

## Work Package 3: Jobs & Skills

# Roadmap towards standardisation for ship-handling simulators

*Draft technical standards for IWT ship-handling simulators for the purpose of examination to promote career progression for IWT crew members and to reduce barriers to labour mobility*

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**CONTENT**

<b>1</b>	<b>Introduction .....</b>	<b>7</b>
1.1	Motivation .....	7
1.2	Approach .....	8
<b>2</b>	<b>Technical sections of ship handling simulation.....</b>	<b>9</b>
2.1	General description of ship handling simulators .....	9
2.2	Conceptional aspects .....	13
2.2.1	General layout of stations.....	14
2.2.2	Layout and equipment of steering stations (ship bridge cubicles) .....	16
2.3	Simulation kernel.....	17
2.3.1	Dynamics of „own ships“ .....	18
2.3.2	Traffic ships .....	40
2.4	Output processing systems.....	46
2.4.1	Visualization System .....	46
2.4.2	Audio System .....	52
2.4.3	Radar-Simulation.....	57
2.5	Databases .....	62
2.5.1	Databases for the calculation of ship dynamics.....	62
2.5.2	Visualization database.....	67
2.5.3	Radar database .....	73
2.5.4	Audio database.....	75
2.6	Further features.....	75
2.6.1	Weather Conditions .....	75
2.6.2	Chart display.....	77
2.6.3	Operational modes .....	78
2.6.4	Storage data and replay .....	79
2.6.5	Interfaces.....	83
2.7	Testing and Certification .....	90
2.7.1	Common definitions.....	91
2.7.2	Basic equations of driving dynamics.....	91
2.7.3	Dynamic characteristics of ships .....	92
2.7.4	Assessment of the mathematical model .....	93
2.7.5	Validation.....	93
<b>3</b>	<b>Quality requirements.....</b>	<b>102</b>
3.1	Standard expressed as quality level of relevant technical features .....	103
3.2	Complementary remarks.....	116



4	Outlook .....	117
5	Literature .....	118

**LIST OF ABBREVIATIONS**

AiF	Arbeitsgemeinschaft industrieller Forschungsvereinigungen "Otto von Guericke" (German Federation of Industrial Research Associations)
AIS	Automatic Identification System
ECDIS	Electronic Chart Display and Information System
ENC	Electronic Nautical Chart (Elektronische Seekarte)
GPS	Global Positioning System
IENC	Inland Electronic Nautical Chart
RheinSchPV	Rheinschiffahrtspolizeiverordnung
RheinSchUO	Rheinschiffahrtsuntersuchungsordnung
SBK	Schifferberufskolleg Rhein
SHS	Ship handling simulator
ZKR	Zentralkommission für die Rheinschiffahrt, Commission Centrale pour la Navigation du Rhin (CCNR)

## FOREWORD – SUGGESTIONS HOW TO USE THIS DOCUMENT

The hereafter-developed “technical standard for Inland Ship Handling Simulators (I-SHS)” has been conceived to determine “Quality Requirements” for Ship Handling Simulators, which can be used upon training and examination of inland shipping crewmember.

This proposal of an EU-Standard for I-SHS can be used for all kind of training and examination purposes mentioned in the documents:

- “Table of Professional Competencies” (EU / Platina II – discussion paper)
- “Stf 15-10 practical examination” (CCNR document)
- “Stf 12-21en-rev 4” Table “Inland Waterways Navigation simulator” (CCNR document).

The systematic approach developed hereafter consists mainly of

- Description of relevant technical performance features
- Description how quality levels of these features can be expressed and tested
- Allocation of quality level per each feature as assumed to be suitable for the scope of defined purpose.

This approach makes it somehow easy, to understand, access and argument on proposed quality levels. "Easy" means for lecture by any stakeholder (training centre, authorities, SHS provider, IWT companies etc).

For those persons who do not want to scrutinise each and any technical aspect or parameter of performance, a shortcut through this document could consist of the following steps:

1. Reading first chapter “3 Quality Requirements”
2. Selecting in the matrix “Technical Standard for I-SHS” some performance features for further investigation and getting more familiar with the systematically approach of the developed I-IHS Standard
3. Reading under chapter “2 Technical section of ship handling simulation” the description of these performance features and the meaning of respective quality levels.

Last not least, using the same systematically approach developed hereafter, each suggested quality level can be discussed in connection with:

- The scope of purpose – as assumed in this document, or
- A “to be revised” scope of purpose / revised assumption in the context of European I-SHS Standard, or
- Any other envisaged scope of purpose.

In order to facilitate the use of this document, the matrix “Technical Standard for I-SHS” references to the respective items in “stf 12-21en-rev 4” table “Inland Waterways Navigation simulator”. Furthermore, this table has been partly copied and amended. It is attached as working document (Annex 1). The amendment consists of indicating per listed item relevant performance parameter described hereafter.

## 1 INTRODUCTION

The inland waterway operators increasingly have trouble finding qualified personnel. One reason is the demographic change, which affects more or less every European country. Another reason might be, that the traditional education on board appears unattractive to young people today.

First, the demographic change, i. e. the shortage of young people, could be compensated by immigration. Even if skilled employees in the field of foreign IWT immigrate, it has to be ensured that they have the same educational level that has been established in Europe. Second, the education of inland skippers could be made more attractive by introducing modern educational concepts and media.

Simulators are well established and widely used as tools to train, control and steer complex technical equipment. For decades training sessions on flight-simulators or on maritime ship-handling-simulators (SHS) are compulsory (international regulations) for respective professional education of pilots, captains etc. In recent years, in some European countries SHS are used for professional nautical training concerning inland ships on inland waterways.

To ensure a high common quality level in education in the EU the European Commission and the Central Rhine Commission have started to regulate the use of Inland SHS (I-SHS). It has to be noted already here that established standards for maritime SHS cannot be adapted to I-SHS, since the significant technical properties differ too much. The definition of quality standards for I-SHS has to be carried out in conjunction with the definition of education standards.

The accordingly developed technical standard for Inland SHS (I-SHS) is a proposal about minimum technical levels simulators should meet as prerequisite to be used for professional education of inland skippers.

### 1.1 Motivation

Compared to the use of real ships for training / examination, the main advantages of SHS are basically:

- Almost any degree of difficulty – deriving from ship type, waterway – or weather conditions and traffic situations can be defined, preset and modified during a session.
- Each exercise / session can be observed from position(s) that is (are) remote from candidate's working place (ship bridge cubicle)
- Each exercise / session can be recorded and replayed for analysis and demonstration
- Less operational costs
- As accidents are just virtual – driving / handling errors do not cause danger or damage and are without financial consequences.

But there is a risk that training on SHS may lead to behaviours of skippers that are not appropriate in the sense of safe and circumspect driving / navigation. Important relevant risk- factors are:

- Coherence between training exercises (program / methods and trainer) and training objectives
- Technical capacity of SHS for a defined training- / examination objectives.

Safe and circumspect driving / navigation can be trained or examined on only those SHS that reproduce / simulate conditions and situation sufficiently correct and close to comparable or similar real context. Such SHS general performance requirements lead to a rather wide and complex spectrum of technical aspects. Therefore, hereafter requirements are translated into technical aspects, performance features and quality level. The technical standard developed in the following shows the assumed appropriate quality level per performance feature.

Inland vessels navigate in so called “confined conditions” (shallow and/or narrow waters). Due to hydrodynamic effects, the motion behaviour of ships is largely influenced by these effects. A close to real simulation of ship’s motion behaviour is a very critical Inland SHS quality criterion. A high level of “close to reality” simulation is necessary to avoid that skippers (or candidates) develop a non-appropriate or dangerous driving behaviour pattern on SHS. As “close to real” is a “simulation challenge” (mathematics, databases, computing etc.), this complex issue is of particular importance for setting a technical standard for Inland SHS.

## 1.2 Approach

As mentioned above, requirements for simulators derive from the application. As long as identical competences are concerned, “training” and “examination” are the same application with the only difference that the instructor is replaced by the examiner. The technical requirements for I-SHS described and defined here, shall apply to examination (and the training preparing for the examination).

Training and examination can either be carried out within a (state- / authority-) regulated context or under commercially agreed service conditions.

The standards developed below relate to the scope of SHS use as mentioned in the following documents:

1. EC document (discussion paper): Table of “Professional competencies » – here SHS is widely mentioned as a method to demonstrate competence
2. CCNR document: stf15\_10, “practical examination” – it describes content of examination. The document further determines that either SHS or real ships can be used as method to check candidate’s competencies.
3. CCNR document: stf12\_21en\_rev4, “Features of the simulator for inland navigation” – it describes several kinds of use of SHS and several requirements related to equipment and performance of SHS.

The following chapter “3.2.5 Standard expressed as quality level of relevant technical features” summarizes the purpose of SHS use based on the above mentioned three papers.

The definition of “SHS performance” is described hereafter under chapter “2. Technical sections of ship handling simulation”. The description reflects a method, which has been developed by DST within the AiF project “SimuStandards”<sup>1</sup>.

Basically this method consists of:

- Technical description of simulators / simulation in common – non technical – wording
- Splitting up of above description into technical fields / aspects
- For each technical field / aspect the relevant performance factors are described.
- For each performance factor three levels (low, middle, high) of performance are described.

The objective of this method is to make the rather complex issue “setting technical standard for Inland SHS” understandable for all potentially involved stakeholders (authorities, training institutes, inland shipping companies, supplier of SHS, etc.).

Within the Platina II – project this method has been “roundtable-discussed” and agreed by the four involved suppliers of SHS.

Using this method, the “appropriate” level of performance has been attributed to each relevant technical feature. “Appropriate” stands here for “sufficient for the scope of use – as summarised on basis of the three listed relevant documents”.

## 2 TECHNICAL SECTIONS OF SHIP HANDLING SIMULATION

Chapter 2 contains all technical aspects of simulation, insofar as they concern ship handling simulators (SHS). Besides other simulators like engineering or safety and security simulators, SHS are also used to train ship operation and offer network possibilities with SHS. They are however not subject of this manual. The following statements are based on own experience, the further development and operation of the inland navigation SHS, discussions with instructors, potential customers and manufacturers as well as the assessment of technical details and performances.

The manual starts with a description of basic terms and ship handling simulators in general. The further structuring results from the basic scheme of SHS.

### 2.1 General description of ship handling simulators

Ship handling simulators (SHS) help to train steering, navigating and communicating under conditions corresponding to normal practice aboard inland ships. Core elements are one or more ship bridge cubicles (called hereafter: steering stations), which are equipped with displays and controls similar to

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<sup>1</sup> The final report (in German) can be downloaded from [http://www.dst-org.de/publications/Fahrsimulatoren\\_Binnenschifffahrt.pdf](http://www.dst-org.de/publications/Fahrsimulatoren_Binnenschifffahrt.pdf). The IGF project (16491 N) was funded by the AiF under the program to promote joint industrial research (IGF) from the Federal Ministry for Economic Affairs and Energy, following a decision of the German Bundestag).

real ship bridges. The simulation conditions like ship type, loading condition, route, weather, current, day-/night-situation, traffic are selectable or adjustable.

Due to this wide range of variation possibilities training scenarios can be adapted to training contents and target groups enabling to practice defined tasks as many times as necessary.

SHS calculate the effect of putting the helm and setting the engine power on the ship's motions, where external influences like bottom topography, current and wind are regarded.

The ship's motion in relation to the environment is displayed in several ways:

- By monitors or projectors from the perspective of the steering position
- By radar image
- Display on an electronic nautical chart (ENC)

Furthermore ambient sounds (e.g. engine sound) and communication (telephone, radio) are simulated. In contrast to flight simulators used for pilot training SHS do not physically reproduce vehicle motions; some simulators however reproduce ship vibrations via subwoofer.

Course players are named as follows:

- Proband (candidate, student, course participant, trainee): He operates the steering station bearing in mind the nautical conditions, controls the displays and acts according to the given situation, i.e. operates all devices to steer and manoeuvre the ship accordingly.
- Instructor (teacher, trainer): He is in charge of the training contents.
- Operator. He is responsible for the preparation and operation of the simulator (if necessary identical to instructor)
- Examiner: He will assess the operation of the probands during examinations (if necessary identical to instructor)

From the proband's point of view it has to be distinguished between the own ship, that is controlled by himself, and other ships called hereinafter "traffic ships". In the simplest case, other ships are controlled by the instructor (so-called traffic ships). If the simulator has more than one control station, the other ships that appear for one user may be the own ships of other users in the same simulation. In this case interactive traffic simulation is possible. Depending on the visibility conditions and distance the own ships see each other and can communicate via radio. The communication with traffic ships is also possible if the instructor takes this role.

In this document the following terms are distinguished:

- Own ship: ship controlled by the proband
- Other ship: ship seen by the proband, which may be
  - A traffic ship: moving on predefined routes without interaction
  - An own ship driven by another proband.

Modern simulators allow recording of all data (distances, rudder angles, speed etc.) and also voice communication to be replayed for a later analysis. This opens extensive opportunities for evaluation

and discussion, which is a valuable advantage compare to the possibilities on board, where everything happens live and is not recorded.

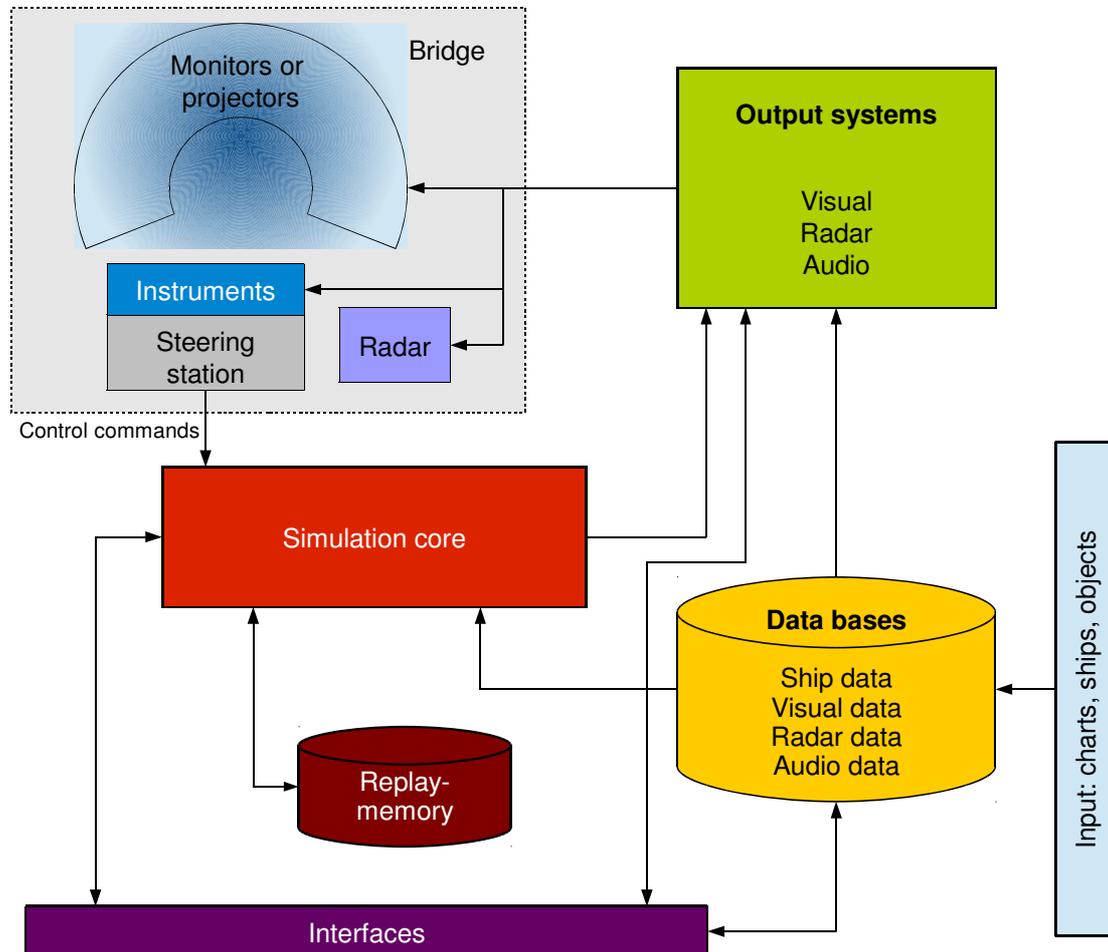


Fig. 2.1 Functional scheme for ship handling simulators

Fig. 2.1 outlines the functional structure of a ship handling simulator. The simulation of the motion of all objects is performed in the simulation core. The motions of the objects (mostly ships) are calculated by temporal integration of their unsteady accelerations. The accelerations are computed from the forces and moments acting on the ships. These are often described by so-called coefficient models. Independent of the actual mathematical model the simulator uses databases, where the relevant data for the calculation of the ship dynamics is stored. This data describes the properties of the ships and the environment (bottom topography, current, etc.). The simulation core takes the control input from the proband(s) and the instructor. Each proband is placed at his own control station, which is equipped with all necessary devices, displays and handles.

There are different output systems to represent the simulation state in the core:

Usually the control station is equipped with a visualization system showing the view from the own ship. This ranges from a single monitor to a complete panoramic projection. The image generation for the view is performed by the visualization system, based on the actual simulation state in the core and using the geometric description of the objects and the environment that is stored in the visualization database.

Additionally to the visualization system commonly used devices (e.g. echo sounder, GPS, ENC, AIS) are used to display state variables of the simulation.

A particularly complex device is the radar whose image is computed in a stand-alone system. The radar image can be displayed on a generic device or the signal of a radar antenna is generated to drive an original radar device. Also, a GPS interface can be simulated in order to control a standalone chart display.

The audio system generates noises matching the simulation by accessing the existing simulation status within the simulation core; they are reproduced at the control station. This can include noises of the environment (for instance engine noise) or individual acoustic signals (e.g. signal horn).

Databases are static components of the simulation system and provide the following data:

- Data of the ships that is used in combination with the implemented mathematical model to calculate the dynamic behaviour of the ships
- Geographic/topological and nautical data of the simulation domains
- Hydraulic and environmental-related data of the simulation domains
- Geometric data of the landscape and the objects for use in the visualization system and the radar system
- Audio data

Databases have a manufacturer-specific structure and format. Manufacturer might offer the possibility to edit the databases and to import or export data. For this reason, all vessels, training areas or records stored in the simulator cannot or if at all only be partly transferred to other simulators of different manufacturers. It is often feasible however to import standard electronic charts (ENC – electronic nautical chart), geo-databases and nautical information, which have mainly be produced to be used aboard of vessels.

In parallel to simulations, a recording system may run, storing all state variables of the simulation so that the simulation can be replayed at a later time. A detailed analysis of the simulation is possible that way.

By additional interfaces of the simulator a static or dynamic exchange of data becomes likely. Several simulators – even remotely ones – can be coupled with the help of such interfaces. Interfaces make it possible to extend the simulator that is delivered as a complete, monolithic system.

Simulators are complex systems and consist of various subsystems to be systematized according to different criteria. The breakdown of this document mainly follows the graph given in Fig. 2.1 (functional scheme of ship handling simulators). The different functional areas determine the structure of this chapter.

As the individual functional areas comprise various components, they have to be further broken down to identify the characteristics which are crucial for the performance features of the simulator. First, characteristics are looked at in detail so that a three-level classification can be established depending on whether the quality level meets low (1), medium (2) or high (3) standards. Additionally, methods and procedures are mentioned for each characteristic in order to test/assess its pure presence (existence) or its level.

In this stage of the standardization process, the definition of quality levels cannot always be defined by precise limiting values. Thus, expressions like “correct”, “tends to” or “close to” are used to delimit the three quality levels. Before the quality levels can be defined by numerical values of certain properties, which have to be reached, reference cases have to be defined. The definition of these reference cases will be very complex, since every boundary condition that influences the specific feature has to be considered. This will be the next step in defining future certification procedures.

In Section 2.2 the design and equipment of the overall system is outlined. These include the user workstations (called stations) and the equipment of the stations, which is in a certain relationship with the required functionality.

Section 2.3 describes the most important components of the simulation; the simulation core and the output systems (visualization system, audio system and radar). Most significant characteristics are given and furthermore their performance features with a help of which a simulator can be evaluated. The driving dynamic of the ships plays an essential role in this connection, as it defines the accuracy of the simulation. Therefore, it will be dealt with in detail. Section 2.3.1 outlines characteristics the quality of which can be assessed by all users. Section 2.7 addresses further examination procedures which require fundamental hydrodynamic knowledge as well as insight into the internals of the simulation software. They can be possibly used within future certification procedures.

Databases are in the focus of the section 2.5. Databases can only be described in a rough manner, as the data structures vary considerably among the different manufacturers. Besides databases might be closed completely, so that their evaluation is based on the functionality they have. The size of the database, i. e. number of different ships and operating relations, will be neglected.

Section 2.6 deals with further features.

## 2.2 Conceptual aspects

This chapter addresses conceptual aspects of the simulator including hardware equipment. Section 2.2.1 focuses on the design. Apart from questions on the required space, the individual stations and their basic structure are looked at more closely. Eventually, section 2.2.2 covers the stations and their relevant control and display elements.

As regards the computer capacity, required for the execution, storage and replay of simulations as well as the provision of all databases, there are no limits today. The manufacturer will equip the system in a way that the offered functionality is ensured. Number, equipment and network connections of the hardware components are manufacturer-specific and do not follow a uniform scheme. Functional limits of the simulation systems might have licence reasons.

The visualization system however places high demand to the computer capacity. At present there is no visualization system available which meets all requirements. Therefore, the visualization system should also be evaluated with regard to the computer hardware.

### 2.2.1 General layout of stations

Simulators can have the following types of stations:

- Steering station (bridge/cubicle): Here trainees are instructed and trained to navigate inland vessels.
- Instructor station: This station enables instructors to design, control and secure a training session as well as examiners to observe steering / navigating “own ships”.
- Briefing-/Debriefing station: Here participants are prepared for a training exercise. Further, any running or recorded exercise can be followed, reviewed, analysed and assessed.

Each simulator has at least one steering station, but usually additional ones to be able to train several students (trainees) at the same time. Consequently, there is the possibility to also train interactive navigation among the trainees. The briefing/debriefing station is generally a separated station, but briefing/debriefing tasks can also be executed at the instructor station.

The space a simulator needs in general, depends on the number of trainees, i.e. the number of steering stations, which are run in parallel for training purposes. Furthermore, the technical features of the visualization system at the bridges are crucial. E.g. to optically visualize the surrounding of a vessel from the bridge perspective requires more space, if a projection system instead of monitors is used. The distance between the steering station and the projection screens should be at least 6 m, which is the distance from which on the eye focusses to infinity. As the projection screen has a cylindrical form, such a room should have a diameter of about 12 m, as far as a 360° field of vision is requested. Without considering any projections screens, steering stations, designed as bridge or cabin, require a minimum size of about 8 m<sup>2</sup>, if usual standards are followed (DIN EN 1864 – wheelhouse inland vessels). An instructor station should at minimum have the size of a pc work station; the size of a separate briefing/debriefing station usually orientates according to the number of course participants. A room of about 20 m<sup>2</sup> appears to be realistic.

In general, the size of the installation should be adequate to the available room capacity. If necessary a compromise has to be found as regards the visualization system, the number of trainee stations or a possible centralization of different tasks. In addition, a simulator may only have one single steering station comprising the complete range of functionalities in one room only. Below some general aspects are dealt with which might be of advice when designing different simulators.

#### a. Steering station (bridge/cubicle)

There are different designs for driving stations:

- Single cabin (one room) having monitors for optical view (only if not being a plain radar simulator)
- Bridge-form: having windows for the supposed outside view.

The visualization system can be realized for both forms by complex projection equipment or by monitors.

If there are several stations, especially steering stations, optical and acoustical equipment should be separated. Voice mail or telephones are to be used for the communication between instructor and trainee to achieve a realistic training situation. Navigation by night needs the possibility to darken the steering station cabin.

To meet basic manning requirements of inland navigation while the trainee is practicing, the design of the steering station should be adjusted properly. This would entail a single person steering station like it is common practice on-board of modern inland vessels. Depending on the design of the station, the presence of an instructor or examiner should be considered.

The levels below follow DIN EN 1864 (design of inland vessel bridges) referring to the spatial design of ship bridges, dimensions of steering stations as well as the arrangement of the control and display elements.

*Quality levels*

- 1 Steering stations resemble those aboard inland vessels as regards form and dimensions without matching the standard however.
- 2 Dimensions and the arrangement of the equipment as well as the grip area of steering stations are in line with § 6.5 of DIN EN 1864.
- 3 In additions to the requirements mentioned under no. 2, there is at least one steering station in a room similar to a bridge. Regarding space used, height, lighting / colours this station complies with § 6.8 of DIN EN 1864.

The testing authority might claim an additional workplace “helmsman” in the immediate vicinity of the steering station for courses particularly aiming at the issue of the radar certificate. If necessary, one additional workplace has to be placed right in the vicinity of the steering station. This workplace without access to the radar and the ENC display (easily done by a curtain) comprises the rudder lever and the turn indicator. This configuration corresponds to old vessels’ arrangements. The assessment scheme however neglects this aspect due to a lacking standardized examination procedure.

**b. Instructor station**

The instructors are responsible for the concept, control and recording of the manoeuvres. Besides, they can also participate in traffic situations, e.g. communication with stations ashore of traffic ships, and ship’s operation, e.g. activities of the crew during anchor setting or establishing of rope connections. Then the latter requires an instructor station that is separated visually and acoustically from the other steering station.

An additional workplace can also meet examination purposes and to observe and record the running training. Optical view and radar display identical to those of the steering station should exist and the possibility to pursue communication as well as turn indicator, rudder position, rate of revolution of the main engine(s) or the position of the levers. To furthermore perform tasks of the ship’s operation, the instructor station must have corresponding control devices.

*Quality levels*

- 1 There is no separate instructor station. Training can also be drafted, controlled and stored at the steering station.
- 2 A separate instructor station is available having all necessary functions necessary for the communication with the steering stations and for the control of the running manoeuvres.
- 3 In addition to the requirements mentioned under number 2, the instructor station can perform the function “rope” and “anchor”.

**c. Briefing/debriefing station**

This station primarily focuses on the analysis of training exercises – a so called simulation session – as replay with the help of stored recordings. For that reason, the reproduction technology and the spatial design are decisive to fulfil this didactic approach during simulator training, which means:

- That instructor and all trainees can watch and analyse the replay of a simulation in one room.
- That there is sufficient furniture (chairs, tables).
- That the existing reproduction technology has an adequate acoustic and display size as well as an optimal position within that room
- That the reproduction technology enables a simultaneous and close together radar and visual display
- That the reproduction technology can be handled in the same room.

A normal training room is needed equipped with the necessary reproduction technology. On the condition that there is sufficient space available, the instructor station can also serve as briefing / debriefing station. Furthermore, the analysis can also take place at a steering station, if a reproduction technology is installed and the room is of suitable size.

*Quality levels*

- 1 Replay (radar, optical view and acoustic) only at steering stations.
- 2 Replay at one instructor station.
- 3 There is a separate briefing/debriefing station allowing classroom debriefing.

**2.2.2 Layout and equipment of steering stations (ship bridge cubicles)**

A fundamental requirement is that – concerning the scope of installed devices and the range of functionalities – the equipment of steering stations meets those mandatory requirements (regulation) as regards bridge equipment, that are applicable for the respective type of ship on the respective waterway / stretch – example: “Rhine Vessel Inspection Regulations (RVIR)” and reflects the bridge equipment of a modern ship. Related to implementation of the requirement are the following aspects:

- a) Installed equipment can be type approved (real) devices or replica devices. Replica must have an similar to “real” arrangement and an identical to “real” scaling of displays, tunings, controls etc,

- b) Some equipment is not – or not in any case – mandatory, but can be considered as “common and modern bridge equipment” – such as radar, inland ENC, GPS, AIS, wind indicator, searchlight etc.

In addition to the above mentioned fundamental requirement, some equipment, like fuel consumption indicator or graph of echo soundings can be considered useful for water depth efficient-driving on shallow waterway routes.

*Quality levels*

- 1 Scope of installed devices and range of functionalities are according mandatory regulation
- 2 In addition to above “1” a range of equipment according to above “b” is installed
- 3 In addition to above “2” equipment consist of type approved (real) devices

**2.3 Simulation kernel**

The whole simulation system consists of many single components. Which components are really needed, depends on the special purpose of application. Only a few are absolutely necessary. This also includes the simulation kernel in which the motions of the dynamic objects are simulated and the databases which describe the objects and the simulation surroundings. They are sufficient to carry out the simulation. Other important components are used for the presentation of the simulation: the visualization system, the audio system and the radar. The components for the control of the simulation, particularly the operating devices on the bridge have already been described. Numerous other components are conceivable which are too special to be treated here.

The simulation kernel simulates the motions of the dynamic objects in the time domain. This is done by temporal integration of the momentary accelerations and velocities in fixed time intervals. The accelerations are calculated from the forces and moments working on the objects and their inertia. The velocities are state variables of the simulation and their temporal integration results in the position and orientation in space.

The most important object class which is simulated, are the own ships – the ships which are controlled actively by the proband and motion behaviour of which is of special interest. When assessing the simulated motion behaviour, it always has to be considered that the outcome of the simulation results from the cooperation of the simulation model with the underlying data from the ship database.

Without analysing the implemented simulation model only the whole simulation can be evaluated. A separate evaluation of the simulation model and the ship database is not possible then. This has to be considered in the following for the suggested test procedures which refer to the performance features of the motion dynamics of own ships. Consequently separate assessment procedures to the motion dynamically ship database in section 2.5.1 can be omitted. Further test procedures which include the simulation model and therefore require detailed hydrodynamic expertise are introduced in chapter 2.7.

In contrast to own ships, the traffic ships and other moveable objects outside the water have no own dynamic. Their motion behaviour is not calculated by the temporal integration of forces and accelerations, but is determined according to certain simple rules. The motion behaviour of traffic ships can be very easy and unrealistic; however, they can also behave deceptively realistic, although they do not interact directly with the surroundings. Traffic ships are described in 2.3.2.

### 2.3.1 Dynamics of „own ships“

The own ship<sup>2</sup> is part of the central components of the simulation. This is the ship that – unlike the traffic ships – is controlled by probands on bridges. In a very advanced simulator an own ship could also be steered by an artificial intelligence. In contrast to a traffic ship it would have the same dynamic qualities like one own ship controlled by the proband.

The calculation of the motion occurs in the simulation kernel. For the description of the dynamics of the own ship quite different mathematical models are used (see chapter 2.7). For the assessment of the quality of the motion dynamics, it is however irrelevant, which is used from the respective manufacturer for the elective ship type. As the hydrodynamic model and ship database are always evaluated jointly by the assessment of the simulated motion dynamics, attention should be paid to carrying out the introduced assessments individually for every ship delivered by the manufacturer. Only by a more detailed assessment the underlying mathematical model is also examined (see segment 2.7). This way it can also be found out whether special qualities are represented by the mathematical model or by especially adapted data in the ship database.

Regardless of the quantifiable exactness or compliance of the simulation with the reality there are some basic qualities and physical effects in the motion behaviour which can be evaluated as performance features of the own ship. Below only the qualities relevant for navigating the own inland ship are listed and described.

#### *Performance features*

- a. Degrees of freedom
- b. Propulsion devices
- c. Control devices
- d. Shallow water effects
- e. Influence of current
- f. Influence of wind
- g. Banking effects
- h. Ship-ship interaction
- i. Squat
- j. Canal effect
- k. Locks
- l. Grounding
- m. Collision ship-shore
- n. Collision ship-ship

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<sup>2</sup> In the database normally different ships or ship types are deposited as a own ship.

- o. Collision ship-bridge
- p. Lifting wheelhouse
- q. Ropes
- r. Anchors
- s. Towing

**a. Degrees of freedom**

To calculate the track of a ship, three degrees of freedom are needed in minimum. They comprise:

- Longitudinal motion (Translation in *x*-direction)
- Lateral motion (Translation in *y*-direction)
- Yaw motion (Rotation around the *z*-axis)

All simulators must be able to handle these types of motion. Additionally, there are three more degrees of freedom (in total 6-dof) in the horizontal plane:

- Roll motion (Rotation around the *x*-axis)
- Heave motion (Translation in *z*-direction)
- Pitch motion (Rotation around the *y*-axis)

Distinctive roll motions can appear in the field of the inland navigation (e. g. heel due to centrifugal forces in curves, rudder forces or free surfaces in partially filled tanks). These roll motions can be significant and have already led to serious accidents.

Heave and pitch motions are barely visible. In contrast to maritime shipping, heave and pitch motions are not excited by wind waves. But in confined waters, especially with a low under keel clearance, significant dynamic sinkage and trim occur, depending on the ship speed and bottom topography. The can lead to grounding and have an important impact on the ship resistance and propulsion characteristics.

The motions in all degrees of freedom are coupled due to different physical effects. There are different approaches, how to model and calculate this coupling. This is described in section 2.7 in more detail.

*Quality levels*

- 1 Simple calculation with only 3 degrees of freedom
- 2 Improved calculation with 4 degrees of freedom (roll motion)
- 3 Detailed calculation with 6 degrees of freedom

*Test procedures*

The degrees of freedom implemented in the simulator can be evaluated by observing the visualization system or by instruments. Therefore, the following manoeuvres are carried out using small vessels which usually move more distinctively and faster than bigger ones.

