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Manoeuvring trials

An evaluation of existing codes, trials and measuring techniques and recommendations for future performance of manoeuvring trials.

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Contents

Summary

This Report contains an evaluation of the present codes for the performing of manoeuvring trials, together with a summary of current knowledge of manoeuvring trials and measuring techniques.
In considering manoeuvring trials from a more scientific point of view, the criteria that have to be met in carrying out the tests have been reviewed. Operational data are obtained from the majority of manoeuvring tests. The collection of these data should be standardized and some recommendations in this respect have been put forward.

1. Introduction

It may reasonably be expected that in the course of the coming years the manoeuvring properties of surface ship's will be judged more and more against the background of safety- and operational standards. It seems advisable therefore to deal with the problem of a ship's manoeuvrability in terms of standardized data concerning the ship's manoeuvring characteristics on the one hand and the development of operational yardsticks on the other.
Since World War II, a number of attempts has been made to standardize the procedures in use in ship's trials. The SNAME-codes (1,2,3) are well known and they were published in 1949, 1950 and 1952 respectively. In 1973, these codes were superseded by the SNAME-code for Sea Trials (4). This last-named code provides definitive information on a ship's sea-trials which are needed to demonstrate that it will perform as specified in the construction contract.
Other organizations also issued codes for manoeuvring trials. The I(nternational) T(owing) T(ank) C(onference) published a revised edition of a manoeuvring code in 1975 during its 14th session in Ottawa (5). It may be assumed that, when towing tanks are involved in manoeuvring trials, these tests will be performed in accordance with the tentative rules contained in this code.
The B(ritish) S(hip) R(esearch) A(ssociation) developed a manoeuvring code which was meant to guide manoeuvring trials with British owned and British built ships (6). The methods of recording the required data were also indicated. They should be adopted in order to obtain a reliable indication of the stopping, steering and manoeuvring performance of a ship.
A certain sequence in the trials has been suggested in order to take into account the time consuming character of the trials as well as the desired priority of information needed to accomplish the ship's mission both safely and economically.
Det Norske Veritas published "Tentative Rules for Navigational Aids and Bridge Systems" (7)
Section 8 of these rules is devoted to testing on board and contains, in part D, information dealing with manoeuvring trials. It is stated that the articles contained in part D comply with the IMCO-Resolution A160 of 27th November 1968, "Recommendations on data concerning manoeuvring capabilities and stopping distances of ships", which can be found in Appendix I.

These various codes have in common the desire to standardize procedures in use during manoeuvring trials. However, they are somewhat different in their approach. The SNAME-code seems to be versatile instrument in designing a trial program which must satisfy different requirements. The B.S.R.A. code is lucid and brief, but the method of standardization adopted is not always particularly well suited for ships which have to accomplish special missions. The I.T.T.C. code has been formulated primarily for the acquisition of data during full-scale trials which also have been measured during the ship's model tests or have been predicted by numerical methods in use by ship-model tanks. The correlation of model- and ship results will provide refinements in model tests procedures and numerical calculation methods.
The Norske Veritas code provides rules for all navigational aids and bridge systems. A letter of compliance is issued when all requirements have been met, with the possible implication of deductions in insurance premiums.

A number of papers deal with the problem of establishing manoeuvring criteria. This problem is hardly solvable, generally speaking, when the ship's mission is not known. Therefore for normal surface ships a broad range of permissable values of turning circle diameter ratios and overshootangles in standard zigzag trials exist.
The development of the criteria occurred primarily on a comparitive basis. A standard ship with known manoeuvring characteristics, judged satisfactory by expert and experienced navigators is used as a reference ship.

When a specific ship performs the trials the results measured are compared with the behaviour of the reference ship. A qualitative measure can then be derived such as:" Steering and manoeuvring properties are satisfactory".

Warning :

The point is here explicitly stressed that this Report considers manoeuvring trials only. No reference has been made at all to shipyard/ classification society/supervising authority acceptance trials.

2. Survey of codes

2.1 The I.T.T.C.-code

The new I.T.T.C.-code, successor to that of 1963, was discussed during the 14th conference held in Ottawa in 1975.
The 1963-code dealt primarily with turning circles, zigzag tests, spiral manoeuvres and change-of-heading tests. Since ship-sizes had increased dramatically and since a variety of new ship-types had appeared, sometimes with very special manoeuvring aids and devices, the need arose for the 1963 code to be reconsidered. In the meantime, modeltesting and prediction techniques, as well as theoretical methods of calculating manoeuvring properties improved to such an extent that, from this point of view, it seemed advisible to adapt the 1963 code.
A number of new tests have been devised to check the ship's ability to perform special duties. Among these are: the ruddercycling test, the pull-out manoeuvre, reverse spiral test and a number of tests with special emphasis on the performance of side thrusters.
In devising the new I.T.T.C. code the recommendations of the I.M.C.O., formulated in a resolution of 12th October 1971 (Appendix 2) were taken into account. From a safety point of view, the following information is needed:

- i the lowest constant engine revolutions per minute at which the ship can steer under normal operational conditions, ballasted as well as loaded to permissable draught.
- ii change of heading diagrams and turning circles to port and starboard indicating advances, transfers and other relevant parameters using maximum rudder from full speed to low speed with constant engine control settings.
- iii turning circles from full speed with maximum rudder and engines stopped.
- iv the approximate time and distance a vessel will travel with a minimum application of rudder if it retains its initial heading at full speed when full astern power is applied.
  The test should be performed in both loaded and ballasted condition. It is recommended to repeat the tests with various levels of astern power as well as with various approach speeds.

All this data should be recorded for calm weather conditions with no current in deep water with a clean hull. These environmental conditions should be clearly displayed in all information gathered.
A warning should be given that the vessel's response may change significantly under different conditions primarily shallow waters.
In Table 1 the manoeuvring test as recommended by the I.T.T.C. are shown.

Manoeuvring trials codes

	BSRA	SNAME	DnV	10th ITTC	14th ITTC
Crash-stop (AV) at full speed	x	x	x		x
Stopping trial at low speed					x
Coasting stop test			x		
Crash-stop (AR)		x			
Stopping by use of rudder			x		
Turning test at full speed	x	x	x	x	x
Turning test at medium speed					x
Turning test at slow speed	x		x		x
Turning test with propulsion stopped			x		
Turning test from zero speed	x				x
Pull-out	x				x
Weave manoeuvre	x				
Zigzag	x	x	x	x	x
Direct spiral	x			x	x
Reverse spiral	x		x		x
Statistical method	x				
Change of heading				x	x
Lateral thruster:					
- Turning test			x		x
- Zigzag test, ahead			x		x
- Zigzag test, astern			x		x
- Course-keep test, astern			x		x

2.2 The S.N.A.M.E.-code

Originally there were four codes dealing with seatrials issued by the S(ociety) of N(aval) A(rchitects) and M(arine) E(ngineers). Panel M-19 was requested to combine, update and expand these codes whilst taking the following points into account:

- i the need to cope with technological advances during the last two decades, such as the development of radiometric tracking which has revolutionized standardization and manoeuvring trials
- ii the desirability of combining the codes under a single cover and format
- iii the increased use of diesel and gasturbine propulsion systems which were not previously covered
- iv the desirability of having a sea trial code which could be utilized by a variety of official organizations throughout the world.

The basic concept followed in preparing this new code was to provide information on a variety of sea trials and tests to enable the owner or acceptance authority to choose those trials, suitable for the type of ship and operation involved. Positive contractual invocation of specific trials is recommended rather than having them invoked as a package without proper examination. This avoids burdening the industry with expensive trials not needed by the owner. The code does however provide a list of trials recommended as necessary to demonstrate that the ship as built and delivered will perform as specified.

The code is advisory only and there is no implication of warranty by the Society that a succesful performance of the trials ensures that the ship will comply with the requirements of the contract specifications or that she performs satisfactorily and safely in service.

The trial objectives can be summarized as follows:

- i demonstration of operability
- ii demonstration of performance
- iii demonstration of endurance
- iv demonstration of economy
- v provision of operating data
- vi provision of forensic data
- vii provision of design data

The following remarks can be made as regards the foregoing points:

- ad i all systems can be shown to operate in their design modes only at sea. A proper operation verifies the correctness of construction, manufacture and installation.
- ad ii attainment of maximum contract levels is important to verify the adequacy of the design of the propulsion plant and supporting auxiliaries. It is important to recognize that draught-dependent variables, such as the ship's speed and manoeuvring capabilities are of limited value when the ship is not at the proper displacement. When modeltests are available it is important that the trials be performed as close as practicable to the modeltest conditions so as to facilitate extrapolating. In the absence of modeldata standardization at other than maximum draught is not advisable.

ad iii demonstration of ability to maintain maximum power and speed for sufficient time to develop equilibrium conditions and to operate for the prescribed period without failure of system components is important for every ship.

ad iv demonstration of the contracted specific fuel consumption is mandatory,when there is a penalty involved.
Attainment of the best possible fuel consumption is important, when there is a bonus involved.

ad v it is desirable to establish a data baseline for a new class of vessel and to a lesser degree for individual ships,so that a standard can be determined for comparison with current operating data.

ad vi it is important for ship operators to have available certifiable data on a ship's manoeuvring capabilities, in the event of the ship being involved in legal action for collision damage.
Data from other shipsystems may be pertinent to litigation involving habitability safety or pollution responsibilities.

ad vii all this data augment the design data and can help to assess the succes of an innovative feature.

Blanket invocation of the code is not intended. Sufficient tests and trials are included to enable the user to select sea trials of any degree of complexibility desired, but invocation of the total code without regard to the objectives to be served or to the utility of data obtained would result in costs incommensurate with value obtained.

2.3 The B.S.R.A. code

The Code of Procedure for Steering and Manoeuvring Trials describes the data required from steering and manoeuvring trials. Because of the time-consuming character of a number of specific trials,an order of priorities for various manoeuvres is suggested.
This code has been established thanks to the heightened interest in the steering and manoeuvring of ships in recent years. The main reasons for performing manoeuvring trials can be summarized as follows:

i to determine whether the performance of the ship is satisfactorily from a contractual point of view
ii to provide the ship's Master with information on the handling characteristics of his vessel
iii to obtain scientific data which can be used to compare ships' performances and to improve methods of predicting manoeuvring characteristics.

The measuring trials are divided into three sections:

i stability trials furnishing information on straight-line or controls fixed stability *
ii steering trials
iii stopping trials

The priority for the manoeuvres to be executed has been suggested as follows:

i stopping trials
ii turning circles, including those from a standstill
iii pull-out manoeuvres
iv weave manoeuvres
v zigzag manoeuvres
vi spiral manoeuvres

* For definition of these quantities see paragraph 5.2

2.4 Det Norske Veritas Code

The Tentative Rules for Navigational Aids and Bridge Systems contain a section devoted to testing on board. Part D of this section 8 treats the manoeuvrability. It is assumed that the ship's loading conditions during the tests are as for normal service operation. Exceptions may be possible when modeltests are available to compare actual and predicted performance and thus allowing an estimate for the deep draught condition with regard to the manoeuvring properties. The tests should be conducted in waters having sufficient depth to avoid shallow-water effects. Wind and sea conditions should be as calm as possible but should not in any event exceed the following maximum values:

Ships having a length $\geq$ 150 m
Sea 4, wind 5;
Ships having a length $<$ 150 m
Sea 3, wind 4

All the data collected during the trials is to be documented in a simple and concise manner for practical use on board.
Trials at low speed are recommended to verify the performance of side thrusters.

3. Survey of trials

3.1 Introduction

In this section, an extensive account of known manoeuvring trials is provided.
Each paragraph describes a trial, and a scale is provided indicating the value of the test considered from a scientific, as well as a nautical point of view.
Another scale is provided indicating the experience gained from this test.
The marks of the first scale range from:
excellent, good, moderate to small.
The marks as regards the experience with the tests range:
much, moderate and none.

3.2 Description of a number of manoeuvring tests

3.2.1. Turning circle

The execution of a turning circle test is obvious. The most important definitions associated with this test are depicted in the following figure. (Fig 1)
Besides these quantities the following data is important

- turning time through 10 degrees change of heading
- ,, ,, ,, 90 ,, ,, ,, ,,
- ,, ,, ,, 180 ,, ,, ,, ,,
- ,, ,, ,, 270 ,, ,, ,, ,,
- ,, ,, ,, 360 ,, ,, ,, ,,
- speed drop at 90 degrees change of heading
- ,, ,, ,, 180 ,, ,, ,, ,,
- ,, ,, ,, 360 ,, ,, ,, ,,

It is advisable, when practicable, to record continuously the heading and the rate of change of heading.
Since speed logs, such as EM-log and Pitottube logs are very sensitive for crossflow effects, the accuracy of readings is low and, consequently, the results may be very erratic.

Turning circle may be executed in different modes:

i with maximum rudder and unchanged fuel supply or throttle setting for a number of different approach speeds
ii with maximum rudder and maximum power available from a complete standstill
iii with maximum rudder on a normal approach speed and the fuel or steam supply shut down.
iv with a number of specific rudder angles with constant fuel supply or throttle settling at various approach speeds.
v with rudder amidships at low speeds and full power of the side thruster.

