AR-004-955

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

WEAPONS SYSTEMS RESEARCH LABORATORY

TECHNICAL REPORT

WSRL-0515-TR

AN IDENTIFICATION THRESHOLD FOR SHIP SILHOUETTES

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S U M M A R Y

Fourier descriptors are used to characterise the binary grey level silhouette images of ship targets. A grey level threshold technique is developed to determine the contour of the ship and comparisons are made between test shapes and library shapes using Euclidean distance as the match criterion. Binary grey level spot image comparisons are found to generate a suitable identification threshold which is successfully adapted to provide a ship silhouette identification threshold.

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1. INTRODUCTION

The design of a terminal phase autonomous guidance package for a weapon system using a TV sensor in the visual part of the electromagnetic spectrum depends upon solving the problems of detection, tracking and identification of targets in real time. Detection and tracking are not addressed in this paper: it is assumed that the target is present in the field of view of the sensor. The technique of identification adopted uses Fourier descriptors, which have been well documented in references 1 to 6. Other techniques that could have been used are Moment Invariants and template matching. Using any method of autonomous identification, problems arise in specifying the threshold at which identification can be said to have occurred and the confidence associated with that threshold.

Johnson's criterion(ref.7) is often quoted when specifying the size of target that can be identified: it has been interpreted to state that a human operator requires an average of 12.8 TV lines over the target to identify it with 50% probability of being correct. There is no comparable value for autonomous identification but a computer can be programmed to store a limited number of images and process them in real time to provide an equivalent autonomous identification. If the target which appears in the field of view is compared with images stored in a computer, one will give the best match with the target, regardless of what the test target is (eg in the case of targets at sea the test target may be an island). The computer can only make comparisons between shapes in its memory and the shape being tested: it does not know that an island is not a ship. However, a value can be obtained for the degree of match and, after many comparisons have been made, a particular degree of match can be chosen which will give a threshold for an identification criterion.

The aim of the work described in the paper was to determine a realistic figure for an identification threshold of a ship target presented as a binary grey level image from the broadside aspect, using techniques which minimised the computational load to allow real time computation between frames of a TV sequence.

2. DIGITISING SYSTEM

A block diagram of the digitising system is presented in figure 1. It consists of an RCA Model TC 1005 monochrome TV camera fitted with a Canon 50 mm lens. An A to D converter and digital store perform the digitisation of the camera output and allow the data to be stored on magnetic tape - the transfer being controlled by the NOVA 1200 computer. The IBM 3033 computer and LEXIDATA 3400 image processor are used to process and display the image.

The specified resolution of the camera is 800 lines per picture height: the camera operates on the standard 625 lines horizontal scan and 50 Hz frequency. Vertical resolution is limited by the number of scan lines used to transmit the image data and brightness distribution of the spot used to scan across the screen. The vertical resolution is calculated to be $625/\sqrt{2} \approx 420$ lines/picture height. The $\sqrt{2}$ factor is obtained assuming a spot illumination of Gaussian distribution(ref.7). The dynamic response of the camera is specified as 200 lines per picture height for 80% grey level change. The "black" silhouettes on the "white" background have a grey level change which approximates to 80% of the grey level range. The number of scan line elements or pixels over which the transition from white to black takes place is greater than 3 and the aspect ratio of these pixels is 4:3.

The digital store has a 512 x 512 pixel memory, each pixel resolved to 6 bits giving 64 grey levels.

3. IDENTIFICATION TECHNIQUE

3.1 Fourier descriptors

The technique of Fourier descriptors depends upon attaining a realistic external contour to characterise the target shape. The co-ordinates X(m) of the closed contour are used as complex input values in a discrete Fourier Transform to generate a Fourier descriptor. A descriptor is computed for each one of several library shapes and a selected number of coefficients is stored for each shape. The coefficients are defined by:

$$C(k) = \frac{1}{N} \sum_{m=0}^{N-1} X(m) W^{km} \qquad k = 0, 1, 2 \ldots N - 1$$

where $W = \exp(-2\Pi i/N)$ and N is the number of samples. The number of coefficients stored is minimised to reduce the storage and computational load, yet is sufficient to give consistent results. The number of samples is a radix 2 value and, in the case when the number of shape contour points is lower than the radix 2 value, the next lower radix 2 value is used.

By normalising the Fourier descriptors (C'(k)) they are made invariant to translation, dilation, rotation and starting point as described in reference 6. This facilitates comparison amongst object shapes extracted from differing source imagery.

3.2 Contour extraction

The method adopted for the extraction of the shape contour has a direct effect on the contour obtained. The simplest technique is the use of a grey level threshold to reduce the component features of the imagery to binary form, ie object and surrounds. This is suitable for high contrast imagery, but does demand a high dynamic response from the video system if the edge transitions are to be extracted with sufficient accuracy to follow the true object shape. If the dynamic response is low then the contour obtained by application of a threshold technique varies with the level of threshold chosen. This effect is illustrated in the sketch in figure 2. In an attempt to avoid problems associated with the use of threshold, other boundary detection techniques were investigated. The Sobel operator was used as the best example of various edge detection techniques based on the first order differential(ref.8). The Laplacian operator was used as an example of a second order differential. Both of these methods have been widely used for edge detection in images. Results of both techniques together with an equivalent example using threshold are illustrated in figure 3. The magnitude of the Sobel and Laplacian operators have been equated to the grey level at the location of the operator centre and it is clearly demonstrated that not only is there a threshold problem to be resolved but the area over which the boundary can be said to extend is considerably increased. It is thus concluded that neither of the differential operators provides a boundary selection technique which is superior to the grey level threshold technique for this application.

The application of a fixed threshold has the following disadvantages:

(a) The contour varies with the threshold value chosen.

(b) The contour varies with the background-target grey level contrast.

The first item has already been illustrated in figure 2. The choice of a threshold value which locates the boundary at the inflection point of the decay or rise curve gives correct relative position of the two boundary points but incorrect absolute position. This choice is equivalent to taking a grey level midway between the peaks of the grey level histogram. If the dynamic response is d pixels then the displacement of a point on the boundary is as much as d/2 pixels. This horizontal translation would not be important if only horizontal changes were involved. However, the same threshold technique applied in the vertical direction is necessary to provide a continuous contour. The vertical dynamic response is mainly dependent on leakage at the vidicon. Vertical response appears to be greater than the horizontal response and therefore translation in the vertical plane is less than that in the horizontal. The result of these two translations is a distortion of the target contour relative to the original target.

By choosing a threshold close to the background level it is ensured that thin structures are included in the boundary contour. For a black target on a white background the white to black boundary occurs close to the background grey level: the same result occurs for black to white transition. This is demonstrated in figure 2. The shape can be extended horizontally by d pixels, which amounts to about 10% (taking d = 3 pixels) at the target range giving identification using Johnson's criterion. However, apart from this error the threshold criterion works well provided that the background grey level is constant. If the background grey level is variable then not only is considerable noise introduced into the background but the contour is likely to be distorted due to noise. Since it has been found difficult to maintain the background at a constant grey level for each scene and for all scenes, (and in the case of a real target the background grey level is likely to vary considerably) and since it is likely that thin structures will be present in the scene, it has been found preferable to set a threshold value at a fixed level below an average background level. The average is determined from 4 x 4 squares located at the upper corners of the image window. This background will normally represent the sky in a blue water situation and the sky, being lighter than the ship, gives a good contrast in most situations.

This solution of selecting a grey level threshold at a fixed value below an average background level is not without difficulties. It is now not known in advance at which absolute threshold level any one image will be analysed and therefore the thresholds for the library and test shapes are likely to be different, even for the same contour. The variation of the matching value, EDS, (see Section 3.3), with threshold is shown in figure 4 for a full size shape, ie test shape size is equal to the library shape size. In this instance the threshold of the library shape and threshold at which there is perfect match (EDS = 0) occurs at the same threshold value: in general the best match occurs at a value of threshold which is close to that of the library shape. It is thus concluded that a search through several threshold levels in the vicinity of the library shape threshold level is required. A series of plots is shown in figures 5 to 9. These demonstrate the application of the technique and the conclusions from the results are:

(a) For best results the threshold of the library shapes should be close to the background grey level but not so close that the contour becomes confused with noise.

(b) A minimum value of match (EDS) occurs close to the library shape threshold for equal library and test shape sizes and equal lighting conditions.

(c) As the test shape becomes smaller the minimum EDS value occurs at a threshold level that approaches the background level.

(d) Minimum value of the match becomes less distinguishable with decrease in size of test shape.

(e) Individual curves become intermingled as the shape size decreases.

As a result of these findings the best solution which has been found for the 6 bit grey level scale is to set the threshold used to obtain library shapes to 10 grey levels below the measured background average grey level and to select as the best match the minimum value of match criterion between limits of threshold from 3 below to 12 below the measured background average level for each test shape. This technique has been observed to have two desirable characteristics:

(1) Preserves much of the target shape.

(2) Provides good sensitivity to shape changes.

3.3 Shape similarity criteria

Euclidean distance (ED) is a common measure of the similarity between shapes. It is defined as:

$$ED = \left\{ \sum_{k=-N/2+1}^{N/2} [Re(C'_l(k)) - Re(C'_m(k))]^2 + [Im(C'_l(k)) - Im(C'_m(k))]^2 \right\}^{\frac{1}{2}}$$

where C'(k) is a normalised complex coefficient of a Fourier descriptor, ℓ and m refer to library shape and test shape respectively and frequencies are taken between -N/2 + 1 and N/2 where N is the number of coefficients for each shape. Real and imaginary parts of the coefficients C'(k) are denoted by Re and Im respectively. The ED measure therefore includes both amplitude and phase effects which may or may not be an advantage. A slightly modified ED value is used in this paper; the square root operation is not effected. This measure is designated EDS. Matching problems(ref.8) have been found when using pentomino shapes due to orientation ambiguities but such problems are unlikely to arise when military targets are used.

A simpler measure which can be used for comparing shapes subsequent to normalisation of the Fourier descriptor is derived from the sum of the squared amplitude difference between two Fourier descriptors (SDS). This measure is independent of rotation and contour starting point which are both dependent upon phase. The sum of the differences squared is defined by:

$$SDS = \sum_{k=-N/2+1}^{N/2} [A'_l(k) - A'_m(k)]^2$$

where $A'_l(k)$ and $A'_m(k)$ are the normalised amplitudes of the coefficients $C'_l(k)$ and $C'_m(k)$ for the shapes l and m respectively.

