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NONELECTRONIC COUNTERMEASURES FOR INFRARED GUIDED MISSILES

PART I - THE COUNTERMEASURE PROBLEM

R. A. Saunders, D. C. Smith, and H. W. Fox

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Approved by:

Dr. W. A. Zisman, Project Coordinator
Dr. P. Borgstrom, Superintendent, Chemistry Division

NAVAL RESEARCH LABORATORY

CAPTAIN F. R. FURTH, USN, DIRECTOR

WASHINGTON, D.C.

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ABSTRACT

The general characteristics of the passive infrared homing device known as the "Dove Eye" are described and used in analyzing the scientific and military problem of rendering ineffective free-falling missiles equipped with homing devices of this type. The desirable functional and tactical criteria for adequate countermeasuring techniques are enumerated. Various techniques are described and available data reviewed in terms of these criteria to show that decoy techniques such as aluminum FLOOR or heat decoys are fundamentally more desirable than other techniques utilizing camouflage, thermal noise, or electronic methods. The necessity and course of further work on both "hot" and "cold" decoy methods is pointed out.

PROBLEM STATUS

This is an interim report. Work on the problem is continuing.

AUTHORIZATION

NRL Problem 32C09-05D, originated at the request of BuOrd (reference BuOrd ltrs, Re9h-HOB/gip S78-1(26)004352 dated 24 July 1947 and (Re9h) SS/jgb 004768 dated 18 November 1947 to Director, NRL) in connection with BuOrd Project No. PSO-171 NO 119-008

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PART I - THE COUNTERMEASURE PROBLEM

INTRODUCTION

During the last few years infrared devices have been developed for military use in connection with detection, communication or signaling, and the guiding of missiles. These devices can be either active or passive. The active device consists of both a source for generating a signal and a detector for measuring the transmitted or reflected signal, whereas the passive device utilizes the thermal energy radiated by the object under investigation. The passive device, therefore, gives no clue to the enemy that he is being observed or acted upon.

Infrared guided or "heat-homing" missiles are passive devices. Guidance information is furnished by an "eye" in the nose of the missile which is actuated by the difference in thermal radiation received from the target as compared to its surroundings. The information so generated is converted into movement of the mechanism which controls the missile's flight.

The missile in operation sees a field of view within which is the target. When the target is "on-axis" no directional information is generated by the eye, but when for any reason the target is "off-axis," i.e., not positioned properly within the missile's field of view, correctional information is immediately generated and the flight of the missile is altered such that it returns to the "on-axis" position.

The military potential of a missile which, night or day, once released, will unerringly seek its target is at once apparent. Since in any future conflict the enemy will undoubtedly make use of similar equipment, it is seen that the need for a countermeasure against such a weapon is a serious and immediate one (1).

Heat-homing missiles may be either the free-falling type or the glide type, the latter usually being propelled under power. Regardless of the type of missile, the heat-homing device can be constructed so as (a) to home on the region of greatest thermal gradient (at the boundary of cold and warm areas), or (b) to home on the thermal center of a target, hot or cold, (with the additional possibility that it may home only on hot and not cold targets, or vice versa). The <u>ideal</u> countermeasure, of course, is one which will provide protection against any missile under any and all conditions, and this is to be kept in mind in considering the general countermeasure problem. However, certain countermeasure techniques will not be equally effective against free-falling and glide angle missiles, since the former missile sees a target against a more-or-less uniform sea background while the latter sees the target silhouetted against the horizon (at low glide angles). Therefore, for the present at least, consideration will be limited specifically to countermeasures against the free-falling type of missile.

Evaluation of all of the countermeasure techniques which might be effective against a particular free-falling missile would of course require that the type of infrared homing device and its detailed operational characteristics be known. However, such knowledge cannot be assumed to be available in the case of an enemy missile. It is therefore assumed, somewhat in anticipation of the countermeasure to be considered later, that a suitable countermeasure can be devised without such knowledge, based only upon consideration of the target and its background. Before considering the countermeasure problem from this point of view, however, it is desirable and necessary to describe in some detail at least one typical heat-homing missile, for purposes of illustrating some of the principles upon which all heat-homing equipment operates. The DOVE heat-homing device is chosen for this purpose. The problem to be considered, however, is that of providing a countermeasure which will be effective not only against free-falling missiles equipped with the DOVE eye but also against those equipped with any similar device.

