SHIP POSITION CONTROL SYSTEM FOR SINGLE ROLE MINEHUNTER

BY

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ABSTRACT

The ship position control system (SPCS) for the single role minehunter uses standard PCBs from the D86 range and is connected to the minehunting system via a 1553B data bus. It automatically controls the vessel during minehunting operations, giving track keeping and hover facilities. Extensive use of a ship simulation was made during development to assist in algorithm design and testing, and a trials logging/tuning facility was developed to simplify trials tuning and troubleshooting. The SPCS has completed its acceptance trials and is now in use in the Royal Navy.

Introduction

Vosper Thornycroft Controls (VTC) is part of the systems group of Vosper Thornycroft (UK) Ltd and is primarily involved in the design and manufacture of control systems for naval vessels.

The ship position control system (SPCS) was designed for use in the SANDOWN Class of single role minehunters (SRMH). Its purpose is to control the vessel automatically during minehunting operations and to provide manual joystick and autopilot control functions.

The vessel is equipped with Voith Schneider propulsors (VSPs), that provide controllable vectored thrust, and a bow thruster (BT). The vessel uses twin diesel engines for non-minehunting operations and electric slow speed drives for minehunting.

The vessel employs a variable depth sonar (VDS) that is lowered through a central well. The deployed depth is adjusted to the optimum for minehunting on the Continental Shelf.

This article covers the techniques used to implement the design and the steps taken to simplify the tasks of testing, setting to work and sea trials, with particular reference to the ship simulation and trials logging facility that were developed during the project.

The system was designed to meet a naval staff requirement and was required to provide several different operational modes. The requirement was to produce a simple and easy-to-use facility to control the vessel during minehunting operations within set accuracy targets. This was intended to reduce operator fatigue and to enable accurate track following over an extended period in a wide range of environmental conditions.

The challenge for the control system was to control the vessel accurately with the low power available from the slow speed drives. Their use is necessitated by the need to keep the acoustic signature of the vessel to a minimum to prevent accidental detonation of acoustic mines.

SPCS MODES

Manual

The system was required to provide a manual joystick mode, where a three-axis joystick is used to control vectoring of the vessel thrusters. The joystick is fitted to the quartermaster's console (QMC), and a portable version can be connected at various positions around the vessel. Hover mode can be selected by operation of a push button adjacent to the joystick. This hovers the vessel at that physical location until the push button is operated again or until another mode is selected.

The joystick is used when berthing the vessel or when recovering and deploying the mine disposal vehicle.

Track Keeping

Track keeping is the mode used for minehunting when following a search pattern. The mine warfare officer (MWO) sets the plan to be followed into the action information organization (AIO) and the co-ordinates of the required waypoints of the track are then transmitted to the SPCS via the weapon system data bus (WSDB). The SPCS then interprets these waypoints as a command to track keep, and indicates to the quartermaster that a request to track keep has been received. The vessel is then automatically manoeuvred along the track between waypoints. The required ship speed is also controlled by the MWO and sent along the data bus with the waypoint data.

This mode is used for minehunting and classification operations. As a waypoint is passed the AIO updates the plan to ensure that the SPCS always has three waypoints in its memory, thus enabling the SPCS automatically to follow a tight circular path.

High speed route surveys are carried out using main engines at track speeds of up to 12 knots. Minehunting with the towed body deployed is carried out at speeds of up to 6 knots over the ground, with classification manoeuvres at speeds as low as 1.5 knots.

Hover

When the AIO sends only one waypoint or the last of a series of waypoints is reached the SPCS will automatically select hover mode. This mode can also be selected by the quartermaster when used in conjunction with the manual joystick.

The single role minehunter is equipped with a small bow thruster that is adequate for all normal berthing operations of the vessel, but does not have sufficient power for hovering using traditional dynamic positioning techniques in all environments encountered during minehunting. In order to overcome this limitation three variants of the hover mode were developed to cater for the range of environmental conditions that the SPCS has to meet.

(*a*) *Hover by dynamic positioning with a command desired heading* (*hover DP CDH*) is used in low environmental conditions with no restriction on the ship's heading. The CDH is set by the MWO and is transmitted along the WSDB.

When operating in hover DP mode, priority is given to maintaining heading. The system calculates Northing and Easting position errors from the hover point and the ship position. The heading error is calculated from the desired heading and the ship heading. The system takes the error information and then processes it to produce pitch setting demands to the VSPs and speed demands to the BT in order to keep the ship at its hover point.

(*b*) *Hover by dynamic positioning with a favourable heading* (*hover DP FH*) is used in more severe environments than DP CDH. The favourable heading, as determined by the SPCS, is that which will minimize the effects of wind and tide on the vessel. It is calculated by measuring the actual wind and tide, and then using a ship model to predict the BT usage at various headings between wind and tide directions. The minimum is found by extrapolating between the sampled headings that produced the lowest BT usage.

(*c*) *Hover using position control by manoeuvring* (*hover PCM*) is used in environments up to the maximum suitable for minehunting. This mode uses the VSP to work against the environment to maintain the required position.

When operating in hover PCM the ship will tend to move in the desired direction to correct any positional errors rather than moving laterally. Under steady state conditions the ship's heading is the favourable heading.

Plan Interrupt

When under control of the MWO, plan interrupt passes control back to the QMC. This is used when an unidentified ground contact is made and the SPCS brings the vessel to a halt as quickly as possible while maintaining any noise limits set.

Once the vessel speed over the ground drops, QMC hover is selected. This mode is maintained until classification is complete or another mode is selected.

Ship Emergency Halt

This mode is similar to plan interrupt but is initiated by operation of a push button on the QMC. This mode is used when a surface floating mine is encountered, as in the Gulf. Noise limits are ignored and the hover mode is automatically selected when the vessel speed drops.

Autopilot

The SPCS implements a traditional autopilot function using the same hardware as for the other automatic modes. The mode is selectable by the quartermaster, and a desired ship's heading entered. The SPCS then controls the VSP lateral pitch to maintain the desired vessel heading. VSP longitudinal pitch is set to full ahead and vessel speed is controlled by adjustment of the main engine speed.

The desired heading is adjusted at the QMC by means of increase and decrease push buttons until the desired heading is displayed on the plasma display; the operator can then enter the new heading into the controller.

A yaw limit and the usable steering pitch are also adjustable by the operator. The autopilot is based on a three-term controller with a wind feed forward term.

Minehunting under SPCS control

FIG. 1 shows a typical minehunting exercise and demonstrates how the automatic modes are used. The AIO transmits a pattern of waypoints, WP1, WP2 and WP3, to the SPCS and the system will select the track keeping mode. The ship will then be steered along the track from WP1 to WP2 at the speed set by the MWO. When WP2 is passed the vessel will turn and head for WP3; the AIO will then pass WP4 to the SPCS.

When an artefact is detected (point A) between WP3 and WP4, the AIO will send a new plan of WP1001 and WP1002. The vessel will then steer from WP1001 to WP1002 and hover at WP1002 while classification takes place. Following further periods of classification at WP1003 and WP1004, the vessel will retreat to WP1005 for disposal.

All these operations will be carried out under automatic control of the SPCS. The quartermaster's only duty is to monitor the vessel performance and to ensure that the selected hover mode is the most suitable for the actual environment.