A match measure often used for matching sequential images in tracking makes use of the correlation coefficient. As for SDS it only uses the amplitudes. The comparative ordering obtained with the correlation coefficient is similar to that from SDS, but the inclusion of mean value and variance terms, combined in the computational form, can lead to apparently smoother results. Further, the correlation coefficient is generally more sensitive to departures from the mis-match condition than from the true match condition. Correlation coefficient (CC) is given by:

$$CC = \frac{1}{N\sigma_1\sigma_m} \sum_{k=-N/2+1}^{N/2} \left[\left(A'_1(k) - \sum \frac{A_1(k)}{N} \right) \left(A'_m(k) - \sum \frac{A_m(k)}{N} \right) \right]$$

where σ_1 and σ_m are the standard deviations relating to shapes 1 and m respectively and the sums within the brackets are taken between the limits -N/2 + 1 and N/2.

In the above, suffix ℓ can be taken as referring to the library shape, whilst suffix m identifies the test shape. In theory, given ideal conditions and perfect match, both EDS and SDS should return a value of zero, and CC should return a value of unity. In practice, the theoretical values will not be attained, due to errors introduced by noise in the imagery and by processing (see Section 3.4). The pairwise comparison of different digitisations of the same object will rarely yield the theoretical value, nor even consistent values over repeated tests. Thus, the best value emergent from comparison with a number of library shapes does not necessarily guarantee correct identification even when it is known that a replica of the test shape is present among those in the library.

The object of the experimentation is to produce an acceptance limit, termed the identification threshold, within which positive identification will be assured. The threshold must allow some latitude for noise and processing errors when the true match condition exists, yet not be so lax as to allow acceptance when the test shape is not replicated in any of the library shapes. Should all comparisons fail the threshold, then the outcome is undetermined, ie the test shape cannot be positively identified. In order to encompass a variety of error sources, the number of test samples should be large, yet not so large that the computational load becomes onerous.

4. EXPERIMENTAL ERRORS

4.1 Errors

The situation for target identification which is being addressed is one where the sensor approaches the target, resulting in a target image which slowly increases in size. At detection, on a clear day, which corresponds to the smallest size of target which is considered, there is considerable distortion of the image. Using Johnson's criterion of 2 TV lines over the target for detection, a circular target is represented by a set of pixels in the shape of a square or a cross, neither of which closely match the true target shape. If the centre of the circular target is not aligned with the pixel grid, nonsymmetries are introduced. As the target increases in size the match between the true target image and the pixel

representation of that image improves, ie the signal to noise ratio increases. Some of the sources of errors for each image in the laboratory are:

(a) Poor and variable contrast.

(b) Illumination variation.

(c) Target displacement and orientation with respect to pixel grid.

(d) Dynamic response of camera.

(e) Digitising system dynamic noise.

(f) Optical adjustment.

(g) Image processing techniques.

(h) Camera adjustment.

(i) Position of the target on the vidicon.

(j) Direction of grey level transition.

(k) Platform or target movement.

For a black silhouette on a white background with controlled lighting conditions, errors are generated by items (c) to (k). Thus identical test shapes stored and compared during repeated experiments and under laboratory conditions will still differ due to errors.

All the individual errors from the various sources cannot be easily measured separately. However, the effect of the overall system errors can be determined by using a basic characteristic of Fourier descriptors - for a perfect circle only one coefficient has an amplitude other than zero. For a centre ordered set of coefficients(ref.6), this amplitude occurs at C'(k) where k = 1. All the phases are zero. Thus values of amplitude or phase greater than zero denote variations which have been introduced by errors in the system.

A representation of a circular spot by square pixels is shown in figure 10. As the diameter of the spot increases the basic shape progresses from a rectangle, through a cross to a circular shape with a contour ripple. This ripple generates errors of increasing frequency as the spot diameter increases. For the largest spot which has a vertical diameter of 11 pixels and a horizontal diameter of 10 the lowest error frequency occurs at k = -1 due to its elliptical shape. Other error frequencies occur at k = -3 and k = -6. The shape arising from individual amplitudes has been specified in reference 6. The effect of misalignment between the pixels and the spot is to introduce coefficients of a frequency which is dependent on the relative size of the shape and pixel.

The method of application of the spot technique for the determination of system errors is described in reference 9.

4.2 Dynamic response of camera

The dynamic response of the digitising system may be determined from the digital output of a black shape on a white background. The response of the camera may be measured by means of a CRO. Measurements were made using these two techniques and the results were described in reference 9.

Improvements in the response of the system have been made and measurement of the current response shows that it now takes about 5 pixels to transit from white to black compared with 9 pixels from previous tests. Most of this delay is due to the camera.

The effect of the dynamic response is large on shapes or parts of shapes which only extend for a few pixels. If it takes d pixels to change from black to white then parts of a contour of a length less than about d/2 will be reproduced at a lower intensity. This effect is particularly damaging for some targets, eg ships where the superstructure, mast and guns may be partially or completely eliminated when thresholded. Furthermore, since the aspect ratio of some targets may be dependent on a slender structure then this basic characteristic of identification may be in error.

4.3 Vidicon nonlinearity

Variation in match due to distortion at the outer extremities of the vidicon are demonstrated by the results of the non-central spots in Table 1. Repeated images of the same shape size give a match criterion minimum value very close to zero, but if the shapes which occur on the boundary of the vidicon are compared with those occurring near the centre, the match value is far from the minimum. Consequently, the library shapes and the test shapes should be located near the centre of the field of view for best match results.

5. DETERMINATION OF IDENTIFICATION CRITERION THRESHOLD

The conditions which were imposed on the spot match comparisons were:

(a) About 20 spots were compared.

(b) Spots were selected from the centre of the vidicon.

(c) The same spots in different images were chosen where possible.

(d) Distance from the camera was increased to produce spots of smaller size.

(e) A threshold grey level of 30 was chosen to extract the boundary.

(f) The value of match criterion for the worst match of each selected batch of spot sizes was taken.

(g) The 95% confidence limit of the worst match for each batch was determined for each match criterion.

(h) The maximum number of coefficients was 32. When the number of shape contour points was less than 32 the nearest lower radix 2 number of coefficients was taken.

On the expectation that the principle error sources would be functionally dependent on spot size, or equivalently, the number of TV lines over test target (TVLT), the experimental process was accomplished as follows. The 'library' image comprised some 20 nominally identical spots dispersed over the image domain. The test shapes were obtained by imaging the library spots at varying distances to yield, for each chosen distance, a corresponding set of spot shapes, different in size to those in the library and produced by a separate, independent digitisation process.

For each test set, the match computations were performed over the test spots in comparison with all spots in the library set, ie up to 400 = 20 x 20 determinations for each of EDS, SDS and CC with respect to the measured TVLT of the test set. The worst match values obtained for each of the test spots were then averaged to yield a mean value, indicative of the average variation attributable to processing errors when the test and library shapes are nominally the same, but in poorest match agreement. In order to accept most of these worst matches, the identification threshold was relaxed to encompass two standard deviation intervals beyond the mean value. Assuming that the distributions for EDS, SDS and CC are approximately normal, the calculated thresholds for each then correspond to approximate 95% confidence limits on the worst match.

The procedure above was repeated for each of the test sets to yield thresholds at the corresponding TVLT.

The results for SDS, CC and EDS are summarised in Table 1 and plotted in figure 11 for SDS and EDS. The CC results were not plotted because they are similar to those using SDS as the match criterion. Given that observation, and the additional computational effort in arriving at CC values, it is considered that CC is least suited to the objective of positive identification.

The plots in figure 11 substantiate the expectation that identification threshold values for SDS and EDS are dependent on spot size, the smaller spots generally requiring more relaxed thresholds to ensure 95% acceptance of true match instances. When plotted to log-log ordinates, as in the figure, both SDS and EDS are substantially linear, as confirmed by regression line coefficients of 0.98 and 0.93 respectively. This is a valuable characteristic, for it simplifies the task of choosing the identification threshold value appropriate to the measured TVLT of an unknown test shape.

The line which coincides with Johnson's criterion of 12.8 TVLT intersects the SDS confidence limit at 6.5×10^{-3} and, coincidentally, the EDS plot at about the same value.

Allowing that SDS and EDS reflect error magnitudes, the identification threshold plots define envelopes for match acceptance, where values to the left are deemed a positive identification, whilst values to the right are subject to unacceptably large error. However, the spot experiments do not consider any other library or test shapes, and so give no indication of error magnitudes arising from real differences between disparate shapes, combined with the errors expected from nominally matching shapes. In higher ranges of TVLT the identification thresholds should be strongly discriminating with respect to disparate, non-matching shapes, since the thresholds allow little latitude for total error. In the lower ranges, where additional allowances for total error exist, the possibility of incorrect identification cannot be discounted, particularly when the errors due to real mis-match differences combine with fortuitously low processing errors. From a library of diverse shapes, several may emerge as satisfying the identification threshold, and there is no guarantee that the overall best is necessarily the correct match. However, the true-matching library shape, if it exists, should always be identified because the threshold is designed to catch 95% of the true-matches under the most adverse conditions.

6. IDENTIFICATION OF SHIP SILHOUETTES

Identification investigations were effected using the EDS match criterion and 10 library shapes of ships which were similar in shape. The EDS measure was chosen in preference to SDS because, although it is the more complex of the two, it is the more command and the results obtained with it may be compared with results obtained by other workers. The silhouettes chosen are depicted in figure 12. Each silhouette is a photographic copy from reference 10, produced using maximum contrast and matt finish. The silhouettes were individually presented, and centred in the display field for each range representation: increasing range was simulated by moving the silhouette away from the camera. Constant background illumination was maintained. Match performance is defined as the number of correct matches above the EDS match criterion stated as a percentage of the total number of test matches at each range of target.

For target sizes equal to the library shape size, match performance using the EDS match measure are found to be 100%, ie the best EDS match value from ten matches denotes the correct target for 10 out of 10 cases of comparison at each range. As the size of the target is decreased the match performance decreases as shown in figure 13. Little or no effect on the performance value is obtained as the number of coefficients is decreased to 8 (8 negative frequencies from a set of 16 centre ordered coefficients). This is demonstrated by the upper line in figure 13 but below this limit there is considerable reduction in the identification for any one size of target as depicted by the lower curve of figure 13. The match performance which corresponds to Johnson's criterion of 12.8 TV lines over target is 20% for the best match results. Alternatively, 50% identification value is obtained from 17 lines over target and requires 8 coefficients (8 negative frequencies from a set of 16 centre ordered coefficients). It is to be noted that match performance is obtained with regard to those targets within the library set only: for identification in the real world a far greater library set is required. But at sea, particularly in blue water, ships make up the majority of targets. Therefore, with a limited number of library shapes plus the match threshold value obtained from Section 5, a high degree of confidence can be put in obtaining identification of targets larger than 17 TV lines provided that at least 8 negative coefficients are used in the Fourier descriptor.

