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MINISIM - A MINI VESSEL MANOEUVRING SIMULATOR.

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1. INTRODUCTION

MINISIM is a low cost micro computer based vessel manoeuvring simulation program. It enables the operator to simulate the behaviour of a vessel. The manoeuvres can be controlled by means of rudder and telegraph orders. The state of the vessel is computed from a semi-empirical mathematical model, taking into account wind, current and shallow water effects.

During the simulation a video display keeps the operator continuously informed of:
- geographical layout
- vessels position, velocity, heading and rate of turn
- rudder and telegraph orders

A hard copy facility is available to check and compare the various manoeuvres carried out under different conditions.

The mathematical model as applied in MINISIM is tested with full scale sea trials of various types of vessels. Presently two vessels are implemented in the simulation program. Other vessels can be implemented on request.

The MINISIM can be applied in various fields:
- passage planning onboard
- training onshore or onboard
- ship design

2. MATHEMATICAL MODEL

The mathematical model is based on the model as developed by Inoue, Hirano, Kijima and Takashina (A practical calculation method of ship manoeuvring motion, I.S.P., Vol. 28, Sept 1981). For application in the MINISIM this model is adapted and extended at some points.

In this section the basic principles of this model will be discussed.

In the derivation of the mathematical model, it is assumed that vessels movements are restricted to a horizontal plane. These movements can be described relative to a fixed coordinate system Xo-Yo-Zo (see fig. 1).
Additionally a coordinate system is defined with its origin in vessels centre of gravity. This coordinate system is referred to as the x-y-z coordinate system (see fig. 1).

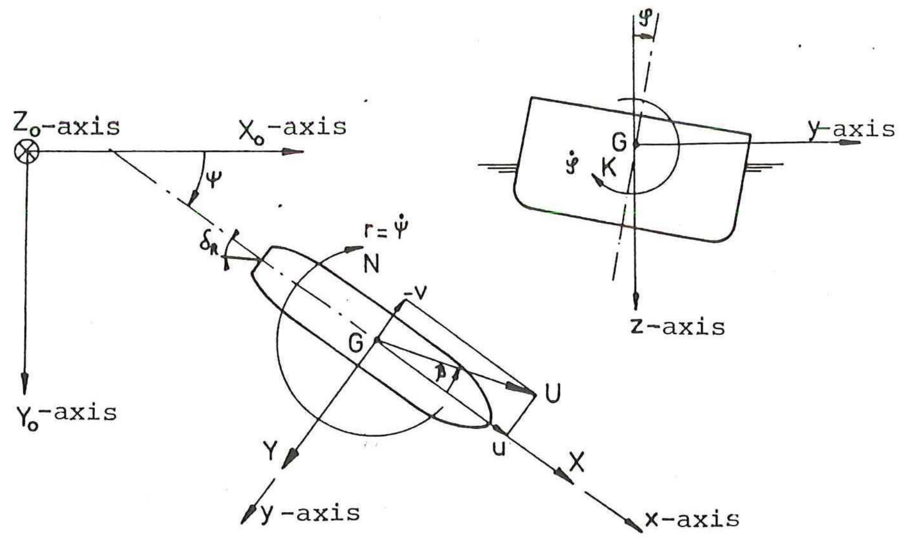

Fig. 1: Coordinate systems

Forces acting upon the vessel can be written as:

$$F_{X_0} = X\cos\psi - Y\sin\psi \qquad \text{(in Xo-direction)}$$

In the same way vessels velocity can be written as:

$$V_{Xo} = u\cos\psi - v\sin\psi \qquad \text{(in Xo-direction)}$$

Combining these two equations in Newtons law, we find:

$$X\cos\psi - Y\sin\psi = m\frac{d}{dt}(u\cos\psi - v\sin\psi)$$

This equation can be elaborated into:

$$X = m(\dot{u} - v\dot{\psi})$$
$$Y = m(\dot{v} + u\dot{\psi})$$

in which the time derivatives are denoted as:

$$\frac{du}{dt} = \dot{u}, \quad \frac{dv}{dt} = \dot{v}, \quad \frac{d\psi}{dt} = \dot{\psi}$$

If we assume that the z-axis remains vertical, the moment equation of vessels yaw movement is written as:

N = Izz
where N - moment
Izz - moment of inertia

These three equations for X, Y and N are the well known equations of Euler, describing vessels movements in a horizontal plane.