DOVE HEAT-HOMING DEVICE

All objects emit infrared radiation to an extent determined by the emissive characteristics of the material and its absolute temperature. The total radiant flux from a perfect emitter or black body is determined only by its temperature as is the spectral distribution of the emitted radiation. The radiant flux at all wavelengths increases with the temperature of the object while the wavelength of maximum emitted flux decreases.

Infrared radiation is selectively absorbed by the atmosphere. There are, however, several regions of low attenuation known as "windows" in the spectral region of 0.7 microns to 15 microns. The transmission within these regions of low attenuation depends upon the amount of moisture, carbon dioxide, ozone, and other absorbing gases and upon the size and quantity of foreign particles in the transmission path. The wavelength regions of the best windows and the transmission within these regions are given in Table 1. The values given are only approximate, since the transmission varies with wavelength within any one window and with atmospheric conditions. Since bodies at or near 300°K (normal ambient temperature) emit radiant energy with a maximum between 8 and 13 microns, the window in this region is the most important for the operation of passive devices. Heat-homing equipment can operate on a thermal signal received through any or all of these windows, however, provided the radiation is sufficiently intense and depending upon the transmission filters, if any, associated with the equipment.

TABLE 1[2]
Atmospheric Transmission of Infrared Radiation in Regions of Low Attenuation

Wavelength, Microns	Percent Transmission*
0.7 - 1.1	100
1.5 - 1.7	100
2.1 - 2.3	100
3 - 4	90
8 - 13	80

* Distance, 600 yds.; water in trans. path, 0.305.; visibility, 5 - 6 miles.

The DOVE heat-homing device is composed of an optical assembly or scanner, amplifying networks, and servo systems which operate the directional control equipment. In the normal scanner the front aperture is 2 inches and the field of view seen by the detecting system is that subtended by a solid angle 20° in diameter. The scanner consists of a rotatable spherical scanning mirror which forms an image of its field of view on the four elements or flakes of a sensitive thermistor bolometer. The optical axis of the mirror is slightly displaced from the spin axis so that upon rotation of the mirror the image of a target is swept in a circular path the radius of which is approximately equal to the displacement of the optical axis. The bolometer flakes are arranged in the form of a cross and mounted symmetrically around the spin axis in the focal plane of the scanner mirror. The length of each flake is equal to the displacement of the optical axis, which in the normal scanner is 0.180″.

Hence, when the mirror is revolving, the image of a target on the spin axis is swept in a circular path of approximately 0.180″ radius and passes over the outer tip of each bolometer flake giving rise to four voltage pulses during each scanning cycle. The vertical flakes and the horizontal flakes each have their own amplifying networks,[1] the up-down channel and the right-left channel, respectively, which control through servo systems the movement of the directing mechanisms.

When the spin axis deviates sufficiently from the target, in, say, a horizontal direction, the signal from one flake is lost completely and that from the other builds up in amplitude as the circle of scan approaches the more sensitive mid-point region of the bolometer flake. Thus, within limits, the restoring force increases with increasing deviation. The signals from the vertical flakes, on the other hand are increased equally by a slight amount. This type of intelligence fed through appropriate servo systems provides a sensitive and fairly fast means of maintaining the scanner axis on target.

The polarity of the flake voltage is such that the image of a target, assuming a cooler background, will produce a positive, negative, negative, and positive signal as it is swept over the up, right, down, and left flake, respectively. For a target cooler than the background the polarity of the signals would be reversed.

Figure 1 illustrates the path of the image over the bolometer flakes and the corresponding signal patterns for each channel, for various positions of the target. When the target is on axis the two signals in each channel are equal and no directing information is furnished the servo mechanisms. When the target is off to the right the signal in the right-left channel actuates the right-left spoilers,[2] which alter the missile's flight so as to return the target image to the on-axis position. The up-down signals remain equal, however, causing no movement of the up-down spoilers, When the target is off in both directions a signal is supplied from both channels and both sets of spoilers are energized to bring it back on center.

Although the operation of a heat-homing missile such as the DOVE can easily be understood in the case of a single target on a uniform background (field of view), the performance of the same missile when operating on a complex field of view containing two or more targets or a nonuniform background depends upon many factors and is not

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[1] The amplifiers are approximately flat in response over the range 5-105 cycles/sec. The scanning frequency is 10 cycles/sec.

[2] A spoiler is a small curved surface mounted in the front end assembly, which can be intermittently ejected into the missile's air stream to alter its flight path.