All of the results of correct and incorrect matches using 32 coefficients and EDS values per pixel of contour are plotted on the graph presented in figure 14. The EDS threshold line obtained by using the spot technique and dividing each EDS value by the contour length in pixels is also plotted. It is shown that the line provides an excellent threshold - only correct identification occurs to the left of the line. It is appropriate for the contours of shapes to be normalised by the contour length because the Euclidean distance measure depends on the sum of the differences of contour point coordinates and therefore the longer is the contour the higher is the value of Euclidean distance. If some degree of false identification can be tolerated, the threshold line can be moved further to the right. In its present location the threshold identification line is given by the relationship:

$$TVLT = 0.17\ eds^{-\frac{1}{2}}$$

where TVLT is the number of TV lines over target and eds is the Euclidean distance measure per contour length in pixels.

The distribution of the correct and incorrect match points plotted on figure 14 suggests other identification threshold criteria. These are:

(a) Choice of fixed value eds = 1×10^{-4} for 100% identification (all the points left of the eds = 1×10^{-4} line are correct matches).

(b) Choice of fixed value eds = 10×10^{-4} for 50% identification (50% of the points left of the eds = 10×10^{-4} line are correct matches).

The ranges associated with the number of TV lines over the target for a 20 m high target are given in the graph of figure 15. The lines have been plotted using the equation:

$$R = 1.3 \frac{F}{TVLT}$$

which has been obtained from basic optics and assuming that there are 625 lines on a 9.6 mm detector and where R is the range in kilometres and F is the focal length of the lens in millimetres. The 100% identification line has been replotted from figure 13 - the enormous benefit accruing from the inclusion of a lens with a long focal length is clearly demonstrated; eg for a 200 mm lens, ship targets can be identified at about 15 km range for 17 lines over target and 50% probability of identification. However, high probability of identification does not result until the target range has decreased to about 6.5 km.

7. CONCLUSIONS

It has been demonstrated that the technique of Fourier descriptors provides a means for the comparison of shapes in the form of ships. An identification threshold value based on Euclidean distance has been derived from a series of tests carried out on binary contrast spots. This identification threshold holds for ship contours provided each EDS value is normalised by the contour length. The relationship between the number of TV lines over target, TVLT, and the match criterion of squared Euclidean distance per unit pixel length, eds, has been shown to be:

$$TVLT = 0.17 \, eds^{-\frac{1}{2}}$$

Although the identification threshold criterion has been investigated using 32 coefficients for circular black spots on a white background, it has been shown that similar results would have been obtained using the negative frequencies of 16 coefficients which have been centre ordered.

Other identification threshold criteria have been suggested by the results. These are:

(a) Fixed value of normalised Euclidean distance for a particular value of percentage identification.

(b) Minimum normalised Euclidean distance value for target height greater than 20 TV lines.

The characterisation of a shape has been shown to be highly dependent on the technique used for the determination of the boundary contour. A suitable technique for the binary grey level images has been developed using a fixed value of grey level threshold for the library shape and a spread of threshold levels for the test shape in the vicinity of the library shape grey level threshold. The minimum value of Euclidean distance was selected as the best identification threshold value.

The silhouettes of ships which were chosen were those of destroyers or ships of a similar silhouette. The autonomous technique developed in this paper is not as good as a trained human operator following from Johnson's criterion. Using a 200 mm lens under ideal conditions of contrast, 50% identification is predicted to occur when the target range has fallen to 15 km, whereas a human operator could be expected to identify the target at about 20 km.

NOTATION

A'	amplitude of normalised coefficient
C	complex coefficient
C'	normalised C
CC	correlation coefficient
ED	Euclidean distance
EDS	Euclidean distance squared
F	Focal length
Im	imaginary part
N	number of samples
R	range from sensor to target
Re	real part
SDS	sum of the amplitude difference squared
W	$\exp\ (^{2\pi i}/N)$
X	complex coordinate values of a closed contour
d	dynamic response - number of pixels to change from black to white
ed	ED/contour length in pixels
eds	EDS/contour length in pixels
σ	standard deviation

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TABLE 1. MATCH VALUE FOR VARIOUS SPOT DIAMETERS

Library spots		Test spots									
Number	Dia * pixels	Number	Dia * pixels	SDS$\times 10^5$	$\sigma\times 10^5$	CC	$\sigma\times 10^5$	EDS$\times 10^5$	$\sigma\times 10^5$	95% SDS$\times 10^5$	95%EDS$\times 10^5$
20	49.58	20	26.18	79.3	52.5	0.99243	574.0	213.0	70.0	184	353
10	48.15	10	19.15	111.0	54.0	0.99148	482.5	264.0	80.7	219	426
20	57.125	21	35.6	32.5	10.8	0.99597	127.3	148.3	28.3	54	204
20	57.125	20	14.8	201.0	139.4	0.98700	782.0	483.4	138.1	479	758
20	57.125	19	8.6	621.3	386.5	0.98840	972.2	464.1	173.5	1393	810
20	57.125	13	5.13	3107.0	1491.0	0.97703	1303.0	610.0	363.0	6089	1336
Non-central spots											
20	26.18	19	26.18	129.7	62.0	0.98486	942.0	459.6	63.9	-	-
20	49.525	16	49.525	40.8	14.4	0.99504	192.0	157.5	58.5		

