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# STATISTICAL TREATMENT OF SHIP MANŒUVRING RESULTS FOR FAIRWAY DESIGN


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## ABSTRACT

The article starts with a description of the ship manoeuvring simulator used. The procedure for design and choice of an exceedance frequency is described and some practical figures are mentioned.

A formula is given on the width of the reliability belt of a certain exceedance frequency and is illustrated in some figures.

The statistical distribution of the ship's swept path is treated and differences are shown between statistical processing based on the assumption that this distribution is normal and taking into account the real distribution.

Examples are given about wrong conclusions that can be drawn based upon erroneously used "deterministic" statistics.

## SOMMAIRE

L'article commence par une description du simulateur de manoeuvre des navires utilisé pour les essais. Il décrit ensuite la procédure pour la conception et le choix d'une fréquence de dépassement et fournit quelques données d'ordre pratique.

Les auteurs donnent une formule pour la largeur de la zone de fiabilité d'une certaine fréquence de dépassement. Celle-ci est également illustrée par des figures.

La distribution statistique de la trajectoire parcourue par le navire est étudiée et l'attention est attirée vers les différences entre le traitement statistique basé sur l'hypothèse que cette distritubion est normale et la prise en considération de la distribution réelle.

La dernière partie de l'article est consacrée à des exemples de conclusions erronées pouvant être tirées au départ de statistiques dites "déterministiques" utilisées à tort.


## 1. INTRODUCTION

Ship manoeuvring simulators and prototype measurements are useful tools in the design of approach channels to ports, the ports themselves and inland navigation channels. This article will be confined to channels, since they are easier for illustration purposes.
The results of trials are usually processed statistically; then the channel width is determined.

When an existing channel has been tested in the simulator and when we have used real-life trials, we have found in both cases that the normally accepted statistical processing sometimes results in an existing channel seeming not wide or not safe enough. Statistical processing of results indicated so-called "exceedance frequencies" of the channel edge which did not tally with years of practical experience.
This could not be due to differences between simulator and reality, since the statistical processing of results from measured real-life trials gave the same effect. It would, therefore, appear to be due to the statistical processing. Consequently, we have developed several methods to make it more reliable and more in line with reality.

Since statistical processing of the results is often based upon simulator trials, we shall start with an outline of the simulator used.

## 2. BRIEF DESCRIPTION OF SIMULATOR CONFIGURATION

The ship manoeuvring simulator consists of two local terminals, from which the ship manoeuvring can be controlled and visualized. The numerical simulation process runs interactively on a HP3000, type 64, mainframe computer.
The bridge-control-terminal gives a read-out of the bridge control instruments and enables input of bridge commands (engine, rudder, tugs, bow-thruster) via the terminal key-board.
The view-terminal gives graphically the moving picture as called for, such as bridge view, radar view and bird's eye view. The terminal display is blown up on a large 1.2 x 1.5 $m^2$ video screen (see figure 1).
The control room outfit has been kept rather simple, which makes it relatively cheap, the advantage also being that the terminals can be placed even out-house, if asked by the Client. There is no ship's bridge; the pilot sits in a normal office room, containing 2 computer-connected terminals and a video screen. The pilot gives the commands to the helmsman, sitting behind the terminal-keyboard.

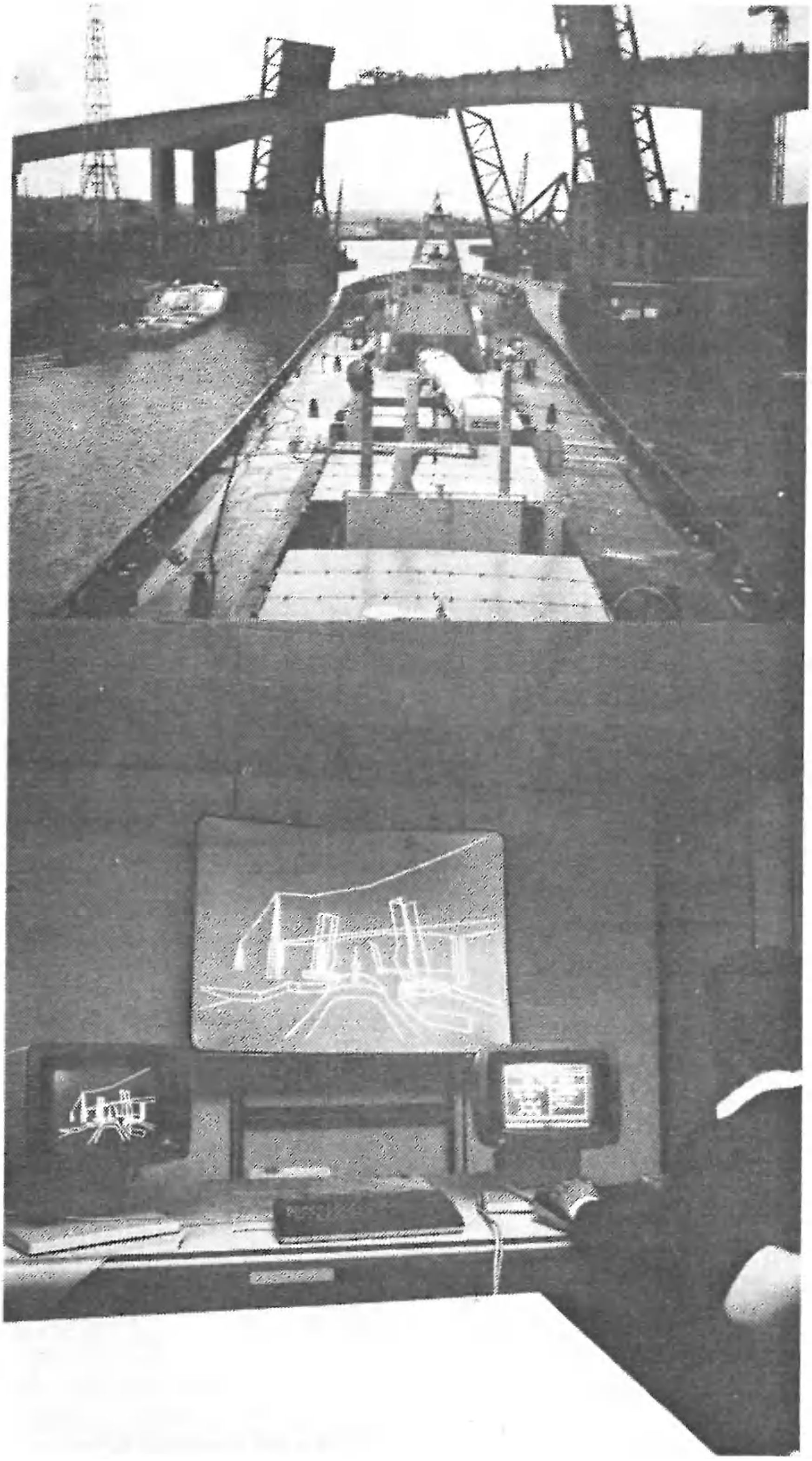


Figure 1 : Comparison between reality and simulator

The software of the simulator consists of two main parts, viz. the SHIP program, which calculates the environmental movements of the ship and the VISUA program, which calculates how the pilot on the bridge sees the visual surroundings.

The pilot can ask different views from the program VISUA; he can look forward and aft, and in both directions he can stand on midbridge and at port and starboard side (see figure 2).