- If the horizon is swinging when looking forward during navigating along curves, the roll motion is implemented.

- If the ship's bow raises and drops with strong longitudinal accelerations, the pitch motion is implemented.
- If the echo sounder display changes when running at higher speeds at constant water depth, the heave motion is implemented (this test implies the modelling of the squat effect).

#### **b. Propulsion and power devices**

Besides the conventional propulsion of a ship using a single fixed propeller on a shaft several different variants are applied in shipping. Among these are:

- Multiple propulsion devices
- Controllable pitch propeller
- Water jet propulsors
- Azimuting propulsors (e. g. rudder propellers, Voith-Schneider-Propellers, pods etc.)

By the very presence of alternatives a simulator stands out from the minimum configuration; it should however be kept in mind that most manufacturers have implemented several different propulsion devices in their own software to meet the customer wishes.

Basically, the proband can control the propulsive power on the bridge. A change of this power must affect the ship's speed. In this context the engine and the propulsion device must not be simulated separately. However, in a refined simulation details of the engine (e.g. the engine speed or the coolant temperature) are simulated requiring at last also a detailed simulation of the propulsion device.

Besides, the following aspects can be considered:

- Power device  
By restriction to diesel engines, fast mode, medium fast mode and slow mode engines are used here. Each type has a typical behaviour which can be more or less exactly modelled. Particularly apparent for the user of the simulator is the reaction of the engine when activating an operating element. In most cases this refers to the speed controller (EOT-handle – Engine Order Thrust) which corresponds to the conservative engine telegraph. Dead times, raising curves and reversing times are responsible for the reaction of the engine. Other possible simulations of the engine equipment deal with temperature, oil pressure, consumption of fuel, alarms and more. Details of the engine simulation can be indicated on the bridge (steering station) using suitable instruments. At least the display of the engine revolutions is usual.
- Propulsion device  
This component converts the power delivered by the engine into thrust to overcome the ship resistance. By restriction to the propeller (this consideration is valid analogously also for other types of propulsion devices) the physical relationship, which means converting torque into thrust, is to be modelled. This can be done quite simply by a proportional translation which however does not correspond, to the state of the simulation technology. On the other hand the use of so-called free running propeller curves considers the relations between rate of revolutions and inflow speed, thereby delivering, e.g. higher thrusts when towing or accelerating.

A high quality simulation necessitates the modelling of both components of the power and propulsion system in combination with other aspects of the simulation (e.g. local flow direction at the devices and water depth).

Thus, influencing factors for a realistic simulation of the acceleration process cover not only e.g. the engine behaviour during speeding-up, but also the conversion of torque in thrust, the rise of the resistance at increasing speed and the inertia counteracting against the acceleration of the ship.

#### *Quality levels*

- 1 The ship reacts to the EOT-handle and achieves a suitable speed.
- 2 The engine reacts with dead times and the propulsion device has a behaviour according to the actual speed.
- 3 The simulation of both components is carried out close to reality and considers all relevant influences.

#### *Test procedures*

The simulation quality of both components “power device” and “propulsion device” can be evaluated only by checking the availability of certain aspects with the help of manoeuvring trials.

- **Engine:** By an accelerating and a stopping test it can be checked whether the engine reacts correctly according to the defined dead and reversing times.
- **Propulsion device:** It is hardly possible to check the physically correct conversion of the engine torque into a propeller thrust by a simple run trial on the simulator. Only if there are outputs of the actual parameters like rpm, torque and thrust available e.g. reduction of the thrust with constant revolutions at increasing speed can be checked.

### **c. Control devices**

All systems which influence the direction of the ship’s motion belong to the control. In the easiest case, this is a rudder which is placed in the propeller slipstream or in the free wake of the ship at the stern. A lateral force initiating the rotation of the ship is induced by the rudder deflection.

Beside the central arrangement in the propeller slipstream, multiple rudders are often used on inland ships. They are possibly installed next to the slipstream to avoid any hindrance and move in with activity of the rudder to use the higher speed in the flow for control purposes.

Other control devices are azimuthing propulsion devices. In this case there exists no rudder blade, but the propulsion jet itself is swung with the propeller or propulsion device. Systems which are placed not in the stern, but in the bow also count to the control devices. As regards inland ships there is either a bow rudder, a bow thruster or an azimuthing thrust device which can be also designed as a 4-canal system.

All these systems serve only to change the direction of the ship’s motion or to cause the motion to deviate from the straight run (e.g. traversing).

It can be assumed that every simulator disposes of at least one control device. Nevertheless, the quality of the simulation can differ. In the easiest case, a lateral force is produced in the stern along with constant revolutions of the propeller proportionally to the applied rudder angle. Provided that no special demands are made, this also leads to a course change.

Higher quality is given when the control device is simulated, e. g. at a realistic rudder rate of turn, and the physical inflow conditions are properly considered. Here, the focus is on the effect that when a

rudder is set to 20° during navigation along a curve it will have an inflow angle of e.g. only 10°, as due to the drift and yaw motion of the ship the local cross velocity is considered in the stern only. On this occasion, the straightening by the flow around the hull should also be considered in the calculation.

The best possible simulation is given when all known influences are considered. It could also be used in addition to compare rudders of different layout and design with each other. To be able to use this functionality, the characteristic of the control device must be stored either in tables with the drag and lift coefficients, or be provided in other form as data or software.

#### *Quality levels*

- 1 The ship reacts to the control device.
- 2 The control device behaves close to reality regarding the rudder rate of turn and considers the most important influences.
- 3 The simulation of the control device is complete and allows e.g. the change of the profile of the rudder blade.

#### *Test procedures*

To test the quality of the simulation of control devices, different investigations can be carried out. Limitations are given where it is not possible to evaluate the behaviour without protocols of state variables.

- **Reaction:** The control device is used in forward and backward motion. It is observed, if changes of the ships direction are initiated.
- **Rudder rate of turn:** The control device is used and the rate of turn is observed on the display. It can be measured, if the rate is realistic.
- **Change of profiles:** The database of the simulator allows the assignment of certain different descriptions of the characteristic of the control device. A trial run, e.g. a turning circle, will be carried out to check if the ship behaves differently according to the expectations.

#### **d. Shallow water effects**

The motion behaviour of a ship changes with the water depth. The increasing blockage under the keel hinders the longitudinal and the cross flow. At the same time the waves generated by the ship change in form and height. With decreasing water depth the resistance increases. Consequently, the speed decreases with constant power or a higher power is necessary to reach the same speed.

In curves, where the ship builds up a centripetal force by a drift angle, this angle is smaller in shallow water due to the hindered cross flow, but the turning circle diameter is greater.

A good simulator should be able to reproduce these general effects for inland navigation. The strategy to reach this target can differ from type to type by the different mathematical modelling.

For a simulation of the motion behaviour with low demands to the exactness there is only limited need for the shallow water influence. An inexperienced proband might not even notice, if this effect is omitted.

As regards the quality when modelling the shallow water effect, it should not only be clarified whether it is used globally for the forces or affecting single coefficients, but also whether the used function leads to realistic results.

#### *Quality levels*

- 1 The shallow water influence is limited to the increased power demand with decreasing water depth.
- 2 The effect of a limited water depth on the power demand and the manoeuvring behaviour tends to be modelled correctly.
- 3 The effect of a limited water depth on the power demand and the manoeuvring behaviour is modelled correct in terms of quality.

#### *Test procedures*

Two types of tests are proposed which allow judging the quality regarding the consideration of the shallow water influence:

- **Running straight ahead:** On different water depths the achieved maximum speed is measured, standardized with the speed on deep water and plotted versus the parameter  $T/h$ . The comparison with existing data from model tests gives information about the quality of the shallow water influence in the simulation (see also 2.7.5.1)
- **Turning circle:** By running a ship at constant power and a rudder angle of  $20^\circ$  on lateral unrestricted water, the stationary values of speed, drift angle, rate of turn and turning circle diameter can be recorded on stepwise reduced water depth. Plotting this data versus  $T/h$  allows determining how drift angle, rate of turn, speed and the diameter change with the water depth.

#### **e. Influence of current**

The hydrodynamic forces affecting the ship are determined by the flow velocity, i.e. the speed of the ship relatively to the water. In rivers a partly complicated, three-dimensional current field, in which the ships move, evolves on account of the slope and the very irregular topography. To what extent this current field can be described in the simulator generally, it is treated under 2.5.1.

At this point, the influence of the current on the motion dynamics of the ship shall be treated. In a homogeneous current field the ship experiences horizontal forces which – according to the current direction relative to the ground – decelerate or accelerate the ship or allow the vessel drifting. If the ship crosses inhomogeneous current fields, hydrodynamic moments arise, in addition, which lead above all to a yawing motion. If the current fields are unsteady, unsteady forces and moments will act on the hull.

The description of the current in the exercise area is only one requirement for the inclusion of current effects in the simulation. The simulation model has also to be able to transfer these details in appropriate motion behaviour. Also here different quality levels are conceivable:

If the current attacks the ship only at one point (e.g. the middle of the ship) a yawing moment cannot be calculated. If a ship modelled that way crosses an inhomogeneous current field, the whole ship is always affected by the current at one single point. This however does not correspond to the integral effect on the complete ship. As a result, unstable force effects arise in unstable current fields. This effect can be reduced, by using the mean current of several positions in the surroundings of the

current measuring point, perhaps, even taking into account the distance square to tone down long-distance effects.

Only if at least two current attack points exist in the ship, a rotation due to inhomogeneous current can be calculated. The exactness raises with a higher number, so that, e.g. local cross currents by lateral discharges can better be considered.

The more detailed the effect of the current on the hull is dissolved spatially, the more exactly a locally irregular distribution of the lateral resistance coefficients can be determined and the yawing moment be calculated. This is especially important with inhomogeneous current fields and ships with distinctive bulbous bows and very flat stern lines.

#### *Quality levels*

Provided that the current influence is simulated, the quality level of this characteristic is categorised by analogy with the above explanations as follows:

- 1 The current is considered only with one single measuring point in the own ship and there is a force strength effect in the horizontal plane.
- 2 There exist several current measuring points on the ship, so that the current yaw moment can be calculated.
- 3 There are many current measuring points aboard the ship, so that the lateral resistance distribution is exactly considered.

#### *Test procedures*

Tests are planned to check the existence of the performance characteristic and its consideration in the simulation:

- If the operator's console of the simulator or the bridge has an indicator for the local current, the number of the current measuring points could be counted. Otherwise this information can be given in the manual of the simulator.
- An own ship without propulsion is put into a river with existing current. It is observed whether the ship is taken by the current. Besides, it is checked whether it is accelerated up to the current speed. If the current follows the river direction, it will be checked further whether the ship slightly rotates.
- A trial with the port entrance from a river with current shows, to what extent the simulator realistically calculates a yawing moment generated by the inhomogeneous current.
- With regard to the question concerning the existence of a lateral resistance distribution it has to be checked whether comparative runs with the above port entrance having very different current fields lead to differences in the motion behaviour.

#### **f. Influence of wind**

Wind (not head wind) does influence the motion behaviour of a ship. Leaving aside a deliberate use of the wind (sails or rotors) wind is annoying in most cases, e.g. because it decreases the ship with head wind or can dissuade it from the course in side wind. Primarily, the shape of the superstructures is responsible for this. While ships are mostly symmetrical with view from the front, this is mostly not the case by the lateral view. Completely loaded inland ships with bulk cargo have a relatively low wind-

exposed area in the region of the bow and the cargo hold; however, at the stern a relatively large projected surface is effective because of the superstructures and the bridge. This unsymmetrical distribution of the wind-exposed areas along the ship does not only cause a lateral displacement, but also generates a yawing moment sometimes not to be neglected.

The wind influence can be considered only if wind attack areas of the ship are described in the database. Alternatively, the wind influence could be also described by algebraic functions as a function of the relative approach angle, as they can be won by wind tunnel tests or CFD calculations.

While the supply of the wind information is classified in 2.5.1.2, at this point the processing of the wind in the own ship calculation is discussed.

In the simplest approach the wind generates translational forces in the horizontal plane. If the shape above the water surface is described in greater detail, the yaw moment can also be calculated. Provided that the simulator disposes of more than 3 degrees of freedom, the rolling moments, which lead to a clearly discernible heel angle with high superstructures, can also be generated by the wind.

Besides it can be relevant whether objects on the shore or other ships lead to a wind shadowing.

#### *Quality levels*

- 1 The wind influence generates forces in the horizontal plane according to the actual wind speed and direction.
- 2 Additional to 1 the wind generates yaw and roll moments.
- 3 Additional to 2 objects on the shore and other ships produce shadowing effects.

#### *Test procedures*

To check the quality level of the wind influence, different tests can be carried out. To be able to easier detect these effects, relatively high wind speeds are to be chosen.

- In an open sea area the ship running straight ahead experiences side wind and headwind. It has to be checked, to what extent the ship becomes slower when running with or without headwind or how much the ship will move sideways with lateral wind and possibly deviate from the course. Further, it has to be observed whether a heel angle occurs in side wind.
- Furthermore it is checked how these effects increase at significant rise of the wind speed.
- The lateral wind-exposed area will be changed in the database (e. g. bridge to the bow) if feasible. Moreover it has to be clarified whether side wind leads to a change of the course divergence.
- It is checked whether fluctuations of the wind as to direction and speed influence the motion behaviour.
- Under wind influence the ship will be steered along a building close to the shore and a big ship. It is observed whether the motion behaviour changes after entering the lee of the building or the ship.

### **g. Banking effects**

When a symmetrical ship is running straight ahead on laterally unrestricted water no side forces and yaw moments are acting on it. As soon as an asymmetry appears in the waters, the flow around the ship is changed and special force effects are noticeable. Such the asymmetry influencing flow is given when the ship runs along a wall. This can be a vertical wall, but also an embankment.

The water between wall and ship accelerates and a low pressure develops which attracts the ship to the wall or to the embankment. The stronger the condition forming this effect is (e.g. distance or speed), the greater the force impacts by the so-called banking effect are. A yaw moment turning the ship off (turning away) the wall originates from the differences in hull form at bow and stern, but above all by the suction of the propeller at the stern.

Simulators for inland navigation should therefore copy this wall effect physically in a correct way, because the navigation in the inland is characterized by low distances between ships and shore. In canals, e.g. the West German canal system with its rectangle profiles and a width of 42 m, this banking effect becomes obvious soon. It leads to the fact that the ship does not go stable straight ahead any more. Depending on the position of the track with regard to the canal axis the vessel is attracted more strongly by the wall closest to the ship. At the same time the bow is turned away more or less intensely by the wall effect. In practice this means that the helmsman of a ship on a canal must compensate this instability by continuous rudder activities.

Like other effects described in this chapter, also the bank effect though not necessary for the pure motion of the ship contributes to adjust the simulation model closer to physical reality. The availability of any modelling therefore is a feature which goes beyond the very basic motion simulation. In addition, the simulation can also consider other parameters as for example the hull form etc. The best possible simulation is marked by the fact that it also considers the propeller suction.

#### *Quality levels*

- 1 A rudimentary modelled bank effect generates a lateral force and a yaw moment.
- 2 The lateral force and the yaw moment tend to change with distance and speed in a proper manner.
- 3 All physical effects (e.g. suction of the propeller) – even of higher order – are regarded in the calculation of the forces.

#### *Test procedures*

For checking the bank effect in the simulator an exercise area is needed which provides an embankment or wall on one side as well as a relatively narrow canal. The following tests can be carried out:

- The ship is running parallel along the wall. It is checked, whether the straight motion is affected remarkably if it is attracted by the wall and turned away from it.
- The distance to the shore is varied and it is observed how the effects change
- Close to the shore it is checked, if the stern is attracted by the wall due to the propeller suction when the propeller revolutions increase.
- It is tested, whether the directional stability changes between lateral unrestricted waters and a canal.

#### h. Ship-ship interaction

Similar to the banking effect, the straight run of the own ship is influenced by other ships located nearby following a change of the symmetry of the flow around the ship. In addition, during encountering and overtaking manoeuvres an additional influence is given by the flow around the other ship.

The flow around the "other" ship is characterized not only by a precurrent and postcurrent at bow and stern as well as a back current along the midship, but it also forms, the so-called primary wave system which affects the own ship by a more or less very distinctive trough (dimensions of influence are e.g. water depth and speed). This trough carried along by the other ship changes the level of the own ship with regard to trim and heel. The gravitational forces due to the local slope of the water surface are acting as accelerating or decelerating force. The current around the other ship is locally changed and also influences the own ship. If the own ship is overtaken and runs in the trough of the other ship, the back current around the other ship will act as a counter current which slows it down.

Both effects, the effect of the trough and the flow around the other ship, act together and are not usually separated within a physical modelling. Besides a modelling using only the additional current effect, there is an approach to use additional forces and moments according to the state of technology. The strategy the simulator manufacturer follows, is not of importance. However, the effects on the own ship resulting from the physical causes described here have to be computed correctly.

In the following listing the reactions of a ship are outlined during overtaking and encountering manoeuvre in their temporal history:

**Own ship is overtaken by another ship:** At the beginning of the overtaking manoeuvre the own ship sinks with the stern into the trough arising from the other ship and thereby decelerates. The stern is pushed away and the own ship turns into the course of the other ship. Then the own ship is slowed down by the back current of the other ship and it is attracted. At the end of the process the own ship is with the bow still in the trough and accelerates following the other ship. The bow is pushed away and the own ship turns off the other ship.

**Own ship is overtaking:** At the beginning of the overtaking manoeuvre the own ship falls with her bow into the trough of the slower ship and accelerates. Her bow turns off the old course. In the middle of the manoeuvre the own ship is attracted. While moving out of the trough at the end of the overtaking the own ship decelerates and turns inward.

**Encountering:** At the beginning of the encountering the own ship goes accelerating into the oncoming trough of the other ship. Her bow turns off. In the middle of the process the own ship is attracted. When leaving the trough at the end of the encountering the own ship delays and turn inwards.

For SHS a general difference is made between own ships and traffic ships. Own ships are controlled by probands actively and it can be expected that they react as it is known from the physical reality. A traffic ship is always treated as object by the own ship with the possibility to interact, as it should be done in case of a good simulation.

This other ship can be a traffic ship steered by the simulator or, however, again another own ship of another bridge in the same exercise. There is only little effort the simulators mostly use for the modelling of the traffic ships, so that a traffic ship causes no interaction effects with other ships. During

the encountering manoeuvre the motion of the own ship is influenced but a traffic ship, as the other ship, will not show any change of her course behaviour. If two own ships with well modelled interaction effects meet, both ships – every ship calculated for herself – will show a suitable reaction. This will be different and possibly more concise because both own ships attract each other and induce yawing moments.

From model tests and numerical investigations the following dependencies from the boundary conditions are known while passing and should be reproduced in case of a "perfect" simulation:

- The effect of the ship-ship interaction decreases with higher passing distance and disappears at a certain distance.
- With increasing water depth the passing ship effects decrease but will not come down to zero at deep water
- The effects while passing increase with about the square of the speed of the other ship.
- Big ships induce larger effects on the own ship than small ones.
- Also moored own ships are affected by the passing ship effect when other ships in the surrounding move in the vicinity of them.

According to application kind of the simulator the modelling of the ship-ship interaction can be of different relevance. In inland navigation the ships often pass at small distances (particularly in canals). Therefore, it is important to reasonably simulate the interaction of overtaking or encountering ships.

#### *Quality levels*

- 1 Only a simplified approach for the ship-ship interaction is available.
- 2 The ships are interacting with each other and realistic effects are computed.
- 3 All dependencies (as distance, water depth, speed, ship size etc.) are considered and the effects are reproduced very close to reality.

#### *Test procedures*

For an entire check of the ship-ship interaction an exercise with two own ships should be started on the simulator, namely in a lateral unrestricted water as well as in a relatively narrow canal. If this is not possible, the test can also be carried out using a traffic ship as the other ship. For a good assessment of the results, the ships should start in parallel courses at a relatively small lateral distance.

- For both overtaking and encountering it will be checked to which extent the own ship shows the reaction described above.
- The water depth is reduced. It will be checked, if the interaction effects increase.
- The distance between the ships will be increased to find out, if the effects decrease.
- The speed of the other ship will be increased. The functional relation between passing ship effect and encountering speed is checked.
- It is tested, if passing manoeuvres in a narrow canal become impossible without collision from a certain speed (less than the maximum allowed speed) upwards.

- It is checked, whether overtaking of two own ships with small speed differences cannot be brought to an end above a certain speed because both ships cannot release each other due to the deceleration of the overtaking vessel and the acceleration of the slower ship.

**i. Squat**

The vertical dynamic change of position of a ship in motion is called "squat". It comprises both trim and sinkage. The dynamic sinkage is due to the sagging of the ship in the trough of the primary wave system (see segment 2.3.1h). By suction of the propeller and different displacement distribution a dynamic trim also appears in most cases.

Ships of high block coefficient tend to trim down by the bow, whereas slender ships tend to trim down by the stern. This displacement effect is overlaid by the propeller influence and the propeller leads to more stern down trimming. Very inclined propeller shafts can also lead to a trim bow down. Fast ships almost always trim to the stern, because they have the trend to climb onto their own bow wave with speed increase and to fall into the displacement trough with the stern. The sinkage is always positive during displacement motion and changes with different boundary conditions.

The following relationships are valid:

- The sinkage increases with the speed.
- The sinkage increases with decreasing water depth.
- The sinkage increases with decreasing width of the waterway.
- Shape and size of the ship also influence the magnitude of the sinkage.

In maritime simulations on deep water, the importance of the squat is rather low. But in the field of inland navigation, where always shallows conditions are to be found, The sinking has an important impact, as it limits the accessible maximum speed of a ship because of the risk of grounding.

While the skipper can detect the squat on at lateral unrestricted waterway only with the depth sounder, this effect is easier to recognise in canals, where the water surface is observed at the canal wall or at the embankment. However, only if the visualization system (see 2.4.1) models the water surface so that the local deformation by the displacement trough is also considered, this effect appears in the simulator.

For the determination of the squat during the simulation different possibilities are given which vary by rising complexity of the calculation or by a higher number of influencing parameters.

*Quality levels*

- 1 Only the dynamic sinkage is modelled by simple approaches. The trim is neglected
- 2 Both dynamic sinkage and trim are modelled in dependency of the speed, water depth and draught.
- 3 Sinkage and trim are modelled considering all influencing parameters (additional to 2: blockage ratio, current velocity) and lead to very realistic results.

### *Test procedures*

This feature is best tested in two different exercise areas, one with lateral unrestricted water and one in a canal situation. Besides, flat riverbed or canal grounds with constant water depth are important.

- With trial runs on open water the existence if the feature “squat” can be checked using echo sounders, preferably at bow and stern.
- Different values for the under keel clearance at bow and stern show whether the ship trims.
- With increasing speed the functional relation between squat (difference between under keel clearance during standstill and motion) and ship speed is checked.
- It is tested, whether the squat increases at constant speed but decreasing water depth.
- It is checked, whether the squat in a canal is greater than on unrestricted water while speed and water depth are constant.

### **j. Canal effect**

For canal-navigation, certain effects – such as banking – have been described in above chapters.

There is a special effect which needs a special parameter for canals is influenced by the other characteristics, not at all or only a little. It is the so-called back flow velocity which was already mentioned in chapter 2.3.1h. The water which is displaced by a ship sailing in the canal must move from the space in front the ship to the space behind it. As the cross section of the canal is reduced by the ship cross section, following Bernoulli’s law, the water must flow along the ship with a higher velocity than in unrestricted water. This back flow reduces the speed of the ship over ground because she runs at constant speed through the water due to the constant power. It has been shown, that so-called “blockage factor”

$$BF = (B \cdot T) / (W \cdot h)$$

is a suitable mean for the quantification of this additional back flow. It derives from the ratio of ship cross sectional area and canal cross sectional area.

### *Quality levels*

- 1 Very simplified or no consideration of the back flow.
- 2 Consideration of the correct back flow .
- 3 The back flow is modelled physically correct and it rises disproportionate to the ship speed.

### *Test procedures*

A canal with constant water depth is necessary as exercise area for the investigation of the effect of the back flow. Wind and current have to be zero. The back flow is measured as a difference between the speed through the water  $V_{tw}$  and the speed over ground  $V_{og}$ .

- It is checked, whether to  $V_{tw}$  and  $V_{og}$  are different when sailing through a canal.
- A comparison between the computed back flow on unrestricted water and a canal shows, whether the presence of the canal walls leads to an increase of the back flow.

- By variation of ship speed, water depth and draught it is tested, in which functional relation the back flow is computed dependent on the varied parameters.

#### **k. Locks**

The ship passage of a lock is an extreme case which only few simulators can model is close to reality. The synergy of many features discussed above as for example shallow water effect, banking effect, squat and canal effect plays a decisive role in this context.

Even if a simulator models all these details well, an additional effect, which has not been described up to now, yet still can be observed. If a ship enters a lock, she pushes the water in front of herself. This is particularly distinct, when the lock width is only slightly wider than the ship breadth and the ship is completely loaded. In this situation the water can only flow along the sides and under the keel very slowly out of the lock chamber while the bow pressure raises the water levels inside the lock.

This enforced outflow leads to a strongly raised back flow decelerating the ship remarkably. In addition, the ship will trim to the stern and considerable downhill-slope forces are active which have to be compensated by the propulsion power. In extreme situations it can occur that the ship stops or even moves back over ground, because the downhill-slope force and the water flowing out of the lock influence the forward motion so strongly that it becomes impossible.

From model tests and numerical calculations with special lock software it is known that the change of the advance speed is not constant. Oscillations may come up by sloshing of the water in the chamber and by the changing of the water level and the under keel clearance at the stern.

#### *Quality levels*

- 1 In a lock the ship experiences the same effects as in a canal.
- 2 Additionally to 1: forces due to the displacement flow are regarded.
- 3 Forces due to displacement flow and waves in the lock basin are calculated precisely in space and time.

#### *Test procedures*

A preferably narrow lock and a rather wide vessel are necessary for the check of the lock effects. A suitable size for the passage of a lock in the German canal system ( $W = 12$  m) is a modern big inland ship ( $B = 11.4$  m).

- It is tested whether the ship slows down while entering the lock at constant power.
- It is checked, whether the ship accelerates while leaving the lock chamber at constant power.
- The presence of an additional back flow like in a canal can be detected by the comparison of the speed through water and the speed over ground.
- The trim to the stern can be observed in the visualization system, provided that it is operating in 6 degrees of freedom.
- It is tested, whether the entrance into the lock with high power and high initial speed leads to a nonlinear change of velocity, trim and sinkage including non-periodic oscillations.

## I. Grounding

The realistic simulation of a grounding situation is of great importance in inland waterway navigation. When modelling the shallow water effects (see chapter d), the extreme case of shallow water is grounding, when the under keel clearance gets down to zero.

Grounding can appear either with steadily decreasing water depth or it can occur as a final event resulting from continuously rising speed and increased sinkage (see segment 2.3.1i). In all cases the speed of the ship should drastically decrease and the vehicle, finally, come to halt.

If possible, the grounding should be accompanied by a suitable sound. However, this is to be seen here, rather as a warning for the skipper and not as a real grounding sound. On account of the distance between bow and wheelhouse it is hardly to be supposed that a helmsman is really able to hear this sound if the bow touches the ground.

Under certain circumstances grounding can also lead to a noticeable change of the ship level. This applies to the stranding on a beach. In this case is to be expected that the bow lifts.

### *Quality levels*

- 1 Grounding can be noticed but has no further influence on the situation.
- 2 Grounding leads to a stop of the ship or to an abort of the simulation.
- 3 Grounding slows the ship down, it can be heard by a sound and the level of the ship changes.

### *Test procedures*

An exercise area with an even as well as a softly rising bottom is necessary for the check of grounding. Here, the existence of suitable depth information in the simulator itself are addressed and not the representation in the visualization system .

- When grounding on a beach it can be tested, whether the ship really stops, and if so, whether it stops abruptly or it slows down.
- During the grounding the change of level can be checked, if the visualization system is capable of 6 degrees of freedom.
- Running over a flat bottom at extreme shallow water it can be tested, whether the ship grounds due to squat while the speed is increased continuously.
- For all groundings it can be checked, if this incident is accompanied by a sound.

## m. Collision ship-shore

In contrast to grounding, a violent reaction is always to be expected in a collision in horizontal direction as a result of the moving mass of the ship and the solidity of the collision object. The motion is stopped almost immediately and with a plastic deformation of a ship a certain crumple zone can be assumed.

For demonstration purposes an accordingly elastic model has to be foreseen for the collision calculation. However, such a model is not necessarily included in every simulator. In case of a sophisticated modelling an elastic push leading the own ship to rebound of the collision object can be also calculated.

Depending on how the simulator software discovers collisions, some objects may lead to a collision and some not. Should the simulator base such calculations on the ENC, it is recommended to check whether those attributes, on the basis of which the software detects collisions, have been assigned to all objects suitable for collisions in the ENC . If not, the ship runs through an object and the impression for the probands is irritating.

In the event of collisions a suitable noise should also sound. In contrast to the grounding, this is even more important, because a real collision is in most cases accompanied by a noise audible on the bridge.

#### *Quality levels*

- 1 Collisions ship-shore are detected (displayed) but have no influence on the simulation. For the calculation only one single point on the ship is used.
- 2 Collisions ship-shore lead to a halt or an abort of the simulation. The calculation of the collision is done using a 2 dimensional shape of the vessel.
- 3 When collisions ship-shore occur an elastic-plastic push is computed including a noise. The calculation uses a 3 dimensional hull shape for the detection.

#### *Test procedures*

Only for exercise areas with different objects on the shore the simulation of the collision ship-shore can be tested.

- By sailing against different objects it can be found, whether the simulator can detect these and react on them.
- For different objects it should be tested, whether there are certain types, for which no collision reaction occurs.
- The sound for the collision can be tested with the audio system of the simulator, if available.
- The observation of the collision in the visualization system shows, whether the collision occurs abruptly or if a crumble zone is simulated.
- A collision with a flat angle at low speed can show, whether an elastic push is computed.

#### **n. Collision ship-ship**

Unlike collisions with solid objects from the map and grounding, collisions ship-ship concern approaches to moving objects in the simulator. In these cases it must be found out whether the distance between them becomes zero.

Mostly ships are used in the map of simulators with their outline. Besides, it plays no role whether it concerns an own ship or a traffic ship. In case of a collision ship-ship only the distance between the outline points of two neighbouring ships are important.

Although sometimes special symbols represent the moveable objects in a simulator, the actual outline should also be defined for a suitable enlargement. Especially regarding simulators for inland navigation with the usual small scales it is important to know the exact contour of the different ships and also to realize it.

As the collision types ship-ship and ship-shore are very similar, the main focus of this feature is on the outline representation. Only with the help of this information a collision ship-ship can be calculated in detail. Moreover, it can be assumed that the quality of the collision calculation is identical. For that reasons the quality levels do not consider a crumple zone or an elastic push.

While for simple systems the use of sharpened rectangles can be sufficient for a collision recognition, in inland waterway navigation – especially with coupled vessels and barge tows – a more exact information of the edge points and the points between is necessary. Only in this way to will be possible to achieve a good agreement of the possible collisions in the visualization system with the collision calculated in the simulator.

#### *Quality levels*

- 1 Collisions ship-ship are detected (displayed) but have no influence on the simulation. For the calculation only one single point on the ship is used.
- 2 Collisions ship-ship lead to a halt or an abort of the simulation. The calculation of the collision is done using a 2 dimensional shape of the vessel.
- 3 When Collisions ship-ship occur, an elastic-plastic push is computed including a noise. The calculation uses a 3 dimensional hull shape for the detection.

#### *Test procedures*

This performance feature can be tested for each exercise area. Under the precondition that it makes no difference for the own ship whether the other ship she is colliding with is another own ship or a traffic ship, different collisions can be carried out.

- It is checked, which reaction occurs on the simulator during a ship-ship collision for the own ship and whether a sound can be noticed.
- At n the instructor station it is checked with sufficient magnification if the outlines of the vessels are used for the collision detection.
- It is tested, if the collision occurs exactly at that moment, when the outlines touch each other.
- It is checked, if there is a precise detection of the collision also for various ships with different shapes.

#### **o. Collision ship-bridge**

A bridge is an object which can be driven under without any collision. In this respect it differs from the fixed objects treated in chapter 2.3.1m.

In the description of the exercise area, which is based on the ENC, for most simulators the information of a passage height for a bridge is available. With a height described in the database of the ship it is possible to find out whether the ship can pass under a bridge.

Specific performance features appear when an arched bridge is concerned. There the vertical clearance is mostly given as the local height at the boundary of the waterway. While a higher ship can pass in the middle of the bridge in reality, it is doubtful whether this also works in the simulator.

A further specific feature is given for the calculation of the vertical collision point. In the simplest case a point which corresponds to the reference point of the ship-fixed coordinate system is used here. This can be freely chosen or is, however, e.g. the centre of the mass of the ship. The ships bridge is mostly to be found aboard inland ships at the stern, i.e. the critical collision point is there too. However, on the other hand, a collision with the front mast can already occur in practice. Also this situation should be correctly calculated if it is a matter of simulating a collision ship-bridge close to reality.