* Average of vertical and horizontal diameters

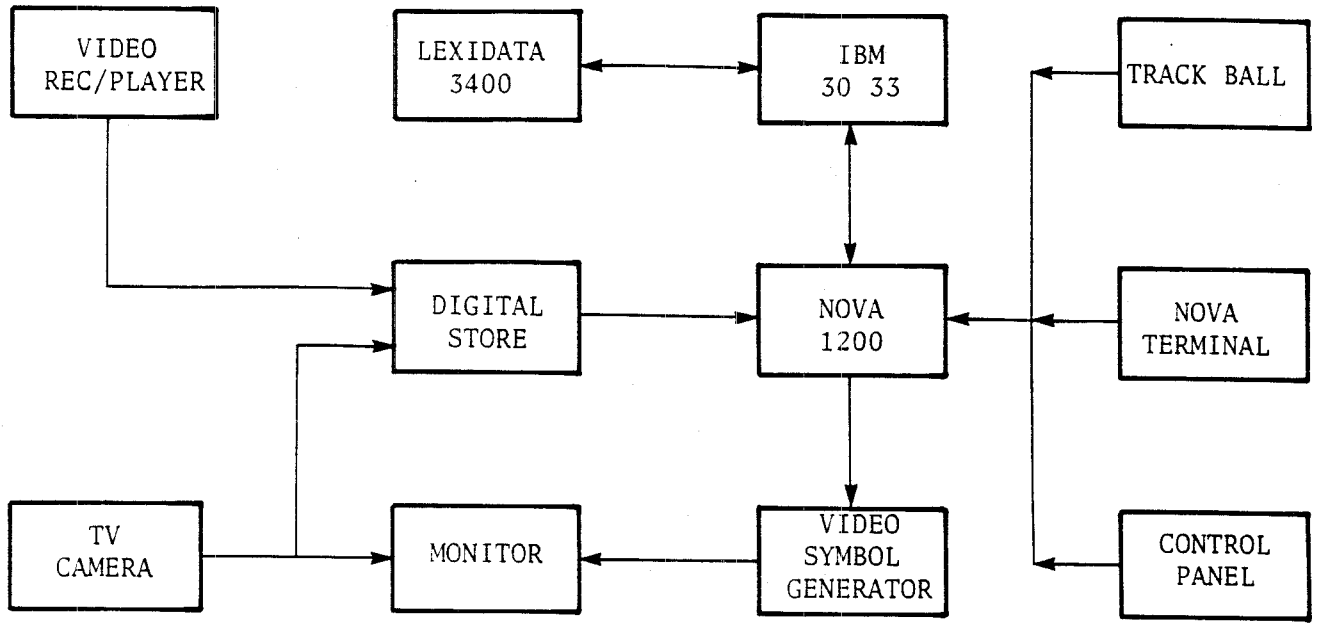


Figure 1. Block diagram of digitising system

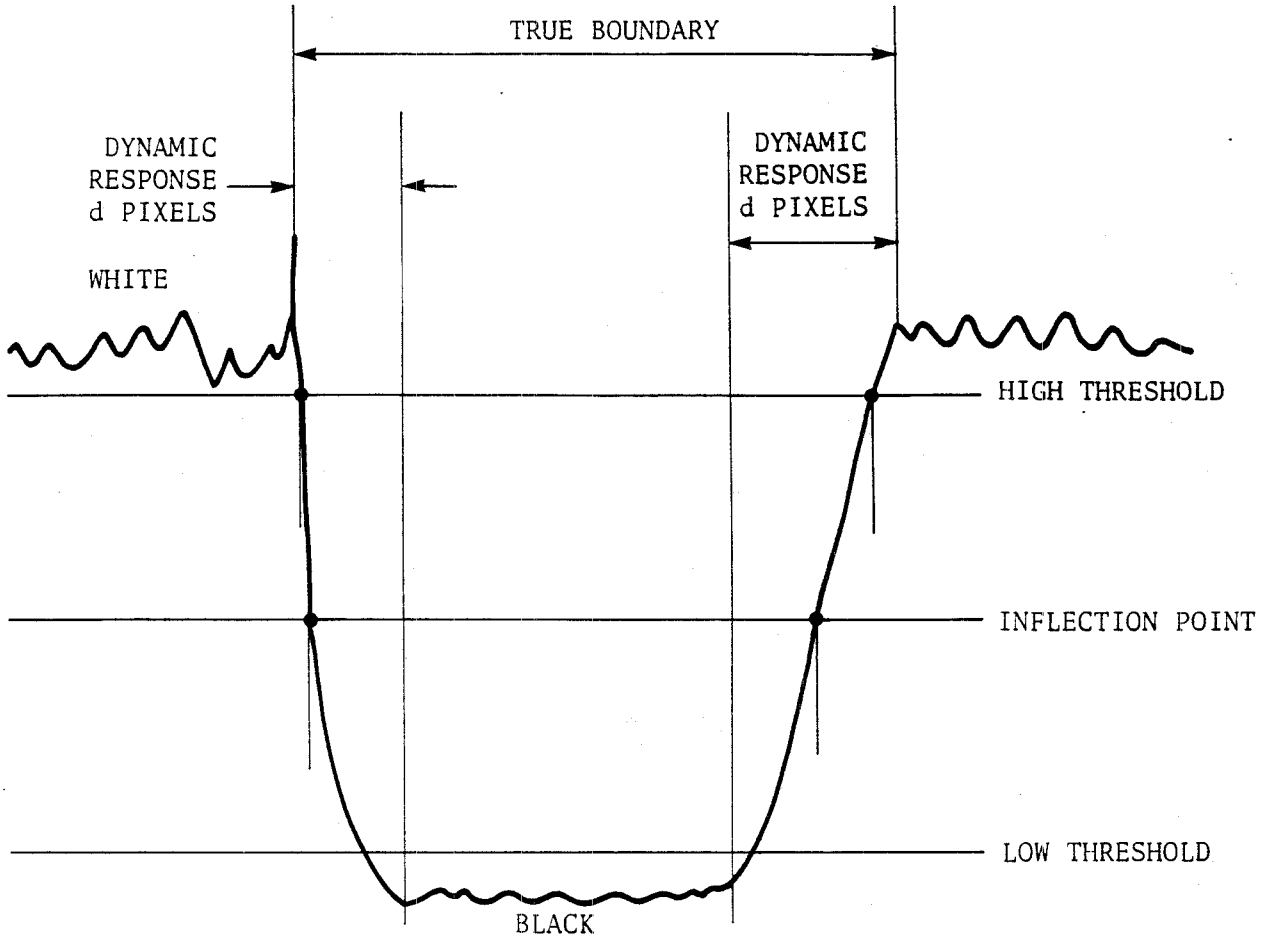
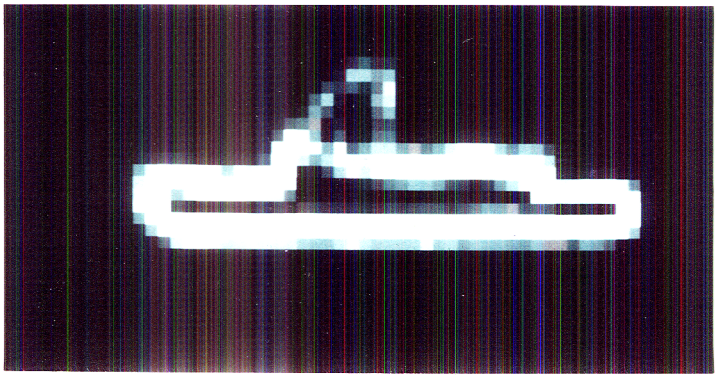
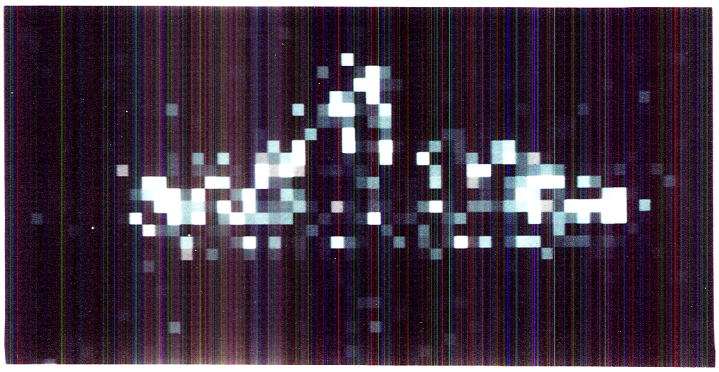


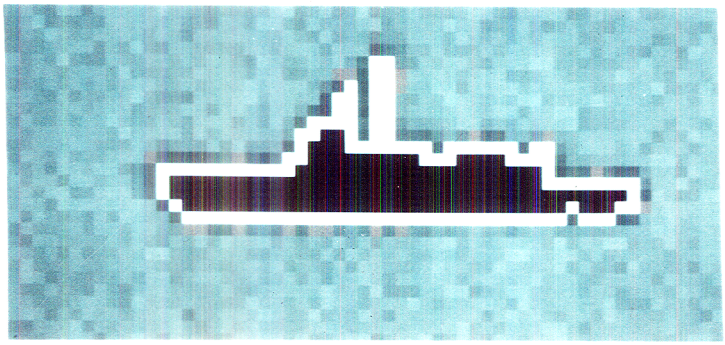
Figure 2. The effect of various threshold criteria