Scientific value	: excellent
Nautical value	: excellent
Experience gained	: much

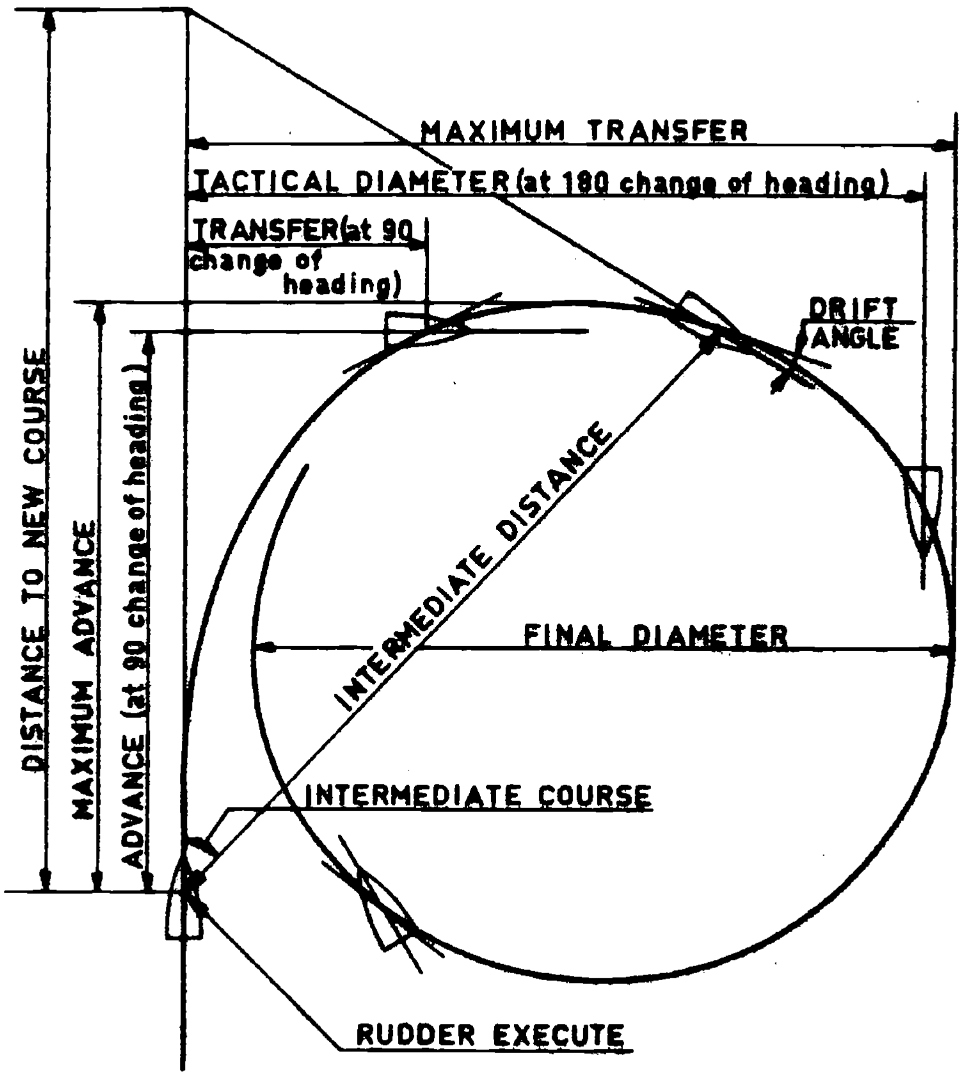

Fig. 1: Definition of important turning circle parameters

3.2.2 Zigzag trial

The zigzag trial was introduced by Kempf (8) in 1944, and this test is used to investigate the course changing abilities as well as the abilities to check a swing.
The execution of this test is shown in Fig. 2 together with a number of characteristic quantities.

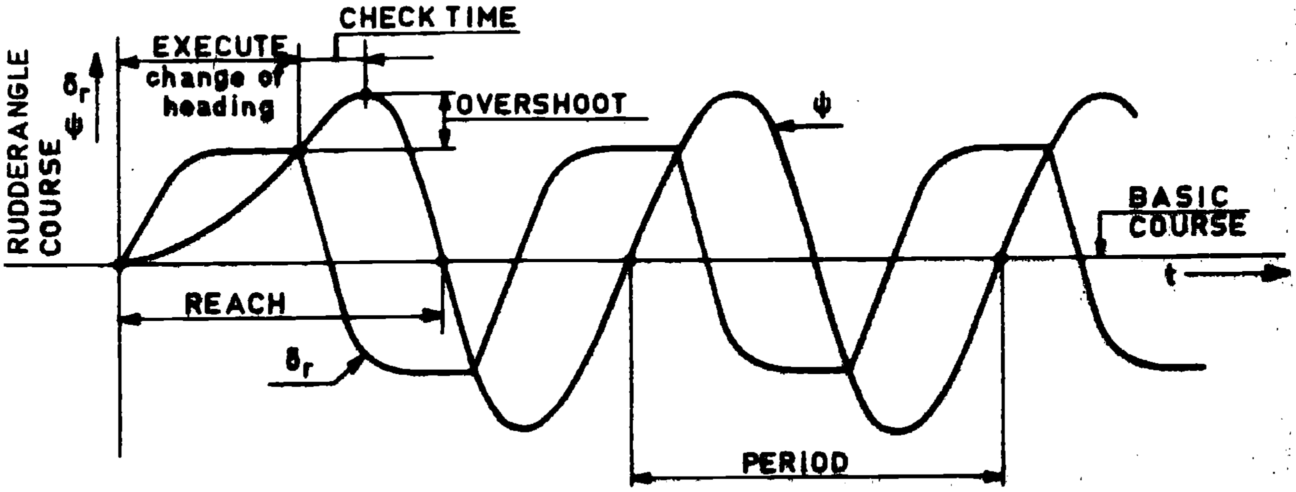

Fig. 2: Definition of some important parameters in a zigzag trial.

The zigzag test is normally terminated when three full cycles have been executed.
For scientific purposes, such as modelmatching technique on the basis of input-output relations,the recordings of time histories of the ship's heading, the rate of turn and the rudder angle should be available and measured with high precision instruments.
Speed recordings, when determined with shipborne sensors, suffer from the same deficiencies as was mentioned earlier.
Comparison with numerical predictions of theoretical models of ship manoeuvrability requires also a precise measurement of the ship's histories, although a measurement every second does not seem to be necessary.

Scientific value	:	good
Nautical value	:	moderate
Experience gained	:	much

3.2.3 Overshootangle test

The overshootangle test can be considered as a special modification of the zigzag test. Special emphasis is placed upon the ship's ability to check a swing with maximum counterrudder.
The next Figure displays a typical example of the overshootangle test. The rudder angle is reversed at the moment that the course change reaches 20 degrees.
The overshootangle may be considered as a measure of the ship's checking ability.
The execution of this test is simple and the total testing time is small. This test provides very useful information as regards: time to initiate a turn and checking ability.

Scientific value	:	moderate
Nautical value	:	excellent
Experience gained	:	moderate

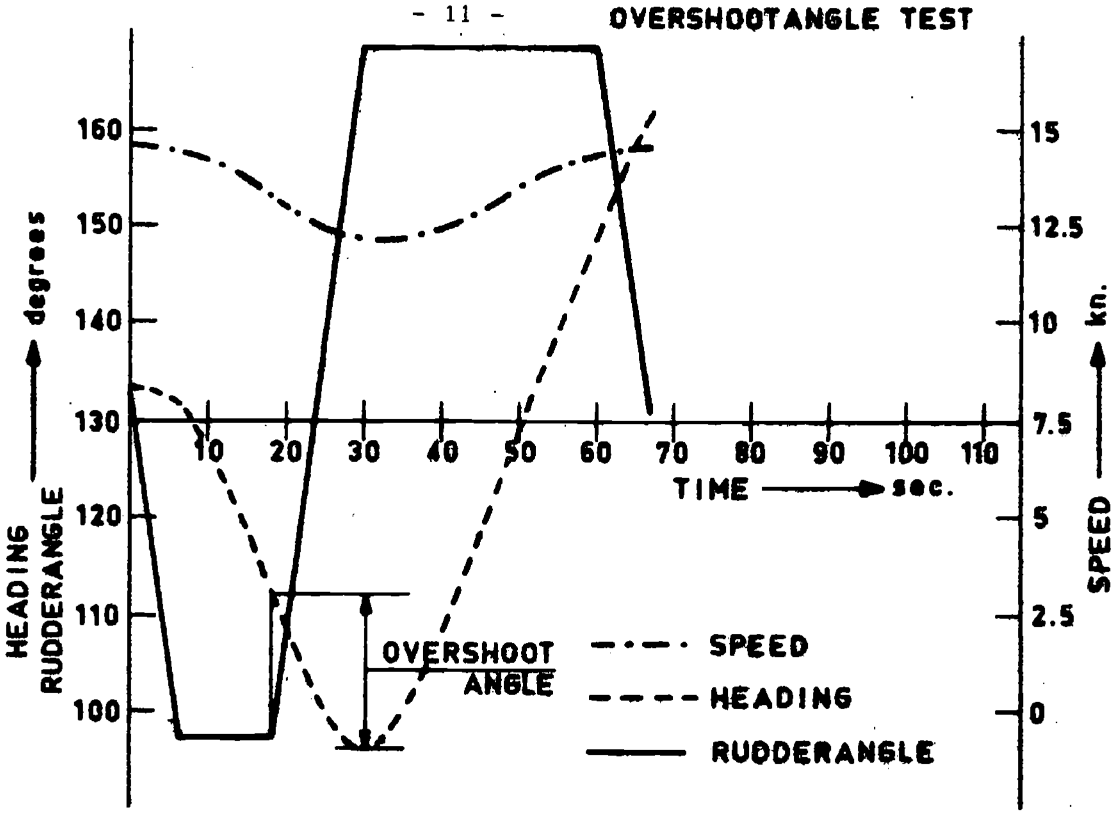

Fig. 3: Overshootangle test: first swing initiated with full rudder and maximum counterrudder is applied.

3.2.4 Course change test

Reference as regards this test is made to (9) where a proper description is provided. This test is meant to provide quantitative information for a ship's course changing abilities. The ship is steered from an initial course to a new course as Fig. 4 indicates. The rudder is put to 20 degrees and as soon as the heading change reaches 20 degrees counterrudder is applied until the ship's rate of change of heading becomes zero. Thereafter the rudder is put amidship's.

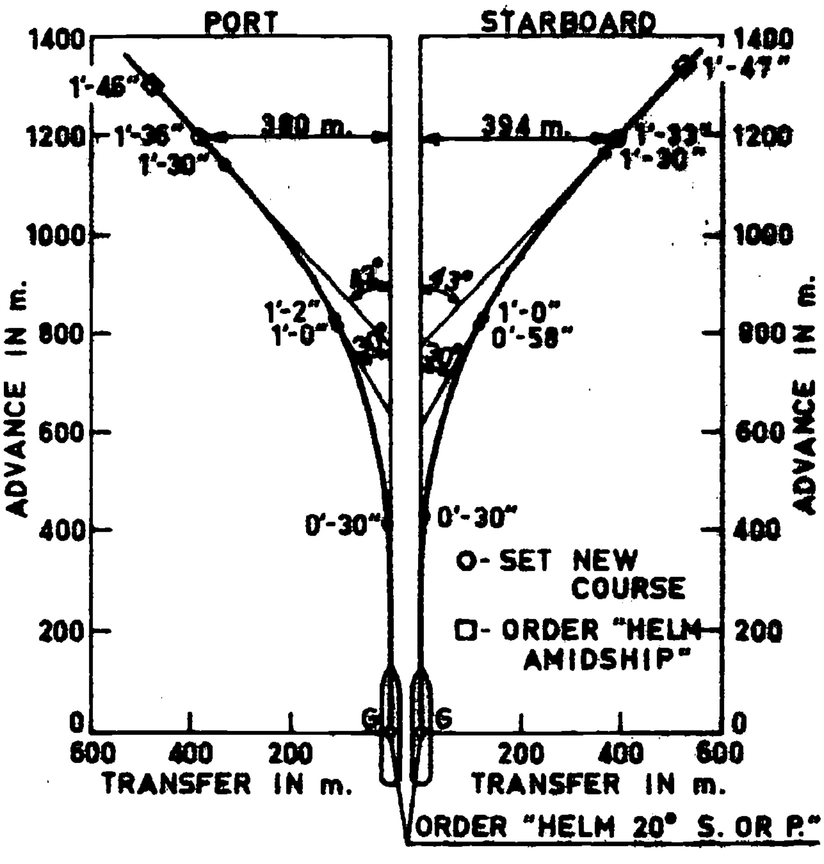

Fig. 4: Course change test.

The following quantities are of primary concern:

i the ship's heading change after one minute
ii the final change of heading
iii the distance between the point where the ship is steady on the new heading perpendicular to the base course together with the total time needed for the manoeuvre
iv time and magnitude of rudder calls applied

Scientific value	:	moderate
Nautical value	:	good
Experience gained	:	none

3.2.5 Modified zigzag trial

This test has been devised by Fujino and Motora (10,11). They considered that the results of straight line unstable ships performing small zigzag manoeuvres tend to diverge and fail to produce steady results. Therefore,it was suggested that small rudder angles with very small switch angles be used indicated in Fig. 5 below.