At last also the width of the bridge should be considered. If only the bridge axis is used for the collision recognition, the collisions are detected too late. Just because in the simulator the view to the front covers the ship completely and the bridge to be passed is well in sight, emphasis should be given to a realistic simulation of a collision, so that the acceptance of the simulator is not affected by such negative details.

#### *Quality levels*

Apart from collision recognition for this feature, the localisation of the collision points is of major importance. As two details (bridge shape and points on the ship) are combined, a certain simulator settled between the three criteria of the requirement categories if only one detail is completely developed.

- 1 Collisions ship-bridge are detected (displayed) but have no influence on the simulation.
- 2 Collisions ship-bridge are detected using a height value and lead to a halt or an abort of the simulation.
- 3 The collision detection considers both the shape of the bridge and the superstructure of the ship and its masts. The collision leads to a halt or an abort of the simulation.

#### *Test procedures*

To examine this achievement, a bridge must exist in the exercise area (ENC). Besides, for a check of criterion 3 an arched bridge has to be available.

- It is checked whether during the passage of a bridge with not enough clearance a collision occurs and what is the outcome for the further simulation.
- It is checked whether a safe passage is possible with sufficient reduction of the water level or increase of the draught. This should also be checked in the visualization system.
- Different runs are necessary to check the collision point on the ship, if only one exists. In this case it can also be also localised whether the bridge causes a collision in the centre line or in the outer boundaries.
- An arched bridge will underrun at different positions and with different water levels. It is checked whether the occurrence or absence of a collision corresponds the reality.

#### **p. Lifting wheelhouse**

Unlike common seagoing ships, many inland (container-)ships have a lifting wheelhouse to be able to pass under relatively low bridges. If no height restriction exists, the bridge is lifted up,

To realise this simulation functionality, the whole wheelhouse must be shifted vertically from a start point to a new position. This does not mean that complete simulator bridge really will be moved. In

practice only the eye point of the visualization system will be shifted vertically and the geometrical description of the ship for the collision detection (see chapter 2.3.1o) is adapted accordingly.

The change of the vertical position of the lifting wheelhouse also influences the wind effect and the rolling behaviour of the ship. To what extent this will be considered, depends on how the system considers the wind influence in the simulation (see chapter 2.3.1 **Fehler! Verweisquelle konnte nicht gefunden werden.**f) and whether the simulation disposes of more than at least 4 degrees of freedom (see chapter 2.3.1a).

However, this functionality concerns both the simulation kernel and the visualization system. The position of the eye point adjusted in terms of height must be transmitted to the visualization system so that it is able to follow this change of position.

I In case of several own ships, which can observe each other, it can also be expected that the visualization models of the other ships also dispose of a visual operating lifting wheelhouse, so that the motion of the wheelhouse is visible for third parties. Also the navigation lights and day signals which are fixed on a real lifting wheelhouse must be integrated in this vertical motion in the visualization system.

On traffic ships a lifting wheelhouse is also possible. But because this addresses only the optical impression in the traffic situation, this functionality can be neglected , as long as it is available for own ships.

#### *Quality levels*

- 1 The lifting wheelhouse only has two positions (up/down). Collision height and eye point are adapted to the position of the bridge.
- 2 Like 1, additionally a continuous motion of the lifting wheelhouse is available.
- 3 Like 2, additionally the position of the lifting wheelhouse (including lights and day signs) is visible for other own ships.

#### *Test procedures*

A precondition for testing this performance feature is the availability of a typical inland waterway vessel, e.g. a GMS 110 m.

- The basic availability of this functionality can be checked by the presence of an operating device for the change of the bridge position.
- The function can be tested on the bridge and it will be checked, whether arbitrary positions can be chosen and whether the motion is abrupt or with realistic speed.
- By positioning another own ship in the vicinity it can be tested, whether this functionality is also available for other ships in the visualization system.
- It can be observed whether also navigational lights and day signs move according to the motion of the lifting wheelhouse of the second own ship in the visualization system.

#### **q. Ropes**

While many simulation exercises put their main focus on the navigation and the control of a ship, the use of ropes in connection with manoeuvring also counts to the possible duties which can be trained

with a simulator. This is relevant above all for simulators used in inland navigation, since mooring manoeuvres are carried out here more often compared to seagoing ships.

When using lines, different applications have to be distinguished:

- **Pure mooring:** In this case a rope is brought to a fixed point on the shore keeping the ship in the actual position.
- **Running into a rope:** Instead of using a rope merely for securing the position it can also be used as dynamic element. If a spring rope is fixed between the bow and the bollard on the shore propeller and rudder can be used to bring the stern to the shore while the spring is preventing the forward motion and thus supporting the mooring manoeuvre.
- **Active warping:** If the rope is equipped with a winch it can be used to move the ship e.g. along a pier actively.

In contrast to a connecting rod which can transfer a force and is marked by a maximum load, a rope owns the additional quality of the elasticity. This allows the connections becoming movable to a certain extent, while the defined distances can vary slightly. These performance features of a rope can be filed in a database. That way a huge number of ropes can be made available to the user. The same applies to perhaps available winches which distinguish themselves by maximum force and haul in speed.

With regard to the visualization system a good acceptance will be created if the slack of a not or only slightly loaded rope is displayed. Though a simple straight line in the 3D representation exposes the rope, but its load state is not assessable optically.

A rope always needs connection points. They can be predefined either in the system, while the positions of the bollards are given or they are freely eligible. This is valid for the ship as well as for attack points on the shore or even on other ships.

#### *Quality levels*

- 1 Simple rope function with a straight line in the visualization system, no winch.
- 2 Like 1, but the rope has a slack due to its own weight and the line force.
- 3 Consideration of all details including elasticity, breaking load, winch and slack in the visualization system

#### *Test procedures*

In an exercise area with a quay wall mooring with a rope and/or a winch can be tested.

- The presence of the rope function is given, if the relevant operating controls are available.
- When using the rope, it can be checked, whether it snaps to certain bollard points.
- The breaking of a rope can be checked by trying to stop the ship with its help from full speed.
- When a ship is placed in the middle of a harbour basin with four ropes to all directions, the elasticity, the functionality of the hoists and the reaction of the ship can be tested in the simulator. It can be checked whether the representation of the slack is displayed by the visualization system realistically if the rope comes loose.

## r. Anchors

An anchor is strongly related to the rope from the modelling. As attack points on the ship the hawsepipes must be defined. Attack points on the shore are not necessary, because an anchor can be set at every place of the waterway.

In reality this attack point however has certain qualities which should be considered in a very realistic modelling. The hold force of an anchor (not to mistake with the breaking load of the chain) is depending on the anchor type, its size or weight and the physical properties of the anchorage. Here coefficients can be defined for the hold strength, depending on how well a certain bottom holds.

If the hold force of the anchor is exceeded, it should slip, i.e. with a certain friction over the bottom. If the tractive force of the chain becomes less than the friction force, the anchor holds again.

The dynamics of the chain corresponds to the rope with the difference that the dead weight cannot be neglected. It can be tight in the maximum case, sag normally and hang down vertically in the other extreme from the hawse and lie on the ground. In all three cases the anchor exerts a different tractive force on the ship. The magnitude of this force is depending on different parameters like the horizontal distance between the hawse and the anchor point, the chain length, the water depth and the weight of the chain per meter.

The breaking load of the chain mostly exceeds the hold force of the anchor. If this is not the case, the chain should break really and the anchor should disappear from the system. However, it is doubtful whether the modelling of this detail is necessary for a simulator (especially for inland navigation). The same applies to the winch power. It may be correct to block the winch when the anchor force is too high. It is yet questionable whether an anchor loss by an excessive chain weight compared with the hoist strength should be displayed.

Setting an anchor is done by dropping. In practice this occurs relatively fast and can be stopped after achieving the desired chain length. Hauling inboard of the anchor takes place slowly and requires a certain time which should also pass by in the real time simulation to copy this process persuasive.

Only if these physical principles are implemented correctly in the simulator, the system is able to reproduce an anchor manoeuvre realistically. Especially the training of emergency manoeuvres can be carried out successfully only if, e.g. the conditions holding, slipping and chain breaking can be simulated clearly with different loads.

### *Quality levels*

- 1 Anchors can be set and hauled in but the water depth, dynamics of the chain or the characteristics of the anchorage are not considered.
- 2 Like 1, additional the water depth and the dynamics of the chain are considered.
- 3 Like 2, additional the characteristics of the anchorage are considered.

### *Test procedures*

In an exercise area with restricted water depth and an own ship with one or several anchors the anchor function can be examined. It is reasonable, if a constant current, the velocity of which can be varied, is available.

- Setting and hauling in of the anchor is only possible if appropriate operating elements exist on the bridge. It has also to be checked whether there are instruments indicating the chain length.
- It is checked whether the speeds differ while setting and hauling in. Besides, it can be also found out whether a suitable sound can be heard.
- By variation of the water depth it can be checked, if the water depth has an influence on the anchor function.
- At low current velocity it will be tested, whether the ship is oscillating and coming to halt after anchoring.
- At continuous increase of the current it will be tested, if the anchor slips and whether the characteristic of the anchorage, the weight of the anchor and the weight of the chain influence this.
- Should a single anchor not hold, it will be checked, if the ship halts, if two anchors are used.

#### **s. Towing**

While entering a harbour with tug support a manoeuvre is often carried out for seagoing ships and trained for simulators, this is seldom the case in inland waterway navigation. The transport using tugs towing barges does not exist anymore and inland ships usually manoeuvre with own propulsion and control systems.

Nevertheless, there is the situation on the river Rhine that in the so-called "Gebirge" with too strong current assistance by tugs is requested. Though this tractor is used not for mooring, but supports only the engine of the towed ship, the modelling of this problem does not differ from the tug assistance of seagoing ships entering the harbour.

Towing exactly like anchoring is related closely to the rope function. The only difference to bringing out mooring lines to the shore is the fact that the attack point is now on a moving object.

When towing in the simulator it is to be distinguished whether the tug is an own ship or a traffic ship is can be. In the simple case of a traffic ship which is steered then, e.g. by the instructor of the exercise or an assistant the motion characteristics of the tug can be reproduced only roughly. This is sufficient in many cases, because in mooring assistance the main intention is moving, e.g. the bow to the side by requesting of a certain force.

Only if both vessels are own ships or ships whose dynamics is simulated completely, an expressive simulation can be performed usable for to an ambitious training. As soon as the dynamics of a ship involved in the towing process is disregarded, the towing behaviour strongly deviates from the reality and the simulation loses explanatory power.

#### *Quality levels*

- 1 A towing connection can be set up between an own ship and a traffic ship.
- 2 While towing the dynamics of both ships and the rope connection are considered.
- 3 Like 2, additional a winch can provide a constant force.

### Test procedures

The exercise area for checking of the towing function can be an open sea area. Besides the towing or towed own ship another ship (own ship or traffic ship) is necessary.

- The basic condition for towing can be tested by bringing out a towing line between an own ship and the other ship.
- If this is not possible, it can be checked whether at least an alternative method for defining a force coming from a virtual tug is given.
- It is checked whether the other ship, used as towing assistance, can accelerate the towed own ship and also initiate a yaw motion by a lateral pull.
- It is checked whether the towing own ship can move the other ship by suitable manoeuvres and stop it and whether the other ship also can be brought into rotation by a lateral pull.
- It is checked whether the tow gets into oscillations after a certain time with variation of the rope length while running straight ahead at constant speed.

### 2.3.2 Traffic ships

Traffic ships are mainly used to participate as visible targets in traffic and to make the exercise more difficult or lively. The term *traffic ship* is not to be confused with the term *other ship*: The other ship is every ship which can be seen from the bridge or on the radar of the own ship. The other ship can mean a traffic ship or an own ship (another proband in the same simulation).

Unlike own ships no special dynamic qualities are simulated with traffic ships. Their motion is controlled by an instructor or the simulator. Besides, traffic ship should behave realistically.

In the visualization representation there is no difference between own ships and traffic ships usually so that the proband – based on the visual image – cannot judge whether the foreign ship is controlled by hand or whether it is led by the simulator.

However, the differentiation between own ships and traffic ships can also become blurred, depending on how the simulator is conceived.

- On simulators of low quality the motion behaviour of the own ship can be modelled in such a simple way that it shows only the quality of a traffic ship.
- Traffic ships can be controlled automatically. This is the case if an autopilot, guidance or positioning system takes over the control of the motion. The motion of the traffic ship is pre-programmed this way being particularly helpful when the same traffic situation should often be repeated.
- In a further stage of development the simulator can control a traffic ship in a way that it behaves – in the sense of artificial intelligence –, as if it was steered by a real person.
- Traffic ships on sophisticated simulators with sufficient computational power can be modelled complexly so that they show many of the characteristics described in segment 2.3.1 (e.g. interaction with other objects).
- Traffic ships can be also controlled by hand. This can occur in the instructors console or by simple consoles which are equipped with rotary regulators for rudder or course and sliders for the

rate of revolution or the speed. A single person can therefore control several traffic ships which as consequence take actively part in the traffic situation instead of following passively way points or routes.

*Performance features*

- a. Quantity
- b. Control
- c. Motion behaviour
- d. Influence of wind
- e. Influence of current

**a. Quantity**

Marine simulators for seagoing vessels do not often need a large number of traffic ships. In inland navigation, however, frequently a lot of different ships have to be traffic participants in order to make the scenario lively, complicated and difficult.

Particularly when the motion behaviour of traffic ships is quite simply conceived, there is nowadays no problem to generate a high number in the system with the computing capacity available. Nevertheless, a large number causes new difficulties.

- **Generation:** Every traffic ship must be defined, while it is selected from a catalogue and is placed in a position of the situation display. This can take up some time according to the number. If the simulator offers the option to load available exercises, this process must be carried out only once.
- **Control:** Every traffic ship should move in a way that the voyage looks very realistic. This means either manual control by an instructor or assistant or there are automatisms which take over the guidance of the traffic ships.

Useful support of the simulator software in generation and control are additional options which improve the use of traffic ships in the daily operation of a simulator, so not only the number of them but also these benefits affect the characteristic of this detail.

*Quality levels*

The simulator should have additional options as described above to be able to handle the larger number of traffic ships. Here it is assumed that these options are available.

- 1 Up to 10 traffic ships, no additional options
- 2 11 to 99 traffic ships, predefined traffic ships can be loaded
- 3 100 and more traffic ships, additionally to 2 predefined routes can be assigned individually

*Test procedures*

The assessment of the feature “number” is rather easy using the instructor console.

- The study of the respective simulator manual gives explanation about the number guaranteed by the manufacturer of simultaneous applicable traffic ships. As regards the possibility of parallel

exercises, it has to be noted whether the maximum number is valid for the complete number of exercises or for every exercise individually.

- Based on the continuous generation of traffic ships in the system it can be checked whether the simulator also delivers the promised performance.
- While setting up an exercise it can be found out whether the simulator allows the loading of available exercises with traffic ships. Moreover, it should be checked whether during or while finishing an exercise the possibility exists to store the actual situation including the generated traffic ships.
- If a traffic ship is generated, it has to be checked whether a controlling option is offered to use waypoints or to let the traffic ships follow a predefined route.

## **b. Control**

The aim of control of traffic ships is to monitor moving objects in the simulation environment, which perform a most realistic motion.

The control can be distinguished between automatic and manual control of motion. The instructor or an assistant are responsible for the manual control, observe the simulation and control one or several traffic ships. The operator console of the simulator should therefore be equipped with input devices or, real or generic elements like button, operating levers or sliders.

The automatic control uses single waypoints or routes. Depending on the simulator they can be stored and loaded or have to be defined each time before undertaking a new exercise.

Waypoints can be used, e.g. to allow a traffic ship leaving a mooring at the request of the instructor. If the traffic ship disposes of this option, it accelerates to the demanded final speed and moves from one waypoint to the next. How it behaves, describes chapter 2.3.2c.

While only coordinates are given by waypoints the ship successively passes, speeds and trajectories can be also defined in routes.

A route can be developed from a polygonal line of waypoints. At the waypoints the track can be defined by radii or other mathematical functions which are also steady in the second derivation. This leads to a rise of the rotational speed up to a maximum value and one slowing down to the value zero with the transition to the next straight line. For route segments the velocities can be given which the traffic ship either accepts jerkily or reaches incremental (see segment 2.3.2 c).

To generate a continuous traffic in the simulator, starting and ending point of a route should merge so that a continuous motion of all ships is guaranteed. The turn places should be placed in the simulation scenario in a way that the probands cannot observe this change of direction in the visualization system.

If the traffic ship is controlled by a simulator with artificial intelligence, a route can be also given, but the traffic ship, however, e.g. carry out evasion manoeuvre independently or adapt the speed to the traffic flow. It may also be possible that the traffic ship performs an independent computer-controlled task (e.g. sailing from A after B with timing).

### Quality levels

- 1 The traffic ships can follow waypoints.
- 2 The traffic ships can follow routes. These routes include characteristics which distinguish them from waypoints by quality.
- 3 Traffic ships can imitate the human helmsman by computer control and can run autonomously under certain conditions.

### Test procedures

In The manual should describe the different possibilities to control a traffic ship. However, in practice the availability of these functions should always be checked.

- The input options for the manual control can consist of keyboard and mouse or of real handles as rotating buttons and levers.
- When using a keyboard input, sometimes it is to distinguish between „command“ and „actual“. This indicates, that a target for e.g. the course is set which will be changed continuously from “command” to “actual” using a predefined finite rate of turn.
- It is to be checked, whether the instructor console provides possibilities of control by waypoints or routes.
- When designing a route it has to be assessed, which additional options are offered and if the simulator can also convert them into practice.
- If the simulator can run vessels autonomously, it should be checked, if the behavior correlates to that of a human being.

### c. Motion behaviour

The programming of object classes in the simulator determines the kind of motion of a traffic ship. According to the different steps described in the following this motion can vary from "jerkily" to "fluently". It should however be kept in mind that some motion types necessitate a control with the help of waypoints, precast routes or manually. The description of the different motion types is in ascending order from "bad" to „very well“.

- Between two waypoints A and B the traffic ship runs at steady speed. During transition from AB to BC (corner points of a polygon) the traffic ship suddenly changes her course and, perhaps, also her speed. This is an example of a simple waypoint control.
- As before, but with the transition from AB to BC the traffic ship changes her course at a steady rotating speed stored in the database. The visualization system still displays a transition of rotating speed zero to the steady rotating speed. Besides, the curvature of the track may lead to an unnatural drift motion.
- Another possible improvement of the motion can be done with the implementation of typical drift behaviour when running along a curve. As a result, the simulation of a natural motion is almost completely realized .
- By manual control the traffic ship can be programmed in such a way that it follows the orders immediately and jerkily. Still, refinements can also be programmed like maintaining a constant

speed of rotation, rising on a maximum value and declining to zero as well as the implementing of an additional drift as a function of the rotation speed.

*Quality levels*

- 1 Jerky motion behaviour
- 2 Reasonably smooth motion behaviour
- 3 Natural motion behaviour

*Test procedures*

To control this quality level on the simulator the manual, the equipment of the simulator and the functionalities of the control console must be consulted.

- The presence of the different levels is checked by test runs of the traffic ships in the simulator. All given control options (manual, waypoints, routes, artificial intelligence) are to be executed and the motion behaviour of the traffic ships is to be observed.
- Thereby the speed has to be recorded with manual or automatic change and to judge the acceleration or deceleration.
- Moreover, the change of the speed of rotation and the occurrence of a drift angle is to be recorded and evaluated.

**d. Influence of wind**

Traffic ships should move along the given course. Nevertheless, the availability of wind influences the motion behaviour of ships in reality.

In side wind the ship (with fixed course) deviates from the planned track to leeward or it follows the track taking a drift angle. Thereby a natural behaviour is produced leading to realistic simulations particularly when sailing in restricted waters like canals.

With headwind a slowing down can be expected and a rise of the speed with tail wind.

The wind consideration can be refined by adding certain characteristics to the traffic ship which describe, e.g. the wind sensitivity (wind-exposed areas) in a simple or elaborate modelling. The model database determines the static way and the instructor the dynamic by interactive procedures. Besides, there is a difference between the pure turning the wind influence on and off and the gradual setting of it.

*Quality levels*

- 1 The traffic ships do not react to given wind, but follow the predefined track.
- 2 The traffic ships react to given wind and steer, e.g. by taking a drift angle, against it.
- 3 The traffic ships react to given wind and the response is predefined, natural and manipulable.

*Test procedures*

For control purposes a traffic ship should be uploaded to any area and wind be defined. In case the simulator does not dispose of the wind option, this test is not practicable and the feature does not exist.

- It is checked whether the ship deviates in side wind either from the given course to leeward (manual course control) or, while following waypoints or a route takes a drift angle with the bow to the wind.
- It is checked whether the traffic ship goes slower in headwind and faster in tail wind.
- Additional options like switching the wind influence on and off or interactive interventions are possible on the condition that these options are available in the operating console.

#### e. Influence of current

In contrast to maritime navigation the current is of particular importance in inland navigation. This applies above all to own ships, however, also to a realistic motion behaviour of traffic ships.

The effect of lateral current is comparable to the side wind – either a displacement occurs or a drift angle is necessary to follow a given track. As to the navigation on rivers, running upstream and downstream are commonly relevant for traffic ships. Besides, the current leads to an increase or decrease of the speed over ground ( $V_{og}$ ) at constant speed through the water ( $V_{tw}$ ). Consequently, attention has to be paid to whether the value is  $V_{tw}$  or  $V_{og}$  when setting the speed of traffic ships..

When entering or leaving areas with current from/into still water zones a ship is affected by the current at different longitudinal positions and a yaw moment is induced. In case of traffic ship which follows a track, this should lead to a steady change of the angle of attack which compensates the displacement caused by the current. However, this steady change can also be generated by a gradient when changing the rotational speed.

#### *Quality levels*

- 1 The traffic ships do not react to given current, but follow the predefined track.
- 2 The traffic ships react to given current and steer, e.g. by taking a drift angle, against it.
- 3 Like 2, additional the traffic ships react to local changes of the current.

#### *Test procedures*

To control this feature a traffic ship sailing upstream, downstream or entering a harbour coming from a river is needed. However, a current must also exist in the simulator as already discussed concerning the current influence on the own ship (see 2.3.1e).

- It is to be tested, whether at constant speed through the water traffic ( $V_{tw}$ ) ship runs faster over ground going downstream and slower going upstream.
- It is to be checked, whether with a commanded  $V_{og}$  the wave pattern is different going up- or downstream (different  $V_{tw}$ ).
- It is to be tested whether a traffic ship following a given track changes it's heading when crossing an inhomogeneous the current field. The drift angle of a traffic ship should vanish, when entering a harbour with no current.
- Additional it has to be checked, whether a traffic ship leaving a harbour is noticeably caught by the current and changes her course or adopts an angle of attack.

## 2.4 Output processing systems

### 2.4.1 Visualization System

The visualization system includes all hardware and software, which is utilised for displaying the simulation area. Monitors or video projectors are used either in a single arrangement or in a group of multiple devices.

For video projections commonly a cylindrical projection screen is used with the proband sitting in the centre of the circle. Alternatively an array of (flat) monitors is used approximating the cylindrical projection screen around the proband. The use of head-mounted displays does not seem reasonable in the area of ship handling simulation. It can be expected, that future generations of curved display are available in larger dimensions for visualization tasks, for which nowadays video projectors have to be used.

The projection or display area should be placed in a distance of at least 6 m from the viewer. This is the minimum distance of the field of depth to infinity for the human eye. Both the displayed object of the virtual reality and its image on the screen have the same focal plane for the eye. Doing so, it is not possible to display objects, which are closer to the observer than the projection distance. This shortcoming could be eliminated by using a stereoscopic projection (known from 3D cinema), but very close objects are generally of minor importance in ship handling simulation and therefore in most instances not visualized. When projecting objects that are nearer than approx. 6 m the focus plane has to be determined by the image generating software, with the consequence that objects far away are out of focus. This effect is well known from 3D-movies.

The graphical visualization corresponds to the point of the viewer. This is commonly the steering station, but it can be virtually switched, so that the view from another point or to another direction is displayed. Additionally the simulation of other on-board imaging equipment, such as video cameras, night-vision devices or binoculars is possible.

Image processing is usually done by dedicated and powerful computers, which work independently from the simulation core. The demand for computing capacity within image processing is very high. While the quality level of the visualization, that is available today, is quite high, further improvement can be expected in the next years.

#### *Performance features*

- a. Image section and size
- b. Resolution and frame rate
- c. Further detailing and display quality
- d. Water surface
- e. Sun, moon, celestial bodies
- f. Weather
- g. composed representations

### a. Image section and size

Image section denotes the horizontal and vertical angle of sight or the relative value of the depicted part of the real angle of sight. The human field of vision has a horizontal angle of about  $180^\circ$  and a vertical angle of about  $130^\circ$ . Additionally the head motions within the projection have to be considered. Therefore the maximum reasonable angle of sight for the view of the skipper from ship's bridge control panel corresponds to the maximum field of view from ship's bridge. Normally the horizontal angle of sight is smaller than  $360^\circ$ , because the back wall of the bridge impedes all-round visibility. The larger the projected angle of sight, the better is the subjective perception of reality.

The angle of view denotes the horizontal and vertical angles with which an image is seen by human beings. Is the angle of view smaller than the angle of sight, the visualization appears minimised, is the angle of view greater than the angle of sight the visualization appears to be extended.

The image size denotes the absolute dimensions of the displayed image and is the result of the projection distance and the angle of view. Image size is of subordinate importance, since it is proportional to the projection distance.

In general terms, it can be noted:

- At an angle of sight smaller than  $180^\circ$ , ships abeam are not visible anymore.
- It can be expected, that the presented angle of sight of imaging equipment corresponds to the angle of sight of the device.
- When visualizing a bridge view, angle of sight and angle of view should correlate to each other.
- If a simulator has only a small display area, the viewing point and direction can be changed by control handles. In this way, it is for example possible to have a side view even while the image section is only  $135^\circ$ .

#### *Quality levels*

- 1 Only a simplified representation with a fixed angle of sight, display detail is not switchable. The horizontal angle is less than  $180^\circ$ .
- 2 The display detail does not include the entire angle of sight. The eye point and the viewing direction can be adjusted by handles. The angle of view approximately corresponds to the angle of sight and allows an all-round visibility by a switching option.
- 3 The visualization system allows a view around the horizon ( $360^\circ$ ). The horizontal field of view may be obtained by a fixed view of at least  $240^\circ$  and additional switchable view(s) for the rest of the horizon. The vertical view allows the view down to the water and up to the sky as it would be seen from the regular steering position in the wheelhouse.

#### *Test procedures*

The angle of view is the result of projection distance and image size. It has to be taken into account that the projected image size may vary from the screen size.

The angle of sight can be determined by modelling a reference grid in the simulation area, which is shown in the simulation image. In the simplest case the reference grid is the lattice model of a sphere, with the eye point of the proband in the centre of the sphere. The lattice model consists of grid lines of a prescribed angular distance of e. g.  $30^\circ$ . It has to be tested subsequently, if the grid lines in the simulated image appear with the same angular distance.

## **b. Resolution and frame rate**

The most important feature for the spatial resolution is the angle of view, which is filled out by a single pixel. The human eye has a resolution of about 1'. Therefore it is sufficient to resolve a horizontal display detail of e.g. 30° with 1800 pixels.

The frame rate specifies the number of images, which are represented by the system per unit of time. The frame rate should be sufficiently high, so that the human eye does not recognize single frames. Computer generated images are usually represented with progressive scanning (noninterlaced scanning). Especially in case of fast rotary motions – this applies e.g. for turning manoeuvres of inland waterway vessels – human beings react very sensitively to too low frame rates. A frame rate of 60 Hz is desirable. For comparison: Cine films have frame rates of 24 Hz, the European television standard PAL 25 Hz and the television standard NTSC 30 Hz.

Resolution and frame rate are essentially restricted by means of the performance of the image generating hardware. Using the same hardware with reduced resolution, a higher frame rate and vice versa can be achieved. As long as the navigationally important details can be recognised, greater emphasis is to be placed on a sufficient frame rate at a reduced resolution. However the native resolution of the projectors and screens should always be followed.

The frame rate is not necessarily constant. In situations with representation of numerous or complex objects, the frame rate may be significantly lower due to the computing power, than in situations with only few objects.

### *Quality levels*

- 1 Only a highly simplified representation.
- 2 The resolution is sufficient for identification of the most important navigational details. The frame rate allows the perception of the current situation in time.
- 3 The resolution reaches the resolution of the human eye. The frame rate (ideally > 50 fps, at least 30 fps even in complex scenes) reveals no jerking.

### *Test procedures*

The resolution is part of the specification of the screens and video projectors. The current frame rate has to be determined with the help of software. It is easily accessible when the frame rate can be calculated and reported by the simulator itself.

Determination of the minimum frame rate is possible during the simulation of simulation areas with highest itemisation and a maximum of traffic volume.

## **c. Further detailing and display quality**

The detailing is mainly predetermined by modelling of the simulation area (see section 2.5.3). Any object consists of its modelled visualization surfaces. The more precisely (more detailed) an object is to be displayed, the more partial surfaces have to be used for its modelling. The observer can be deceived by using textures for larger partial surfaces, instead of modelling numerous single surfaces. Textures allow reducing the level of detail while generating an equivalent optical impression.

Beside the representation of objects in the scenery, further effects, such as shadowing, reflections, secondary reflections and transparencies may increase the level of reality.

The computational costs increase with the number of displayed partial surfaces, as well as the size and number of used textures. For increasing the frame rate during image composition, smaller and unimportant objects can be represented in simplified form or can be omitted.

It is not possible to define a quantitative measure for the display quality. The minimal requirements are the identification of all navigationally important objects. The best display quality can be obtained, if all details of the visual model can be represented from database.

#### *Quality levels*

- 1 Only a highly simplified representation.
- 2 The resolution is sufficient for identification of the most important navigational details in appropriate distance.
- 3 The itemisation is not restricted to any object in the visual model. A limitation of itemisation is possibly given by the visual database.

#### *Test procedures*

Navigationally important and unimportant details are observed from different distances. It can be determined in this way how far the representation changes. The closer an object is, the more details can be identified. Once a certain distance is reached, visible details do not increase any longer and the itemisation is limited by the visual database.

#### **d. Water surface**

The water surface differs from all other surfaces by its size and dynamic.

Due to the huge amount of data and the high data rate, the calculation of the wave motion on the water surface is often done by the visual system. In this case simplified mathematical models for the simulation of wave motions are used. Advanced ship handling simulators are able to calculate the waves outside the visualization system.

The representation of waves is independent from the method of calculation. The forces of waves acting on a ship are not discussed in this section.

The ship-induced waves depend on the hull form, ship velocity and the water depth. A typical wave system of a ship consists of the primary and secondary wave system as well as the wake. The primary wave system can only be observed in confined water. The secondary wave system in deep water typically consists of transversal and diagonal waves (Kelvin angle), which separate at the fore and aft shoulder. In confined waters the water depth has a major influence on the secondary wave system. At a subcritical velocity condition the wave angle depends on the Froude depth number, at critical ship velocity solution waves separate from the ship and run ahead in front of ship's bow. In a supercritical condition transversal waves disappear completely. An experienced skipper is able to estimate the velocity of his ship on basis of the induced wave system. Especially diagonal waves are weakly damped and remain over long distances. Finally the wake denotes the troubled water behind the ship due to the propeller rotation.

Wind induced waves can be approximated by applying a suitable wave spectrum. In the simplest case an on-dimensional wave spectrum can be used. With respect to the available computing power two-dimensional wave spectra should be used. The used spectrum should be valid for the specific simulated waters.

Additionally the influence of the previous history has to be considered. Alternating wind conditions result in crossing seas, which are very important from the navigational point of view. Long waves are the result of wind conditions from the past, short waves and spray follow the wind force and direction very directly.

It is conceivable to calculate the propagation of waves – taking additionally into account the topography of the water – outside the visualization system.

Besides the form of the waves, their visual representation plays an important role. From sea state 3 on whitecaps develop on the wave crests, which are additionally breaking from sea state 6 on. Colour and texture have to match in connection with the sky. Reflections from sun, moon or artificial lights should be visible.

#### *Quality levels*

- 1 Only a highly simplified representation.
- 2 Ship induced waves depend on the ship velocity. Water depth is considered. Wind induced waves comply with a realistic wave spectrum.
- 3 Ship induced waves depend on the ship velocity and the water depth. The influence of the ground topography on development and propagation of waves is realistic. Wind induced waves comply with a realistic wave spectrum. Short waves and spray indicate the wind direction. The simulation of crossing seas and heavy seas is possible.

A full implementation of all influences on the wave development and propagation (quality level 3) would improve the quality of simulation significantly. For the calculation of wave development and propagation in confined waters simplified mathematical definitions are available. However the requirements concerning computing power are so challenging, that currently no ship handling simulator is able to meet the demands. Provided that research and development deal with the outlined problems solutions can be expected in a medium term.

#### *Test procedures*

Ship induced waves are assessed for the own ship as well as for passing external ships for different ship velocities and water depths. During the assessment of the own wave system, the propagation of waves in direction to the bank has to be taken into account. Additionally it has to be verified if ship's wake traces the path of the ship.