SOBEL



LAPLACIAN



THRESHOLD

Figure 3. The effect of various edge operators on contour definition

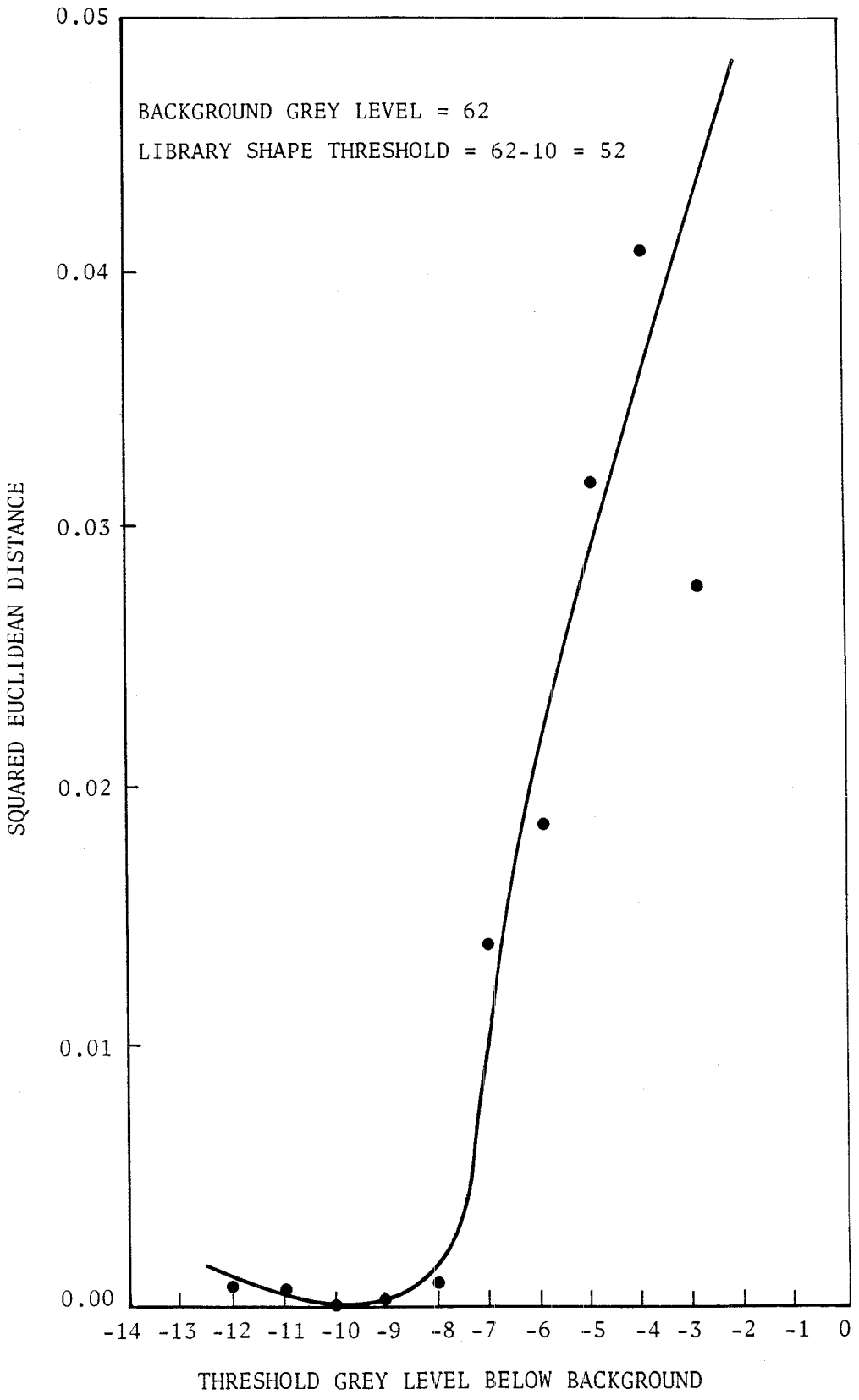


Figure 4. Variation of squared Euclidean distance value with threshold

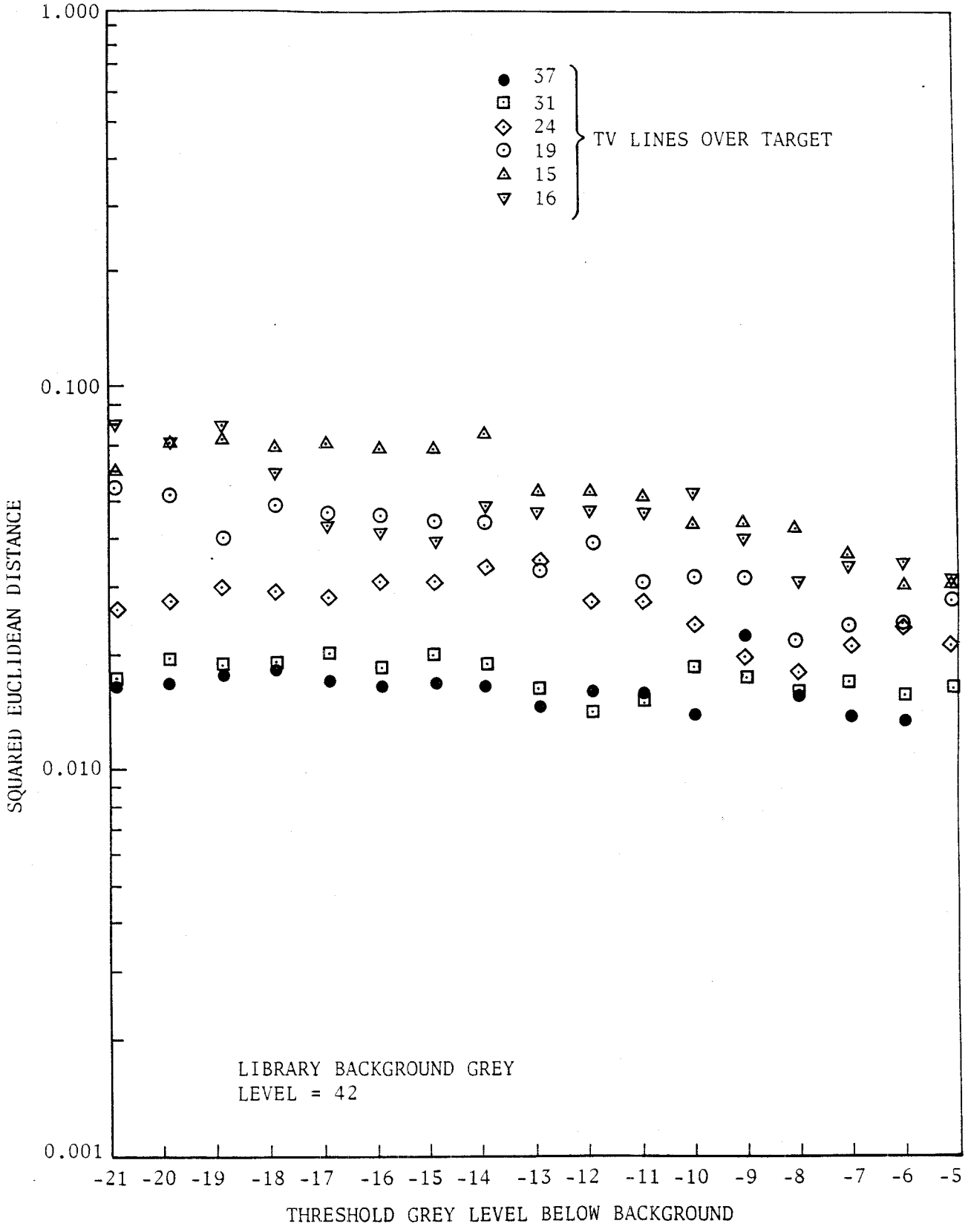


Figure 5. Squared Euclidean distance for one ship - library shape threshold = 40

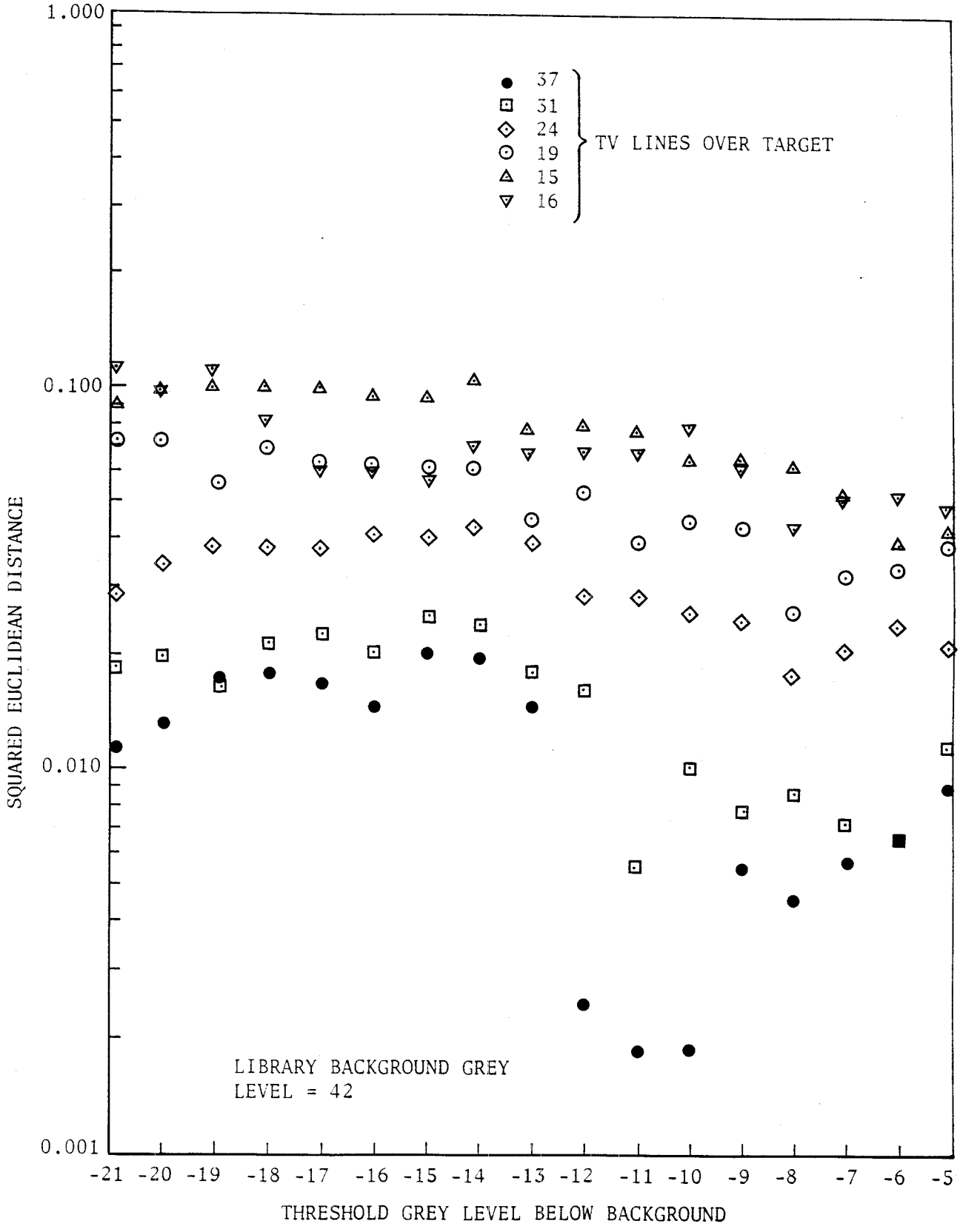


Figure 6. Squared Euclidean distance for one ship - library shape threshold = 35