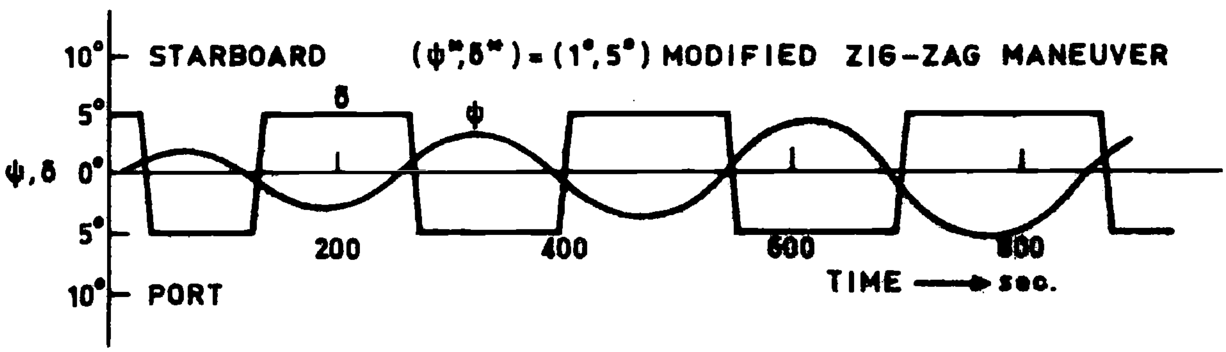

Fig. 5: Modified zigzagtrial; rudderangle 5 degrees, switch angle 1° degree.

It thus becomes possible to bring the diverging motion to a steady state. Critical combinations of rudder angle and heading angle may be obtained within which the zigzag motion will converge. This test puts special emphasis on open loop steering problems. The analysis will greatly facilitated by having the signals on magnetic tape for easy data handling.

Scientific Value	:	excellent
Nautical value	:	small
Experience gained	:	none

3.2.6 Weave manoeuvre

This test was devised by Burcher (12) and the results are associated with the straight line stability. The execution of the manoeuvre is as follows: the rudder is put to port and starboard respectively. If the amplitude of the rudder movement is smaller than the halfwidth of the hysteresisloop characteristic for straight line unstable ships, the ship will not change its heading enough to change the sign of the rate of turn. When larger amplitudes of the rudder motion are applied, the ship behaves in a normal fashion.
A disadvantage of this method is the difficult execution of the manoeuvre, especially for large ships. A sufficiently long time is needed in order to create a possibility to respond to a change of rudder, since large ships usually have large time constants. Confusion can arise in the mind of the leader of the test as regards the waiting time when a change of rudder position is ordered.

Scientific value	:	good
Nautical value	:	none
Experience gained	:	none

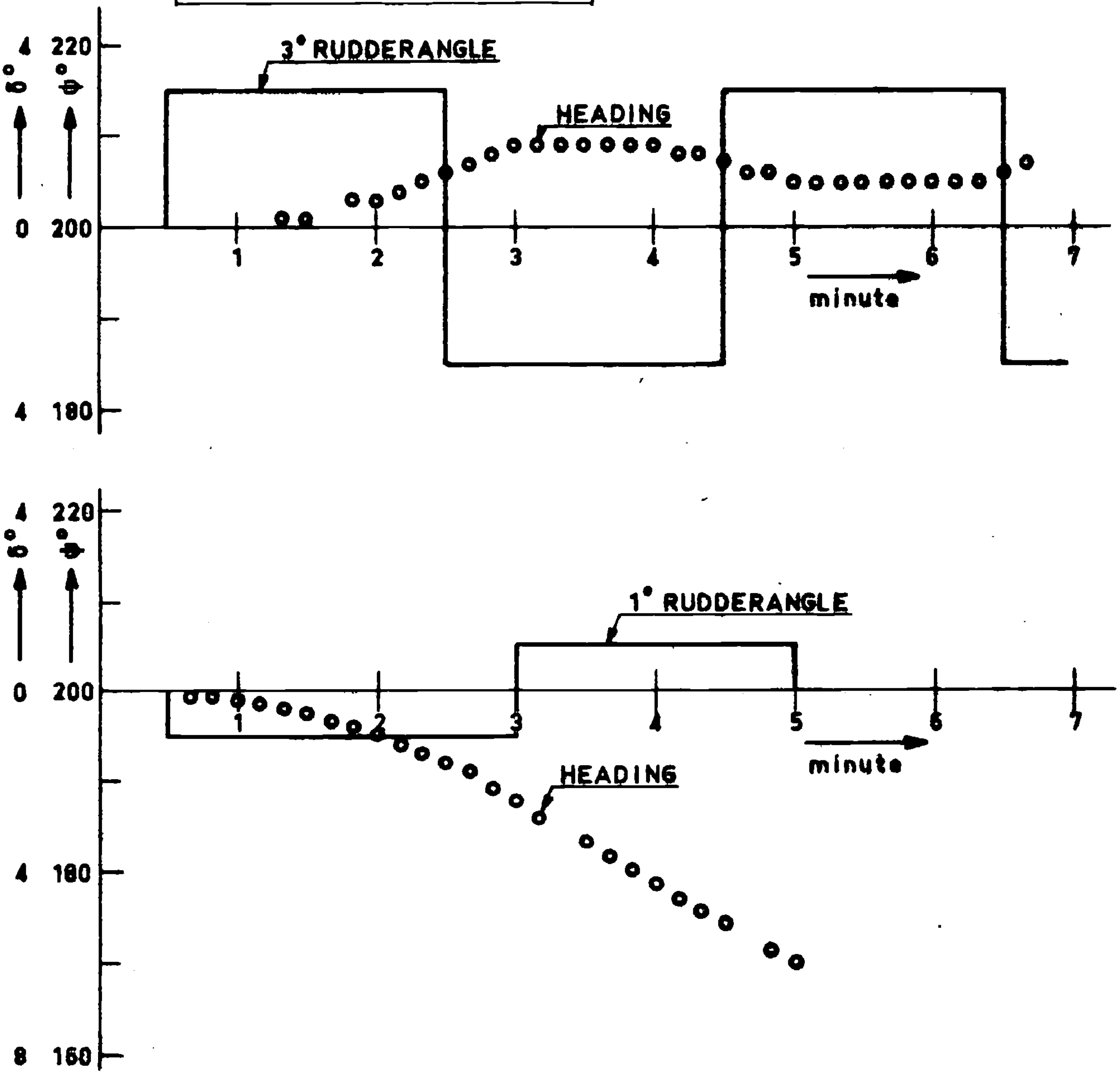

Fig. 6: Examples of a weave manoeuvre with a straight line stable and unstable ship.

3.2.7 Pull-out manoeuvre

This test was also devised by Burcher (12). Its execution begins with a turning circle. When the ship has a constant rate of turn in the turning circle, the rudder is put amidships. The heading and rate of change of heading is measured. The final rate of change of heading is indicative for the straight line stability of a ship, as is shown in the next Figure.

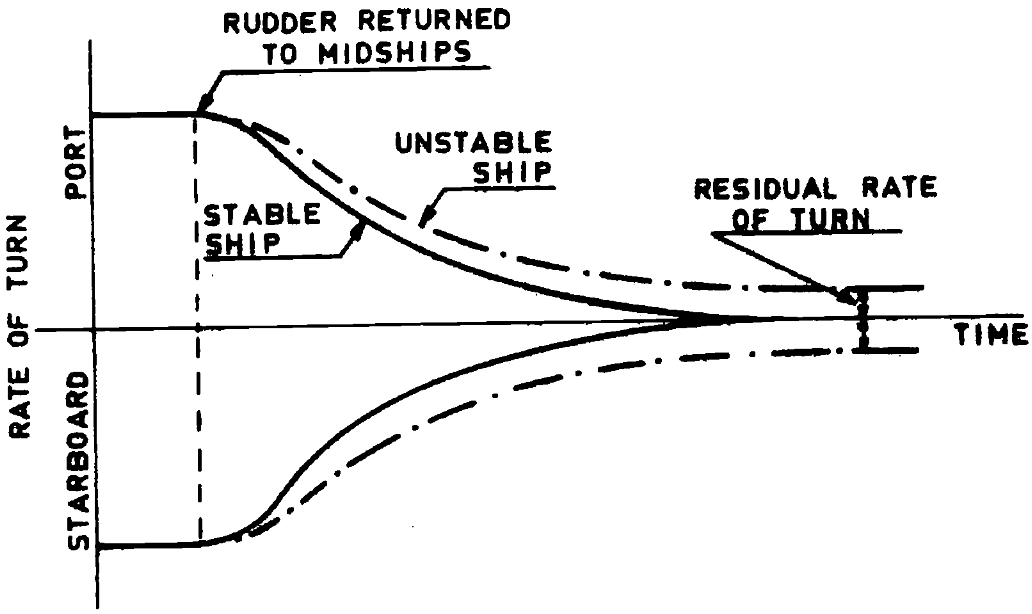

Fig. 7: Pull out manoeuvre
The residual rate of turn indicates straight line instability.

When the ship has made the first leg of the manoeuvre with port-rudder, the second leg of the manoeuvre should be made with starboard rudder. If the final, or residual, rates of change of heading coincide the ship is straight line stable, otherwise the ship is straight line unstable.

Scientific value	:	good
Nautical value	:	none
Experience gained	:	none

3.2.8 Dieudonné spiral test

The execution of this test is as follows:
A ship is brought to turn with approximately 20 degrees port rudder . When the ship has a constant rate of turn one commences to measure this rate of turn* for a sufficient lenght of time. After this measurement the rudder angle is decreased to 15 degrees Again constant turning conditions must exist before the next measurement of the rate of turn can be undertaken.

* In this report, the semantics of: rate of turn or rate of change of heading are identical.

The rudderangle is changed again and the whole procedure is repeated.
In the region between 10 degrees port to 10 degrees starboard changes in rudderposition of 2 degrees are advisable. The direction of change of rudder is reversed when 20 degrees is attained. This lengthy test is terminated when 20 degrees port rudder is once more attained. The rates of turn measured are plotted against the rudder angle applied thus producing graphs as shown in the Figure 8.
There is no need to emphasis the time-consuming character of this test, when large ships are involved. Small ships suffer from wind effects at the small rates of turn involved when the ship is not tested in a flat calm.

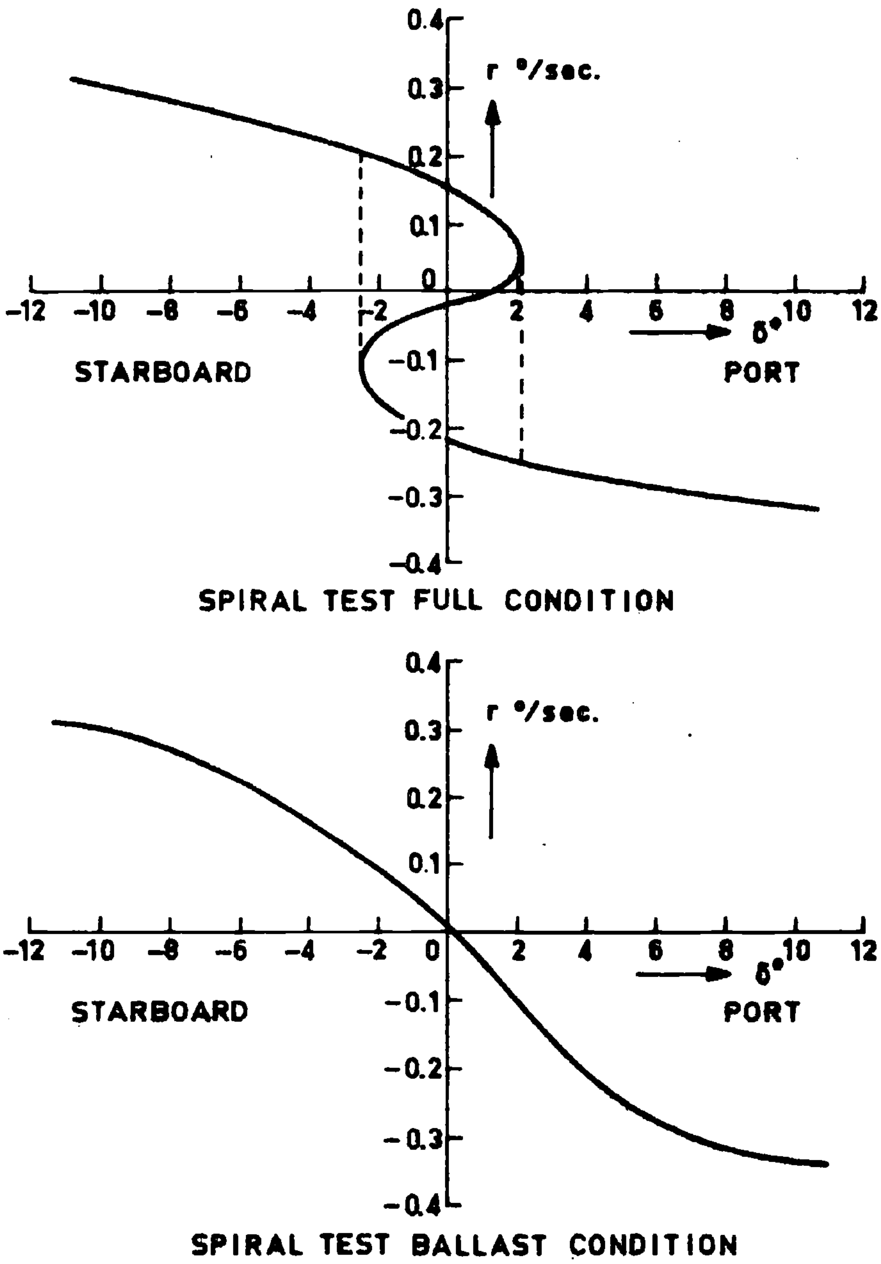

Fig. 8: Spiral test results for a straight line unstable and a straight line stable ship.