Height and length of wind induced waves can be examined via modelled test marks. It can be at least checked, if the significant wave height corresponds to the used wave spectrum.

For validation of short waves and spray, the wind direction is changed during simulation independently from the wave direction.

Colour, texture and characteristic of reflections are reviewed concerning their realistic appearance.

**e. Sun, moon, celestial bodies**

Sun and moon are usually represented as a light source, whose position is defined by the time of day. Similarly additional celestial bodies are represented in accordance to their position in the sky. For the calculation of the celestial position place, date and time of simulation can be taken into account. A more precise representation is only useful, if the view from ship's bridge contains a certain section of the sky. In this case it might be necessary, that the projection is made within an arched dome.

*Quality levels*

- 1 Only a very simplified representation.
- 2 Sun and moon follow a 24-hour interval. The positions do not exactly correspond to place and date of the simulation. The night sky consists of arbitrary stars.
- 3 Position of sun and moon (including moon phase) are exactly calculated for place, date and time of simulation. The night sky or at least the most important stars correspond to the real view.

*Test procedures*

Date and time are varied. The representation of sun, moon and night sky is compared with the reality.

**f. Weather**

Especially for vessels operating at sea and near the coast, the weather is of vital importance. But also for inland waterway shipping fog or rainfall can lead to low visibility and also have major influence on the navigation. Clouds, rainfall, fog, haze and lightnings can be visually represented. Additionally it is possible to represent the effect of wind (waving flags, smoke trails).

The specification of the weather or weather development is done by the instructor. The representation is made without complex simulations in the visualization system, because the weather development is independently from the ship operations within the simulation.

High cloud layers are normally projected as a background image to the sky. Subjacent levels of single clouds have to be modelled as individual objects and require a much higher computing power. These individual clouds are significant indicators for wind direction and velocity as well as the weather development. Therefore the modelling of individual clouds is an important contribution to a realistic simulation.

The representation of fog, haze and lightnings is state of the art. Furthermore the illustration of rainfall (rain, hail and snow) is not really difficult; however, in reality the rainfall is located in the space between observer and screen. Hence a realistic representation is only possible with a stereoscopic representation. This applies in particular to rainfall against windows of ship's bridge.

Even at clear atmospheric conditions the visualization system is able to consider that distant objects appear increasingly pale and bluish than objects in close proximity to the observer.

It is not possible to represent wind force and direction directly, but the effect of wind to objects can be represented and highly supports a realistic simulation. An experienced skipper is able to estimate the characteristics of wind by means of moving objects and thus is in a position to take action. The motion of objects depending on the wind force and direction requires an appropriate modelling in the

visualization database. At this it is sufficient to model the reaction of concerning objects (flags, clouds, wind turbines) for normal wind conditions.

*Quality levels*

- 1 Only a highly simplified representation.
- 2 Stationary high cloud layers are represented. Furthermore rainfall, haze and fog can be displayed.
- 3 It is possible to represent moving cloud formations with all forms of rainfall as well as thunderstorms. The clouds are moving according to the wind direction. The effect of wind on rainfall and other objects is visible.

*Test procedures*

One after the other all available cloud formations and rainfalls are tested. In this regard wind direction and force are varied and the effect of clouds rainfalls and other objects is reviewed.

**g. Composed displays**

In case of a large angle of sight, a single video projector or monitor is not sufficient to display the complete representation. Hence the overall view has to be composed of several partial views. Following aspects have to be taken into account. The field of view straight ahead should be free of stitching partial views. Seams are always slightly visible and disturb the simulation, especially in the view straightforward. Consequently the complete representation, provided that no 360° representation is intended, must contain an odd number of partial views. In case of monitor, devices with narrow edges should be used. During use of video projectors suitable apertures are necessary, to configure the transitions as seamlessly as possible. The colour consistency of video projectors is often not satisfying. In this case it is not possible to achieve a uniform appearance of the simulation. Therefore devices should be test in detail prior to their use.

*Quality levels*

- 1 Only a highly simplified representation.
- 2 Transitions between partial views are visible but do not disturb in the view straightforward.
- 3 Transitions between the partial views are barely detectable und are not perceptible in the running simulation.

*Test procedures*

A simulation exercise with a highly monotonous colouring is loaded. Afterwards it can be determined to what extent transitions between partial views are visible.

**2.4.2 Audio System**

The human auditory system is besides the eyes the second most important sense. While seeing is mainly consciously controlled, hearing is often an unconscious process, which cannot be switched off. Although for ship navigation – apart from the communication – seeing is of greater importance than hearing, it is necessary for a realistic simulation.

There is a variety of noises, which can be perceived on ship's bridge. They are grouped in ambient noises, which are constantly heard in the background and single acoustic signals, which deliberately arrest attention. Means of communication like phones or radiotelephony are not dealt with in this section.

Ambient noises (e.g. operating noises) are normally not consciously perceived, but expected as a background noise. Missing operating noises cause irritations and reduce the acceptance of the simulation, just like inappropriate or unrealistic background noises. Low-frequency structure-borne sound, caused by the main engine or the propeller, is also part of the operating noises.

Single acoustic signals are initiated purposefully and perceived consciously. They can be initiated by the skipper himself (e. g. horn) or are sequences of events in the simulation (e. g. collision noises).

The audio output is commonly produced using previously recorded noises (samples) from the audio database. The kind of noises from database is defined for the different objects. It is for example defined for each ship, which engine noise is played, or it can be defined for each port which harbour sounds ring out. The stored samples in the audio database are composed and transformed by the simulator with regard to distance and direction to the own ship for a realistic sound on ship's bridge.

If composed samples are used during playback, the transitions must not be heard. This is especially important for the playback of periodic noises (e.g. engine noise). Often the length of the samples is the same as the time period. Even in the case of periodic noises, the sense of hearing subconsciously perceives variations. Therefore the simulation is even more realistic when the same sample is not simply repeated.

During playback losses in quality can occur, caused by devices of poor quality (e.g. sound cards, amplifier, speakers) or by configuration errors (e.g. ground loops, over modulation). Additionally the room acoustic (e.g. echoes, reflections, shadowing effects, arrangement of speakers) has to be taken into account.

The audio system may provide the opportunity to transmit noises from ship's bridge –including the conversation of the bridge crew – to another room (e.g. listening of the instructor). These noises may also be recorded for a later simultaneous replay along with the simulation in order to analyse the whole situation.

#### *Performance features*

- a. Ambient noises
- b. Single sound sources
- c. Acoustic signals by bridge devices
- d. Listening
- e. Recording

#### **a. Ambient noises**

Ambient noises which can be heard on ship's bridge have their origin in different sound sources. For example:

- Operating noises from on-board machinery (engine, pumps, generators etc.) and equipment.
- Low-frequency structure-borne sound (e.g. induced by main engine or propeller)
- Wind and wind induced sound
- Rain, hail, thunder
- Noises from waves
- Traffic and working noises on the shore or on bridges

The volume level of all mentioned sounds is relatively low and they remain in the background. If this background noise attracts the attention it often sounds unnatural. Nevertheless these incidental sounds are expected by the skipper and enhance the degree of reality of the simulation, but it is necessary to ensure, that the sounds are suitable for the particular situation.

The most important ambient noise is the noise of the (diesel) engine. The used engine noise has to be suitable for the installed ship engine (number of cylinders, engine speed) or the drive system (e.g. diesel-electric). The motor noise (volume level and frequency) changes depending on the engine speed. This applies to all aggregates individually, if they are controlled separately.

The low-frequency vibrations of ship's bridge (structure-borne sound) also belong to the engine noise. In most cases these vibrations can be generated by powerful subwoofers. In a similar manner cavitating propellers or rudders may produce vibrations, which can be perceived by the skipper on the bridge. Especially cavitation noises have to be precisely suitable for the current situation (thrust and rudder loading).

The weather noises have to match with the weather in the simulation. The perception of eyes and ears has to coincide. If strong wind induces noticeable and navigationally important forces, appropriate wind noises have to be audible. In case of severe storm other wind induced sounds (e.g. clattering and banging objects and flags) may be heard. If the simulation includes thunderstorms and lightning are visible, the corresponding thunder noises have to be clearly heard. Additionally rain or hail that is pattering against the windows has to be considered. Within an advanced technical stage with a multi-channel-playback the direction of the rainfall is recognisable. Furthermore the noise of thunder has to correspond to the location of the thunderstorm (runtime, volume level, direction).

Noises induced by waves are usually of low noise level. They are hardly hearable in a closed bridge. Only extreme sea states with breaking waves and surf ashore lead to perceivable noises.

Traffic and working noises from the near and wider surroundings may improve the virtual reality. Typical noise sources are road and rail transport as well as noise generated by machinery in industrial parks and ports. At has to be taken into account, that seeing and hearing are compatible and the volume level is realistic.

The ambient noises additionally cover external operating noises from the simulator system (e.g. cooling fans of video projectors and computers).

#### *Quality levels*

- 1 Only a highly simplified playback of ambient noises.
- 2 Engine noises are reproduced in a realistic manner. If further ambient noises are reproduced, they correspond to the simulated situation in a realistic way.

- 3 Engine and weather noises are reproduced in a realistic manner. If further ambient noises are reproduced, they correspond to the simulated situation in a realistic way.

#### *Test procedures*

The engine noises can be tested in quiet weather and sea conditions by assessing the noises for all engine speeds. It can be directly determined if the engine sound is audible and if volume level and sound are appropriate.

For testing the weather noises all available weather modules in the simulator system are played one after another without engine noise. In that way it can be assessed in detail, how far the single noises for wind, rain, hail, thunder, etc. are represented properly.

For testing the additional traffic and working noises, the provided simulation areas are navigated with low ship velocity and quiet weather. Afterwards it can be assessed how far the noises have been perceived in a realistic or artificial way.

In many cases the volume level of the different noises can be controlled individually. It has to be examined how this can be done with the corresponding simulator system and which settings satisfy the optimum requirements.

#### **b. Single sound sources**

Single sound sources attract the attention of the bridge crew and can be located acoustically. The most important sound sources are the horn, sirens and collision noises. In addition, there are noises from buoys, beacons or further navigational aids.

Furthermore there are single sound sources of auxiliary power units, which are operating discontinuous (e. g. ground tackles). These sounds usually cannot be located by human ears, but they are consciously perceived, by reason of the fact, that they are a response to a desired action.

It should be possible to play all navigationally import acoustic signals. This applies for the own ship, external ships and for signals from shore or buoys etc.. Furthermore signals should acoustically locatable, which requires at least stereo sound with a constant phase position or a multi-channel playback in the simulation room. The acoustic position of the signal has to correspond to the optical representation.

#### *Quality levels*

- 1 Only a highly simplified playback of single sound signals.
- 2 Single sound signals are played in a realistic way, but cannot be located acoustically.
- 3 All single sound signals are played realistically. Nautically important sound signals can be acoustically located in a realistic way, regardless of direction and distance.

#### *Test procedures*

As a first step on the bridge of the stationary own ship, all available sound signals are activated one after the other. It is assessed, whether the sound signals are realistic regarding sound and volume level. In the second step the same sound signals are activated on an external ship, whereas the distance to the ship is varied. It has to be examined, if the correct signal sounds and if the acoustical directions as well as the volume level are played in the right way.

All operable auxiliary power units (e. g. anchors) on ship's bridge are activated separately. It is verified whether the operating status is acoustically perceivable.

**c. Acoustic signals by bridge devices**

Most devices on ship's bridge emit sound signals. As long as real equipment is used in the simulator, the real acoustic signals of the single devices are audible. These signals no longer have to be tested, because they are already realistic.

If bridge equipment is replaced by generic devices, which means a simulation via computer screens, this simulation also must contain all acoustic signals. Generic devices only appear realistic, if the sound signals are emitted by the device itself and not by the normal speakers for the simulation.

*Quality levels*

- 1 Acoustic signals from bridge devices are only played unrealistically.
- 2 Acoustic signals from bridge devices sound realistically, but are played by the speakers of the simulator.
- 3 Acoustic signals from bridge devices sound realistically and are played by the (generic) devices themselves.

*Test procedures*

All acoustic signals of all available bridge devices are activated one after the other. It is tested, whether the signals are emitted by the devices themselves or by the speakers of the simulator and how far they sound realistically.

**d. Listening**

It is very useful for the instructor, if all noises from ship's bridge can be transmitted to the instructor panel. Therefore the instructor may experiences the same situation like the proband and is able to evaluate his behaviour correctly. This also includes verbal statements of the simulation participants.

Listening, as a rule is possible by directly recording all noises on ship's bridge via microphones. For this a single channel recording is sufficient. Especially important is the good speech intelligibility of the simulation participants and a good perceptibility of single sound signals.

*Quality levels*

- 1 The instructor is only able to listen to the generated sounds by the simulator.
- 2 The instructor is able to listen to all noises from the ship's bridge.
- 3 The volume level of single noises from bridge (ambient noises, acoustic signals, conversation, etc.) is individually adjustable.

*Test procedures*

Within the scope of a simulation it has to be tested, whether sounds from ship's bridge are transmitted clearly and understandably and if the volume level is adjustable for the requirements of the instructor panel.

**e. Recording**

It should be possible to record the same noises from ship’s bridge, which are audible by the instructor to analyse the behaviour of the simulation participants afterwards. Beside noises from bridge, it is reasonable to record the communication via radio and telephone as well. It has to be taken into account that it is only allowed to record phone calls within the simulation. If phones on ship’s bridge can be additionally used for external calls, it is necessary to ensure, that no recording is possible. It is important to ensure a synchronous recording along with the simulation.

*Quality levels*

- 1 Noises from ship’s bridge are recorded independently from the simulation.
- 2 Noises from ship’s bridge are recorded synchronously from the simulation.
- 3 Noises from ship’s bridge as well as radio and telephone communication can be recorded selectively and synchronously with the simulation.

*Test procedures*

An exercise is recorded, while at specific time defined sound signals are activated and conversations are conducted. It has to be tested whether these sounds and conversations occur at the same time in the replay.

**2.4.3 Radar-Simulation**

In inland waterway shipping neither general radar carriage requirements are valid, nor is radar knowledge an important prerequisite for the formal qualification as skipper. Nevertheless nowadays radar practically belongs to the standard equipment of inland waterway vessels. Radar is of fundamental importance, because in situations of poor visibility, the operation of inland vessels is only allowed with an approved radar device and if at least one crew member on-board has a radar license (Rheinschiffs-Polizeiverordnung RheinSchPV). Approved radar units amongst others have to meet the requirements of the standard ETSI EN 302 194-1<sup>3</sup>.

Besides the so-called radar view, modern radar devices are able to display the position of the ship in electronic navigation charts (Inland Electronical Navigational Charts – IENC) in conjunction with GPS. Furthermore these devices are also able to generate displays of AIS (Automatic Identification System) as well as prepare and display additional information. The handling of radar and the mentioned navigation systems is due to its complexity and importance as well as the risks in cases of incorrect use, relevant for education and training to a high degree.

Radar engineering is based on acoustical logging of electromagnetic radiation (microwave radiation). This strongly bundled radiation is emitted by an antenna (scanner) turning on its own vertical axis. The bundling of radiation is achieved by a so-called radar lobe and depends on the form of the scanner. Emitted microwaves which are hitting objects are reflected. In the field of view of the radar, reflected radiation is received by the scanner and is visually represented as illuminated dots on the radar screen. Depending on the distance and the reflecting surface (material, inclination, surface structure)

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<sup>3</sup> [www.etsi.org](http://www.etsi.org)

objects are represented as small or large and as weakly or intensely shining echoes via luminous points.

The selectivity (resolution), that is the representation of objects very close to one another as separate echoes, is depending on the form of the radar lobe (Opening angle of radiation) and the wavelength of the micro waves (e. g. in the range of 3 cm or 10 cm). The interpretation of radar images on board an inland vessel is additionally made difficult by spurious echoes. These echoes arise situational (adjusted range, weather conditions, external signals, highly reflective objects, etc.) and have to be considered within the interpretation of radar images.

In case of a so-called river radar, as it is used in inland waterway shipping, the representation of the radar image is compulsory “head-up / relative motion”. Within this representation the heading of the ship is always centred in the upper part of the screen. This means, on a radar screen the environment is shifted, when the vessel is moving.

In radar simulation following major tasks can be defined: Since within the simulation no electromagnetic radiation is emitted and received, the distance and direction of objects in relation to the ship or the assumed position of the antenna as well as the intensity and magnitude of the echo have to be calculated and converted to input data for the radar device. Basis for the calculations are certain information with regard to current positions of moving objects, in particular the own ship. This information is on request provided by the simulation kernel. Additionally access to different databases and if necessary to other components has to be provided, to obtain information about the environment and additional objects as well as about the own ship itself.

A particular challenge is the detection of the ability for radiation reflection of the objects, depending on their reflecting area (form and size as well as material and surface structure). This presupposes, that deposited information in the database are not only suitable for optical representation but also meet the requirements for the radar simulation.

Following performance features are appropriate to evaluate the capabilities of radar simulators:

*Performance features*

- a. Conformity
- b. Resolution
- c. Shadowing
- d. Noise echoes
- e. False echoes

In principle these performance features also apply to ship handling simulators as well as for pure radar simulators.

**a. Conformity**

The horizontal conformity of the radar display is given, if:

- The displayed heading line is parallel to the longitudinal axis of the ship and the display of the position refers to the position of the antenna

- Radar bearings of single objects correspond with the optical bearings from the location of the antenna.

The vertical conformity is given, if e.g. approaching a bridge, the bridge is displayed with regard to antenna position and vertical radiation angle. In a certain distance the bridge disappears from the display and appears again after passage.

*Quality levels*

- 1 The angular accuracy for horizontal bearing is between 2 and 4 degree.
- 2 The angular accuracy for horizontal bearing is better than 2 degree. Effects because of the vertically limited opening angle are identifiable e.g. at passages of bridges.
- 3 Additionally to the mentioned requirements in item 1, effects due to the limited vertical opening angle, boundary conditions (angles, distances, etc.) and dynamically changing position of the ship (e.g. trim) are considered

*Test procedures*

Conformity “horizontal”: Comparison of optical and radar bearing of objects with a distance of at least 400 m.

Conformity “vertical”: Simulation of bridge passage with consideration of:

- The height of the antenna above the water surface at current draught,
- The radiation angle in accordance with the radar lobe and the trim of the ship,
- The height of the bridge between lower edge of the bridge and the water surface.

Further references for possible tests may result from the ETSI EN 302 194-1.

**b. Resolution**

Radial resolution means the distance between objects, from the point when two objects are displayed separately for the same bearing of radar antenna.

The azimuthal resolution depends amongst other things of the horizontal opening angle of the radar lobe and marks the angular distance from the point when two objects in the same distance to the radar antenna are display separately and not as a merged echo.

*Quality levels*

- 1 The resolution “radial” and “azimuthal” are roughly realised.
- 2 Additionally to the mentioned requirements in item 1, the resolution changes conformably to the distance.
- 3 The resolution “radial” and “azimuthal” correspond to the real representation of similar approved devices.

*Test procedures*

For reviewing the resolution, movable target objects can be shifted in the simulation.

Further references for possible tests may result from the ETSI EN 302 194-1.

**c. Shadowing**

The height of the radar antenna is essential for the “range of vision” of the radar as well as for shadowing due to objects. The position of the radar antenna on the ship defines the extent of vertically obstructed view and horizontal shadowing (blind spots), which arise from superstructures and / or cargo (e.g. container) of the ship. Dynamic motions of the ship (e.g. trim or heel) affect the shadowing.

*Quality levels*

- 1 The shadowing of nautically important objects is represented in a nearly proper way.
- 2 Shadowing corresponds to the trigonometric relations, but do not consider changes of the dynamic position of the ship.
- 3 Additionally to the mentioned requirements in item 2, the dynamic motions of the ship are considered.

*Test procedures*

The level of reality of the shadows on the radar screen can be easily tested by means of simulated constellations as illustrated in Fig. 2.2. Initially stationary objects can be positioned and moved in a simulation exercise, until the echoes step inside or outside a radar echo. In doing so, e.g. an abaft trim of a ship means an increase of the shadowing in front of the ship. Distance and azimuth can be taken from radar display and validated graphically/trigonometrically.

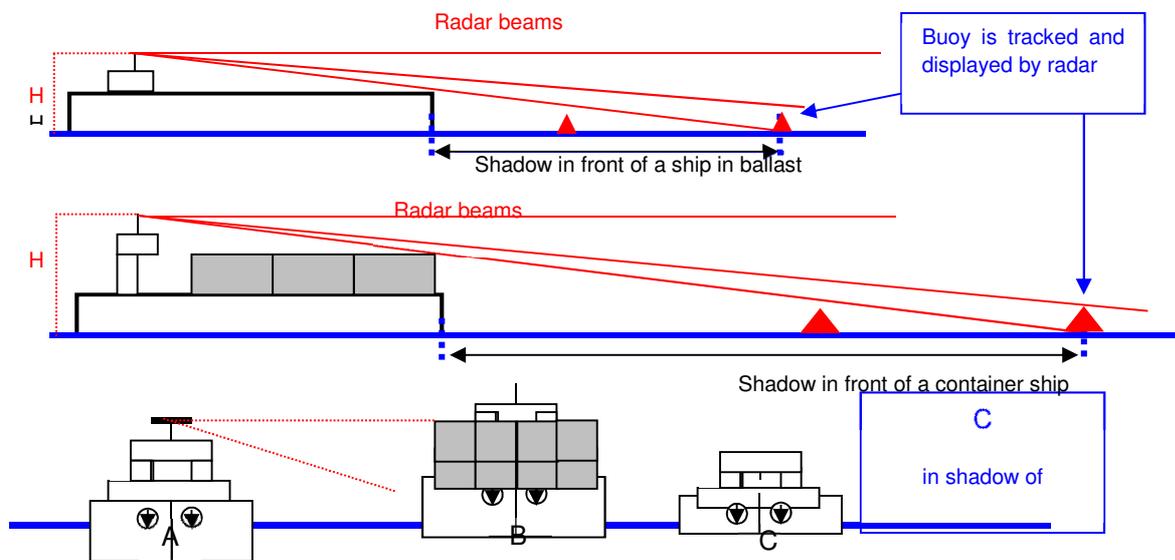


Fig. 2.2: Tests for vertical shadowing

**d. Noise echoes**

Echoes of waves or rainfall may impede or prevent the identification of nautically important objects.

Echoes caused by waves (sea clutter) primarily depend on the form of the water surface and are represented as luminous points on the radar screen. At the centre of the radar image the

concentration of the luminous points is very high and decreases radially. A very high concentration may lead to situations where echoes of other objects, e. g. buoys or ships are not any longer visible. Therefore radar devices have adjustable filter (seaclutter), which gradually suppress sea clutter effects. In case of an appropriate use of the filters important objects can be recognised more easily.

Echoes caused by rainfall primarily depend on the density of the rainfall and the size of the particles of the rainfall (e.g. raindrops). Because of this radar echoes in a high concentration and lighting intensity can occur, that nautically important objects are not any longer recognisable. Therefore radar devices have adjustable filter (rainclutter), which gradually suppress rain clutter effects. In case of an appropriate use of the filters important objects can be recognised more easily.

*Quality levels*

- 1 It is possible to switch filters on and off, the effect is recognisable.
- 2 It is possible to adjust filters, the effect is recognisable and nearly correct.
- 3 The adjustment of filters and their effect correspond to the magnitude of real approved devices.

*Test procedures*

An assessment is done by switching on and adjusting the filters.

Further references for possible tests may result from the ETSI EN 302 194-1.

**e. False echoes**

Besides noise echoes caused by rainfall and waves additional spurious echoes can occur which are denoted false echoes. This includes multiple echoes, external echoes and ghost echoes.

The reason for multiple echoes normally is a short distance in conjunction with intense reflections due to the surface structure or the position of the echo area of an identified object. With increasing distance to the echo area multiple echoes decrease or disappear completely.

External echoes of other unidentifiable radar sources or echo areas only occur sporadically for a short time.

*Quality levels*

- 1 False echoes are randomly generated.
- 2 The frequency of multiple echoes changes with the distance nearly correct.
- 3 Additionally to the mentioned requirements in item 2 it is possible to change the characteristics of reflections for selected objects (e.g. ships or bridges). Additionally the frequency of ghost echoes is adjustable.

*Test procedures*

Since ghost echoes and multiple echoes are unsteady events, no test procedures are able to review false echoes. The generation of false echoes should be documented by the manufacturer.

## 2.5 Databases

As already explained, the information stored in the Database is used during the simulation. The processing of this data is done dynamically, while the data itself is static. The data is the basis of the simulation. Important are the level of detail and information density. The required size of the databases is depending on the application.

Without substantial databases real-time simulations would not be possible. If applicable, databases need maintenance and updates. One obvious example is the electronic nautical chart (ENC): If, in reality a traffic sign is installed or removed and high reality of the ENC is claimed, the ENC in the simulator has to be corrected accordingly. Instead of such individual corrections it may be out-reaching to install at intervals newer versions.

Databases have to be seen in conjunction with the respective simulation processes or components which have been described in sections 2.3 and 2.4.

While the basic functionality of the simulator is determined by its software, databases can be modified and extended theoretically unlimited; this will be described in section 2.6.5. Depending on the implementation of the simulator databases can be modified by the owner, the manufacturer or a third party. Herefore appropriate software tools have to be available. These can be delivered by the manufacturer. Also conversion programs can be used to exchange data with third party software.

### 2.5.1 Databases for the calculation of ship dynamics

Two Databases are necessary for the simulations performed by the simulation core. The first holds the data describing the dynamics of the ships. The second holds data about the waters. The specific format and amount of data depend of the used mathematical model and the required accuracy.

#### 2.5.1.1 Ship database

There are several types of mathematical models describing ship dynamics, i.e. the forces acting on the ship.

In the prevalent coefficient model the forces are described by algebraic functions of the state variables and their derivatives. These functions contain ship specific coefficients. While the state variables are calculated steadily, the coefficients are constant. These coefficients are stored in the ship database. It can be very important for the user to be able to modify these coefficients or to add new sets of coefficients for new ships to the database. Common coefficient models describe particular force components (hull, propeller, rudder forces etc.) by separate functions, so that particular effects can be influenced by certain coefficients.

The coefficients can be obtained by model or full scale measurements, or by numerical computations (CFD). Furthermore approximation methods are available to calculate the coefficients for standard ships based on some general ship data.

Every ship is described for every load and equipment condition by a separate set of coefficients. The failure of a force generating ship component– assuming a corresponding functionality of the simulator – can be simulated by setting the corresponding force component to zero. Separate coefficient sets are not necessary herefore.

A different force model uses a huge database, in which the functional relation between state variables and forces is given by discrete values. The actual force values are calculated by interpolation in this data set. This data set is created for each ship using data from model tests or CFD-calculations. They usually cannot be modified by the user.

Since the specific implementation of the database can vary strongly, no general evaluation criterion can be defined. Decisive for a good quality of the simulation is that the simulator software generates a realistic simulation possible in conjunction with the data from the databases.

Conversely, an insufficient quality of the simulation, i.e. the simulated ship behavior deviates too much from reality, may originate from insufficient data in the ship database or from a basic shortcoming in the mathematical model.

As explained in section 2.3, in means of ship dynamics, the ship database can only be evaluated in combination with the mathematical model. Thus, a separate evaluation criterion for the ship database will not be given.

#### 2.5.1.2 Database for waters

The descriptions of the waters depend on the implementation of the particular simulator. In the simplest case the water is defined by a constant depth and the shoreline. On the other hand the bottom topography can be described very detailed. Additionally steady and unsteady flow fields and tidal bores can be defined. Especially for simulations in restricted waters these information is very important to achieve a realistic simulation.

The database may also comprise additional information about wind and weather conditions that influence the simulation.

In section 2.3.1 the influence of these conditions on the simulation has already been explained. Here quality criterions of these conditions and their provision are defined.

#### *Performance features*

- a. Water depth
- b. Current
- c. Tides
- d. Wind

#### **a. Water depth**

The flow around the ship is influenced by the water depth respectively the bottom topography. In general, with decreasing water depth the increasing obstruction reduces surge, drift and yaw motions. In order to consider this influence, the simulator has to provide the local water depth at the location of the vessel.

The most common type of location information in navigation is a map. In the simulator, an electronic nautical card (ENC) is used –other conceivable alternatives are not considered here because they are not standardized.

For the ENC, there is a worldwide recognized standard, which is used both in sea and inland shipping. The standard for inland shipping is called IENC and complements the standard for sea shipping to some specific attributes that affect only the IWT.

From this map, the simulator can take the information and boundary conditions at the location of the vessel in order to calculate the driving characteristics can.

Based on the IENC standard, there are three ways to display the depth of water:

#### Bottom areas

In the map some areas are identified as „Depth Area“. These areas have an attribute specifying the local water depth. This most simple way of description allows not representing natural bottom topography, since the water depth in the area is constant.

#### Bathymetric contours

These are polygons („Depth Contour“), i.e. horizontal cuts through the bottom topography at a constant depth. Typically, the simulator interpolates the depth a reference point from the neighboring contours.

#### Soundings

Soundings are single depth values given at certain locations. Using a large number of soundings, also complex bottom topography with scouring and shoals can be described very precisely. Again, the simulator must calculate the water depth used for calculation by interpolation.

The depth of water depth must always refer to a base level. For sea charts the base level is the mean sea level (MSL). Inland charts refer to local levels for canals or lakes. For Rivers with slope local reference levels are used, e.g. GIW (“Gleichwertiger Wasserstand”).

The bottom topography can be described independent of the navigational chart in any other form. Ultimately is crucial that the water depth is defined at each point in the simulation domain.

#### *Quality levels*

- 1 Only a constant water depth can be defined.
- 2 The water depth is determined by a few bottom surfaces, the resolution is coarse.
- 3 The bottom topography is described in detail by bathymetric contours and soundings or in any other form in a high resolution, as far as data is available.

#### *Test procedures*

Most commonly there is an instructor station, which has a view of the electronic chart and input options for local conditions. This can be the alternative used for testing purposes. The presence of display options of specific details (e.g. bathymetric contours), however, does not mean, that this information will actually be taken into account in the simulation. This can only be checked, by testing the shallow water effect.

The specifications or the manual provides information on whether and in what form water depth data can be defined.

The possibility to adjust the water depth at the instructor station is a strong hint, that the water depth is regarded in the simulation.

The display of bathymetric contours or soundings in the ECDIS (electronic chart display and information system), indicates that this information is used and the influence of restricted water depth is regarded in the simulation.

If it is possible to import the bottom topography from external data, it shows possibilities and limits on the resolution of the bottom topography.

## **b. Current**

In inland navigation most of the traffic is handled on rivers, where the Rhine has a particularly important significance because of the high traffic volume. It is characterized by variable flow, which runs approximately parallel to the direction of the flow axis. Due to the meandering areas with higher current velocities can be found at the outer curves and areas with lower current velocities at the inner curves.

The higher the water level the higher is current velocity. In harbour basins and canals the current velocity can be assumed to vanish. At the transition between harbour and river an complex inhomogeneous current field with unsteady vortices can be found.

For modelling of the flow several strategies are possible, the realism increase with the expense.

In the simplest case, only a steady homogeneous flow field can be defined. In this case the ship encounters only drift motion but no additional hydrodynamic forces. Homogeneous flow fields are only reasonable in lateral unrestricted waters.

An improvement for rivers is a flow field the is automatically aligned to the shorelines.

Meander effects can be realized by adding a velocity gradient to mean current velocity, representing the flow velocity at the outer curve.

Areas of stillwater in harbours and canals can be identified from the ENC-attributes.

The most detailed and precise information of the flow field can be given by vector field with a high spatial resolution. A 2D flow field can also be contained in the ENC. Defining a 3D flow field is only reasonable, if a highly sophisticated mathematical model of the simulator uses this information.

### *Quality levels*

- 1 Only a homogenous can be defined.
- 2 The current follows the river (shore lines) with a gradient corresponding to curvature of the river. In harbour basins and canals there is no current.
- 3 The current can be arbitrary defined by vector fields with a high resolution.

### *Test procedures*

First, the user manual shows, in which way currents can be defined. This can be tested using the simulator software. Similar to the water depth, the effect of current on the ship can only be tested by evaluating its motions while sailing in different current fields.

If the simulator can auto-generate current fields following the river, the generated field should be displayed at the instructor station. The effect of this current field on the motions of the ship should be evaluated.

If it is possible to import external flow data, this should be tested according to the descriptions in the manual.

Further is has to be tested, whether harbour regions are automatically detected and the current velocity vanishes there.

### c. Tides

Provision of tide information is mostly relevant for maritime simulators. But there are some waters with effective tides where inland vessels operate.

Tides are waves with a long period generated by the gravitational influence of the moon. At any earth bound location the tidal waves lead to an oscillating water level combined with a current. A Simulator must be able to handle changing water levels and currents to model tidal effects.

The local water depth that is calculated by the bottom topography and the mean water level is superimposed by the changing water level from the tidal wave, just as the local current is a superposition of the mean current with the tidal current.

The propagation of the tidal wave depends on the bottom topography. There are different ways to achieve a realistic representation of the tide. The superposition of the water level and the current with a sinusoidal tidal wave that follows the river (shore line) is a very simple approximation. A better way is to provide data of the time dependent water level and current velocity from a CFD calculation or measurement in a high spatial and temporal resolution. Modern computers provide enough computing power to perform real-time calculations of the propagation of tidal waves.