Since the influence of a roll angle caused by rudder forces cannot be neglected for a number of ships, a relation describing this influence is added to the original set of equations. Also the variation in the number of revolutions of the propellor has its impact on propellor thrust and rudder force. This influence is added to the set of equations.

Hence we find:

$$Xh + Xr + Xp = m(\dot{u}-vr) \qquad \text{(surge)}$$
$$Yh + Yr = m(\dot{v}+ur) \qquad \text{(sway)}$$
$$Nh + Nr = Izz\,\dot{r} \qquad \text{(yaw)}$$
$$Kh + Kr = Ixx\,\ddot{\varphi} \qquad \text{(roll)}$$
$$Qe + Qp = 2\pi Ipp\,\dot{n} \qquad \text{(propellor revolutions)}$$

where: X,Y - forces; h - hull
N,K - moments; r - rudder
Q - torque; e - engine; p - propellor

In order to compute the forces and moments acting upon the hull, these relations are written in a Taylor expansion with respect to the velocities u, v and r and the rudder angle δ r and their time derivatives.
The partial derivatives of X, Y, N and K with respect to the velocities and accelerations are called hydrodynamic derivatives.
The mathematical model of Inoue et al includes up to the third order derivative. These hydrodynamic derivatives are computed from semi-empirical formulas.

The propellor thrust and torque are computed from propellor characteristics.

The torque of the main engine is derived from the appropriate engine characteristics.

Finally, the rudder force and moment are computed from semi-empirical formulas.

In order to make the control of the vessel as realistic as possible, the following relations are added to the original set of equations:
- a first order approximation describing the behaviour of the steering machine
- a model describing the control of the main engine
- a method to compute vessels resistance
- a propellor model valid for reversed engine operations

Also some environmental influences are included:
- Wind
  The influence of wind is computed from Isherwoods empirical formulas.
- Current
  Homogeneous current can simply be superimposed on vessels movements. Non-homogeneous current is split up in several components along vessels hull. From these components vessels additional velocity and yaw are computed.
- Restricted waterdepth
  The influence of restricted waterdepth is computed according to Clarke (The application of manoeuvring criteria in hull design using linear theory, The Naval Architect, March 1983).

This final set of equations constitutes a non-linear second order set of differential equations. This set can be reduced to a non-linear first order set, in which the accelerations are explicit functions of the velocities. This set of differential equations is solved by using the numerical integration method of Heun.

3. COMPUTER PROGRAM

The simulation program is based on the Hewlett Packard series 200 micro computer. The basic hardware configuration consists of a HP 9816 micro computer (including video screen and keyboard), a HP 9121D dual disc drive and a HP 2671G printer. If necessary, this configuration can be extended with a control console.

Due to the sophisticated programming techniques supported by the HP 9816, it was possible to develop a user friendly simulation program. Input of data is organised by means of selection menu's. This way it is possible to change data at any point of time in almost any part of the program. Control orders can be entered online via the keyboard and/or via the extended control console.

The simulation program, as seen from the users point of view, can be split up in three sections:
- preparations
- simulation
- results

Each section will be discussed briefly.

PREPARATIONS

Previous to the actual simulation, the user must select a number of items and enter some data:
- Ship
  At the moment two models are implemented in the program:
  42 m survey vessel
  200.000 dwt tanker
  The user can select one of these.
- Loading condition
  If necessary, draught and trim can be altered.
- Start conditions
  Items like velocity, heading, rate of turn and control orders can be adapted to users wishes.

- Harbour
  Harbour layouts can be specified by the user. These layouts are stored on disc and can be retrieved very easily.
- Wind
  Wind force and direction can be specified. Both are stored on disc.
- Current
  The user can specify a current pattern, which is stored on disc and can be retrieved if necessary.