The limits of the region of straight line instability, when present, provide valuable information as regards the ship stationary open loop behaviour.

Scientific value	:	excellent
Nautical value	:	none
Experience gained	:	much

3.2.9 Bech reversed spiral test

It is impossible, without special measures, to measure within the instability loop displayed in Fig 8a. Bech (13) devised a method, once applied which is capable of entering the unstable zone. This method is a kind of active steering by a helmsman or a special purpose autopilot. The helmsman or autopilot is so ordered to steer in such a manner that a pre-set value of the rate of turn should be maintained . Therefore, ruddermovements are needed to accomplish the order given since disturbances are always present. The mean rate of turn associated with a mean rudder angle are determined and these quantities are plotted as is indicated in the next Figure.

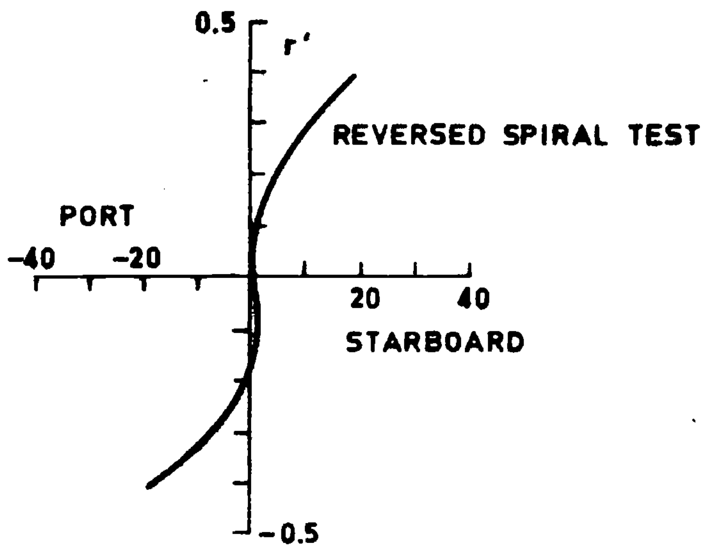

Fig. 9: Reversed spiral test.

In order to facilitate the analysis of results, time histories of the rudder angle and the rate of turn should be available.
Another feature, not generally known, is associated with this kind of test.
Quasi-steady states are essential for the measurement of the relevant data.
One should bear in mind that the time constant in longitudinal direction, associated with the acceleration and deceleration of ships, is interrelated with changes of heading, since speed

drop will occur in these conditions, so that a long time is necessary to develop a steady state. This phenomenon is generally overlooked since it is often claimed that an appreciable reduction in measuring time can be accomplished by applying the Bech spiral test. This,however,is hardly the case. Generally speaking this test should be executed very carefully.

Scientific value	:	good
Nautical value	:	none
Experience gained	:	moderate

3.2.10 Crash stopping manoeuvre

A crash stopping manoeuvre is started on a steady course and speed by giving the order "Full Astern". The helmsman is ordered to compensate for course errors by applying rudder angles.
Time histories of speed, rpm and heading are important assets for the analysis of the manoeuvre. By means of land-based navigational positioning systems the path over the ground of the ship can be determined.
The Dutch log method can also be used for the determination of the distance travelled in the stopping process. This method makes use of an object thrown over board. When this object passes an observer at a fixed and known distance to the man throwing the objects over board a signal to the latter man is given and a new object goes over the side. The number of objects which have passed the observer gives the distance travelled by the ship.
It is important to note the prevailing wind conditions since these affect the ship's trajectory to a great extent,especially in the period when effective control on the ship's motions can be no longer exercised. Fig 10 exemplifies a crash stopping manoeuvre; the stopping distance has been determined by a radiometric position system. In the same Figure a definition is given of the reach .

It is also important to know the time which has elapsed between the commencement of the manoeuvre and the moment when the rpm equals zero, together with the elapsed time between commencement and the moment when maximum astern rpm has been reached.

Scientific value	:	excellent
Nautical value	:	excellent
Experience gained	:	much

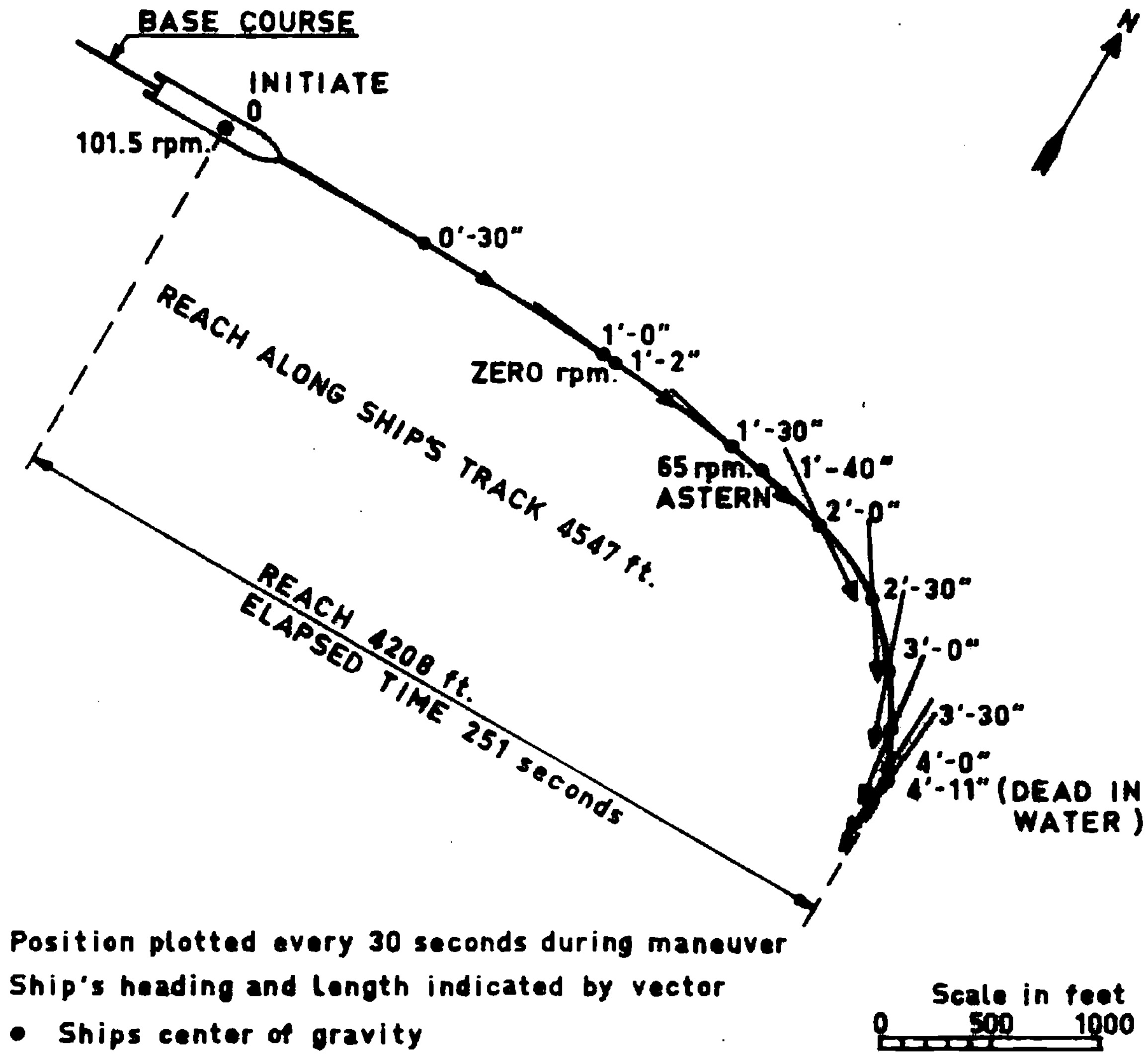

Fig. 10: Crash stopping manoeuvre.

3.2.11 Coasting manoeuvre

This test resembles the crash stopping manoeuvre, with the exception of the order "Full Astern". This order is replaced by "Stop", thus implying that the fuel supply or steamsupply is shut off. Wind effects will probably play a more important role since the duration of this trial is longer than of the crash stopping trial, due to smaller deceleration values.
The coasting distance can again be determined by either radiometric systems or the Dutch log method. One should note the elapsed time between the order " Stop " and a complete standstill of the propeller,when applicable,in the case of direct driven dieselships.

Scientific value	:	excellent
Nautical value	:	good
Experience gained	:	moderate

3.2.12 Fishtail manoeuvre

This manoeuvre is often exercised by experienced masters to reduce the ship's speed in the vicinity of pilot stations, where plenty of water is available and the peculiar heading changes do not cause confusion to the surrounding ship traffic. For this manoeuvre,no prescribed sequence of rudder angles and telegraph orders are available.The essential feature is that a sensible use of the longitudinal component of the ship's centrifugal force will augment the ship's resistive forces.
In the first phases of this manoeuvre,one does not need to reverse the propellor direction, since the rudderforces initiate the successive swings which create the centrifugal longitudinal force component. Control of motion is possible to a greater extent than in the regular crash stopping manoeuvre since "FULL ASTERN" is given in the latter part of the manoeuvre, thus indusing directional instability. The times at which course and speedorders are given should be noted, together with the normal quantities measured course, speed, rudderangle, rpm.

Scientific value	:	none
Nautical value	:	good
Experience gained	:	moderate

3.2.13 Rudder cycling manoeuvre

This manoeuvre resembles the fishtailtest mentioned in the preceding paragraph. However, the sequence of orders to be given is predetermined, as a detailed consideration of the speedgraph and the rudderangle shows (Fig 11). Clarke (14) suggested this trial. The proposed sequence of events is tentative and prone to modification as the results of simulation studies and full scale trials would seem to indicate.

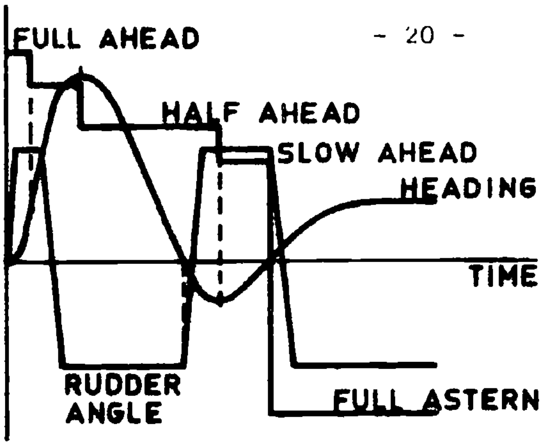

Fig. 11: Rudder cycling test as proposed by ref(14)

Discussion of this proposed manoeuvre revealed that when applied on an other VLCC it does not necessarily produce satisfactory results. However, the attempts to improve this manoeuvre should be carefully watched. It is the author's view that an optimal combination between speed and course or rudderorders exists which satisfies the requiremenents of minimum stopping distance and maximum duration of full motional control.

Scientific value	:	moderate
Nautical value	:	excellent
Experience gained	:	none

3.2.14 Zigzag test with side thruster

To a great extent, this manoeuvre resembles the normal zigzag test. The rudder is presumed to be kept amidships; the speed is very low (2-4 knots)
The execution of this manoeuvre starts with switching on the thruster. The ship starts to turn in the direction indicated by the thruster's action.
The thruster is reversed when the change of heading exceeds 20 degrees or any other appropriate value. This procedure is repeated a couple of times.

Scientific value	:	good
Nautical value	:	good
Experience gained	:	moderate

3.2.15 Statistical test of rudderangle position

It was suggested by Lyster (15) that a histogram of rudder angle positions at regular 20 seconds intervals with the ship on a steady course would reveal the ship's limits of straight line instability, if any.
Two pronounced peaks in the histogram indicate the limits of straight line instability. If the histogram is smooth with a single peak in the vicinity of the rudder's midship position, no instability may be expected
The following Figure illustrates the two types of histograms.

