Intuitive operation and pilot training when using marine azimuthing control devices

AZIPILOT

Report Title: Encapsulate knowledge using 'Task Analysis' feedback

Work Package: MARINE SIMULATION

Task Number: 2.5

Task Title: Encapsulate knowledge using 'Task Analysis' feedback

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EXECUTIVE SUMMARY

D 2.5 work has been completed along with the recognition of current shortcomings of each azimuthing control device (ACD) system and possible ways forward. The condensed finding of the task analysis specific to different types of ACD has shown that there are quite a large number (6) of different Azimuthing propulsion devices and these often differ in great extend from each other and rather represent the individual view of the manufacturer than a general philosophy regarding such mechanical devices. This is also the case regarding ACD (around 14). Furthermore improvements can be made in the design or layout of some of these ACD control components.

It has been found that some ACD manoeuvres can be very stressful for the bridge team (i.e. harbour tug boat operations while undertaking towing/pushing work).
Within the various bridge layouts, the number of ACD consoles range from 1 to 4 (the centre of the wheelhouse, the bridge wings and the rear of the wheel house). Two new layouts have been identified for the double ended ferry and the inland waterway vessel. For ACD consoles, a force indicator which combines the thrust direction (forward or backwards) and the angle of the direction of the ACD (0° to 360°) in one instrument is thought to be the best solution.

The Options for control layout and use (Simulators) has shown that simulation applications of ACD's differ mostly in the type of propulsion system and the additional control instruments as bow thrusters etc. In principle, all control handles can be used in a simulator as long as the signals form from each handle can be transformed and inter phased with the propulsion system concerned. A number of such modularised simulator console setups for ACD's have been shown as presently in use at the inland navigation simulator SANDRA (DST) along with planned future extensions thereof.

The possibilities regarding helm response variation depending on configuration of the selected ACD control systems has shown that a response signal in the form of a vibration signal seems to be the best for angular feedback on ACD for the helmsman. When multiple ACD control consoles are installed on a vessel, the non active console(s) are best fitted out with handles that move and follow the position of the handles of the active console (even though this means that overload sensors should be installed at these consoles to protect unwanted blockage of any of these handles due to any items placed on such consoles).

The options for bridge systems and use has produced proposals for bridge systems and bridge layout related to the ACD control and systems information for the following ship types: Merchant marine, pipe/cable layers, ice breakers and sea going tugs.

It is recommended that more work be done to produce more harmonized and optimal designed ACD control systems fully fit for use by the ship handlers in various manoeuvring circumstances. Also that official standardization for operating systems should further be consulted as well as experienced users in order to come to a standardized bridge layout for ACD's. and that the use of ACD's and standardized bridge layout should be supported by educating and training at the very least by simulator training and, if possible, supplemented by on site training.

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1 INTRODUCTION

What more can an ACD user ask than to be provided with clear recommendations and guidelines for the use of the chosen ACD along with a list identifying any current shortcomings linked with possible ways forward.
Task 2.5 answers such user’s wishes and culminates in Recommendations and Guidelines for the use of Azimuthing Control Devices. These recommendations for best-practice when selecting and specifying bridge systems for ACD’s, encapsulate knowledge gathered in other tasks, including the Task Analysis as performed in Task 2.4. The guidelines aid the selection of appropriate controls for the different types of azimuthing devices and provide guidance on their use. Also current shortcomings are listed and linked with possible ways forward.

There are two project members (DST and STC) involved in task 2.5. Their main areas of focus within task 2.5 were to:

DST
- Condense findings of the Task Analysis specific to azimuthing control device type.
- Sum-up options for control layout and use.
- Sum-up possibilities for helm response variation depending on the configuration of the selected control systems.

STC
- Sum-up options for bridge systems and use.
- Produce a task report that will delineate the above aims and objectives and will constitute one deliverable.

To date contributions have been received from DST and STC.

