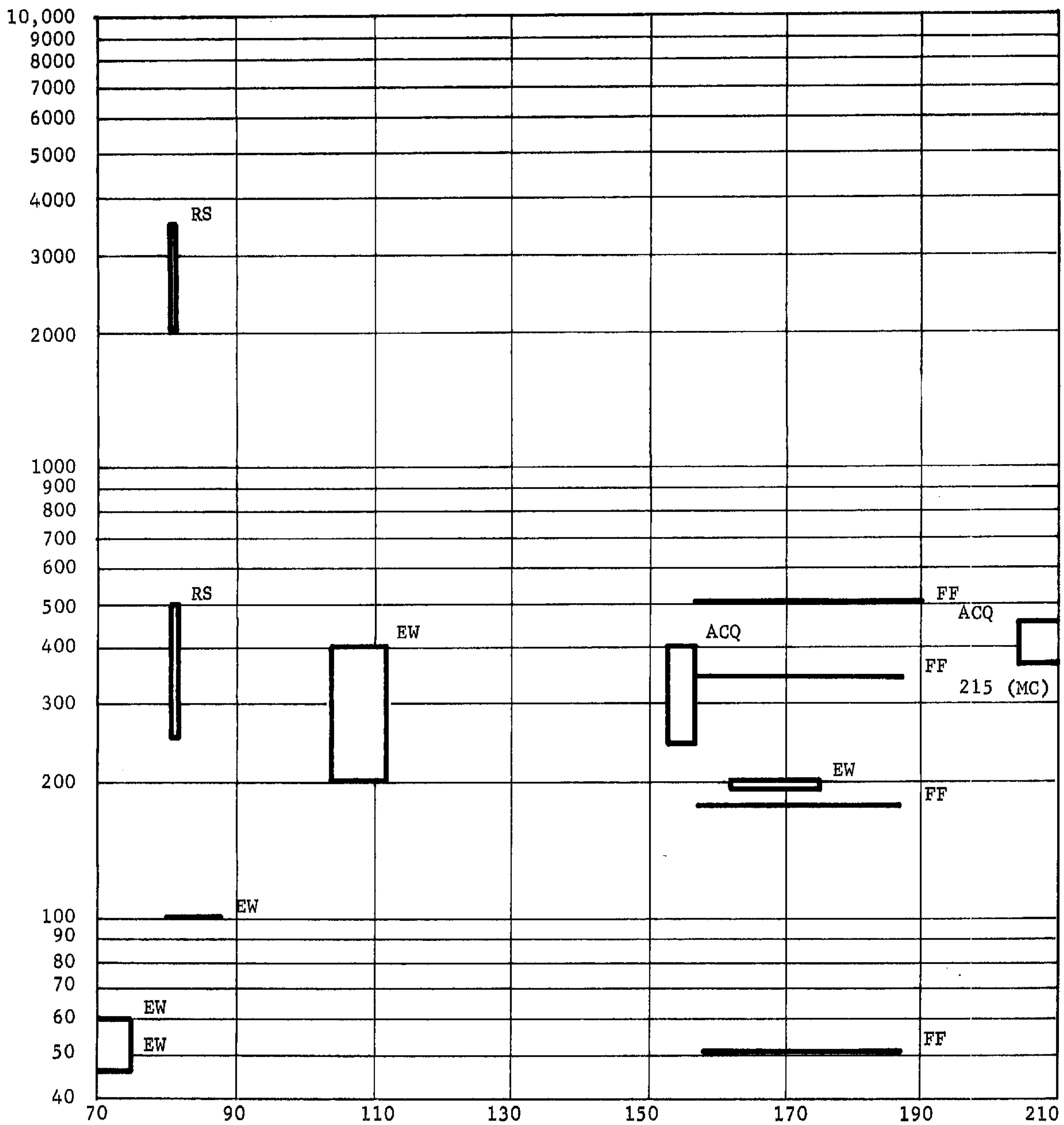

Fig. 6-2 — Soviet radar disposition (No. 1) RF frequency vs pulse repetition frequency.