Scientific value	:	small
Nautical value	:	small
Experience gained	:	none

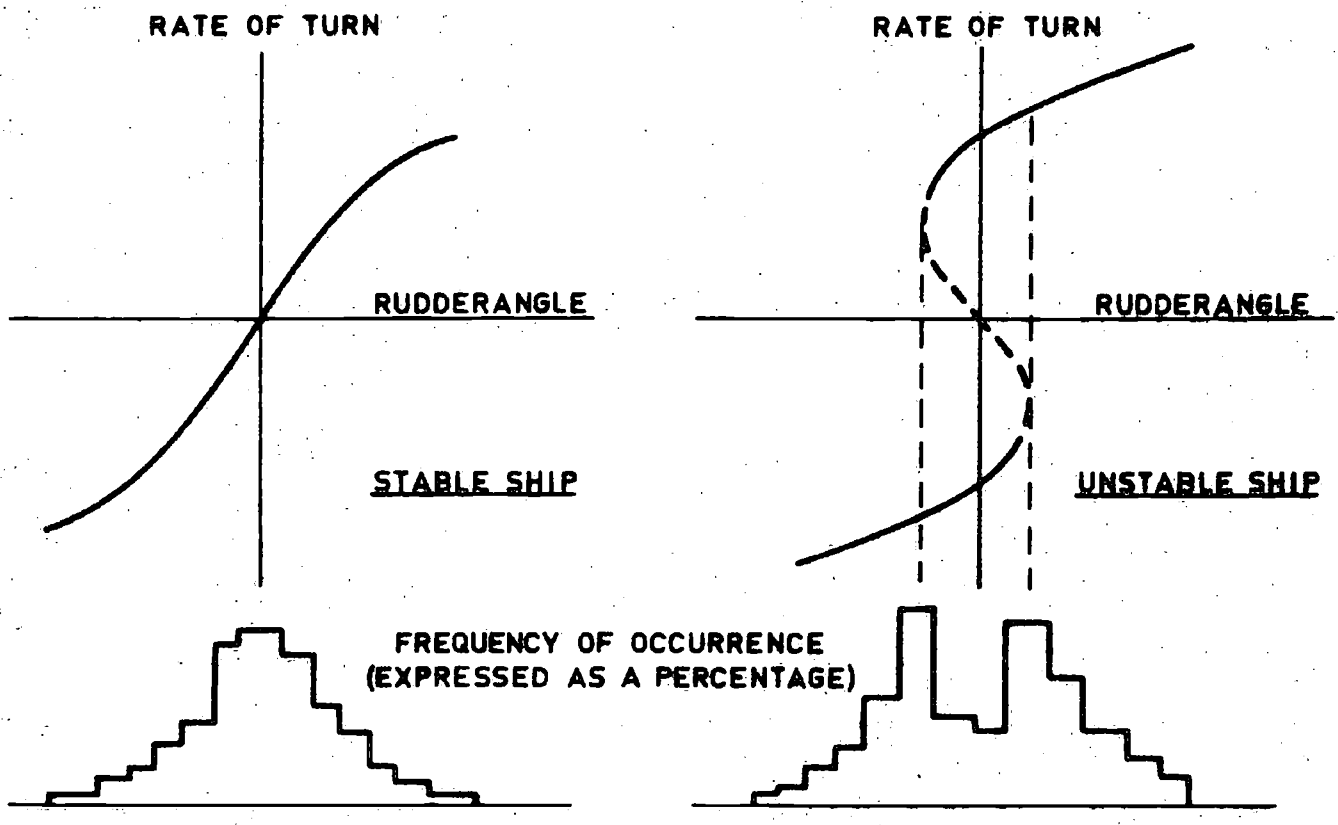

Fig. 12: Histograms of a statistical test of ruddelangle position

3.2.16 Acceleration test

The execution of this test is straightforward. The ship is dead in the water and then " Full Ahead" is ordered on a specific heading which is to be maintained with minimum rudder. The rpm, speed and headway should be recorded at regular time intervals. The test should be terminated when the ship's speed exceeds 99% of the final anticipated speed.

Scientific value	:	good
Nautical value	:	excellent
experience gained	:	moderate

3.2.17 Sinusoidal test

In this test the rudder should be sinusoidally moved with different amplitudes and frequencies as the input for the system "ship".
The rate of turn, heading and speed are measured when the ship is in a quasi-steady state. The results of this test are plotted in Bode diagrams, e.g. amplitude and phase characteristics.
The linearity of the ship's response to rudder signals can be determined with the aid of the diagrams mentioned above, together with a determination of the characteristic "time constants".

The generation of a sinusoidal ruddermovement is difficult owing to the typical characteristics of most steering gears, which do not allow very small rudder speeds.

Scientific value	: excellent
Nautical value	: small
Experience gained	: none

3.2.18 Test with a trapezoid rudder signal

This test is meant to overcome the difficulties mentioned in the preceeding paragraph as regards the generation of rudder signals.
A trapezoid rudder signal can easily be made, and the first harmonic component of this signal bears resemblance with the sinustype test. Again, varying amplitudes and frequencies should be generated. The rate of turn, course and speed are recorded.
A Fourier analysis is made of the input and output signals; the first harmonic components of these signals are related to each other in a manner mentioned in the paragraph above.

Scientific value	: excellent
Nautical value	: small
Experience gained	: none

3.2.19 Rudder effectiveness test

This test is meant to establish the critical ship speed below which no response of the ship to helmorders may be expected, when the propulsion units are ordered to "Stop"
The rudder should be put hard over the first time. When the deviation reaches a value of say 10 degrees then the rudder is commanded to the opposite side. When the ship responds to this rudder angle the rudder is ordered to the opposite side. The test should be terminated when no significant response occurs, thus implying the critical speed. Fig. 13 depicts the general character of this test.

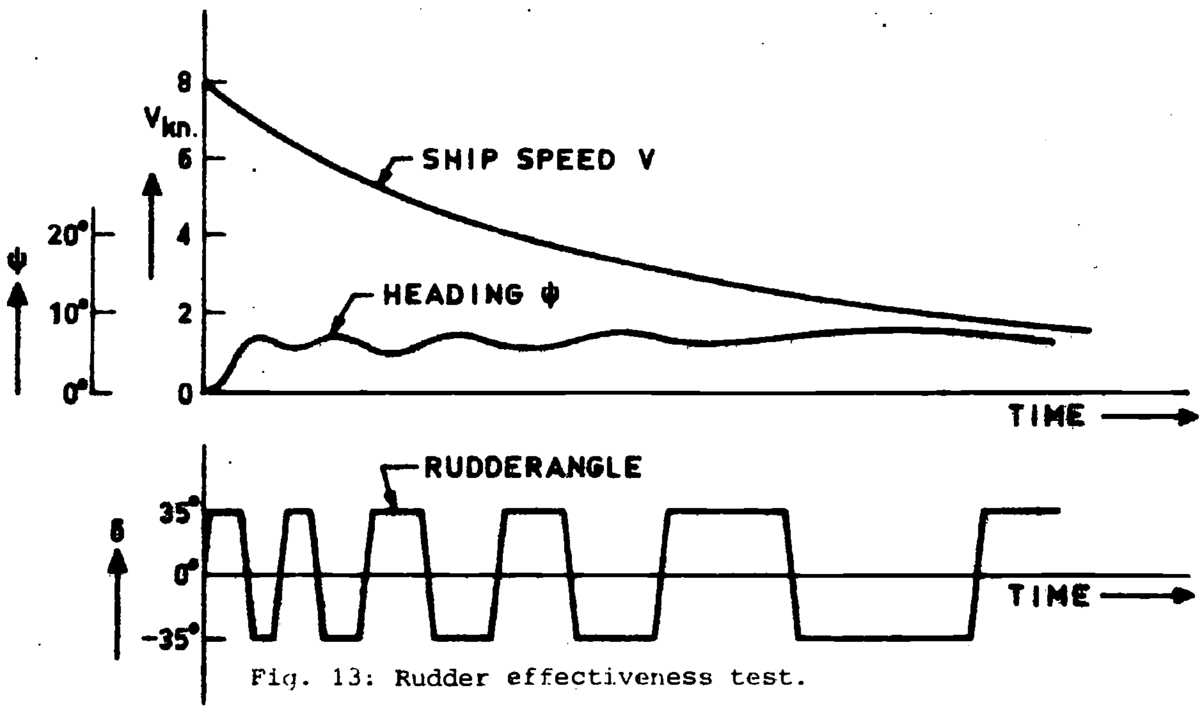

Fig. 13: Rudder effectiveness test.

Scientific value	:	moderate
Nautical value	:	good
Experience gained	:	none

3.2.20 <u>Wind effect trial</u>

This test has been devised to measure the leeway, luffing up or falling off characteristics of a ship. The speed should be very low and the rudder is kept amidships. Windspeed and - direction are measured together with the ship's response, especially the heading and ship's path over the ground,for a variety of conditions such as regards the wind direction.

Scientific value	:	moderate
Nautical value	:	good
Experience gained	:	none

4. Survey of measuring techniques

4.1 Shipborne measuring technique with shipborne commercial navigation equipment.

It is not difficult to measure manoeuvring properties of a ship with shipborne navigation apparatus.
Every ship is normally equipped with a high precision course indicating gyro compass and a speed indicator connected to either a pitottube as sensor or an electromagnetic transducer. Logs operated on the Doppler principle are gaining acceptance and become more and more common on bridges of modern merchant vessels. Rudder angle indicators, under certain circumstances compulsory * are very often used to provide the navigator with the instantaneous position of the rudder. Tachometers indicate the propulsors' rpm, and these instruments can often be found in ship's conning positions.
These instruments provide the information needed when executing manoeuvring trials.
The accuracy of normal navigational equipment has been generally determined with the basic ship's mission in mind. This can often be adequatly described by long range sailing from one point to another. The implication of this general statement is that the ship's heading indicator should be precise.
Other variables concerning the ship's dynamic behaviour need not to be measured with high precision gear, since navigational aids and procedures in use in practice provide the necessary information to any degree of accuracy required.
However, this means that the instruments mentioned above suit "macro"-navigation purposes, but fail sometimes to provide accurate data for "micro"- navigation. "Micro"-navigation as opposed to "macro"-navigation may be defined as that kind of navigation where the ship's dynamic properties come into play. The next question to be resolved is the degree of accuracy needed for the measurement of the pertinent parameters. Navigational information on manoeuvring properties need not always be of a high order of accuracy. The main reason is given by the varying meteorological conditions, geographical conditions as well as the seastate which might drastically affect calm water manoeuvring properties. A prudent master or navigator will take these external effects into acoount, and consequently the parameters of manoeuvrability are used indicative rather than absolute. Hence it follows that the parameters of manoeuvrability for practical and nautical purposes need not to be measured with high precision.
Scientific information on manoeuvring properties is needed for a number of objectives:

- i to compare a ship's behaviour with prediction on the basis of numerical hydrodynamic methods
- ii to compare a ship's behaviour with extrapolated modeltest results
- iii to extract input-output ratios to identify the system (i.e. the manoeuvring ship) from the time histories of the relevant parameters.
  These relations are used for:

* for instance in the Suez- and Panama canals

a. adapting autopilot characteristics to a specific ship aiming at the most satisfactory performance of the total system (ship and autopilot)
b. providing realistic mathematical models for research, development and training with manoeuvring simulators.

With regard to the items (i) and (ii), a higher degree of precision is needed than necessary for navigational purposes. Item (iii), however, requires a very precise measurement of signals in continuous form, in order to manipulate time histories of different signals on a computer. Very often smoothing and noise suppressing techniques have to be applied before identification techniques are tried. Model matching and identification will prove successful when :

i the structure of the mathematical model is adequate for the information available
ii the information density is sufficient
iii the signal-noise ratio is capable to suppress noise by filtering

The signals to be measured may be distinguished as follows:

1. heading
2. rate of change of heading (rate of turn)
3. speed
4. revolutions per minute of propulsor(s)
5. rudder angle
6. speed orders
7. track information
   either supplied by radarplots or supplied by precise electronic position fixing equipment.

It seems possible in a number of cases to connect recording apparatus to the sensors involved, either of the pen type or U-V-type.
If this possibility is not present it is most advisable to introduce an audible signal system connected to a timer which provides a signal every 5, 10 or 15 seconds to all members and observers of the measuring team to enable them to make a simultaneous reading of their assigned instrument and to record the value on a preprinted special form.

Great care should be paid to the interpretation of the speed signal which often appears to be erroneous when the ship is engaged in tight turning manoeuvres.