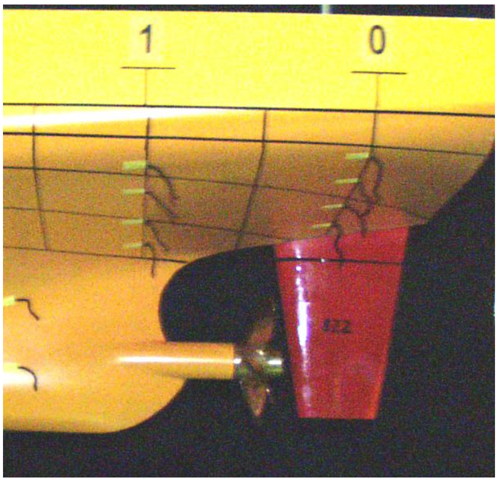
The DST contribution made use of the knowledge gained from other tasks including task 2.4 and condensed the findings of the Task Analysis specific to azimuthing control device type.
The second DST contribution consisted of producing a Sum-up of the options for control layout and use.
The third DST contribution examined and produced a sum-up of the possibilities for helm response variation depending on the configuration of the selected control systems.

The first STC contribution consisted of a sum-up of options for bridge systems and use.
The second STC contribution produced an executive summary of task 2.5.
The third STC contribution produced a task report (task 2.5) that delineated the above aims and objectives and constituted one deliverable.

2 CONDENSE FINDINGS OF THE TASK ANALYSIS SPECIFIC TO AZIMUTHING CONTROL DEVICE TYPE (SHIPS)

2.1 Summary of azimuthing propulsion types and control devices

In general the control of ships nowadays is performed by handles which are connected to an electrical system which transmits the settings to a so called rudder steering engine which rotates the rudder or the azimuthing propulsion system. Before discussing the different control devices it is necessary to list the rudder/propulsion systems used in practice.



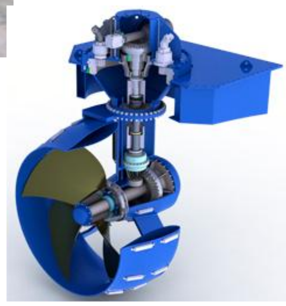
A) Conventional rudder-propeller system[1]

The propeller is mounted on a fixed shaft and behind it one or more rudders are positioned in the propeller slipstream.

B) Azimuthing propeller

The propeller is mounted on a short shaft which is rotatable around the vertical axis. The power can be either transmitted by an electrical engine on the horizontal shaft (the so called podded drive[2])

or by an angular underwater gear and an electrical engine on the vertical shaft (the L-drive[3])



or by a second gearbox inside the ship and an engine with a horizontal shaft – mostly a diesel engine (the Z-drive[4]).

In most cases no additional rudder is provided but the devices are often equipped with a nozzle.

[1] Photo: by DST
[2] Photo: www.ship-technology.com
[3] Photo: *www*.nauticexpo.de
[4] Photo : www.thrustmastertexas.com

Special Azimuthing control devices

By other means a directional force vector can be generated, e.g.

a) VSP (Voith-Schneider-Propeller) [5]

This ACD uses vertical profiles rotation on a horizontal mounting plate. The angle of attack is oscillated during the rotation and thus a force can be produced from zero to maximum in any direction of the horizontal plane.

b) SPJ (Schottel Pump Jet) [6]

mounted inside the hull at the bottom of the ship the water in taken into the system from below by a propeller with a vertical axis and pumped out of it underneath the hull in any direction by rotation of the whole pump housing.

C) Waterjet propulsion [7]

Using a horizontal shaft the water is taken into the jet from the underside of the hull and accelerated through an outlet nozzle. The horizontal direction of the outlet can be changed in a limited way and a backward force can be created by deflecting the jet under the hull.

The different control devices can be classified using their technological principle. The major field of application is noted at the control device.

1) Separate operation of directional device and speed device

The rotor control can be performed by a traditional wheel [8]

or a more modern version of it [9].

[5] Photo : www.imcbrokers.com
[6] Photo: www.schottel.de
[7] Photo: www.wikipedia.de
[8] Photo: www.heinbloed-cruiseblogs.blogspot.com
[9] Photo: www.geolinde.musin.de

On inland vessels often not a wheel but a simple lever is installed [10].

The lever is used as it were a backwards pointing rudder itself. Instead of proceeding clockwise when applied clockwise like known from a car or a wheel in (9) the ship moves anticlockwise when the lever is applied clockwise.