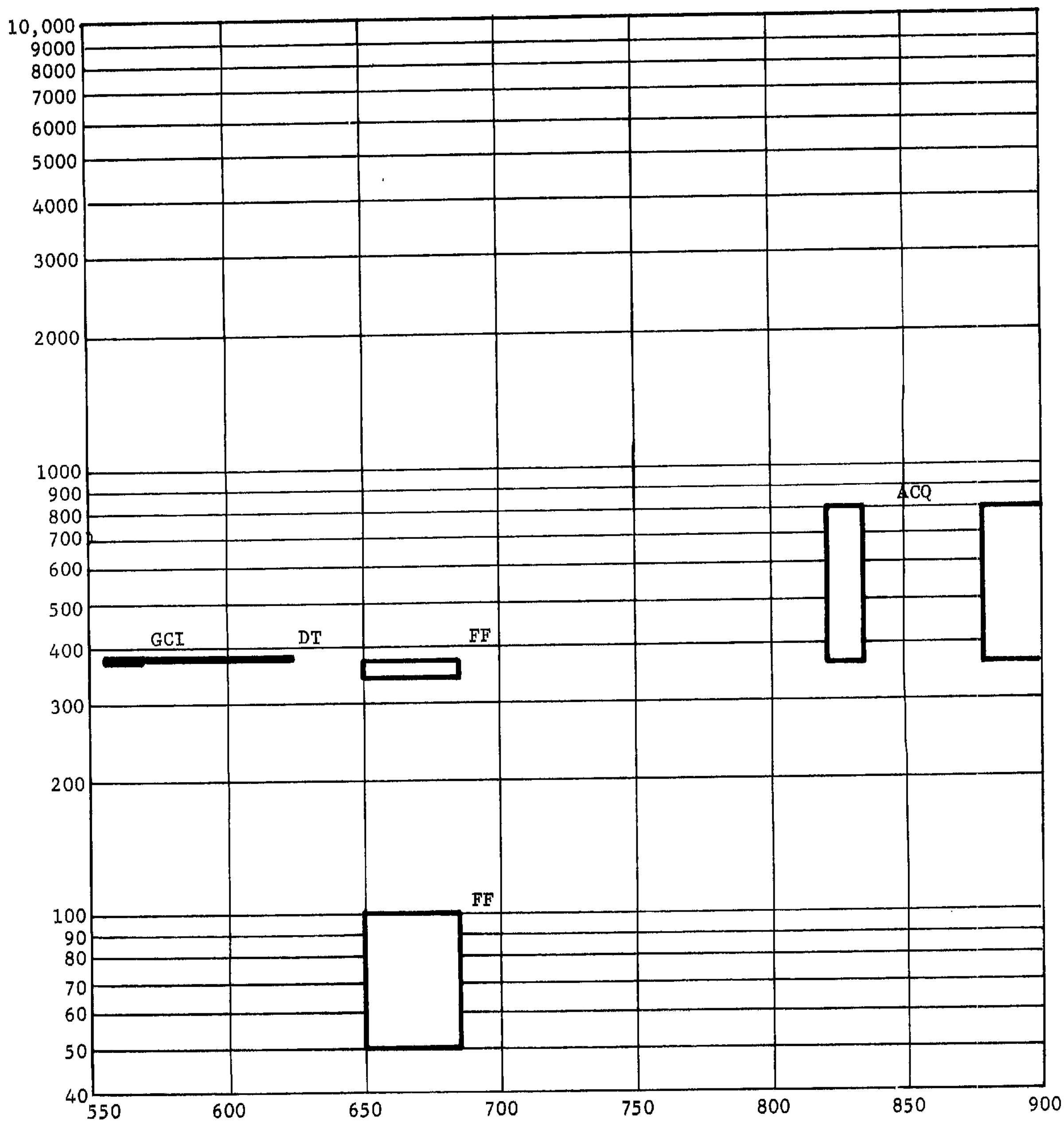

Fig. 6-3 — Soviet radar disposition (No. 2) RF frequency vs pulse repetition frequency.