4.2 Shipborne high precision measuring technique

As mentioned in the preceeding paragraph a very precise measurement of the ship's responses is necessary in a small number of occasions, in particular when modelmatching techniques are involved.
The time history of the ship's heading can be measured with a very precise course gyro or a repeater connected to the ship's gyro compass, together with a servomechanism which transduces the gyro angular's displacement to a potentiometer adapted to a recorder (magnetic tape or paper type). A description of such a measuring system may be found in (14).
The rate of change of heading may be obtained by differentiating the heading signal.
However,differentiating a noisy signal introduces a lot more noise in the differentiated signal. Filtering techniques may be employed by using digital filters(16), but a disadvantage is that sometimes valuable information is disregarded.
A linear voltage output rate generator connected to a suitable element of the main gyro compass may be used to provide the rate of change of heading signal. A separate sensor may also be used,but the specifications of rate gyro's ought to be rather high, since very slow moving objects are involved. No hysteresis loop should be allowed and for the maximum attainable turning rate maximum signal output should be obtained. With a separate rate gyro a servo mechanism needs to be used to rotate the measuring potentiometer. A severe setback is that the calibration of the rate gyro on board ships is extremely difficult,since the moving platform does not allow for a long period of steadiness in motion.
Again reference is made to (14). Rudder angles and steering wheel movements may be measured by potentiometers connected to the rudderstock or the steeringwheel central axis. However,high precision potentiometers are very sensitive to vibrations and external disturbances. Again the calibration of the sensor is difficult to achieve, owing to lack of precise mechanical calibration indicators.
Speed may be measured in the same way as the heading. The accuracy of the entire measuring system highly depends upon the sensor's accuracy. Commonly speed logs are calibrated on the measured mile for normal ahead sailing and they are normally not very well suited for oblique sailing of the ship, which is always the case when the ship is in the process of manoeuvring. It may be possible that logs operating on the Doppler principle improve the accuracy of speed measurements.An interesting method of measuring the speed is published in the Proceedings of a recent Symposium (17), referred to as the sextant method.
This method is based on fixes according to Snellius. Snellius' method of calculating is still one of the most accurate ways of establishing the position. A restriction is that two experienced navigators are involved in the process and three readings per minute seem to be the maximum rate attainable.
An improved method has been devised as follows.
Ten turn potentiometers should be attached to the sextants and the signals should be registered on a tape recorder. From these measurements the ship's position relative to three obstacles can be calculated and by smoothing and differentiating the ship's speed can be calculated.

All these signals, measured during manoeuvring trials have to be processed afterwards with the aid of a digital or hybrid computer. Therefore,a time reference signal is needed to provide a time base. Tape-recorders were very sensitive and expensive equipment but,in recent years the hardware has been greatly improved and better portability has been achieved as well. Performing precise and accurate measurements with regard to manoeuvring parameters requires a very careful organization of the total measurements procedure, including co-ordinated handling of the ship during the entire measurement period. Neither should the handling and processing of the raw data be forgotten. The financial investment in the preparation of the measurements and the processing of the data are seldom commensurate with the results obtained.

Future trends would seem to indicate, however, that the possibility of accurate measurements is increasing, since the quality or sensors and recorders is improving while the costs are decreasing.

4.3 The use of land based systems

4.3.1 Electronic systems

Tracking a ship's position in intricate manoeuvring trials is possible with the aid of an inertial navigation system installed on board. (18) However, the results achieved so far indicate that the use of an inertial navigation system is rather restricted, not the least from the viewpoint of investment which is not commensurate with the value of the results obtained.

Land based systems such as DECCA, HIFIX and SEAFIX are frequently used in determining the ship's track Special pre-calibrated decometers are installed on board and photographs are taken at regular intervals of these meters together with stopwatchtime.
It is stated in a number of papers (19,20) that when these measurements are performed in an optimal fashion a very precise determination of the ship's speed is possible and that they can easily replace the trials on the measured mile.
However, the speed which may be calculated with high precision refers to average speeds in the intervals between the readings by the camera, and can not be considered as the instateneous speed. Special areas exist where the camera readings of the DECCA lanes can be easily transformed to cartesian co-ordinates by a computer program thus allowing a time saving in plotting and calculating. Special care should be devoted to atmospherical disturbances which may greatly affect the accuracy of the systems mentioned here, especially the periods of morning and evening twilight should be avoided. Also observations at night will render generally inferior results in comparison to daylight measurements, due to differences in propagation conditions. Short range systems like for example HIFIX will probably produce the best results owing to the relatively small area covered by the transmitters, the frequency used and the consequently small lane width.

4.3.2 Visual systems

These systems are not very common in tracking the ship's position in manoeuvring. Visual aids operated on the shore track a specific mark of the ship. They supply either bearing and distance or only bearing. In the latter case,two visual aids (like theodolites) are necessary.
The method very briefly described above, is in use on a manoeuvring pond or basin where a self-propelled model makes remote-controlled manoeuvres. A special mast is often fitted to facilitate tracking. Another example of the use of this system is the towing of a very heavy concrete off shore structure with a draught of over 100 meters out of a Norwegian fiord. Precise track information was needed to keep this gigantic construction within the very narrow limits of the available manoeuvring lane. The system was also adopted to measure the exact track of a tanker during launching. In (21) a method has been described to measure turning circle data.

A great disadvantage is that the entire manoeuvring area is on sight distance from the shore,thus complicating the sequence of the manoeuvres which might endanger coastal or inland traffic.

4.4 The use of buoys

In order to find a ship's track, one could use a buoy whose bearing should be measured from two known locations on board of the ship. This method is quite similar to the method referred to in paragraph 4.2 and is costly in manpower. Only a small number of readings can be taken. Simultaneous readings are difficult to realize in remote places and require some form of synchronizing aid. The results of the tracking plot are relative to the free floating buoy, which may be affected by the wind in a different way as the ship, since the buoy is operating in another region of the wind boundary layer than the ship. Thus, the ship's path over the ground will not be known with certainty. Another possibility, but only of restricted use, is provided by a distance meter, which gives the distance between observer and buoy. This method requires simultaneous range and bearing measurements of the buoy by two observers. Good synchronization is therefore again an important requirement.

Special buoys with radiometric equipment may be capable of providing distance and bearing, but the use of such a system is expensive, since much preparation is needed for a successful accomplishment.
Raydist is a system that has been used in this way during the trials of the American Liner ss "United States".

5. Scientific evaluation of manoeuvring trials

5.1 Introduction

This section is devoted to a definition and discussions of the scientific quantities in use in the analysis of ship manoeuvring and - steering properties. The trials described in section 3 are reviewed with a special emphasis on the scientific character once the aim of manoeuvring trials has been assessed.

5.2 Definition of manoeuvring properties

With regard to the motion stability of a ship a number of definitions are used indicating the complexity of the problem.

Straight line stability or controls fixed stability

" A ship travelling with the rudder amidships which returns to a new straight course after being disturbed without rudder aid is called straight line stable or controls fixed stable".

One should note that no action with the rudder is undertaken either by the helmsman or by the autopilot. In fact, this kind of stability is of academic interest,although a controls fixed unstable ship can sometimes hardly be stabilized by a helmsman's or autopilot's action.

Directional stability

" A ship which returns by autopilot action or by a helmsman correcting actions to its initial course after being disturbed is called directionally stable".

This kind of stability is of paramount importance in ship steering behaviour. One should note that, as opposed to controls fixed stability, directional stability depends upon the ship's characteristics,as well as the autopilot performance or the helmsman's control behaviour.
A controls fixed unstable ship can be stabilized as regards her direction by an autopilot or, very often, by a helmsman.

Path stability

" A ship which returns by autopilot action or by a helmsman's correcting actions to its predetermined path over the ground after being disturbed is called path stable".

This kind of stability plays a very important role when navigating a ship in confined and traffic dense areas as well as in bouyed channels. Again,this kind of stability is dependent upon the system characteristics: ship and controller. A path-automate needs the lateral deviation to the predetermined track as an input parameter. When the ship is navigating under human control the conning officer or the pilot orders the courses to be steered for accurate trackkeeping if the ship is disturbed. The magnitude of the disturbance is estimated and translated in courses to steer or rudder orders. The navigator as well as the helmsman are two main elements of the path control mechanism.

Stability of motion is one important aspect of the ship's total manoeuvring behaviour. Other aspects which should not be overlooked are:

i turning capacity
ii ability to initiate a turn
iii ability of check a turn

ad i Turning capacity may be defined as the ratio between turning diameter and shiplength when full rudder is applied.

ad ii The ability to initiate a turn may be defined by the time elapsed from ordering a rudder angle to a 99% value of the appropriate rate of turn

In fact, the time elapsed is approximately three times the so-called "time constant" of a ship.

ad iii The ability to check a turn is defined by the overshoot angle. When a ship turns steadily and a counter rudder order is given and developed, the rate of turn decreases and eventually crosses the zero. The overshoot angle is the difference in heading between the moment of execution of counter rudder and the heading as the rate of turn passes zero.

A number of properties defined here are interrelated to two important mathematical parameters of a first order differential equation, i.e., the time constant and the magnification factor.
This equation reads as follows:

$$T\dot{r} + r = K\delta$$

where
T = time constant
K = magnification factor
r = rate of turn
δ = rudderangle

Basic steering and manoeuvring research is very often started with a "mathematical model" of this kind, the most simple being the equation shown above.
We will forego an extensive treatment of these equations, since a close scrutiny of all problems involved with mathematical modelling is beyond the scope of this Report.

5.3 Purpose of trials

Generally speaking, the purpose and aim of manoeuvring seatrials may be defined as "determination of the coefficients of an assumed mathematical model". Once these coefficients are known, the model can be solved for all types of input signals (arbitrarily chosen rudder angles). It is then, implicitly, assumed that the adopted model is valid for the ship's behaviour under all circumstances and conditions. This assumption is very often preposterous, since ship's manoeuvring characteristics are commonly rather complicated and not to be characterised in simple expressions such as first order differential equations. However, by applying such a model, it is possible to derive coefficients from experiments. Apart from making predictions they may serve as a measure for ship behaviour comparison.
This means, that such comparison has to be made with dimensionless quantities; speed and length are often used as "non-dimensionlizers".

When is it known that a ship with measured coefficients is said to behave satisfactorily and another ship has the same coefficients, one is inclined to believe that this ship will react in the same manner. The coefficients serve as a basis for comparison in general, not quantified, terms of aspects of manoeuvring. Nomoto's analysis (22) is very well known in this respect and a lot of information on time constants T and magnification factors K exist.

As the disadvantages of the Nomoto analysis became clear, new methodes of "Modelmatching" were devised.
Model matching techniques are based on the assumption of a certain mathematical model. It is found that non-linear models frequently seem to describe ship's behaviour better than linear models. A number of emperical, as well as theoretical, non-linear models have been developed. The time histories of the input- and output signals are recorded and all this information is used in the process of determining the coefficients with the aid of a computer.
Very often, it appears that when not all available information of manoeuvres with a variety of rudder angles are used, the results of predictions are disappointing, especially with emperical models.
Since accurate measuring techniques are involved together with elaborate computer processing, the results are very often not commensurate with the effort involved.
On the other hand one should not be too pessimistic with regard to the use of mathematical models, how simple they may be. Even these models can produce a profound insight in the physical behaviour of a ship in response to a rudder angle. Qualitative measures of properties are very important even then, when these measures cannot be accurately quantified. Nomoto's treatment of manoeuvring ship in terms of a first order differential equation is one of the highlights in the development of the theory of steering and manoeuvring and certainly provides the student of the theory of ship's steering with a clear insight in the physical phenomena involved.
The objective of researchers in this field lies, however at another level; they want a precise description of the ship which is capable of forecasting the ship's response to any form of input signal. This ultimate aim has not been achieved yet, as will be shown by the present state of the art.

In this paragraph, it is obvious that "manoeuvring" is only related to manoeuvres of a ship initiated by a change of the helm's position. This restriction usually causes confusion to the mariner who considers changes in speed as well as rudder angle changes under the heading "manoeuvring"

The development towards mathematical models which includes the possibility of changing the ship's speed at will was accellerated by the introduction of simulators. These devices offer the opportunity of changing speed; very often backing the ship is among the capabilities offered.

Navigation and manoeuvring in open seas are not the main areas of interest to those using a simulator. Confined waters navigation under the adverse effects of gusts and currents or bank effects when the ship is making slow headway executing intricate and complex manoeuvres associated with berthing procedures under extreme conditions are the principal issues. These problems cause extended models to be developed capable of introducing shallow waters effects, banksuction etc. The characteristics of the prime prover either connected to a fixed blade propeller or to a C.P.Propeller have to be correctly simulated.
Special low speed manoeuvring devices as well as the effect of tug assistance should be properly represented so as to allow the simulator to cover an extensive problem area.
Special emphasis is sometimes placed on the conception and design of new canals or channels capable of safely accomodating large ships and their precarious passing and overtaking manoeuvres. The representation of ship's interaction in close proximity is a prerequisite for solving these problems with a simulator. Fundamental research is lagging behind. Nevertheless answers have to be provided. In this case, rough estimations of the effect of phenomena involved may be made by combining the results of existing, far from perfect, theories, together with practical data. To provide this data resort has to be made to full scale trials.
When the training and education of human beings is the primary goal of simulator use, it is quite helpful for the desired accuracy to assess the limits of human perception.
If this human being feels he is on the bridge of a real ship and if he feels that "the ship" is responding in the same way as he anticipated, he will be apt to accept the experience gained and will use it in practical situations.
The limits of percention play a paramount role. Experimental evidence exists that an accurate simulation is unnecessary when training and education is the primary target.
However, design studies of the lay-out of waterways require a more precise and accurate description of all physical phenomena involved. Model tests, captive as well as free running, are then necessary to gather the basic material for mathematical modelling. Since model tests are liable to scale effects which are, in part, imperfectly understood, scaling up the results to the full-scale ship is a ticklish matter. These facts make some full scale trials in comparable situations desirable in order to establish the extent and effect of the change of scale for a particular ship.