The speed control is performed by a device which orders values between -100% and + 100%. This can be a traditional machine telegraph [11]

or a more modern lever for a single screw propulsion system [12]

or for vessels with twin engines [13].

A special application is used for the Voith-Schneider-Propeller (see B(a)) where the EOT lever (engine order telegraph) is used for the longitudinal thrust component of the ACD and a special wheel [14] is used for the lateral component of the thrust.

2) <u>Combined operation using the polar coordinate system</u>

The standard control for an ACD is a device based on the principle of the polar coordinate system. This means that the handle uses can be both rotated (mostly by 360°) for the directional control and pushed for the engine control. The type of control is strongly dependant on the manufacturer of the ACD. An incomplete representation is given by the following pictures.

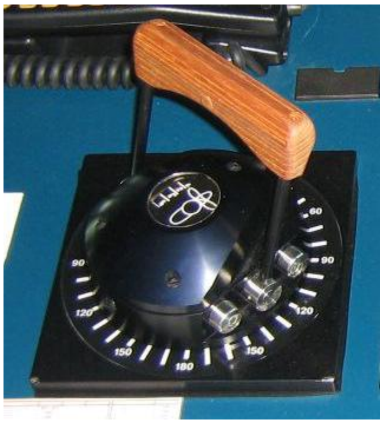
[10] Photo: by DST
[11] Photo: www.de.academic.ru
[12] Photo: www.pitopia.de
[13] Photo: www.durchdenker.de
[14] Photo: www.voithturbo.de

The Schottel Rudder Propeller (SRP) is controlled by a handle using a half wheel and a special lever for the rate of revolutions on top of it [15]

Another system is available where the thrust control is dominant and the directional control mounted between the thrust handles [16].

A Control system with similar functionalities like that for the SRP (15) is shown in the right picture (Aquamaster) [17]

The vessel “Fox Luna” is equipped with another variation of handles [18]



Handle type on “Costa Crociere” [19]

Generic handle on “Venere”[20]

[15] Photo: www.rclineforum.de
[16] Photo: www.tecnautic.com
[17] Photo: Azipilot, Deliverable 2.4
[18] Photo: Azipilot, Deliverable 4.4
[19] Photo: Azipilot, Deliverable 4.4
[20] Photo: Azipilot, Deliverable 4.4

Controls of two rotatable thrusters in the bottom (like (6)) of the inland vessel "Colombo"[21].

In this case the directional control and the thrust control are besides each other and not on a single control handle. (Note: the two stick between the small azimuth handles are not joysticks, but push-pull-handles which are used as time-dependent EOT-controls.

3) <u>Combined operation using the Cartesian coordinate system</u>

Instead of using the polar coordinate system which uses azimuth (direction) and radius (thrust) for the control application also the Cartesian coordinate system can be used. By applying a simple algorithm based on sine and cosine functions the Cartesian signal can simply be transformed into a polar one.

It has to be noted, that the VSP-control system using EOT and a wheel (14) is in reality also a Cartesian control because the EOT controls the longitudinal force in x and the wheel the lateral force in y.

Joysticks on "Venere" [22]

Joystick on the inland vessel "Futura Carrier" [23]

4) <u>Multiple devices</u>

Joystick, generic handles and Voith-wheel with twin EOT at the Voith marine simulator[24] (These multiple control devices can not be all used at the same time unless they are all linked up to a follow up system that locks on to the control that is momentarily in use. Very expensive control system.)

[21] Photo: by DST
[22] Photo: Azipilot, Deliverable 4.4
[23] Photo: www. wikipedia.de
[24] Photo: www.voithturbo.de

Rudder handle, Joystick and polar handle on the inland vessel "Futura Carrier"[25]

All these systems are direct control devices which affect the propulsion and control system directly.
Not discussed at this place are the indirect control devices. These can be classified as DP-Devices (Dynamic Positioning). The main difference is the fact, that the control request is a specific motion of the ship (longitudinal and transversal translation and rotation) which is processed by an onboard computer to a special setting of the different propulsion and control devices of the ship.
Contrary to that the direct control devices request a specific force to manoeuvre the ship, e.g. rudder force, propeller thrust, thruster force etc.