Once the user is satisfied, all initial conditions as selected and/or edited can be printed. The following options are available:
- vessels main dimensions and loading condition
- start conditions
- wind and current information
- harbour layout

A few examples are given in fig. 2 and 3.

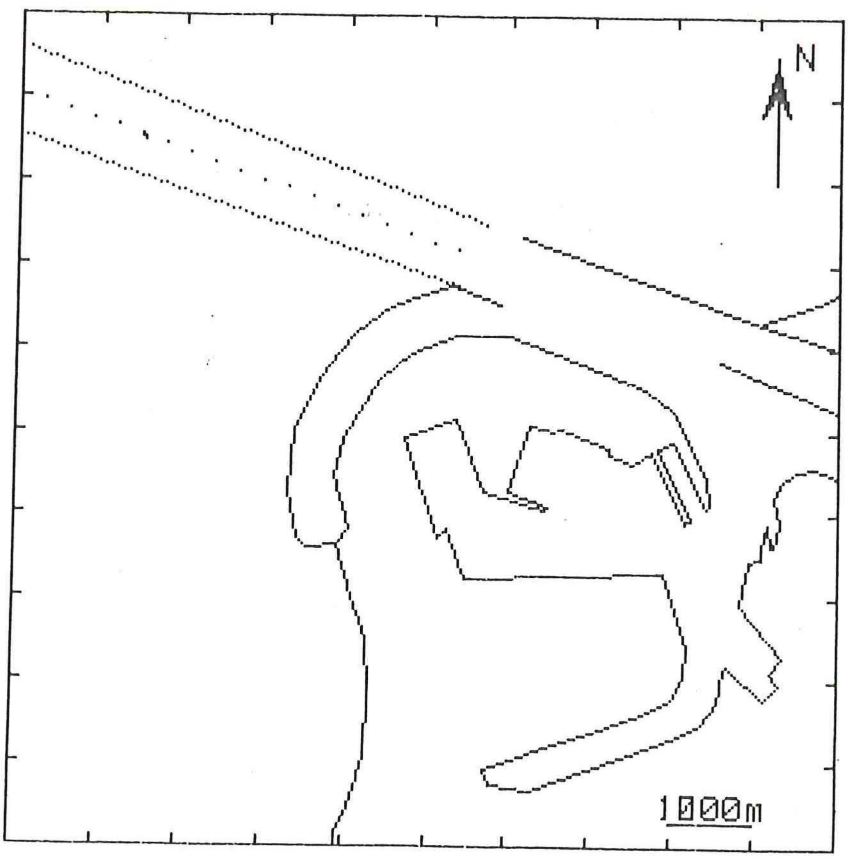

Fig. 2: Harbour and channel layout

MACOMA : MAIN DIMENSIONS AND LOADING CONDITION

Main dimensions:

Length between perp.	-	310.00	m
Beam	-	47.16	m
Depth	-	56.00	m
Maximum draught	-	18.90	m
Deadweight	-	200000	ton

Loading condition:

Draught	-	18.90	m
Trim on forward perp.	-	0.50	m
Cb	-	0.85	
Long. centre of gravity	-	8.91	m to Lpp/2

Fig. 3: Vessels main dimensions and loading condition

When at this stage one or more input items appear to be incorrect, they can be altered very easily by simply selecting the corresponding menu page and changing the item.

SIMULATION

As soon as the preparations are completed the actual simulation can start.
A video display keeps the user constantly informed of the vessels state in its geographical environment.
Vessels position and the harbour and channel layout are displayed in a birds eye view. The scale of the display can be adapted according to your demands at any time.

Next to this display some numerical information is presented. This information consists of vessels actual state, represented by its velocity, heading, rate of turn, propellor revolutions and of the actual rudder angle and telegraph setting.
Also the actual control orders of rudder and telegraph, which may differ from their actual state, are presented. The display is refreshed every cycle.

Control orders can be entered online via the keyboard, using the special function keys and the rotary control knob, or via a special control console, provided with two joysticks.