#### *Quality levels*

- 1 Water level and current velocity are modified continuously manually to approximate the effect of tide.
- 2 Tidal data is given in a coarse spatial and/or temporal resolution.
- 3 Tidal data is given in a fine spatial and/or temporal resolution or calculated in real time at any required point and time.

#### *Test procedures*

The manual gives information in which way tidal data is handled and how external data can be imported. There, also the possible spatial and temporal resolution is defined.

The effect of the tide on floating objects can be evaluated by simulating a preferable small floating object without any propulsion or other forces (e.g. from wind or ropes). There should be no mean current velocity, so that the object follows the tidal current (see 2.3.1e). By changing the time of day, it can be found whether the tidal current and water level a time dependent and realistic. The water level can be directly seen at the echo sounder, and can be recorded for a full day to be compared with measured or calculated data.

#### d. Wind

Usually wind is defined with a constant (mean) speed and direction in the whole simulation domain. In reality, the wind is unsteady in space and time, both in speed and direction. Especially strong gusts can have a substantial impact on the motions of a ship.

There are several ways to describe the wind. In the simplest way a constant wind speed and direction can be given. Inhomogeneous but invariant wind can be described by a vector field. Unsteady wind can be described by a directional spectrum. Also the definition of one or more local (moving) wind field(s) superpositioning the mean wind is possible.

In reality, the wind is influenced by objects like buildings, trees, embankment, mountains, other ship, etc. In the simulation the influence of objects on the wind, e.g. lee or venturi effect, can be calculated by the simulator or pre-calculated in the wind field given by the user (only for stationary objects and steady wind).

The definition of wind in the simulator is only useful, if the wind influence is regarded in the simulation of the ship dynamics.

##### *Quality levels*

- 1 Only a homogenous, steady wind field can be defined.
- 2 Fluctuations and wind fields can be defined.
- 3 Interaction between objects and wind is regarded in the simulation.

##### *Test procedures*

The manual gives information, in which way wind can be defined in the simulation. The simulator gives possibly a view of the (unsteady) wind field, e.g. as a vector plot in the chart view of the instructor.

If an anemometer is “installed” onboard the instrument on the bridge should display the actual wind speed and direction. The influence of different wind fields on the ship dynamics can be tested (see 2.3.1f).

The interaction between wind and objects can be tested by using the same wind field in different simulation domains or by using a homogenous wind field and passing different objects.

## 2.5.2 Visualization database

The 3D view uses the geometric and texture information from the visualization database. This database determines at which quality level the visualization is possible. Depending on the implementation the same visualization database can be used to calculate the radar image. But also a separate radar database can be used.

Objects can be distinguished between fixed or moveable objects.

### 2.5.2.1 Fixed objects

Fundamental to the positioning and involvement of all objects in the environment is the terrain model that is essential for a correct view of the land area. The surface can be covered with textures analogue to the typical use of the land (forest, field, settlement).

In order to increase the recognition value and establish a relationship to specific places or river-kilometres, prominent objects (e. g. selected buildings) are modelled very detailed. The surfaces of such buildings are textured with photographs of the real building.

For relevant nautical objects (especially traffic sings) correct position, shape and colour/texture are essentially. Some examples for crucial dimensions of fixed objects: the clearance profile of bridges, length and width of lock basins, length and height of quays.

Usually, for nautical relevant objects the critical attributes are taken from the ENC/IENC. From this charts the visual shore area can be taken (regarding the actual water level).

ENC/IENC contains all data necessary for navigation, especially:

- Water areas with and without currents
- Water depth (low tide for ENC, for IENC there are unfortunately no detailed depth data available but only an appropriate level corresponding to the maximum loaded draught)
- Land areas
- Buoyage
- Signage
- Kilometre markers
- Bridges (incl. clearance)
- Quay
- Significant buildings
- Water level at GLW over NHN
- Shore condition (sand, grass, quay, ...)

Additionally several objects and its attributes, which are not nautical relevant, can be included in the ENC/IENC. These objects help to improve the the realism of the display.

When generating the digital terrain model and its texturing and placement of fixed objects manufacturers of simulators back to different data sources in different formats. Also, there are different methods of data compilation.

For this reason, if the user is at all possible to edit the visualization database, no general performance features with respect to the structure of the database and possible edit methods are formulated. Only the quality of the display can be evaluated.

#### *Features*

- a. 2D/3D-modells
- b. Level of detail
- c. Day/night-models

### a. 2D/3D-Modelle

With the computing power available today it is basically always possible, to display three-dimensional models of the stationary objects. In very complex sceneries it might be necessary to reduce the level of detail for objects far away. One method of reducing the level of detail is to replace the 3D-model by a 2D surface.

#### Quality levels

- 1 All objects are represented by two-dimensional surfaces that are fixed in space and recognized as surfaces.
- 2 Near objects are represented by three-dimensional objects, Only objects far away are represented by two-dimensional surfaces, but they are automatically turned, so that they are facing to the observer.
- 3 2D replacements of objects are only allowed for objects far away and are not recognized.

#### *Test procedures*

While a ship is moving in the whole simulation area, that has to be validated, fixed objects are observed. It can be found, at which distance and in which way the level of detail is reduced and whether 2D-modells are used.

### b. Level of detail

Decisive for the quality of the visual representation of stationary objects is the level of detail, which refers to both the form as well as on the surface.

The shape of an object can be an approximation by a single geometric basic body in its simplest form. Thus, a high-rise building can be modelled with a single cuboid. On the other hand, the shape of an object in the most elaborate representation is modelled by numerous geometric elements. For example, a historic crane on the bank could be modelled with each rivet.

The same applies to the surfaces of objects. These can be monochrome in its simplest form, thus giving an abstract representation, while not looks realistic, but sufficient for some exercises. In the most elaborate form, the surfaces are designed photorealistic.

Deficiencies in the detailing of the form may be partially offset by textures with so-called. bump mapping. Thus, for example, a polyhedron can appear like a sphere.

#### Quality levels

- 1 A simple detail in shape and surface makes the objects recognized as such. Navigationally important objects are as such precisely identified.
- 2 A good level of detail can appear realistic objects, although simplifications are recognizable in shape and surface.
- 3 A very good level of detail makes the objects appear photorealistic.

#### *Test procedures*

The training area to be assessed will be loaded and an own-ship is set. It is first necessary to examine whether all navigationally important objects are precisely identified. Does the scenery at first glance

realistic, the quality level 2 is reached. Does the scene even after prolonged viewing and driving through realistic and can be identified hardly modelling artefacts that quality level 3 is reached.

### c. Day / night models

The data stored in the database layer models can basically be used in any lighting situation. With the onset of dusk and especially at night many different light sources appear in the real world. These are especially relevant when operating near to the banks and should be visible in nightly simulations due to their disturbance effects.

Navigational important fixed light sources, such as beacons, can even flash in a certain rhythm.

If no separate view model for darkness exists or can be created by the user, this feature is not available.

#### Quality levels

- 1 In the darkness, only the navigationally important objects are illuminated.
- 2 In the darkness, any object can be illuminated. Navigationally important light sources can emit light in a predetermined rhythm.
- 3 In addition No. 2 the illumination of any object can be switched during the simulation by the instructor. Relevant information is stored in the database.

#### *Test procedures*

The training area to be assessed will be loaded and an own-ship is set. The Simulation time is set to midnight. It is first necessary to examine whether all navigationally important objects are just as illuminated in the simulation like in reality. Furthermore it should examine whether other objects are illuminated. If the simulator software has this feature, the instructor switches the lighting of the intended items on and off.

#### 2.5.2.2 Moveable objects

In the first place vessels or other waterway vehicles as well as moveable objects are training relevant. The same applies to drifting objects.

Moveable objects are e.g. driftwood or lifebelts. In particular, lifebelts are relevant for the training when practicing emergency manoeuvres. Further, the training, how to avoid a collision with drifting tree trunks (driftwood) for example, can be relevant. If necessary, these objects are imported into an exercise (switchable).

Although land vehicles or aircraft and other moving objects outside the waterway can reinforce the impression of reality, they are however more likely to be classified as an animated simulation and are therefore not dealt with here.

Something different is the meaning, for example of flags or rotors of wind turbines. Provided that such elements would align at least after the wind in the simulation, the optical realism of the simulation would consequently deepen. Relevant to navigation would be at best a flag at the foremast of own ships, as it is located in the central field of vision and conclusions can be drawn about the wind direction. However, it may in particular be omitted if a wind indicator is set up at the helm.

Since the replication of wind effects on flags or rotors requires a special modeling and computing capacity, but is hardly training relevant, these animated elements can in principle be given up. Does the simulator not foresee that these elements orientate according to the wind, flags should not appear and wind turbines are presented only with rotors in the locked position.

Visual models of ships are usually created from the General Plan. With the help of the Master Plan, a 3-D model is generated which is then textured with pictures. The photos for texturing can be derived from similar ships. E.g. photos of ships can also be changed by appropriate image processing software, thus creating a new color scheme for the computer-generated ship.

As regards own ships, it should be noted that any additional viewpoints like cameras or wing stations have to be considered, allowing the view of surfaces and objects, which from the bridge or from the steering station perspective are in the obstructed field of vision.

*Performance features*

- a. 2D/3D models
- b. Degree of detail
- c. Setting of light and day signals
- d. Day/night models

**a. 2D/3D-models**

Also moveable objects can – similar to other objects – be outlined by a flat, two-dimensional surface. This procedure is valid for many drifting objects. It is appropriate when charting objects with symmetric rotation, e.g. buoys or tons.

Quality levels

- 1 Moveable objects are charted by a flat surface und can be identified as such during evasive manoeuvres.
- 2 Drifting objects are charted by a flat surface which always turns to that extent that the surface normal faces the observer.
- 3 Two-dimensional objects are only used in the background (large distance) so that they are hardly apparent. Otherwise 3D-models are taken.

*Test procedures*

The training area to be assessed is loaded and an “own ship” selected. The training area is completely ran; at the same time the available moveable objects are used, observed and evaluated to determine whether they have flat surfaces turning to the observer.

**b. Level of detail**

The level of detail as regards form and surface of drifting objects may vary to a large extent. The same applies as in section 2.5.2.1a.

Quality levels

- 1 A modest level of detail as to form and surface indicates the objects as such. Objects which are important for the navigation can be accurately identified.
- 2 In case of an improved level of detail realistic objects are presented, though forms and surfaces appear in a simplified way.
- 3 Photorealistic objects are shown upon a very good level of detail.

*Test procedures*

An „own ship“ runs within an arbitrarily selected operating area. Assessable drifting objects are used. If they appear in a realistic way at first sight, level 2 is met. If they appear in a realistic way after long observation and navigating around without detecting significant modelling artefacts, level 3 is fulfilled.

**c. Setting of light and day signals**

It applies to all vessels that navigation lights, light signals, signal posts and other day's signals defined by applicable rules (e. g. RheinSchUO) shall be maintained. As to simulation this means that these lights and characters are stored in a library and can be assigned to ships (for example switchable) or that ships are saved several times with different signal or guide lights.

*Quality level*

- 1 Ships can be assigned to all relevant constellations of lights and signals. Depending on the required configuration own view model of the vessel shall be used.
- 2 The light and signal routing can be switched individually, i.e. all the lights and signals are separately stored in the database and are positioned according to the requirements of real ships.
- 3 In addition to 2 the light positions exactly correspond to the modelled ship.

*Test procedures*

In close proximity to a traffic ship an own ship is used in any training area. As far as possible, the instructor sets all kinds of daily signals and traffic lights aboard the traffic ship. If the simulator allows, a second own ship is used instead of the traffic ship. On the second own ship all kinds of light and day signals are also set. At the steering station of the first own ship it will be checked which light and day signals are visible on both foreign ships.

**d. Day-/ Night models**

All visual models stored in the database can basically be used regardless of the lighting scenario. With the onset of dusk and especially at night there is the possibility to switch on light sources at the drifting objects. Those light sources might even flash in a certain rhythm (flashing, blinking).

As long as there is no specific visual model available for darkness or produced by the user, this characteristic is missing.

*Quality levels*

- 1 Drifting object may have light sources at night.
- 2 Light sources can flash in a certain rhythm.
- 3 In addition to 2 the instructor can switch on and off light sources during simulation. The database contains according information.

Test procedures

An „own ship“ navigates within an arbitrarily selected operating area. Simulation time is set to 24:00 h. All assessable drifting objects are used. As far as possible, the instructor switches on all available light sources installed at the objects.

2.5.3 Radar database

As described in chapter 2.4.3, the radar device can only display pictures which are continuously produced by the simulation. The radar antenna placement towards surrounding objects and terrain is used to calculate the radar display. Their characteristics regarding radar radiation (reflectivity, absorption, distribution) are stored in a database.

Ship handling simulators usually resort to the visualization database; but the geographic position and the attributes of the individual objects may be derived from ECDIS and other databases. An additional database can also contain radar characteristics of the objects and terrain models.

Key element is that visualization and radar databases store terrain models as well as form, size, direction, reflection characteristics und position of the individual objects in 3D format. Direction and position of moveable objects result from simulation process.

Therefore, statements given on visualization also apply to radar simulation.

*Performance features*

- a. Radar reflectivity
- b. False echoes caused by waves
- c. False echoes caused by precipitation (e.g. rainfall)

**a. Radar reflectivity**

Appropriate characteristics should be considered, as in practice design (e.g. open or closed construction) surface structure and surface material (e.g. wood or steel) influence the attributes of an object with respect to radar reflectivity.

A quite similar problem deals with traffic signs (e.g. buoys and beacons) having radar marks. They should appear earlier in the display than objects identical in construction without marks.

The display shows objects even more clearly, which are equipped with “Racon” (racons, transponder). The database should for that reason assign the characteristic “Racon” those objects according to ECDIS. Racon does only refer to inland vessels on maritime waterways.

*Quality levels*

- 1 Form and size determine reflecting characteristics.
- 2 Reflecting properties consider at least one additional factor (design structure, surface structure, material).
- 3 The reflecting characteristics can be adjusted individually regarding objects with nautical reference.

*Test procedures*

The description of the system or the operating manual of the manufacturer, respectively, describe the extent, to which the reflecting properties have to be considered as attributes of objects and how to trigger or modify them.

**b. False echoes caused by waves**

As chapter 2.4.3d shows, waves appear above a certain form and height on the radar display. As far as waves are not calculated, respective patterns of waves and water surface should be stored in the database.

*Quality levels*

- 1 False echoes are stored as a set of uniform, dimensionally stable objects.
- 2 False echoes are stored for typical wave patterns also covering the range of sea state levels.
- 3 In order to display false echoes caused by waves as a result of wind direction and strength, characteristics are also stored.

*Test procedures*

The radar display showing a simulation with respect to the framework conditions wind (strength and direction) and/or level of sea state and direction with a differing adjustment degree will be observed. In case the object density raises dependent on wind force or level of sea state, level 1 is reached. Strong wind force or sea states ensure that small objects will not or only scarcely be displayed and if at all only by applying a seaclutter filter.

If false echoes have an arrangement typical for noise echoes, level 2 is implemented.

If, in addition to 2, the arrangement of the false echoes aligns according to wind and sea state direction, level 3 is implemented.

**c. False echoes caused by precipitation (e.g. rainfall)**

Similar to waves likewise precipitation effects, the sight system also has access on, can be stored in a database.

*Quality levels*

- 1 False echoes are stored with variable and adjustable density in quantities of uniform and dimensionally stable objects or uniform impulses, respectively.
- 2 In addition to 1, attributes as to particle size and/or their impulse intensity as single echo (among others representative for the kind of precipitation) are considered.

- 3 Characteristics of spreading are stored, i.e. precipitation fields can be defined.

#### *Test procedures*

The radar display showing a simulation with respect to intensity, kind and spreading of precipitation with a differing adjustment degree will be observed. It will be checked whether it is possible to at least activate precipitation (level 1) and to vary their intensity (level 2). If precipitation patches and their distribution can be defined, level 3 is reached.

At high precipitation density and further dependent on the adjustment of conditions “precipitation” small objects do not or only scarcely appear on the display or at all when using the rainclutter filter. Areas of precipitation can be identified. When entering a field of precipitation, the radar conditions get worse by false echoes resulting from precipitation.

#### 2.5.4 Audio database

Noises appearing during simulation are stored in a database. Usually short sound pieces (samples) are stored. They can be put together to achieve longer noises which are played during simulation. As to noises that are often used during simulation attention has to be paid to proper boundaries. However, these noises should slightly differ to avoid a synthetic character.

Chapter 2.4.2 already dealt with the quality of noises and the sound reproduction. Noises or sounds stored in the audio database can only be evaluated, if the database has a relevant interface. In general this step can be neglected, as the samples are played directly in a few cases only. Usually the simulator adjusts all samples during simulation to the given situation (for example distance und direction of sound source towards the bridge).

For this reason, assessment criteria for the audio database are missing.

Objects and operating areas can be modified or added; consequently this should also apply to the respective noises or sounds.

## 2.6 Further features

Apart from interfaces with external data or processes, the following aspects rather focus on functional aspects like chart and language settings, the possibility to train different manoeuvres on a simulator in parallel, to store and to replay them. Only, weather conditions could influence a simulation.

### 2.6.1 Weather Conditions

The database can store stationary wind fields together with the training area; however in case of non-stationary wind fields the simulator will continuously calculate them during simulation. Nearly the same applies to the water surface. It can appear in a non-disturbed condition or the waves are small enough, respectively, not having any impact on the vessels. As soon as there are higher waves affecting the vessels, the simulator has to continuously calculate them.

### 2.6.1.1 Waves

Rough sea or heavy waves are significant to inland navigation only occasionally. They should however be considered in case there are trainings on large open inland waters, like the Lake Constance, or coastal waters (i.e. with a seagoing inland vessel). Usually, rough seas occur when waves with different length and direction overlay. A specified wave spectrum reflects the energy distribution of rough seas, also helping to deduce the wave heights of the individual wave components. With the help of the wave scale according to Petersen the total power of the sea state can be determined. For simulators with simulation of the sea state the strength of the rough sea should be adjustable.

Heavy seas cause ship motions in all 6 degrees of freedom; above all pitching, rolling and heaving motions can be noticed. To simulate the impacts of the sea state, the simulator has to manage at least 4 degrees of freedom, for the complete consideration however, all 6 degrees of freedom. To achieve a realistic simulation, it is important that the vessel moves compatibly to the given sea state and that those motions are displayed by the visualization system, even though the coupling of wave and manoeuvring forces and -moments is negligible for most ship types.

#### *Quality levels*

- 1 Sea state and wave direction can be adjusted; the ship does not move or according to the sea state.
- 2 Sea state and wave direction can be adjusted; the ship moves realistically.
- 3 Sea state can be defined by a two-dimensional spectrum; the ship moves realistically.

#### *Test procedures*

Though the provision of environmental conditions for the simulation is the predominant task, the test procedures also revert to the visualization system, as this is the best way to demonstrate the impacts of the sea state.

Like all details referring to the fairway, also here the operating manual and the steering console should be looked at to identify all options the simulator offers as regards this feature. It is necessary to see whether it is feasible to enter the sea state force.

Consecutively, all sea state forces and wave directions are adjusted to observe how the “own ship” behaves in heavy seas. Simultaneously, also the speed varies.

### 2.6.1.2 Precipitation

Weather conditions do not really matter for the simulation of a ship’s trip. Restrictions of view caused by mist, fog, rain, hail or snow do not influence the motion behaviour, but the activities of the trainee. In addition, precipitations are disturbing the radar display.

It might also happen that the wind (force and direction) is changed during the simulation. Depending on the characteristics of the “own ship”, the wind may impact the motion behaviour (cf. 2.3.1 ff).

The simulator should have various adjustment options for weather conditions regardless of realizations by the visualization system. The visibility distance or attributes like light, medium or heavy may describe the fog. Fog patches represent a helpful support. Comparable to wind fields they allow for locally limited changes of the visibility conditions. When entering a fog patch (the same applies to the manual change of the global visibility) it should be kept in mind that the intensity of the fog does

not change abruptly but gradually over a certain time period. The intensity of rainfalls should be adjusted the same way. Wind force and –direction should determine the fall direction of precipitation.

Some weather conditions like rain or hail are associated with noise (cf. 2.4.2). An appropriate noise background will emphasize the impression of reality on the simulator. Also the wind produces noises.

Weather conditions are usually based on given recallable settings; some simulators therefore allow for the adjustment of this database. Consequently, the modification of available and/or the production of certain new weather specifications covering specific training areas are feasible.

#### *Quality levels*

- 1 Only weather conditions restricting visibility can be adjusted (e.g. mist, fog or smoke).
- 2 In addition to 1, precipitations can be adjusted.
- 3 All weather conditions (restriction of visibility, precipitation, lightning, cloud formation) are available resulting in a coherent picture.

#### *Test procedures*

In order to verify the results of the weather adjustments, an “own ship” with sight system is needed.

The operating manual advises the instructor how to set which weather conditions at the console. All weather conditions are set consecutively. The idea is to analyse the way they appear (sight system, audio system, radar system) and whether there is an abrupt or continuous transition between the weather conditions.

### 2.6.2 Chart display

ENC/IENC can be applied at two different locations of the simulator which may differ considerably:

Bridges of inland vessels are usually equipped with normal ECDIS-devices of different manufacturers. The steering station of a simulator however should have systems of the same kind, which are fed with virtual data from the simulation. The display of the charts on the bridges thus corresponds to real practice.

- **Instructor console:** It is necessary for the instructor to follow the simulation on a chart. Preferably it is the same ENC /IENC, but even compatible or similar charts can be used. However, this console has more functionalities than the normal ECDIS has. They comprise various interactive options to be able to place or influence objects within the simulation environment. Trajectories of ships, measurement instruments as well as other functionalities are further additional display possibilities within the chart, which enable or facilitate the handling of the simulator or the control of an exercise.

#### *Quality levels*

- 1 Chart options are rather limited.
- 2 ECDIS has all standard functionalities and simulator can be managed with available chart options.
- 3 ECDIS has complete functionalities and operating options are comprehensive and comfortable.

*Test procedures*

A familiar area is chosen to start an exercise; it will be checked – possibly by direct comparison with an original device – whether the functionalities of the ECDIS act in accordance with the standard. Moreover, it will be checked, whether all functionalities, necessary to control a simulation, are available at least within the chart display at the instructor console.

2.6.3 Operational modes

2.6.3.1 Measuring units

The units usually used in inland waterway navigation differ from those used in maritime navigation. A Simulator that is not only intended for use in inland water navigation should be able to switch the units according to the simulation exercise.

*Quality levels*

- 1 The simulator uses maritime units (NM, kn).
- 2 The simulator uses units for European inland waterway navigation (km, km/h).
- 3 The simulator uses varying units according to the exercise and the simulation region.

*Test procedure*

Different exercises on varying exercise areas (inland water, sea) are started. The displayed units are evaluated.

2.6.3.2 Language options

As the English language is internationally used within maritime navigation; for that reason the operating instructions of nearly all simulators for maritime vessels are in English. This also covers the inscriptions of screens as well as the drafting of operating manuals.

Within inland waterways (especially addressing the river Rhine) however, several languages are commonly used like German, Dutch or French. When extending the operating area further to the east, additional languages have to be considered.

Local language options mainly refer to the labelling of instruments as well as texts on different screens on the bridge or the trainee stations.

Usually, instructors can easily operate a simulator with English inscriptions and also trainees in most cases have no difficulties to handle for example radar stations with English labels.

*Quality levels*

- 1 Only one language chosen by the manufacturer is available.
- 2 The language of the user is available
- 3 At least 2 different languages for displays and devices can be chosen.

*Test procedures*

Operating manuals, operating console and instruments show which language option is valid for the respective simulator.

### 2.6.3.3 Quantity of exercises running in parallel

In case of several bridges it has to be clarified whether all trainees can simultaneously practice within a common scenario or whether technical features of the simulator allow for the parallel running of different exercises. The last-mentioned offers the possibility to carry out different courses in parallel.

#### *Quality levels*

##### a. Quantity of exercises

- 1 Only one exercise can run at one time. All own ships (trainees) belong to the same exercise.
- 2 The maximum amount of different exercises running in parallel is smaller than the number of steering stations. Some own ships running in the same simulation.
- 3 The maximum amount of different exercises running in parallel is not smaller than the number of steering stations. Each own ship can run its own simulation.

##### b. Quantity of own ships

- 1 Only one own ship can run in the same simulation.
- 2 The maximum amount of own ships in one simulation is smaller than the amount of steering stations.
- 3 The maximum amount of own ships in one simulation is not smaller than the amount of steering stations. All steering stations can run the same exercise.

#### *Test procedures*

The operating manual of the manufacturer or the performance description give information on the number of exercises which can be carried out simultaneously and independently. A test run will verify the potential number of exercises running in parallel.

### 2.6.4 Storage data and replay

Usually, the simulator is used to train specific navigating and traffic situations. As human interaction is a key component, individual simulations can hardly be reproduced. Therefore, simulations have to be recorded for the purpose of a subsequent analysis to detect and outline possible manoeuvring errors.

#### *Performance features*

- a. Storage of simulation values
- b. Recording of crew's behaviour
- c. Replay at a debriefing station
- d. Replay with the entire simulator
- e. Restart a simulation
- f. Analysis possibilities and export of data
- g. Storage

**a. Storage of simulation values**

Simulation values mean all data, entering the simulator ( e.g. position of lever and switches) or being calculated during simulation (ship position, ship speed, forces, displayed data of bridge equipment, radar displays).

Data quantity (or set of simulation values) which is stored, can be adjusted to the requirements. In case of simple training internal simulation values need not be stored. Only those data should be saved which ensure that the steering station is in the same condition like during simulation. As regards special manoeuvres (towing, anchoring, encountering) additional data have to be recorded which are not displayed at the steering station. They help to better understand the training procedure subsequently. This refers to rope and hydrodynamic forces.

If a simulation shall be replayed up to a certain stage, to restart it there, all data have to be saved.

*Quality levels*

- 1 Simulation recorded only as documents or snapshots
- 2 Storage of all simulation values which are necessary for a restart of the simulation
- 3 All simulation values are saved.

*Test procedures*

The terms of reference or the manual provides information which, if any simulation values can be stored. To check a simulation is started and the storage carried out, either before or when you exit the simulation according to the instructions. According to the manual simulation is reloaded. It will determine whether and which data are available for individual or any timing.

**b. Recording of the crew’s behaviour**

The core task of a SHS is to train the crew behaviour when navigating a ship and to improve it with the help of an error analysis.

Apart from storing the handling of the bridge devices the voice recording is significant. They encompass both discussions at the steering station as well as conversations by voice radio or telephone with other ships or stations ashore. Occasionally, it helps to film the behaviour of the skipper.

It is also possible to adjust the recording of the crew behaviour to the requirements. In particular, if only in one own ship boat sails in the simulation and no instructor acts as voice remote, a voice recording can be waived. However, as soon as there act more own ships in the simulation or the voice radio conversation is simulated with other transport users or sites ashore, a voice recording is important.

*Quality levels*

- 1 Voice communications can be recorded.
- 2 In addition to 1 conversations at the steering station can be recorded.
- 3 In addition to 2 the situation on the bridge is filmed.

*Test procedures*

The terms of reference or the manual provides information on whether and which conversations on the bridge are recorded, if necessary they can be recorded by video. When checking, make sure that the record is synchronized with the other simulation values.

**c. Replay at a debriefing station**

To evaluate a simulation in a debriefing it should be possible to replay them on the debriefing station in a compact form. The presentation can possibly be made visible with a projector for all participants. Basis of presentation is the map with a freely selectable cutout. For this purpose, it should be possible to superimpose (position of control levers, rudder angle) selected simulation values.

The simulation should – also in time lapse – be fast forward and rewind, so that individual behaviour can be analysed in detail. It should be possible to set bookmarks and run a replay from and up to any (bookmarked) stages.

*Quality levels*

- 1 Replay of the simulation is limited to the map display.
- 2 Replay of the simulation is limited to the chart and radar display.
- 3 As 2, in addition arbitrary values can be displayed.

*Test procedures*

The terms of reference or the manual provides information about whether and by what options replay on a steering station is possible. To check a saved simulation is loaded on the steering station and displays the radar picture of one or more ships as far as possible. Any simulation values are displayed – if possible – to the extent possible.

**d. Replay with the entire simulator**

When analysing trainings with important devices of one or more participating steering stations, it is advantageous to reproduce the stored simulation with all components of the simulator. The simulator then behaves just like during the simulation, except that he does not accept entries that would alter the course of the simulation. All presentations and properties match the stored simulation, as well as any noise. Only operating levers that have no drive will not be provided. The simulation can be rewind, even in fast motion as often as required.

*Quality levels*

- 1 A replay with the entire simulator is only possible as a radar view / ECDIS.
- 2 A replay with the entire simulator is possible.
- 3 In addition to the requirements referred to in number 2 all instruments have a drive and put themselves in the position that they had during the simulation.

*Test procedures*

The terms of reference or the manual provides information about whether and by what options a replay with the entire simulator of a workstation is possible. To check a saved simulation is loaded and

reproduced with the entire simulator. It can be found here, which systems (visual, audio, radar, instruments) will be used during replay.

**e. Restart of a simulation**

If a reproduction with the entire simulator is possible, the replay can be stopped at any point. The simulator can be switched to the simulation mode from this state of replay. That way, difficult situations can be repeatedly trained and learned from mistakes. If an old simulation will continue as an alternative a new simulation arises, which can be stored separately again.

An ongoing simulation could be stopped at any time and be rewound at an earlier date. You can then re-started during operation.

*Quality levels*

- 1 Resumption of a stored simulation is possible in the sense of a continuation. It is generated no alternative simulation, but the old continues.
- 2 Resumption at the starting point or at another time of a saved simulation is possible. It is generated no alternative simulation, but the old continues.
- 3 A running simulation can be stopped any number of times, rewound and restarted. Each time you start, an alternative simulation is stored.

*Test procedures*

The terms of reference or the manual provides information about whether and by what options a resumption of a saved simulation is possible. To check the performance is to follow the instructions in the manual.

**f. Analysis options and data export**

For the analysis, it may be necessary to look at the time recording of selected simulation values. Either the simulator manufacturer provides a suitable analytical tool for this purpose or there is the possibility to export selected time recordings in order to analyse them with another program.

The export of data to a free or commonly accepted data format (CSV, Open Document, Excel) is preferable, because at the time of purchase not all required analysis functions are known or they may change in the course of use.

As far as an analysis tool is provided with the simulator, time recordings of selected simulation values should be displayed, printed and exported as a graphics file. Also, the navigation chart should be presented within the presentation of ship's positions or webs.

*Quality levels*

- 1 Presentation or export remains with the manufacturer.
- 2 A display of time recordings is possible.
- 3 An export of all data is possible

*Test procedures*

The terms of reference or the manual provides information on whether and what data can be exported from stored simulations. To check the performance is to follow the instructions in the manual. Thereafter, the exported data are to be controlled.

**g. Storage**

If simulations have to be saved for examination purposes for example, it is necessary that the simulation data will be stored project-related.

Depending on the operational environment, it may be necessary that the access to stored simulations is limited to specific users.

The simulation data should be backed-up on an external storage device. The technical realization of the backup should be freely selectable to match with an existing IT infrastructure.

*Quality levels*

- 1 Storage is possible only by paper printout.
- 2 Storage is only possible within the simulator system.
- 3 Storage can be done on external data carriers.

*Test procedures*

The terms of reference or the manual provides information on whether and in what form the archiving of stored simulations is possible.

**2.6.5 Interfaces**

Even if the simulator is supplied as a complete system with all the required features, it may be of great importance that data between the own and other simulators can be exchanged.

So time and cost for their creation can be saved by transferring vessels, objects or exercise areas. The transmissions of recorded simulation runs allow a further utilization independent of device or location.

If data can be imported into a database, this data may come from different sources. They can be taken from other simulators or from third parties. In any case, the data must be available in the appropriate format or be converted into. These conversion programs are not necessarily included in the delivery.

The exchange of static data (e.g. of ship models, terrain models, flow data) can be carried out quite easily. Far more difficult is the exchange of dynamic data, i.e. the data exchange during the running simulation.

The ability to exchange data is not the sole property of the own simulator, but results from the combination of the two simulators involved. Even if the simulator is basically capable for an exchange of data, it may be that different software versions could prevent a data exchange between simulators of the same manufacturer and the same type. Furthermore, licensing rights are to be observed if necessary.

In the end, the evaluation of the interface must be performed individually for each combination of the two simulators involved.

#### *Performance features*

- a. Exchange of ship models
- b. Exchange of digital terrain models
- c. Exchange of training areas
- d. Exchange of flow data
- e. Exchange of tide data
- f. Transfer of recorded simulation runs
- g. Coupling with external calculation methods
- h. Coupling with other simulators
- i. Audio Data

#### **a. Exchange of ship models**

Ship models consist of the view model that is used for presentation, the mathematical model that is used for the simulation of the ship dynamics, and other information (e.g. definition of engine noise).