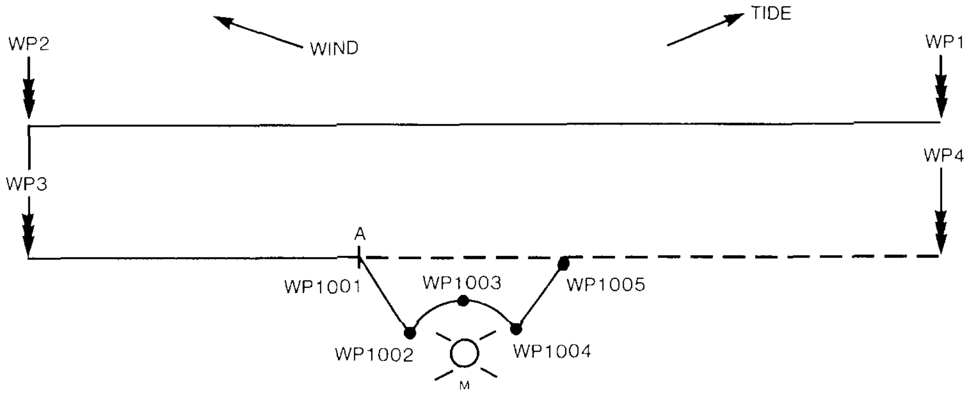


FIG. 1—A TYPICAL MINEHUNTING EXERCISE

A: point of detection
M: mine
WP: waypoint

SPCS DESIGN

There are three main sections to the SPCS design:

- the hardware design;
- the software design;
- the control algorithm design.

The Hardware

The system is implemented using processors and interface cards from the VTC range of D86 printed circuit boards (PCBs), as already used on various other RN vessels: the Type 23 frigate, the Type 2400 submarine and the Trident submarine, as well as foreign naval vessels.

Special precautions had to be taken to protect the electronics from the harsh electromagnetic compatibility (EMC) environment encountered on board glass reinforced plastics (GRP) vessels. This included fitting any vulnerable electronics within double screened enclosures, and filtering supply and signal cables.

The SPCS system is housed within the QMC mounted on the bridge and interfaces with the direct control system (DCS), also housed in the QMC and supplied by VTC. The arrangement is shown in FIG. 2.

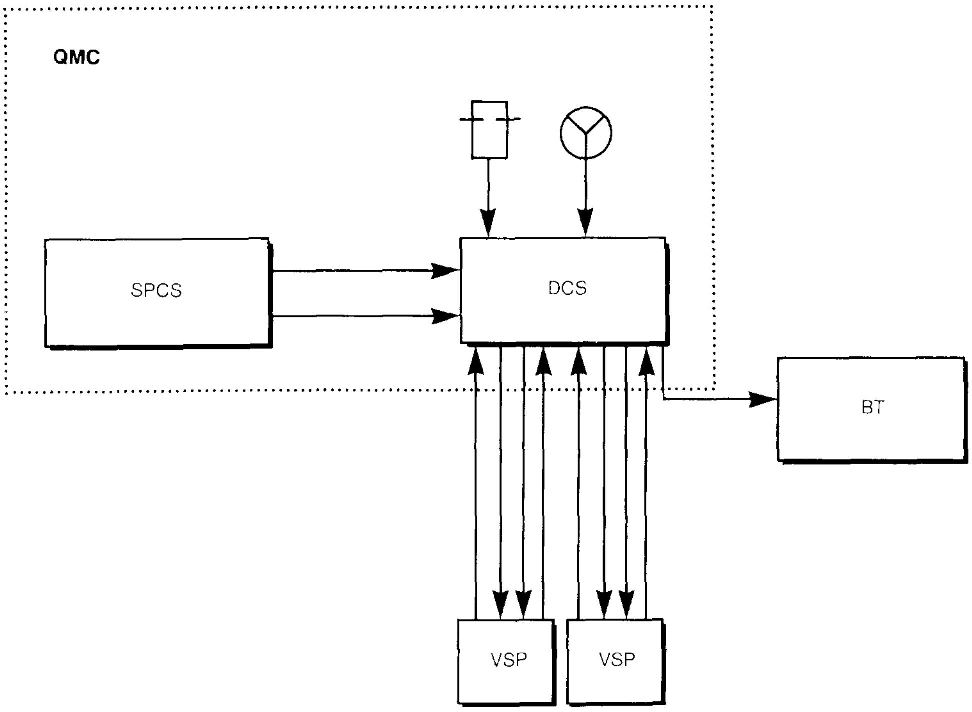


FIG. 2—SYSTEM INTERFACES WITH PROPULSION MACHINERY

BT: bow thruster
DCS: direct control system
QMC: quartermaster's console
SPCS: ship position control system
VSP: Voith Schneider propulsor

Ship Position Control System (SPCS)

The SPCS consists of one rack of electronics with all necessary power supplies, interfaces, and man machine interface (MMI) mounted in a console that forms half of the QMC.

The MMI comprises a plasma display, a fall-back display and all necessary push button switches and indicators. The plasma display has a dedicated page for each mode that gives all the relevant data for that mode. FIG. 3 shows the display for the track keeping mode. Three status pages are also available to give further useful parameters.

The fall-back display provides sufficient information to enable the system to function correctly on failure of the primary plasma display and consists of arrays of indicating lamps showing across track error, along track error and heading error.

As most of the SPCS modes are fully automatic, the function of the MMI is primarily surveillance, and alarms or warnings will be raised should any system or interface problem arise, as well as providing all relevant vessel and environmental data.

Direct Control System

The DCS is the normal method of controlling the vessel when not minehunting and provides independent longitudinal and lateral control of the Voith Schneider propulsor pitch as well as bow thruster control.

The VSP pitch is controlled by hand levers and a helm wheel providing demands to dedicated electronics that provide closed loop control of the BSP actuators. The DCS interfaces with the propulsion systems are shown in FIG. 2.

Each control loop is independent and was designed to achieve a high reliability. This was achieved by minimizing the component count, component screening and the elimination of single point failures.