The maximum ratio between the time interval in reality and the simulated time interval of a manoeuvre depends on the step size as applied in the numerical integration and of course on the cycle time of the computer program. The maximum step size depends on the type of ship being simulated. The larger the ship, the smaller the accelerations and the larger the step size can be. The cycle time varies within close limits, mainly depending on the presence of a non-homogeneous current pattern. It was found that for large vessels a time ratio of about 4:1 can be realised.

During the simulation vessels state can be printed every minute. Control orders are printed as soon as they are entered. An example is given in fig. 4.

TIME	E	N	Vx	Vy	Hdg	RoT	Rev	Rudder	Pitch	Fuel
00.00.14	1598	10719	7.0	-1.5	118	+0	186	0	60	100
00.00.36	1687	10691	9.0	-1.5	119	+6	310	4	60	100
00.00.51	1754	10665	9.5	-1.6	124	+11	310	-1	60	100
00.01.00	1795	10645	9.9	-1.5	125	-2	287			
00.01.06	1823	10631	10.2	-1.5	124	-8	264	-1	85	100
00.01.21	1896	10595	10.6	-1.6	126	+19	264	2	85	100
00.01.36	1969	10555	10.7	-1.5	128	-10	265	-1	85	100
00.01.51	2042	10513	10.9	-1.5	127	-1	266	0	85	100
00.02.00	2086	10488	10.9	-1.5	127	-1	266			
00.03.00	2385	10322	11.0	-1.5	127	-0	266			
00.03.17	2468	10276	11.0	-1.5	127	-4	266	-2	85	100
00.03.32	2544	10237	11.1	-1.4	122	-21	266	0	85	100
00.04.00	2696	10173	11.2	-1.5	119	-2	266			
00.05.00	3022	10049	11.2	-1.5	118	-0	266			

Fig. 4: Log of a simulation manoeuvre

RESULTS

When the simulation manoeuvre is terminated the sailed track can be displayed and printed. An example is given in fig. 5. Together with the online log information this will provide the user with sufficient information for debriefing and comparising purposes.