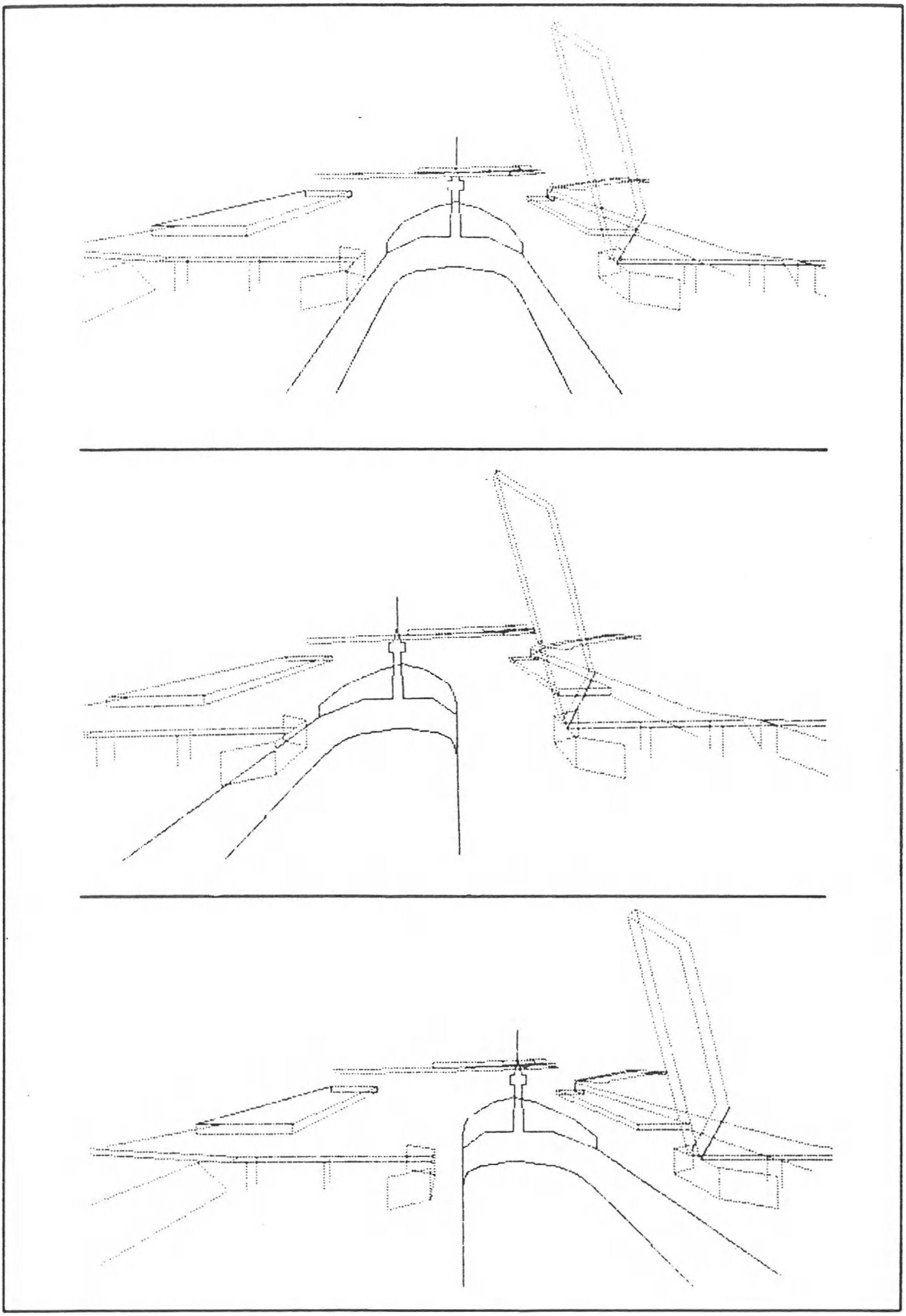


Figure 2 : Different bridge view options of simulator

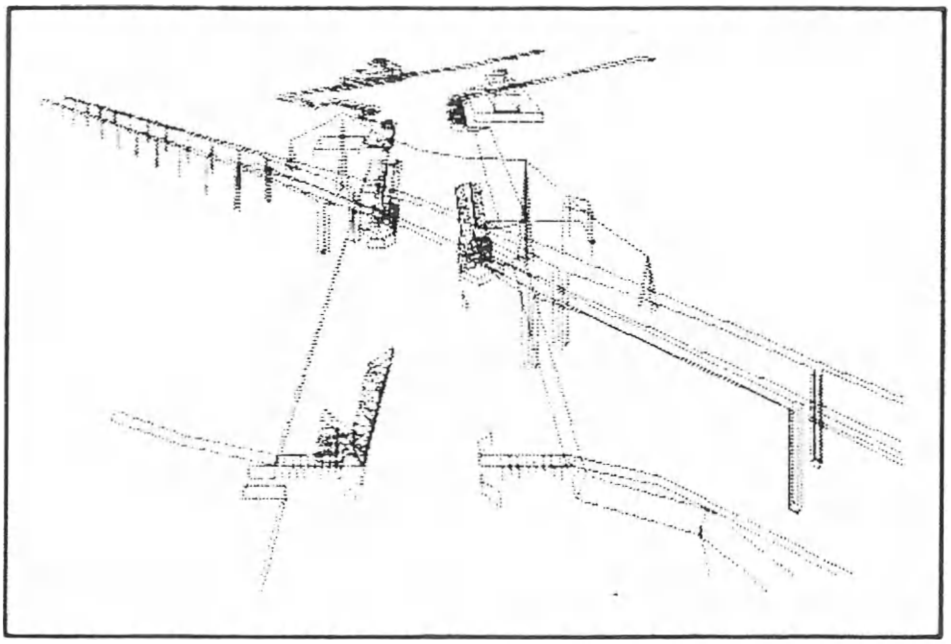


Figure 3 : Overallview of complete surroundings for visualization in simulator

If the visual surroundings are very complicated, as in figure 3 for instance, the surroundings is drawn priority-wise, i.e. only the foreground and characteristic parts of the background, which is updated continuously.
Apart from the bridge image view, the pilot can change to a bird's eye view and to a radar view. The bird's eye view (figure 4) can be scaled to any size the pilot wants. In the bird's eye view, the ship is moving in fixed surroundings; with the radar view the opposite is the case.

The basis for the SHIP program was published in [1]. It is a numerical model in which the integration of the three equations of motion is carried out in a finite difference scheme with a time step of 1 second. The model is very comprehensive.
It takes into account currents and current gradients, shallow water effects, wind, wave drift forces, adjustement of RPM and rudder in the period following a certain command, as well as the influence of RPM on rudder

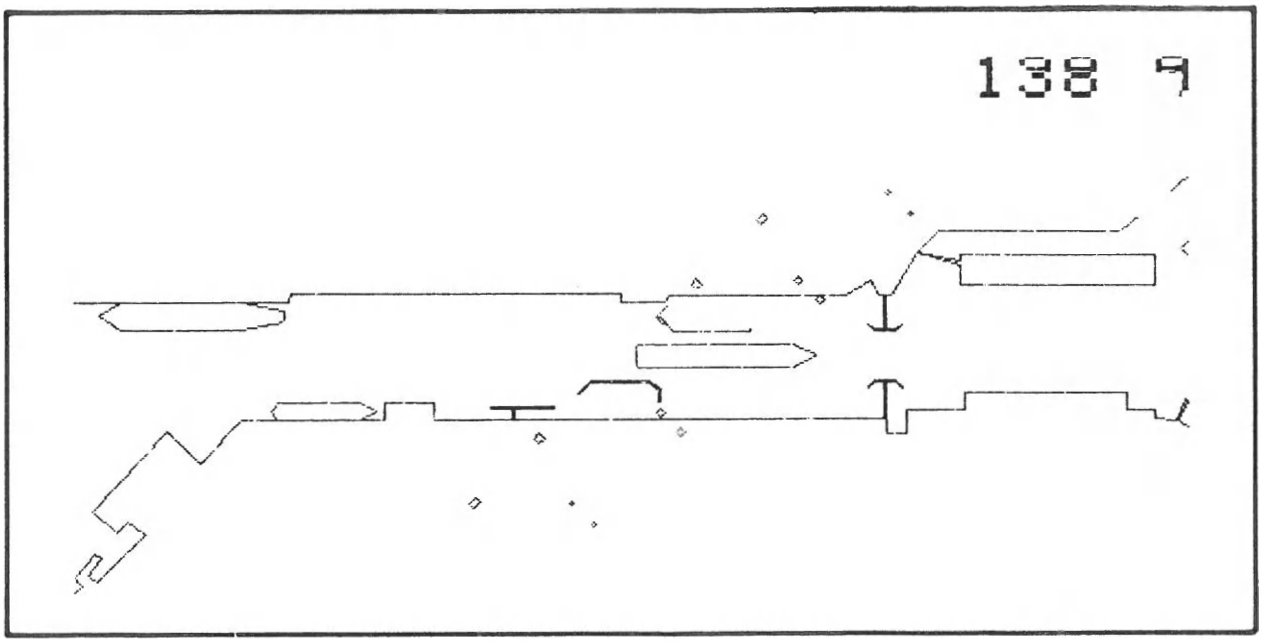



Figure 4 : Bird's eye view option of simulator

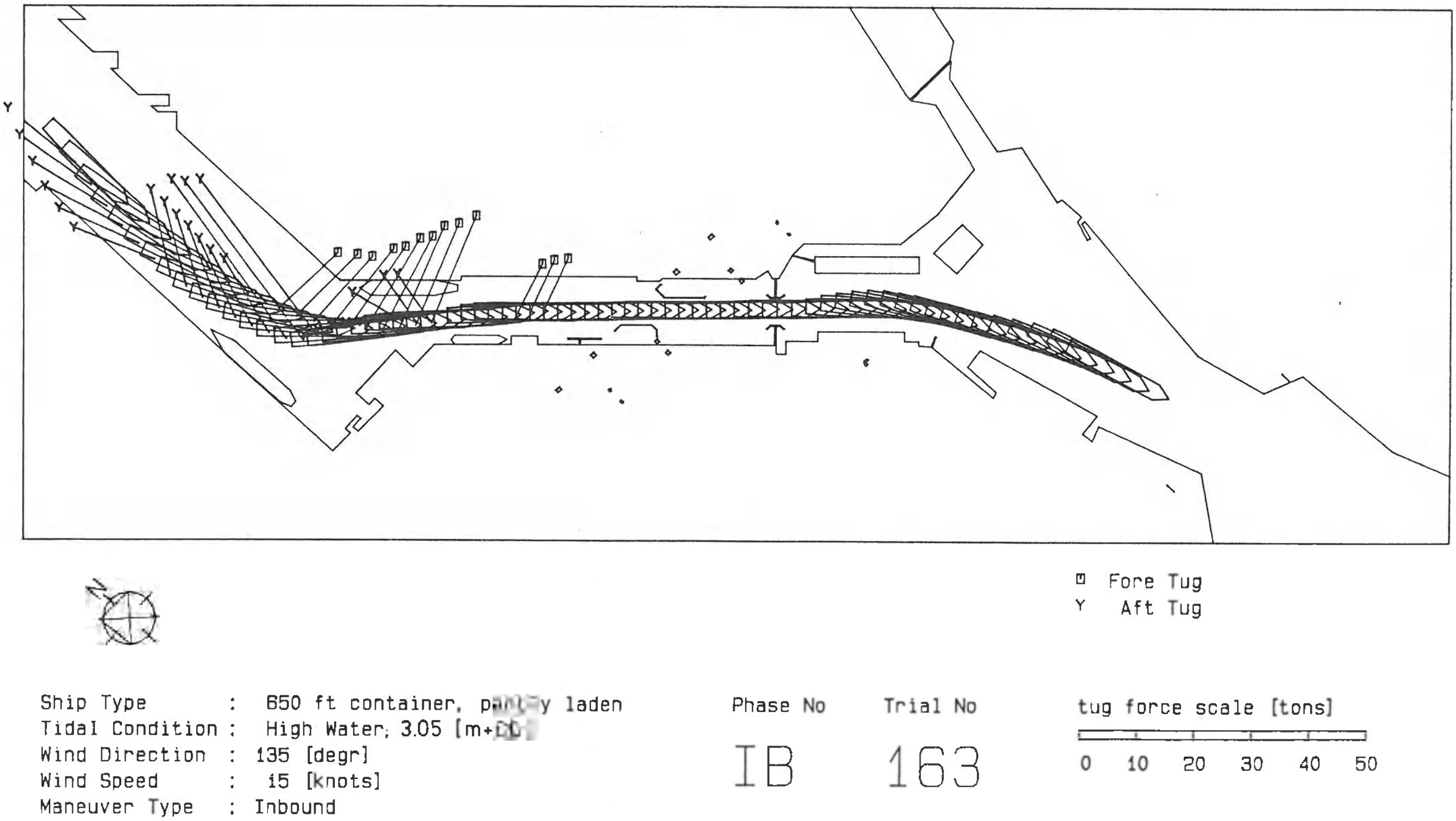



Figure 5 : Example of plot of manoeuvre made in the simulator

efficiency. It also allows for the effect of turning (to starboard) and the decrease in propulsion- and rudder efficiency, when the engine is in reverse.

Tugs and bow-thrusters are also incorporated in the model and can be used at the pilot's request. The pilot selects a force and a pulling angle for the tugs and the program calculates whether the tug can deliver the required force, according to the pulling angle and the forward speed of the vessel. If the pilot requests too much (risking capsizing the tug) the program automatically reduces the force to the maximum available for that speed and pulling angle. The time needed for the tug to shift from one position to the other is also simulated in the program.

One thing of relevance to a pilot, and which he perceives differently, is the fact that in reality he can look perpendicular to the ship's axis and look over the ship's hull. In the simulator this can only be overcome by switching to the bird's eye view, which is different from reality. Only very expensive simulators may overcome this disadvantage.

An important point of the above described configuration, is that the pilot is really able to sail in a narrow channel under bridges, etc. The simulator is not equal to reality but is fairly close.