2.2 Assignment of ships, ACD types and bridge / control layouts

In the deliverable 2.4 (Review of ability to model bridge systems and human interface), Item 5 (Review of similarities between different (sister)ships when considering bridge lay out and manoeuvring operations) the different manoeuvring situation and ship types are linked and an tabulated. The result of this investigation is summarized in the table below[26].

	TYPE OF SHIP								FEATURES											
	Merchant marine	Navy	Harbour tugs	Inland ferry	Offshore supply vessels	Pipelayers	Icebreakers	sea going tugs	automatic / manual	coupled (C) / uncoupled (UC)	change to other console	in combi with other thrusters	position shiphandler relative to azipod console	ENVIRONMENTAL VIEW at azipod console	Observation of RADAR/ARPA from Azipod console	Observation of ECDIS from Azipod console	Observation of COURSE&SPEED from Azipod console	VHF at the AZIPOD console	Depth information at the AZIPOD console	Intensity of manoeuvring
Open sea	X	X				X	X	X	auto	C	No	No	A	A	Yes	Yes	No	No	No	
Confined waters	X	X				X	X	X	auto/man	C	No	No	A	A	Yes	Yes	Yes	No	No	
Anchor areas	X	X			X	X	X	X	man	C / UC	N							No	No	
Narrow channel / rivers	X	X	X	X	X	X	X	X	man	C/UC	No	No	A	A	Yes	Yes	Yes	Yes	Yes	
Open sea off shore					X				auto/ man	C / UC	Yes	Yes	A/B/C/D	A/B/C/D	Yes	Yes	Yes	Yes	No	
Port basins	X	X	X	X	X	X	X	X	man	UC	Yes	No / Yes	B/ C	A/B/C/D	Yes	Yes	Yes	Yes	Yes	
Terminal approach	X	X	X	X	X	X	X	X	man	UC	Yes	No/ Yes	B / C	A/B/C/D	No	No	Yes	Yes	No	
Short track ferry				X					man	UC	No/Yes	No	A/D/E	A/B/C/D or E	Yes	No	Yes	Yes	No	
Tug operation			X						man	UC	No	No	E	E	Yes	Yes	Yes	Yes	No	

[25] Photo: www. wikipedia.de
[26] Azipilot, Deliverable 2.4, page 26

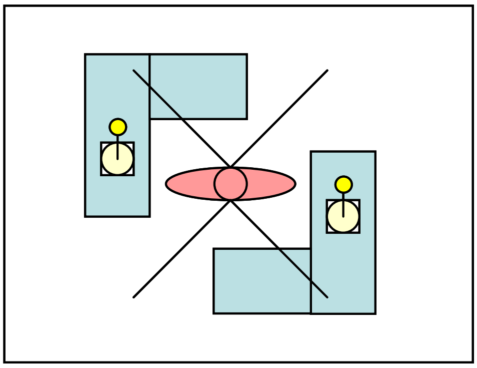
Also some variants of bridge layout are shown, discussed and assigned to the different ship types. An extended summary of bridge layouts is given in the following table. They differ in

- the number of control stations
- the position of the control stations
- the direction of view for the control stations

Ship type	Number of control stations	Centre looking forward	Centre looking aft	Wings
Merchant ships	1	X		
Harbour / escort tugs	2	X	X	
Cruise ships, ice breakers, pipe layers	3	X		X
Offshore supply vessels	4	X	X	X

The layout of the different control stations is also discussed in Deliverable 2.4. Some special cases have not been identified and are added now (Environmental view at Azipod console F and G). Special attention is given to the arrangement of the control handles and is usage.

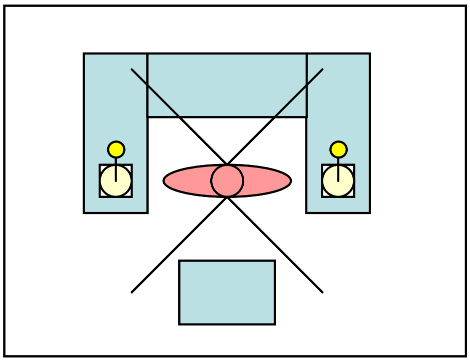
2.2.1 ACD at bow and stern (Environmental view at Azipod console F)



This ship type (e.g. double ended ferries) is designed for travelling in both directions with the same priority. For that reason it is important to have a bridge and console layout which is completely symmetrical.