Summarizing the purpose and aim of full-scale trials leads to the following three points.

- i they are needed to gather material and data for the comparison of coefficients which implicitly means comparing manoeuvring behaviour.
- ii they are needed to gather material and data which facilitates the description of the ship's behaviour to suit a number of application in the simulator field.
- iii they are needed to check the results of modeltests, either captive or freerunning.

5.4 Manoeuvring trials to suit scientific purposes

If one regards a ship as a black box, one can define the system characteristics by relating the input to the output.
In control engineering, a number of simple input signals are used; the most important being; response to a step signal, response to a sinusoidal signal with varying frequencies and amplitudes.

The step response defines the system behaviour in the transient phase as well as in the steady state. Translating this into more nautical expressions, the step response may easily be identified with a turning circle. Once the helm is put over the ship starts (nearly in all cases) to move in the direction governed by the rudder's position and starts to loose speed. Eventually, the ship is steady in the turning circle. Advance, transfer and to some extent the tactical diameter symbolize the transient phase; the turning circle diameter represents the steady behaviour.

When the magnitude of the step applied is intensified the ship's response generally increases. Linearity and the magnification factor may be deduced from these results.
Sinusoidal inputs are very often used.
The reason is given by the well-known fact that a sinusoidal input produces a sinusoidal output when linear systems are involved.
At a given frequency, the amplitudes of input- and output signals are compared together with a determination of the phase lag. The results of tests with different frequencies are plotted; these graphs are often called the Bode diagrams or the amplitude and phase characteristics.
However, two aggravating circumstances exist.
In the first place, the ship is not always a linear system and, secondly the generation of a sinusoidal input signal is often beyond normal possibilities without preparatory and expensive measures owing to the properties of the rudderengines.
Kempf (8) devised the zigzagtrial and this trial may be used to good purpose. The trapezoidal input signal can be thought to exist of different sine components with increasing frequencies, the so called Fourier series. The output signal, for instance the rate of change of heading (interrelated to the heading by integration) should be expanded in the Fourier series as well. The first harmonic components of the input- and output signals provide the same information as is the case with a pure sine-test.
The zigzagtrial has, however, one characteristic frequency due to the special condition of ruddercycling. This means that only one point of the Bode diagrams is obtained.
More points are provided by the trapezoid test with varying frequencies.

The linearity may be checked by enlarging the amplitude of the input signal twice and determining the ratio of input-output amplitudes. Linearity exists when this ratio is independent of the magnitude of the input signal.
Real ships very often show a saturation effect at the higher rudder angles which might be explained with physical reasons. This effect introduces a "non-linear" behaviour.

A pull-out test may be regarded as a test serving the same objectives as a turning circle. In fact, the application of a step must, in mathematical sense, bear a close resemblance to the removal of a step.

In section 3.2 a scientific evaluation is given of all the trials under the heading of:
SCIENTIFIC VALUE
The indication there provided, is based on considerations developed in this particular paragraph.

5.5 Desired accuracy

The accuracy of the measurements is dependent on the ultimate goal of the trials.
If one wishes to derive comparative yardsticks, the accuracy does not need to be very high and shipborne instrumentation will provide satisfactory results, also because very often ship's speed is not an essential parameter. Modelmatching techniques require careful measured signals which may not normally be provided by shipborne instrumentation, since navigation equipment specifications are usually lower than is necessary for full-fledged model matching techniques. Paragraph 4.2 provides adequate information in this respect.

6. Nautical evaluation of manoeuvring trials

6.1 Assessment of information needed

The needs on specific data regarding manoeuvrability are quite different from the subjects treated in the preceeding sections when practical seafarers are concerned. Practical quantities are important for the master and the pilot to assess the possibility and feasibility of a number of intended intricate meanoeuvres.
Among the practical quantities, the following list may be regarded as having great practical usefulness:

- i What is the ship's headreach after ordering "FULL ASTERN" with different approach speeds?
- ii Advance, transfer and tactical diameter, together with the times to turn through 30, 90 and 180 degrees in turning circles initiated with different rudder angles and different approach speeds?
- iii How fast will the ship start to turn?
- iv How fast will counterrudder check a ship's swing?
- v Is the ship directionally stable during the stopping process?
- vi What are the coasting characteristics of the ship?
- vii How does a bowthruster affect the rate of change of heading at the ship's lower speeds in the berthing process near the terminal?
- viii What is the ship's minimum speed which is necessary to maintain control of movements?
- ix What are the falling off and luffing up characteristics of the ship under different wind conditions?
- x What is the normal and maximum path width in channels or canals at different shipspeeds and different wind conditions.
- xi What are the optimal escape manoeuvres in developing dangerous situations, with and without limited sea room?
- xii What are the average response times of the prime movers?
- xiii Is the ship directionally stable when making sternway?
- xiv Is the speed - rpm curve available?
- xv Is the ship equipped with a right or left propeller or in case of two propellers are they inboard or outboard turning?
- xvi What is the maximum available astern power and how long can it be maintained without causing damage to critical parts of the machinery?
- xvii Are critical combinations between speed and rpm values present as to minimize or avoid damage to machinery and ship's structure?
- xviii What are the advance notice times from sea speed to manoeuvring speed and from ignition of the boiler fires to manoeuvring speed?

The answers to a number of these questions are severely affected by shallow waters and these influences are of utmost importance for the mariner.
He might be interested in the ship's manoeuvring characteristics on the open sea , unrestricted in width and depth, with no traffic at all, under very light weather conditions and under the absence of swell, which, incidentally, are the most ideal conditions for a researcher to determine the system responses as a result of one input signal and one alone.
It is, however, a neccessity to have the answers ready when planning manoeuvres for a geographically difficult, traffic-dense area which

preceeds the phase of berthing. These answers should have such an accuracy that no unexpected dangerous situations develop after a specific avoidance-or other manoeuvre is applied.
Quick reactions on the part of the conning officer are imperative in these circumstances, so as to master the situation.
A manoeuvring booklet containing the answers on problems which may arise is a valuable and worthwhile aid. The effect of confined waters very often changes the ship's properties to a large extent.
The magnitude of these variations are often unknown, so endangering the ship's safe conduct in the passage of these difficult navigable waters. It seems inescapable therefore to perform manoeuvring trials in shallow waters as well,especially when ships of a large size are concerned.

6.2 Purpose and aim of trials

The purpose and aim of trials to suit nautical purposes is to provide answers to the quantities mentioned in paragraph 6.1
One should note that in unrestricted waters only,a limited amount of information is needed. A great number of questions concerns only safe passage of the ship through the final stages of the voyage to the terminal area and vice-versa.This means that manoeuvring trials have to be performed in shallow waters, not the place where prudent ship-masters, harbourauthorities, pilotage services and the hydraulic public services want such manoeuvres to take place in view of the gigantic ecological problems involved once a shipborne system of such a complex industrial product as a ship, failes and causes major disaster.

There is a need for gathering manoeuvring data in restricted waters to avoid unpredictable and thus sometimes uncontrollable situations in the ship's behaviour during its passage through these restricted and difficult navigable waters. On the other hand the risks involved in deliberately planned shallow water trials generally forced the responsible authorities to refuse the execution of such trials.
Generally speaking,these trials should be scheduled in those waters where the risks involved, such as ecological pollution and damage due to collision,are reduced to an acceptable level. However,such areas are remote and the sailing to and from such an area is both time-consuming and expensive.

One may suggest that modeltests should be used to find some of the badly needed ship properties regarding shallow water behaviour.
Undoubtly,these trials might provide valuable information concerning the ship's critical characteristics. However due to the necessary simple and schematic approach and set-up of modeltrials,essentials may be easily overlooked.
There is no substitute for reality!

6.3 Manoeuvring trials to suit nautical purposes

The most usual and common manoeuvre is the turning circle. The information needed can be extracted from the parameters measured. Turning circles performed in the following fashions may suffice:

i full initial speed, full power, maximum rudder
ii half initial speed, half power, maximum rudder
iii zero initial speed, full power, maximum rudder

The stopping tests provide head reach, controllability during the stopping process, time to reverse the main machinery and the path width.

Valuable information regarding the swing checking abilities may be obtained with an overshootangle test. Typical values will be provided when maximum counterrudder is provided.

Acceleration values can be provided with a ship at complete standstill and subsequently giving maximum ahead power.
Deceleration values may be obtained by the so-called coasting test. The moment of a complete standstill of the propeller when the driving pressure forces of the water are insufficient to rotate the propeller connected to the machinery is of importance.
At slow ship's speeds a number of tests may establish the effectiveness of a bow thruster while the rudder is kept amidships. Normally,the time to turn through 90 degrees is important.

Falling off an luffing up characteristics as well as making leeway may be measured in a condition where the ship is making little headway and making no attempt to affect the ship's behaviour by use of the rudder and/or extra revolutions of the propeller.

6.4 Desired accuracy

The accuracy of the data measured need not to be high. This stems from the fact that a manoeuvre is in reality never reproducible and is highly dependent upon local geographical and meteorological conditions which will never be exactly the same. The manoeuvre is also dependent on the experience, character and psychology of the person in actual command of the conning and ship handling process. This fact should not be overlooked and constitutes an important reason why manoeuvres are not reproducible.
The practicing mariner will take a measured value as a reference point but will always make allowances for prevailing circumstances.
The desired accuracy is, furthermore, of a slightly lower order when the ship proceeds on the high seas than navigating in difficult navigable waters in dense traffic areas.
However with the normal margins of safety as exercised by prudent navigators, measurements with shipborne instruments are sufficient.
Since on board speed measurements are often difficult, it seems a good precaution to additionally use land based electronic position systems to determine the ship's path and consequently the ship's speed, currents being the possible disturbing element in determining the ship's path through the water by land based position systems.

7. Recommended codes

7.1 Recommended code for scientific purposes

The SNAME code provides the most complete guide for all types of sea trials with all types of vessel involved. It seems to be the most flexible code and should be used by the shipyard officials as a basis for detailing an entire seatrials program.
The assessment of the aims clarifies the type of trials needed. Since this Report is only concerned with manoeuvring trials,the use of this code seems exaggerated owing to an appreciable amount of superfluous articles and remarks.

The B.S.R.A. code contains a number of trials which are doubtful in a scientific code. Examples are weave manoeuvre and the rudder calls measurement to detect possible margins of instability.

The D.N.V. code is primarily oriented towards practical use. The inclusion of measurements of performance of bow thrusters is very worthwhile.

The I.T.T.C. code seems to be the code to be applied when scientific purposes are involved, although,even in this code,a number of scientific trials are lacking due primarily to the fact that no experience has been gathered.
This code has recently been updated and will be updated each time new developments will change the pattern of manoeuvrability.
An other advantage is that this code will be used by people well aware of modeltesting techniques, thus facilitating comparisons between ship- and model performances.

In conclusion, the I.T.T.C. code seems to be the standard code to refer to when planning and execution of manoeuvring trials for specific scientific purposes are involved.

7.2 Recommended code for nautical purposes

When selecting a proper code for nautical purposes one has to answer the question as to how valuable the results of the intended trials are for the mariner. No confusion whatsoever exists as regards the turning circle. Without exception all manoeuvring codes recommend this trial and put emphasis on the importance of turning circles.
The same applies for the crash stopping manoeuvre. These two trials are the nucleus of a succesfull manoeuvring trials program.

The SNAME code has again the disadvantage referred to in the preceeding paragraph. It is too complicated for manoeuvring trials alone, but should be thoroughly investigated by those planning a complete seatrial owing to its degree of versatality in application to different goals.

The I.T.T.C. code contains a number of trials which will not advise the mariner properly in nautical terms. Spiral tests do not provide the mariner with extremely important information as they do the hydrodynamiscist.
The same remark holds in fact, for the B.S.R.A. and D.N.V. code. Spiral tests should not be recommended when the sole and ultimate goal is gathering operative data.

With a view to the structure of the codes, the author has a very slight preference for the D.N.V.-code, since, in a number of aspects it best suits the mariner. When stringent reasons exist not to use D.N.V.-code resort may be made to the B.S.R.A.-code.

However, manoeuvring trials are only a minor part of seatrials. In the event of an entire program for seatrials having to be devised, the author would give preference to the SNAME-code.

8. The manoeuvring booklet

8.1 Data which ought to be contained in this booklet

It seems appropriate to incorporate at least the following items in a manoeuvring booklet

i general dimensions of the ship and other relevant particulars
ii total fuel consumption and fuel consumption of the prime mover
iii maximum and minimum speed in restricted waters
iv acceleration and deceleration figures
v results of stopping trials
vi results of coasting trials
vii results of turning circles
  a. advances
  b. transfers
  c. tactical diameters
  d. final diameters
  e. time to turn through 90, 180 and 360 degrees
  f. loss of speed due to turning
viii speed - rpm curve
ix times and overshoot angles associated with an overshoot angletest with full counter rudder
x lines of sight and height restrictions

All this data should be provided in (a) condition(s) which represent(s) the average operational condition(s). For example, in the case of a VLCC, there are two distinct conditions, fully loaded and ballasted. One should know that these conditions produce very different manoeuvring characteristics.(It is obvious for the mariner that the loaded VLCC condition is the condition which might impose difficulties to the shiphandler.) Their full forms create a marked difference in behaviour due to large differences in draught and a tremendous amount of trim, this being the major factor in their radical change of behaviour.