## 3. PROCEDURE FOR DESIGN AND CHOICE OF EXCEEDANCE FREQUENCY

When sufficient manoeuvring trials have been carried

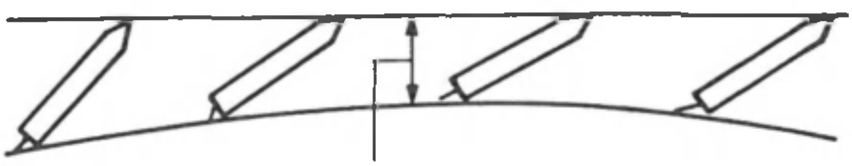



Figure 6 : Definition of swept path

out, they can be processed statistically. This means that averages and standard deviations can be determined for all signals recorded during the trials, such as RPM and speed, rudder and course angle, tug assistance and bow-thruster use.
Indications can be obtained from these about difficulties in the channel, adequacy of tug assistance, etc., but ultimately it is always the analysis of the swept path that is most important. The swept path is determined by two lines formed by the two most extreme points of the ship's hull in relation to the center line of the channel (see figure 6).

For each channel cross section there are a number of ship passings, equal to the number of trials; these ship passings have a certain distribution over this cross-section (see figure 7). This distribution can be made for either side of the ship. Based upon this distribution it is possible to determine the 10 %, 1 %, etc., probabilistic exceedance frequencies, which means that 10 %, 1 %, etc., of the ship passings is beyond this point in the cross-section.
When this is done for all cross-sections along the channel axis, exceedance frequency lines can be determined all along the channel.

The acceptable exceedance frequency f should be determined in advance, either - briefly - in an optimization process [2], or from an overall acceptable chance of strandings over a longer period.
Assuming that the ship transits are stochastically independent, the acceptable value of f can be determined

The pilot - or the Client - can choose in advance between tractor tugs (VOIGT - SCHNEIDER) and conventional tugs, which have different characteristics.

For the bow-thruster the program calculates the force, according to the ship's forward speed as well.

A special option in the program is bank suction forces and moments. This option is only used in small channels where this effect plays a role. The bank suction forces and moments acting on the ship are calculated according to the ship's excentricity, ship/canal blockage ratio, course angle with respect to channel axis, and the ship's speed relative to the water, her length, draught and keel-clearance.

Pilots from various ports have sailed in the simulator and their reactions were very positive.
Figure 5 plots a manoeuvre made in the simulator.

The relevant point in the above description of the simulator is that there is little difference between reality and simulator. The pilot has the same feelings about what is happening with his ship as he has in real life; he sees the surroundings as he normally would from the bridge.
Of course there are differences : the pilot does not hear the engine, he does not feel the oscillations caused by waves, there is no real steering-wheel or engine telegraph, but these aspects are less relevant with regard to the other important ship reactions. Our experience is that a pilot can distinguish between these relevant and irrelevant matters very well. His mind works like a screen, sieving out and forgetting things that do not really influence his ship.

by using the following Poisson distribution for a large number of transits :

$$P = 1 - (1 - f)^N \qquad (1)$$

where :

P = overall probability that a ship will exceed a certain limit one or more times during the considered period

f = individual average exceedance frequency per transit

N = total number of transits during the considered period

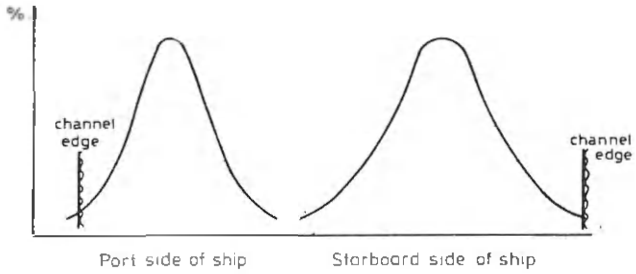



Figure 7 : Statistical distribution of swept path

This overall probability has been given in figure 8 as a function of the individual frequency per transit and the total number of transits.

In our opinion the value of P should be in the order of 10-70 % for a practical period of, say, 20 years.
The lower probability would apply with a relatively cheap channel (not too much deepening and maintenance) and relatively large damage if the ship were to strand (steep slopes, or even quay walls, bridges or expensive protection structures). Overall probabilities less than 10 % are "paid" with very small individual exceedance frequencies, making the channel expensive.

The higher probability would apply for a relatively expensive channel (considerable deepening and/or maintenance) and relatively small damage with stranding. Overall probabilities higher than 70 % make it pretty sure that one of more strandings will occur during the considered period of 20 years, thus increasing the costs caused by strandings.
If the above figures are applied, optimum channel width is probably approximated. Of course other requirements, such as safety, if dangerous cargoes or pollution are involved, may affect the choice of the overall probability.

The advantage of selecting a value for overall probability over a period of, say, 20 years, is that the individual exceedance frequency f is determined by the expected traffic intensity, which is realistic.

Once a criterion is known for the value of f, the design procedure should continue as follows :
The channel is assumed to meet the set criterion. This is called the "null-hypothesis". The test in the simulator is used to determine whether the null-hypothesis should be rejected or not. As long as the null-hypothesis cannot be rejected, it remains valid. If the null-hypothesis should be rejected, the alternative hypothesis becomes valid, this alternative hypothesis being that the channel edge is exceeded by a higher percentage than the set design exceedance frequency.

## 4. TEST PROCEDURE

It will be clear that the trials made in the simulator should be considered as a test. In other words : the results must be treated as a sample, and a sample only provides an indication of the total population. It is not the total population. A sample is often, mistakenly, equated with the population. This is called "deterministic" statistics, which is used than for probabilistic purposes. Probabilistic statistics relate always to margins and reliability, and can never be used to give exact answers.

The average $\mu$ and standard deviation $\sigma$ of the population are determined by the average m and standard deviation s of the sample in the following ways :

$$m - t.s/\sqrt{n} < \mu < m + t.s/\sqrt{n} \qquad (2)$$

$$(1 - a_1).s < \sigma < (1 + a_2).s \qquad (3)$$

where

$\mu$ = average of population

$\sigma$ = standard deviation of population

m = average of sample

s = standard deviation of sample

t = reliability factor for average obtained from Student's t-distribution with n-1 degrees of freedom

n = number of trials in the sample

$a_1$, $a_2$ = reliability factors for standard deviation obtained from chi-square distribution with n-1 degrees of freedom

The values of t and of $a_1$ and $a_2$ depend on desired reliability; for example 95 %.

So statistical distribution of the population can vary between the extremes given in figure 9.
In other words, when we have selected a 0.1 % exceedance frequency as the design criterion, and we have decided for our null-hypothesis, that the channel edge may not be exceeded by 0.1 % of the ships, the edge should be between the minimum and maximum values indicated in the sketch. As long as it does, there is no evidence that the null-hypothesis should be rejected.
In deterministic statistics, where the distribution of the sample and the population are wrongly considered equal, the channel edge would not fulfil the design criterion, in figure 9.

Admittedly, the most likely value for the 0.1 % frequency of the population is at the location determined by the sample (figure 9a). But this is not definite. An example of this can be seen in figure 10 where we have given the 95 % reliability belts for the 0.1 % exceedance frequency lines for both channel edges, but for different sample sizes (comprising 54 and 12 trials, respectively;

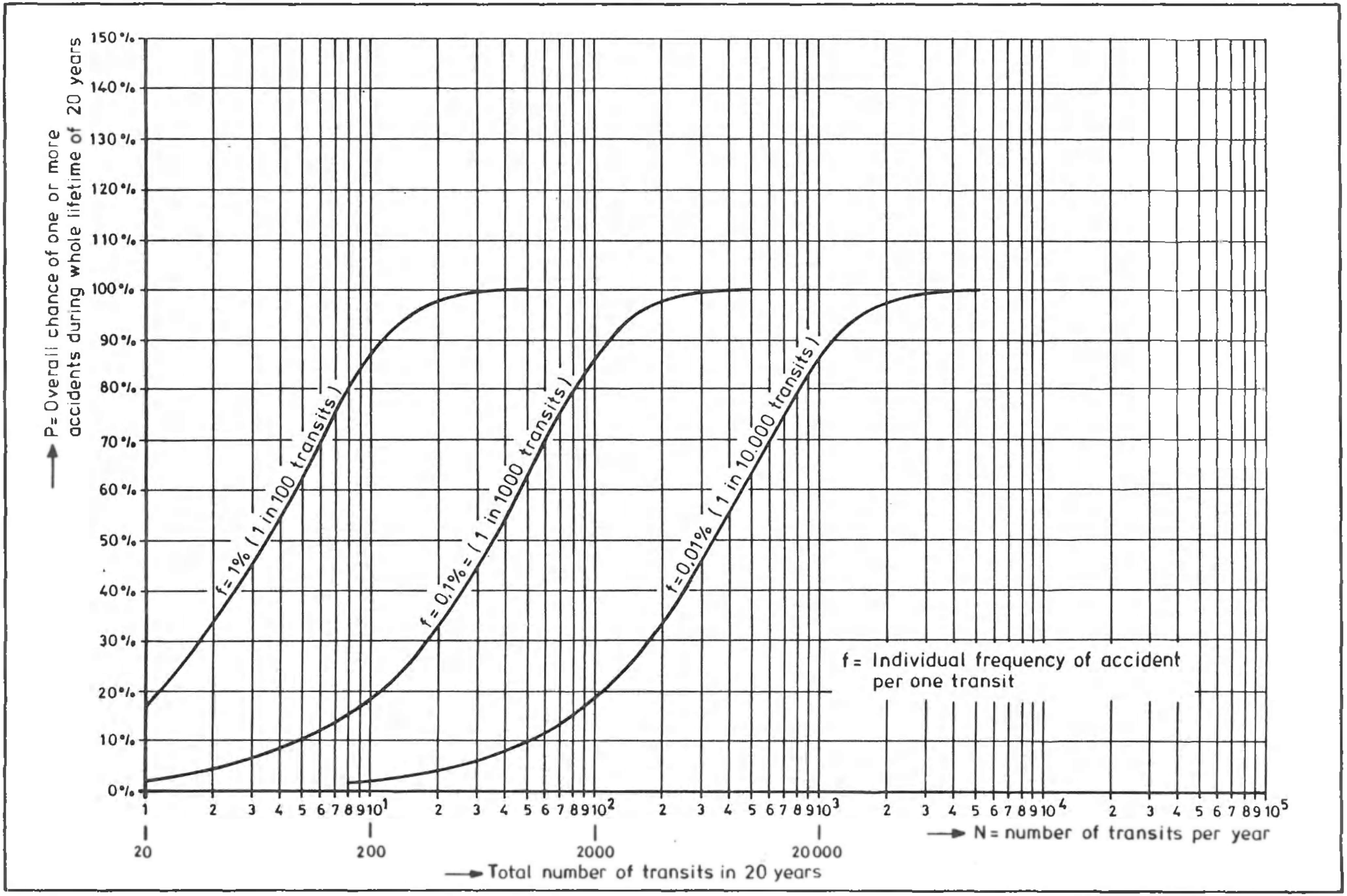



Figure 8 : Overall probability of accident for a large number of transits
all having a (small) individual probability of accident