Due to the fact that the ACD are mounted at the bow and the stern (whatever this means) the handles have to be positioned on a different longitudinal level. By that it is intuitive to identify, which ACD is (in the direction of motion) the forward one – in the case shown always that on the left side of the helmsman.

2.2.2 ACD on port and starboard (Environmental view at Azipod console G)



The most common version of ACD propulsion is a twin arrangement side by side, either in the centre (passenger vessels on the river Rhine have this) or at the bow (some tugs) or mostly at the stern.

For this case the layout has to be modified slightly by moving the handles to the same longitudinal position. In the sketch shown forward motion has the priority, if a double ended ferry is equipped with ACD side by side in the centre, the symmetrical console arrangement above is recommended but with the same longitudinal position of the ACD-handles.

2.2.3 Flow versus force

For a ship equipped with ACD two variants of control configuration can be considered.

- The EOT-lever is used to set the direction of the **propeller flow**.

  The propeller slipstream is pointing aft when a forward motion is considered. This would mean, that a handle has to be set back in normal travelling condition. An application like this is absolutely <u>not intuitive</u> and cannot be recommended.

- The EOT-lever is used to set the direction of the **force**.

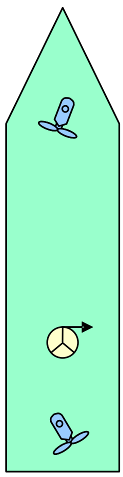
  This configuration is, what everybody would expect. In forward motion the lever is also pointing forward – that is intuitive.

2.2.4 Force versus motion

A. <u>Setting of the direction</u>

When using an ACD two variants of rotation are possible. Both have the same relevance in practice but differ significantly.

a) The “car driving application”

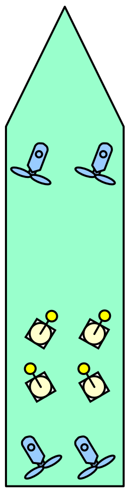


If the vessel is controlled by a wheel (see ([9]) or ([15]) an intuitive expectation will be, that the wheel is used as it is in a car: a rotation clockwise should result in a right turn (also clockwise).

This means for a ship, which has the ACD installed at the stern, that they have to be rotated anticlockwise as it is done with a rudder. Contrary to that a ship like a tug, which may have the ACD mounted in the front the action has to be different. For a right turn (clockwise) the ACD also have to be set clockwise, as it is known from a car. This means, that depending on the longitudinal position of the ACD a conversion of the rotation has to be applied to generate a behaviour as it is known from a car.

If a lever as shown in ([17 – 20]) is used, it is not intuitive to use it as a wheel in a car. So this variant can be only be recommended for installations using a real steering wheel.

b) The “force direction application”

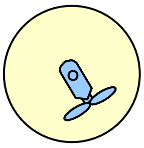


Using special handles as shown in ([17 – 20]), that do not look like a steering wheel, the expectation would be to use it as a simple rotator for the shaft of the ACD. In that case the direction of the rotation of the control is identical to a conventional rudder and (for a vessel with the ACD in the stern) the motion of the vessel will be clockwise, it the handle is rotated anticlockwise as the rudder will be rotated.

This view is intuitive, if the thinking of the helmsman is, to control the force direction. On special ships like double ended ferries (see 2.2.1) it has to be known, that a clockwise rotation of the aft ACD delivers a different motion result than a clockwise rotation of the forward ACD. But in the major manoeuvring situations it is most intuitive to use the handles as force setting instrument.

B. Indication of the direction

A problem often discussed is the indication of the direction of the ACD's on the instruments. Regardless of the method of the setting of the direction chosen, the instruments should always show the **actual angle** of the shaft. Unclear situations can be created by the different types of ACD's and their EOT settings.



e.g. does the instrument on the left indicate

- a **pushing** ACD set to 30° port or
- a **pulling** ACD set to 210° starboard ?