The data mentioned here should be gathered during sea trials. This is preferable to the simple adoption of the results of modeltests. Up scaled results of modeltests should only be used in a tentative way, unless evidence can be produced about the real life validity of the model test results.
The master should be given ample warning that appreciable departures of the displayed curves and values might be possible in the event of real ship data as well as in the event of upscaled modelresults.

8.2 Different trials for different ships

In the preceeding paragraph the contents of a manoeuvring booklet have been summarized for a general case. Departures from this approach may be allowed as special missions of circumstances dictate.

Generally, the following considerations affect the choice of trials to be performed and thus the data to be incorporated in the manoeuvring booklet:

i the ship's mass
Large ships with large masses are very sluggish in helm response

ii the ship's rudder and propeller configuration
A ship equipped with two propellers is capable of manoeuvring with the aid of propellers and thus having an extra possibility for control.
The location of the rudder is of absolute importance for the generation of the rudder's normal force which initiates a turn. The efficiency of this force generation is dependent upon the waterspeed on the rudder profile.

iii the ratio between the lateral area exposed to wind and the underwater lateral area.
This ratio can be appreciable changed by the ballast condition and affects the average sustained speed in restricted areas and difficult navigable waters.

iv the ship's service or mission.
The following sub-items are of importance:
a. the ratio between total voyage sailing time and the time spent in difficult areas where the ship proceeds under manoeuvring speeds
b. the ratio of total voyage sailing time and time spent in areas with dense traffic flows.
c. the ratio of total voyage sailing time and time spent in geographically difficult areas.

v the ship's special manoeuvring devices.
These devices may affect the ship's handling in a particular way. The presence of sidethrusters and other reputed but non conventional appliances for easy manoeuvring may reduce the number of trials necessary.

vi the ship's risk factor.
This factor may be composed of the following items:
a. the nature and quantities of the cargo commodities transported
b. the number of crewmembers
c. the capabilities of the crewmembers
d. the protection to minimise collision effect
e. ship size

vii the ship's prime mover.
Sometimes appreciable differences in respons times exist with various prime movers.
The ratio of ahead and astern power is important.
The risk factor of the prime mover should also be taken into account.

On the basis of these considerations, the following factors might be used to determine the number and the nature of the manoeuvring trials to be performed:

i ship's displacement
ii rudder-propeller configuration
iii ratio lateral wind area/underwater area
iv ship's service i.e.:
1. ratio manoeuvring - normal sailing time
2. ratio traffic dense area sailing - normal sailing time
3. ratio geographical difficult areas - normal areas sailing time
v ship's special manoeuvring devices
vi nature transported commodities
vii nature prime mover

The weight of these factors should be established in order to arrive at a priority class which indicates the minimum amount of manoeuvring trials to be performed.
In Appendix III a possible realisation of the concepts outlined here has been set forth.

9. The actual performance of manoeuvring trials

9.1 The need for standardization

Since it is recommended that the ship's manoeuvring characteristics be available on the bridge, there is a need for standardizing these data. All information needed should be presented in a lucid manner either by use of Diagrams or Tables, and should be readily available on the bridge. The uniform appearance of the data displayed greatly facilitates its use. The best method for standardization is not easily established since a number of people involved have different ideas as to the standardization desired. In fact, the way to standardize is immaterial; the important option to understand is that a certain manner of standardization is needed so as to facilitate its use.

9.2 Main features for performing manoeuvring trials

The following factors should be underlined when one seeks to perform manoeuvring trials:

- i the execution of manoeuvring trials should be given ample time in the trials' schedule as to warrant proper and usable results.
- ii the measuring team should be provided with written instructions and should be extensively briefed as regards to the specific tasks to be accomplished.
- iii since nautical importants tests are performed it seems reasonable to measure with shipborne equipment.
- iv when it is judged necessary to measure distances with radiometric systems, one should establish a set-up for simultaneous measurements with shipborne instruments.

These factors will be incorporated in a manual for the performance of manoeuvring trials. This manual may be considered as a separate addendum to this Report.

APPENDIX I

International Maritime Consultative Organization

ASSEMBLY - 4th extraordinary session

Agenda item 4

RECOMMENDATION OF DATA CONCERNING MANOEUVRING CAPABILITIES AND STOPPING DISTANCES OF SHIPS

RESOLUTION A.160(ES.IV) adopted on 27 November 1968

THE ASSEMBLY,

NOTING Article 16(i) of the IMCO Convention concerning the function of the Assembly,

HAVING REGARD to the variety of the circumstances and to the manoeuvring capabilities of the ship,

TAKING INTO ACCOUNT the provisions of the International Regulations for Preventing Collisions at Sea, 1960,

HAVING EXAMINED the Recommendation on data concerning manoeuvring capabilities and stopping distances of ships adopted by the Maritime Safety Committee at its seventeenth session,

RECOMMENDS to Governments that they ensure that the master and officers have readily available on the bridge all necessary data concerning the manoeuvring capabilities of the ship and stopping distances under various conditions of draught and speed.

APPENDIX II

International Maritime Consultative Organization

ASSEMBLY - 7th session

Agenda item 8

RECOMMENDATION ON INFORMATION TO BE INCLUDED IN THE MANOEUVRING BOOKLETS

RESOLUTION A.209(VII), adopted on 12 October 1971

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THE ASSEMBLY,

NOTING ARTICLE 16(i) of the Convention of the Inter-Governmental Maritime Consultative Organization concerning the functions of the Assembly,

RECALLING Resolution A.160(ES.IV) by which it adopted the Recommendation on Data Concerning Manoeuvring Capabilities and Stopping Distances of Ships,

DESIRING to ensure uniformity in the information to be included in the manoeuvring booklets available on board, particularly in large ships and ships carrying dangerous chemicals in bulk,

HAVING EXAMINED the Recommendation by the Maritime Safety Committee at its twenty-first session,

ADOPTS the Recommendation on Information to be Included in the Manoeuvring Booklets, the text of which appears at Annex to this Resolution,

INVITES all governments concerned to take steps to give effect to this Recommendation as soon as possible.

Appendix III

A Proposal for a Minimum Number of Manoeuvring Trials

1. Introduction

The concepts of this proposal are mentioned in paragraph 8.2

2. The definition of rating

The total rating TR is defined by:

$$TR = R - D \qquad [1]$$

In expression [1] the two quantities R and D are defined as follows:

$$R = \sum_{i=1}^{6} R_i \qquad [2]$$

$$D = \sum_{i=1}^{3} D_i \qquad [3]$$

Equation [2] is composed of the different ratings R_i corresponding to the items of table 1.
Equation [3] is composed of the different deductions D_i corresponding to the items of table 2.

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Table 1

Ratings R_i as function of a number of relevant factors

No.	Description	Value of rating				
1	Displacement R_1	< 5.000 1	< 30.000 3	≤ 100.000 5	> 100.000 7	
2	Rudder-Propeller Configuration R_2	2 Rudders 2 Propellers 1	1 Rudder 2 Propellers 3	1 Rudder 1 Propeller 4		
3	Ratio wind lat.area to lat. underwater area R_3	small 1	moderate 3	large 5		
4	Ship's mission					
	1. Ratio full speed Manoeuvring speed $R_{4,1}$	high 1	moderate 2	low 3		
	2. Dense Traffic Areas $R_{4,2}$	none 1	moderate 2	often 3		
	3. Geographical Difficulties $R_{4,3}$	none 1	moderate 2	often 3		
5	Nature transported Commodities R_5	Containers Gener.cargo 1	Bulk 2	Crude 4	Chemicals Kerosine 5	LNG 6
6	Nature Prime Mover R_6	Elect.Diesel 1	Diesel 2	Turbine 2	Gasturb. 4	Nuclear 7

Table 2

Deductions D_i for special manoeuvring devices

No.	Description	Value of deduction
1	Side thruster	$D_1 = 5$
2	Voith Schneider propeller	$D_2 = 10$
3	C.P.P.	$D_3 = 3$

3. Classification in priority classes

Once the Total Rating is known the priority class can be determined. Total Rating is the entry in table 3;the result is a priority class.

Table 3

The determination of priority class as a function of Total Rating (TR)

TR	Priority class
30 ≤ RT ≤ 38	I
25 ≤ RT ≤ 29	II
17 ≤ RT ≤ 24	III
10 ≤ RT ≤ 16	IV
RT ≤ 9	V

4. Determination of available tests

Table 4 presents the code for each trial, discussed in chapter 3.

Table 4

Translation table

Description	Code
Turning Circle	TC
Zigzag Trial	ZZT
Overshoot Angle Test	OT
Courge Change Test	CCT
Modified Zigzag Trial	MZZT
Weave Manoeuvre	WM
Pull-Out Manoeuvre	POM
Dieudonne Spiral Test	DST
Beck's Reversed Spiral Test	BRST
Crash Stopping Manoeuvre	CSM
Coasting Manoeuvre	CM
Fishtail Manoeuvre	FTM
Rudder Cycling Manoeuvre	RCM
Zigzag Side Thruster	ZZTST
Static Test Rudder Positions	STRP
Acceleration Test	AT
Sinusoïdal Test	ST
Trapezoid Rudder Signal Test	TRST
Rudder Effectiveness Test	RET
Wind Effect Trial	WET

In table 5 the manoeuvring trials are classified with regard to their nautical value which may be considered as the governing factor, when one seeks to present manoeuvring properties of a specific ship to a navigator.

Table 5

Summary of the nautical value of manoeuvring trials

Qualification	Trials
Excellent	TC, OT, CSM, RCM, AT
Good	CM, FTM, ZZTST, CCT, RET, WET
Moderate	ZZT
Small	MZZT, WM, POM, DST, BRST, STRP, ST, TRST

The treated manoeuvring trials contain well established trials as well as trials recently devised.
The experience gained should be a governing factor in the ultimate selection of trials. No compulsory trials should be ordered unless reasonable experience has been gathered. In table 6 the experience gained has been summarized.

Table 6

Summary of the experience gained with manoeuvring trials

Qualification	Trials
Much	TC, ZZT, DST, CSM
Moderate	OT, BRST, CM, FTM, ZZTST, AT
None	CCT, MZZT, WM, POM, RCM, STRP, ST, TRST

The following table indicates the final tests which should be used for the determination of nautical manoeuvring properties.

Table 7

Tests to be used for the determination of nautical manoeuvring properties

Qualification	Trials
Excellent	TC, OT, CSM, AT
Good	CM, FTM, ZZTST
Moderate	ZZT

Table 8 depicts the test which should be recommended to gain more experience. In a later stage the results may be evaluated and some tests may be transferred to the columns of table 7.

Table 8

Tests to be recommended for the determination of nautical manoeuvring properties

Qualification	Trials
Excellent	RCM
Good	CCT, RET, WET
Moderate	-

5. Manoeuvring trials for the different priority classes

The following assumptions have been made to establish the number of needed trials.

i The manoeuvring tests with the mark "excellent" for nautical value should be performed by all ships independent of the priority class.

ii For the priority classes I and II a number of tests have to be performed on shallow waters

On the basis of these assumptions the following table may be suggested.

Table 9

Compulsory trials for different priority classes

Priority Class	Compulsory Trials
I	TC, OT, CSM, AT, FTM, ZZTST*, CM, ZZT
II	TC, OT, CSM, AT, FTM, ZZTST*, CM, ZZT
III	TC, OT, CSM, AT, FTM, ZZTST*, CM
IV	TC, OT, CSM, AT, FTM
V	TC, OT, CSM, AT

* when appropriate

Differences in the priority classes I and II exist, especially with regard to TC, OT, CSM trials, which are more extensive in the former case. These trials should be repeated in shallow waters.

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The following table indicates the trials which should be recommended.

Table 10

Recommended trials for different priority classes

Priority Class	Recommended Trials
I	RCM, CCT, RET, WET
II	RCM, CCT, RET, WET
III	RCM, CCT, RET
IV	RCM, CCT
V	RCM

6. Examples

The next table illustrates the determination of the needed manoeuvring trials.
The ships chosen, are:

i dry cargo ship, 10.000 tons deadweight, dieselpropulsion
ii VLCC, 220.000 tons deadweight, turbine propulsion
iii "KHV" general cargo liner, 3.000 tons deadweight, diesel-propulsion
iv Container vessel, 45.000 tons deadweight, side thruster

Table 11

Example of the calculation of the Total Rating (TR)

	DCS	VLCC	"KHV"	CV
R_1	3	7	1	5
R_2	4	4	4	3
R_3	1	3*	3	5
$R_{4,1}$	2	1	3	1
$R_{4,2}$	2	2	3	3
$R_{4,3}$	2	3	2	2
R_5	1	4	1	1
R_6	2	2	2	2
D_1	0	0	0	5
D_2	0	0	0	0
D_3	0	0	0	0
TR	17	29	19	17
Priority Class	III	II	III	III

* 50% of time in ballasted condition