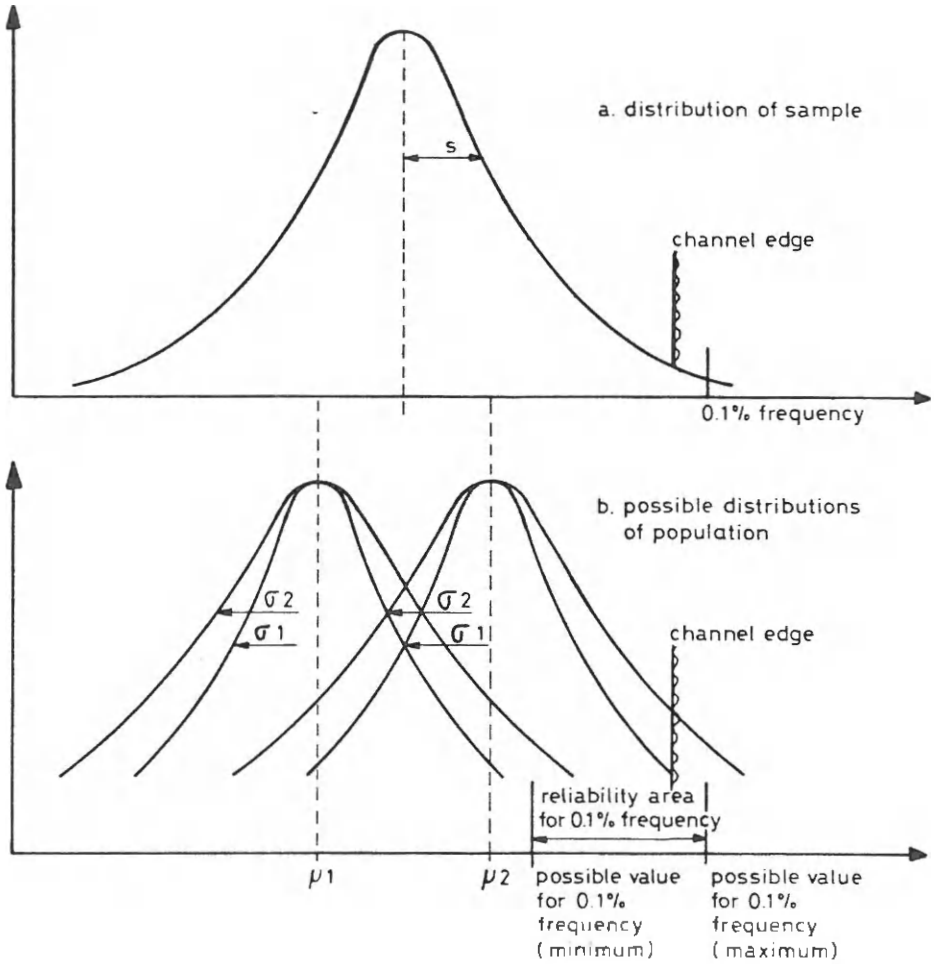



Figure 9 : Distribution of sample (a) and possible distributions of population (b)

sample of 12 trials is taken at random from the sample of 54 trials). Since we have assumed here a normal distribution, the 0.1 % distribution frequency is in the middle of each reliability area.

From the figure it is clear that if we had selected - in deterministic statistics - the 0.1 % frequency of the sample of 12 manoeuvres, we would have made a big mistake, since the sample of 54 manoeuvres indicates (with 95 % reliability) that this 0.1 % value lies somewhere else (see locations indicated with arrow, for instance). Consequently, the hypothesis that the channel is wide enough for a 0.1 % exceedance-frequency may not be rejected at the indicated locations.

Since the alternative hypothesis is that the channel edge is exceeded by more than 0.1 % of the ships, we are in fact only interested in the minimum value of the reliability area, so we can test with a one-sided reliability of, say, 95 %.

We have adopted the following procedure for determining the limits of the reliability belt for a given exceedance frequency of the swept path.
These limits are the result of a linear combination of two random variables, viz. μ and σ , determined by equations (2) and (3).

Assuming a normal distribution the expectation and reliability of the swept path can be expressed as :

$$\mathrm{Exp}\{y\} = m + u.s$$

$$\mathrm{Rel}\{y\} = \sqrt{[(t^2/n + \{u.\ (a_1 + a_2)\ /2\}^2]}\ .s \quad (5)$$

where :

y = swept path for selected exceedance frequency

u = excentricity factor for the selected exceedance frequency

t, $a_1$, $a_2$ = reliability factors, determined for a one-sided reliability of, say, 95 %.

The above solution is analogous to and valid over a wider area than a method outlined in Shen [5] for Gumbel and Log-Pearson type III distributions.

As we test only one-sided for the narrowest swept path, the following expression for the confidence limit can be derived :

$$\mathrm{Yconf.} = \mathrm{Exp}\{y\} - \mathrm{Rel}\{y\} \quad (6)$$

As long as the confidence limit is still within the channel edge, the null-hypothesis may not be rejected. When the confidence limit is beyond the channel edge, the null-hypothesis should be rejected and the channel must be considered as insufficient wide for the set criterion.

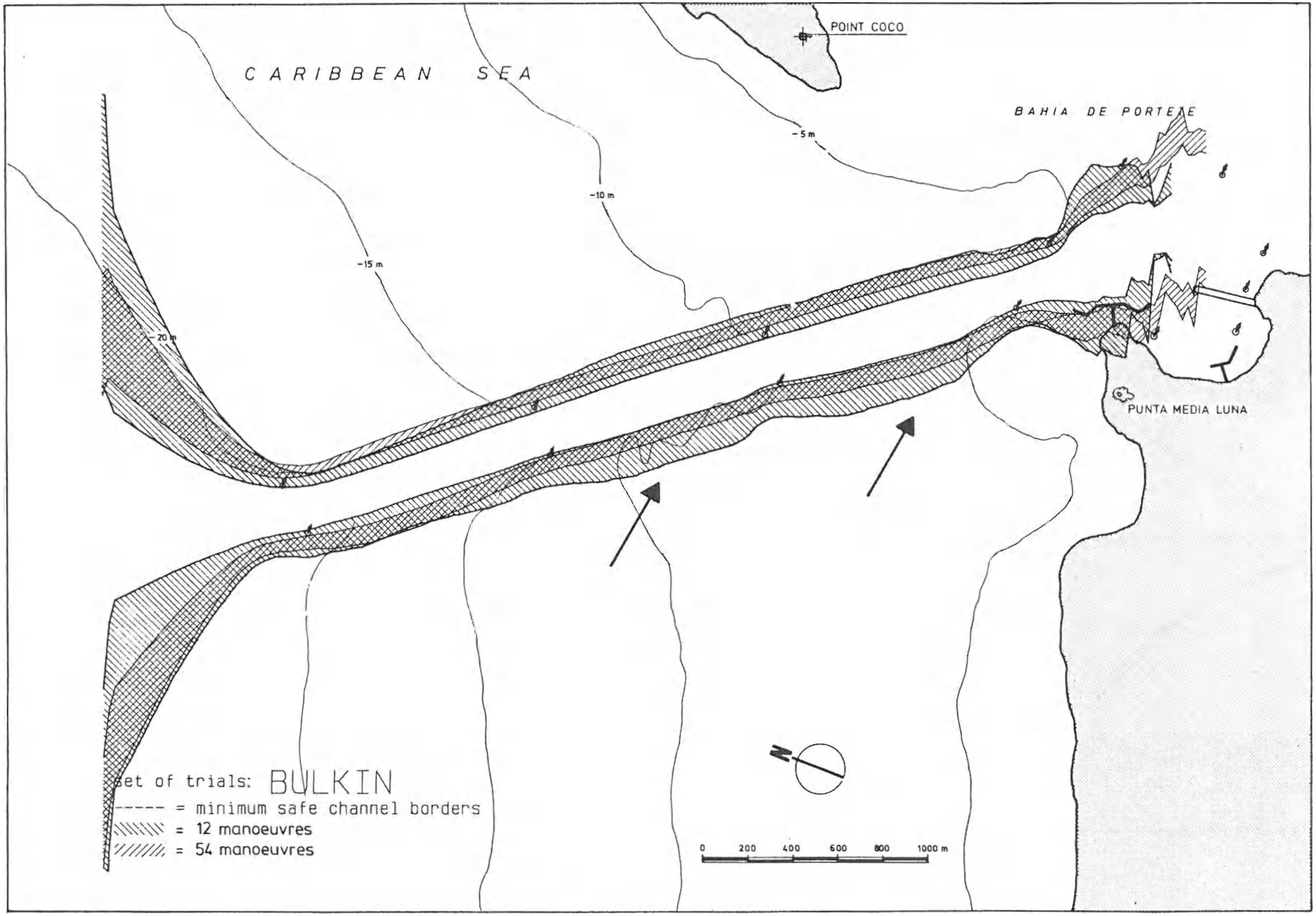



Figure 10 : Comparison of reliability belts of 0.1 percent exceedance frequency obtained from sample of 12 trials and sample of 54 trials

## 5. DISTRIBUTION OF THE SAMPLE

So far distribution of the sample has always been assumed to be normal. As long as the opposite cannot be proven, this is not a bad supposition. However, there are reasons to suppose that distribution is not normal but skewed sometimes.

A pilot may, in theory, remain in the middle of the channel; so distribution could be normal, with the average of the ship's center in the middle of the channel.

However, one might suppose that the closer the ship comes to the channel edge, the more the pilot will try to stay away from it. This could give a distribution as indicated in figure 11.

Let us call this distribution "skewed to the left side", meaning that the flattest side of the distribution is left of the average.

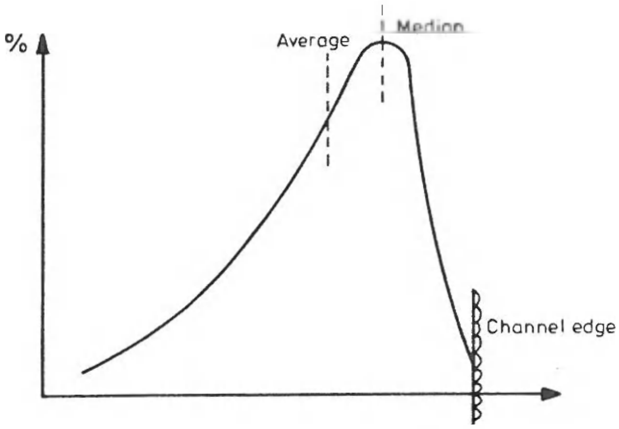



Figure 11 : Example of skewed distribution

Since the two sides of the ship are connected, the distributions at either side of the ship generally have skewnesses to the same side. However, they are not completely related, since we are dealing with distributions of the swept path, which is not only determined by the ship's excentricity in the channel, but also by her heading in relation to the channel axis. Distributions of either side of the swept path may therefore be oppositely skewed.