- The intuitive answer for a tug captain or for a helmsman of an inland vessel would be "pushing", because that is the more common version of L- and Z-drives ([3] and [4]).
- A crew member of a cruise ship would answer "pulling" because the common application for those ships is a pulling podded-drive as shown in ([2]).

So it is recommendable, not to use a sketch of the ACD on the instrument displaying the angle of direction because a pilot not accustomed with a vessel needs an explanation, what the instrument shows. This maybe clarified by placing extra information regarding angle of Azipod direction necessary on the pilot card on board

A better variant is, to use a force vector as discussed in 2.2.3. This seems intuitive and free of potential errors, but there is another problem. The force vector can only be displayed for a positive force with the propeller of the ACD rotating in the design direction for forward thrust. Even if it is not recommendable to rotate an ACD by 180° and set it to backwards to move a ship forward (poor efficiency and the ACD is not designed for that usage) this is still a possible configuration which can put the users to misinterpretations of both the settings and the displays.

This can be avoided by the design of the handle. If it is strictly asymmetrical between the forward and backward direction (for positive thrust) as it is shown in the photos 15 and 17 such faults cannot occur while symmetrical designs as shown in photos [18] – [20] need a second look either to the direction indicator ([19]) or the colour at the EOT ([20]).

The best solution is a force indicator which combines the thrust direction (forward or backwards) and the angle of the direction of the ACD (0° to 360°) in one instrument. As this is problematic for mechanical instruments, an electronic solution with a display may be the best variant of an intuitive instrument without the potential of misinterpretations.

3 OPTIONS FOR CONTROL LAYOUT AND USE (SIMULATORS)

In a simulator the trainees shall refresh the ability of controlling a ship in a most realistic environment or they shall learn how to control new ships in order to avoid potential accidents due to unknown behaviour and reactions.

This is one of the applications of a ship handling simulator. Other applications (but out of the scope of this document) may be the training of the whole bridge crew in standard and/or extreme situations or the training of special manoeuvres like towing and more.

For the training with a great variety of ships it is required to provide bridge equipment which covers as many situations as possible. It is obvious, that a tug captain cannot be trained on a full mission bridge of a big cruise ship, but if the bridge equipment is reduced to a single control station it can be used for many purposes.

These applications differ mostly in the type of propulsion system and the additional control instruments as bow thrusters etc. The problem for the simulation facility is the fact, that the different propulsion systems as

- Conventional rudder – propeller arrangement
- Single or multiple propellers
- ACD's of the various types
- Waterjet propulsion
- etc.

use special handles for their proper operation. Different classes of these control elements are outlined in chapter 2.1, but in each class several types of control handles are on the market.

In principle all control handles can be used in a simulator, if it is capable to transform the signals and process them according to the desired propulsion system. The problem is to choose the bridge equipment (control handle type) for a certain application and provide a technique to change the handles for different ship types.

Within the great variety of handles shown in the previous chapter, each simulation facility has to choose those applications which are most common in the range of clients of that simulator and provide a selection of handle types for the ships mostly used in the simulator.

Using the example of the inland navigation simulator SANDRA (Simulator for Advanced Navigation Duisburg – Research and Application) of the DST the chosen strategy and the realisation of a system of modular handles for different ship types in one simulator is shown.

3.1 Strategy

Based on the existence of actual ships and the planning for future extensions, a list of different control elements for the left and the right console of the simulator has been created (shown in Tab 1). The following handle types for the different propulsion systems have been chosen:

Propulsion system	ACD handle types
• Conventional rudder – propeller arrangement	Lever (photo [10]) and EOT
• ACD : Pod, L-drive or Z-drive	Schottel-handle (photo [25])
• ACD : Voith-Schneider-Propeller	Wheel (photo [14]) and EOT
• Various ACD	Joystick (photo [23])
• Multiple thrusters	Direction & thrust (photo [21])

The first 3 types have recently been installed, the other two variants are planned for the future.