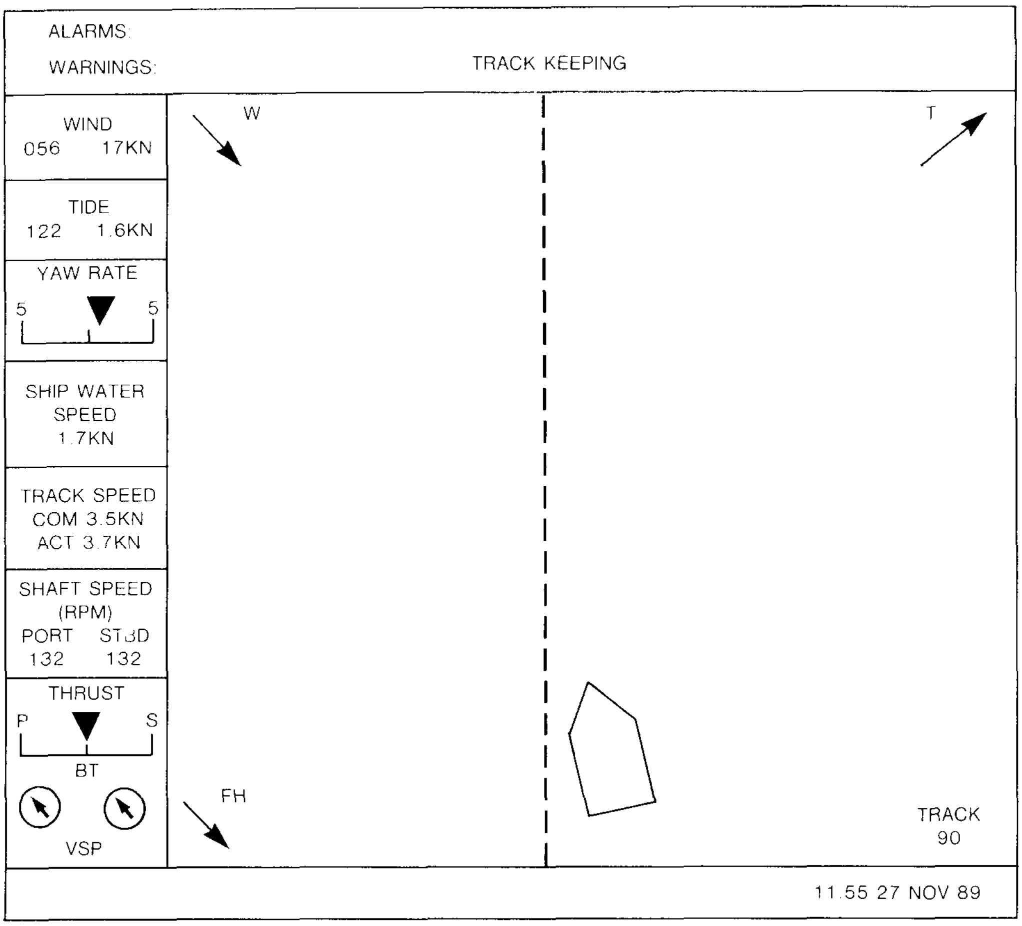


FIG. 3—TYPICAL PLASMA DISPLAY—TRACK KEEPING

The inclusion of the high reliability control system was to ensure that vessel safety was not compromised by common mode failures. The transfer from SPCS control to DCS control can be achieved by the operation of a single mode select switch on the QMC.

The SPCS controls the vessel by the use of isolated analogue inputs in the DCS, so any SPCS failures will not affect DCS availability.

The main engine speed control, and hence VSP shaft control, also forms part of the DCS and is independent of the SPCS. Each engine speed is controllable by means of an array of push buttons that control the governor setting by means of a stepper motor. Setting the governor to minimum when the slow speed electric motors are running causes the automatic changeover of the self-synchronizing and shifting (SSS) clutches.

Interfaces

FIG. 4 shows the interfaces with the other ship's systems and navigation aids. All positional data is received via the WSDB, as well as sonar positional data and system time.

The SPCS has been designed to function correctly with a variety of navigational aids, with the x y co-ordinates being received from the AIO via the WSDB. Hyperfix is the normal navaid used, due to its extensive coverage of UK coastal waters. The SPCS has been designed to work with a variety of primary navaids including Hyperfix, Microfix, Syledis, Global Positioning System (GPS), Trisponder, Radar fixing and Decca; the SPCS performance is dependent upon the primary navaid accuracy.

Ship's heading and wind direction are received via synchro interfaces. Wind speed is received via an analogue signal.

Correlation Electromagnetic Speed (CMS)

Surge and sway ground and water speed are received via an RS422 link directly from the CMS log. This system has been developed in a military version by Vosper Thornycroft for the SRMH. The system provides an accurate measurement of surge and sway ground speed, and also incorporates an electromagnetic log that provides along and athwartship water speed.

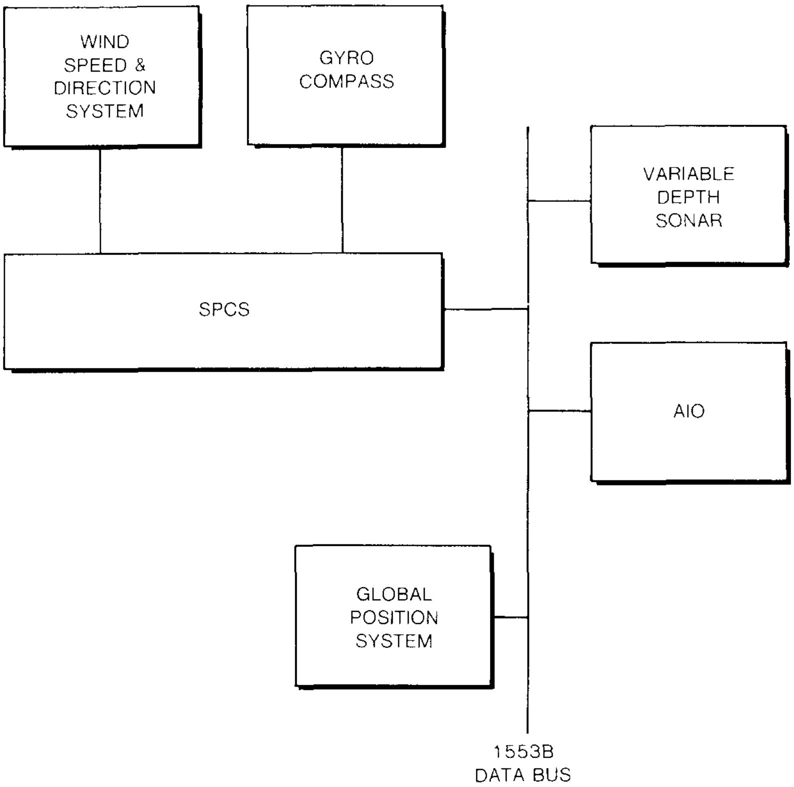


FIG. 4—SPCS/NAVAID INTERFACES

The Software

The application software was implemented using tried and tested standard VTC software modules. This use of proven software reduced risk and simplified the task of integration and test. The code is mainly written in CORAL 66 with assembler used where dictated by speed, and was developed within a CONTEXT environment.

Structured analysis and design techniques were used in the development of the system software. Rigorous testing of software modules was employed to reduce the integration time.

The application specific software consisted of code to handle control mode transitions, to handle the MMI and to call the relevant control algorithms. Functions such as the database management, I/O handling and comms handling, all used standard VTC modules.

The software incorporates extensive diagnostics and failure detection to simplify and speed up fault identification and repair.

The Control Algorithms

The development of the control algorithms was carried out by running a ship simulation on a μVax computer. The algorithms went through many design stages and took many forms before the final designs were settled upon.

Eventually conventional three-term controllers were found to be the most suitable option. After initial testing of the designs the algorithms were coded in CORAL for inclusion into the system software. The designs were also included in an SPCS model within the simulation, the simulation then being used to evaluate the algorithm performance over the full range of environments and conditions.

Separate algorithms were developed for each mode: autopilot, track keeping, hover DP and PCM, plan interrupt and ship emergency halt, as well as for the favourable heading calculation. The favourable heading module is used to calculate the best heading for hovering for the environment. This is achieved by calculating the hydro, aero and sonar forces on the vessel for a range of headings with the actual wind and tide, and then calculating the required use of the BT for that heading. The heading that gives the minimum use of the BT is the favourable heading.

The algorithm gains and limits were then tuned and adjusted as the result of extensive simulation work.

Once the algorithm gains had been finalized, the system was subject to a full stability analysis. This involved analysis of the SRMH system without any controller and then adding the analysis for each controller. The analysis was carried out by examining the response of a linearized model of the system to small control inputs and disturbances. The results of the linear model analysis were compared with results from the non-linear model to ensure accuracy of the model. The linear model was then exercised over a wide range of environments in order to find any areas of instability. The stability analysis indicated that the SPCS would be stable across all required operating scenarios.

Fall-back Modes

While the vessel will normally have all the required thrusters available for minehunting, the SPCS has been designed to operate with only one VSP functional. This means that in most environments the SPCS can function with little or no loss of performance when only one shaft is available.

The SPCS can also function with the shafts at different speeds, again with little effect on performance. This flexibility means that the SPCS can make maximum use of the thrusters available.

Various essential navaids can be replaced by estimated data in the event of navaid failure. Thus loss of the non-critical navaids will not mean total loss of the system.