This means that there are reasons, which often we do not know, why the distribution is either positively or negatively skewed. This skewness should be taken into account, however, since we are otherwise likely to underestimate - when looking to the flattest side of the distribution - or overestimate - when looking to the steepest side of the distribution - the 1 %, 0.1 % etc., exceedance frequency values.

The procedure we apply is a transformation of the original distribution with a certain skewness, to a normal distribution (with zero-skewness) and we carry out all statistical elaborations with this normal distribution. Once we have determined the exceedance frequency values, we transform back to the original system.

The transformation principle resembles the phenomenon that it is impossible that the radius, surface-area and contents of a random number of spheres can all have a normal distribution, but that as soon as it is certain that one is normal, conclusions can be drawn about the other two.

Another item is the "kurtosis correction", as it is called. Kurtosis is a measure for the bell-shape of distribution; a normal Gaussian distribution has a kurtosis of 3. Kurtosis correction factors can be determined for distributions with deviating kurtosis values ([5] and [6]).

The final result is that transformations and corrections are carried out for skewness and kurtosis, respectively, after which the distributions can be treated as normal Gaussian.

These transformations and corrections should be carried out separately for every cross-section in which the ship passes.

## 6. EXAMPLES

We should now like to illustrate how wrong conclusions can be drawn from statistical maltreatment. We have used three cases in which prototype or simulator-investigations were made, and one imaginary case involving tests for research purposes only.

### A. PORT OF ZEEBRUGGE; APPROACH CHANNEL

The first case relates to the Port of Zeebrugge, Belgium (figure 12), where prototype measurements were carried out.

We can see the difference between statistical processing, using the correction for skewness, and omitting the correction for skewness, which is equal to assuming normal distribution. When distribution is corrected for skewness, a completely different picture results as far as the exceedance frequencies of the sample are concerned : in the bend, where water depth is still sufficient for some ships (container-vessels), distribution is skewed to the inner-bend. In the actual approach channel (below arrow), distribution is skewed to the downstream side of the channel. If skewness were not corrected, exceedance frequencies for the upstream (West) channel edge would be overestimated.

(It should be borne in mind that this analyses was also made for the two different types of vessels (VLCC's and container vessels) separately. This is necessary since the VLCC uses the approach channel over a greater distance than the container vessel. These separate analyses give the same effect in the actual approach channel, but in the bend it is different. In the bend there are, in fact, two different distributions : one for the container vessel, which is not bound to the channel, and one for the VLCC, bound to the channel. This is the main reason for skewness in the bend. This example is purely to illustrate the effect of skewness on exceedance frequency values).

In order to prove how well the distribution corrected for skewness compares with reality we have plotted in

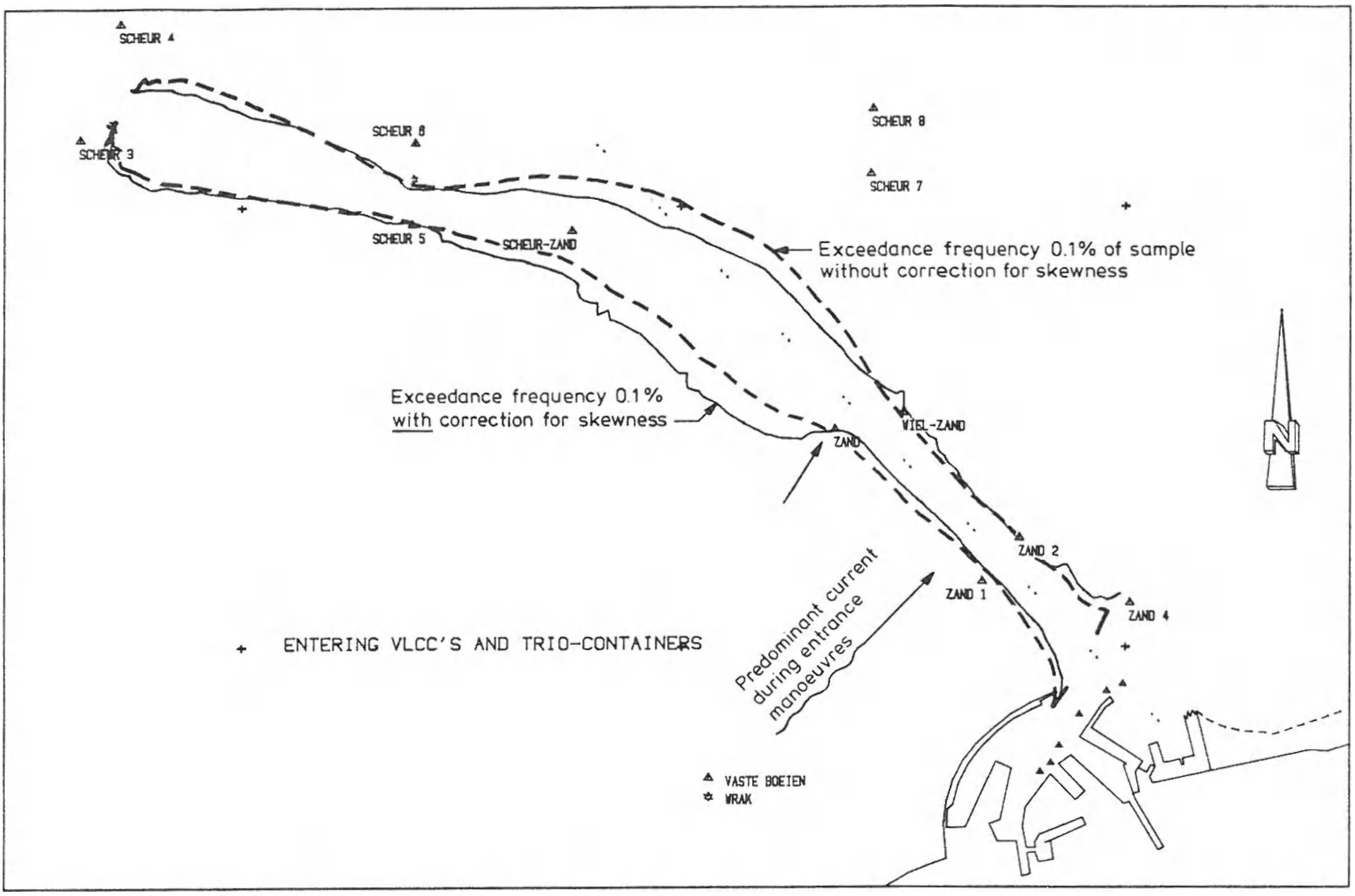



Figure 12 : Approach channel Port of Zeebrugge; comparison between distribution assumed as normal and real distribution

figure 13 the maximum swept path realized during the 40 prototype measurements and the 2.5 % exceedance frequency line, both corrected for skewness, and assuming a normal distribution.

The maximum realized during 40 trials should, in principle, be equal to the 2.5 % exceedance frequency, albeit that occasional deviations may occur. From figure 13, it is clear that the corrected distribution follows the reality very close, whereas the assumed normal distribution does not.

B. PORT OF SEATTLE; DUWAMISH WATERWAY

Figure 14 shows the situation, for an inland navigation channel, viz. the Duwamish Waterway in the Port of Seattle, Washington, U.S.A. It is clear that there is again a difference between statistical processing taking into account real distribution, and the assumption of normal distribution. In our experience, distribution in bends is mostly skewed to the outer bend. (The case of Zeebrugge was different for reasons already explained). This probably results from the method of steering of a ship : the aft ship is moving, and it seems fairly easy to keep the bows on track. However, this sometimes causes large deviations in the track desired for the stern.

Figure 14 shows that in one and the same cross-section the skewness for either side of the swept path may be opposite, and may, at both sides, produce an increase in the required width compared to normal distribution.

The two foregoing examples both relate to the exceedance frequency of the sample. The aim was to illustrate the difference between statistics using the real distribution, and statistics based on the assumption of normal distribution.

It is now interesting to see some examples of mistaken conclusions in deterministic statistics, where the distribution of sample and population are assumed to be equal.

C. PORT OF ANTWERP; APPROACH TO KALLO-LOCK

This example deals with an investigation regarding the entrance manoeuvre of a car-carrier to the outer port of Kallo-lock at Antwerp, Belgium.

In figure 15 we have given two 0.01 % exceedance frequency lines, both for a maximum flood condition, and both based on 10 trials. One line relates to a wind-force of 3 Bft, the other to 5 Bft, both from the same (North-Westerly) direction. The two lines in figure 15 are