	Left	Right		Left	Right
1 now	EOT	Rudder + Flankingruder	6 future	EOT	Rudder + Flankingruder + Thruster bow + Thruster stern
2 plan		ACD - SRP	7 future		Joystick
3 plan	ACD - SRP	ACD - SRP	8 future	Joystick	Joystick
4 plan	EOT	ACD - VSP	9 future	VSP	VSP
5 future		4 Thruster	10 future		Thruster bow + Thruster stern

Tab 1 – Actual, planned and future console layouts for the modularization

For the first step of the modularization of the bridge consoles the variants 3 and 4 (ACD for the Schottel-SRP and ACD for the Voith-Schneider-Propeller) have been selected. The variant 2 can be neglected because it is identical with variant 3 omitting the left SRP-handle. Also variant 7 and 8 are identical for the same reasons, the same applies for variants 5 and 10. Variant 9 is uncommon and will not be realized in a future second step.

Additional to the handles different types of displays are needed. While the rudder lever needs an indicator for the actual angle the ACD need separate indicators for the rotation of the vertical shaft over the full range of 360°. In the table above the displays for the conventional system are in light blue and the new displays for the ACD are in light green.

The main point of the modularization is the determination of

- the modules and the cuts in the bridge consoles and
- the electrical preparation with a plug system for all different handles.

The fact, that those modular handles should be mounted on two different bridges made the concept more complicated because of slight differences in the space available.

Fig 1 – Main bridge no.1 and development station bridge no. 6

3.2 Realization

There were already mounting plates in the consoles but they have been found too small for the three control types planned

- Conventional rudder – propeller arrangement Lever and EOT Green
- ACD : Pod, L-drive or Z-drive Schottel-handle Red
- ACD : Voith-Schneider-Propeller Wheel and EOT Blue

At first drawings had to be made to determine the maximum space needed. While the size of the ACD-handles defined the lateral position of them, the handles for the conventional control were put as far as possible to the inner side of the plates, see Fig 2

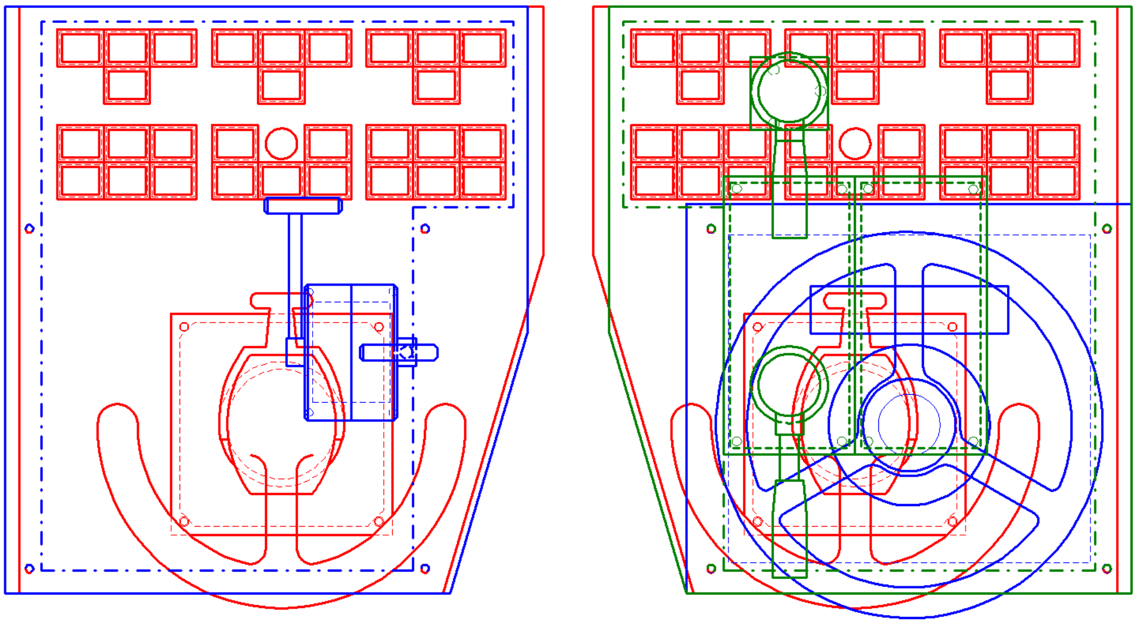


Fig 2 – Arrangement of the different handle types

A template (see Fig 3) has been made for the exact determination of the cuts in the consoles and for the fitting pins both in the consoles and in the mounting plates. The slight difference in the outline of the plates was caused by the size of the Voith wheel and the usage of the existing plates of the Schottel handles. The positions of the fitting pins were that of the bolts already existing at the Voith wheel.