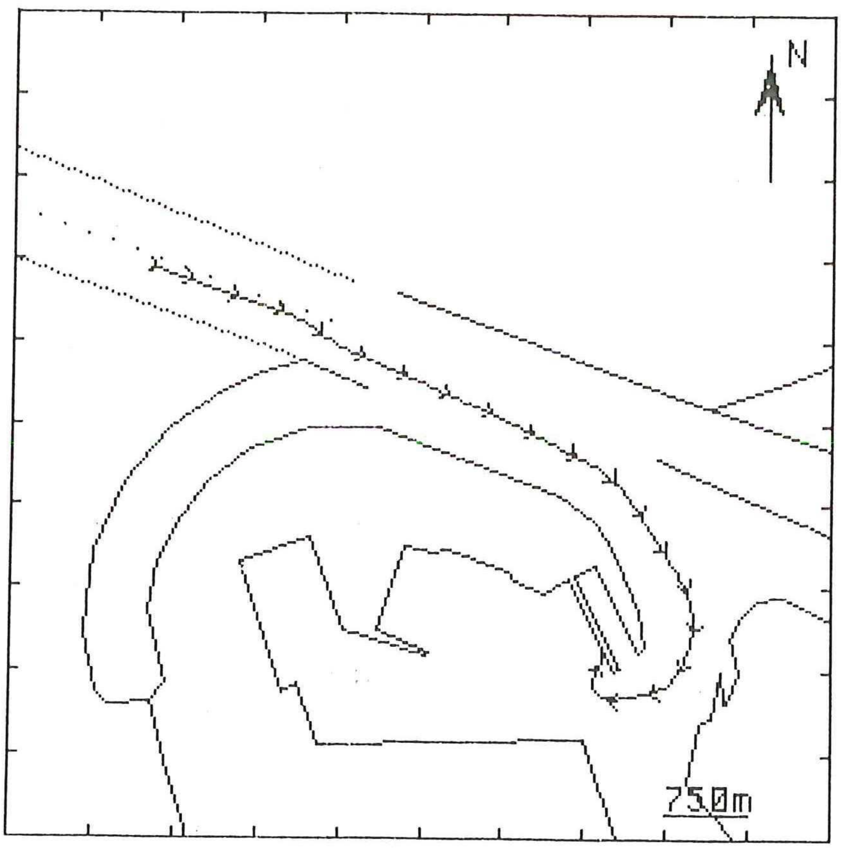

Fig. 5: Sailed track

VALIDITY

The validity of the mathematical model is verified by means of a comparison between simulated manoeuvres and full scale manoeuvres. Inoue compared his model with various full scale tests. The extended model as applied in MINISIM is compared with full scale manoeuvres as carried out with the Macoma (200.000 dwt), Betelgeuze (42 m) and a Mariner type vessel (161 m). Some results are presented in fig. 6 till 10.

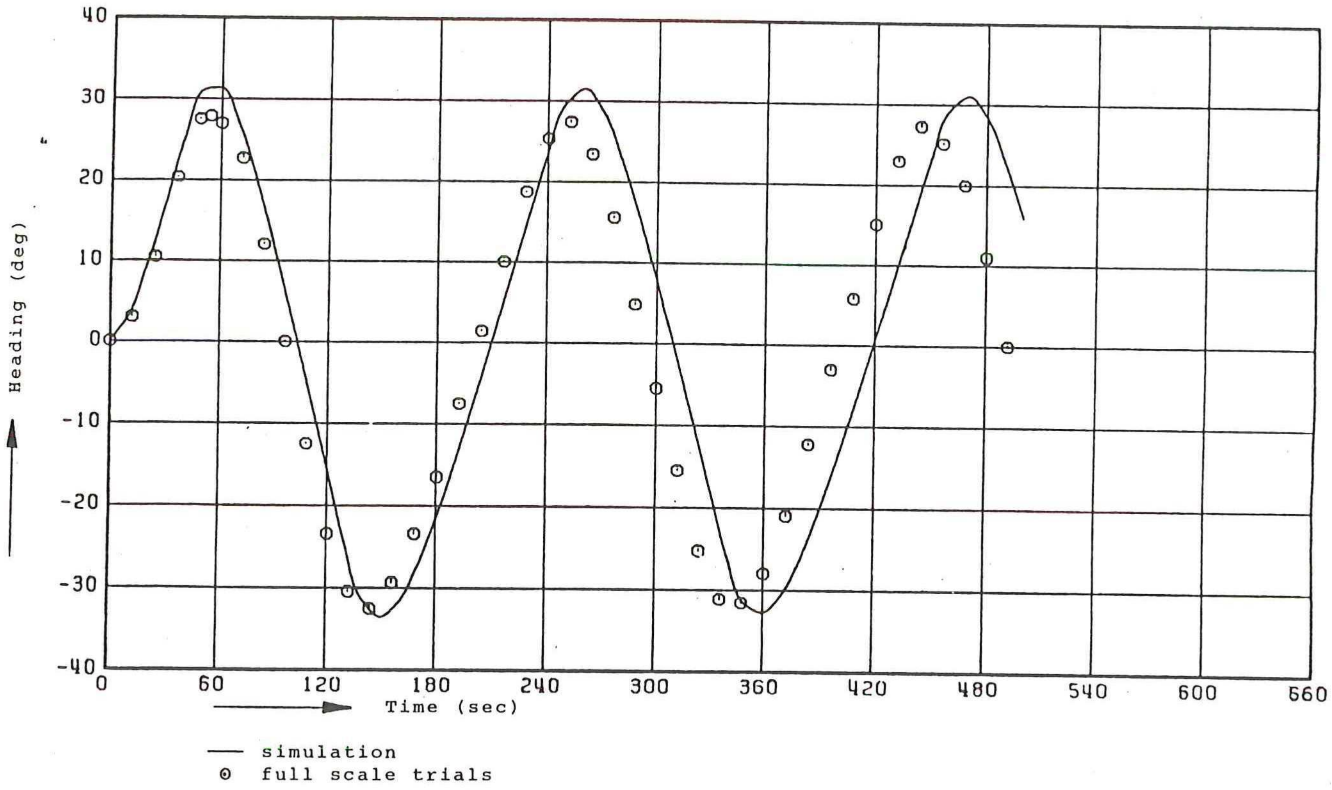

Fig. 6: Mariner zig/zag test (20.5/20.5, v = 15 kn)