Noise-Limiting Algorithms

Provision has been made to limit the SPCS usage of thrusters in order to limit thruster noise. The noise-limiting algorithms will be determined after noise ranging of the vessel and can be incorporated with no software redesign.

The algorithms will take the form of limiting the BT speed and VSP rate of change of pitch.

THE SIMULATION

A complete ship simulation was developed and included hull and machinery models provided by the shipbuilder and the Ministry of Defence.

The simulation also included models of the SPCS, CMS log, AIO and WSDB, as well as a full environmental model. The simulation was enhanced and expanded as algorithm design progressed. This included the addition of enhanced graphical displays and monitors for the calculation of performance figures. The improved MMI greatly simplified the task of analysis of large quantities of trials results.

The primary purpose of the simulation was to model accurately the real operating environment of the system in order to establish the system functionality and to enable realistic testing of the system. This was in order to reduce the setting to work time required on board the vessel.

The simulation was then used to form the basis for a system test facility where the vessel, the ship interfaces, and the environmental conditions were simulated in order to test the complete system functionally.

The simulation was also used to define the effects of tuning the algorithms. Thus maximum and minimum values and the sensitivity of each parameter were known before sea trials.

Various failure modes of ship's equipment were simulated in order to test the fall-back systems within the SPCS and the design's ability to withstand degraded sense performance.

TRIALS LOGGING FACILITY

As sea trials time was going to be very limited, and due to the dynamic nature of the SPCS, it was important to make full use of all ship time. In order to achieve this, and to ensure that any unexplained or transient phenomena were recorded, a data logging facility was developed. The main functions of this facility are:

- the logging of internal SPCS parameters;
- the tuning of algorithm gains;
- the production of performance figures.

The facility was implemented using a μVax computer connected via an RS422 link to the SPCS display processor. The display processor was then able to access the main SPCS database and supply the required parameters to the logging computer. The parameters to be logged can be selected from the logging computer and this selection passed to the SPCS; thus only selected parameters are passed down the data link.

Several parameters can also be logged from the port and starboard machinery control and surveillance console.

The data available to the logging facility are algorithm gains and limits, controller outputs, filter and navaid data, as well as SPCS mode and thruster information. Over 300 different parameters are available for monitoring or tuning, of which any 100 can be logged at any one time.

This facility is also used during system integration and test, to log system parameters in order to troubleshoot faults when connected to a system on the test facility. The performance monitor is used to provide performance figures during factory acceptance tests.

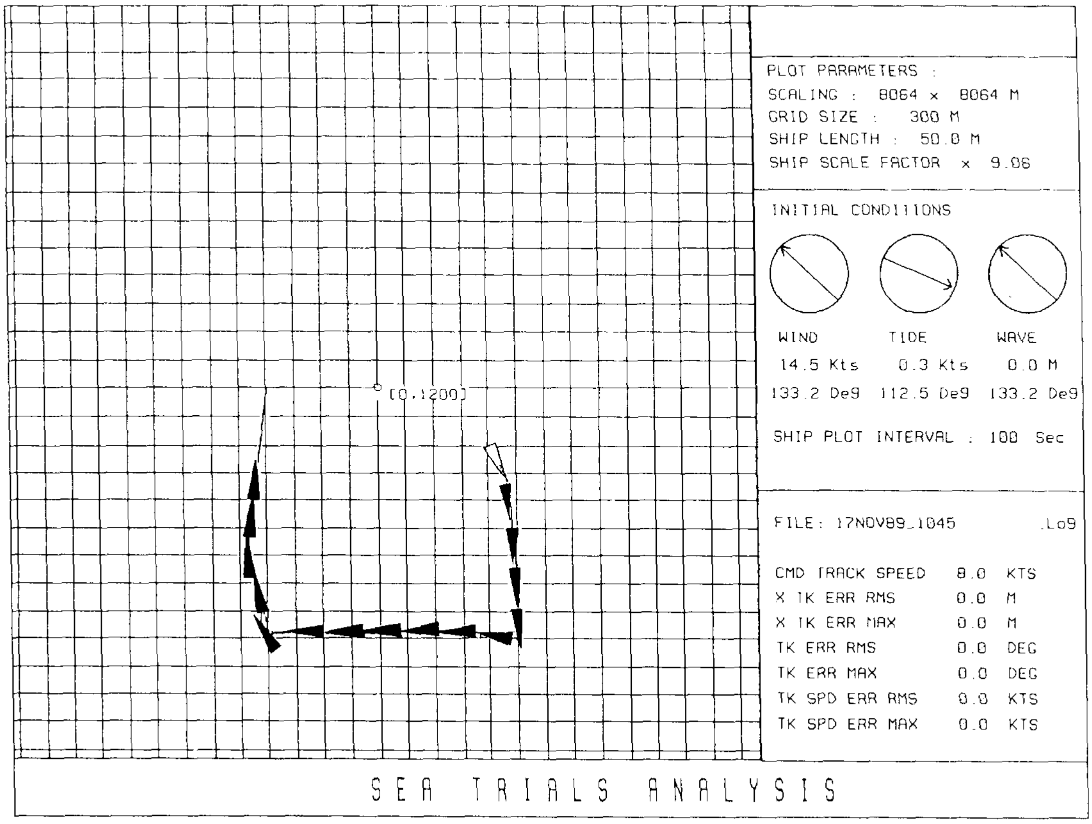
Algorithm tuning is required to adjust the performance of the algorithms on board the vessel to give the required performance. Thus the effect of inaccuracies in the simulation database can be minimized. Before sea trials the effect of algorithm tuning was tested on the simulation. Maximum and minimum safe levels for each gain were determined using the simulation. Thus the tuning of algorithms could be undertaken without affecting the system stability.

Once a parameter has been selected for display the facility can log it to a disk file for processing at a later date. This data can then be post-plotted to give a permanent record of any trial or manoeuvre. An example of the plotted data is given in FIGS. 5, 6 and 7. In FIG. 5 the vessel position is plotted at regular intervals to indicate the heading and at a scale that will not obscure the path. FIGS. 6 and 7 show various SPCS parameters throughout the logging period, thus enabling different parameters to be compared with each other at any time during the trial.

The output of each term of each three-term controller can be examined to analyse the controller performance and give a guide to any tuning required.

During the trails of the SPCS system over 500 Mbytes of data have been recorded, and the analysis of the sections relevant to the SPCS has been simplified by use of the graphical output of data.

The data recorded represents a unique library of information of a minehunter in many different sea conditions.



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PLOT PARAMETERS :
SCALING :  8064 x  8064 M
GRID SIZE :   300 M
SHIP LENGTH :  50.0 M
SHIP SCALE FACTOR  x  9.06

INITIAL CONDITIONS

WIND          TIDE         WAVE
14.5 Kts      0.3 Kts      0.0 M
133.2 Deg     112.5 Deg    133.2 Deg

SHIP PLOT INTERVAL :  100  Sec

FILE: 17NOV89_1045              .Log

CMD TRACK SPEED     8.0   KTS
X TK ERR RMS        0.0   M
X TK ERR MAX        0.0   M
TK ERR RMS          0.0   DEG
TK ERR MAX          0.0   DEG
TK SPD ERR RMS      0.0   KTS
TK SPD ERR MAX      0.0   KTS

SEA TRIALS ANALYSIS
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FIG. 5—VESSEL PATH DURING THE LOGGING PERIOD

TRIALS

Harbour Acceptance Trials/Linking

The harbour acceptance trial (HAT) and linking trials to various ship systems were carried out during the setting-to-work period. The purpose of these trials was to prove the functionality of the interfaces to other ship's equipment and to ensure that the SPCS had been correctly installed prior to going to sea.