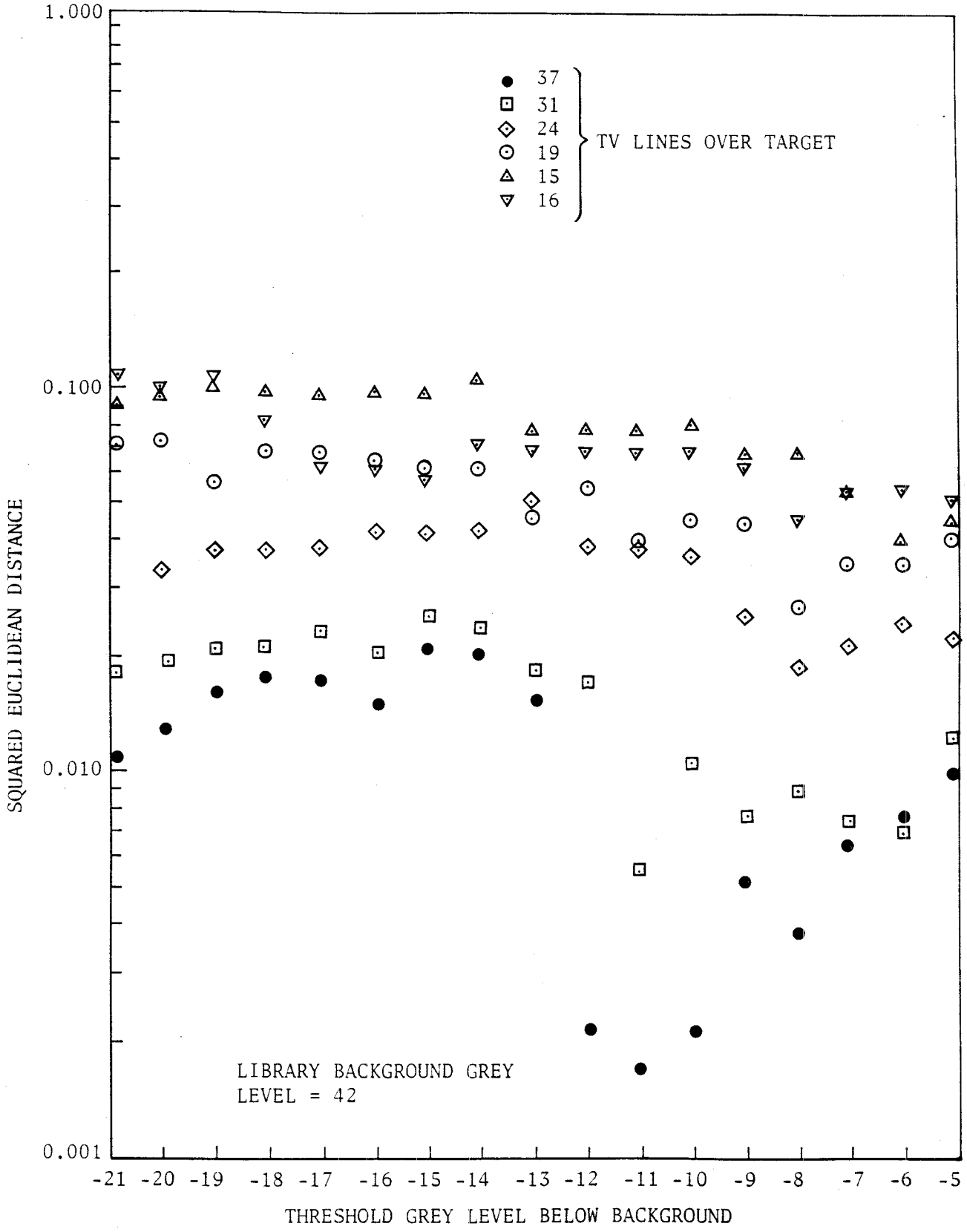


Figure 7. Squared Euclidean distance for one ship - library shape threshold = 30

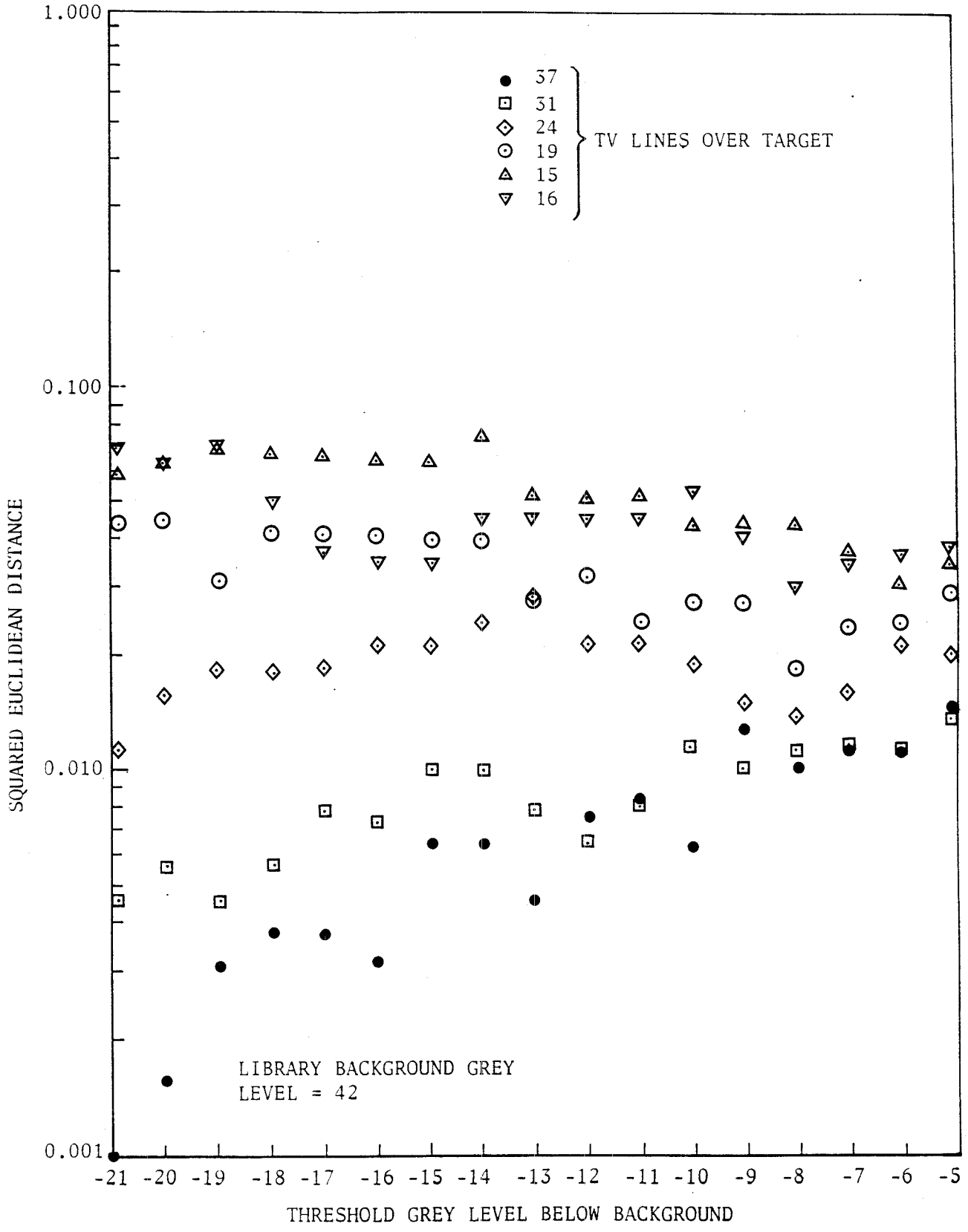


Figure 8. Squared Euclidean distance for one ship - library shape threshold = 25

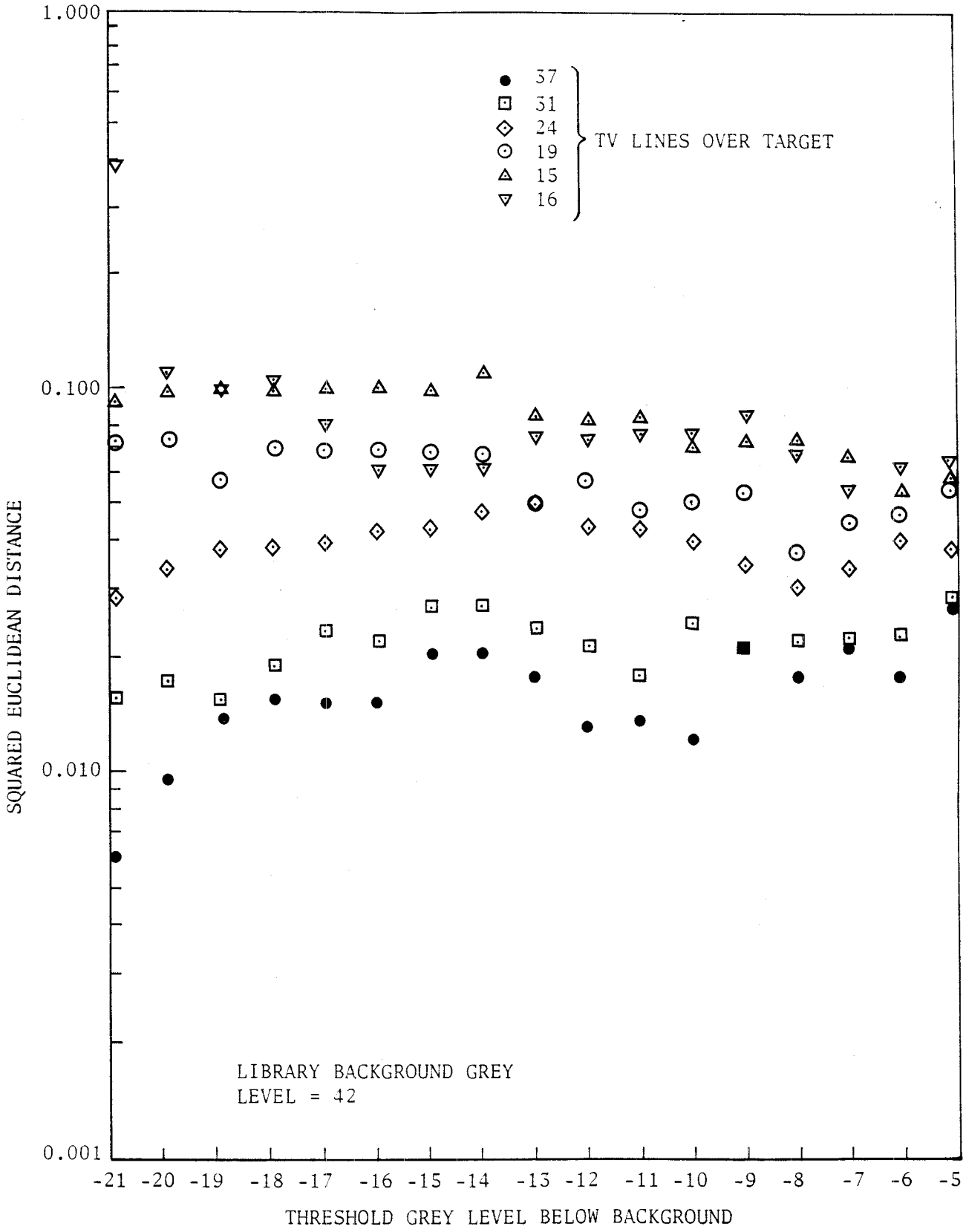


Figure 9. Squared Euclidean distance for one ship - library shape threshold = 20

