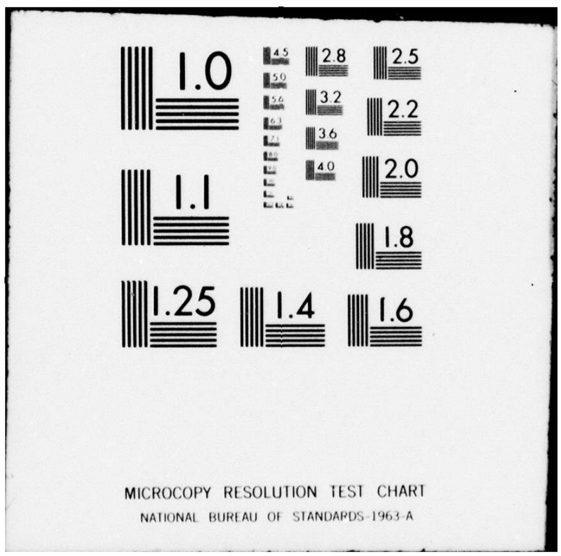
AD-A064 180 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 17/9
RADAR CLUTTER EFFECTS IN A TARGET CLASSIFIER.(U)
DEC 78 J M RENAUD
UNCLASSIFIED AFIT/GE/EE/78-37 NL

1 OF 1
AD
A064180

END
DATE
FILMED
4-79
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AFIT/GE/EE/78-37

LEVEL II

(1)

ADA064180

DDC FILE COPY

RADAR CLUTTER EFFECTS IN A

TARGET CLASSIFIER

THESIS

AFIT/GE*78D JOSEPH M. RENAUD
CAPTAIN USAF

(14) AFIT/GE/EE/78-37

(6) RADAR CLUTTER EFFECTS IN A

TARGET CLASSIFIER

THESIS

(9) Master's thesis,

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air Training Command

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

(10) Joseph M. Renaud [redacted].

Captain USAF

(11) Dec 78

(12) 71p.

Approved for public release; distribution unlimited

(16) 7622

(17) Ø1

012225 [illegible]

Acknowledgements

My sincere thanks is extended to my advisor, Dr. Matthew Kabrisky, for his valuable guidance and inspiration. I would also like to thank Maj Joseph Carl and Capt Gregg Vaughn for their critical reading of this thesis. I am especially grateful to Maj Clay Stewart for the many hours he devoted to guiding me in this project. Thanks are due to Mehdi Shirazi, of the Radar Branch of the Air Force Avionics Laboratory, for his interest and encouragement during this work. A special thanks to Mrs. Sandra Hastings for her professional typing of this thesis. Lastly, my dear wife Deborah, deserves my eternal gratitude for her constant support, encouragement, and patience during my graduate work.

Contents

List of Figures

List of Tables

Abstract

A previously proposed algorithm for the classification of periodically amplitude modulated targets is studied for its possible use in an air-to-ground radar situation. The assumptions necessary for the use of the algorithm are discussed and the limitations and scope of the problem are presented. Classification probabilities of error are presented based on worst case analysis of clutter conditions in the received radar signal. Analysis is provided for a two class problem and a three class problem using both nearest neighbor rules and stepwise discriminant analysis for classification. The clutter in these problems is studied under conditions of spectral spreading and increased clutter signal power. The effect on probability of error is found to be small enough that there are definite possibilities for the use of this algorithm in some air-to-ground applications.

I Introduction

The purpose of this thesis is to examine a proposed technique for the automatic identification of radar targets. This thesis will investigate the applicability of this technique for the air-to-ground environment. The introductory chapter will outline the reasons for this study and will develop a possible scenario for the use of the technique.

Radar

Radar is an acronym for radar detection and ranging. A radar is, however, not limited to that amount of information. The other types of information that can be extracted from a typical radar signal include: range, relative velocity, angular direction, target size, and target shape. In order to estimate target shape, a synthetic aperature radar is usually required and the target must be stationary or moving at a constant velocity relative to the radar (Ref 21:8-11). In addition, vibration or rotation can be detected by spectral analysis of the received signal.

After the radar signals are processed, they are displayed for interpretation by a radar operator. A skilled operator may be able to classify the target type through experience and a priori knowledge of expected targets. One problem is that the skilled operator may not always be available. Another is that the operator may not always be in a position of having sufficient a priori information available.

Target Classification

One solution to these problems would be to develop a machine that could classify the targets based on some a priori knowledge of possible target characteristics. This machine could automatically make this type of decision at a remote site or when mounted on a remote vehicle. Then, the radar information would not have to be sent to the central site for processing. The class of the target would be the only thing that is sent. This would greatly reduce the number of operators required, the amount of information traffic, and the number of errors in data transmission (Ref 6:5).

A highly accurate, remote sensor could be used to extend the visual range of the operators. Today, there exist weapons with high accuracy that could be employed in a long range tactical situation. If target classes must be confirmed visually, the full value of these weapons can not be realized. In the Department of Defense Annual Report for Fiscal Year 1979, Secretary Brown emphasizes the need for accurate targeting information, in order to employ tactical long range weapons and reduce the possibility of self-inflicted loss (Ref 5:263-7).

The emphasis in this area, is shown by the Non-Cooperative Target Recognition Workshop held at Rome Air Development Center in October, 1978. At that workshop, the needs of the services and potential solutions were discussed. The possible areas of interest extend from the use of a single sensor, such as radar, to the use of multiple sensors integrated into a unified classification scheme (Ref 24).

The Air Force efforts in this area are partially directed toward the possibility of classifying ground targets through the use of existing X-band radars on airborne platforms (Ref 19). Data bases have been gathered for use in the study. In working with this data, it has been determined that there may be sufficient information available in the sidebands of modulated radar signals to classify the targets as members of particular classes; such as truck, jeep, or tank (Ref 23:9).

Scenario

A typical Air Force scenario might consist of an aircraft or remotely piloted vehicle flying at low altitude over a known or suspected area of enemy concentration. The vehicle would be flying low enough, fast enough, and at distances far enough from the targets to avoid its being detected. The radar mounted on the vehicle would receive the signals which would be fed into an onboard computer for classification. This information would then be acted upon, in the case of a manned aircraft, or be sent to a central unit for further action.

Proposed Classifier

In order to separate one class of objects from another, one must first determine the characteristics of each class that make the classes distinct. This is a fairly simple task when done visually by a human observer. However, it is quite another type problem when done by a machine using a received radar signal.

A classifier based on radar signals will have to perform in the presence of noise and radar clutter. In addition, the classifier will have to use features that are independent of the aspect angle, velocity, and range of the target. Since the received radar signals are in the time domain, the classifier can be built in the time domain or any invertible transformation of the time domain. A useful transformation is the Fourier transform, which allows the classifier to be built in the frequency domain.

The frequency domain naturally reflects certain aspects of the physics of the problem such as determination of the skin line, the harmonics of the skin line, the sidebands, the noise level, and the clutter in the received signal. This is due to the doppler effect which is present due to the movement of the vehicle, the agitation of the metals, the modulation of the moving parts of the vehicle, the movement of the radar platform, the vibrations of that platform, the scanning of the antenna, and the movement of the illuminated background due to wind or vibrations. By first finding the skin line in the frequency domain, a classifier can be built that has a search routine to find the remaining components of the signal (Ref 22:58-60). Pattern recognition procedures could be then used to extract representative features for separating the classes.

This thesis will deal primarily with a previously proposed model for a classification scheme that classifies ground vehicles based on returns received by a fixed radar antenna (Ref 22). The model will be studied as to its applicability to an air to ground environment. By assuming that the radar is mounted on an airborne platform, the problem of distributed clutter in the frequency domain must be dealt with. It is the intent of this thesis to determine whether the model merits further study requiring actual air-to-ground data.

Assumptions

The primary assumption for this thesis is that the radar antenna is locked on and tracking the target. This assumption is necessary because of the manner in which the radar data was taken and it is not within the scope of this paper to deal with the problems of finding and locking onto the target. One other useful assumption is that the power in the clutter signal is known and that this power remains constant when applied to the airborne problem. The last general assumption is that the noise in the received signal is additive white Gaussian noise.

The second chapter of this thesis will look at the previously proposed classification scheme. The third chapter will deal with application of that scheme to the air-to-ground problem. The fourth chapter will show the results of this work and the fifth chapter will give the conclusions and recommendations.

II Analysis of Proposed Classification Scheme

This chapter discusses the main aspects of the classification scheme. The chapter will only highlight the previous work and discuss relevant points. A more complete description of the underlying techniques can be found in Stewart's dissertation (Ref 22).

The Procedure

In his dissertation, Stewart used a set of data that was generated independently for the study of radar detection of agitated metals (RADAM). Since the data set is costly and time consuming to gather, the best set already available was chosen for this work. The data were then converted from analog to digital form so that they could be processed in a digital computer. A Hanning window was used to filter the time signals and the amplitude spectra were computed by a fast Fourier transform algorithm. The resulting frequency domain signals were thresholded to check if there actually was a target within the range gates of the radar. The signals were then checked for positiveness and reversed, if the target skin line was found to be negative. The spectra were then checked for a skin line minimum velocity of two mph. The signals were then bandlimited to between zero and one KHz. This finished the preprocessing of the signals. The result was a digitized amplitude spectrum that contained the skin line and second harmonic of the skin line for all vehicles travelling at a minimum of two mph within the range gates of the of the radar.

The amplitude spectra were then mapped into a feature space. The components of the feature space consists of 40 features. These features were chosen heuristically to separate the targets into the three classes. The features were chosen to be relatively aspect invariant, velocity independent, acceleration independent, and location independent.

In order to construct the features, the amplitude spectra were divided into six frequency bands (Fig 1). These bands, in order, are: the clutter band, the lower side band of the skin line, the skin line band, the upper side band of the skin line, the band containing the harmonic of the skin line, and the noise band. These bands vary in width and location, depending on the location of the skin line. The skin line location being the result of doppler effect. The features are then derived from the properties of these bands. The properties used are: peak signal within a band, the total signal voltage within a band, the total signal energy within a band, and the voltage variation within a band. The features are then based on the statistics of these properties and the ratios of these statistics between bands (Ref 22:77).

Nearest neighbor routines and stepwise discriminant analysis (SDA) are the used to classify the targets. Because of the close physical similarity of targets 2 and 3, classification is performed for a two class problem and a three class problem. The results of these problems are evaluated for each type of classifier. In addition, a voting scheme is used with multiple looks in an attempt to improve the performance.

This summary of the methods used in the classification scheme is presented as a basis for examining the limitations of the study because of the limitations of the data, the necessary assumptions for the

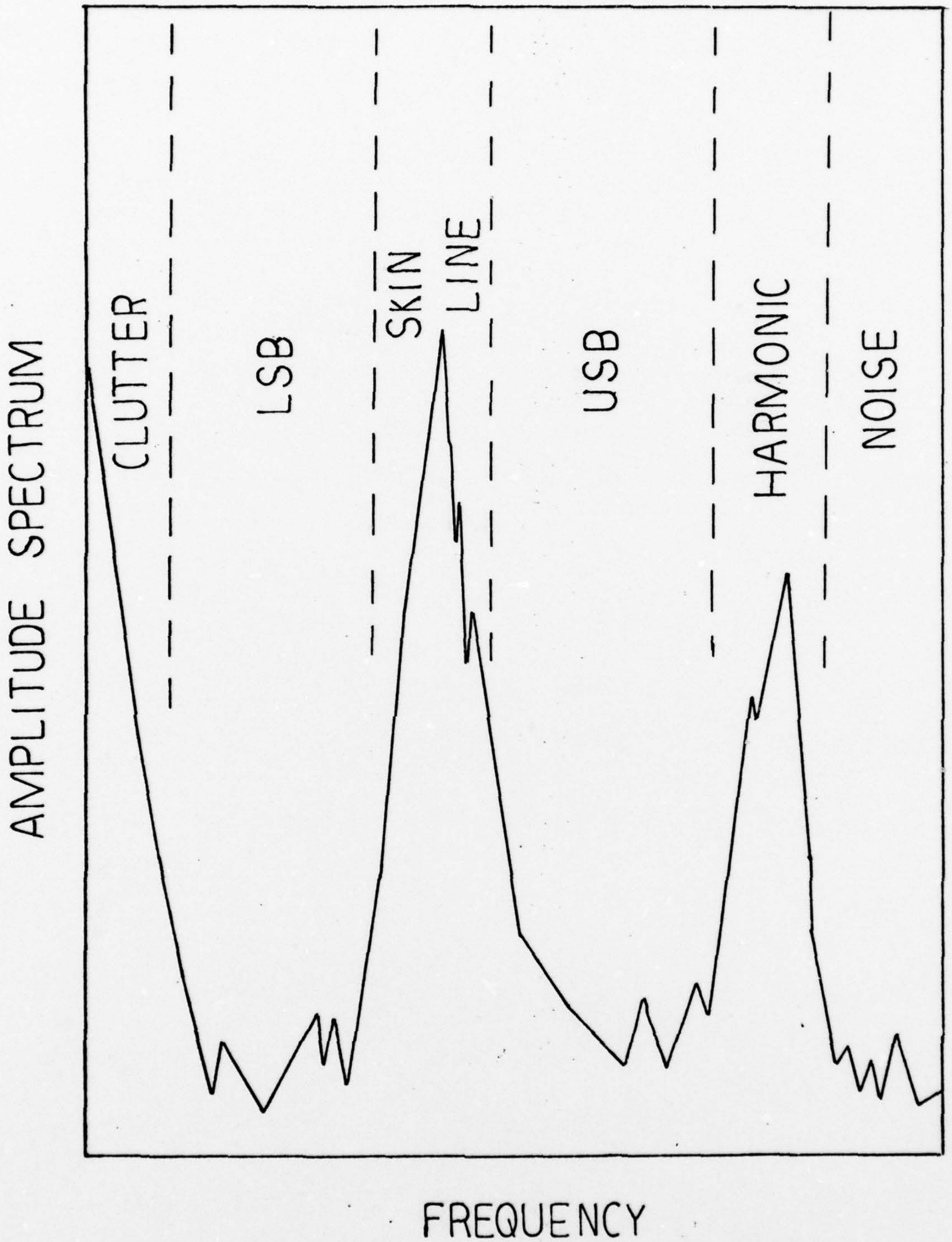


Fig 1. Frequency Bands in an Amplitude Spectrum of a Typical Signal

use of the data, and the scope of the problem. A more complete description of the preprocessing and feature extraction is contained in Stewart's dissertation (Ref 22).