Due to the dynamic nature of the SPCS it was not possible to test the system fully with the vessel secured alongside a harbour wall.

Pre-Sea Acceptance Trials

Before the formal sea acceptance trials (SATs) a period of setting to work and tuning at sea was made available and was referred to as the pre-SATs period. The aims of this period were to test each mode to ensure correct functionality; to gather data about the real ship to compare with the simulation models; to carry out tuning of the algorithms if required; to test the system dynamically; and to enable ship's staff to familiarize themselves with the system before handover.

The pre-SATs period was split into several sections as determined by the ship part 4 trial programme. The first week of trials took place at Portland in November 1989, and was characterized by extremes of environment. The first day was absolutely calm followed by three days of gales. However, the trials were a success with all modes functioning and the logging system proven.

The autopilot proved to work satisfactorily and the manual joystick in both local and remote modes was proved. Track keeping was tested and functioned correctly despite the very high winds; hover testing was more affected by the environment as only the PCM mode could be used.

FIGS. 5 to 7 show the results of a track keeping trial from the pre-SATs period. The vessel follows tracks of 170, 270, 345 and 15 degrees. FIG. 5 shows the vessel manoeuvring around the required track as well as plot information. FIG. 6 shows various vessel parameters, including wind and tide speed and direction. FIG. 7 shows some track keeping parameters, including track speed and direction.

A few minor interface problems were discovered during this week in both SPCS and ship's interfaces and these were corrected before the second week when it was intended to test the hover and track keeping modes fully. These modes have to function correctly with, and without, the hunt sonar deployed, and these tests were carried out off Rosyth in April 1990.

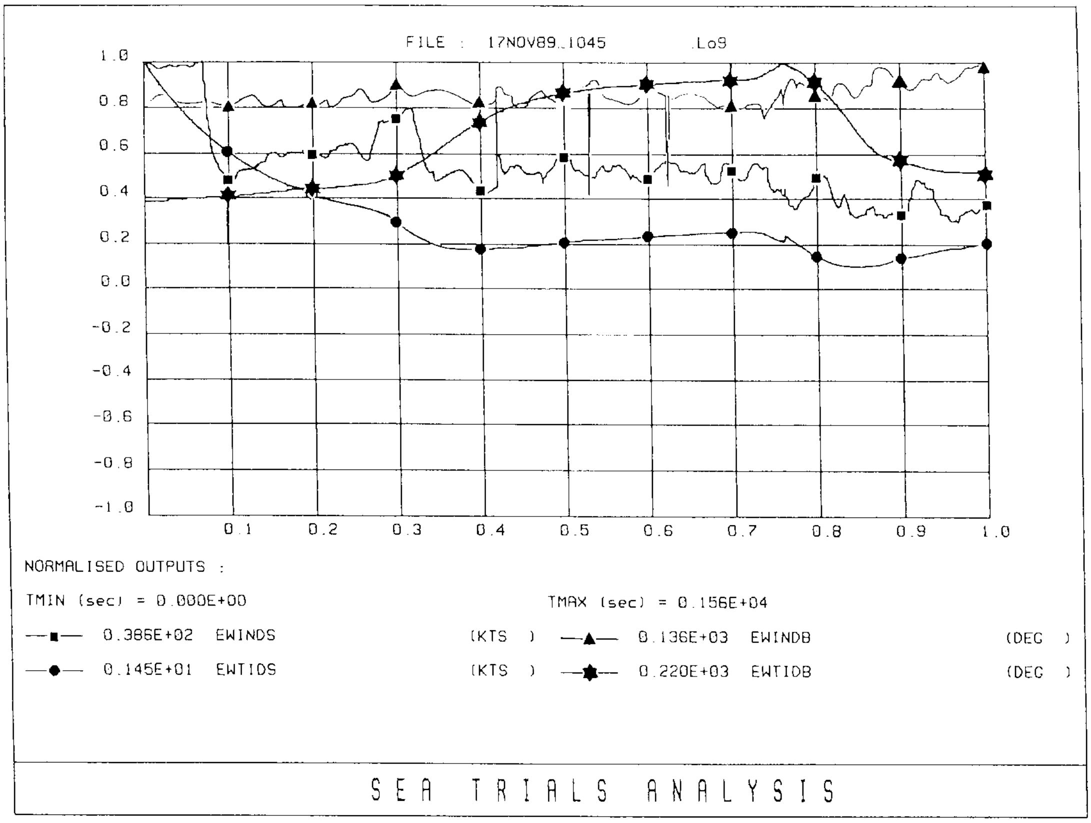


FIG. 6—VESSEL PARAMETERS, INCLUDING WIND AND TIDE SPEED AND DIRECTION

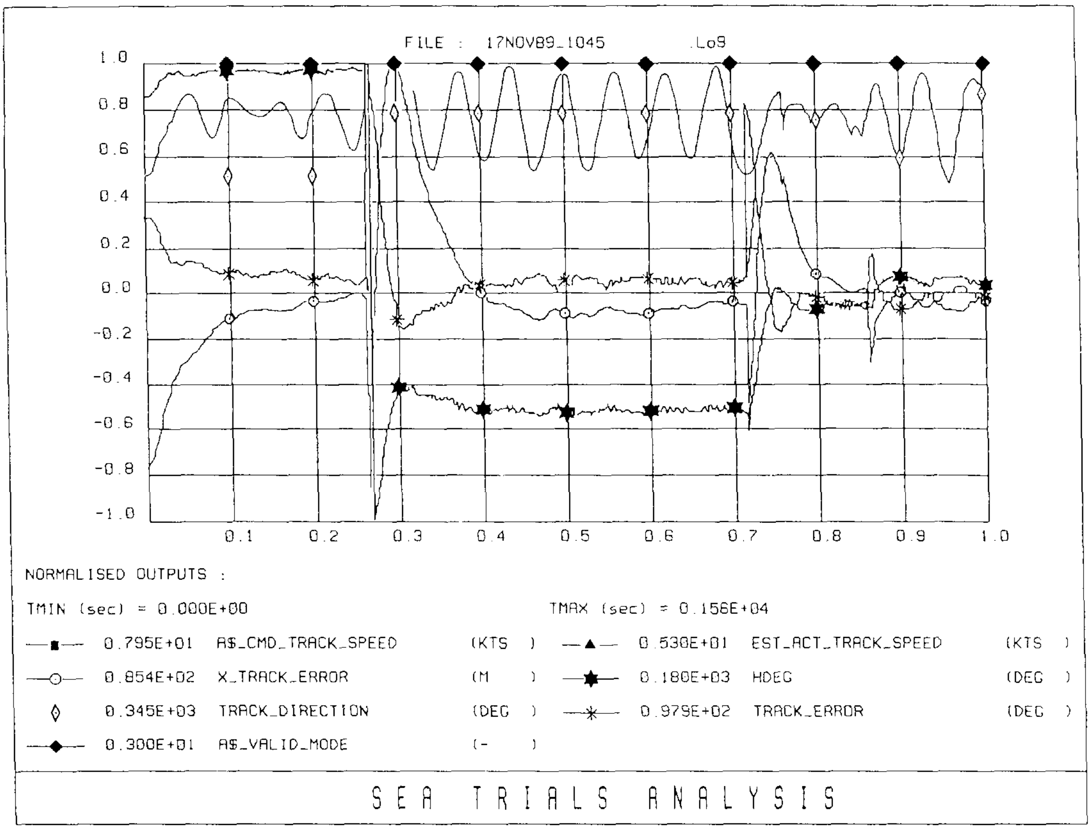


Fig. 7—Track keeping parameters including track speed and direction

One of the objectives of the pre-SATs was to gather as much data as possible regarding the system and vessel performance. When a trial had been conducted satisfactorily it could be rerun on the simulation in order to check the simulation validity. Once the simulation has been shown to be accurate, or any differences explained, the extensive simulation results become an accurate system performance definition, and future operational problems or changes can be tested against the simulation.