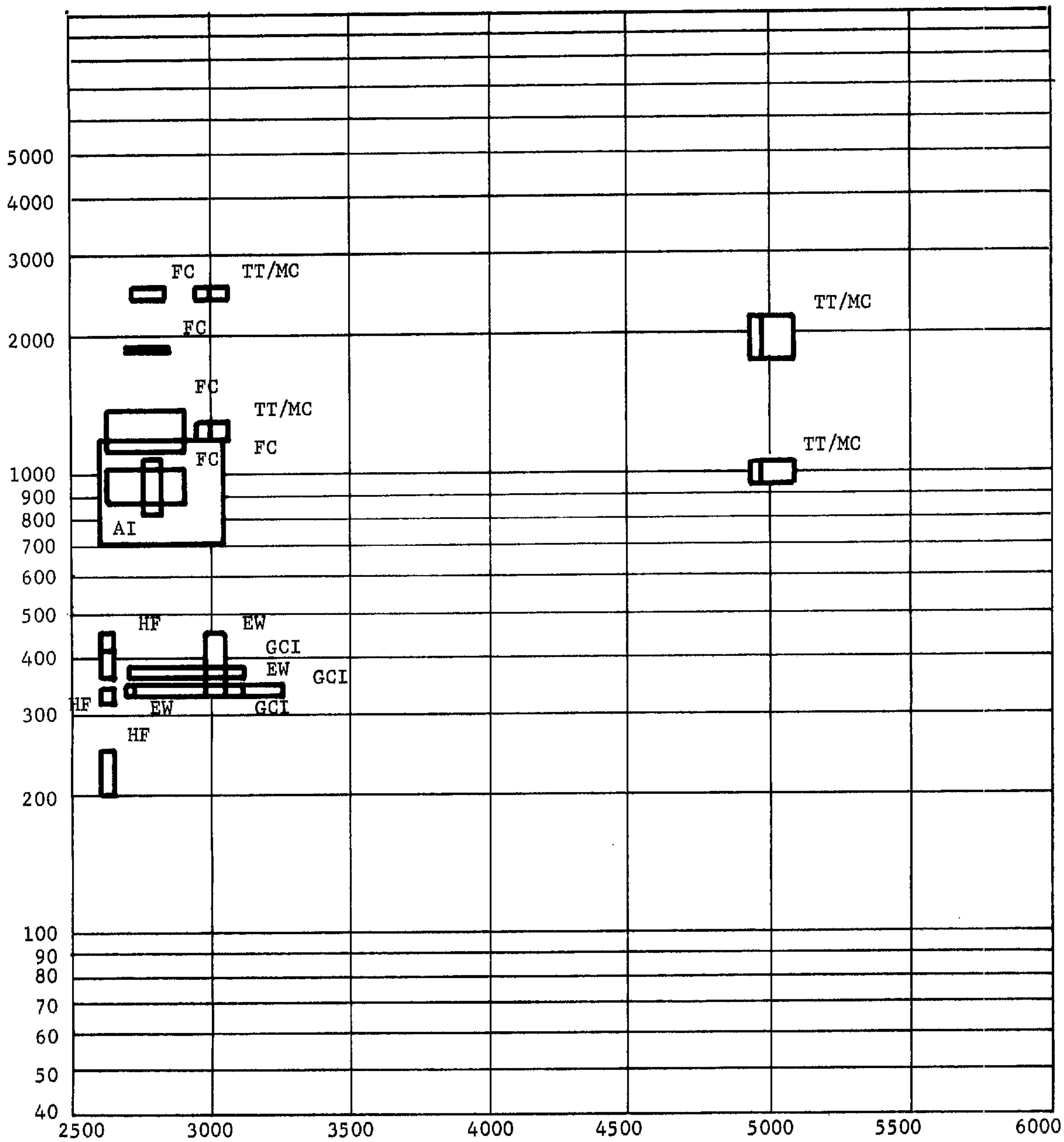

Fig. 6-4— Soviet radar disposition (No. 3) RF frequency vs pulse repetition frequency.