The Data Base

A high pulse repetition frequency, coherent radar was used to collect the data. The radar had a transmission frequency equivalent to the frequency used by many airborne mapping radars in the current Air Force inventory. The received radar signals consisted of time domain signals resulting from ground vehicles being driven through the radar beam of a fixed antenna. The targets were at a slant range of 325 m and an antenna depression angle of 3.5° below the horizon.

There were three targets in the data base. For consistency with Stewart's work, they are labeled 1, 2, and 3. All targets were ground vehicles with the running gear on target 1 being dissimilar to that of targets 2 and 3.

The data base necessitates some limitations on the scope of the study. Since all of the targets were moving through the range gates, the classifier is limited to man-made, moving objects with an exposed running gear. This is not a serious limitation when looking at the types of vehicles used in today's warfare. This could, however, be a serious limitation when heavy duty vehicles are built that float on cushions of air.

The fact that the antenna is fixed eliminates some clutter that would be present due to platform motion, scanning, and vibrations. The depression angle is typical of depression angles used for airborne performing a mapping function. However, the slant range is much closer than would be normally experienced in any type of airborne radar classification scheme. The power in the received signal is related to the slant range as follows:

$$P_R = k \frac{1}{d^4} \tag{1}$$

where P_R is the received power, d is the slant range, and k is the constant associated with a particular radar. In order to simulate a situation where the radar is at a greater distance from the target, the power received must be reduced in proportion to the fourth power of the slant range to the target. Since the power received is directly related to the power transmitted, the transmitted power must be reduced accordingly. In order to achieve results equivalent to those for the data base this relationship of slant range to power must be taken into account.

The type of clutter present for the data was farmland clutter. Since clutter power is a function of its radar cross section, introducing other types of clutter could effect the received signal. One would expect there to be more power in the clutter band for a wooded environment and less power in the clutter band for a desert environment.

Assumptions

There were some assumptions that were made throughout Stewart's dissertation. A major assumption is that the target has already been detected (Ref 22:1). This is no small problem when it is realized that detection means that a radar or some other detection device has classified a target as a man-made moving object. There was no attempt to build in a reject class of targets other than man-made moving objects. This was a necessary assumption to make since it would take a much more complex classifier to solve the problem. The limitation on the scope of the project must nevertheless be recognized.

An assumption made prior to Stewart's work is that a radar would be a good sensor in the classification scheme. Since this was the available data base, it is a major assumption that a radar would be either the best sensor or the most available sensor. Other sensors or even other radars might serve the purpose more adequately. Since the other data are not presently available in sufficient quantities, it is difficult to make realistic comparisons. Whatever the sensor is, however, it is useful to note the methods used in the classification.

For a portion of the disseration an assumption on tracking had to be made (Ref 22:38). If the radar were to track the target, the radar cross section of the clutter would constantly be changing. In addition, the movement of the antenna required for the tracking operation would introduce additional clutter. This did not pose much of a problem in the ground-to-ground environment because it was assumed that the clutter existed only in the lower frequencies. Thus, these lower frequencies were ignored during the classification. In the air-to-ground situation, there may be some spectral spreading present that would creep into the higher frequency components of the signal. This would then have some bearing on the classification.

The local stationarity assumption (Ref 22:27) is very important to the study. By choosing an observation interval sufficiently short to maintain stationarity, a short-time amplitude spectrum was computed.

This assumption, coupled with the assumption of additive white Gaussian noise, allows for a very tractable and useful amplitude spectrum of the signal. Mainly, by assuming that there is a relatively small target signal in the noise band, the statistics of the noise can be determined. By knowing the statistics of the noise, the characteristics of the clutter and target returns can be examined for use in the feature extraction process.

Hypothesis

The basic hypothesis that motivated the proposed classification scheme is that there exist parameters of the received radar signal associated with particular targets that are invariant from return to return. These parameters are then useful in the classification of the radar targets. Since the targets all have moving parts, they will experience some doppler spread in the frequency domain. Therefore, it was thought that the frequency domain would be a likely candidate for the existence invariant target parameters.

III Air-to-ground Classification

This chapter will focus on the application of the classification scheme for the air-to-ground environment. Specifically, the effects of ground clutter on target recognition will be discussed.

Radar Clutter Problem

Clutter is the received radar signal from any illuminated object other than the target of interest. It is the result of the target's surrounding environment. The clutter can be from the natural environment, such as, rocks, trees, grasses, water, and the terrain itself. The clutter can also include man-made objects that are not targets of interest, such as, roads, fences, buildings, and equipment.

The reason that clutter presents a problem is that the desired features in the target may be masked by the presence of clutter. The problem is different from that of thermal noise because it is difficult to predict the nature of the clutter. If the same area were continuously searched for targets, that particular area would represent some average clutter statistics which could be incorporated into a target classifier. This would not be the case in the usual air-to-ground situation where the target must be classified where it is located, regardless of the surrounding environment.

Since the target classifier is to be used in various environments, it is necessary to decide whether the features it uses are sufficiently robust to function up to a prescribed standard in the presence of clutter. One approach to this problem would be to use the worst case amplitude statistics and spectra of the clutter (Ref 20:1). If the features worked in the worst case, then they would work in a less severe environment.

Clutter turned out not to be a major factor in the development of the classifier proposed by Stewart; by inspection, Stewart determined that the clutter was confined to a frequency band between 0 and 14 Hz and it was easy to take advantage of this spectral quality to eliminate the clutter energy from the classifier. He simply did not use any information from this frequency band to construct target features.

In the air-to-ground, however, situation there will be some spectral spread of the clutter due to platform motion (Ref 14:20). These effects must be taken into account when judging the applicability of the classifier to the air-to-ground situation. Additionally, it must be taken into account that the clutter signal may be different from that experienced when the data was generated.

Clutter Equation

Assuming that the thermal and receiver noise power is negligible compared to clutter power, the clutter power at the receiver for small grazing angles is (Ref 12:63-67):

$$C = \frac{P_t G_c^2 \lambda^2}{(4\pi)^3 L R^4} \left[\sigma_o \theta_a R \frac{c\tau}{2} \sec \gamma \right] \tag{2}$$

where,

C is the clutter power

P_t is the transmitted power

G_c is the antenna gain in the direction of the clutter

λ is the radar wavelength

L is the system loss factor

σ_o is the scattering cross section of the clutter element

θ_a is the azimuthal beam width

c is the speed of light

τ is the pulse width

γ is the grazing angle

For a particular radar system all of the terms are constant except for slant range, the scattering cross section of the clutter element, and the grazing angle. The slant range and grazing angle will be functions of the clutter location with respect to the radar platform. The clutter cross section will be a function of the type of clutter encountered. It is interesting to note that the total clutter power is not a function of any platform motion or motion of the clutter itself; therefore the clutter power can be assumed to be the same for a fixed antenna or a moving antenna operating under the same conditions.

The effect of grazing angle on clutter power is minimal. If the angle is allowed to vary between zero and ten degrees, the clutter power varies by only one and one-half percent. This leaves the slant range and clutter cross section as the major contributors to clutter power. In Stewart's dissertation the features were normalized by the peak power in the return of the skin line. This calls for an analysis of the signal to clutter ratio.

The signal to clutter ratio is (Ref 12:63-67):

$$S/C = \left[\frac{G_t}{G_c}\right]^2 \left[\frac{1}{\theta_a \frac{c\tau}{2} \sec \gamma}\right] \frac{\sigma}{\sigma_o} \cdot \frac{1}{R} \qquad (3)$$

where,

G_t is the antenna gain in the direction of the target σ is the target radar cross section

In this formulation, it is evident that the effects of range are reduced from a fourth power relationship to a first power relationship. In addition, the use of the ratio eliminates any effects of transmitted power. Thus, analysis based on a normalized signal return, is effected by slant range to the target, the radar cross sections of the clutter and the target, and to a small extent by the grazing angle.

Radar Cross Section of Clutter

The factors that determine the radar cross section of clutter include the radar frequency, the transmit/receive polarization pair, the grazing angle, and the terrain type. The terrain type is also altered by the type of vegetation, the weather, and the season of the year (Ref 4:4). For the particular radar which provides the data used in this study, the terrain type is the only significant variable in determining the radar cross section of the clutter.

Clutter can be considered to be the result of either distributed or discrete scattering. In the distributed case, the dominant scatterers are continuous in nature, such as, farmland. For the case of discrete scattering, the dominant scatterers are isolated objects, usually manmade. The most common approach to clutter is to characterize it as homogeneous with a constant radar cross section (Ref 3:1).

Four generic terrain types are usually used to identify the type of clutter. These types are Farmland, Sea/Lake, Desert, and Woodland (Ref 4:4). Sea/Lake is not a factor when considering land vehicles, but the other three types can occur. For a comparison of the effects of the terrain type on the radar cross section, there exists a study of ground clutter measurements at X-band frequencies (Ref 7). For grazing angles of less than ten degrees, the average radar cross section per unit area measured in the Summer and the Fall is represented in Table 1.

Table I. Average Measured Radar Cross Sections of Clutter in dBSM

	OVERALL AVERAGE			RANGE OF AVERAGES	
	Summer	Fall	Standard Deviation	Low	High
Trees	-30.5	-29.4	4.4	-41.0	-24.0
Fields	-38.0	-29.2	1.3	-42.0	-22.5
Rocky Ground	*	-28.5	1.1	-31.0	-25.0

*Not Measured

This data is from a limited number of sources and a limited number of measurements. However, the results are consistent with other studies for the types of terrain measured (Ref 7:73). The measurements for desert would most likely approximate those of rocky ground for the purposes of this study.

The implication of the radar cross section, for a clutter measurement with a fixed illuminated area, is that the signal-to-clutter ratio could vary by 20dB. This could effect the performance of the classifier significantly if the measurements were made with low radar cross sections. The data used in this investigation was taken with a farmland clutter background. If the background clutter is considered to have an average radar cross section, the signal-to-clutter ratio could vary as much as 13dB worse under some extreme differences in terrain radar cross sections.

The classifier should be tested to see how it performs under the more extreme conditions.

Clutter Spectrum

Independent of the clutter signal power is the spread of clutter in the frequency domain. Clutter spread must be taken into account when dealing with low velocity targets, such as, ground vehicles (Ref 14:23). Depending on the amount of clutter spread, the clutter return and the target return can both be present in the frequency bands used for target classification (Fig 2). Since it is impossible to isolate the clutter from the target signal, under conditions of low target velocity and high clutter spread, the classification scheme needs to be tested for its effectiveness under these adverse conditions.

An assumption must be made that the aircraft platform has access to its own velocity and the scan angle of the antenna. This allows for an amplitude spectrum that is demodulated by the doppler shift from relative velocity of the platform with the illuminated area. Therefore, the amplitude spectra of all of the target samples can be compared regardless of platform velocity or scan angle.

One cause of clutter spread is the motion of the illuminated clutter background, either due to the wind or ground vibrations. The spectral width of the clutter signal due to internal ground motion is seldom more than one foot per second (Ref 14:20). This is equivalent to 19 Hz, which is 5 Hz beyond the clutter spread for the fixed data base.