Sea Acceptance Trials

The sea acceptance trials (SATs) resulted in all modes being demonstrated but poor performance was seen in some fall-back modes and, while a certificate of clearance for use was issued, some further tuning was required.

When this tuning was carried out Vosper Thornycroft took the opportunity to incorporate new algorithms for the track keeping to hover transitions. When the SATs were repeated, complete acceptance was achieved with all modes demonstrated. Figs. 8 to 13 show some of the results of these trials.

The sea trials showed that the system not only met its contractual requirements but also will prove to be a useful and flexible minehunting tool.

Other Vessels

SATs have recently been completed on the SPCS for the Royal Saudi Naval Force Minehunters. This SPCS has the same facilities as the RN one, with the algorithms modified to take account of the different propulsion fit. This vessel uses microfix as its primary navaid and the improved accuracy of the navaid is reflected in the SPCS performance.

The second vessel in the Sandown Class, HMS *Inverness*, is also approaching SPCS SATs following completion of pre-SATs.

A similar system is also under evaluation in a Hunt Class Mine Counter Measures Vessel. This system has only a manual joystick mode but can incorporate the full SPCS modes should the trials prove successful.

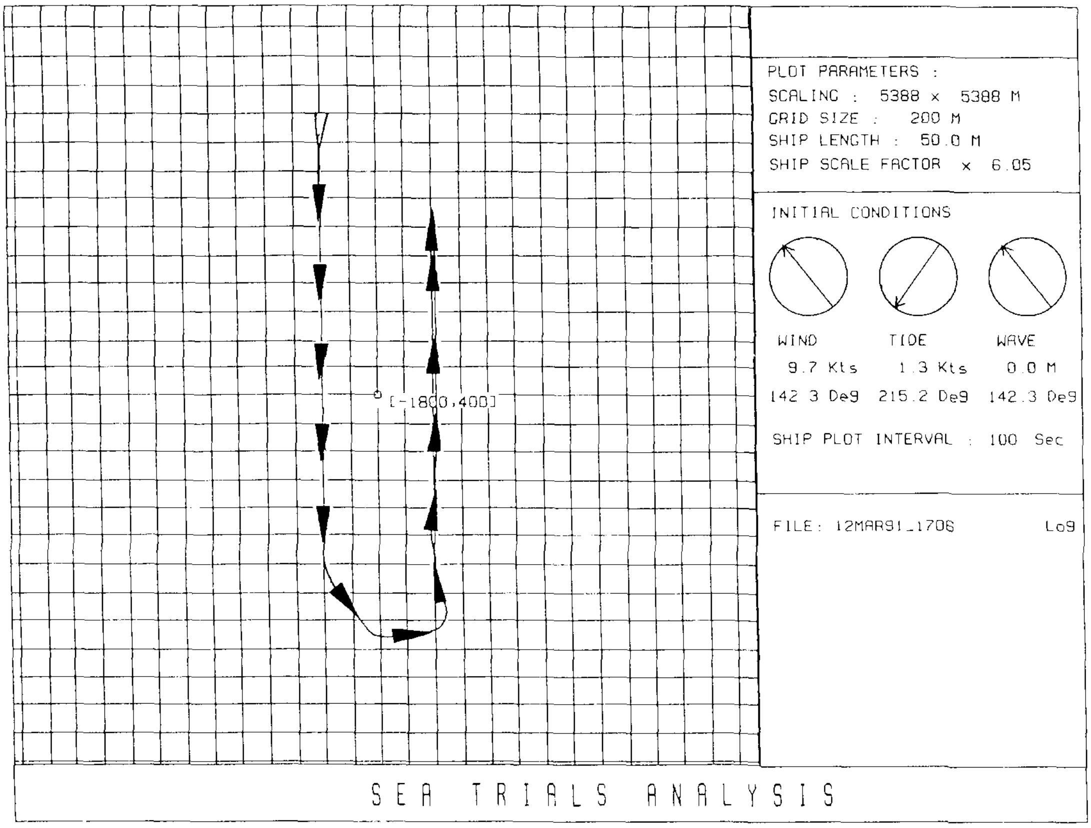


FIG. 8—HIGH SPEED TRACK KEEPING RUN AT 12 KNOTS WITH SONAR IN HULL MOUNT POSITION

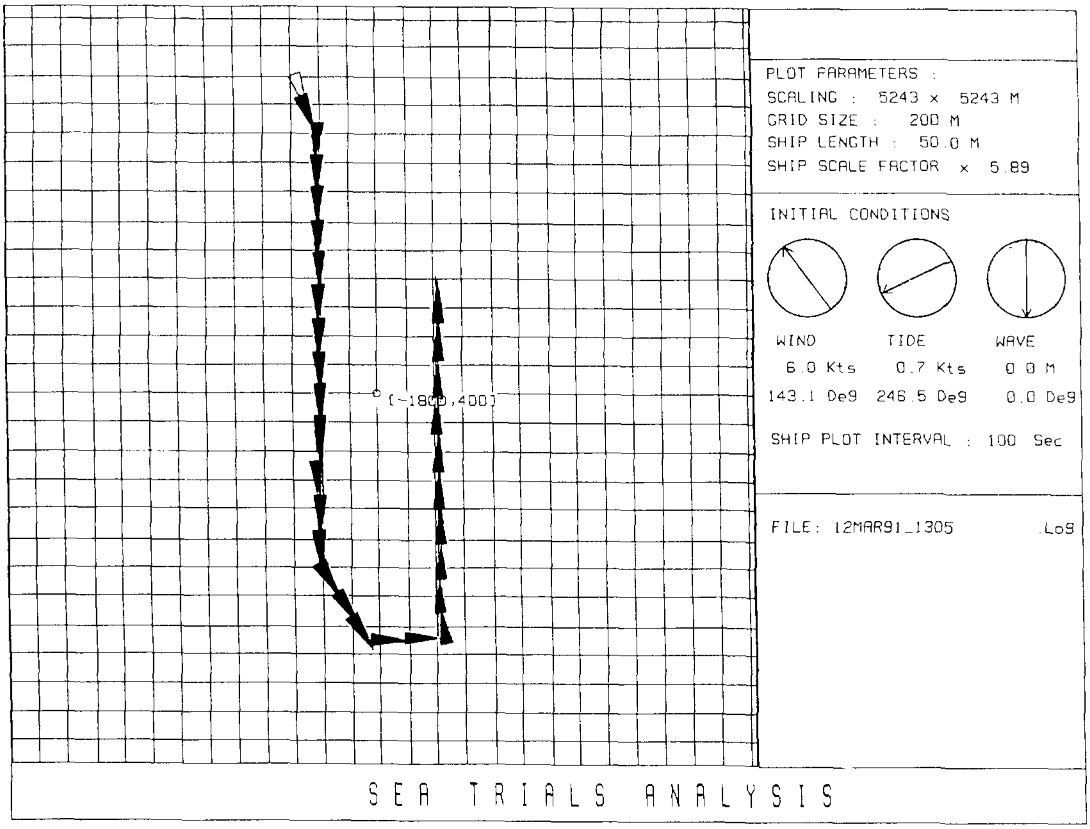
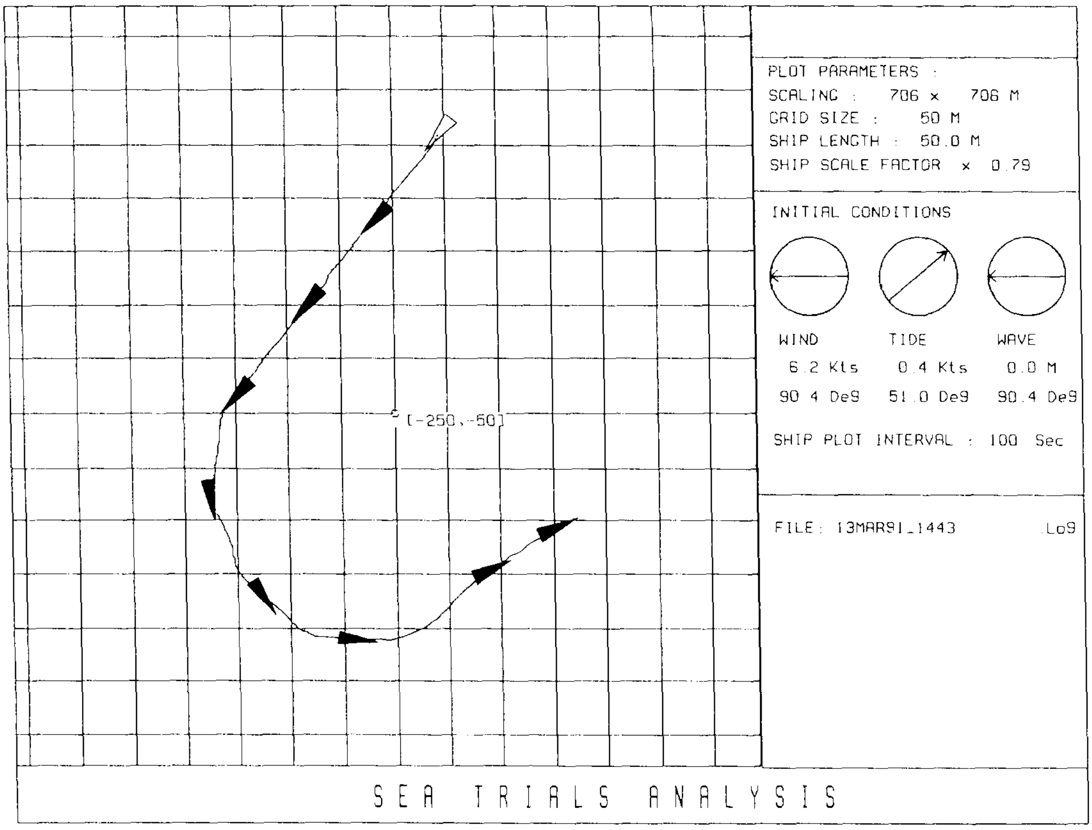


FIG. 9—TRACK KEEPING RUN AT 6 KNOTS, WHICH IS THE NORMAL MINEHUNTING SPEED, WITH SONAR DEPLOYED TO A DEPTH OF 60 m



PLOT PARAMETERS :
SCALING : 706 x 706 M
GRID SIZE : 50 M
SHIP LENGTH : 50.0 M
SHIP SCALE FACTOR x 0.79

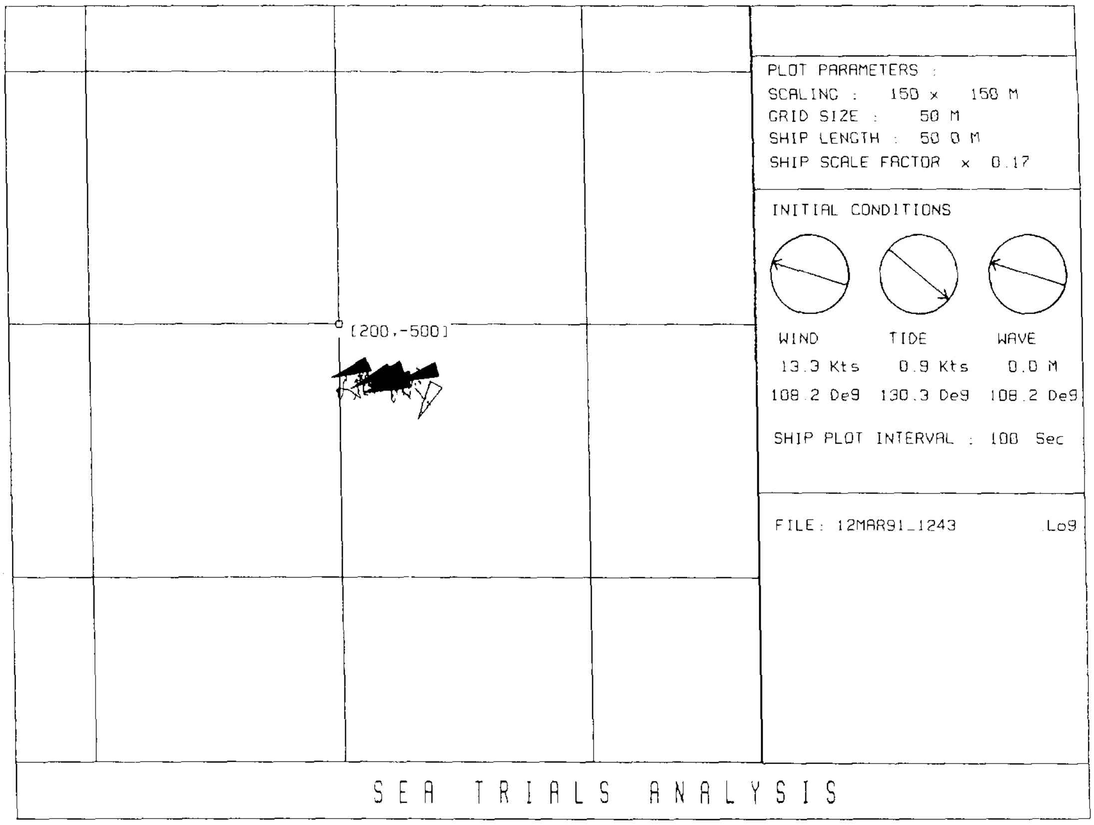
INITIAL CONDITIONS

WIND 6.2 Kts 90.4 DeG
TIDE 0.4 Kts 51.0 DeG
WAVE 0.0 M 90.4 DeG

SHIP PLOT INTERVAL : 100 Sec

FILE: 13MAR91_1443 .LoG

Fig. 10—Slow speed track keeping run, with sonar deployed around a 150 m radius semi-circular track. This represents a classification manoeuvre at 2 knots