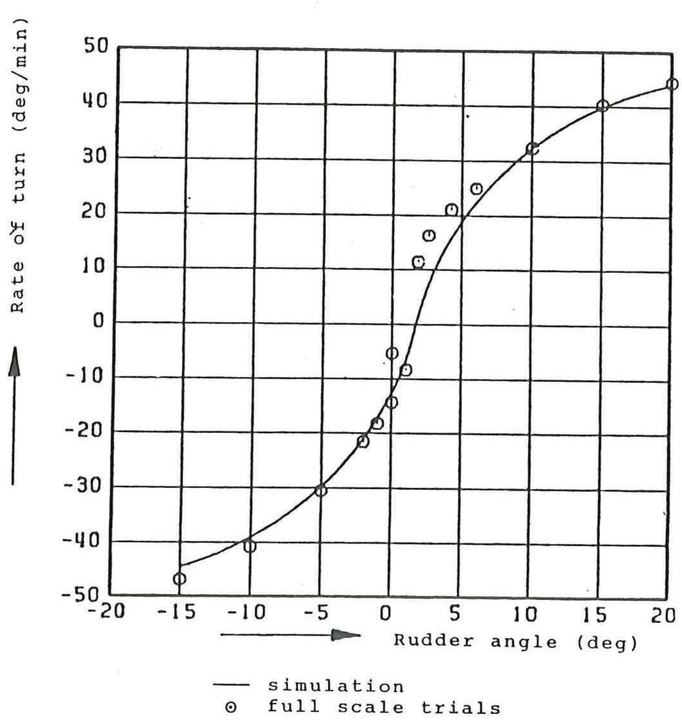

Fig. 7: Mariner spiral test (v = 15 kn)