One study (Ref 9) attempted to model clutter spread due to wind velocity for an X-band radar illuminating a wooded area. The maximum

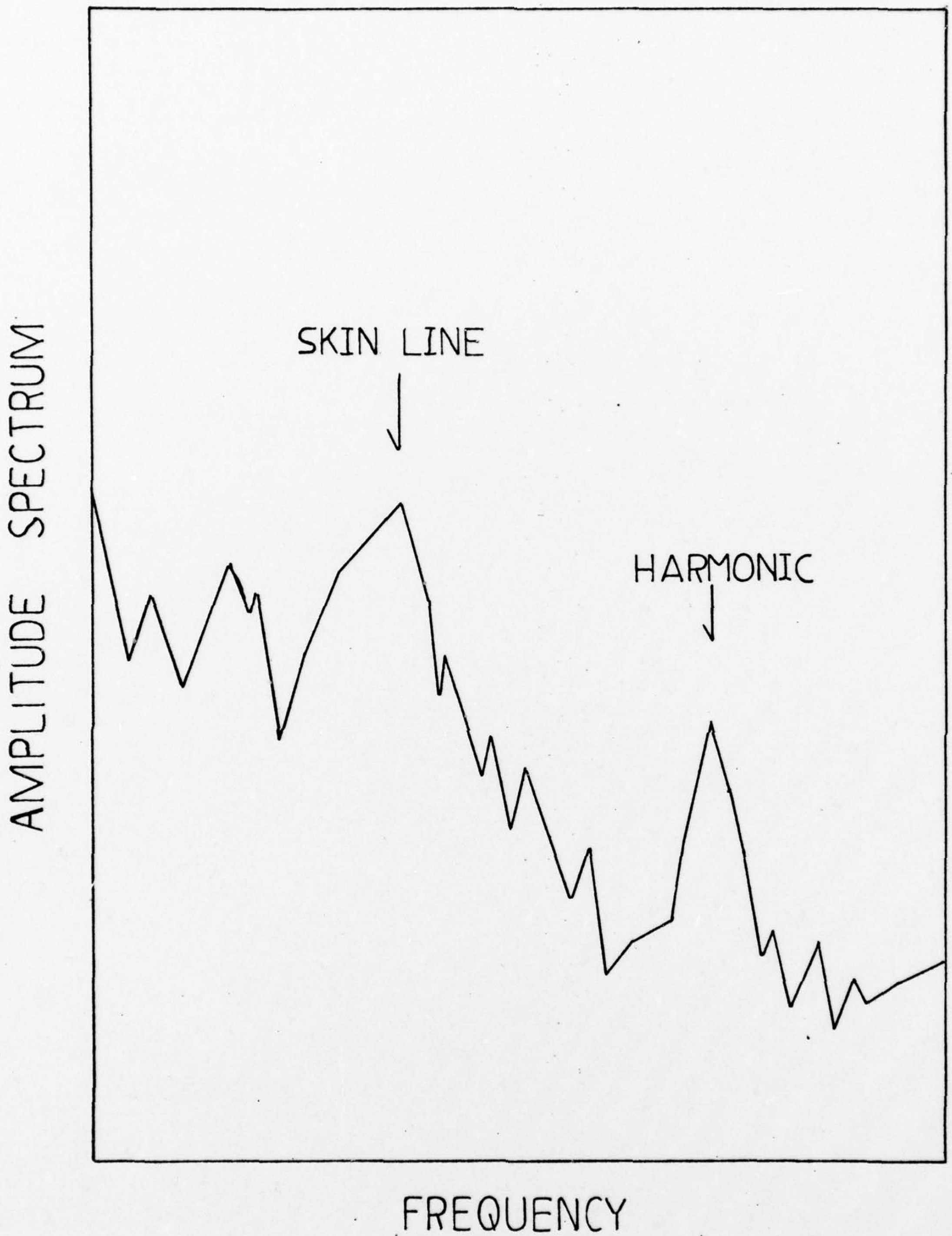


Fig 2. Effects of Clutter Spread on a Typical Received Target Signal

frequency of the clutter was

$$f_c = 1.33\ e^{(.14\ w)}\ \text{Hz} \tag{4}$$

where w is the wind velocity in knots. A wind of 25 mph would then cause a maximum clutter spread of 28 Hz. This is 14 Hz above the spread encountered in the data base. The choice of 25 mph is an extreme, but possible, situation where the classifier would reasonably be expected to work.

In addition to the motion of the ground objects, clutter spread is caused by any antenna or platform motion in an airborne radar situation (Ref 15:270). These motions are due to scanning, maneuvering, platform velocity, and instabilities either in the platform or the antenna. The clutter spread due to these can be much more significant than the causes previously mentioned (Ref 14:20).

If the target is not on the aircraft centerline, then the velocity component of the clutter perpendicular to the aircraft centerline will induce clutter spread. The frequency component of the clutter is

$$f_d = \frac{2\ V_x}{\lambda}\ \sin\theta \tag{5}$$

where V_x is the velocity component perpendicular to the aircraft centerline in meters per second, λ is the wavelength of the signal in meters, and θ is the angle of the clutter from the antenna centerline (Ref 21:18-6). A target that is 10 degrees off the aircraft centerline, of an aircraft moving at 400 mph, will have a velocity component perpendicular to the centerline of 69 mph. If the beamwidth of the radar is 4.5 degrees and the target is in the center of the illuminated area, then the clutter will be 2.25 degrees from the antenna centerline. This would result in a clutter doppler frequency of 76 Hz. That is considerably above the clutter band used to build the classifier for the ground radar situation. The scanning, maneuvering, and instabilities of the radar platform will also contribute to the clutter spread in a manner that has not been determined.

Implications

The power in the clutter signal is dependent on the radar cross section of the clutter, which is in turn dependent on the type of terrain. The spread of the clutter is dependent on motions of the ground and of the radar platform. These both act to change the returned signal. The classifier proposed by Stewart was built for a fixed radar antenna illuminating a constant clutter background. If the algorithm is to be applied to an air-to-ground situation, it must be able to classify targets under a variety of clutter backgrounds and various clutter doppler shifts.

IV Results

This chapter discusses the procedures used to gather the data, the methods used to evaluate the data, and the results of the evaluation.

Data Gathering

Chapter two discussed the data base used in this work. This data base was generated through use of a fixed radar antenna. As discussed in chapter three, the clutter signal had to be altered so that the data might approximate the data that would be expected from an airborne radar platform. The total power in the clutter signal must be held constant, but spread spectrally, for the case where an airborne radar illuminates the same clutter background used in the original data base. This requires a measurement of total clutter power in each sample, an indication of the shape of the expected clutter spectrum, and the doppler shift of the clutter.

Since the doppler shift is dependent on many variables, it was allowed to vary between 0 Hz and 270 Hz. Based on the given equations in Chapter 3, this would be a reasonable range of expected frequencies. This range was also chosen because it extends beyond the average skin line doppler frequency of the targets which is approximately 200 Hz (Appendix C).

The clutter in the original data was considered to lie between 0 Hz and 14 Hz for the purposes of this study. These frequencies were determined by inspection of the amplitude spectrum (Ref 22:72). The total power was then measured in the clutter band for each sample. The power was then held constant for each individual sample during the spectral spreading. The power was held constant on a sample basis rather than use an average power for a target, a run, a class, or an overall average. This allowed measurement variations that might be expected and it did not introduce any bias that would result in a lower than expected classification probability of error. The shape of the spectrum was modeled after Figure 3. This figure was the result of a computer generated clutter model averaged over a number of samples (Ref 18:6-7). This model indicates that the spectrum has most of its power lying the the lower frequencies with the power in each narrow frequency band continuing to decrease as the frequency increases. While it can not be said that the power in each narrow frequency band is strictly decreasing (Ref 7:82), the model represents the average case where the trend is in that direction.

For the case where the radar cross section was allowed to vary, the other variables were held constant. This allowed for a comparison of probability of performance under conditions of equal spectral spread with increased power in the clutter signal. In this study, the clutter power was allowed to vary from 0dB to 20dB to approximate what the signal might appear to be under varying terrain conditions. There was no attempt made to alter the shape of the spectrum, although one might expect a slightly different shape for each class of terrain. This was done because the shape of the clutter spectrum cannot be reliably predicted. The shape would be highly dependent on the individual terrain conditions. This was considered to be a minor consideration because the general shape of the clutter spectrum will still closely approximate the shape of the model.

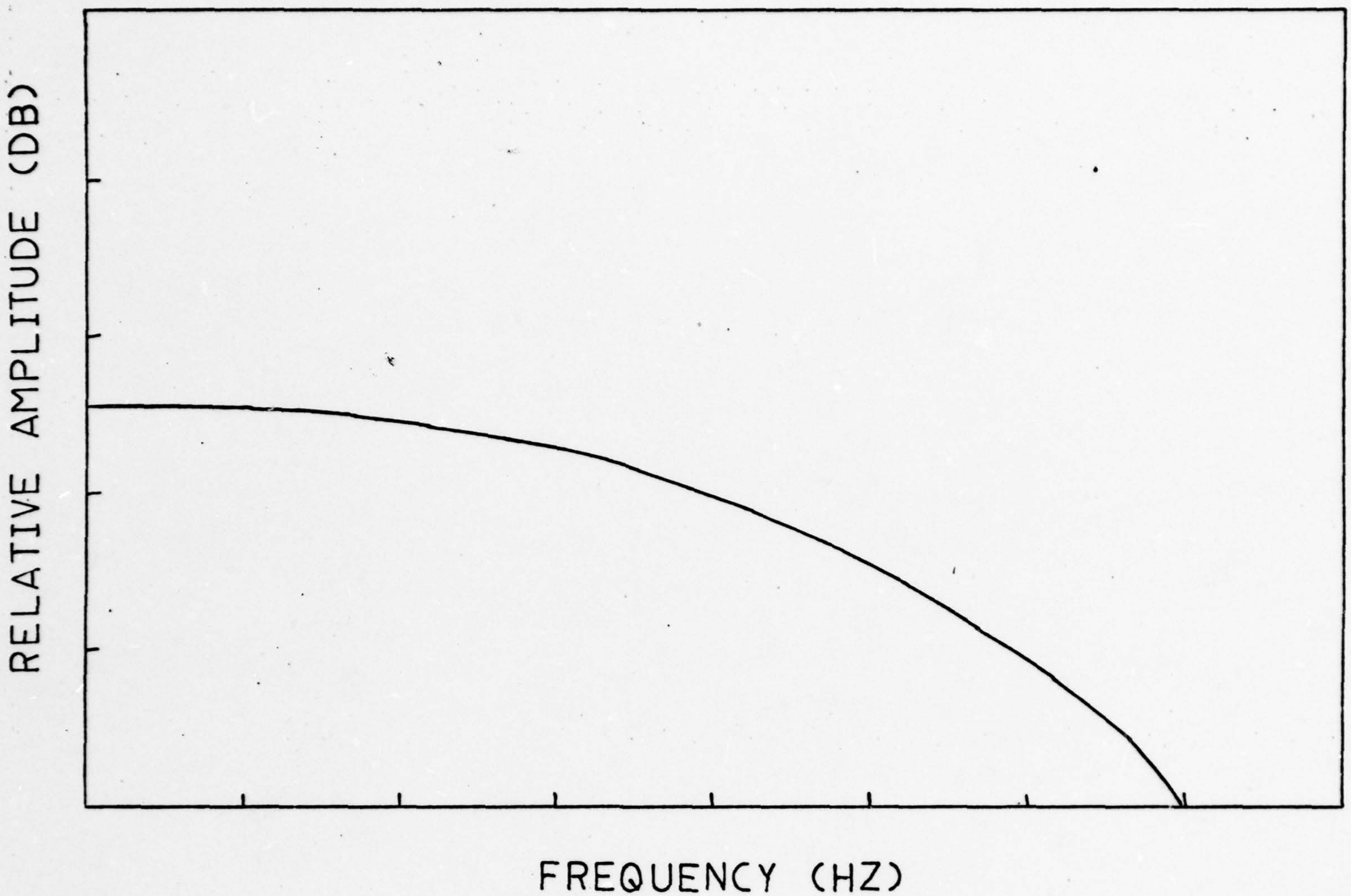


Fig 3. **Approximate Shape of Typical Clutter Amplitude Spectrum (Ref 18:7)**

Data Evaluation Methods

Since this thesis is based upon a previous study, the methods of evaluating the data are the same as used in that study (Ref 22). The methods are stepwise discriminant analysis (SDA) and nearest neighbor (NN) classification (Ref 10, 8). These techniques are adequately discussed in Stewart's work. The three nearest neighbor rule was not used because it did not yield significantly different results than the single nearest neighbor rule based on the increased computational costs.

Classification was performed on the two class problem, where targets two and three are considered to be in the same class, and on the three class problem. Selected cases were also chosen to see if performance improved significantly for seven looks at a target prior to a decision.

Spread Spectrum Results

There were 1442 samples remaining from the original data base after preprocessing. Of these, 1387 were classified by Stewart (Ref 22). The remaining 55 samples formed a reject class. These samples were rejected either because the peak voltage in the skin line was too low or because the skin line location was less than 14 Hz (Ref 22). These rejected samples were not from any one run. but were from a large cross section of the runs. These samples were not used in the calculation of probability of error because a rejection is not the same as making an error. Rejected samples merely reduce the size of the population in the study. Any samples falling in the reject class would then be considered as an undetected vehicle.

As the clutter spread frequency (f_c) increased in value, there was initially an increase in the reject class with the maximum number of rejected samples being 255 samples at approximately 40 Hz (Fig 4). Of these rejected samples 214 were from target 1, 21 were from target 2, and 20 were from target 3. Although this was almost one-third of the total samples in target 1, all runs were still present in the calculation. The runs in target 1 that lost the most samples were at aspect angles of 45 degrees and 315 degrees. These runs lost up to 60 percent of their samples with the exception of one short run at 315 degrees that lost 4 of its 6 samples. One possible explanation for the loss at these angles is that there was a significant amount of power in the sidebands of target 1 at angles 45 degrees from the antenna, when compared to other targets and other aspect angles. The addition of clutter power in the same location as these sidebands could have resulted in one of the frequencies being picked as the target skin line frequency. If this skin line frequency was below 14 Hz, the classifier would reject the target.