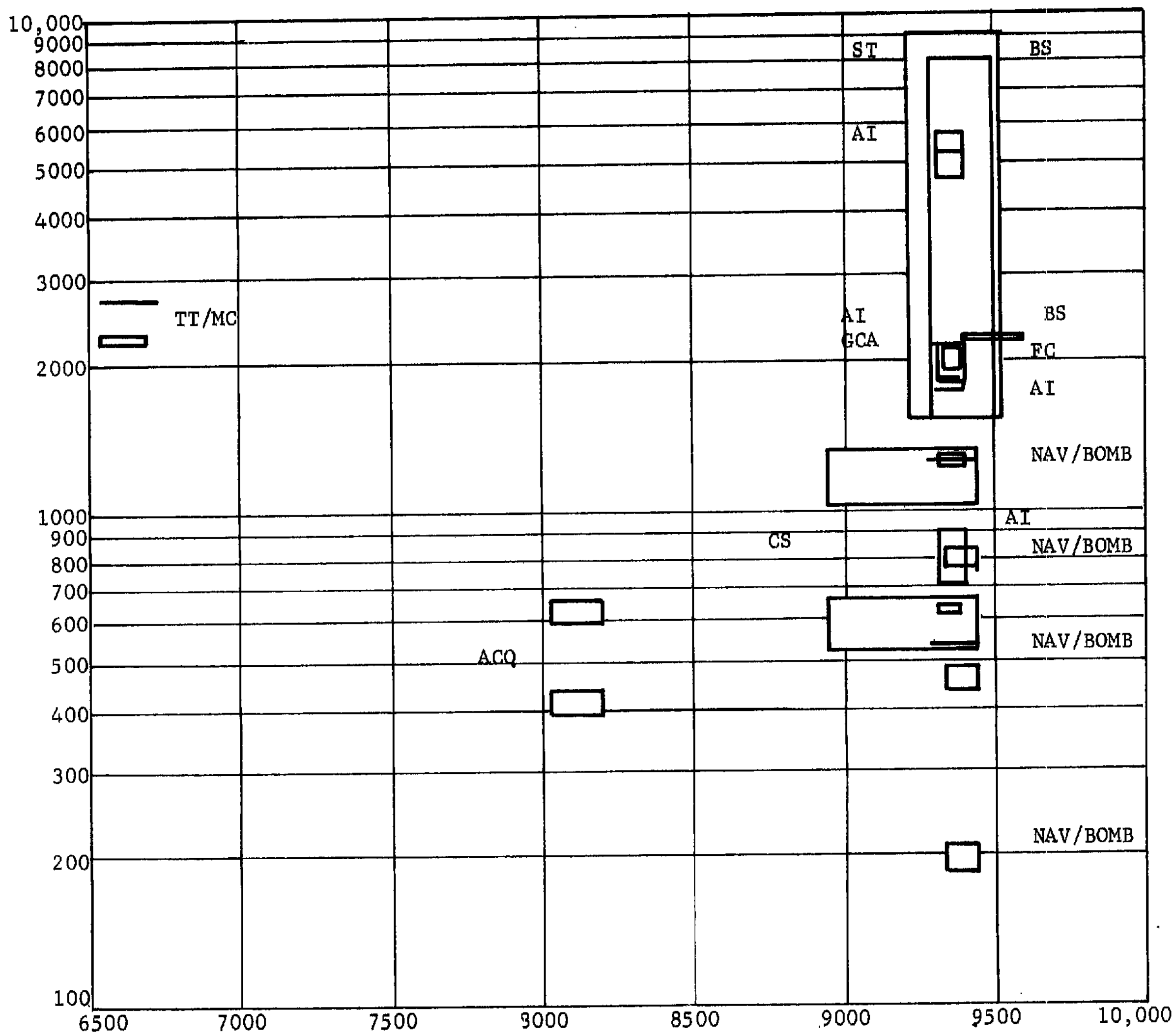

Fig. 6-5— Soviet radar disposition (No. 4) RF frequency vs pulse repetition frequency.

functions appearing on this plot contain no ambiguities. It may also be observed from this plot that a gap appears between 6700 and 8000 megacycles.