To replace the vision model is crucial that the same data format for the geometry model and the textures will be used or that a conversion is possible. Unless the same geometry model is used and a conversion programme is missing, at least the data formats must be documented. Modelling errors may occur during a conversion when the geometry entities of a format cannot be accurately mapped to the other. According to today's state of the art however no major deviations are to be expected. It must also be proved in each case whether a geometry model to be imported for the simulator is too complex (e.g. number of polygons, size and number of textures).

If both simulators use the same mathematical model, only the model parameters have to be exchanged. Otherwise, the model of a simulator needs to be converted into a form as equivalent as possible for the other simulator. To this end, both mathematical models must be documented. The more similar the two models used are, the lower is the number of transmission errors. If both models are parameter models, the transferability is usually very good. Also parameter interpolation models allow for a good transmission into each other. During transfer from one to another interpolation model the size of the data space plays a crucial role.

Once the modelling of the ship – even partially – is carried out by real-time CFD methods, a transmission is extremely difficult.

Export and import are not necessarily of the same design. There are good reasons for manufacturers of simulators to allow the import of ship models and to prevent the export. This may be regulated differently for different ships.

##### *a.1) Quality levels*

- 1 An exchange of ship models is possible only by the manufacturer.

- 2 Ship models can be exchanged in theory. Available data formats are documented, but not compatible.
- 3 Ship models can be exchanged. The data formats are compatible, possibly by using existing conversion software.

*a.2) Levels of licensing*

- 1 An exchange of ship models is possible only by the manufacturer.
- 2 Ship models can be imported.
- 3 In addition to number 2, ship models may (at least of other manufacturers) be exported.

*Test procedures*

The terms of reference or the manual provides information on whether and in what form ship models may be imported and exported.

**b. Exchange of digital terrain models**

The terrain models include geometry data and textures that are used in the visualization system. For the exchange is crucial that the same data format for the geometry model and the textures will be used or that a conversion is possible. Also an exchange of individual geometry models like buildings, bridges, may be important.

As terrain models are just one part of the exercise areas, the exchange opportunities will be determined by the software that is used to create the training areas. If any exercise areas can be created and edited by the user, it is however part of the delivery of the simulator.

Geometry models are used in many technical fields. Therefore, there is a large number of programmes for modelling, and in most cases a software can be found to convert the available data formats.

If the simulator is not using a common file format and also no conversion software is included, it is necessary to fully document the data format so that appropriate software can be created subsequently.

*b.1) Quality levels*

- 1 An exchange of ship models is possible only by the manufacturer.
- 2 Ship models can be exchanged in theory. Available data formats are documented, but not compatible.
- 3 Terrain models can be exchanged. The data formats are compatible, possibly by using existing conversion software.

*b.2) Levels of licensing*

- 1 An exchange of terrain models is possible only by the manufacturer.
- 2 Terrain models can be imported.
- 3 In addition to number 2, terrain models may (at least of other manufacturers) be exported.

*Test procedures*

The terms of reference or the manual provides information on whether and in what form terrain models may be imported and exported.

**c. Exchange of training areas**

The essential component of an exercise area is the description of the navigable water areas of the ship. This is often done by electronic charts (ENC / IENC). Furthermore, a terrain model can belong to the training area. The electronic chart can be supplemented by detailed bottom topography and a detailed flow field. Only all time-invariant objects belong to exercise area; the exchange of flow data is outlined below.

The simple exchange of training areas is generally possible only between simulators of one manufacturer. This concerns very large amounts of data, which often spread over a large number of files and database entries. If there is no support for the exchange of entire exercise areas by the manufacturer, a detailed documentation of the complete data structure is necessary so that an own software can be created for the exchange.

*c.1) Quality levels*

- 1 An exchange of training areas is possible only by the manufacturer.
- 2 Training areas can be exchanged in theory. Available data formats are documented, but not compatible.
- 3 Training areas can be exchanged. The data formats are compatible, possibly by using existing conversion software.

*c.2) Levels of licensing*

- 1 An exchange of training areas is possible only by the manufacturer.
- 2 Training areas can only be imported.
- 3 In addition to number 2, training areas may (at least of other manufacturers) be exported.

*Test procedures*

The terms of reference or the manual provides information on whether and in what form training areas may be imported and exported.

**d. Exchange of flow data**

Detailed flow data can complement the training area and lead to a much more realistic simulation. Flow data can be obtained from numerical simulations or from field measurements. They are provided in many different data formats. As a rule, a conversion program will have to be used to customize the specific data format to its own simulator. It is therefore necessary that the data format is well documented.

The export of flow data is hardly necessary, as they are not often delivered by the simulator manufacturers, but usually represent external data.

*d.1) Quality levels*

- 1 An exchange of flow data is possible only by the manufacturer.
- 2 Flow data can be exchanged in theory. Available data formats are documented, but not compatible.
- 3 Flow data can be exchanged. The data formats are compatible, possibly by using existing conversion software.

*d.2) Levels of licensing*

- 1 An exchange of flow data is possible only by the manufacturer.
- 2 Flow data can only be imported.
- 3 In addition to number 2, flow data may (at least of other manufacturers) be exported.

*Test procedures*

The terms of reference or the manual provides information on whether and in what form flow data may be imported and exported.

**e. Exchange of tide data**

In the end, tide models represent an extension of the data flow. Tide currents are transient, i.e. cyclically with the period of the lunar orbit. Simultaneously, the static water level changes periodically with the flow. As regards large areas the static water level will turn into a (long) tidal wave, i.e. time-dependent static water levels and flow velocities are specified by the tide model across the flow area or at discrete points.

The underlying data structures and the flow data are manufacturer-specific. A specific program, which can be supplied by the manufacturer for a documented data format, is required for the import.

If the tide model has a different data format, a separate conversion programme must be created. Some simulators have integrated interpolation models to calculate the tide flow for which very few data points suffice. When exchanging tide models, the characteristics of the stored tide models must be considered.

Exporting tide data is hardly necessary, as they are rarely delivered by the simulator manufacturer, but usually represent external data.

*Quality levels*

- 1 An exchange of tide models is possible only by the manufacturer.
- 2 Tide models can be exchanged in theory. Available data formats are documented, but not compatible.
- 3 Tide models can be exchanged. The data formats are compatible, possibly by using existing conversion software.

*Test procedures*

The terms of reference or the manual provides information on whether and in what form tide models may be imported and exported.

#### **f. Transfer of recorded simulation runs**

If several separate simulators are available, it can be very useful to transfer recorded simulation runs from one simulator to another. In this way, for example the originally used simulator can be used for further simulations, while a second analyses the recorded simulation runs. An analysis of a simulation run can also be performed without simulator (cf. 2.6.4f).

##### *Quality levels*

- 1 An exchange of recorded simulation runs is possible only by the manufacturer.
- 2 Recorded simulation runs can be exchanged in theory. Available data formats are documented, but not compatible. Software for data conversion has to be created.
- 3 Recorded simulation runs can be exchanged. The data formats are compatible, possibly by using existing conversion software.

##### *Test procedures*

The terms of reference or the manual provides information on whether and in what form recorded simulation runs may be imported and exported.

#### **g. Coupling with external calculation methods**

Much more complex than the exchange of static data is the dynamic coupling of the simulator with external calculation method. As a result, parts of the simulator calculations can be supplemented or replaced. This can lead to a much more accurate and consequently more realistic simulation.

As prerequisite, the simulator has to provide a software interface that can communicate with external processes. The external calculation method must be able to communicate with this simulator interface and it must work strictly synchronously with the simulator. Furthermore, the external calculation method has to use the same database as the simulator.

The complexity of the interface depends on the complexity of the external calculation methods. With simple external calculations for instance additional forces can be implemented into the simulation of the own ship. This may be necessary to simulate force-effects, which have not been considered in the simulator (e.g. sloshing forces), or mathematical force models in the simulator are replaced by more accurate ones. Other method of calculation could help to realize for example special control algorithms for traffic ships.

Real-time CFD methods belong to the most complex calculation methods. They require high computing power and partly a powerful data interface. When using CFD method to only calculate the ship dynamics, an interface to the sumlator core is obligatory. If in addition the free surface is calculated, an interface to the visualization system is also necessary.

The specific requirements for the interface depend on the external calculation methods the simulator is to be linked to.

##### *Quality levels*

- 1 Customer-specific interfaces to external processes can only be implemented by the manufacturer.
- 2 The simulator has interfaces to external processes.

- 3 Interfaces of the simulator can be adjusted.

*Test procedures*

The terms of reference or the manual provides information on whether and in what form a coupling with external calculating methods is feasible.

**h. Coupling with other simulators**

For very large simulations if, for example the number of steering stations in a simulator is not sufficient, but also for other reasons it may be necessary to control the participating own ships from different (spatially separated) locations. For this purpose, simulators must be coupled in the simulation mode, so that all have the same simulation carried out synchronously.

The standard IEEE1516 (High Level Architecture) already sets the required techniques. Depending on the simulators used also proprietary techniques can however be used.

The coupling must ensure that the data transfer rate between all participating simulators permits for a synchronous real-time operation. All simulators must use the same training areas.

The same environmental conditions (weather, sea passage, tide, etc.) should prevail in the simulation. The environmental conditions within a training area may vary from location to location, i.e. a ship can even ride in a rain front in a simulator, while another ship in another simulator runs without rain in the same training area.

It is not necessary that the mathematical models and calculation methods of own ships are identical, as the own vessels of one simulator appear as traffic ships in the other simulators.

The visual presentation of both the terrain model and the vessels should be identical.

A communication (e.g. voice radio) between the simulators must be possible.

*Quality levels*

- 1 Customer-specific interfaces to other simulators can only be implemented by the manufacturer.
- 2 The simulator has an interface to other simulators of the same manufacturer.
- 3 There is a general interfaces to other simulators according to IEEE1516, MIL-STD or other international standards.

*Test procedures*

The terms of reference or the manual provides information on whether and in what form a coupling with other simulators is feasible.

**i. Audio data**

The need to exchange audio files is usually connected with the exchange of other simulation objects that generate noise. Also, it may be necessary to exchange audio data, if the quality of existing noises is not satisfactory.

The format of the audio data can vary significantly from manufacturer to manufacturer. However, a variety of programmes are available, with which audio data can be processed in any known format.

#### *Quality levels*

- 1 Only the manufacturer can exchange audio data.
- 2 Audio data can be exchanged in theory. Available data formats are documented, but not compatible.
- 3 Audio data can be exchanged. The data formats are compatible, possibly by using existing conversion software.

#### *Test procedures*

The terms of reference or the manual provides information on whether and in what form audio data can be exchanged.

## **2.7 Testing and Certification**

### **Tests**

Each performance criteria / feature mentioned under above chapter “2 Technical sections of ship handling simulation” can be checked by the specific tests. The tests described herein allow per performance feature to identify / check the level of performance (low, medium or high).

As tests concern different technical areas (hydrodynamic, computing, visualization etc.), at least some tests need specific technical knowledge. Of particular importance and complexity are tests to check the behaviour of ships in confined (shallow and / or narrow) waters and related hydrodynamic interactions.

For this reason and to achieve sound comparability between different SHS products, ideally reference cases should be defined. These reference cases – consisting of the same “own-ship (s)” and the same “test area” under same sailing conditions (current, wind etc.) – would ease a sound approach to tests. This vision was widely approved upon discussions with SHS suppliers. Such reference cases are the basis for a future certification process. In the following sections some hydrodynamic basics concerning manoeuvring are described. All this has to be regarded when setting up reference cases.

### **Certification**

As SHS can be considered as a rather complex technical tool, certification should be based on technical audits that are appropriate and comparable. This can be achieved if audits are carried out according to approved audit-procedures and competent auditors.

Amongst other aspects and definitions of such audits, it would be preferable to define a least one or more “own-ship(s)” for the purpose of technical audits. Ideally it would be the same ships to be used upon “practical test / examination (stf1)”. Also types of waterway stretches covering relevant “typical waterway-difficulties” (confinement, curves, aircraft etc.) for such examinations should be defined as one or more “fictitious test area(s)”. Alternatively a minimum choice of reproduced “real existing stretches” could be defined as compulsory elements of SHS databank.

In the case of SHS is likely to be used for training and examination of KSS – knowledge of specific situations (Streckenkunde), the reproduction of relevant “real existing waterway stretches (km)” could be an additional element of certification.

Once competent authorities want publish a technical standard for inland SHS, the issue “SHS Certification” may become relevant.

### 2.7.1 Common definitions

Within this section following ship-fixed coordinates are used. The x-y-plane coincides with the plane of the waterline. The x-axis is defined positive towards ship’s bow, y-axis is positive to port side and z-axis upwards. The origin is located in the centre line plane, amidships between the perpendiculars.

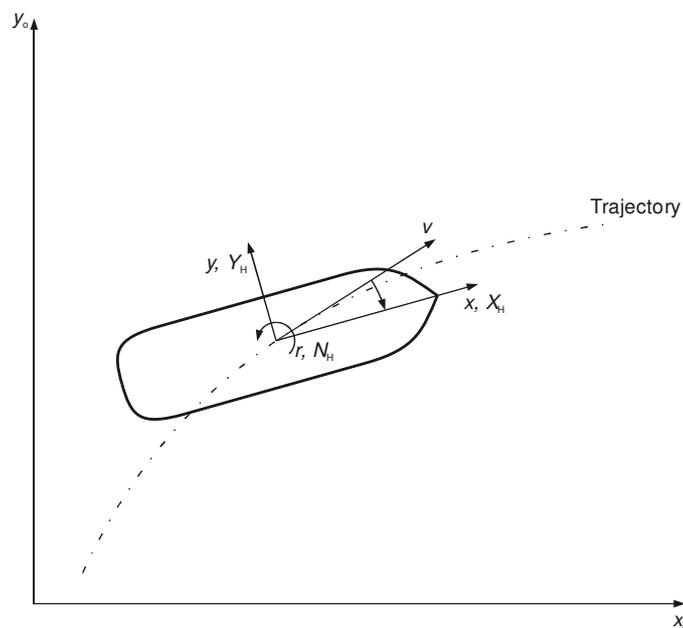


Fig. 2.3: Used coordinates: ship-fixed coordinates  $x, y, z$ , surge and sway forces  $X_H$  and  $Y_H$ , yawing moment  $N_H$ , trajectory velocity  $v$  and rate of turn  $r$  from [4]

In earth-fixed coordinates the origin of the ship-fixed coordinates is defined by  $(x_0, y_0, z_0)$ . In a non-operating state the earth-fixed coordinate system coincides with the ship-fixed coordinates (see Fig. 2.3 **Fehler! Verweisquelle konnte nicht gefunden werden.**). The position of the ship in earth-fixed coordinates can be defined by the angles  $(\varphi, \theta, \psi)$ .

### 2.7.2 Basic equations of driving dynamics

The driving dynamics of ships are based on the equations of motions (principles of linear and angular momentum) of a rigid body:

$$m \cdot \ddot{\vec{x}}_0 = \sum \vec{F}_0$$

$$\frac{d(I_0 \cdot \bar{\omega}_0)}{dt} = \sum \bar{M}_0$$

$m$  is ship's mass,  $\ddot{\bar{x}}_0$  the translational acceleration vector,  $\bar{F}_0$  the vector of external forces,  $I_0$  the mass moment of inertia of the ship in earth-fixed coordinates,  $\bar{\omega}_0$  the rotatory velocity vector and  $\bar{M}_0$  the vector of external moments.

For solving the equations of motion external forces and moments are needed (see [4]). These are hydrodynamic and aerodynamic forces and moments acting on ship's hull and the appendages, as well as additional external influences. If the external forces and moments are known, accelerations can be determined. A detailed description of the equations of motion is given in [1].

Integrating the above equations twice leads to the motions of the ship. For this purpose different numerical methods are used. In the simplest case the integration in time is a two-step process: Accelerations are integrated first, which leads to the current velocities. These are integrated afterwards, resulting in the position of the ship in earth-fixed coordinates. Particular situations (e.g. towing operation) may lead to stiff differential equations. In this case the accuracy of the numerical solution is significantly enhanced by solving the dual integration in a single step. In case of a dynamic interaction of different ships, the system of equations should contain the description of all ships.

The above statements apply in general for the motion simulation of solid bodies. The key element for the accuracy of the simulation is the accuracy of the external forces and moments acting on the ship.

The nowadays used mathematical force models for the simulation of ship manoeuvres can be divided mainly into two types: On the one hand so-called regression models are used, in which forces and moments acting on the ship are approximated by modified Taylor series for the kinematic and geometric quantities. On the other hand modular simulation algorithms are used, in which forces on ship's hull and the appendages as well as additional external influences are considered in separate modules. A presentation of the different force models is given by Oltmann et al. [3].

There is no fundamental difference in quality between both approaches. As long as the database is prepared carefully, both models provide the same accuracy. Setting up an adequate database requires model tests, full scale trials or CFD calculations.

### 2.7.3 Dynamic characteristics of ships

Driving dynamics of ships are essentially defined by following characteristics:

- Propulsion characteristics sailing straight ahead
- Dynamic trim and sinkage
- Starting ability: Longitudinal acceleration from a standing position
- Stopping ability: Distance and time until standstill
- Initial turning ability: Ability to initiate ship's turning
- Course-changing ability: Ability to decelerate and change direction of ship's turning
- Turning ability: Achievable rotation rate, turning radius

- Interactions in confined water
- Dynamic positioning

The individual characteristics, as listed above, have to be tested for different loading conditions (also liquid cargo) and environmental conditions (confined water, wind, current, etc.). The underlying mathematical model has to be capable to represent such manoeuvres. Tests are mainly performed by means of standard manoeuvres, whereas often with a single manoeuvre several characteristics can be obtained simultaneously. Dynamic positioning is a capability, which is especially important in offshore technology, but has very little meaning in inland shipping.

For a more in-depth analysis of the driving dynamics, the above outlined two-part test procedure is proposed.

#### 2.7.4 Assessment of the mathematical model

For reviewing the manufacturer of the simulator has to submit a document, which contains a description of the used mathematical model. The mathematical model has to be analytically checked for completeness. This means to verify, if all forces and moments acting on the ship are considered in the modelling. Dynamic properties of a ship, as mentioned above, should be represented sufficiently precise. The manufacturer has to give details about the type of ships, which can be represented by the ship handling simulator. Actually the concept for the mathematical model should be independent of type of ship and ship size. Basis for modelling should be the non-linear equations of motions for rigid body motion in six degrees of freedom (s. 2.7.4).

Models for the representation of interactions between hull, propulsion and control devices as well as confined waters and cargo displacement have to be described. Especially interactions with the ground topography are of vital importance. Most studies on the manoeuvrability of ships and consequentially developed force models refer to deep water conditions.

Furthermore the manufacturer has to state the way from raw data (model test or full scale trials) to data for the database. Additionally internal validation procedures should be outlined. Thus the simulation quality can be estimated for additional ships, which are not tested explicitly. Each manufacturer is of course free to choose reference data for validation of his simulator.

#### 2.7.5 Validation

For internal validation by the manufacturer as well as validation of particular ships by the operator, following standard manoeuvres, as described below, can be used. As a reference, model tests and full scale trials as well as possibly CFD calculations can be used.

Certain results from full scale trials are as a rule normally available for seagoing ships. These refer to sea trials, which on the one hand serve as review for the ship performance, as provided in the contract between customer and shipyard and on the other hand for the preparation of a standardized (IMO) documentation of handling and manoeuvring characteristics (for deep water conditions). This document belongs to the obligatory equipment of every seagoing vessel. If necessary, appropriate model tests are carried out in the design stage of a new building.

For inland waterway vessels only the compliance of prescribed regulatory minimum requirements with regard to some driving and manoeuvring characteristics has to be proved.

This means for the validation of inland waterway vessels, that normally no data of full scale measurements or model tests is available in advance, but these tests have to be planned and performed for confined conditions. The extent of full scale measurements is possibly limited, due to the circumstances of the waterways in the area of application. In these cases a combination of full scale and model tests is possible.

Several tests as described below are standard manoeuvres for seagoing vessel and are generally not (yet) performed for inland waterway vessels. Hence no comparative values are available, which could be given as illustration of the range.

For validation the maximum deviation of the reference values between full scale and the values of the simulation is generally compared for the relevant simulation values. Thereby a given limit (e.g. 10%) must not be exceeded. It is conceivable to define different quality levels with different limits.

While model tests can be performed in very controlled conditions, a certain uncertainty for extrapolation to full scale exists. Many of the acting forces and moments during ship manoeuvres depend on the Reynolds number. Additionally restrictions of the towing tank may lead to limitations of the model test.

Full scale measurements do not include scale effects, but it is not possible to exactly determine all boundary conditions in natural waters.

If the database is obtained by CFD calculations, there is still a degree of uncertainty, which is defined by the used numerical methods.

Validations should include different water depths and all relevant loading conditions. For cargo ships ballast and design draught are suggested.

For assessment of accuracy of the simulation following described manoeuvring simulations have to be performed. The associated reference data has to be determined with greatest care by analysis of full scale or model test. Finally the reference data is obtained by the same manoeuvres as the database for the simulation (e.g. set of coefficients).

#### 2.7.5.1 Sailing ahead in confined waters

In confined water, especially in confined water depth, the ship shows a significantly different driving behaviour than in deep water, even without any steering manoeuvre. Ship resistance at constant ship velocity increases significantly with decreasing water depth and also dynamic sinkage and trim are changing. Sidewise restrictions lead to an additional increase of the mentioned effects in narrow channels.

The test described as follows is not a particular manoeuvre, but the repetition of the usual propulsion test or the trial run in shallow water.

The ship or a towed unit is gradually accelerated from a standing position to service speed or mandatory speed. The single steps of velocity are always kept until a constant velocity is achieved. Within one step, the breadth and depth of the water must not be changed. The time curve of distance,

velocity over ground, trim angle and sinkage in relation to stationary position are determined and compared to the reference measurement. The simulation has to be performed for three different ratios of draught to water depth ( $T/h < 0.1$  (deep water),  $T/h \approx 0.5$  und  $T/h \approx 0.8$ ) under ballast and design draught.

**Note:** It is to be expected, that model tests performed at DST do not show a significant influence of the water depth on the propulsion characteristics up to an value of  $T/h \approx 0.3$ . Above this value the influence increases, until a value above  $T/h > 0.6$  means, that the achievable velocity in shallow water is significantly lower than in deep water for the same engine power Fig. 2.1 shows an example for the loss of speed in dependence of the ratio of draught and water depth. On the other hand the dynamic behaviour of trim is rarely influenced by the ratio  $T/h$ . In fact it is a function of the Froude depth number  $Fr_h$ . (see Fig. 2.2).

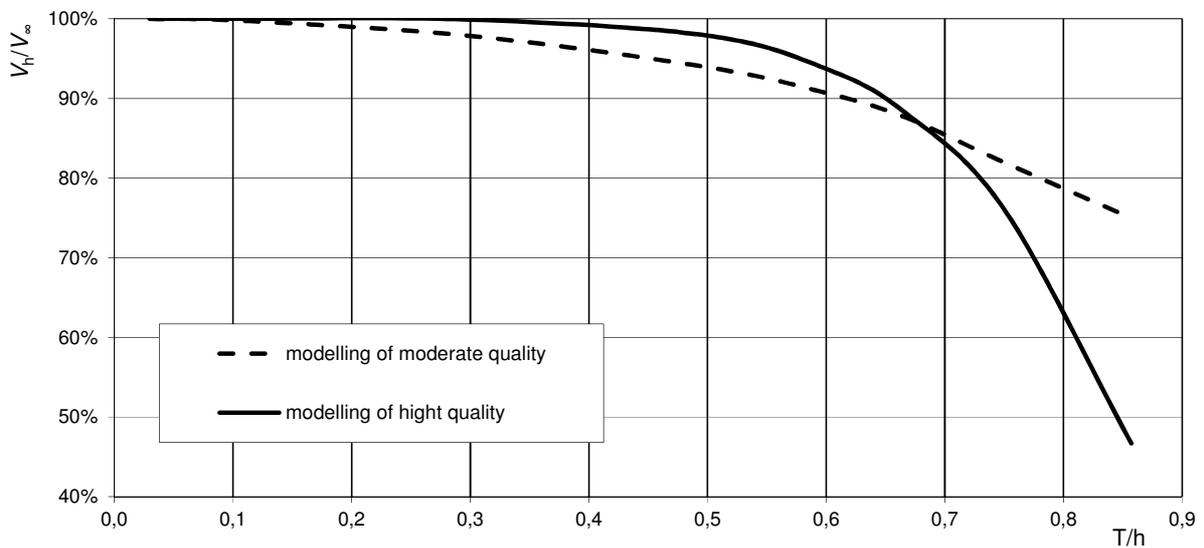


Fig. 2.1: Example of loss of speed for different ratios of draught to water depth

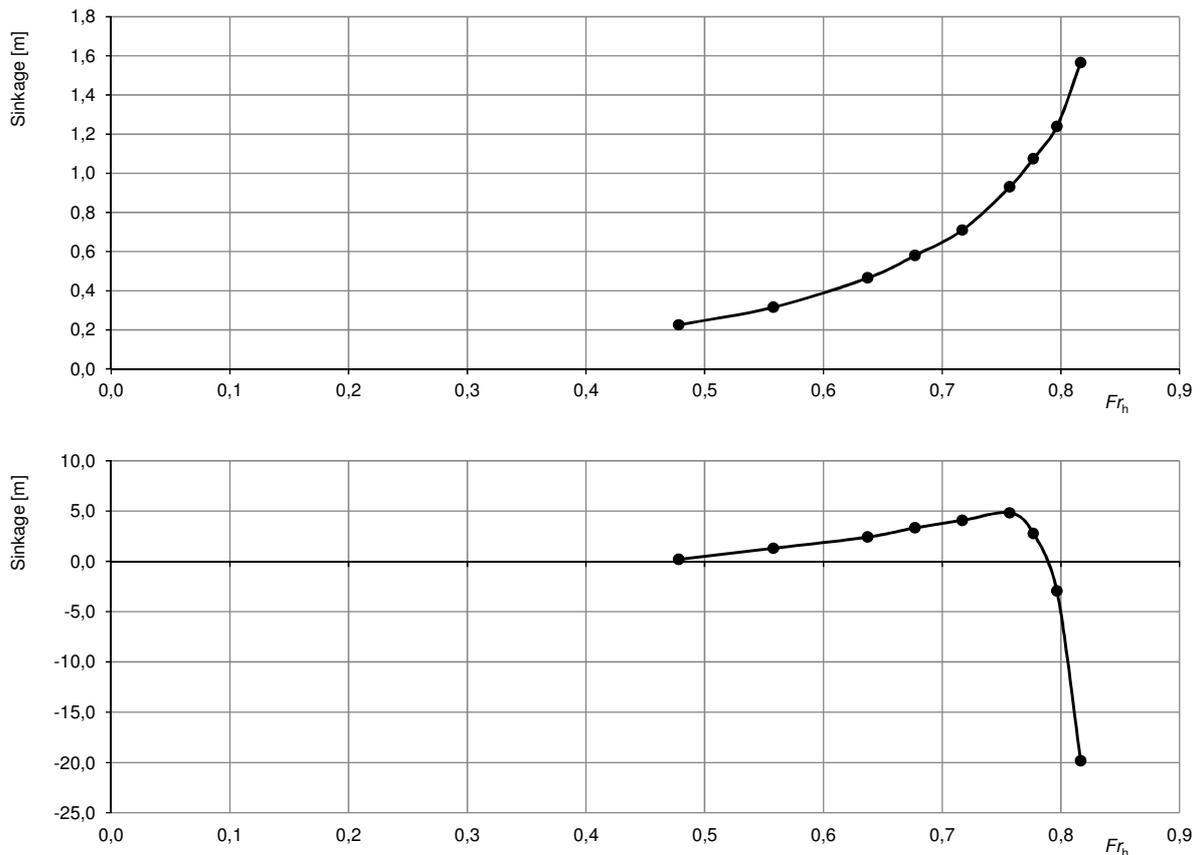


Fig. 2.2: Example of course of sinkage and trim as a function of the Froude depth number

### 2.7.5.2 Stopping trial

The stopping trial serves for testing the stopping ability of the ship. During sailing straight ahead at constant service speed or mandatory speed the engine is reversed (in case of fixed pitched propeller the engine is stopped and reversed as fast as possible, in case of a controllable pitch propeller, reversing is done by changing the pitch). Control devices are adjusted, so that the ship is sailing on a straight course before the manoeuvre. The simulation is finished, when the ship has stopped. The advance and the stopping time are calculated. The simulation has to be performed for three different ratios of draught to water depth ( $T/h < 0.1$  (deep water),  $T/h \approx 0.5$  and  $T/h \approx 0.8$ ) under two different loading conditions (e.g. ballast and design draught).

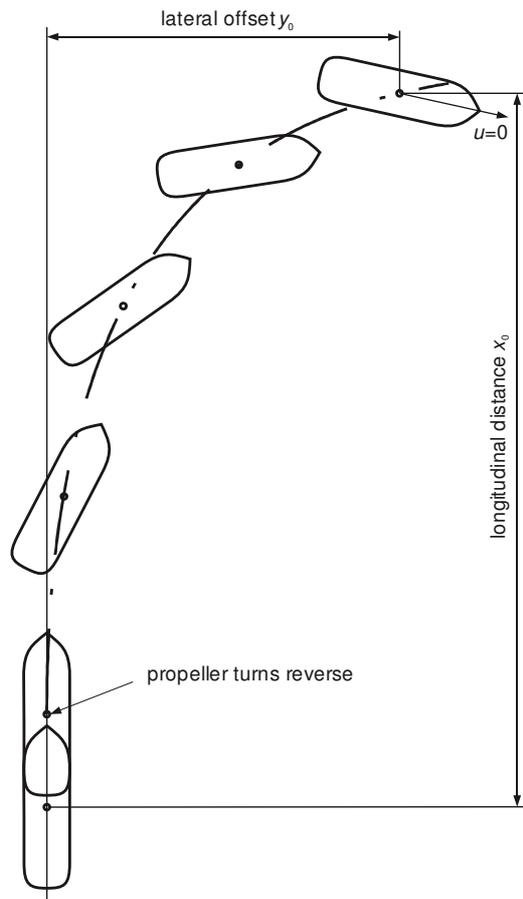


Fig. 2.3: Stopping trial: transfer  $y_0$ , advance  $x_0$  from [1]

Note: For many ships the advance is in the range of about three ship lengths. The transfer is normally not measured for inland waterway vessels; hence no orientation values are available.

### 2.7.5.3 Z-manoevre

During sailing straight ahead at constant service speed or mandatory speed, helm is put to an angle  $-\delta$  (to starboard) and kept constant until the course angle is  $+\psi$ . Then helm is put to  $+\delta$  and kept constant until the course angle is  $-\psi$ . The angle combinations of  $\delta$  and  $\psi$  which are to be tested are  $10^\circ/10^\circ$ ,  $20^\circ/20^\circ$  and  $20^\circ/10^\circ$ . As a result the initial turning time, time to check yaw, overshoot angle and the rudder speed have to be calculated. The simulation has to be performed for three different ratios of draught to water depth ( $T/h < 0.1$  (deep water),  $T/h \approx 0.5$  und  $T/h \approx 0.8$ ) under two different loading conditions (e.g. ballast and design draught).

The Z-manoevre is performed to test the initial turning and the course-changing ability of a ship.

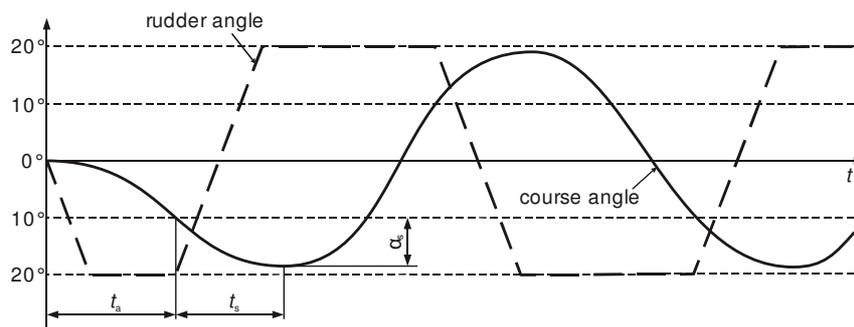


Fig. 2.4: Z-manoeuvre for 20°/10°: initial turning time  $t_a$ , time to check starboard yaw  $t_s$ , starboard overshoot angle  $\alpha_s$  from [1]

Note: Normally, for inland waterway vessels, instead of the z-manoeuvre, the theoretically equivalent R-manoeuvre is performed. Hence for the Z-manoeuvre no orientation values are available.

#### 2.7.5.4 R-manoeuvre

In inland waterway shipping the R-manoeuvre (instead of the Z-manoeuvre) is preferred. During sailing straight ahead at constant service speed or mandatory speed, helm is put to an angle  $-\delta$  (to starboard) and kept constant until the yaw rate is  $+\dot{\psi}$ . Then helm is put to  $+\delta$  and kept constant until the yaw rate is  $-\dot{\psi}$ . The combinations of  $\delta$  and  $\dot{\psi}$ , which are to be tested are 20/6, 20/8 and 30/8. As a result the initial turning time, time to check yaw, overshoot angle and the rudder speed have to be calculated. The simulation has to be performed for three different ratios of draught to water depth ( $T/h < 0.1$  (deep water),  $T/h \approx 0.5$  und  $T/h \approx 0.8$ ) under two different loading conditions (e.g. ballast and design draught).