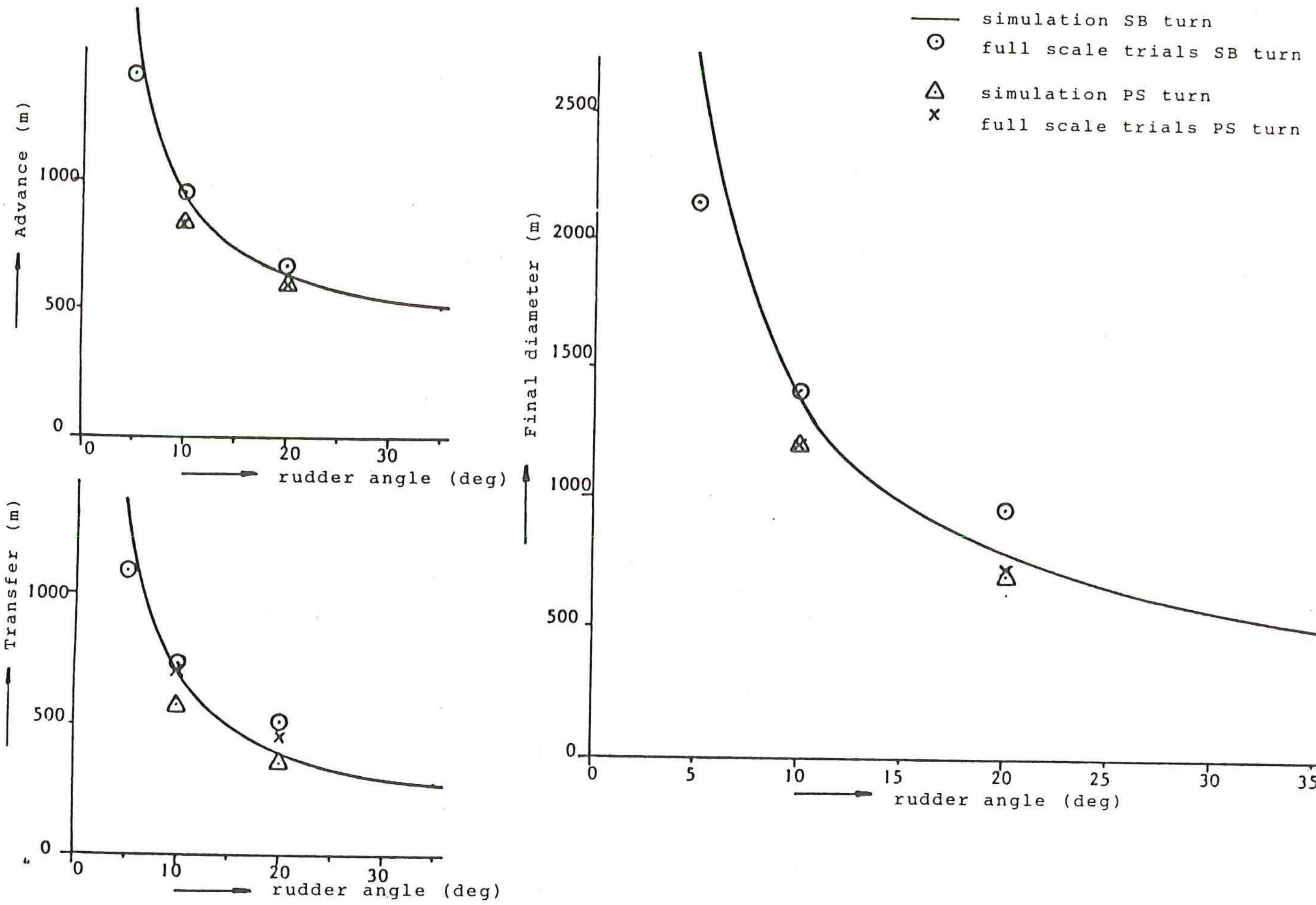

Fig. 8: Mariner turning circles (v = 15 kn)