The previous discussion has shown that, for the most part, the Soviets have grouped their emitter functions in separate frequency-PRF regions. This would indicate that an ELINT sensor can successfully perform the task of target and threat identification. However, some problem areas do exist in correctly identifying certain targets and threats because of the overlapping of some emitter parameters. The most serious of the function ambiguities occurs in the X-band region where certain ground emitters, having battlefield surveillance and shell tracking functions, can be mistaken for airborne interceptor radars. This situation may be a problem to an ELINT reconnaissance system only when the mission is performed at high altitudes. For low altitude reconnaissance, emissions in this frequency range would undoubtedly be received from the ground emitters only. A similar situation occurs within the S-band region where a single airborne interceptor emitter appears within a ground fire-control region.

At present no intercepts have been received from any operational emitters in the frequency range above 10 gigacycles. However, it is known that the Soviets are doing developmental work in the K-band region and that there will be traffic in this band sometime in the future. Although the functions of these developmental emitters are not definitely known, it is felt that their usage will be for tactical functions, such as battlefield surveillance, shell tracking-mortar location, tank fire control radars, etc. In addition, some future traffic may appear within those areas where currently "gaps" appear.

7. TARGET/SENSOR MATRIX

7.1 GENERAL

The target/sensor matrix is an attempt to apply a quantitative evaluation to each sensor's ability to provide interpretable imagery of the three groups of targets described in Table 3-2. It is postulated that such a comparative evaluation will provide an indication of which sensors should be used independently or concurrently against various targets, or which sensors will provide the best information about the target.

The wide range of variables that can be encountered in a tactical reconnaissance operation have been discussed in some detail. In order for a quantitative evaluation to have any validity, an operational condition must be assumed; deviations from this condition will enhance or degrade the performance of the sensors. The matrices presented below are based on the assumption that the sortie will be accomplished under conditions which permit each of the sensors to operate at its maximum potential. If the matrices were to be used in the field, the many factors that would degrade this capability would have to be considered, and the appropriate values reduced accordingly.

It is apparent from a study of the preceding discussions of sensor performance that altitude has a profound effect on performance. This effect is seen in image scale, resolution capabilities, object contrasts, areal coverage, image motion, and other factors. For this reason, two matrices are presented, one for operations at the 1000 foot altitude range, and the other at the 30,000 foot range.

7.2 MATRIX FORMAT

The sensors are evaluated in terms of their ability to provide interpretable imagery of each of the three groups of targets defined as "Gross", "Medium", and

"Fine" located in Table 3-2, and which is repeated here for convenience. These are listed in the first column of the matrices shown in Table 7-1.

The low altitude matrix lists "Frame Vertical" and "Panoramic/Oblique" cameras. The frame vertical cameras are assumed to have lenses with 1.5 or 3-inch focal length and to use 70mm square formats. The panoramic camera has a 3-inch lens and a 70mm by 24-inch format. A 6-inch lens and a 5-inch square format are used for the oblique camera.

The cameras in the high altitude matrix are grouped according to their scale range (Medium - 1:;5000 and Small - 1:30000). It is assumed that focal lengths will range between 12 and 24 inches. Formats will be 9 by 9 inches, 9 by 18 inches, or (for the panoramic camera) 5 by 40 inches. (It is recognized that cameras with short focal lengths can be used at high altitude to obtain mapping-type photography, but this usage is regarded as being outside the realm of tactical reconnaissance as defined in this study.)

It is assumed that the radar and infrared systems will be adjusted for optimum performance at each of the two altitude ranges.

Provision is made in the format to evaluate each of the sensors alone, and both radar and infrared when used together with photography. An evaluation of a three-sensor combination was attempted, but the results did not materially differ from those in the two-sensor combinations.