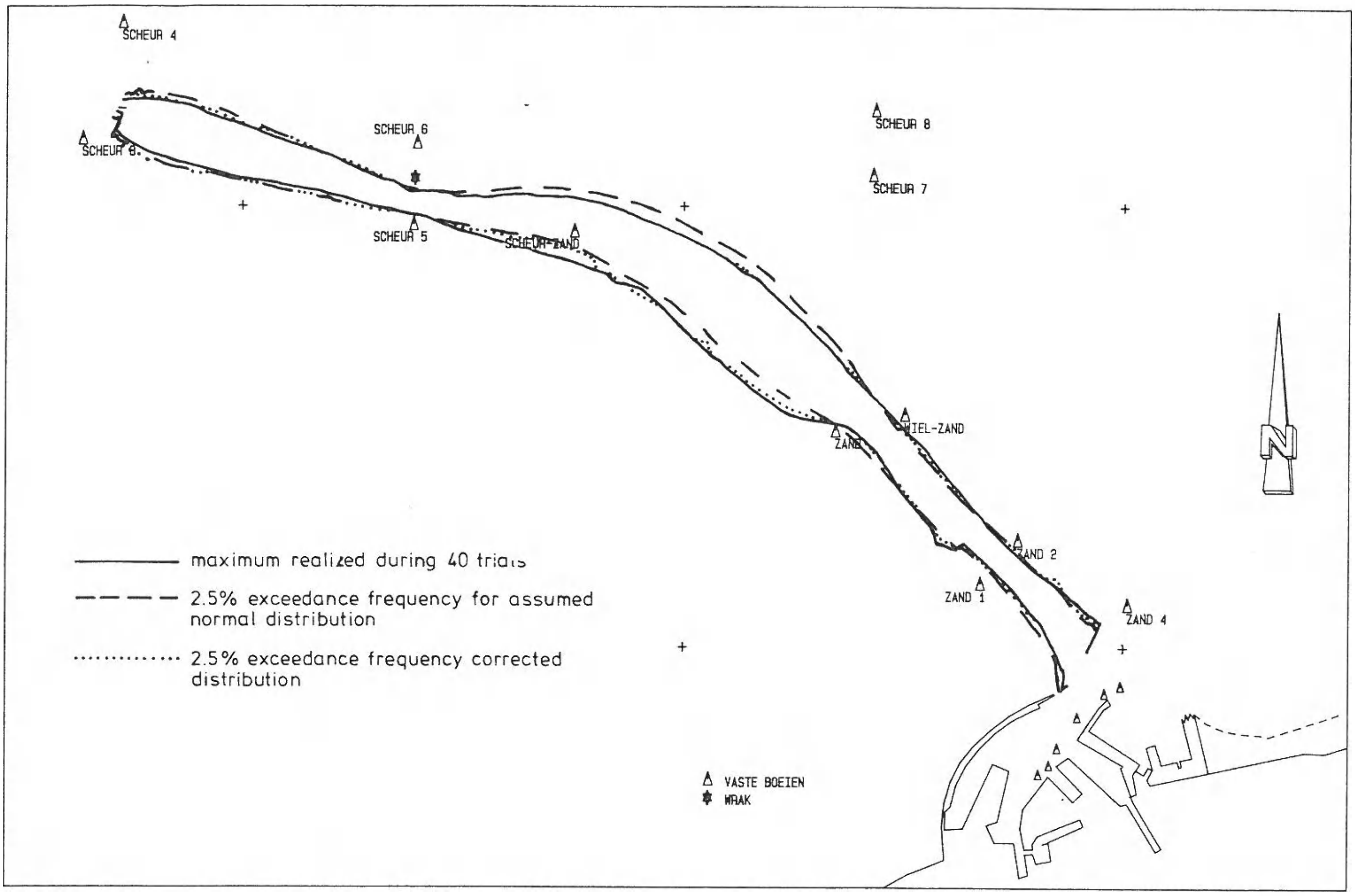



Figure 13 : Approach channel Zeebrugge; comparison real values with distribution assumed as normal and corrected distribution

exceedance frequencies of the sample, but in deterministic statistics would, erroneously, be considered as exceedance frequencies of the population. The incorrect conclusion would be that Bft 3 is a more severe condition than 5 Bft at the critical location indicated by the arrow.
In actual fact, Bft 3 is an easier condition for this ship (a 200 m long car-carrier with 30 m freeboard) and consequently the pilots were sailing less carefully. The outcome is a larger standard-deviation, which in turn means that the exceedance frequency line of the sample is further away at the critical point. However, the closer the pilot comes to this critical point, the more he can be expected to try and avoid it; this will influence distribution. Our supposition is that more trials for both cases would probably show that Bft 3 is indeed an easier condition.

Therefore, in figure 16 the minimum lines of the reliability belts (the confidence limits) are given, for both cases, of the 0.01 % exceedance frequencies.
From figure 16, the right conclusion can be drawn : the null-hypothesis that the critical point is sufficiently safe for a 0.01 % exceedance frequency cannot be rejected, either for a 3 Bft wind, or for a 5 Bft wind from NW direction.

D. EXPERIMENT WITH CURVED NAVIGATION LANE

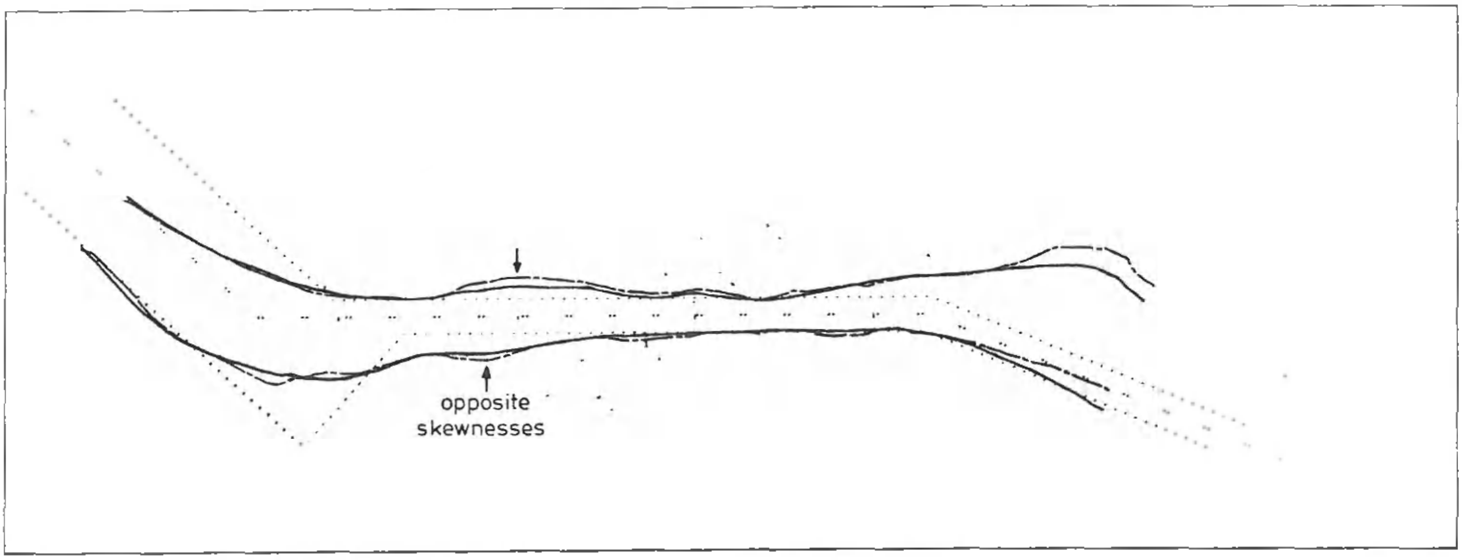
The last example involves an experiment made on the simulator; it does not relate to a real case.
We made tests in a curved navigation lane with different widths indicated by buoys, viz. 100 m and 200 m. Water depth was equal in all locations and current and wind had the same direction everywhere (current 0.5 m/s; wind 20 knots). The tests were made with a 21.000 dwt bulk carrier (170 m length).

In figures 17 and 18 the 1 % exceedance frequency lines of the samples (each sample consists of 26 trials) are shown (thick lines). Assuming that these sample lines are equal to those of the population - deterministic statistics - the inference would be that neither of the two lanes is wide enough for the 1 % criterion.
Just as we saw earlier, this conclusion is wrong : perhaps the wider lane is used to its full width, causing a larger standard deviation. The closer the pilot comes to the lane edge, however, the more he will try to keep his ship within it, and this influences statistical distribution. It may

again be possible that the standard-deviation for instance decreases when more trials are made.

The right conclusions can be drawn by taking the thin lines in figures 17 and 18, these lines indicating the reliability belts for the 1 % exceedance frequency lines of the populations. For the 100 m channel the hypothesis (i.e. the lane is wide enough for the 1 %-criterion) must be rejected. It cannot, in view of the test, for the 200 m channel.

1. It is not allowed to assume a normal Gaussian distribution for the swept path of ship passages in a channel. The skewness and kurtosis of the distribution must be taken into account. This can be done by transformation of the realized distribution to a normal distribution with zero-skewness and kurtosis 3.
2. The skewness of such swept path distributions is unpredictable, both in sign and magnitude.
   It is therefore necessary that skewness and kurtosis



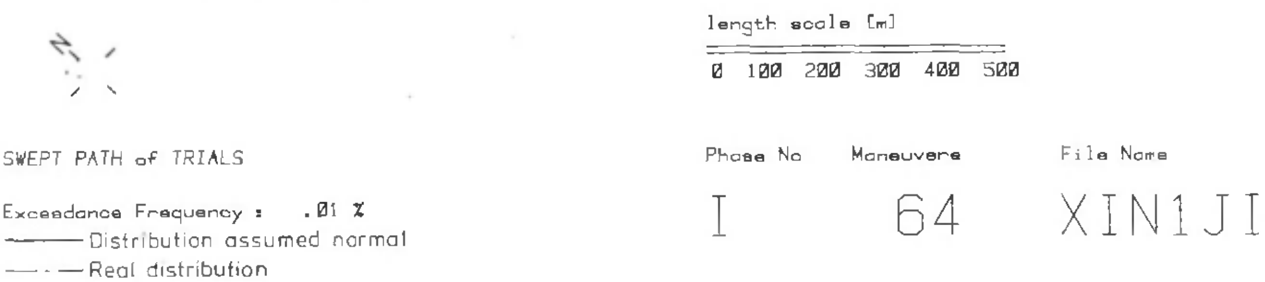




Figure 14 : Duwamish Waterway, Port of Seattle; comparison of different distributions

We decided to check whether a 300 m wide lane might still be insufficient based upon a deterministic 1 %-criterion, carrying out tests in this channel. The results are presented in figure 19, where both the 1 % value of the sample, and the reliability belt for the 1 % exceedance frequency of the population are given. In this case the deterministic 1 %-criterion did not mean that the lane was not wide enough.

The inference from the above is, that erroneously used deterministic statistics would have revealed that a lane of 300 m would just be sufficient, whilst, based upon the test, there are no terms to suppose that a lane of 200 m width is insufficient.

## 7. CONCLUSIONS

The following conclusions can be drawn from the foregoing sections :

correction are carried out for each cross-section separately.