The R-manoeuvre is also suitable for testing the initial turning and the course-changing ability of a ship.

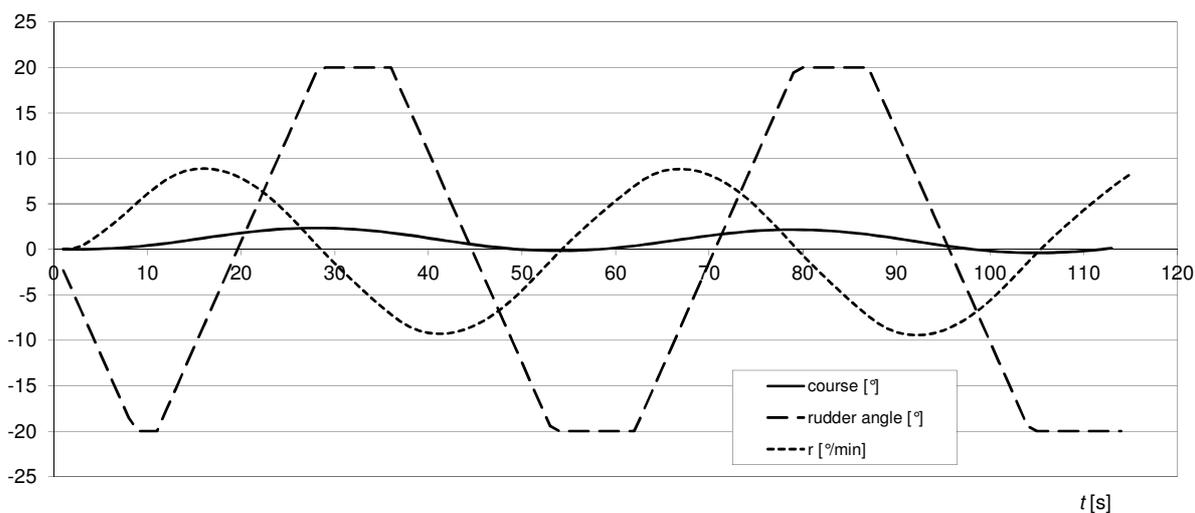


Fig. 2.5: Time history of a simulated R-manoeuvre for 20°/8°

**Note:** In the RheinSchUO requirements for ship's characteristics in emergency turns are given as well as procedures for assessing the rudder effectiveness are described and minimum values are presented.

### 2.7.5.5 Turning circle test

During sailing straight ahead with constant service speed or mandatory speed, helm is put to an angle of  $60^\circ$  within a time of 30 seconds in case of an inland waterway vessel and to an angle of  $35^\circ$  within a time of 15 seconds for seagoing vessels. The rudder is kept constant until the ship turned  $540^\circ$ . As a result the tactical diameter, the advance at  $90^\circ$  change of heading, the transfer at  $90^\circ$  change of heading as well as ship's forward speed and turning rate have to be calculated. The simulation has to be performed for three different ratios of draught to water depth ( $T/h < 0.1$  (deep water),  $T/h \approx 0.5$  und  $T/h \approx 0.8$ ) under two different loading conditions (e.g. ballast and design draught).

It is often not possible to perform a turning circle test completely, due to the limited dimensions of the towing tanks or the waterways. Then the validation is done by using a segment of the circle.

The turning circle test is performed to test the turning ability of a ship.

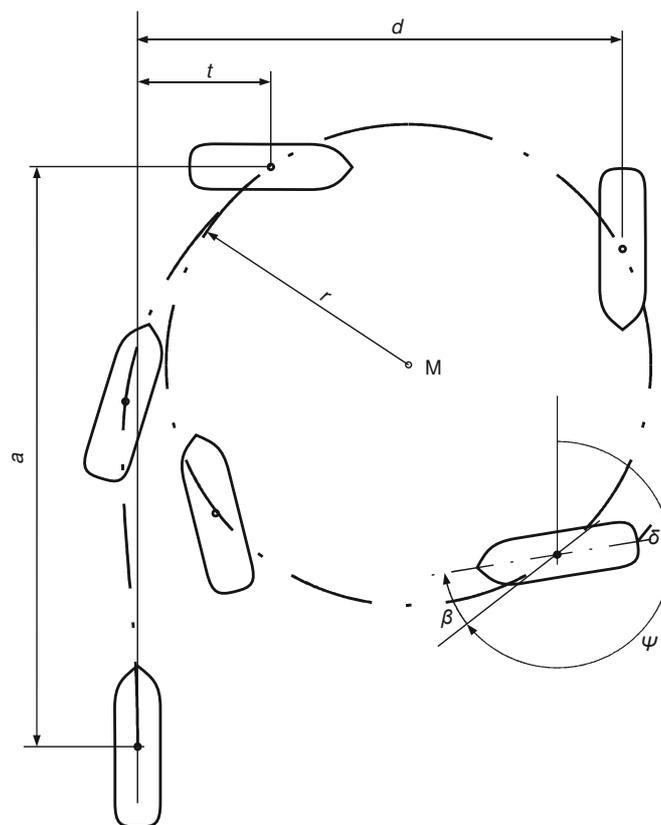


Fig. 2.6: Turning circle test: Advance at  $90^\circ$  change of heading;  $t$  Transfer at  $90^\circ$  change of heading;  $d$  Tactical diameter at  $180^\circ$  change of heading;  $r$  Stationary turning radius;  $\beta$  Drift angle;  $\Psi$  Course angle;  $\delta$  Rudder angle from [1]

Note: Due to the circumstances on inland waterways, it is not possible to carry out turning circle tests with inland waterway vessels. Thus no orientation values exist.

#### 2.7.5.6 Banking-Effects

The influence of a limited water depth on the propulsion characteristics and the dynamic floating position of a ship are increased by an additional sidewise confinement. Furthermore, a ship operating in close vicinity to the bank experiences additional drift forces and yaw moments. A quantitative validation requires data from corresponding model tests or full scale measurements. This kind of tests is usually not performed regularly within the scope of ship development.

In a test the ship or the ship model is sailing with neutral rudder angle and 70% of service speed or mandatory speed in a channel with constant water depth. Then the distance to the bank is gradually decreased, based on the centre of the channel. The lateral forces and yaw moments, acting on ship's hull lead to a deviation of the originally intended course in direction of the channel. The measured course can be compared to the simulation. Tests and simulations should be performed for three different ratios of draught to water depth ( $T/h < 0.1$  (deep water),  $T/h \approx 0.5$  und  $T/h \approx 0.8$ ) under two different loading conditions (e.g. ballast and design draught).

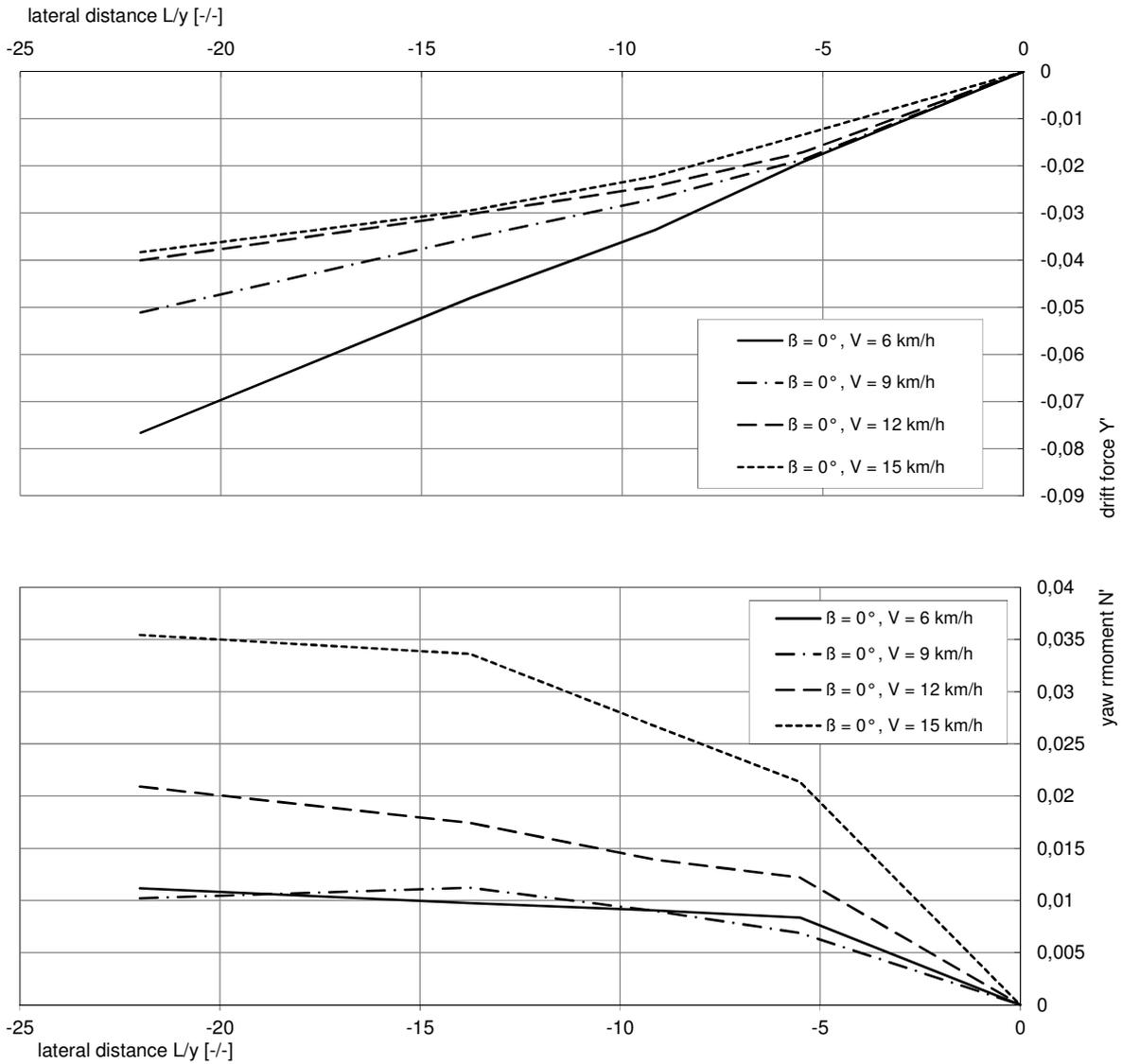


Fig. 2.7: Influence of the wall distance on drift force and yaw moment as an example of an inland waterway vessel

### 3 QUALITY REQUIREMENTS

Ship handling simulators are used for different purposes. Some typical applications are:

*Education at a basic level* – the training is focused on steering of a ship without other traffic participants.

*Education on an advanced level* – the ship is navigating in traffic in compliance with traffic rules.

*Knowledge of specific situations (KSS)* – navigation in specific situations is trained and the special characteristics of waterway stretches are learned.

*Radar navigation* – navigating in traffic in compliance with traffic rules only by radar is trained. The special status of radar navigation is reflected in the current legal expression, which provides its own radar patent.

*Patent examination* – special exercises according to the examination regulations are performed and evaluated.

*Individual advanced training* – special aspects (e.g. fuel-saving driving) of inland navigation are trained.

Apart from professional education such as training and examination, there are other purposes of use for I-SHS, such as investigations for infrastructure projects, ship development, investigation on accidents, occupational medicine etc. Such purposes might be taken into consideration upon purchase of a SHS, but have not been taken into account upon defining the I-SHS Standard (chapter 3.1).

All these applications impose different requirements on the equipment and its quality. For example, for the training of pure steering at a low level, there is no need, that the simulator can handle traffic ships. For radar training, a visualization system is not necessary respectively its quality does not matter.

Basically the quality requirement for the whole simulator can be defined by a set of minimum quality level required for each technical feature described in chapter 2. Following the idea, that different applications require different quality levels, for each application a set of minimum quality levels could be defined.

There are good reasons not to do so. First of all, for many technical features (especially concerning dynamic behaviour of the ship, see. 2.3.1) there is no economic advantage in reducing the quality level. Limitations of a simulator that are accepted at the moment of investment could perhaps later not be corrected when the need for other applications arises.

Furthermore, even for basic education the dynamic behaviour of the ship and the equipment for the control station should be realistic enough, to be accepted as reality. The proband should ever experience the most realistic dynamic behaviour of the ship, otherwise wrong behaviour patterns are learned. Using a simulator for education should not reduce the quality in comparison to learning on board.

When the simulator is used for patent examinations, it has to fulfil all the requirements of the examination regulations. These should be the highest requirements, since the examination in a

simulator should not fall behind the examination on board in means of quality. It seems not reasonable to have a simulator that is used for education and thus for preparation for the patent examination, while the simulator would not qualify for examination.

So far each technical feature the minimum quality level will be defined that fits to the demand of all applications. That does not mean that for every technical feature the highest quality level (3) is necessary. For several features the highest quality level, that can be realized, is higher than necessary.

### 3.1 Standard expressed as quality level of relevant technical features

As mentioned under §1 introduction the technical standard described hereafter has been defined according the scope of use as mentioned within one EC document and two CCNR documents.

#### a) EC document: “table of professional competencies navigation”

Concerning the use of SHS these documents can be summarized as follows:

- For a large range of competencies SHS is considered as a suitable method to demonstrate competence of skipper at operation and management level
- Reference is made only to “approved SHS”.
- The range of inland waterways including those with a maritime character
- Waterways or stretches thereof have not be specified or named, however for the use of SHS upon checking the competence “local knowledge” (Streckenkunde) is mentioned as “approved simulator, where appropriate”

This document will be finalised within “Platina II” as a proposal to be submitted to Member States.

#### b) CCNR document: “stf15\_10, practical examination”

A practical test/examination – either on board a ship or on a SHS – shall make it possible to check the fitness of a candidate to skipper a vessel under normal “sail conditions” and to cope with exceptional circumstances / situations. In this document a range of “sailing conditions” and types of circumstances are listed that candidates shall face upon examination.

Concerning the use of SHS this document can be summarised as follows:

- As examination method / -environments “SHS” and “real ship” are considered as equivalent alternatives
- The listed competencies and tasks stand for a level of nautical experience, that is understood as pre-requisite for skipper licence examination. However KSS “knowledge of specific situation” (Streckenkunde) is not considered as a competence to be checked upon this “practical examination”
- Examination inland waterways or stretches are not specified or named
- Examination difficulties related to sailing conditions – such as weather, current, density of traffic, confinement due dimensions and curves of waterway – are not defined.
- Examination type of vessel is not defined

**c) CCNR document: “stf12\_21en\_rev4, features of inland SHS”**

This document enumerates functional requirements such as tasks a candidate must be able to carry out using a simulator. They stand for actions that are carried out or are controlled by skippers at ship’s bridge upon navigation or manoeuvring a vessel. Also (sailing-) conditions/circumstances are mentioned that candidate must be able to cope with. Also five different types of ships are listed as a minimum of simulator’s “own-ship database”.

Candidate target groups are listed as: “initial training”, “practical examination”, “in-service training”. However this document does not define these three categories.

The document further enumerates several technical requirements related to simulator’s kernel, computing capacity, mathematical model, database, visualization systems as well as other systems and equipment. Above chapter “2” addresses these technical aspects and allows to translate all listed requirements into technical consequences.

Out of the above three documents the following purpose aspects are considered as basic points for setting an “inland SHS standard”.

- Use for training and for demonstrating / checking nautical competence to skipper inland vessels on inland waterways – including stretches having a maritime character
- Range of competencies are: steering, manoeuvring, navigation inland ships
- Level of competence: operational level and management level, however KSS -knowledge of specific situations (local knowledge / Streckenkunde) is an optional purpose SHS could be used for

The three documents together allow resuming somehow directly some basic technical requirements to simulators / simulation:

- Concerning equipment and layout of ship bridge / cubicles (candidates working places) reference is to be made to inland ships with modern navigation equipment
- All kind of typical ship related difficulties such as technical failure (rudder, engine, anchor, radar etc.) must be possible to be generated
- The simulated motion of vessel must be “realistic” (especially effects in narrow and or shallow waters, but also effects on stretches having a maritime / estuary character)
- All kind of difficulties related to weather, traffic, day / night as well as those related to waterway. A data bank “waterway” must cover a wide range of typical waterway-born difficulties such as hydrodynamic confinement, curves, currents, bridges, locks, port basins, type of piers, anchorage zones, view- and radar shades (due to obstacles or kind of terrain) and contain the full range of EU nautical waterway signs/lights (such as buoys, lighthouse, panels) as and of those EU estuary stretches on which inland vessels are allowed to navigate.
- The reproduction of real waterway stretches is not required, unless SHS is used for KSS
- The visualization system should allow a horizontal view of 360 degree of which at least 240 degree as a “ship-bridge window-scene”.

The standard is defined in the table hereafter as the entirety of the quality levels of all relevant technical fields/performance features. I-SHS to be used in the frame of above-summarised scope of purpose should meet the level of technical performance printed **bold**.

The descriptions in above chapter “2 Technical sections of ship handling simulation” of performance features and respective quality levels makes it easy to determine quality level to any purpose – any content / level of training / examination or any purpose apart from professional education.

Standards for technical performance of <u>Inland Ship Handling Simulators (I-SHS)</u> for use in examination		
Technical Fields / Performance Feature	Quality level description (recommended level printed bold)	selected relevant chapters within “stf 12-21”
<b>2.2.1 General layout of stations</b>		
a. Steering stations	1 Steering stations resemble those aboard inland vessels as regards form and dimensions without matching the standard however. <b>2 Dimensions and the arrangement of the equipment as well as the grip area of steering stations are in line with § 6.5 der DIN EN 1864.</b> 3 In additions to the requirements mentioned under no. 2, there is at least one steering station in a room similar to a bridge. Regarding space used, height, lighting / colours this station complies with § 6.8 der DIN EN 1864.	2.1 Equipment of candidate’s working position
b. Instructor station	1 There is no separate instructor station. Training can also be drafted, controlled and stored at the steering station. 2 A separate instructor station is available having all necessary functions necessary for the communication with the steering stations and for the control of the running manoeuvres. <b>3 In addition to the requirements mentioned under number 2, the instructor station can perform the function “rope” and “anchor”.</b>	2.2 Equipment of examiner’s station
c. Briefing/debriefing station	1 Replay (radar, optical view and acoustic) only at steering stations 2 Replay at one instructor station <b>3 There is a separate briefing/debriefing station allowing classroom debriefing</b>	2.3 Debriefing station
<b>2.2.2 Equipment</b>		
Layout and equipment of steering stations	1 Scope of installed devices and range of functionalities are according mandatory regulation <b>2 In addition to above “1” a range of equipment according to above “b” is installed</b> 3 In addition to above “2” equipment consist of type approved (real) devices	2.1 Equipment of candidate’s working position
<b>2.3 Simulation kernel</b>		
<b>2.3.1 Dynamics of „own ships“</b>		
a. Degrees of freedom	1 Simple calculation with only 3 degrees of freedom 2 Improved calculation with 4 degrees of freedom (roll motion) <b>3 Detailed calculation with 6 degrees of freedom</b>	1.1.6 / 1.1.9 / <b>1.2.1</b> / 2.1.31

Standards for technical performance of <u>Inland Ship Handling Simulators (I-SHS)</u> for use in examination		
Technical Fields / Performance Feature	Quality level description (recommended level printed bold)	selected relevant chapters within "stf 12-21"
b. Propulsion devices	1 The ship reacts to the EOT-handle and achieves a suitable speed. 2 The engine reacts with dead times and the propulsion device has a behaviour according to the actual speed. <b>3 The simulation of both components is carried out close to reality and considers all relevant influences.</b>	1.1.7 / <b>2.1.3</b>
c. Control devices	1 The ship reacts to the control device. 2 The control device behaves close to reality regarding the rudder rate of turn and considers the most important influences. <b>3 The simulation of the control device is complete and allows e.g. the change of the profile of the rudder blade.</b>	2.1.4
d. Shallow water effects	1 The shallow water influence is limited to the increased power demand with decreasing water depth. 2 The effect of a limited water depth on the power demand and the manoeuvring behaviour tends to be modelled correctly. <b>3 The effect of a limited water depth on the power demand and the manoeuvring behaviour is modelled corrects in terms of quality.</b>	<b>1.2.1</b>
e. Influence of current	1 The current is considered only with one single measuring point in the own ship and there is a force strength effect in the horizontal plane. <b>2 There exist several current measuring points on the ship, so that the current yaw moment can be calculated.</b> 3 There are many current measuring points aboard the ship, so that the lateral resistance distribution is exactly considered.	<b>1.2.1 / 1.2.3</b> / 2.1.19
f. Influence of wind	1 The wind influence generates forces in the horizontal plane according to the actual wind speed and direction. 2 Additional to 1 the wind generates yaw and roll moments. <b>3 Additional to 2 objects on the shore and other ships produce shadowing effects.</b>	1.2.1 / 1.2.2 / 2.1.19
g. Banking effects	1 A rudimentary modelled bank effect generates a lateral force and a yaw moment. <b>2 The lateral force and the yaw moment tend to change with distance and speed in a proper manner.</b> 3 All physical effects (e.g. suction of the propeller) – even of higher order – are regarded in the calculation of the forces.	1.2.1
h. Ship-ship interaction	1 Only a simplified approach for the ship-ship interaction is available. <b>2 The ships are interacting with each other and realistic effects are computed.</b> 3 All dependencies (as distance, water depth, speed, ship size etc.) are considered and the effects are reproduced very close to reality.	<b>1.2.1</b> / 1.2.8

Standards for technical performance of <u>Inland Ship Handling Simulators (I-SHS)</u> for use in examination		
Technical Fields / Performance Feature	Quality level description (recommended level printed bold)	selected relevant chapters within "stf 12-21"
i. Squat	1 Only the dynamic sinkage is modelled by simple approaches. The trim is neglected. <b>2 Both dynamic sinkage and trim are modelled in dependency of the speed, water depth and draught.</b> 3 Sinkage and trim are modelled considering all influencing parameters (additional to 2: blockage ratio, current velocity) and lead to very realistic results.	1.2.1 / 1.2.8
j. Canal effect	1 Very simplified or no consideration of the back flow. <b>2 Consideration of the correct back flow .</b> 3 The back flow is modelled physically correct and it rises disproportionate to the ship speed.	1.2.1
k. Locks	1 In a lock the ship experiences the same effects as in a canal. <b>2 Additionally to 1: forces due to the displacement flow are regarded.</b> 3 Forces due to displacement flow and waves in the lock basin are calculated precisely in space and time.	1.2.1
l. Grounding	1 Grounding can be noticed but has no further influence on the situation. <b>2 Grounding leads to a stop of the ship or to an abort of the simulation.</b> 3 Grounding slows the ship down, it can be heard by a sound and the level of the ship changes.	1.2.1 / 1.2.4
m. Collision ship-shore	1 Collisions ship-shore are detected (displayed) but have no influence on the simulation. For the calculation only one single point on the ship is used. <b>2 Collisions ship-shore lead to a halt or an abort of the simulation. The calculation of the collision is done using a 2 dimensional shape of the vessel.</b> 3 When collisions ship-shore occur an elastic-plastic push is computed including a noise. The calculation uses a 3 dimensional hull shape for the detection.	1.2.1
n. Collision ship-ship	1 Collisions ship-ship are detected (displayed) but have no influence on the simulation. For the calculation only one single point on the ship is used. <b>2 Collisions ship-ship lead to a halt or an abort of the simulation. The calculation of the collision is done using a 2 dimensional shape of the vessel.</b> 3 When Collisions ship-ship occur, an elastic-plastic push is computed including a noise. The calculation uses a 3 dimensional hull shape for the detection.	1.2.1
o. Collision ship-bridge	1 Collisions ship-bridge are detected (displayed) but have no influence on the simulation. <b>2 Collisions ship-bridge are detected using a height value and lead to a halt or an abort of the simulation.</b> 3 The collision detection considers both the shape of the bridge and the superstructure of the ship and its masts. The collision leads to a halt or an abort of the simulation.	1.2.1

Standards for technical performance of <u>Inland Ship Handling Simulators (I-SHS)</u> for use in examination		
Technical Fields / Performance Feature	Quality level description (recommended level printed bold)	selected relevant chapters within "stf 12-21"
p. Lifting wheelhouse	1 The lifting wheelhouse only has two positions (up/down). Collision height and eye point are adapted to the position of the bridge. <b>2 Like 1, additionally a continuous motion of the lifting wheelhouse is available.</b> 3 Like 2, additionally the position of the lifting wheelhouse (including lights and day signs) is visible for other own ships.	1.1.8
q. Ropes	1 Simple rope function with a straight line in the visualization system, no winch. <b>2 Like 1, but the rope has a slack due to its own weight and the line force.</b> 3 Consideration of all details including elasticity, breaking load, winch and slack in the visualization system	2.1.25
r. Anchors	1 Anchors can be set and hauled in but the water depth, dynamics of the chain or the characteristics of the anchorage are not considered. <b>2 Like 1, additional the water depth and the dynamics of the chain are considered.</b> 3 Like 2, additional the characteristics of the anchorage are considered.	1.1.2
s. Towing	1 A towing connection can be set up between an own ship and a traffic ship. <b>2 While towing the dynamics of both ships and the rope connection are considered.</b> 3 Like 2, additional a winch can provide a constant force.	2.1.38
<b>2.3.2 Traffic ships</b>		
a. Quantity	1 Up to 10 traffic ships, no additional options <b>2 11 to 99 traffic ships, predefined traffic ships can be loaded</b> 3 100 and more traffic ships, additionally to 2 predefined routes can be assigned individually	2.1.29
b. Control	1 The traffic ships can follow waypoints. <b>2 The traffic ships can follow routes. These routes include characteristics which distinguish them from waypoints by quality.</b> 3 Traffic ships can imitate the human helmsman by computer control and can run autonomously under certain conditions.	2.2.10
c. Motion behaviour	1 Jerky motion behaviour <b>2 Reasonably smooth motion behaviour</b> 3 Natural motion behaviour	2.2.10
d. Influence of wind	1 The traffic ships do not react to given wind, but follow the predefined track. <b>2 The traffic ships react to given wind and steer, e.g. by taking a drift angle, against it.</b> 3 The traffic ships react to given wind and the response is predefined, natural and manipulable.	2.2.11

Standards for technical performance of <u>Inland Ship Handling Simulators (I-SHS)</u> for use in examination		
Technical Fields / Performance Feature	Quality level description (recommended level printed bold)	selected relevant chapters within "stf 12-21"
e. Influence of current	1 The traffic ships do not react to given current, but follow the predefined track. <b>2 The traffic ships react to given current and steer, e.g. by taking a drift angle, against it.</b> 3 Like 2, additional the traffic ships react to local changes of the current.	2.2.11
<b>2.4 Output processing systems</b>		
<b>2.4.1 Visualization system</b>		
a. Image section and size	1 Only a simplified representation with a fixed angle of sight, display detail is not switchable. The horizontal angle is less than 180°. 2 The display detail does not include the entire angle of sight. The eye point and the viewing direction can be adjusted by handles. The angle of view approximately corresponds to the angle of sight and allows an all-round visibility by a switching option. <b>3 The visualization system allows a view around the horizon (360°). The horizontal field of view may be obtained by a fixed view of at least 240° and additional switchable view(s) for the rest of the horizon. The vertical view allows the view down to the water and up to the sky as it would be seen from the regular steering position in the wheelhouse.</b>	2.1.34 / 2.1.35
b. Resolution and frame rate	1 Only a highly simplified representation. 2 The resolution is sufficient for identification of the most important navigational details. The frame rate allows the perception of the current situation in time. <b>3 The resolution reaches the resolution of the human eye. The frame rate (ideally &gt; 50 fps, at least 30 fps even in complex scenes) reveals no jerking.</b>	2.1.32
c. Further detailing and display quality	1 Only a highly simplified representation. <b>2 The resolution is sufficient for identification of the most important navigational details in appropriate distance.</b> 3 The itemisation is not restricted to any object in the visual model. A limitation of itemisation is possibly given by the visual database.	2.1.32
d. Water surface	1 Only a highly simplified representation. <b>2 Ship induced waves depend on the ship velocity. Water depth is considered. Wind induced waves comply with a realistic wave spectrum.</b> 3 Ship induced waves depend on the ship velocity and the water depth. The influence of the ground topography on development and propagation of waves is realistic. Wind induced waves comply with a realistic wave spectrum. Short waves and spray indicate the wind direction. The simulation of crossing seas and heavy seas is possible.	2.1.32

Standards for technical performance of <u>Inland Ship Handling Simulators (I-SHS)</u> for use in examination		
Technical Fields / Performance Feature	Quality level description (recommended level printed bold)	selected relevant chapters within "stf 12-21"
e. Sun, moon, celestial bodies	1 Only a very simplified representation. <b>2 Sun and moon follow a 24-hour interval. The positions do not exactly correspond to place and date of the simulation. The night sky consists of arbitrary stars.</b> 3 Position of sun and moon (including moon phase) are exactly calculated for place, date and time of simulation. The night sky or at least the most important stars correspond to the real view.	2.1.32
f. Weather	1 Only a highly simplified representation. <b>2 Stationary high cloud layers are represented. Furthermore rainfall, haze and fog can be displayed.</b> 3 It is possible to represent moving cloud formations with all forms of rainfall as well as thunderstorms. The clouds are moving according to the wind direction. The effect of wind on rainfall and other objects is visible.	2.1.32 / 2.1.30
g. Composed representations	1 Only a highly simplified representation. <b>2 Transitions between partial views are visible but do not disturb in the view straightforward.</b> 3 Transitions between the partial views are barely detectable und are not perceptible in the running simulation.	2.1.32
<b>2.4.2 Audio system</b>		
a. Ambient noise	1 Only a highly simplified playback of ambient noises. <b>2 Engine noises are reproduced in a realistic manner. If further ambient noises are reproduced, they correspond to the simulated situation in a realistic way.</b> 3 Engine and weather noises are reproduced in a realistic manner. If further ambient noises are reproduced, they correspond to the simulated situation in a realistic way.	2.1.24
b. Single sound sources	1 Only a highly simplified playback of single sound signals. <b>2 Single sound signals are played in a realistic way, but cannot be located acoustically.</b> 3 All single sound signals are played realistically. Nautically important sound signals can be acoustically located in a realistic way, regardless of direction and distance.	2.1.15 / 2.1.16
c. Acoustic signals from bridge devices	1 Acoustic signals from bridge devices are only played unrealistically. <b>2 Acoustic signals from bridge devices sound realistically, but are played by the speakers of the simulator.</b> 3 Acoustic signals from bridge devices sound realistically and are played by the (generic) devices themselves.	2.1.15 / 2.1.16 / 2.1.1
d. Listening	1 The instructor is only able to listen to the generated sounds by the simulator. <b>2 The instructor is able to listen to all noises from the ship's bridge.</b> 3 The volume level of single noises from bridge (ambient noises, acoustic signals, conversation, etc.) is individually adjustable.	2.2 Examiner's station

Standards for technical performance of <u>Inland Ship Handling Simulators (I-SHS)</u> for use in examination		
Technical Fields / Performance Feature	Quality level description (recommended level printed bold)	selected relevant chapters within "stf 12-21"
e. Recording	1 Noises from ship's bridge are recorded independently from the simulation. 2 Noises from ship's bridge are recorded synchronously from the simulation. <b>3 Noises from ship's bridge as well as radio and telephone communication can be recorded selectively and synchronously with the simulation.</b>	2.3 Debriefing station
<b>2.4.3 Radar</b>		
a. Conformity	1 The angular accuracy for horizontal bearing is between 2 and 4 degree. <b>2 The angular accuracy for horizontal bearing is better than 2 degree. Effects because of the vertically limited opening angle are identifiable e.g. at passages of bridges.</b> 3 Additionally to the mentioned requirements in item 1, effects due to the limited vertical opening angle, boundary conditions (angles, distances, etc.) and dynamically changing position of the ship (e.g. trim) are considered	2.1.23
b. Resolution	1 The resolution "radial" and "azimuthal" are roughly realised. 2 Additionally to the mentioned requirements in item 1, the resolution changes conformably to the distance. <b>3 The resolution "radial" and "azimuthal" correspond to the real representation of similar approved devices.</b>	2.1.23
c. Shadowing	1 The shadowing of nautically important objects is represented in a nearly proper way. <b>2 Shadowing corresponds to the trigonometric relations, but do not consider changes of the dynamic position of the ship.</b> 3 Additionally to the mentioned requirements in item 2, the dynamic motions of the ship are considered.	2.1.23
d. Noise echoes	1 It is possible to switch filters on and off, the effect is recognisable. <b>2 It is possible to adjust filters, the effect is recognisable and nearly correct.</b> 3 The adjustment of filters and their effect correspond to the magnitude of real approved devices.	2.1.23
e. False echoes	1 False echoes are randomly generated. <b>2 The frequency of multiple echoes changes with the distance nearly correct.</b> 3 Additionally to the mentioned requirements in item 2 it is possible to change the characteristics of reflections for selected objects (e.g. ships or bridges). Additionally the frequency of ghost echoes is adjustable.	2.1.23
<b>2.5 Databases</b>		
<b>2.5.1 Ship dynamics</b>		
<b>2.5.1.1 Ship database</b>		
<b>2.5.1.2 Database for waters</b>		