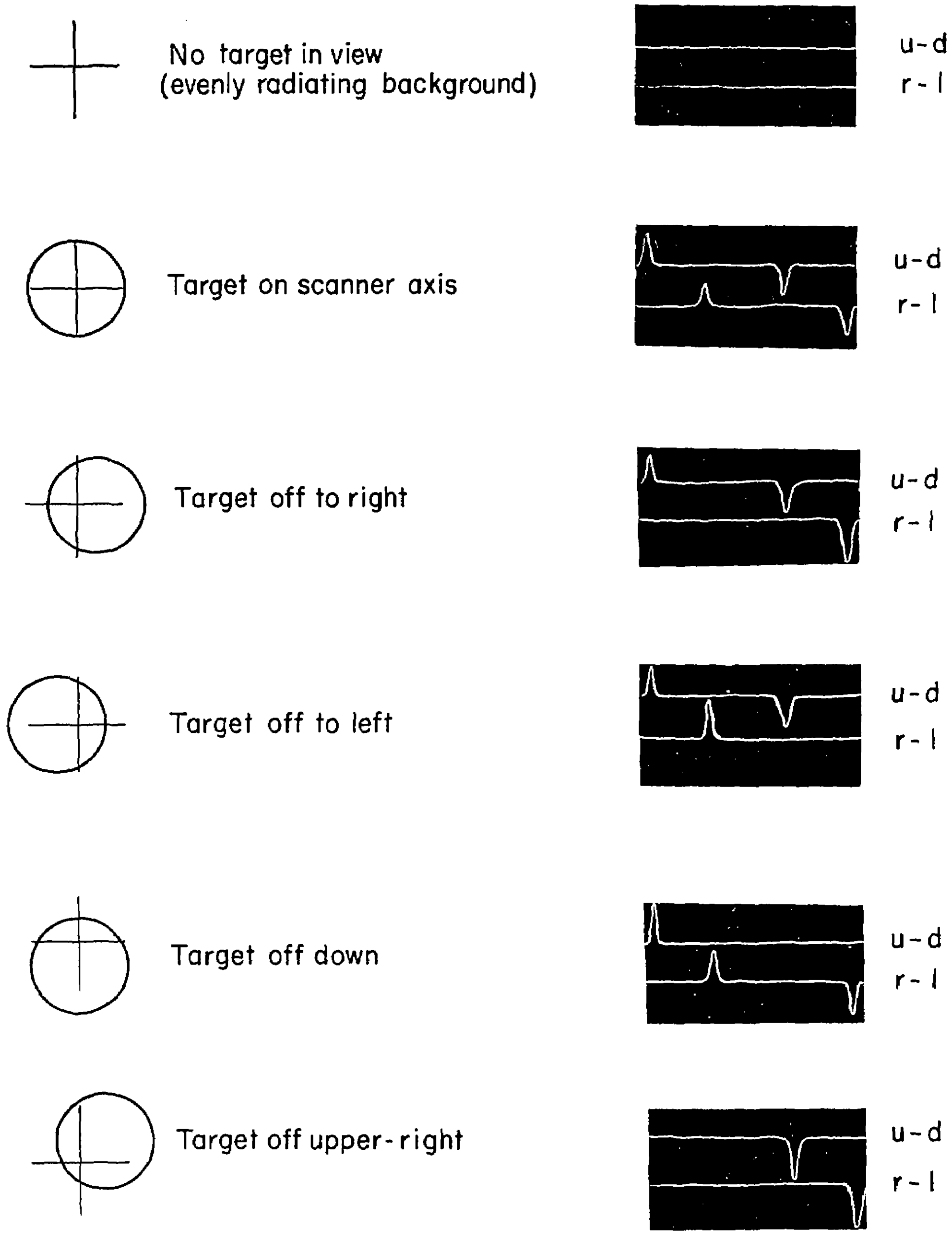

Figure 1 - Path of the target image over the bolometer flakes and corresponding (ideal) signal patterns for each channel, for various positions of the target

easily predicted. For a single target on a uniform background the only condition necessary for the missile to home on the target is that it receive a detectable signal. In other words the voltage pulse produced by the image of the target on the bolometer flake must be larger than the random voltage fluctuations or "noise" inherent in the thermal detector and electronic amplifying system. This will depend upon the response characteristics (e.g., sensitivity and noise level) of the device and upon the magnitude of the thermal signal from the target. The latter depends upon the emissivity of the target, its difference in radiant temperature from the background, and the relative area it fills in the detector's field of view. It will be noted that this requires no presupposition as to the radiant temperature of the target except that it be different from the background. If the target is cool, rather than warm, relative to its surroundings the polarity of the voltage pulses caused by the thermal signal will merely be reversed and the operation of the missile will not be effected. The term "heat-homing missile" is somewhat misleading, therefore, since it can home equally well on a warm or cold target.