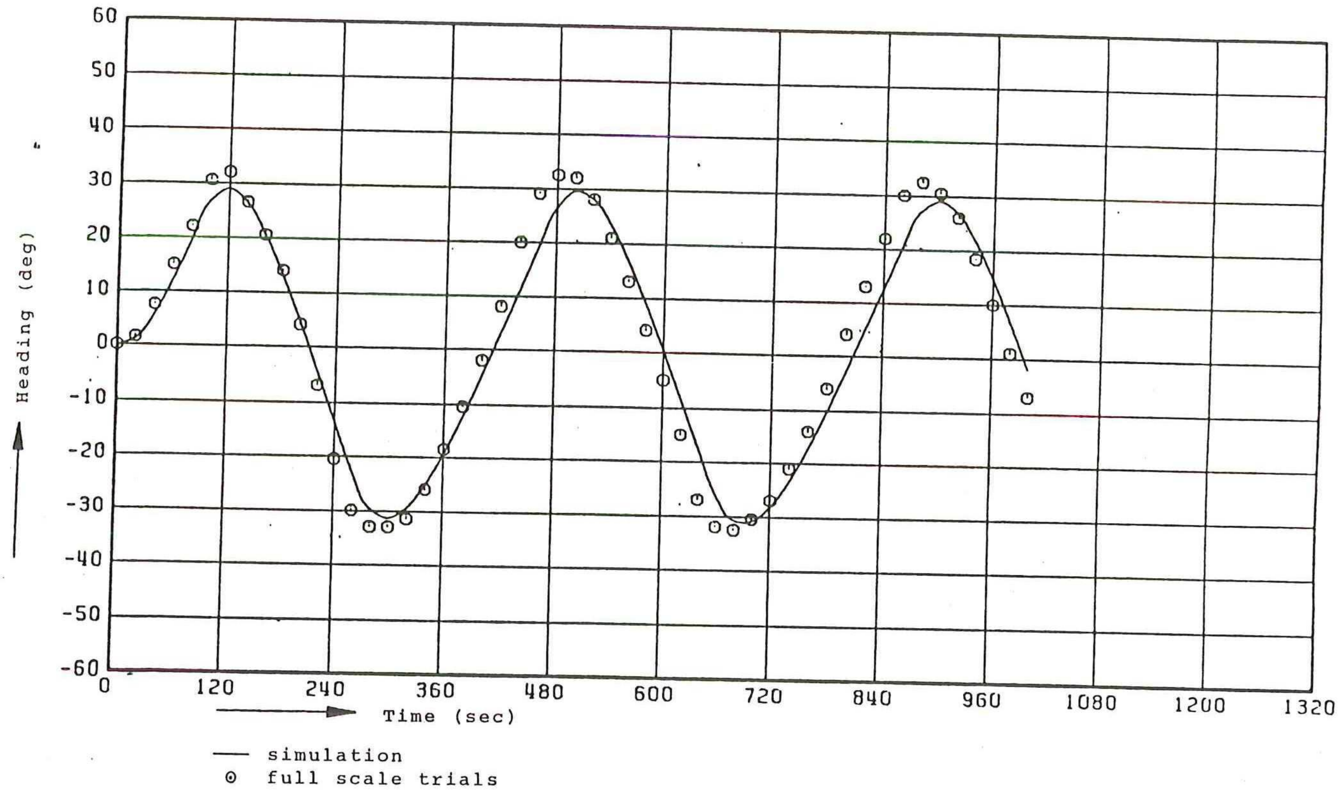

Fig. 9: Macoma (ballast condition) zig/zag test
(20/20, v = 16 kn)

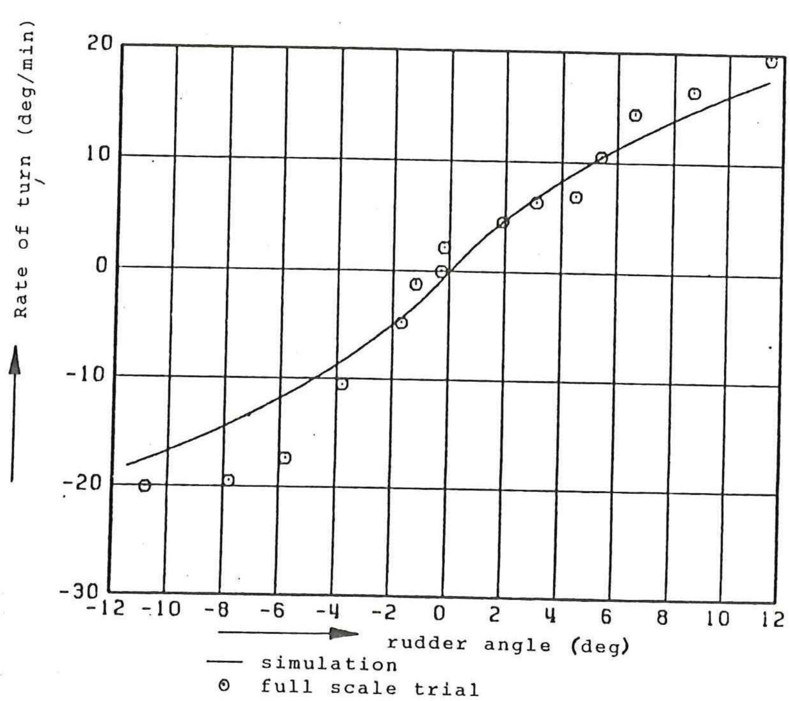

Fig. 10: Macoma (ballast condition) spiral test
(v = 16 kn)

APPLICATIONS

MINISIM can be applied in various fields:

- Passage planning onboard
  Different manoeuvring tactics can be tested under various environmental conditions previous to the actual passage.
- Training onshore and onboard
  Students can familiarize themselves with the manoeuvring behaviour of various ship types under different circumstances. The navigation team onboard can get acquainted with the manoeuvring capabilities of their vessel.
- Ship design
  In an early design stage various designs can be compared with respect to their manoeuvring behaviour. Since the hydrodynamic derivatives in the mathematical model are derived from semi-empirical relations, no expensive and time consuming model tests are required.