3. Tests in a simulator and prototype measurements should be treated as tests, i.e. the results must be processed in terms of sample theory.
   This means that a null-hypothesis should be established, such null-hypothesis being that the channel edge will not be exceeded by more than 1 %, 0.1 %, etc. of the ship transits. The sample shall be used to reveal whether or not this null-hypothesis must be rejected.
   If the null-hypothesis cannot be rejected, based upon the test, it remains valid.
4. The number of trials in the sample must be sufficiently large in order to obtain a relatively narrow reliability belt. In the case of a relatively wide belt, the sample is not sufficient to decide on the validity

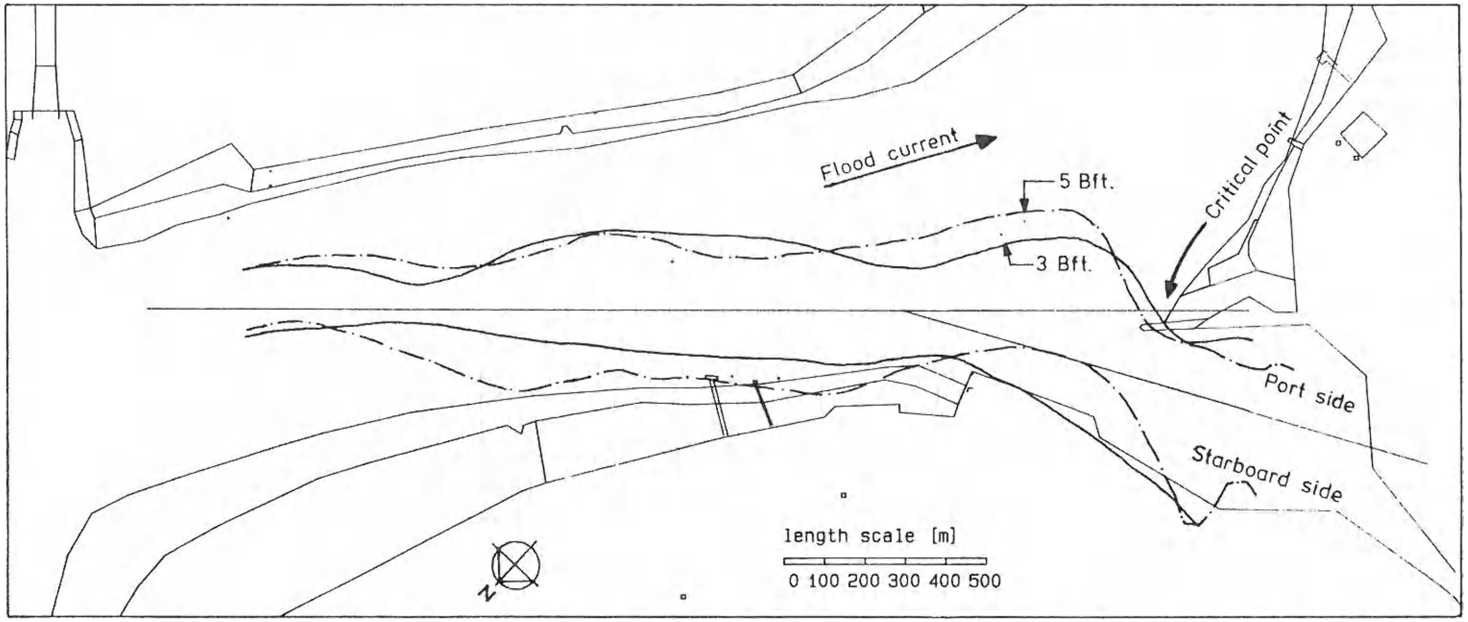



Figure 15 : Approach to Kallo lock, Antwerp;
sample exceedance frequency lines of 5 Bft and 3 Bft wind

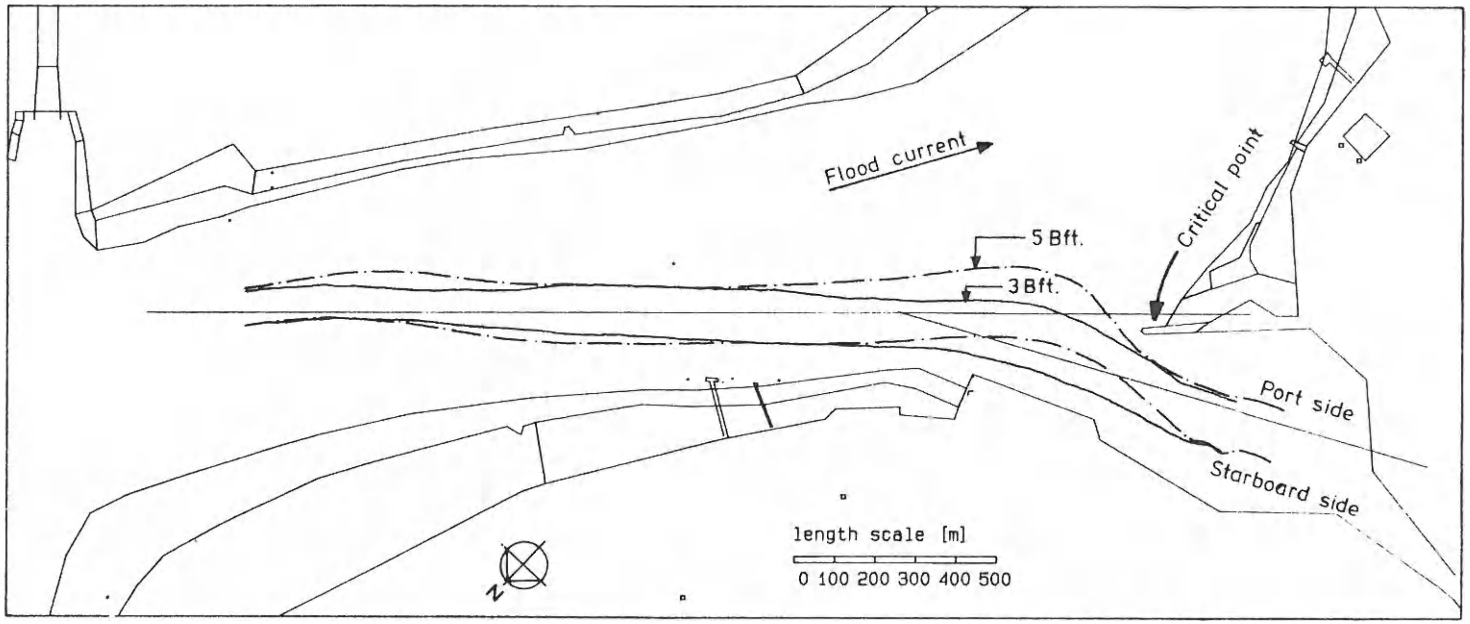



Figure 16 : Approach to Kallo lock, Antwerp;
confidence limits for 5 Bft and 3 Bft wind

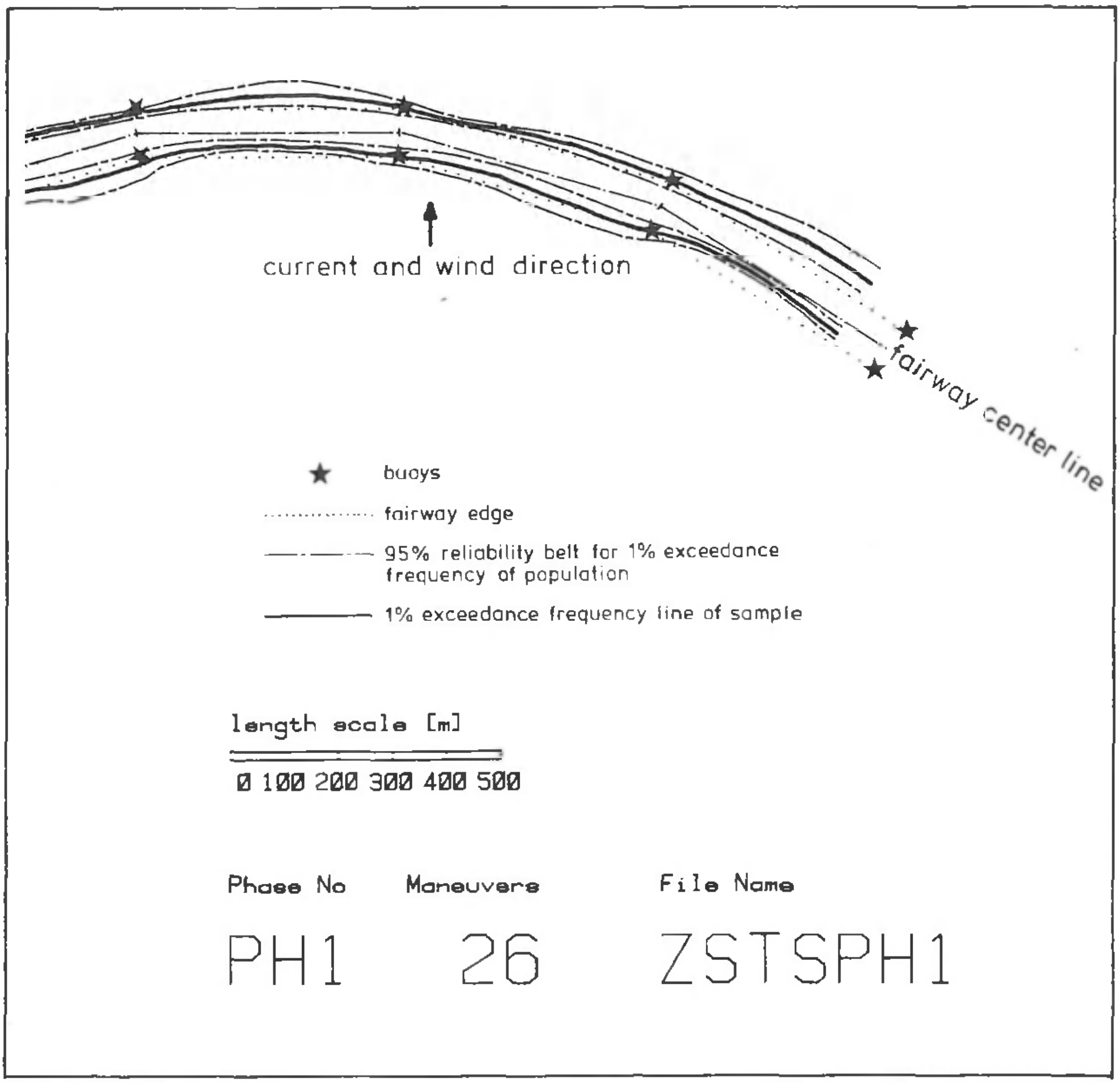



Figure 17 : Curved fairway 100 m width; 1 % exceedance frequency

of the null-hypothesis (the fact that the null-hypothesis cannot be rejected may also be due to the inadequacy of the sample).

A sample with a relatively large standard deviation requires a larger number of trials in the test, since the width of the reliability belt depends also on the standard deviation of the sample.

**BIBLIOGRAPHICAL REFERENCES**


1. BURGERS, A. A mathematical model for the calculation of the harbour entrance manoeuvre, 7th International Harbour Congress, Antwerp, May 1978.
2. BURGERS, A. and PEERLKAMP, K.P. On the determination of the width of harbour approach channels, 8th International Harbour Congress, Antwerp, May 1983.
3. KENDALL M. and STUART A. The advanced theory of statistics, Charles Griffin and Company Ltd., Volume 1, 1977, Volume 2, 1979.
4. YATES, F. Sampling methods for censuses and surveys, Charles Griffin and Company Ltd., London, 1981.
5. SHEN, H.W. Modelling of rivers, John Wiley and Sons, New York, 1979.
6. SINGH, K.P. Software design for a versatile flood frequency analysis, Adv. Eng. Software, 1983, Vol. 5, no. 2.
7. BOX, G.E.P. and TIAO, G.C. Bayesian inference in statistical analysis, Addison-Wesley, Reading, May 1973.

**RESUME**

Le traitement statistique des essais de manoeuvre de navires - soit par simulateur, soit par mesures sur prototypes - démontre souvent des fréquences de dépassement de l'extrémité du chenal qui ne sont pas conciliables avec l'expérience pratique. La raison en est un traitement statistique incorrect des résultats.