In the case of a more complex field of view, for example one containing two targets, the point upon which the missile will home and also the point where impact will occur will depend upon whether the signals from the separate targets are resolved or integrated by the scanner (and hence upon the relative size and position of the targets in the field of view) as well as upon the flight characteristics (range of correction, etc.) of the missile and upon other factors already mentioned.

Consider first two identical ships close to one another on a uniform sea. At a sufficiently high altitude the signals from the separate ships will not be resolved and the integrated signal will be larger than that from either ship alone. At some lower altitude the signals from the individual ships will eventually be resolved, depending upon the resolution of the scanner and the separation of the ships. If the ships are close together, so that this occurs too near the end of the missile's flight, the missile will tend to strike between the ships and may cause damage, depending upon the accuracy of the homing and the proximity of the ships. If the ships are farther apart, then upon resolution of the separate signals by the detector the missile will "hunt" and fall between them or, depending upon their position in the field of view, select one of them by chance upon which it would then home. In the latter case the missile would still tend to fall between the two ships, but closer to one than the other. In either case, however, each ship offers some protection to the other and the combination should be less vulnerable than either alone.

In cases where two or more nonidentical targets appear within the field of view, not only the emissive power of each target, but also their relative size as compared to the total area of the field of view may be important in determining where the missile will home or strike. And since a given target will occupy an increasingly large portion of the shrinking field of view during the missile's fall, it is possible that a missile may change its attitude toward a particular target during flight. Consider the hypothetical case where a small target (ship) is nearby a relatively large target, e.g., a rock mass protruding above the ocean surface, or a larger ship, or a decoy-type countermeasure. Further, consider that the emissive power (watts per unit area) of the ship is greater than that of the rock mass, but that the latter, being larger in area, radiates more total energy (watts). If a DOVE missile were released such that it received a detectable signal when its initial field of view was that of (a) in Figure 2 and its height were sufficient that it could not resolve the two separate targets, then it would tend to home on the weighted geometrical center of the combined targets. The field of view at later successive intervals would be that shown in (b) and (c). In a still later interval, such as at (d), when the missile has fallen far enough so that the targets can be resolved, its center of view may be approximately the same. During the next interval, however, as shown at (e), the rock mass may become the predominant area in the field of view and it is probable that the relatively small water area would now appear as a cold target area with the rock mass as a