The unique characteristics and capabilities of ELINT sensors are such that they are not included in the matrices. ELINT records may be of value as a cue to the interpreter (or the aircrew), in deducing the nature of a target from the characteristics of associated emitters, and in providing locational information. In general, it would seem appropriate to assign an increased rating of one point in any case where ELINT records are available for use with those of any sensor used independently or in combination.

7.3 QUANTITATIVE EVALUATION

Sensor performance was evaluated in terms of the confidence factor an interpreter could place on his identification of the targets in each group. The numbers 1 to 4 are as follows:

Table 3-2. Targets Categorized by Detail Level

GROSS DETAIL — Targets in this group can be identified from imagery with ground resolution of not better than 10 feet.

- Airfields (paved runways)
- Ports and harbors
- Military installations
- Industrial installations
- General terrain information
- Large vessels
- Large buildings (hangars, etc.)
- Large open storage areas
- Tank farms
- Railyards and facilities
- Transportation network
- Towns and villages
- ICBM/MRBM sites
- Large dams

MEDIUM DETAIL — Targets in this group can be identified at ground resolutions of 2 to 10 feet.

- Operational details on targets in preceding group
- Types of vehicles, railroad cars, aircraft, smaller vessels
- Types of materiel in open stores
- Underground bunkers; revetments
- Large radar antennas
- Large weapon emplacements, guns
- Sodded airfields, helicopter pads
- Minor roads, trails
- Passive defenses (trenches, wire, tank obstacles, etc.)
- Trafficability of sectors of transportation network
- Field command posts, bivouacs, camps
- Beach gradients, trafficability, exits
- Vehicular activity
- River ports
- Agriculture, vegetation (general information)
- Surface-to-air missiles

FINE DETAIL — Targets in this group can be identified at ground resolutions better than 2 feet. This group includes components of larger targets; identification of these components permits a more detailed or exact determination of the identity and military significance of the "parent" target.

- Operational details on the preceding groups of targets
- Individual personnel, personnel shelters, foxholes
- Beasts of burden; porter trains
- Detailed designation by type and model of vehicles, weapons, aircraft, vessels, etc.
- Details on crops
- Detection of military use of civilian vehicles, river boats, etc.
- Ambush and surveillance sites
- Anti-helicopter landing stakes
- Cooking fires, campfires
- Trails, small streams, fords
- Mine fields
- Automatic weapon emplacements

1 - An image can be detected, but the target cannot be identified

2 - The target can be identified as a "possible"

3 - The target can be identified as a "probable"

4 - The target can be positively identified.

A value of 5 is given in some instances of photo-radar and photo-infrared combinations. This indicates that radar or infrared records can be used for their ability to cue, or for their ability to penetrate camouflage or atmospheric conditions, or that an "absolutely positive" identification can be made using both records to corroborate each other.

In assigning the values described above, it was assumed that the rating would be valid at least 75 percent of the time. This provision compensates to some degree for haze, poor illumination, and similar degrading factors.

Some sensor/target combinations do not have a numerical rating. This indicates that the sensor will not produce useful imagery of that target group at that altitude. On the low altitude matrix, for example, the areal coverage of the vertical cameras and the radar and infrared sensors is less than would be required to completely cover most of the targets in Group I in one pass. It is recognized that less-than-total coverage is adequate to identify many of the targets in this group, but this capability is taken care of by the evaluation for Groups II and III.

Table 7-1. Target/Sensor Matrices

(A) Low Altitude

Group	Frame Vertical	Panoramic Oblique	Radar	Radar/ Photo	IR	IR/Photo
I Gross Detail		3				
II Medium Detail	4	4	2	5	2	5
III Fine Detail	4	4	1	4	1	5

(B) High Altitude

Group	Small Scale 1:30,000	Medium Scale 1:15,000	Radar	Radar/ Photo	IR	IR/Photo
I Gross Detail	4	4	2	5	2	5
II Medium Detail	4	4				
III Fine Detail	4	4				