Standards for technical performance of <u>Inland Ship Handling Simulators (I-SHS)</u> for use in examination		
Technical Fields / Performance Feature	Quality level description (recommended level printed bold)	selected relevant chapters within "stf 12-21"
a. Water depth	1 Only a constant water depth can be defined. 2 The water depth is determined by a few bottom surfaces, the resolution is coarse. <b>3 The bottom topography is described in detail by bathymetric contours and soundings or in any other form in a high resolution, as far as data is available.</b>	2.1.41
b. Current	1 Only a homogenous can be defined. 2 The current follows the river (shore lines) with a gradient corresponding to curvature of the river. In harbour basins and canals there is no current. <b>3 The current can be arbitrary defined by vector fields with a high resolution.</b>	2.1.39
c. Tide	1 Water level and current velocity are modified continuously manually to approximate the effect of tide. <b>2 Tidal data is given in a coarse spatial and/or temporal resolution.</b> 3 Tidal data is given in a fine spatial and/or temporal resolution or calculated in real time at any required point and time.	2.1.5 / 2.1.19 / 2.40
d. Wind	1 Only a homogenous, steady wind field can be defined. 2 Fluctuations and wind fields can be defined. <b>3 Interaction between objects and wind is regarded in the simulation.</b>	1.1.3 / 1.2.2 / 2.1.12 / 2.1.19 / 2.2.1 / 2.2.14
<b>2.5.2 Visualization database</b>		
<b>2.5.2.1 Fixed objects</b>		
a. 2D/3D-models	1 All objects are represented by two-dimensional surfaces that are fixed in space and recognized as surfaces. 2 Near objects are represented by three-dimensional objects, Only objects far away are represented by two-dimensional surfaces, but they are automatically turned, so that they a facing to the observer. <b>3 2D replacements of objects are only allowed for objects far away and are not recognized.</b>	2.1.32
b. Level of detail	1 A simple detail in shape and surface makes the objects recognized as such. Navigationally important objects are as such precisely identified. <b>2 A good level of detail can appear realistic objects, although simplifications are recognizable in shape and surface.</b> 3 A very good level of detail makes the objects appear photorealistic.	2.1.32
c. Day/night models	1 In the darkness, only the navigationally important objects are illuminated. <b>2 In the darkness, any object can be illuminated. Navigationally important light sources can emit light in a predetermined rhythm.</b> 3 In addition No. 2 the illumination of any object can be switched during the simulation by the instructor. Relevant information is stored in the database.	2.1.30
<b>2.5.2.2 Moveable objects</b>		

Standards for technical performance of <u>Inland Ship Handling Simulators (I-SHS)</u> for use in examination		
Technical Fields / Performance Feature	Quality level description (recommended level printed bold)	selected relevant chapters within "stf 12-21"
a. 2D/3D-models	1 Moveable objects are charted by a flat surface und can be identified as such during evasive manoeuvres. 2 Drifting objects are charted by a flat surface which always turns to that extent that the surface normal faces the observer. <b>3 Two-dimensional objects are only used in the background (large distance) so that they are hardly apparent. Otherwise 3D-models are taken.</b>	2.1.32
b. Level of detail	1 A modest level of detail as to form and surface indicates the objects as such. Objects which are important for the navigation can be accurately identified. <b>2 In case of an improved level of detail realistic objects are presented, though forms and surfaces appear in a simplified way.</b> 3 Photorealistic objects are shown upon a very good level of detail.	2.1.32
c. Setting of lights and day signals	1 Ships can be assigned to all relevant constellations of lights and signals. Depending on the required configuration own view model of the vessel shall be used. <b>2 The light and signal routing can be switched individually, i.e. all the lights and signals are separately stored in the database and are positioned according to the requirements of real ships.</b> 3 In addition to 2 the light positions exactly correspond to the modelled ship.	2.1.27
d. Day/night models	1 Drifting object may have light sources at night. <b>2 Light sources can flash in a certain rhythm.</b> 3 In addition to 2 the instructor can switch on and off light sources during simulation. The database contains according information.	2.1.30
<b>2.5.3 Radar database</b>		
a. Radar reflectivity	1 Form and size determine reflecting characteristics. <b>2 Reflecting properties consider at least one additional factor (design structure, surface structure, material).</b> 3 The reflecting characteristics can be adjusted individually regarding objects with nautical reference.	2.1.32
b. False echoes caused by waves (only applicable, if the wave echo is not calculated in the simulation)	1 False echoes are stored as a set of uniform, dimensionally stable objects. <b>2 False echoes are stored for typical wave patterns also covering the range of sea state levels.</b> 3 In order to display false echoes caused by waves as a result of wind direction and strength, characteristics are also stored.	2.1.32
c. False echoes due to rainfall, snow etc. (only applicable, if the echo due to precipitation is not calculated in the simulation)	1 False echoes are stored with variable and adjustable density in quantities of uniform and dimensionally stable objects or uniform impulses, respectively. <b>2 In addition to 1, attributes as to particle size and/or their impulse intensity as single echo (among others representative for the kind of precipitation) are considered.</b> 3 Characteristics of spreading are stored, i.e. precipitation fields can be defined.	2.1.32

Standards for technical performance of <u>Inland Ship Handling Simulators (I-SHS)</u> for use in examination		
Technical Fields / Performance Feature	Quality level description (recommended level printed bold)	selected relevant chapters within "stf 12-21"
<b>2.5.4 Audio database</b>		
<b>2.6 Further features</b>		
<b>2.6.1 Weather conditions</b>		
<b>2.6.1.1 Waves</b>	1 Sea state and wave direction can be adjusted; the ship does not move or according to the sea state. <b>2 Sea state and wave direction can be adjusted; the ship moves realistically.</b> 3 Sea state can be defined by a two-dimensional spectrum; the ship moves realistically.	1.1.3 / 1.2.1 / 2.1.42
<b>2.6.1.2 Precipitation</b>	1 Only weather conditions restricting visibility can be adjusted (e.g. mist, fog or smoke). <b>2 In addition to 1, precipitations can be adjusted.</b> 3 All weather conditions (restriction of visibility, precipitation, lightning, cloud formation) are available resulting in a coherent picture.	2.1.30
<b>2.6.2 Chart display</b>	1 Chart options are rather limited. <b>2 ECDIS has all standard functionalities and simulator can be managed with available chart options.</b> 3 ECDIS has complete functionalities and operating options are comprehensive and comfortable.	2.1.8 / 2.1.9
<b>2.6.3 Operational modes</b>		
<b>2.6.3.1 Measuring units</b>	1 The simulator uses maritime units (NM, kn). <b>2 The simulator uses units for European inland waterway navigation (km, km/h).</b> 3 The simulator uses varying units according to the exercise and the simulation region.	
<b>2.6.3.2 Language options</b>	to be defined	
<b>2.6.3.3 Quantity of exercises running in parallel</b>		
a. Quantity of exercises	to be defined	
b. Quantity of own ships	to be defined	
<b>2.6.4 Storage data and replay</b>		
a. Storage of simulation values	1 Simulation recorded only as documents or snapshots <b>2 Storage of all simulation values which are necessary for a restart of the simulation</b> 3 All simulation values are saved.	2.3 Debriefing station
b. Recording of crew's behaviour	1 Voice communications can be recorded. <b>2 In addition to 1 conversations at the steering station can be recorded.</b> 3 In addition to 2 the situation on the bridge is filmed.	2.3 Debriefing station
c. Replay at a debriefing station	1 Replay of the simulation is limited to the map display. <b>2 Replay of the simulation is limited to the chart and radar display.</b> 3 As 2, in addition arbitrary values can be displayed.	2.3 Debriefing station
d. Replay with the entire simulator	1 A replay with the entire simulator is only possible as a radar view / ECDIS. <b>2 A replay with the entire simulator is possible.</b> 3 In addition to the requirements referred to in number 2 all instruments have a drive and put themselves in the position that they had during the simulation.	2.3 Debriefing station

Standards for technical performance of <u>Inland Ship Handling Simulators (I-SHS)</u> for use in examination		
Technical Fields / Performance Feature	Quality level description (recommended level printed bold)	selected relevant chapters within "stf 12-21"
e. Restart a simulation	1 Resumption of a stored simulation is possible in the sense of a continuation. It is generated no alternative simulation, but the old continues. <b>2 Resumption at the starting point or at another time of a saved simulation is possible. It is generated no alternative simulation, but the old continues.</b> 3 A running simulation can be stopped any number of times, rewind and restarted. Each time you start, an alternative simulation is stored.	2.3 Debriefing station
f. Analysis possibilities and export of data	1 Presentation or export remains with the manufacturer. <b>2 A display of time recordings is possible.</b> 3 An export of all data is possible	2.3 Debriefing station
g. Storage	to be defined	
<b>2.6.5 Interface</b>		
a. Exchange of ship models	1 An exchange of ship models is possible only by the manufacturer. <b>2 Ship models can be exchanged in theory. Available data formats are documented, but not compatible.</b> 3 Ship models can be exchanged. The data formats are compatible, possibly by using existing conversion software.	not mentioned
b. Exchange of digital terrain models	1 An exchange of ship models is possible only by the manufacturer. <b>2 Ship models can be exchanged in theory. Available data formats are documented, but not compatible.</b> 3 Terrain models can be exchanged. The data formats are compatible, possibly by using existing conversion software.	not mentioned
c. Exchange of training areas	1 An exchange of training areas is possible only by the manufacturer. <b>2 Training areas can be exchanged in theory. Available data formats are documented, but not compatible.</b> 3 Training areas can be exchanged. The data formats are compatible, possibly by using existing conversion software.	not mentioned
d. Exchange of flow data	1 An exchange of flow data is possible only by the manufacturer. <b>2 Flow data can be exchanged in theory. Available data formats are documented, but not compatible.</b> 3 Flow data can be exchanged. The data formats are compatible, possibly by using existing conversion software.	not mentioned
e. Exchange of tide data	1 An exchange of tide models is possible only by the manufacturer. <b>2 Tide models can be exchanged in theory. Available data formats are documented, but not compatible.</b> 3 Tide models can be exchanged. The data formats are compatible, possibly by using existing conversion software.	not mentioned

<b>Standards for technical performance of Inland Ship Handling Simulators (I-SHS) for use in examination</b>		
<b>Technical Fields / Performance Feature</b>	<b>Quality level description (recommended level printed bold)</b>	<b>selected relevant chapters within “stf 12-21”</b>
f. Transfer of recorded simulation runs	to be defined	not mentioned
g. Coupling with external calculation methods	to be defined	not mentioned
h. Coupling with other simulators	to be defined	not mentioned
i. Audio data	to be defined	not mentioned

If a simulator does not meet the recommended requirements with regard to its individual performance, it must be examined whether by its suitability regarding the application areas is questioned in principle or whether its individual learning objectives are affected. In the latter case, although the possibilities are limited or excluded for certain tasks, the simulator however otherwise keeps its full potential for the remaining fields. Whether and to what extent such limitations can be tolerated, can only be decided in the individual case again.

In any case, such restrictions are particularly critical, as they carry the risk that through the training on the simulator wrong patterns of behaviour may be strengthened. Therefore, – this statement comes from the project advisory committee – certain exercises should be waived in cases of doubt, where a compliance with the requirements set out cannot be guaranteed. Lock manoeuvres are an example, and should only be trained on the simulator, if the modelling of driving dynamics at least corresponds to central claims.

### 3.2 Complementary remarks

The quality level defined under chapter “3.2.5 Standard expressed by quality level of relevant technical features” would be widely considered by any major supplier of SHS as common technical standard for marine SHS. Those performance factors that are of particular importance for inland SHS, have been considered by the four involved SHS supplier as feasible or as already available.

Close to real simulation of “ship motion behaviour” can only be achieved by correct hydrodynamic modelling of a ship and waterway. For this only validated data – based on “EFD” Experimental Fluid Dynamic tests and / or “CFD” Computational Fluid Dynamics calculations -should be used.

Same applies for the suggested set of “own –ships” and “virtual waterway areas” to be used upon SHS test and examination. In case of “KSS examination” the validated data of a reproduced “real stretch” should include specific local currents / tide – as provided or approved by competent authorities.

#### 4 OUTLOOK

As stated before and apart from some particular inland-related requirements the above-defined Standard for Inland SHS is within the range of actual common technical level of SHS. SHS suppliers are prepared to provide Inland SHS according to the defined standard.

However and beyond the above-defined purpose of SHS use, there are visions of further development, such as

- Simulation of ship motion behaviour in case of “free surface in tanks” (example: tanker accident “*Waldhof*”)
- SHS-exercise data available on Internet for the purpose of E-Learning (similar ideas are formulated in project “SMART Qualification”)
- Simultaneous Interfacing SHS-centres of different brands across Europe, to train complex traffic situations interactively during the same running exercise from different remote locations (see also project “Monalisa”)
- Interfacing inland SHS with ISES-Inland Ship Emergency Simulator\* (fire, flooding, smoke, spill out of dangerous goods) to train ship crew but also shore-side actors for evacuation – passenger-ships, environment protection, firefighting, etc. But such ISES are another vision only.

## 5 LITERATURE

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ANNEX 1

**Inland Waterways Navigation simulator**

-“stf 12-21” - partly copied and amended version working document-

- Only columns “A”, “B” and “C” have been copied from official “stf12-21”
- Column “D” has been inserted

A	B	C	D
1	<b>Tasks that the candidate must be able to carry out using the simulator</b>	<b>Technical consequences</b>	<b>Technical consequences most relevant chapters in Handbook “I-SHS Standard”</b>
1.1.1	The candidate will be familiar with the navigation operations of an inland waterway vessel.		1.2 Approach
1.1.2	The candidate will understand the operational procedures for the relevant bridge equipment e.g.: <ul style="list-style-type: none"> <li>- auto pilot (automatic maintenance of direction) in the different operating modes: adjustment of turning speed, emergency steering in the event of a breakdown, etc (see RVIR or European rules)</li> <li>- radar</li> <li>- electronic chart</li> <li>- VHF radio equipment</li> <li>- anchor controls: circumstances for using anchors, vessel reactions, etc</li> <li>- navigation lights controls, including manoeuvring lights</li> <li>- engine controls, indications and alarms</li> <li>- bow thruster controls</li> <li>- internal communication equipment</li> <li>- inland AIS</li> <li>- audible signals and blue panels</li> <li>- vertical moveable wheelhouse controls</li> </ul>	<ul style="list-style-type: none"> <li>- The simulator must have a suitable mathematical model for simulating the reactions of the vessel when the anchor is or has been dropped.</li> <li>- The control station must be fitted with an anchor button; in general it must correspond to a modern wheelhouse (see item point 2.1.1).</li> </ul>	2.5 Database 2.6 Other features
1.1.3	The candidate is able to navigate in: <ul style="list-style-type: none"> <li>- clear weather, day, dawn/dusk, and night conditions</li> <li>- restricted visibilities, rain, snow for day, dawn/dusk, and night conditions</li> <li>- different types of waterway (canal, free-running river, etc)</li> </ul>	<ul style="list-style-type: none"> <li>- Define 3 or 4 water levels that can be tested, over several sites of sufficient length and suited to representing the technical difficulties, representing canals, lakes, rivers and</li> </ul>	2.5 Database 2.6 Other features

	<ul style="list-style-type: none"> <li>- waters with and without current</li> <li>- different water levels</li> <li>- lakes</li> <li>- locks</li> <li>- bridges (static and opening)</li> <li>- estuary and river areas near sea</li> <li>- near coastal waters</li> <li>- in various wind conditions</li> </ul>	<p>seaways;</p> <ul style="list-style-type: none"> <li>- Give preference to different water level situations rather than diversifying locations for the exercises.</li> <li>- Use real navigation sites for examinations.</li> </ul>	
1.1.4	<p>The candidate is able to communicate in an appropriate fashion with:</p> <ul style="list-style-type: none"> <li>- other vessels</li> <li>- vessel traffic control</li> <li>- navigational civil engineering structures, such as bridges and locks</li> </ul>		<p>2.2 Bridge Equipment 2.4.2 Audiosystem</p>
1.1.5	<p>The candidate must be able to demonstrate his manoeuvring skills on:</p> <ul style="list-style-type: none"> <li>- passing through a lock</li> <li>- passing under a bridge</li> <li>- crossing a river with current</li> <li>- entering a port from a river with current</li> <li>- passing through a narrow or narrowed stretch</li> <li>- mooring and un-mooring in still water and current conditions</li> <li>- turning his vessel into or with the current on a river</li> <li>- anchoring with bow anchors (1 and 2)</li> <li>- anchoring with bow and stern anchors</li> <li>- passing near moored vessels with restricted speed and restrictive manoeuvring</li> <li>- passing and overtaking another vessel (Arts. 6.03 to 6.11 of the RPNR)</li> <li>- reversing</li> </ul>		<p>2.3 Kernel 2.5 Database</p>
1.1.6	<p>The candidate understands the changing manoeuvring capabilities due to changes in:</p> <ul style="list-style-type: none"> <li>- available water depth in relation to the draft of the vessel</li> <li>- ship's speed</li> <li>- loading condition (loaded or empty vessel)</li> <li>- ship's stability (connected with navigation conditions, not load)</li> <li>- proximity of walls, banks, other vessels (interactions)</li> </ul>	<p>The mathematical model (for cargo vessels) should take account of two levels of loading – laden and empty. Aim: to attest the candidate's understanding of the effects of a manoeuvre on the vessel's stability.</p>	<p>2.3 Kernel 2.5 Database</p>
1.1.7	<p>The candidate is able to navigate and manoeuvre different kinds of vessels and formations of different sizes:</p> <ul style="list-style-type: none"> <li>- with one or two propulsion propellers</li> <li>- with a bow thruster</li> <li>- with rudders</li> </ul>		<p>2.2.2 Layout and equipment of driving /navigation stations (cubicles / bridges) 2.3.1 Behaviour of „own ships“</p>

	- with different engine powers		
1.1.8	The candidate must be able to calculate a safe passing height for his ship, based on actual water level, bridge (or cable) height and the air draft of a ship. The simulator will show a collision if the vessel cannot navigate safely under the bridge (or cable) in the given circumstances. The actual height of a movable wheelhouse (vertical movable) will be taken into account.	The geometric aspect is taken into account, but not the behaviour of the vessel.	2.3.1 o Collision ship –bridge 2.3.1 p Lifting bridge 2.5.1.1 ship – data base 2.5.2.2 Movable objects
1.1.9	The candidate will be able to perform safe passage under a bridge with the aid of a vertically movable wheelhouse. Changing effects from the vertical movement (lowering and rising of the position of the eye in the visual database, changing radar horizon) will be taken into account.		2.5.1.1 ship data base 2.5.2 visualisation data base 2.5.3 radar data base
1.1.10	The candidate will be able to perform safe navigation according to the existing police regulations applying to the waterway		This is not a technical issue

## 1.2 Models

Although the creation of the models is up to the supplier, the compliance matrix is drafted with the following models in mind.

1	Minimum mathematical models for simulators	Technical consequences	Technical consequences most relevant chapters in Handbook “I-SHS Standard”
1.2.1	Hydrodynamic model, with mandatory 6 degrees of freedom : 1. Forward/Backward 2. Left/right 3. Up/down (heave) Deemed necessary for simulating crossing situations, narrowing of navigable channel, and sudden change of hydrography 4. Yaw 5. Pitch Deemed necessary for simulating operating on sea routes 6. Roll	Corresponding to the 6 types of movement of the vessel.  The six degrees of freedom are considered important, although degree 5 less than the others.	2.3.1 Behaviour of “own ships”
1.2.2	Wind model		2.3.1 f Wind influence
1.2.3	Current model, with current layers allowing different current patterns at different		2.3.1e. Current influence

	depth under water		
1.2.4	Bottom profile model (hydrography)		2.5.1 Databases for the calculation of ship dynamics 2.3.1d. Shallow water, 2.3.1g. Banking effect 2.3.1i. Squat 2.3.1j. Canal effect 2.3.1l. Grounding
1.2.5	Tide model		2.5.1.2 Database for waters
1.2.6	Visual models for own ships and other traffic		2.5.2 Visualisation data base
1.2.7	Visual models for navigation area's (visual databases)		2.5.2 Visualisation data base
1.2.8	Dynamic model for interaction between vessels (crossing, etc)		2.3.1h. Interaction "ship-ship" 2.5.1 Databases for the calculation of ship dynamics

## 2. Working environment

### 2.1 Candidate's working position

2	Minimum equipment for candidate's working position	Technical consequences	Technical consequences most relevant chapters in Handbook "I-SHS Standard"
2.1.1	The ship's bridge layout and equipment will be in accordance with the rules for construction and equipment of inland waterways vessels for the river Rhine by the Rhine Commission (the Boat Certificates). The wheelhouse will be designed for one-man steering operations.	Configuration of a modern wheelhouse, in compliance with the RVIR.	2.2.1 General layout of stations a. steering station (ship-bridge cubicle)
2.1.2	Equipment and consoles are to be installed, mounted, and arranged in a ship-like manner.		2.2.1 General layout of stations a. steering station (ship-bridge)

2	Minimum equipment for candidate's working position	Technical consequences	Technical consequences <i>most relevant chapters in Handbook "I-SHS Standard"</i>
			cubicle)
2.1.3	Controls of propulsion plant operations, including engine telegraph and thrusters. There shall be indicators for shaft(s) revolutions and pitch of propeller(s). There shall be independent controls for all propellers and at least one bow thrusters		2.2.1 General layout of stations a. steering station (ship-bridge cubicle) 2.2.2 Layout and equipement of driving / navigations 2.3.1b Propulsion devices
2.1.4	Steering console, including recognized facilities for hand steering and automatic steering with controls for switch over. There shall be indicators of rudder angle and rate of turn.		2.2.1 a. steering station (ship-bridge cubicle) 2.2.2 Layout and equipement of driving / navigations
2.1.5	Compass (or repeater) with an accuracy of at least one degree [required in maritime areas].		2.2.1 a. steering station (ship-bridge cubicle) 2.2.2 Layout and equipement of driving / navigations
2.1.6	At least one inland waterway radar, functionality similar to type approved equipment		2.2.1 a. steering station (ship-bridge cubicle) 2.2.2 Layout and equipement of driving / navigations 2.4.3 Radar-Simulation
2.1.7	Communication equipment - Alternative internal intercom - 2 independent VHF radio communication systems, inland waterway type		2.2.1 a. steering station (ship-bridge cubicle) 2.2.2 Layout and equipement of driving / navigations
2.1.8	Inland ECDIS, type approved in navigation mode		2.2.2 Layout and equipement of driving / navigations 2.5.1.2 Database for waters 2.6.2 Chart display

2	Minimum equipment for candidate's working position	Technical consequences	Technical consequences <i>most relevant chapters in Handbook</i> <i>"I-SHS Standard"</i>
2.1.9	Inland waterways AIS (may be emulated, functionality as in reality), AIS information to be shown on ECDIS and RADAR		2.2.1 General layout of stations 2.2.2 Layout of steering station
2.1.10	GPS (Global Positioning System)		2.2.1 General layout of stations 2.2.2 Layout of steering station
2.1.11	Echo-sounder		2.2.1 General layout of stations 2.2.2 Layout of steering station
2.1.12	Instrument for indication of wind speed and relative force.		2.2.1 General layout of stations 2.2.2 Layout of steering station
2.1.13	Means of giving the prescribed sound signals, by foot pedal(s)		2.2.1 General layout of stations 2.2.2 Layout of steering station
2.1.14	Night-time navigation lights panel, with controls and indication of status		2.2.1 General layout of stations 2.2.2 Layout of steering station
2.1.15	Engine alarm system		2.2.1 General layout of stations 2.2.2 Layout of steering station
2.1.16	Fire alarm system (optional)		2.2.1 General layout of stations 2.2.2 Layout of steering station
2.1.17	Searchlight controllable from steering position		2.2.1 General layout of stations 2.2.2 Layout of steering station
2.1.18	Anchoring arrangements		2.2.1 General layout of stations 2.2.2 Layout of steering station
2.1.19	The model shall permit realistic visualisation of the vessel's hydrodynamics, including the effects of winds, waves, tides and currents.		2.5.1 Databases for the calculation of ship dynamics
2.1.20	The model shall permit realistic visualisation of the vessel's hydrodynamics in restricted-width waterways (including the interaction of shallow water, banks, other vessels, and		2.4.1 Visualisation System 2.4.2 Visualisation Database

2	Minimum equipment for candidate's working position	Technical consequences	Technical consequences <i>most relevant chapters in Handbook "I-SHS Standard"</i>
	shear currents).		
2.1.21	The simulator shall include mathematical own ship models of at least five representative types of vessel with different methods of propulsion, including: - one small vessel (may be a tug) - one medium vessel (86 m) - one large vessel (110 to 135 m) - one formation - one 4- barge push array		2.5.1 Databases for the calculation of ship dynamics 3.1 Standard expressed as quality level of relevant technical features (types of ships according to <u>purpose</u> and to stf 12-21) 3.2 Complementary remarks
2.1.22	Not found		
2.1.23	The radar simulation equipment shall be capable of modelling weather, tidal streams, current, shadow sectors, spurious and false echoes and other propagation effects, and must be able to generate river banks, canals, port areas, coastlines, and navigational buoys		2.4.3 Radar-Simulation
2.1.24	The simulator shall generate realistic own-vessel engine noises reflecting the power output and sounds from the surroundings and other traffic.		2.4.2 Audio System 2.5.4 Audio database
2.1.25	The simulator shall be designed in such a way that all mooring procedures are realistic.		2.3.1q. Rope function
2.1.26	The simulator must be able to represent at least 10 different types of target vessels.		2.3.2 Traffic ships 2.5.2.2 Movable objects
2.1.27	The target vessels shall be equipped with navigational lights, shapes and sound signals, according to "rules of the road" in force. The signals may be individually controlled by the examiner, and the sound signals shall be directional and fade with range.		2.2.2 Layout and equipment of driving /navigation stations (cubicles / bridges) 2.4.2 Audio System 2.5.4 Audio database
2.1.28	A vessel under way shall generate the corresponding bow- and stern-wave.		2.3.1d. Shallow water influence 2.4.1d Water surface 2.5.1 Databases for the

2	Minimum equipment for candidate's working position	Technical consequences	Technical consequences <i>most relevant chapters in Handbook "I-SHS Standard"</i>
			calculation of ship dynamics
2.1.29	The simulator shall represent a minimum number of target vessels to reflect a realistic situation for the route. The examiner is able to programme voyage routes for each target vessel individually. Targets should include: - 20 m vessel - 50 m vessel - 86 m vessel - 110 m vessel - 135 m vessel - 4-barge push array (o: different formations, corresponding to RPNR requirements) - 6-barge push array - fast craft		2.3.2 Traffic ships 2.5.1.1 Ship data base  3.1 Standard expressed as quality level of relevant technical features (types of ships according to <u>purpose</u> * and to stf 12-21)  3.2 Complementary remarks  <i>* some sea-ships in case of estuary navigation area</i>
2.1.30	The simulator shall provide a realistic visual scenario by day, dusk or by night, including variable meteorological visibility, changing in time. It shall be possible to create a range of visual conditions, from dense fog to clear. The simulator will visually as well as on radar show the effects of rain and snow.		2.5.2 Visualisation database 2.5.3 Radar database
2.1.31	The visual system shall replicate the motions of the vessel being handled.		2.4.1 Visualisation System
2.1.32	The viewing system shall allow fluid, realistic animation for the intended exercise.		2.4.1 Visualisation System
2.1.33	It shall be possible to use binocular systems for observations and bearings and zooming lateral cameras.		2.4.1 Visualisation System
2.1.34	The visual system shall present the outside world by a view around the horizon (360 degrees). The horizontal field of view may be obtained by a view of at least 240 degrees and where the rest of the horizon may be panned (to move the "camera"). This may be done with the binocular system		2.4.1 Visualisation System
2.1.35	The visual system shall present at least 30 degrees of vertical field view. In addition by any method, it shall be possible to observe the ship's side and the dock during mooring		2.4.1 Visualisation System

2	Minimum equipment for candidate's working position	Technical consequences	Technical consequences <i>most relevant chapters in Handbook "I-SHS Standard"</i>
	operations		
2.1.36	The visual system shall present all navigational marks according to charts used		2.5.2 Visualisation database
2.1.37	The visual system shall show objects with sufficient realism (detailed enough to be recognized as in real life)		2.5.2 Visualisation database
2.1.38	The visual system shall show mooring and towing lines with sufficient realism.	Mathematical model simulating cable tension and vessel's reaction	2.3.1 Rope function 2.5.2 Visualisation database
2.1.39	The current model, with current layers allowing different current patterns at different depths beneath the vessel shall influence the behaviour of the vessel in a realistic way.		2.5.1 Databases for the calculation of ship dynamics 2.5.1.2 Data base for waters
2.1.40	Tidal heights will be available, time dependant according to a real situation for that area.		2.5.1.2 Data base for waters / c; Tides
2.1.41	The simulation shall include the depth according to charts used, reflecting water level according to tidal water situation.		2.5.1 Databases for the calculation of ship dynamics
2.1.42	The simulator may, as an option, provide at least two different wave spectra, variable in direction height and period (navigation at sea).		2.5.1 Databases for the calculation of ship dynamics
2.1.43	The simulator shall contain at least one ship model with a telescopic wheelhouse showing the effects in eye point in the visual projection and in the radar images.		2.3.1p. Vertical lift wheelhouse
2.1.44	The simulator wheelhouse shall provide for sufficient space for observation of the candidate's actions.		2.2.1 General layout of stations

## 2.2 Examiner station

2	Minimum equipment for examiner's station	Technical consequences	Technical consequences <i>most relevant chapters in Handbook "I-SHS Standard"</i>
2.2.1	Creating new exercises and save them for future use. Possibility of selecting from a set of pre-programmed stored exercises, including the chosen ship model as well as the environment, including: <ul style="list-style-type: none"> <li>- Other ships</li> <li>- Water depth</li> <li>- Bottom type and profile</li> <li>- Time of day</li> <li>- Visibility</li> <li>- Wind</li> <li>- Current</li> <li>- Different navigation sectors (see 1.1.3)</li> </ul>		2.6.4 Storage data and replay
2.2.2	Starting exercises		2.6.4 Storage data and replay
2.2.3	Monitor the performance of the candidate, including video image of the bridge operations.		2.2.1 General layout of stations 2.2.1b Instructor station
2.2.4	Freezing a running exercise and starting it again from the frozen point in time.		2.6.4 Storage data and replay
2.2.5	Record exercises, discussions and activities taking place in the wheelhouse for subsequent playback (including bridge operations).		2.6.4 Storage data and replay
2.2.6	Place bookmarks during an exercise that will facilitate quick moving to the bookmark during debriefing.		2.6.4 Storage data and replay
2.2.7	All relevant data for debriefing shall be logged (including a survey map of the situation prior to the exercise start as well as a survey map after the exercise is stopped).		2.6.4 Storage data and replay
2.2.8	Additional station(s) must be available for the operator/examiner to be physically separated from the candidate's wheelhouse.		2.2.1 General layout of stations
2.2.9	The operator/examiner station shall be equipped with at least two VHF radios and intercom equipment to communicate with the candidate. The operator/examiner will be able to see what VHF channel the candidate is working on. The operator/examiner shall		2.2.1 General layout of stations 2.2.1b Instructor station

2	Minimum equipment for examiner's station	Technical consequences	Technical consequences <i>most relevant chapters in Handbook "I-SHS Standard"</i>
	be able to see what intercom station the candidate is calling.		
2.2.10	The operator/instructor shall be able to influence the tracks of pre-programmed targets for optimal interaction between the candidate's own vessel's behaviour and the behaviour of other vessels in an appropriate fashion (usual track for upstream and downstream traffic according to navigation points and at realistic speeds).		2.2.1b Instructor station 2.3.2 Traffic ships
2.2.11	The behaviour of targets (manoeuvring characteristics) will be realistic.		2.3.2 Traffic ships 2.5.1 Databases for the calculation of ship dynamics
2.2.12	The simulator shall cover areas of waterways representing the technical difficulties to be assessed.		3.2 Complementary remarks
2.2.13	Exercise areas shall be available, where the relevant operations can be carried out for the different models. The visual databases shall cover at least the sectors of navigation mentioned in point 1.1.3.		3.2 Complementary remarks
2.2.14	The operator/examiner shall be able to introduce environmental effects during the exercise (wind, reduced visibility, weather conditions, brightness).		2.2.1b Instructor station 2.6.1 Weather conditions

### 2.3 Debriefing station

The examiner will be able to do a proper debriefing, using a separate debriefing station, or when ergonomic use will allow it use the operator/examine station for debriefing:

2	Item	Technical consequences	Technical consequences <i>most relevant chapters in Handbook "I-SHS Standard"</i>

2	Item	Technical consequences	Technical consequences <i>most relevant chapters in Handbook "I-SHS Standard"</i>
2.3.1	Freezing a running exercise and starting it again from the frozen point in time.		2.6.4 Storage data and replay
2.3.2	Record exercises for playback. This includes the recording of video of the bridge operations.		2.6.4 Storage data and replay
2.3.3	Place bookmarks during an exercise that will facilitate quick moving to the bookmark during debriefing.		2.6.4 Storage data and replay
2.3.4	Debriefing will log all relevant data for debriefing.		2.6.4 Storage data and replay