After this maximum number of 255 samples was rejected, the number of rejected samples decreased until the value of f_c was about 200 Hz. At this point there were only 40 samples rejected. The number of samples in the reject class then leveled off at about 40 to 42. Because of a discrete frequency spectrum and a limited amount of computer resources, it was impossible to check every frequency and determine the number of samples rejected. There were, however, no points tested that did not observe the trend of an initial increase in the number of samples rejected, followed by a gradual decrease in the number of

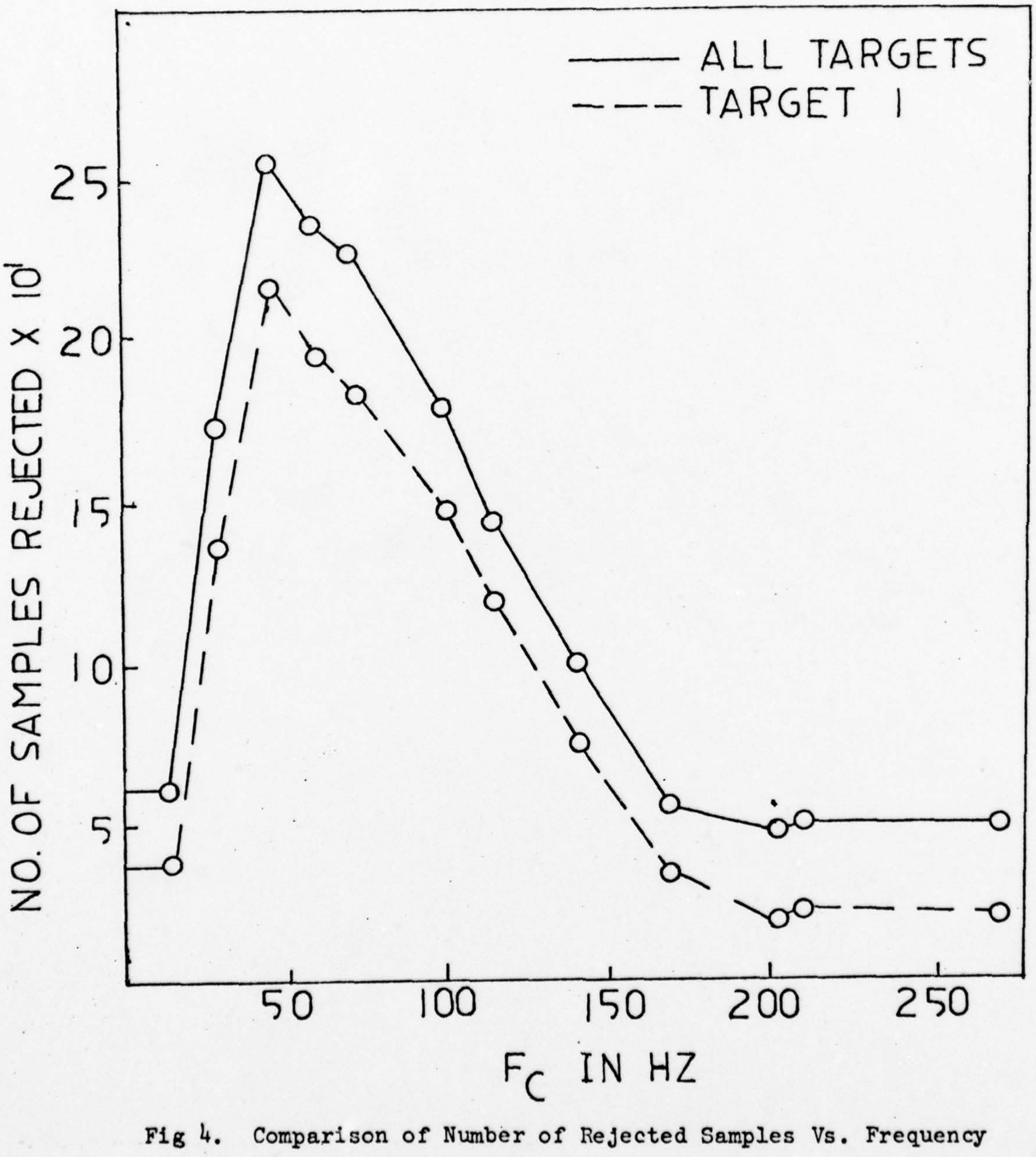


Fig 4. Comparison of Number of Rejected Samples Vs. Frequency For All Targets and Target 1 for the Clutter Spread Problem

samples rejected.

The following experiments will be labeled with letters, for example experiment A, experiment B, etc. This is to avoid confusion when comparing the results with Stewart's work (Ref 22). There will be numbered experiments in his work that correspond to the lettered experiments shown here, but using the same numbers would imply that the data tested was exactly the same. Experiments A through D are frequency spread clutter experiments with no increase in clutter power.

Experiment A was a two class problem using SDA. As f_c increased the probability of error increased from .061 at 14 Hz to .089 at 200 Hz (Table II). The probability of error then decreased, going down to .069 at 270 Hz (Fig 5). At 200 Hz the probability of error for seven looks at the target, using a majority voter, was .040 as opposed to .026 when there was no clutter spread.

Table II. Confusion Matrix for f_c = 200 Hz in Experiment A

		CLASSIFIED	AS
		1	2
TRUE	1	540	94
CLASS	2	23	745

The majority of errors occurred on target 1 (classified as target 2); when the target was at an aspect angle of 0 and 180 degrees, moving in the forward direction, and at a constant speed. This agrees with Stewart's conclusion (Ref 22:93).

As the clutter frequency shifted, the order of feature selection fluctuated considerably. A list of features is contained in Appendix D.

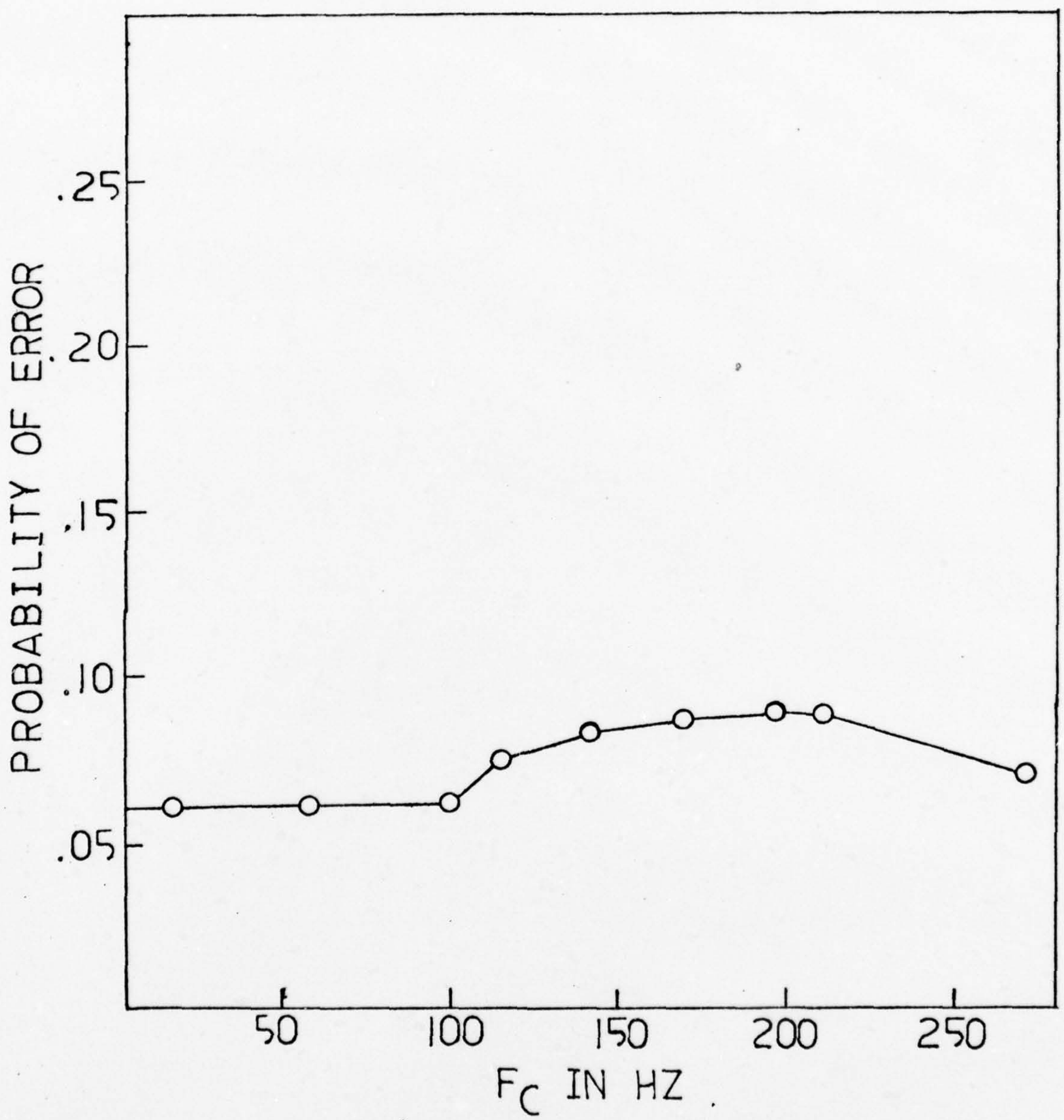


Fig 5. Probability of Error Vs. f_c For Experiment A

Although feature 28 (the total harmonic signal in the sidebands including the second harmonic) was the best feature in 7 out of 13 test frequencies, it was not included until the 35th step when the f_c was 70 Hz. This was most likely because of a significant amount of clutter power residing in the sidebands of the samples. Feature 28 increased in significance as f_c increased beyond 70 Hz.

The features were checked to see which features performed best throughout the range of possible clutter frequencies. This was done by averaging the step number where that feature was entered for each tested frequency. The best feature based on consistent performance was feature 25 (peak signal in the second harmonic). Feature 36 (a shape factor based on standard deviation) was the next best feature followed by feature 26 (the peak energy in the second harmonic). The next two best features were features 38 and 28. Feature 38 is a shape feature based on the mean difference of the side bands and feature 28 was mentioned in the preceding paragraph.

Experiment B was a two class problem using a NN rule. Unlike the previous experiment, there was no simple relationship between probability of error and f_c (Fig 6). The probability of error varied in an undetermined manner, but stayed within a range of .085 and .122 for the points tested. For the case where no clutter was present above 14 Hz, the probability of error was .097. However when the clutter was spread to 28 Hz, the probability of error increased to .122. Interestingly, a value of .085 occurred at an f_c of 210 Hz. The probability of error remained within these established limits through 270 Hz.

When 7 looks were taken before making a classification, the probability of error reduced to .048 as opposed to .029 for an f_c under

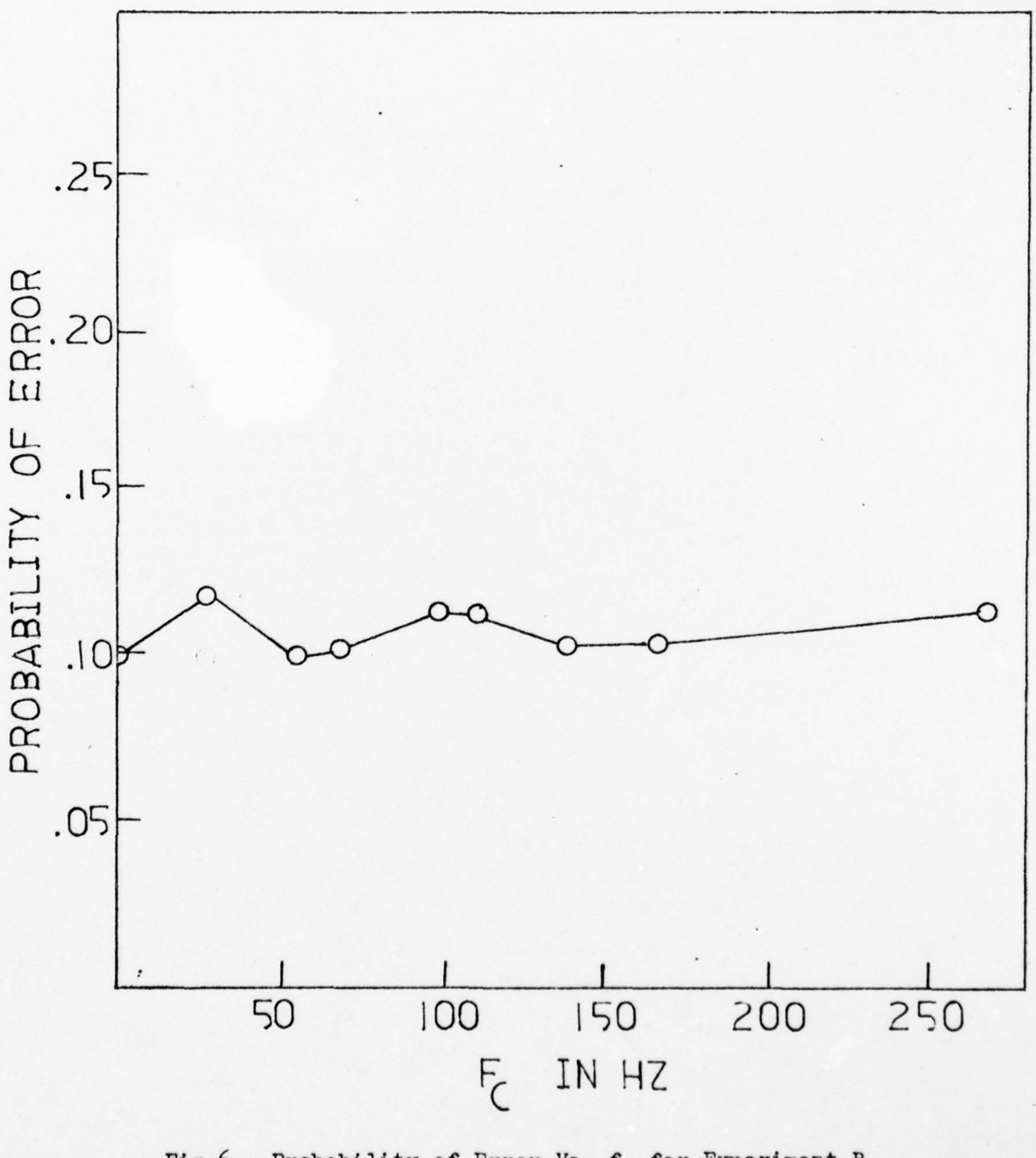


Fig 6. Probability of Error Vs. f_c for Experiment B

14 Hz. The run on target 1 at 0 degrees was misclassified on 17 out of 27 samples. This accounted for 21 percent of the misclassifications on target 1 in the single look test. By taking seven looks on target 1 at 0 degrees, the number of errors was only reduced to 15.

Experiment C was a three class problem using SDA. As stated previously, the three class problem is defined as viewing targets 2 and 3 as separate classes, Initially, the spread of clutter to 56 Hz reduced the probability of error to .210 from the value of .219 achieved for a single look with no clutter spread (Fig 7). The probability of error then increased to a value of .255 at 140 Hz where it leveled off near that value through 210 Hz. The probability of error eventually decreased to .219 at 270 Hz. The 7 look probability of error at 140 Hz was .215 as opposed to a value of .150 under no clutter spread.