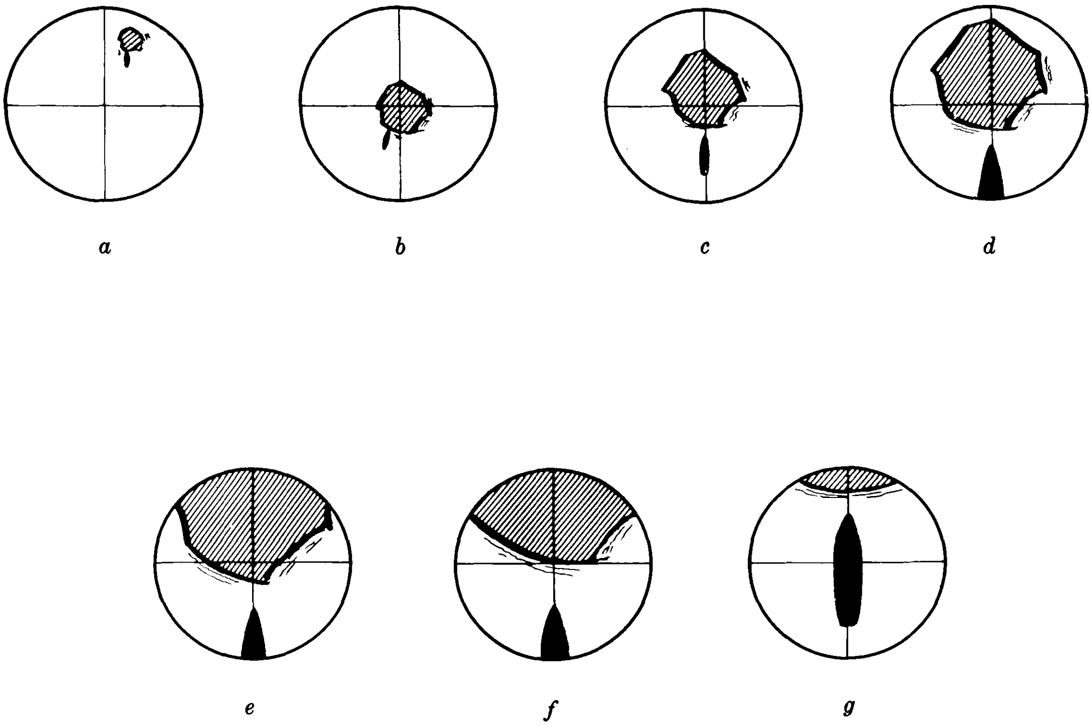

Figure 2 - The field of view of a DOVE missile at successive intervals in its fall on a hypothetical target. A more complete legend is given in the text

background. Under these conditions the missile may shift, as in (f) and (g), so as to eventually home on the ship which is now a concentrated hot area against the water. The actual point of impact is not easily predictable. When the field of view is as depicted in (e) and (f), the remaining flight time of the missile is practically exhausted and whether or not the missile would center on the ship, as shown in (g), would depend almost entirely on its range of correction and flight characteristics.

GENERAL REQUIREMENTS OF A COUNTERMEASURE

Except for the somewhat remote possibility of providing a means for exploding or otherwise destroying a missile in flight, all countermeasure techniques may be grouped conveniently into two general categories, namely decoys and nondecoys. In a decoy-type countermeasure the homing principle of the missile is utilized to divert it from its true or intended target. Nondecoy types, on the other hand, either minimize or destroy the ability of the missile to "home" on the target.

In actual use a heat-homing missile is dropped from an altitude of 10,000 to 20,000 feet and the eye is held inoperative until the missile enters the approximately straight portion of its trajectory[3] and can no longer see the horizon. Since the range of correction is limited, the missile must be accurately sighted on release. Therefore, even though the correctional device were inoperative the missile might still strike within possible damaging range of the target. For this reason a countermeasure which merely renders the homing device inoperative is not very desirable; rather, a decoy-type countermeasure technique utilizing the homing principle should be used to divert the missile away from its natural or intended destination.

[3] At 8,000 to 12,000 feet.

If a countermeasure technique is to have maximum effectiveness, therefore, it is desirable that it satisfy the following requirements, which may be considered as functional criteria. The countermeasure should:

(a) consist of a decoy technique,

(b) produce a thermal signal greater than that from the target,

(c) be confined within an area slightly smaller, but similar in shape to the true target,

(d) be and remain within an optimum distance from the true target, and

(e) remain effective for a sufficient length of time.

Requirements (b) through (d) involve the sensitivity, resolving power, and flight characteristics of the missile, factors which are not fixed and which may not be known in the case of an enemy missile. It is difficult, therefore, to state these requirements in more explicit terms. This much is certain, however. Any heat-homing missile capable of homing on a given target will be decoyed if the false target (1) is slightly smaller than the true target, (2) gives a somewhat greater thermal signal, and (3) comes within the missile's field of view.[4] A countermeasure fulfilling these conditions need not be concerned, therefore, with the operational characteristics of the missile. Requirement (e) will depend mainly upon the nature of the attack and the type of countermeasure technique, i.e., whether it is applied but once, intermittently, or continuously.

Even though the foregoing criteria ensure effective protection, they do not guarantee that the countermeasure will be of maximum practical or military value. In addition to the functional requirements listed above, the following features are desirable for tactical reasons. The countermeasure should:

(a) afford maximum maneuverability to the target vessel,

(b) be capable of rapid dispensation in an effective form,

(c) require a minimum of personnel, effort, and equipment for effective dispensation,

(d) not place neighboring vessels in jeopardy,

(e) comprise noncritical materials,

(f) be nonhazardous, and

(g) require minimum stowage space.

In all cases it is desirable that the countermeasure not reduce the military security of the target vessel and/or neighboring vessels, although this would appear to be of lesser importance in most tactical cases.

It is probable that not all of the tactical criteria can be embodied in a single countermeasure technique. They should not, therefore, be considered as rigid requirements, but rather as a list of desirable features.

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[4] The protection offered by an adequate decoy will depend upon the damaging range and accuracy of the missile. In general, the decoy should be placed as close as possible, but, of course, beyond the damaging range.

METHODS OF COUNTERMEASURE

The techniques which may be of value as countermeasures against heat-homing missiles may be classified as follows:

A. Decoy techniques

(1) Cold decoys FLOOR

(2) Hot decoys

B. Nondecoy techniques

(1) Camouflage

(2) Noise

(3) Electronic.