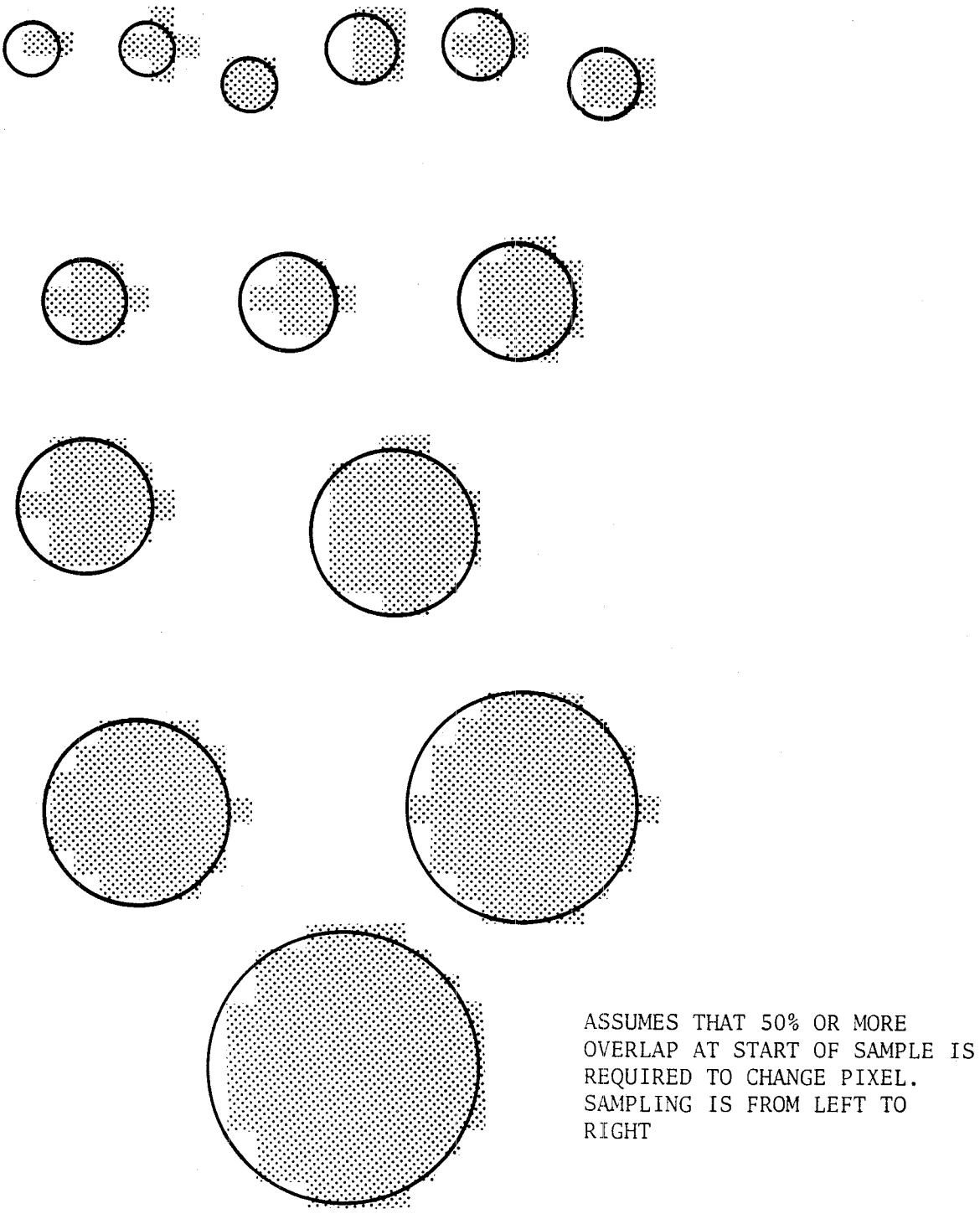


Figure 10. Pixel representation of spots for a horizontal scan

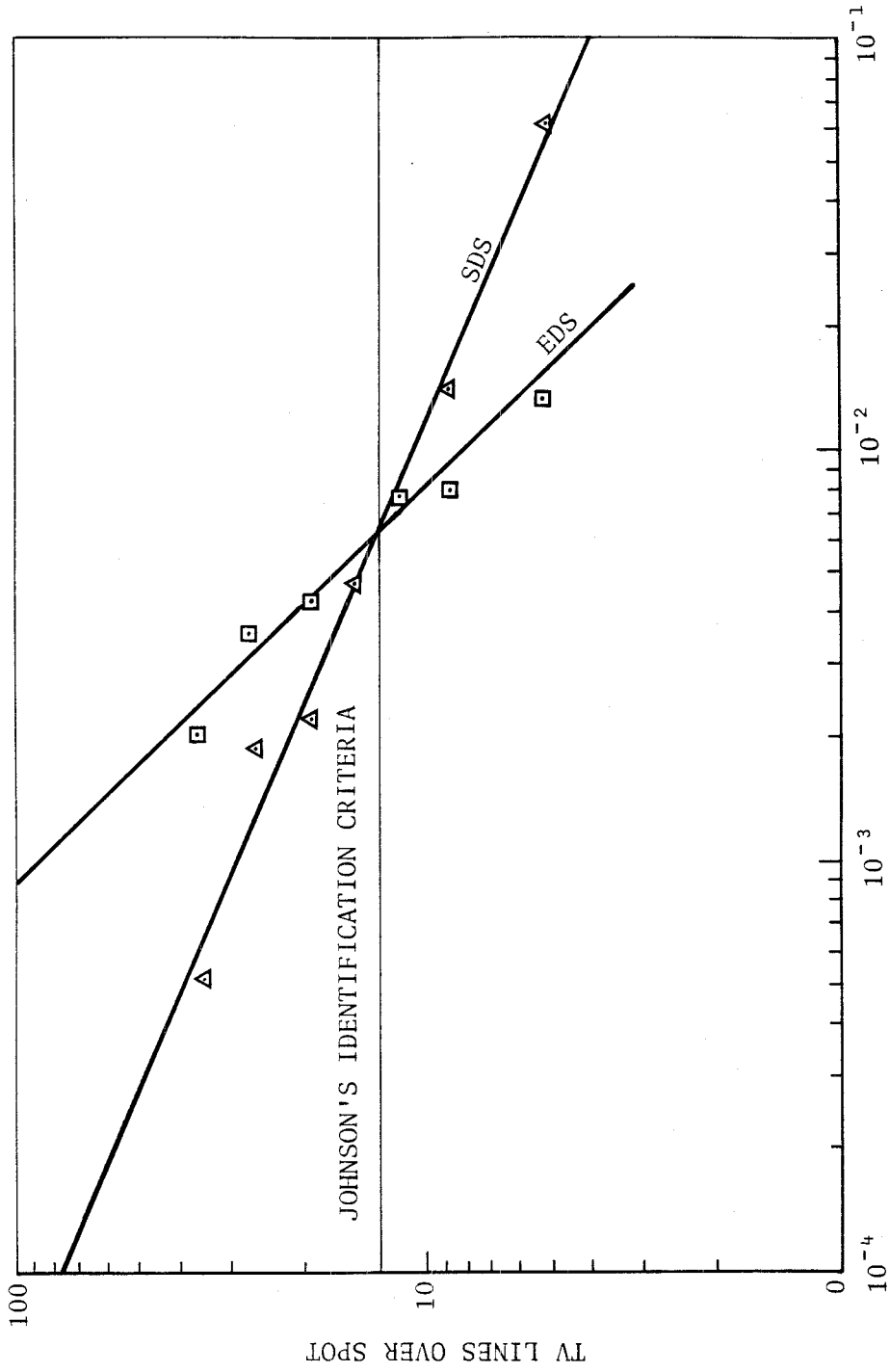


Figure 11. Spot match criterion using 95% confidence limit data points

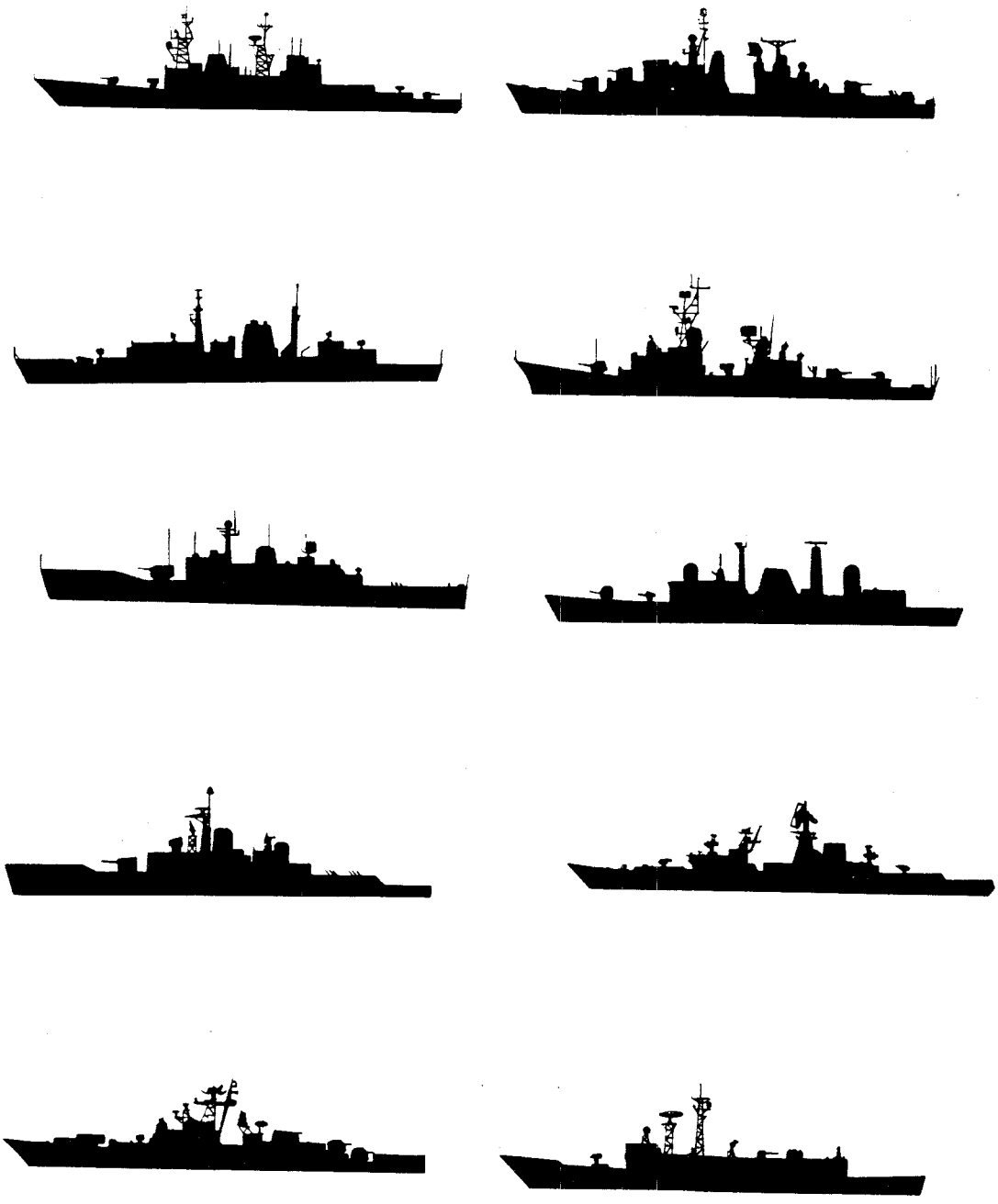


Figure 12. Silhouettes of library shapes

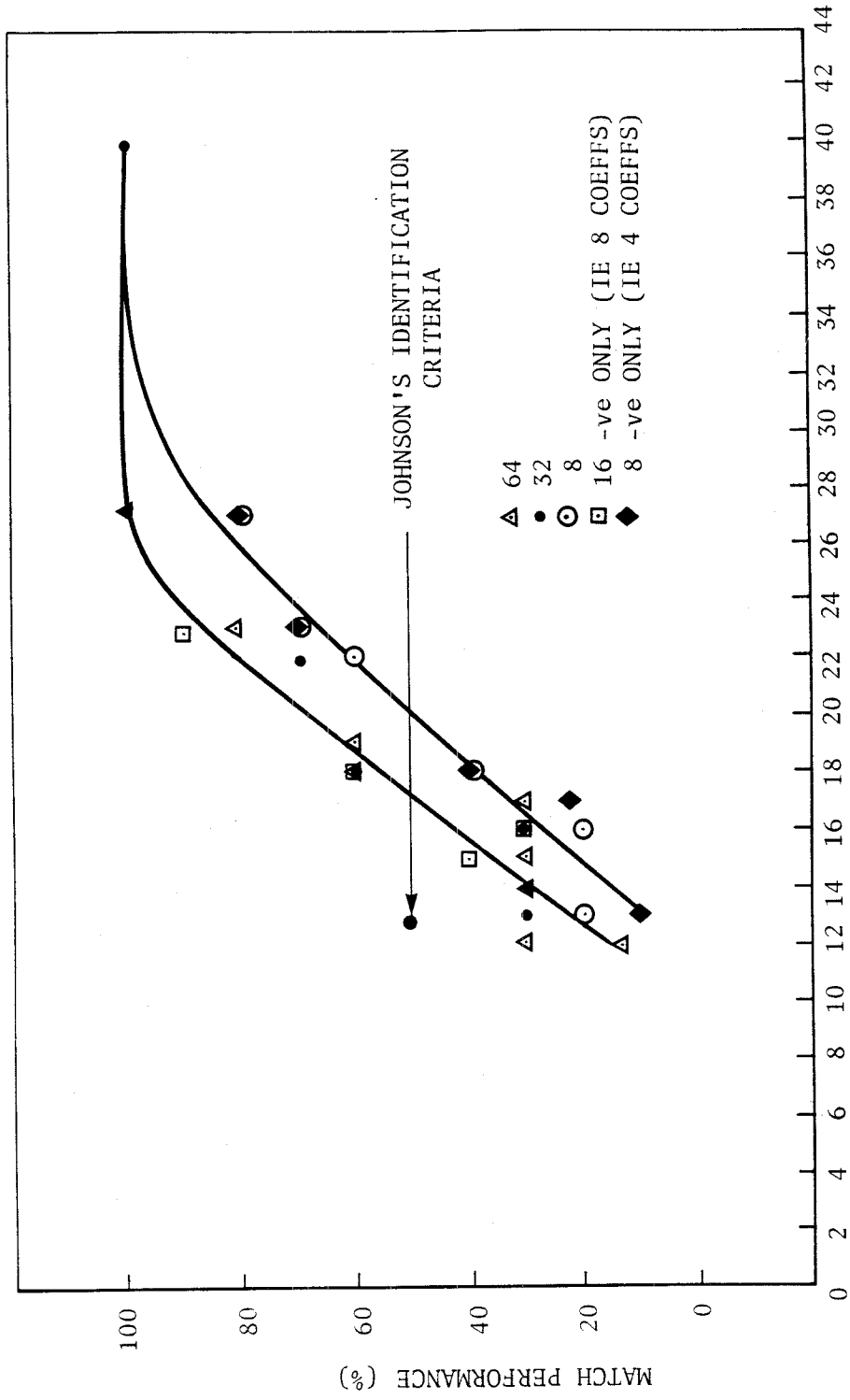


Figure 13. Percentage identification of ship targets for various Fourier descriptor coefficients