It is difficult to explain why the probability of error for this experiment and the last experiment fell below the initial levels, where no clutter was present. The only apparent explanation would be that the classification was not performed by a Bayes optimal classifier. Considering this and the fact that the data was taken on two separate days, allowing for possible differences in the shape of the clutter spectrum, a slight reduction of probability of error at high value of f_c is possible. Since this study is attempting to determine the possible extension of the proposed classifier to the air-to-ground problem, the exact values of the probabilities of error are not as important as the overall trends in probability of error. Therefore, a slight reduction in probability of error at various frequencies is not a problem for this study.

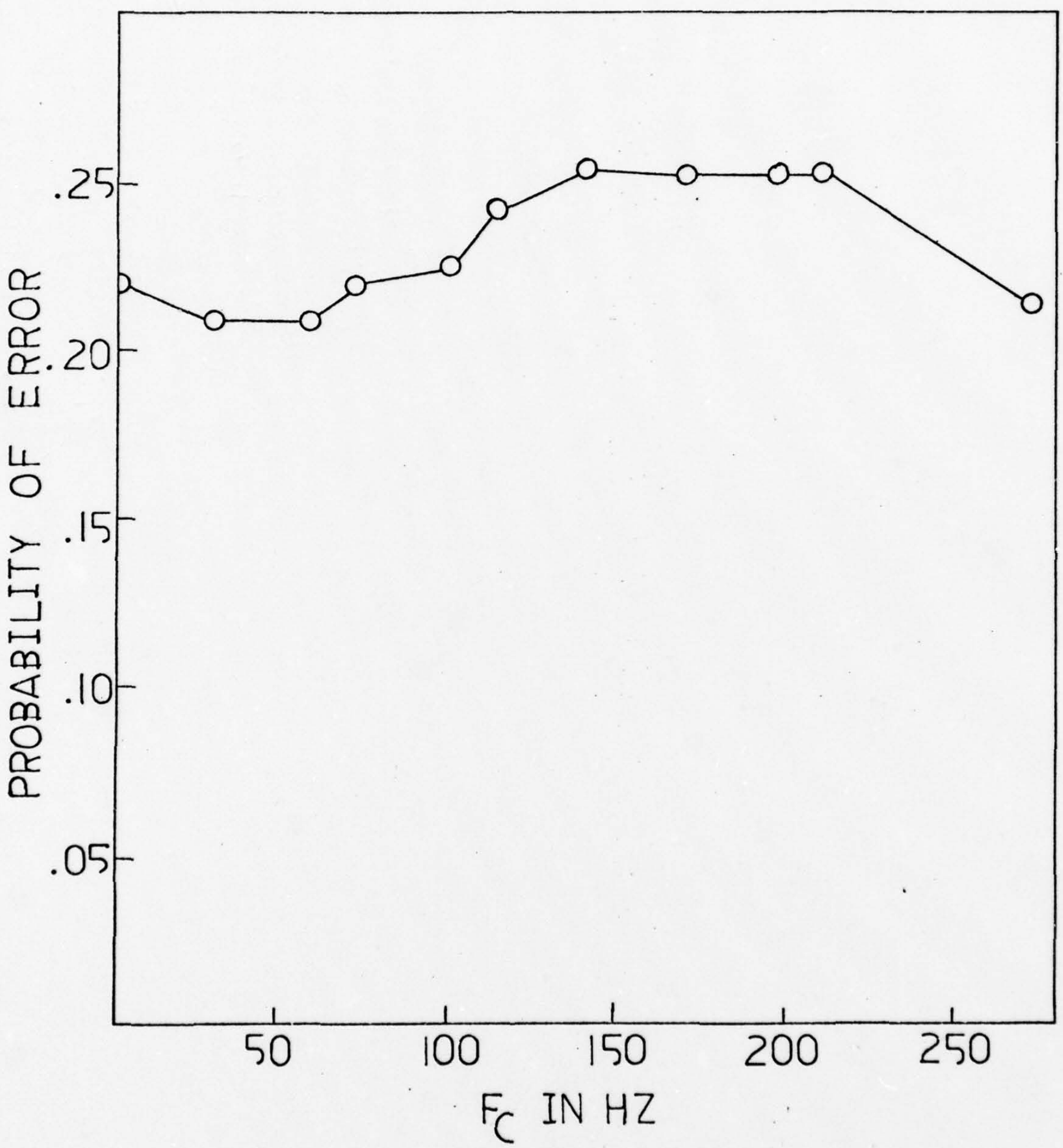


Fig 7. Probability of Error Vs. f_c for Experiment C

After the initial reduction in probability of error, the results of this experiment were similar to those in experiment A. The probability of error increased as f_c increased, eventually peaking at some higher frequency and then began to decrease back to its original value. This reduction in probability of error at the higher frequencies can be explained because the clutter spectrum is being spread over such a broad band that there is not enough clutter power in any single frequency band to cause any significant differences.

Experiment D was a three class problem using a NN rule. The probability of error in this experiment, unlike the two class problem in experiment B, had a definite trend (Fig 8). The trend was again similar to that experienced in experiment A. In this experiment, the probability of error increased from .208 at an f_c of 14 Hz to a value of .253 at 28 Hz. This level of increase is larger in magnitude than for the previous experiments, but is quite similar in a relative sense.

After the initial increase the probability of error then gradually increased to a value of .279 at 168 Hz. As in the previous experiments, the probability of error began to decrease after this peak. In this experiment that decrease was a little slower with the probability of error only decreasing to .256 at 270 Hz. At 168 Hz, where the peak value of probability of error occurred for a single look, the seven look probability of error was .178 as opposed to .126 under conditions of no clutter spread.

Increased Clutter Power Results

A thorough study of the effects of increasing clutter power was not performed because of the large amount of computer resources that

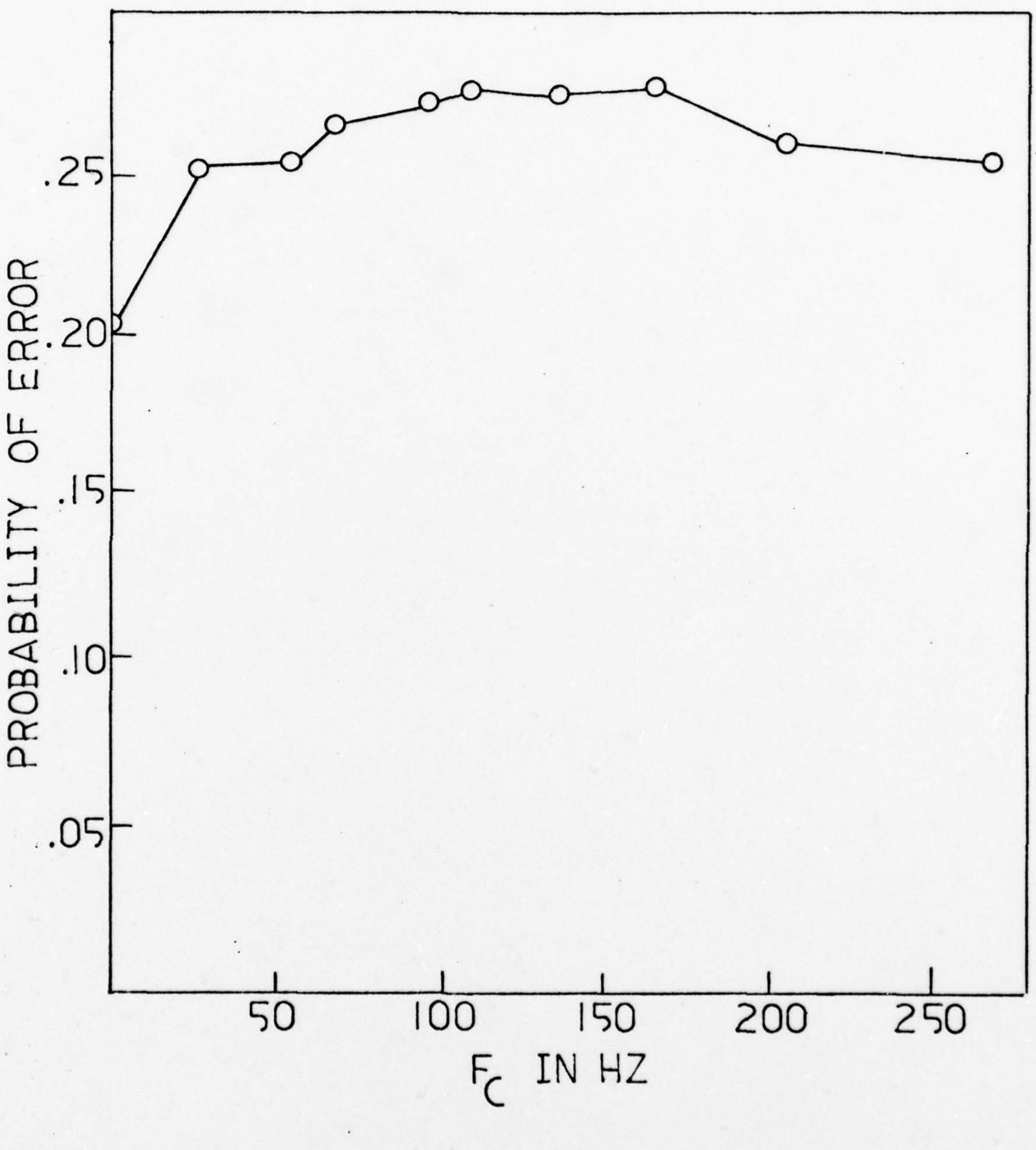


Fig 8. Probability of Error Vs. f_c for Experiment D

would have been required. Instead, clutter power increases were studied at a low frequency spread and a high frequency spread. For the low frequency tests, 56 Hz was chosen because the highest number of rejects occurred at that frequency. For the high frequency tests, 270 Hz was chosen because this represented a clutter spread through the entire spectrum used in this study.

Clutter power was varied from 0 dB to 20 dB at both frequencies. The effects of this variation were quite different between the two frequencies. At 56 Hz, the number of rejected samples varied from 255 at 0 dB to 465 at 20 dB. While at 270 Hz, the number of samples rejected varied from 42 at 0 dB to 28 at 20 dB.

These differences can be explained by the rejection criteria. As in the earlier discussion on clutter spread, the majority of rejected samples came from target 1. The number rejected from each target class were 379 from target 1, 32 from target 2, and 54 from target 3. In spite of 56 per cent of the samples in target 1 being rejected, each run in target 1 was still represented by at least one sample. The highest percentage of rejects occurred on a run at 315 degrees, where 20 out of 21 samples were rejected. Again the high number of rejects can be explained by the clutter adding to the lower side band of the skin line and making it appear that the skin line is at that lower frequency. If the apparent skin line falls below 28 Hz, the sample is rejected as being too low in doppler spread to identify.

The decrease in the number of rejected samples at the higher clutter spread is due to the other rejection criterion. That criterion is that a sample is rejected if the skin line voltage is below a nominal value (a derived receiver characteristic). An increase in clutter power, throughout the spectrum where the average skin line frequency occurs would tend to raise the skin line voltages. Therefore, there were 14 less rejections when 20 dB of power was added to the clutter at this higher clutter frequency. Experiments E through H are increased clutter power experiments.

Experiment E was a two class problem using SDA. At 56 Hz, there was little change in probability of error from 0 dB to 14 dB. When 20 dB was reached, the probability of error increased to .070 from its earlier value of .061. Similarly, the probability of error at 270 Hz increased from .069 to .075 at 20 dB (Fig 9). The major difference being that the increase occurred at 14 dB. For 7 looks at an f_c of 270 Hz with 20 dB increase in power, the probability of error is .028. This value is very close to the .026 probability of error achieved for no increase in clutter spread or power.

Experiment F was a two class porblem using a NN rule for classification. At 56 Hz, the probability of error increased from .094 at 0 dB increase to .158 at 20 dB increase (Fig 10). In contrast to this, the probability of error decreased at 270 Hz when 14 dB was added to the clutter power. This decrease was not expected and a more typical reaction of an increase in probability of error occurred when the power was increased by 20 dB.