Lorsqu'un simulateur est utilisé pour déterminer la largeur d'un chenal d'approche, le simulatuer doit refléter correctement la réalité du double point de vue du comportement du navire et de la représentation de l'environnement visuel du pilote.

En dernier ressort, le traitement statistique des résultats se limite à l'analyse de la trajectoire parcourue par le navire (fig. 7). Cette analyse devrait être réalisée en toute conscience du fait que l'on ne dispose pour ce faire que d'un nombre limité d'essais. En conséquence, en effet, il n'est pas possible de préciser exactement l'endroit d'un chenal où survient une certaine fréquence de dépassement. Il faut donc considérer les résultats d'essais sur simulateurs ou de mesures sur prototypes comme un échantillon de taille limitée qui ne peut donner qu'une indication de la population concernée qui est quant à elle, en principe, illimitée.

Sur la base de cet échantillon, il est néanmoins possible de tracer une zone de fiabilité pour une certaine fréquence de dépassement de la population, zone d'autant plus précise que l'échantillon est grand. En outre, la largeur de la zone dépend de l'erreur-type de la trajectoire parcourue ainsi que de la fréquence de dépassement envisagée.

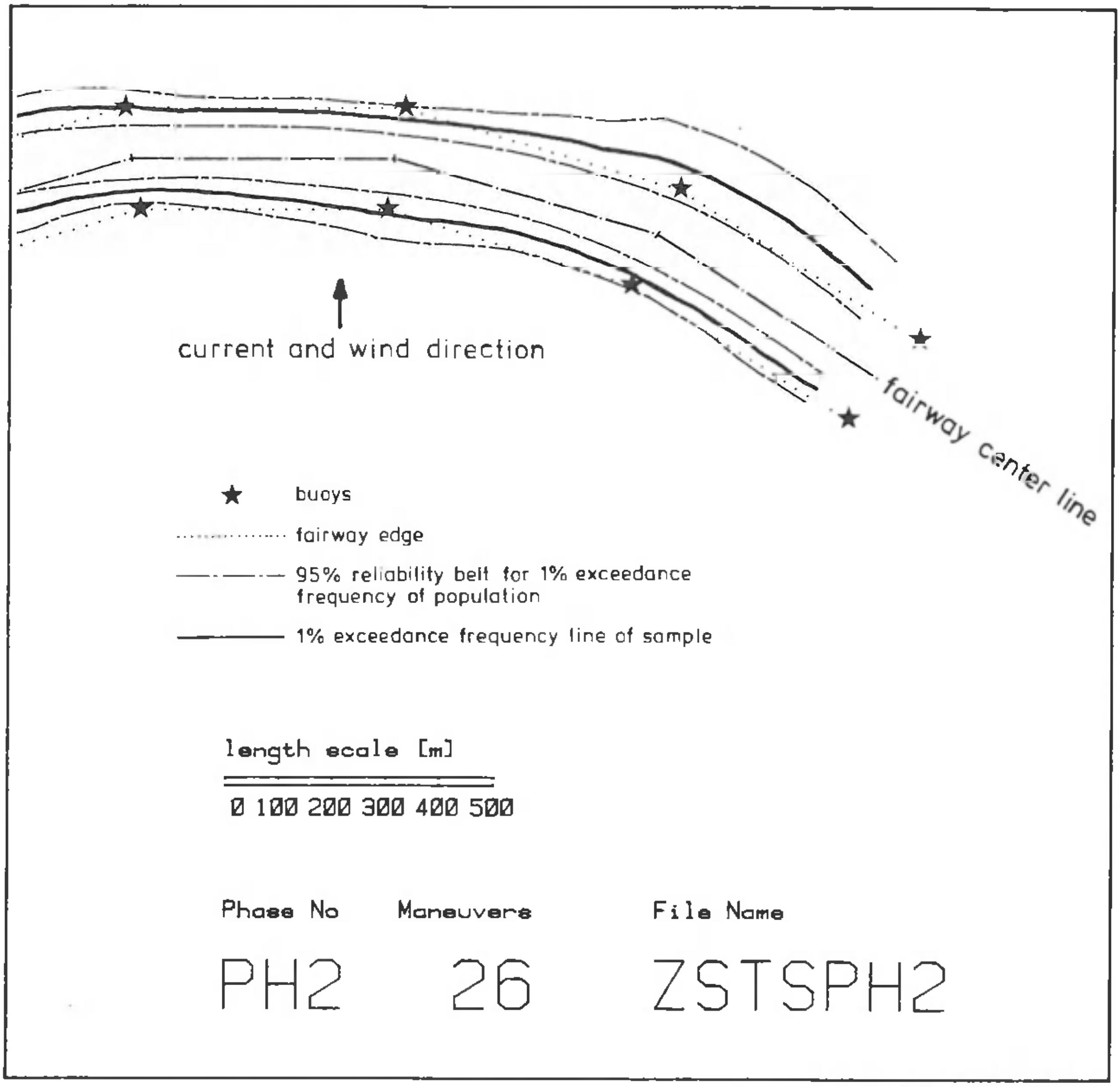




Figure 18 : Curved fairway 200 m width; 1 % exceedance frequency

Cette fréquence de dépassement doit être déterminée en tout premier lieu. Ceci est possible sur la base d'une probabilité globale acceptable d'un ou de plusieurs talonnements au cours d'une période donnée, de 20 ans par exemple (fig. 8). Une fois déterminée cette fréquence de dépassement individuelle, le chenal est supposé répondre à ce critère. C'est ce qu'on appelle l'hypothèse nulle, hypothèse qui *demeure valable aussi longtemps* que l'échantillon ne démontre pas le contraire.

L'hypothèse selon laquelle la distribution statistique est normale est en fait souvent incorrecte. Dans de nombreux cas, la trajectoire parcourue répond à une distribution asymétrique dotée d'une convexité s'écartant de 3. La prise en considération de cette asymétrie et de cette *convexité déviante de la normale* conduit à des résultats très proches de la réalité (fig. 13). Asymétrie et convexité peuvent être neutralisées en transformant les distributions originales en distributions normales.

On donne des examples des différences de traitement statistique lorsqu'on suppose une distribution normale et lorsqu'on tient compte de l'asymétrie et de la convexité déviante. L'hypothèse d'une distribution normale conduit quelquefois à une sous-estimation et quelquefois à une sur-estimation de la sécurité. En d'autres termes, le chenal n'est pas assez large en certains endroits et trop large en d'autres.

On donne aussi des exemples de respect des statistiques dites "déterministes" qui ignorent toute zone de fiabilité, ce qui conduit à des conclusions erronées : l'approche de l'hypothèse nulle eût donné de meilleurs résultats. Le dessin de la zone de fiabilité atteste en outre la qualité de l'énoncé sur la fréquence de dépassement et permet d'éviter de fonder des conclusions trop radicales sur un échantillon trop petit.

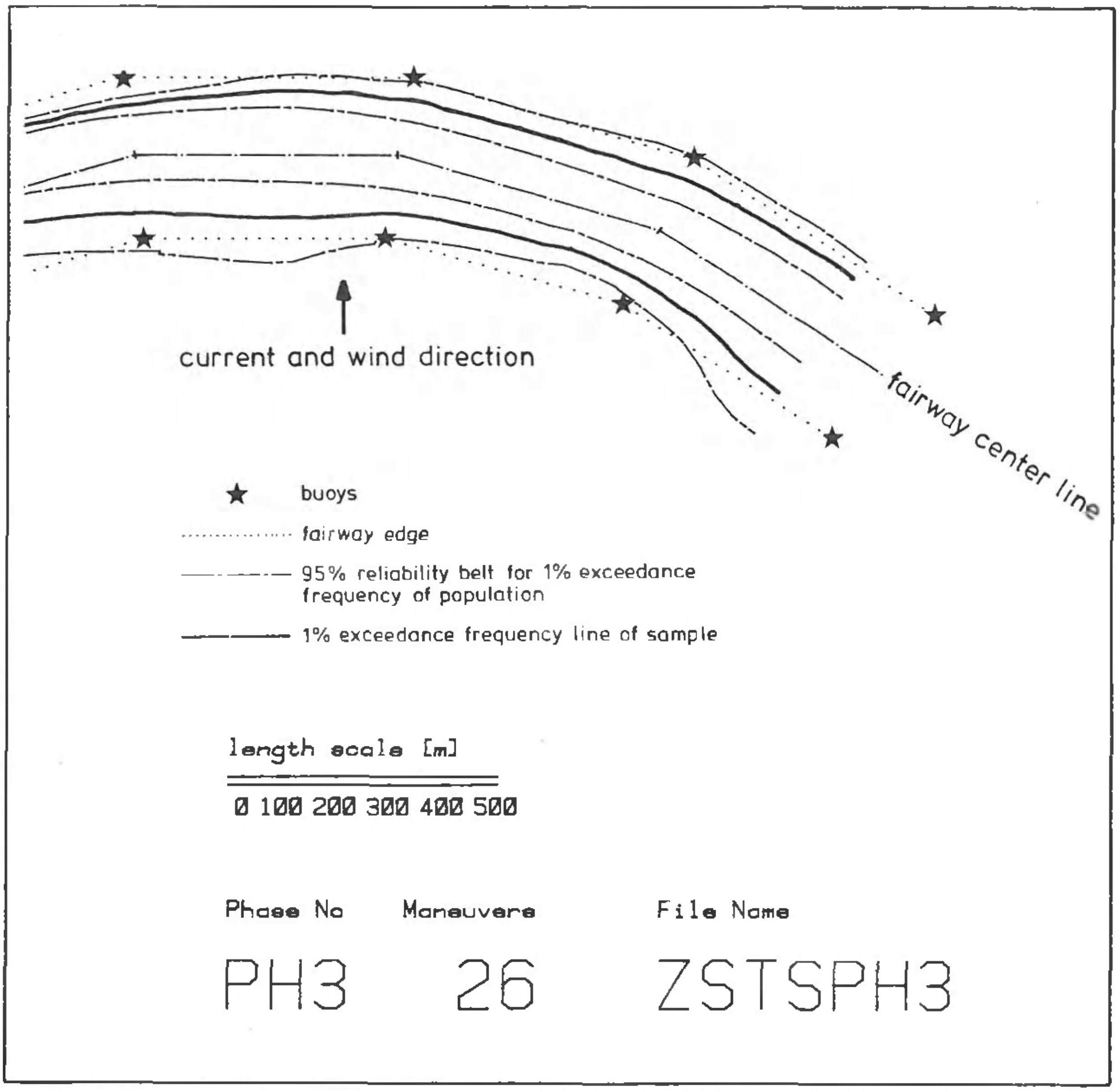



Figure 19 : Curved fairway 300 m width; 1 % exceedance frequency