PLOT PARAMETERS :
SCALING : 150 x 150 M
GRID SIZE : 50 M
SHIP LENGTH : 50.0 M
SHIP SCALE FACTOR x 0.17

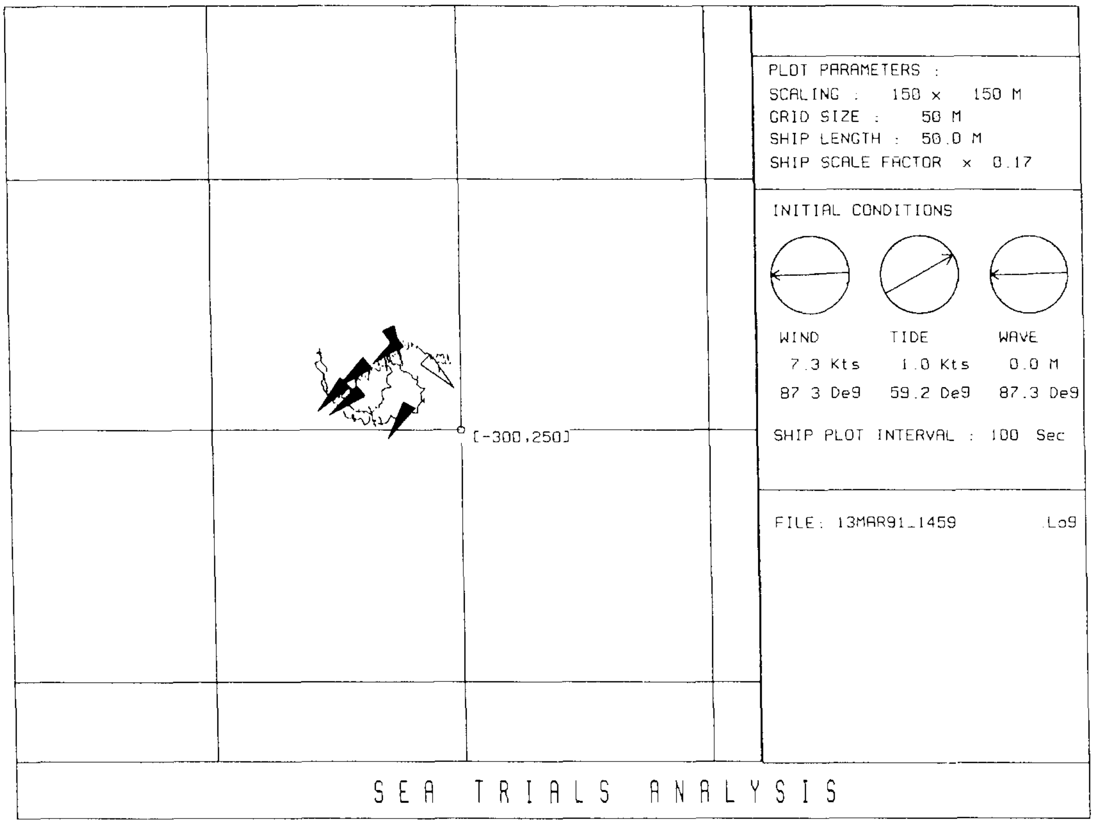
INITIAL CONDITIONS

WIND 13.3 Kts 108.2 DeG
TIDE 0.9 Kts 130.3 DeG
WAVE 0.0 M 108.2 DeG

SHIP PLOT INTERVAL : 100 Sec

FILE: 12MAR91_1243 .LoG

Fig. 11—Hovering manoeuvre with sonar deployed, using hover DP CDH preselect



PLOT PARAMETERS :
SCALING : 150 x 150 M
GRID SIZE : 50 M
SHIP LENGTH : 50.0 M
SHIP SCALE FACTOR x 0.17

INITIAL CONDITIONS

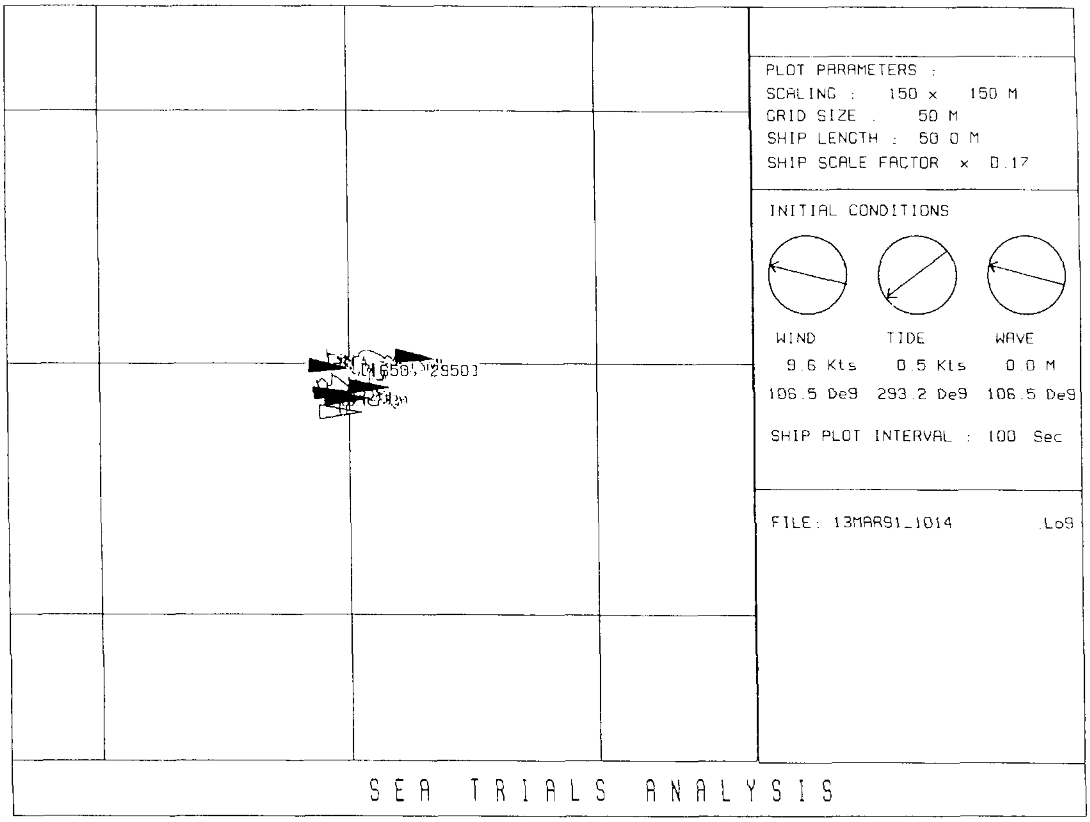
WIND	TIDE	WAVE
7.3 Kts	1.0 Kts	0.0 M
87.3 Deg	59.2 Deg	87.3 Deg

SHIP PLOT INTERVAL : 100 Sec

FILE: 13MAR91_1459 .Log

SEA TRIALS ANALYSIS

FIG. 12—HOVERING MANOEUVRE WITH SONAR DEPLOYED, USING HOVER DP FH PRESELECT



PLOT PARAMETERS :
SCALING : 150 x 150 M
GRID SIZE : 50 M
SHIP LENGTH : 50.0 M
SHIP SCALE FACTOR x 0.17

INITIAL CONDITIONS

WIND	TIDE	WAVE
9.6 Kts	0.5 Kts	0.0 M
106.5 Deg	293.2 Deg	106.5 Deg

SHIP PLOT INTERVAL : 100 Sec

FILE: 13MAR91_1014 .Log

SEA TRIALS ANALYSIS

FIG. 13—HOVERING MANOEUVRE WITH SONAR DEPLOYED, USING HOVER PCM PRESELECT

CONCLUSIONS

While all design requirements and performance limits have been achieved there are several areas that have been found during the system development where improvements can be made to further enhance performance, and it is hoped that these can be included in the near future. Work is also under way to develop the algorithms for use on other similar vessels.

The SPCS has now been accepted by the Royal Navy and has proved its ruggedness and suitability for the harsh environment that it will be required to operate in.

The usefulness of extensive simulation work in the design and analysis stages of a project such as this has been proved.

The inclusion of a fully automatic ship control system will greatly improve the overall minehunting effectiveness of the vessel due to good predictable performance over a wide range of environments with minimal operator involvement.