At 14 dB, the reduction was a result of a better classification on both classes of targets. The most reduction in errors was achieved on target 2, where the number of errors decreased from 76 to 63. The explanation for this change must lie in the fact that the classifier

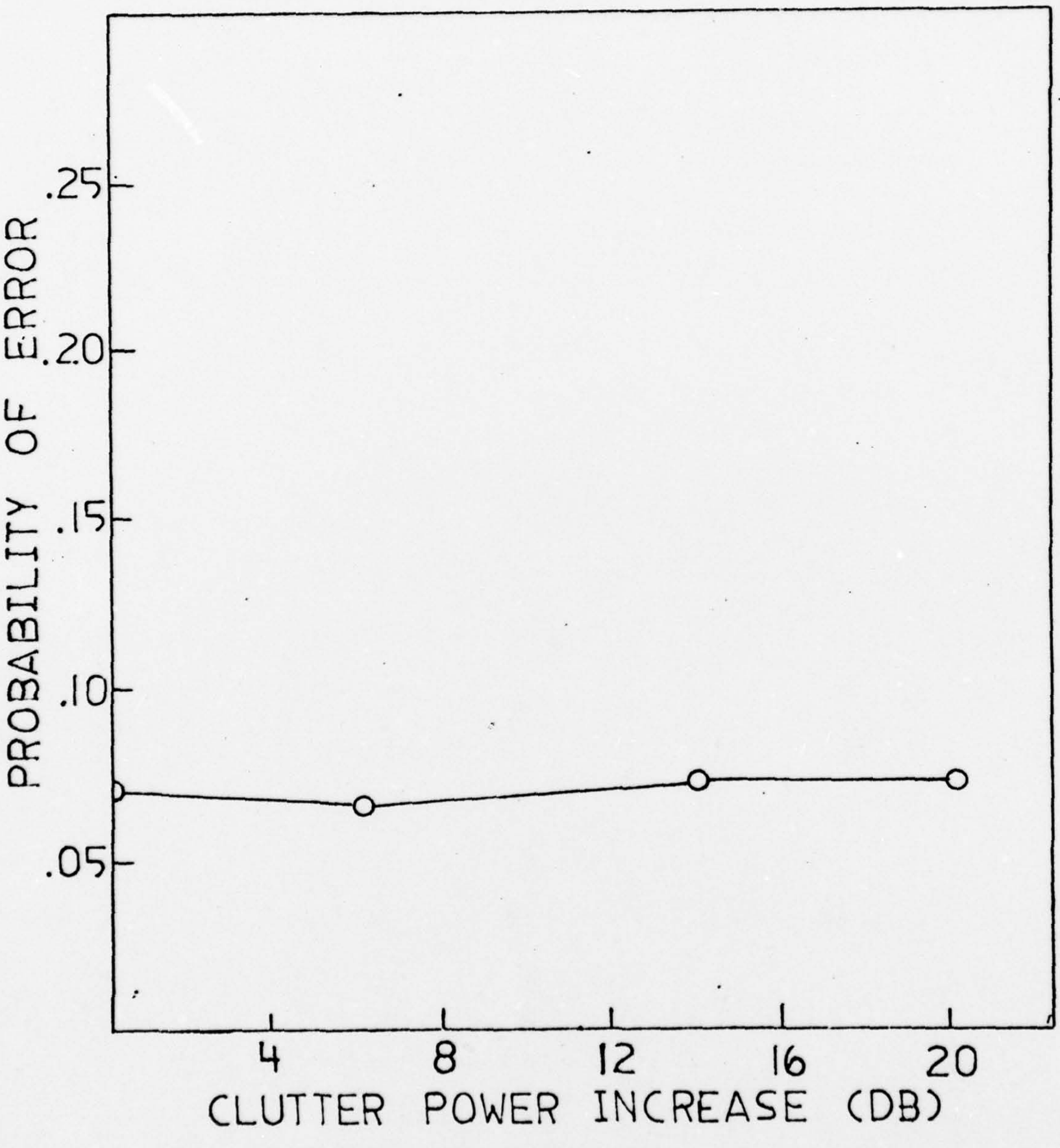


Fig 9. Probability of Error Vs. Clutter Power Increase for Experiment E ($f_c^{\cdot}$ = 270 Hz)

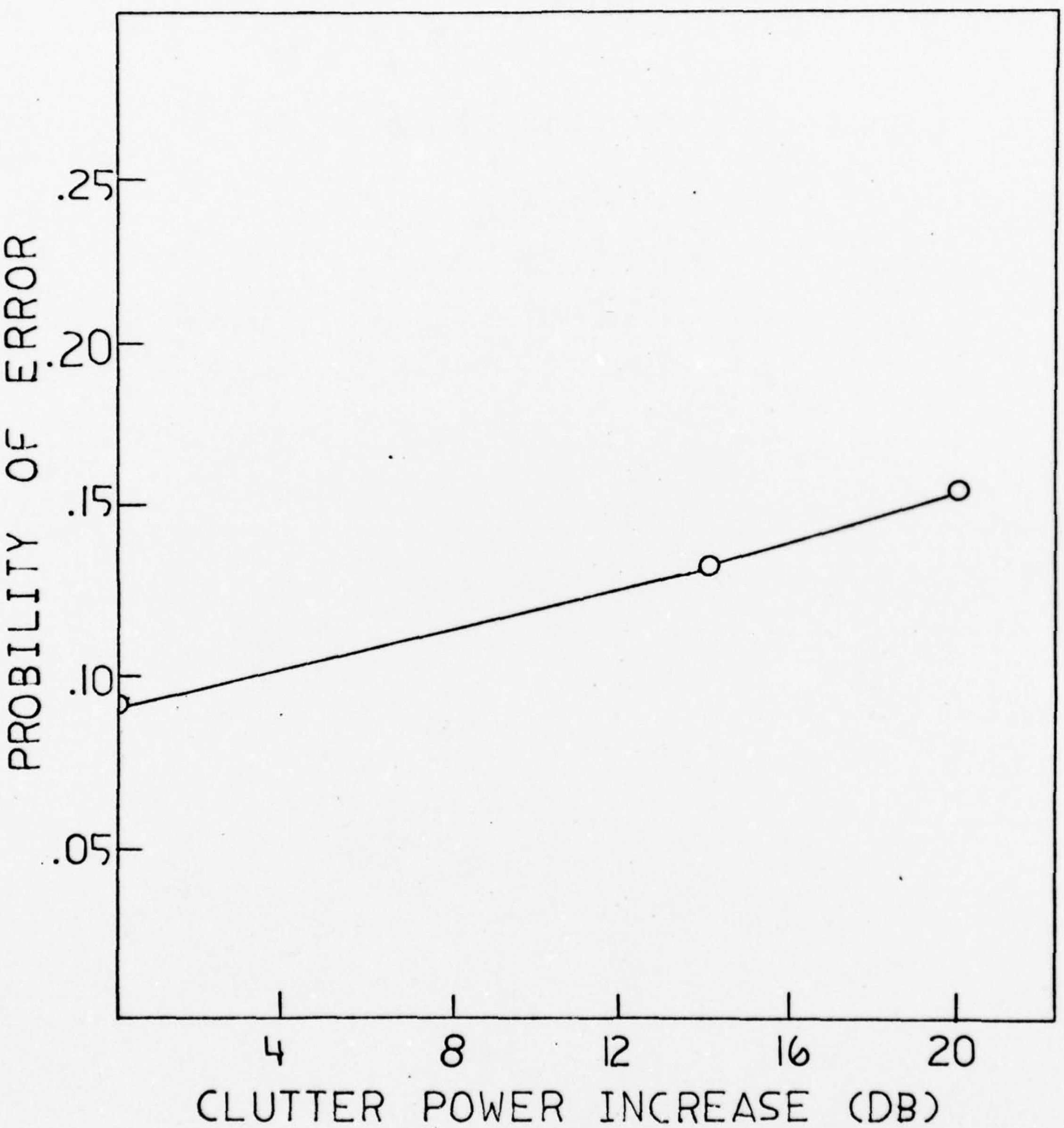


Fig 10. Probability of Error Vs. Clutter Power Increase For Experiment F (f_c = 28 Hz)

is suboptimal. One could expect slight variations in performance due to this fact.

Since the highest probability of error occurred for a 20 dB increase in clutter power at 56 Hz, the results were examined for 7 look performance. The 7 look probability of error was .071 in contrast to .029 for no clutter spread or increased clutter power.

Experiment G was a three class problem using SDA. Recall that in experiment C the probability of error initially decreased when the clutter was spread to 56 Hz. When 6 dB of clutter power was added at a clutter spread frequency of 56 Hz, the probability of error increased to .221. This value was slightly higher than the value of .219 achieved for no clutter spread or power increase. As the power was raised by 14 dB, however, the probability of error decreased to .203. This improvement, unlike the improvement in experiment C, was a result of better classification of target 1. This improvement occurred because of the high number of rejected samples from target 1. Illustrating this fact, the probability of error given target 1 was present was only .111 for a 14 Db increase in clutter power.

The test at 270 Hz of clutter spread behaved more as would be expected (Fig 11). The probability of error steadily increases from .215 at 0 dB to .219 at 20 dB. When 7 looks are used, the probability of error decreases to .163 at an f_c of 270 with a 20 dB increase in clutter power. This is slightly higher than the .150 for the case where no clutter spread or power increase is present.

Experiment H was a three class problem using a NN rule. At both frequency spreads, the probability of error increased with increasing

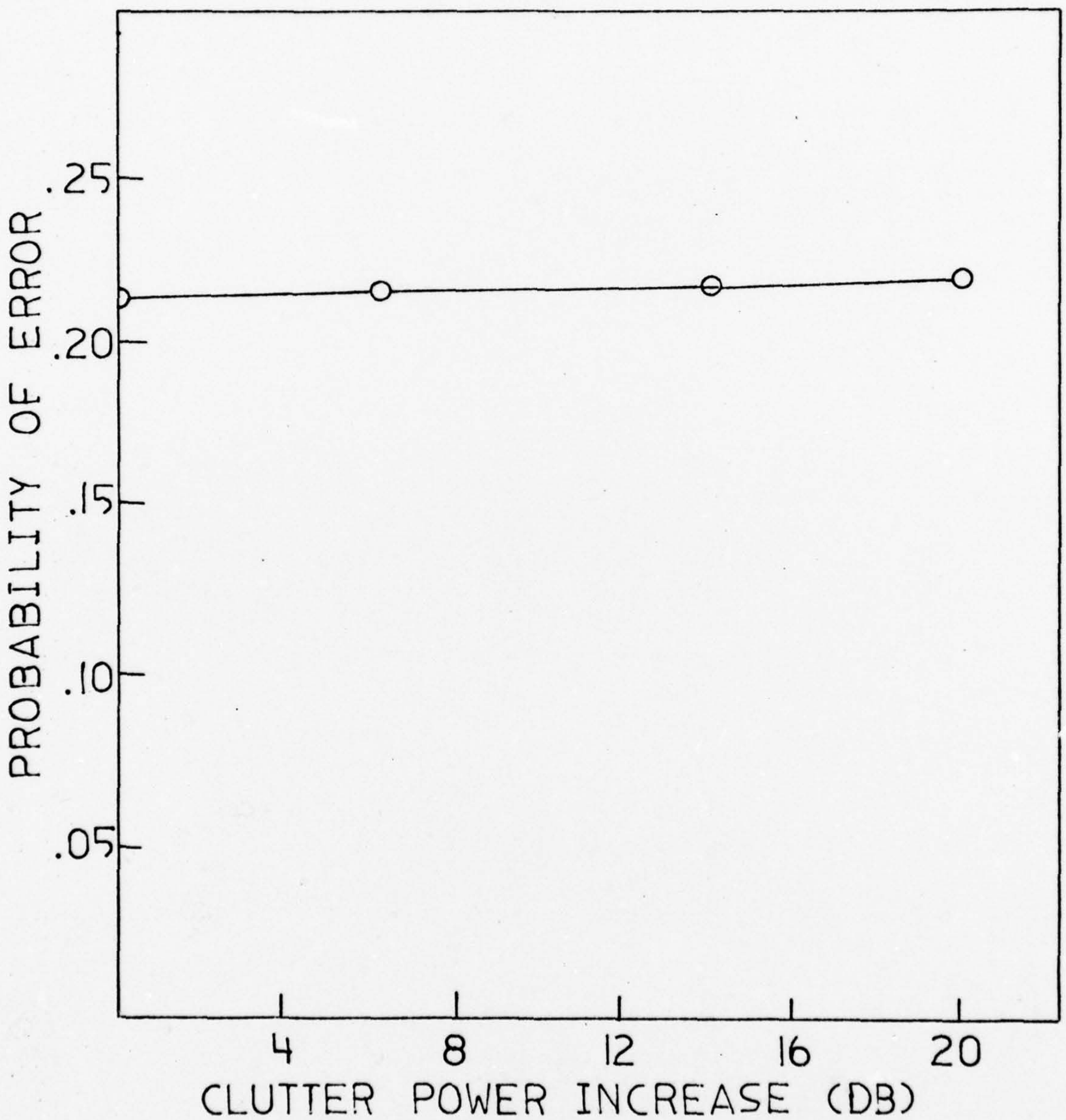


Fig 11. Probability of Error Vs. Clutter Power Increase

For Experiment G (f_c = 270 Hz)