The decoy techniques are by far the most promising.

The effectiveness of cold decoys depends upon providing a radiating area, the energy from which is less than that from the target background. Such an area could be provided for example by exposing a refrigerated surface, a mass of dry ice, or possibly by releasing a compressed gas which would cool upon expansion, or by the use of FLOOR, which is defined as a reflecting film (such as aluminum powder) on the ocean surface (3). Cold decoys will be effective against missiles such as the DOVE which home upon either hot or cold targets and against those which home on a thermal gradient (provided that the decoy is confined within an area having definite boundaries) but not against those (if any) which home only upon hot targets.

The effectiveness of a hot decoy, of course, depends upon providing a radiating area which emits more energy than the target. Since naval targets are usually warm compared to the sea, any missile which will home on a naval target will be attracted by a heat decoy.

Some countermeasure techniques may function in two or more ways. Both hot and cold decoys, for instance, may also act under some conditions as a source of thermal noise. The use of smoke as a countermeasure technique may function as a heat decoy, a source of thermal noise, or as a camouflage. A brief description of the way in which each of the basic techniques functions as a countermeasure and their merits in relation to the desired features is given below:

"Floor"

A large patch of FLOOR on the surface of the ocean presents to a free-falling missile an image of the sky. The radiation from a blue sky is extremely weak in the infrared region of 8-13 mu and corresponds in intensity to the emission of a black body near 220°K (-50° C) (4). A black body at the temperature of sea water (approximately 290°K) on the other hand, has its peak intensity of emission in the spectral region 8-13 microns. Since bodies which are very good reflectors are poor emitters, the FLOOR, which is a good reflector, will radiate very little energy to the detector even though it is at the same temperature as the sea water. The only radiation reaching the missile's detector from the FLOOR patch is that reflected from the sky. Since this radiation is extremely weak in the infrared the FLOOR will appear to the detector as a cold area relative to the sea. During the initial part of the fall, while the area of its field of view is large and the FLOOR area relatively small, a missile such as the DOVE will home on the geometric center of the FLOOR patch. As the missile falls, however, the FLOOR area fills a larger proportion of its field of view and eventually the detector sees more FLOOR than water. It is probable under these conditions that some portion of the FLOOR-water boundary will take control of the missile's direction. The impact will undoubtedly take place within the FLOOR area, its proximity to the edge depending on the missile's flight characteristics, the size and shape of the FLOOR patch, and the position and nature of nearby targets. To receive protection the vessel must not penetrate the FLOOR area, for it would then be seen by the detector in greater thermal contrast against the FLOOR than against the sea water.

The use of FLOOR is effective both at night and in daytime since the radiant intensity of the sky, which it reflects, is the same night and day under equal meterological conditions. There are several conditions, however, under which protection is considerably lessened. On a cloudy day the FLOOR reflects radiation from the clouds. Depending upon its height and the air and sea temperature, a cloud might appear as either hotter or colder than the sea but in no case will it appear as cold as the clear sky. On a completely overcast day the protection offered by FLOOR is reduced tremendously, depending, of course, upon the temperature of the air at the height of the overcast as compared to that of the sea water. If this differential is too small, the signal from the true target might overcome that from the FLOOR and control the missile's direction. There are other conditions which render FLOOR less effective, such as rough water, high wind, or heavy rain, which tend to chop up, stream out, or sink the film. In addition to these limitations FLOOR entails a serious loss of maneuverability. It is also somewhat of an explosion hazard and cannot easily be dispersed as rapidly as might be desired.

When the FLOOR exists in many separate patches on the water surface, either because of the method by which it was laid or because of the action of wind and waves, it functions as a thermal noise source and tends to confuse the heat-homing device, inasmuch as the latter sees many cold targets against a warm background. When the FLOOR is in this condition it is immaterial whether the vessel desiring protection penetrates the FLOOR area or remains on its edge. By and large, however, the effectiveness of FLOOR as a countermeasure technique depends upon its appearance as a cold target. The usefulness of FLOOR as a countermeasure is considered in detail in Part II of this report published separately as NRL Report 3704.