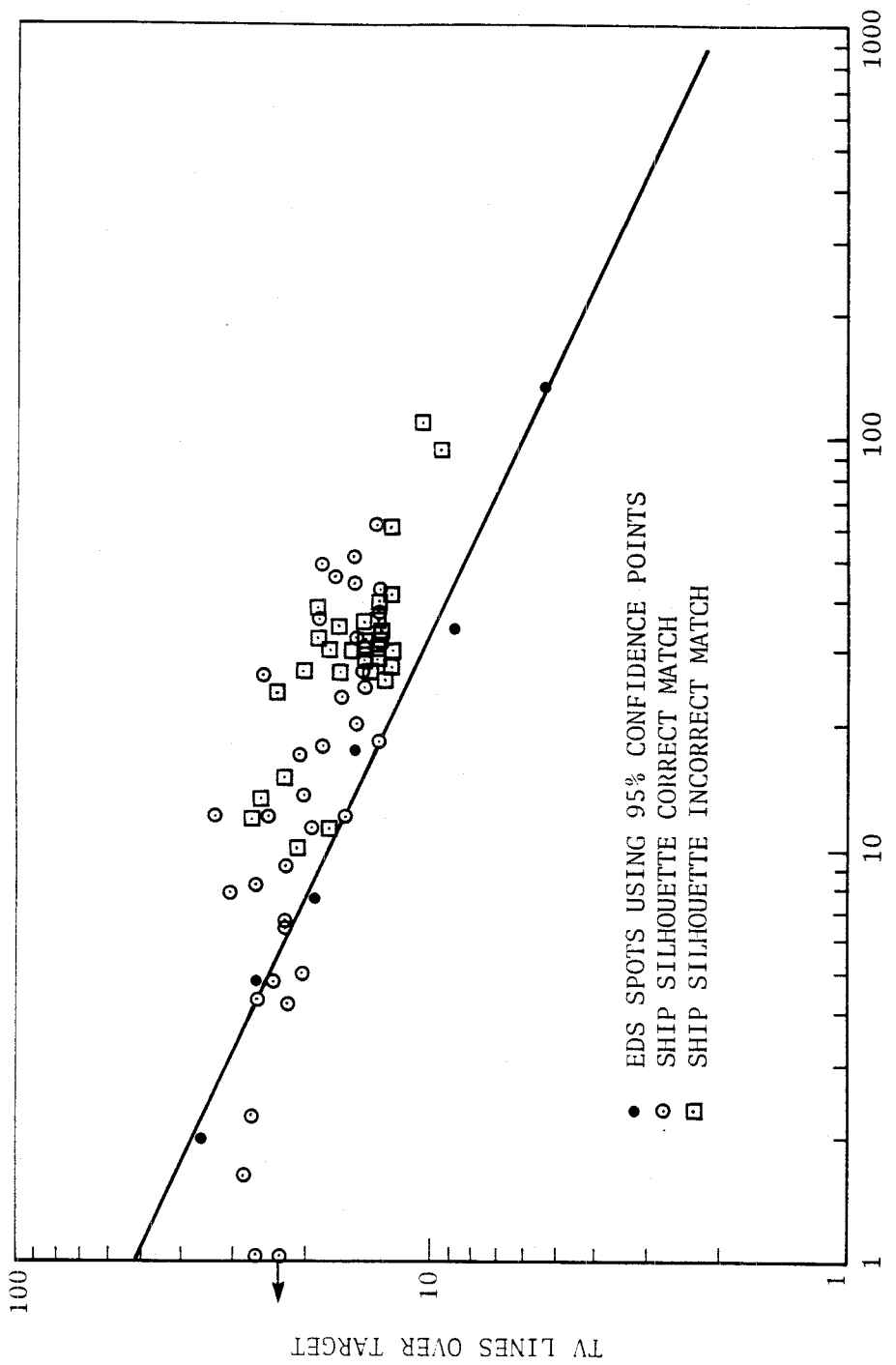


Figure 14. Correct and incorrect match points compared with spot match identification threshold

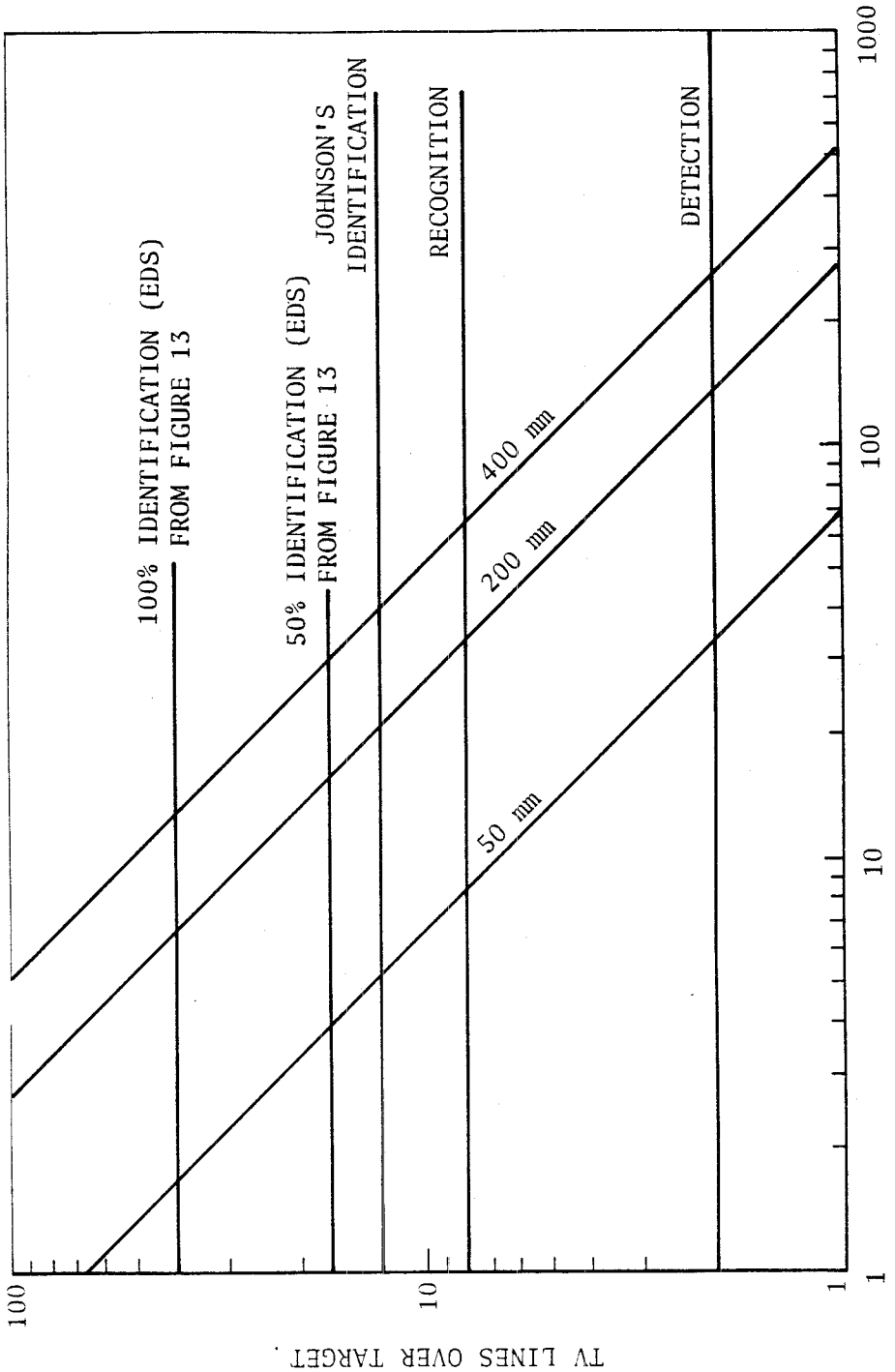


Figure 15. Range versus TV lines over target for various lens focal lengths

DOCUMENT CONTROL DATA SHEET

Security classification of this page: UNCLASSIFIED

1 DOCUMENT NUMBERS

AR Number: AR-004-955

Series Number: WSRL-0515-TR

Other Numbers:

2 SECURITY CLASSIFICATION

a. Complete Document: Unclassified

b. Title in Isolation: Unclassified

c. Summary in Isolation: Unclassified

3 TITLE

AN IDENTIFICATION THRESHOLD FOR SHIP SILHOUETTES

4 PERSONAL AUTHOR(S):

B.E. Furby

5 DOCUMENT DATE:

May 1987

6 6.1 TOTAL NUMBER OF PAGES 29

6.2 NUMBER OF REFERENCES: 10

7 7.1 CORPORATE AUTHOR(S):

Weapons Systems Research Laboratory

7.2 DOCUMENT SERIES AND NUMBER

Technical Report 0515

8 REFERENCE NUMBERS

a. Task: DST 91/485

b. Sponsoring Agency:

9 COST CODE:

42Y-CS-323

10 IMPRINT (Publishing organisation)

Defence Research Centre Salisbury

11 COMPUTER PROGRAM(S) (Title(s) and language(s))

12 RELEASE LIMITATIONS (of the document):

Approved for Public Release

Security classification of this page: UNCLASSIFIED

Security classification of this page: UNCLASSIFIED

13 ANNOUNCEMENT LIMITATIONS (of the information on these pages):

No limitation

14 DESCRIPTORS:

a. EJC Thesaurus Terms: Identification systems; Ships; Silhouettes

b. Non-Thesaurus Terms: Target identification; Fourier descriptors

15 COSATI CODES:

0063F

16 SUMMARY OR ABSTRACT:
(if this is security classified, the announcement of this report will be similarly classified)

Fourier descriptors are used to characterise the binary grey level silhouette images of ship targets. A grey level threshold technique is developed to determine the contour of the ship and comparisons are made between test shapes and library shapes using Euclidean distance as the match criterion. Binary grey level spot image comparisons are found to generate a suitable identification threshold which is successfully adapted to provide a ship silhouette identification threshold.

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