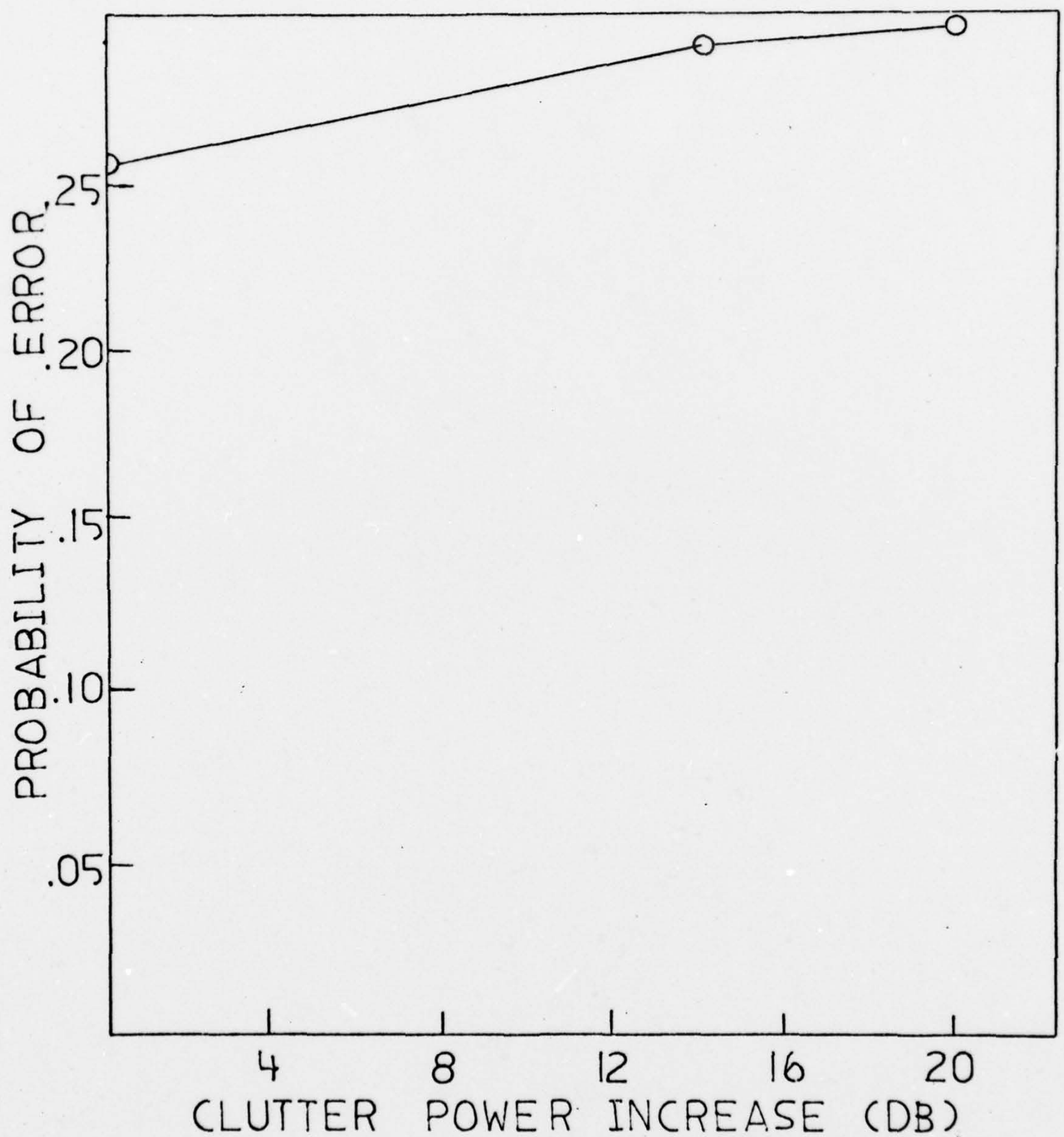


Fig 12. Probability of Error Vs. Clutter Power Increase For Experiment H (f_c = 28 Hz)

clutter power (Fig 12). The largest increase took place at 56 Hz, where the probability of error increased from .257 at 0 dB to .296 at 20 dB. The probability of error for 7 looks at 20 dB reduces to .206 as compared to .126 under conditions of no clutter spread or power increase.

V Conclusion and Recommendations

This chapter presents a summary of the work performed, the conclusions drawn, and the recommendations for further research.

Summary

A proposed classification scheme has been studied for its possible application to an air-to-ground environment. In order to do this it was necessary to study the clutter characteristics associated with air-to-ground radar targeting. The aspects of clutter studied were clutter spectral spreading and variations in radar cross section of the clutter. These aspects were then applied to the data set used in building the original classifier. The effects on classification were studied and recorded. The data set and classification algorithms used by Stewart (Ref 22) were used so that the reader could use this tudy as a logical extension of Stewart's work.

Conclusions

The spectral spreading of clutter due to platform motion and the increase of clutter radar cross section effect the classifier similarly. With the spectral spread of clutter, the rejection rate of target samples first increases sharply. After reaching a maximum, the rejection rate then decreases with increasing clutter spread frequency. Finally, the rejection rate levels off at some frequency beyond the average target skin line frequency.

With an increase in clutter radar cross section, the rejection rate increase. The effect is more noticeable at the lower frequencies. At frequencies beyond the target skin line frequency, an increase in clutter power does not increase rejections. In the higher frequencies, the number of rejections sometimes decrease because the weaker signals have enough power in them to overcome the minimum skin line voltage criterion.

As stated earlier, it is important to view the effects of clutter as a worst case problem. In Table III are listed the results of the experiments listing only the worst case information. Also provided are the results for a classifier with no increase in clutter spread or clutter power. A comparison between these results might prove useful.

A conclusion will not be made as to whether or not this classifier could not be used for a specific air-to-ground situation. Clearly there are situations where the costs of an error are so high that only very small probabilities of error are acceptable. Likewise, there may be situations where there is relatively little cost associated with making an error. For these situations a probability of error such as shown for this classifier would be more than sufficient.

It would appear from the results that the classifier bears some consideration for the air-to-ground target classification problem. Since the given classifier is not optimal, there is some room for improvement both by better feature selection and improved classification methods. The results shown in this study seem to justify the research effort.

Recommendations

Since this study used data that was generated by a fixed antenna, it is recommended that actual air-to-ground data be taken. That type of data would be necessary to prove or disprove the validity of this

Table III. A Comparison of Worst Case Probabilities of Error for the Points Tested Vs. Probabilities of Error Under Conditions of No Clutter Spread or Increase in Clutter Power

Exp.	No. Classes	Classifier	Clutter Freq.	Clutter Power	Prob. of Error 1 look	Prob. of Error 7 looks
A	2	SDA	200 Hz	0 Db	.089	.040
			14	0	.061	.026
B	2	NN	28	0	.122	.048
			14	0	.097	.029
C	3	SDA	140	0	.255	.215
			14	0	.219	.150
D	3	NN	168	0	.279	.178
			14	0	.208	.126
E	2	SDA	270	20	.075	.028
			14	0	.061	.026
F	2	NN	56	20	.158	.071
			14	0	.097	.029
G	3	SDA	270	20	.219	.163
			14	0	.219	.150
H	3	NN	56	20	.296	.206
			14	0	.208	.126

approach for the air to ground problem. The data should be taken while keeping in mind the scenario in which the classifier will be used. In that way the data will be more representative of the entire set of possibilities. This might require that vehicles be tested while moving at constant speeds in a forward direction. Since it might be more practicle to fly along main roads when searching for vehicles, it may be beneficial to concentrate on aspect angles within 30 degrees of 0 and 180 degrees. Also, noting the number of errors that occurred at 0 and 180 degrees, it might prove more reliable to fly at slight offsets from the roads instead of directly over them.

Unitl a new data set is generated, studies could be conducted that developed features and classification procedures that worked better under clutter conditions. Such things as combining features of the time domain or cepstral domain with features of the frequency domain have not been exploited.

Bibliography

1. Blomfeld, D. L. H. A Land Clutter Model Which Includes the Effects of Dominant Scatterers. TR-74-11, Admiralty Surface Weapons Establishment, Portsmoth Hants, England, 1974. (AD 923 595).

2. -----. Clutter Statistics from a Frequency Agile Radar. TR-74-24, Admiralty Surface Weapons Establishment, Portsmoth Hants, England, October 1974. (AD B003 579L).

3. Boothe, Robert R. The Weibull Distribution Applied to the Ground Clutter Backscatter Coefficient. Report No. RE-TR-69-15, Research and Engineering Directorate, U. S. Army Missile Command, Redstone Arsenal, AL, June 1969. (AD 691 109).

4. Brindley, A. E. Distributed and Discrete Clutter Map Generating Routines. Technical Memorandum No. 6, Overland Radar Technology Program, Contract F33615-69-C-1387, IIT Research Institute, Chicago, IL, March 1970. (AD 868 362).

5. Brown, Harold K. Department of Defense Annual Report Fiscal Year 1979.

6. Chen, C. H. Preprocessing and Feature Extraction For Automatic Recognition of Radar Images. AFOSR-TR-74-1415, Air Force Office of Scientific Research, Arlington, VA, July 1974. (AD 785 427).

7. Currie, N. C., F. B. Dyer, and R. D. Hayes. Radar Land Clutter Measurements at Frequencies of 9.5, 16, 35, and 95 GHz. EES/GIT Project A-1485, Technical Report No. 3, Engineering Experiment Station, Georgia Institute of Technology, Atlanta, GA, 2 April 1975. (AD A012 709).

8. Dixon, W. J., ed. BMD Biomedical Computer Programs. University of California Press, Berkeley, CA, 1970.

9. Fishbein, Wm., S. W. Graveline, and O. E. Rittenbach, Clutter Attenuation Analysis. ECOM Technical Report ECOM-2808, March 1967.

10. Fix, Evelyn and J. L. Hodges. Discriminatory Analysis: Nonparametric Discrimination. Project 21-49-004, Report 4, USAF School of Aviation Medicine, Randolph AFB, TX, February 1951.

11. Mahapatra, P. R. and S. Ramakrishna. "Compact AM Signals for Maximum Clutter Rejection," IEEE Transactions on Aerospace and Electronics Systems. 414-418. July 1977.

12. Nathanson, F. E. Radar Design Principles. McGraw-Hill, 1969.

13. Patriarche, M. V. A Computer Simulation for Scan-modulated Radar Clutter and Its Application to Study of a Pulse Compression/MTI System. CRC Report No. 1238, Communications Research Centre, Department of Communications, Ottawa, Canada, Arpil 1973. (AD 912 030).

14. Pollon, G. E. Topics in Radar Clutter Modelling. Course Lecture Notes, Technology Service Corporation, Santa Monica, CA, March 1973.

15. Povejsil, Donald J., Robert S. Raven, Peter Waterman. Airborne Radar. Edited by Captain Grayson Merrill USN (Ret), D. Von Nostrand Co. Inc., Princeton, NJ, 1961.

16. Ringel, Melvin B. "An Advanced Computer Calculation of Ground Clutter in an Airborne Pulse Doppler Radar," Proceedings of the National Aerospace and Electronics Conference. 921-928. IEEE, Dayton, OH, May 1977.

17. Rosenbaum, E. and E. G. Klimchak. Target (Tank) Recognizer. Final Report, Bendix Communications Division, Bendix Corporation, Towson, MD, August 1974. (AD 922 333).

18. Schleher, D. C. "Radar Detection in Weibull Clutter, "IEEE Transactions on Aerospace and Electronics Systems. AES-12, No. 6:736-743, November 1976.

19. Shirazi, Mehdi. Automatic Classification and Identification of Tactical Ground Targets. Radar Branch, Air Force Avionics Laboratory, Wright-Patterson AFB, OH, 1978.

20. Simpkins, William L., Vincent C. Vannicola, James P. Ryan, Seek Igloo Radar Clutter Study. RADC-TR-77-338, Rome Air Development Center, Griffiss AFB, NY, October 1977. (AD A047 897).

21. Skolnik, M. Radar Handbook. McGraw-Hill, 1970.

22. Stewart, Clayton V. Identification of Periodically Amplitude Modulated Targets. Ph D Disseration, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1978.

23. Sweeney, L. E. Jr., A. J. Bahr, and V. R. Frank. Analysis of Radar Detection of Agitated Metals (RADAM). Contract F44620-75-C-0046, Stanford Research Institute, Menlo Park, CA, May 1976.

24. Technical Abstracts of the Non-cooperative Target Recognition Workshop. Surveillance Technology Branch, Rome Air Development Center, Griffiss AFB, NY, 2 October 1978.

25. Warden, M. P., et al. A Review of Clutter, 1974. Technical Note No. 783, Royal Radar Establishment, London, England, September 1974. (AD A014 421).

Appendix A: Variables in the Data Base

The data base was created by varying three conditions for each of the three vehicles. These variables were acceleration, direction and aspect angle. The vehicles were either moving at a constant velocity or accelerating for the entire run through the range gates. The direction of the vehicle was either forward or reverse moving along a straight path. The aspect angle was determined by the vehicles path in relation to the radar antenna. The following chart is provided to show the manner in which these conditions were varied during the tests.

Table IV. Number of Runs Under Various Conditions

	Accelerating								Constant				
	Forward				Reverse				Forward				
	Target 1	Target 2	Target 3	Total	Target 1	Target 2	Target 3	Total	Target 1	Target 2	Target 3	Total	Total
0			1	1		1	1	2	1	1	1	3	6
22.5									2	1	1	4	4
45	1		1	2	1		1	2		1	1	2	6
67.5									2	1	1*	4**	4**
90			2*	2*			1*	1*	1*	1*	1*	3*	6*
112.5									1	1	1	3	3
135	1	1		2	1			1	1	1	1	3	6
157.5		1		1		1		1	3**	1	1	5	7
180		1		1			1	1	1	1	1	3	5
202.5			1	1			1	1	1	1	1	3	5
225	1			1	1			1	2	1	1*	4	6
247.5			1	1			1	1	1	1	1*	3	5
270									1*	1*	1*	3*	3*
292.5									1	1	1*	3**	3**
315	1			1	1	1		2	2	1	1	4	7
TOTAL	4	3	6***	13***	4	4	6***	14***	23***	16***	16***	55***	82***

* None of these runs were used in the algorithm because the skin line velocity was less than two mph.

** One of these runs was not used for the above reason.

*** This total contains runs that were not used for the above reason.

Appendix B: Conditional Probability of Error Estimates

This analysis is provided so that some insight might be gained into where most errors in classification occur. The analysis is not intended to provide accurate figures averaged over the entire range of possibilites. It is only intended to show estimates of what those probabilities of error might be. For this purpose, the case where the clutter is spread to 196 Hz with a 0dB increase in clutter power was chosen. The reason for this choice was simply because this choice provided more decisions than any other variation in clutter spread or clutter power. For this combination, 1402 decisions were made out of a possible 1442 samples. Therefore, there was a probability of .029 of not making a decision.

The three class problem was chosen because it was believed that it would be more desirable to build a classifier for three classes than for two classes. Some a priori knowledge of situations that might lead to errors could improve the performance of the classifier through selective data gathering techniques. The probabilities of error provided were obtained through SDA.

The probabilities of error are conditioned on aspect angle, vehicle direction, and vehicle acceleration. Aspect angle is measured from 0 degrees (vehicle oriented facing the antenna) to 337.5 degrees by increments of 22.5 degrees. Vehicle direction is either forward gear or reverse gear and the vehicle is either moving at a near constant velocity or it is accelerating.