Heat Decoys:

Another promising countermeasure technique lies in providing an area which emits more radiation than the target for which protection is desired. Pools of flaming gasoline jelly or other materials which undergo exothermic chemical reactions, either at the surface of the water or in the air, have been suggested and investigated as a means of accomplishing this (5). Reactions at or on the surface of the water are probably the less desirable. Heat decoys of this type require the vessel to remain near its protecting device throughout the attack. For various tactical reasons this might not be practical. For small or reasonably small decoys there is some danger that the first missile would either destroy or scatter it with possible damage to the vessel. In any event the vessel would be left without any protection from missiles immediately succeeding. Heat decoys involving reactions in the air, on the other hand, hold considerable promise of satisfying all the requirements and desirable features of an effective countermeasure. These will be considered in detail in a third report of this series.

Smokes:

There are three ways in which smoke may serve as a countermeasure: first, by acting as a thermal screen or camouflage; secondly, as a cloud of hot particles which functions as a heat decoy; and thirdly, as hot particles which produce thermal noise. In addition some white smokes may diffusely reflect solar radiation to the missile's detector and thus have some value as a countermeasure against missiles not equipped with a far infrared filter (12). For short time intervals after formation certain smokes in reasonable quantities have been found to emit one to two times as much radiant energy in the 8-12 micron spectral region as medium sized naval vessels (6). When dispersed in small clouds, it may similarly serve as a source of thermal noise. Present naval smokes are unsatisfactory for thermally screening a target (7), since they do not attenuate the transmission of 8-13 mu radiation very strongly. However, none of the smokes tested were strong absorbers in the 8-13 micron region. Further, since the size of the particles comprising naval smokes is approximately 1 micron or less in diameter, as is necessary for effective visible screening, these smokes do not scatter long wavelength radiation and hence are transparent in the infrared. The efficiency of smokes for thermal screening could be improved by increasing the particle size, although at the expense of suspension time, or by using smokes which absorb strongly in the 8-13 micron spectral region.

Camouflage:

A vessel whose radiant power is equal to that of its background may be said to be thermally camouflaged. To thermally blend a vessel into its background it is necessary to decrease its emissivity. This can be partially accomplished by painting the vessel with a paint which is a good infrared reflector, especially for 8-13 micron radiation. Infrared reflecting paints which are also excellent reflectors in the visible spectral region (i.e., aluminum or bronze paints) are undesirable for tactical reasons. The use of infrared absorbing paints should be avoided, since they serve to raise the emissivity of the vessel. It should be understood that any static method for thermally camouflaging a vessel is fundamentally undesirable as a countermeasure technique because the vessel can be thermally camouflaged for only one given set of conditions. Normal variations in solar radiation from daylight to darkness, the appearance of clouds or overcast, or any change in the air, sea, or ship temperature would undoubtedly render the vessel thermally visible. The radiation from a ship is the sum of that emitted and that reflected at its exposed surface, and this sum must remain constant, or, more precisely, must vary exactly with the radiation from the sea if it is to remain thermally camouflaged. Even if this were possible, the method still suffers the more basic objection that it does not decoy the missile away from its natural destination.

Thermal Noise Sources:

Thermal noise as generated by FLOOR has already been dicussed. It may also be generated by certain types of heat decoys and by some smokes. Its predominant effect on the missile is to lower its signal-to-noise ratio and thereby decrease its sensitivity.

While this might be effective in enhancing the protection offered by a decoy type of countermeasure it is a relatively poor technique when used solely by itself since it is not a decoy technique and does not serve to divert the missile from its target.

Electronic:

The signal from a sensitive heat detector must be electronically amplified in order to provide the necessary power to drive the directing system and so there arises the possibility of electronically jamming the amplifying networks of the missile and thus depriving it of directional control. It seems unlikely that the amplifiers could be completely jammed, however, since the only microwave or radio frequency detecting element is the bolometer which can be easily shielded as can the associated electronic circuits. Even so, the fact that the missile is not necessarily diverted from its target is sufficient reason why such a countermeasure technique is undesirable. It would be a far better technique to utilize the correcting device as a means of diverting the missile.

SUMMARY OF PREVIOUS WORK

Little was known prior to 1944 concerning the nature and effectiveness of countermeasures against infrared heat-homing missiles. All available information pertinent to the problem was summarized in April 1944 (8). During the remainder of 1944 many measurements were made of importance to the evaluation of various techniques as countermeasures. Generalized conclusions based upon these measurements have been given by Stewart, Nolan, and Ballard (9). Thermal signals from naval targets observed from 5:1 glide angles have also been measured and summarized (10). Table 2 lists some previously-measured values of the radiant flux above background from typical naval and inland targets.