Table V. Error Probability Estimates Conditioned on the Aspect Angle

Aspect Angle	Target 1 # of Errors	Target 1 # Poss.	Target 2 # of Errors	Target 2 # Poss.	Target 3 # of Errors	Target 3 # Poss.	$Pr(e\|\theta)$ 1 Look	$Pr(e\|\theta)$ 7 Looks
0	21	32	1	16	17	84	.31	.28
22.5	3	50	16	21	2	37	.29	.29
45	5	48	15	18	7	53	.36	.28
67.5	11	27	14	14		0	.47	.36
90		0		0		0		*
112.5	6	18	7	9	7	21	.48	.29
135	7	70	10	20	8	26	.30	.27
157.5	0	40	14	30	9	26	.27	.21
180	13	27	3	11	22	53	.39	.38
202.5	0	31	1	27	8	76	.05	.00
225	7	104	3	16		0	.08	.00
247.5	8	15	3	14	9	34	.34	.08
270		0		0		0		*
292.5	7	15	11	11		0	.49	.49
315	10	78	21	39	0	30	.22	.21
337.5	2	79	0	27	0	32	.01	.00

*Although the $Pr(e|\theta)$ is technically undefined, since no misclassifications were made, the $Pr(e|\theta)$ is assumed to be high at any small angular difference where a decision would be made. Note the relatively high $Pr(e|\theta)$ at angles that differ by 22.5 degrees.

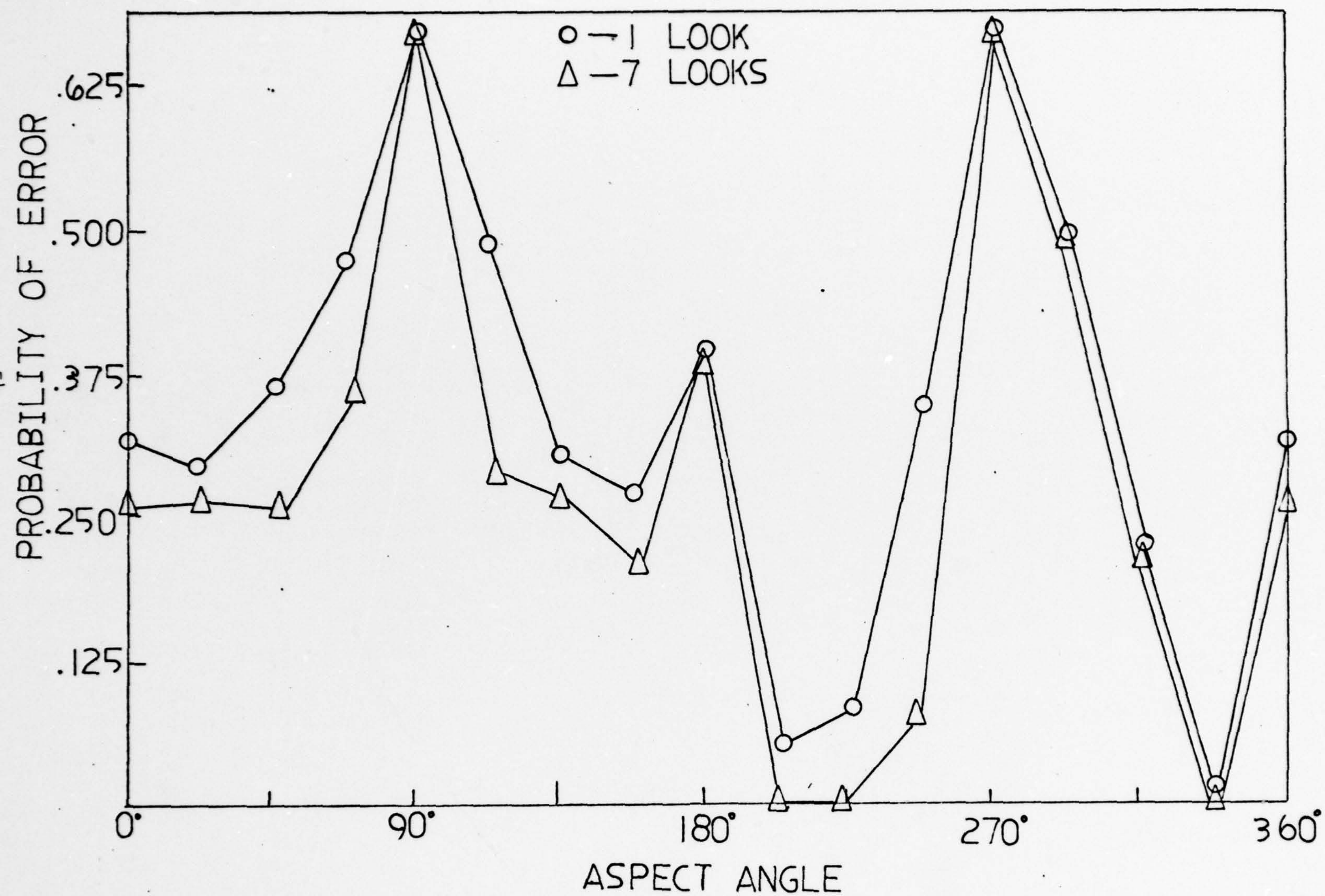


Fig 13. Probability of Error Estimates Conditioned on Aspect Angle

Table VI. Error Probability Estimates Conditioned on Vehicle Direction and Error Probability Estimates Conditioned on Acceleration

	Target 1		Target 2		Target 3			
Dir.	# of Errors	# Poss.	# of Errors	# Poss.	# of Errors	# Poss.	$Pr(e\|d)$ 1 Look	7 Looks
Fwd.	76	502	120	234	68	369	.28	.23
Rev.	24	132	1	62	21	103	.13	.01
							$Pr(e\|\Delta v)$	
Acc.	28	225	3	92	37	176	.12	.02
No Acc.	72	409	118	204	52	296	.31	.26

From the tables it would appear that the probability of error would be reduced by targeting only vehicles that are at aspect angles between 90 degrees and 270 degrees, accelerating, and moving in a reverse direction. This would be true given that these cases were independent. However, tests were not performed to measure independence. The 1 look probability of error estimate for the above conditions is .16 and the 7 look probability of error is estimate is .00. The opposite case conditioned on angles between 270 degrees and 90 degrees, constant velocities, and moving in the forward direction had probabilities of error of .27 and .21 respectively.

It is doubtful that, under field conditions, vehicles would be found accelerating or moving in a reverse direction any significant percentage of the time. It is evident, however, that probabilities of error could be reduced by targeting the vehicles from the rear. This would require, in the airborne case, flying along the same general routes and in the same direction as the suspected target vehicles.

Appendix C. Statistics of the Targets

The target samples were analyzed to determine the mean skin line frequencies, the signal-to-noise ratios, and the signal-to-clutter ratios. The mean skin line frequency was determined by finding the mean skin line frequency for each run within a target class. Each run was then given an equal weight and the mean skin line frequency for the target was determined. The signal-to-noise ratio is the total signal power for a sample divided by the total noise power in that sample. The runs were again given equal weights in determining the average target signal-to-noise ratio. The signal-to-clutter ratio was determined in the same manner by using the total clutter power in a sample.

Table VII. Statistics of the Targets

Target Number	Mean Skin Line Frequency	SNR	SCR
1	203 Hz	54 Db	144 Db
2	184 Hz	63 Db	147 Db
3	152 Hz	62 Db	144 Db

Important to note is that target 1 experienced a larger doppler shift than the other two targets. Due to the method used for the classification the amount of shift should not be a factor except when the shift causes the skin line frequency to fall outside the band between 14 Hz and 500 Hz. Target 1 also has a lower signal-to-noise ratio than the other targets. In target 1, the runs with the three lowest signal-to-noise ratios were all at an aspect angle of 315 degrees. However, the target 1 runs at this aspect angle were misclassified only 10 times out of 78 samples (see Appendix B). That probability of error is not high enough to imply that error performance was degraded by a low signal-to-noise ratio.

Appendix D. Features Used in the Study

For the reader's convenience Table VIII lists the features used in the study. An explanation of the symbols used is given here. For a complete mathematical definition and description see Reference 22:72-77.

Recall that the amplitude spectrum is divided into six frequency bands. The argument found in the name and definition of each of the 40 features designates which band was used for the calculation. The following is a list of the bands and an explanation of the symbols.

Band 1 - The clutter band

Band 2 - The lower side band of the skin line

Band 3 - The band containing the skin line

Band 4 - The upper side band of the skin line

Band 5 - The second harmonic of the skin line

Band 6 - The noise band

A(·) - The variance in a band

C(·) - The skewness of a band

E(·) - The energy in the band

F(·) - A particular feature number

M(·) - The mean of a band

Max(·,·) - The maximum value of the arguments

P(·) - The peak signal in the band

R(·) - The location of the peak signal in a band

T(·) - The total signal in a band

V(·) - The variation from the largest to the smallest signal in a band

W(·) - The width of a band

Table VIII. Features

Symbol	Name	Definition
F(1)	Peak 2	P(2)/P(3)
F(2)	Total 2	T(2)/P(3)
F(3)	Mean 2	F(2)/W(2)
F(4)	Peak energy 2	$[F(1)]^2$
F(5)	Total energy 2	$E(2)/[P(3)]^2$
F(6)	Mean energy 2	F(5)/W(2)
F(7)	Total variation 2	V(2)/P(3)
F(8)	Mean variation 2	F(7)/W(2)
F(9)	Peak 4	P(4)/P(3)
F(10)	Total 4	T(4)/P(3)
F(11)	Mean 4	F(10)/W(4)
F(12)	Peak energy 4	$[F(9)]^2$
F(13)	Total energy 4	$E(4)/[P(3)]^2$
F(14)	Mean energy 4	F(13)/W(4)
F(15)	Total variation 4	V(4)/P(3)
F(16)	Mean variation 4	F(15)/W(2)
F(17)	Peak 2,4	Max[F(1),F(7)]
F(18)	Total 2,4	F(2)+F(10)
F(19)	Mean 2,4	F(18)/[W(2)+W(4)]
F(20)	Peak energy 2,4	Max[F(4),F(12)]
F(21)	Total energy 2,4	F(5)+F(13)
F(22)	Mean energy 2,4	F(21)/[W(2)+W(4)]
F(23)	Total variation 2,4	F(7)+F(15)
F(24)	Mean variation 2,4	F(23)/[W(2)+W(4)]
F(25)	Peak 5	P(5)/P(3)
F(26)	Peak energy 5	$[F(25)]^2$
F(27)	Peak 2,4,5	Max[F(17),F(25)]
F(28)	Total 2,4,5	F(18)+T(5)/P(3)
F(29)	Mean 2,4,5	F(28)/[W(2)+W(4)+W(5)]
F(30)	Peak energy 2,4,5	Max[F(20),F(26)]
F(31)	Total energy 2,4,5	$F(21)+E(5)/[P(3)]^2$
F(32)	Mean energy 2,4,5	F(32)/[W(2)+W(4)+W(5)]
F(33)	Total variation 2,4,5	F(23)+V(5)/P(3)
F(34)	Mean variation 2,4,5	F(33)/[W(2)+W(4)+W(5)]
F(35)	Mean difference 2,3,4	$\|M(2,3,4)-R(3)\|/R(3)$
F(36)	Standard deviation 2,3,4	$[A(2,3,4)]^{1/2}/R(3)$
F(37)	Skewness 2,3,4	$[C(2,3,4)]^{1/3}/R(3)$
F(38)	Mean difference 2,4	$\|M(2,4)-R(3)\|/R(3)$
F(39)	Standard deviation 2,4	$[A(2,4)]^{1/2}/R(3)$
F(40)	Skewness 2,4	$[C(,24)]^{1/3}/R(3)$

Note: Reference 22:77

VITA

Joseph Martin Renaud was born on October 5, 1948 in St. Louis, Missouri. He graduated from high school in 1966 and entered the United States Air Force Academy. Upon graduation in 1970, he attended undergraduate pilot training at Columbus Air Force Base, Mississippi. His initial assignment was to Pope Air Force Base, North Carolina where he flew tactical airlift C-130 aircraft. In 1973, he was assigned to a special operations C-130 squadron which later moved to Hurlburt Field, Florida. During these time periods he had numerous extended temporary duty assignments in both Alaska and South America. In June 1976, he entered the School of Engineering, Air Force Institute of Technology. He is currently completing the requirements for an MSEE degree.

Permanent Address: 1942 Brassie Drive
St. Louis, Missouri
63114

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER GE/EE/78-37	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Radar Clutter Effects in a Target Classifier		5. TYPE OF REPORT & PERIOD COVERED MS Thesis
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Joseph M. Renaud Captain USAF		8. CONTRACT OR GRANT NUMBER(s) 62204F
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Institute of Technology (AFIT/EN) Wright-Patterson AFB, Ohio 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 7622-01-31
11. CONTROLLING OFFICE NAME AND ADDRESS Radar Branch (AFAL/RWM) Air Force Avionics Laboratory Wright-Patterson AFB, Ohio 45433		12. REPORT DATE Dec 1978
		13. NUMBER OF PAGES 68
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLAS
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Approved for public release; IAW AFR 190-17

Joseph P. Hipps, Major, USAF
Director of Information 1-23-79

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Clutter, Radar Clutter, Radar Classification, Target Recognition

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A previously proposed algorithm for the classification of periodically amplitude modulated targets is studied for its possible use in an air-to-ground radar situation. The assumptions necessary for the use of the algorithm are discussed and the limitations and scope of the problem are presented. Classification probabilities of error are presented based on worst case analysis of clutter conditions in the received radar signal. Analysis is provided for a two class problem and a three class problem using both nearest neighbor rules and stepwise discriminant analysis for classification. The clutter in these problems is

Over Page

(20) studied under conditions of spectral spreading and increased clutter signal power. The effect on probability of error is found to be small enough that there are definite possibilities for the use of this algorithm in some air-to-ground applications.