Most ships radiate at least 0.4 ergs/cm^2/sec. as measured by Farrand equipment (BuOrd Test Unit, Mark 7) from 8,000 to 10,000 feet (11). The maximum clear day signal measured from this height was 0.5 erg/cm^2/sec. per 10,000 sq ft of ship surface normal to the line of sight (9). In cases where ships were near piers or land masses, the signals obtained indicated that the latter would ordinarily act as efficient heat decoys (11). Vessels in small harbors and narrow rivers are thus practically invulnerable to heat-homing missiles. Dams have likewise been found to be well protected by river banks (12).

Measurements taken on a large sheet of rolled aluminum, laid on an airstrip to simulate a perfect specular FLOOR, showed that the FLOOR appears as a cold target, more so on a clear than an overcast day (11). Clouds have appeared as both hot and cold targets relative to sea water, depending upon their height and the air and sea temperature (13). The signals obtained from various targets were not lessened appreciably during rainfall, but the noise was increased (14). The noise above that inherent in the measuring device probably depends upon the roughness and depth of the water (14). The difference in signal between target and water was considerably less when the air and water temperature was high (13). Targets in tropical waters, therefore, will be much less vulnerable.

It has been observed that the radiant flux from FLOOR (reflected sky radiation) may be as much as -12.5 watts/sq ft relative to background (3). Forty pounds of flaming gasoline gel spread on the water surface covered 100 sq ft and had a burning time of 3

TABLE 2
Average Signals from Typical Targets

Target	Average signal above background from 10,000 ft as received by Farrand equip. (ergs/cm^2/sec. per 1/2° sq field of view	Comment	Ref.
CVE at pier	1.35		11
DE off shore		Negligible compared to land	11
Freighter	2.0	Larger than usual signal	11
Tanker	1.0 }	Air temperature 15°F above	11
Sea Wall	1.5-2.0 }	sea temperature	11
Richardson Rock	0.6	From 6,000 ft } 1°F above	11
	0.4	From 8,500 ft } sea temp.	
Aircraft plants	3.4		11
"Black top" (oil treated rolled stone surface)	0.6-0.8	Appeared cold against desert background	11
20 buildings	1.09	From 9,000 ft.	12
Piers	1.5-3.0		12
Open fire (refinery)	>7.75		12
Trash dump fire	>7.75		13
Ammunition ship	.05- .10		15
Destroyer	.05- .15		15
Freighter	.10- .25		15
Cargo ship	.30- .40	From 6,700 ft	15
Large freighter	.40- .60	From 6,700 ft	15
Battleship (New York)	.15- .25	From 5,000 ft	15
Tanker	.10- .30		15
Power house	.50-1.75		15
14 buildings (factory group)	1.47	From 7,000 ft.	15

minutes (5). The radiant flux from such a film was 3000 watts/sq ft, one tenth of which was in the 8-13 micron spectral region. From measurements made on one occasion the total radiant flux above background from a battleship (approximately 60,000 sq ft in area) was estimated to be 290 kilowatts and hence 400 pounds of gasoline gel or 25,000 sq ft of FLOOR were considered necessary for effective protection.

CONCLUSIONS AND RECOMMENDATIONS

From the analysis of the principles of operation of passive, free-falling infrared guided missiles, such as those equipped with the "Dove Eye," and of the principles involved in various countermeasuring techniques, it is concluded that decoy type countermeasures which utilize the "homing" ability of the missile to divert it from its natural or intended destination are preferable to all other techniques which merely minimize or destroy the homing ability of the missile, or which conceal the target.

"Hot" and "cold" decoys are, in principle, equally effective against all heat-homing missiles except those which home only upon hot target, in which case only the hot decoys are effective. Previous work on FLOOR (aluminum powder on water), which functions as a cold decoy, and on burning gasoline jelly, a hot decoy, has shown that either type of decoy offers adequate protection under some conditions. However, the effectiveness of FLOOR has not yet been evaluated under many conditions which might arise at the time a countermeasure is needed, nor has any attempt been made to determine, for comparison with existing data, the theoretical potentiality of FLOOR as a countermeasure. Past work on heat decoys is again inadequate and this technique has not been treated generally in the records available.

Both "hot" and "cold" decoy-type countermeasure techniques deserve further consideration. There is needed, first a detailed analysis of each technique in terms of the predictable performance of ideal materials.[5] Secondly, a comparison between actual and ideal performance should be made in order to determine the most useful technique and the means of achieving maximum advantage thereof.

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[5] A detailed analysis of hot and cold decoys is made in a second and third report of this series.

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