The enlarged size of the plates caused some rearrangements of the existing placing of items on the console table, especially on the development station (bridge 6). There the decision was made to manufacture complete new boards, particularly because the monitor on the left side needed more space.

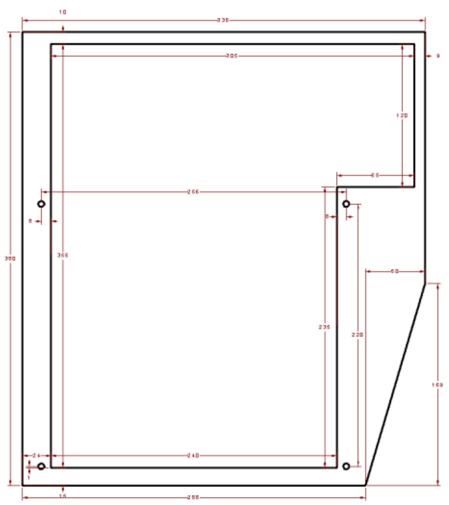


Fig 3 – Template for the handle plates

For the different instruments also exchangeable mounting plates have been designed. They were placed on the back plates of the bridges. While on bridge 1 only the positions had to be mixed and wider cuts had to be made the back plates of bridge 6 have both also been made new, now in black as the console table to give the bridge a more realistic look.

Fig 4 - Triple instrument (rpm, pitch, angle)

While for the conventional and the Voith control the existing (large) instruments were used, for the Schottel control a triple instrument arrangement is provided. The additional display is the 360° angle indicator discussed in chapter 2.2.4B. It is shown in Fig 4. The Fig 5 below shows the drawings for the two instrument plates, also equipped with fitting bolts for positioning them in the cuts of the back plates of the two bridges.

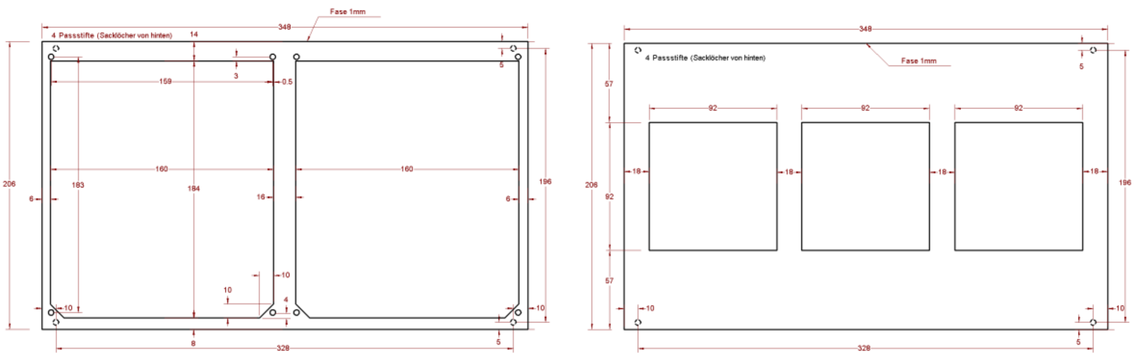


Fig 5 – Instruments plates for conventional and ACD control

Fig 6 – Rudder lever

In Fig 6 the conventional rudder lever is installed in bridge 1 the lower lever is used for the main rudder, the upper one can be either used for a bow rudder or a flanking rudder for the backward motion. On the r right side of the lever the controls for the autopilot is installed.

Fig 7 – Voith wheel

Fig 7 shows the Voith

wheel instead of the levers. On the left console the twin EOT handle is mounted, which is used for these two controls variants.

Fig 8 – Final installation of the ACD handles for the Schottel propulsion

The alternative of using two ACD controls for the Schottel drive is displayed in Fig 8. The three fields with yellow buttons are

- Emergency control for the angle of rotation.
  Using a switch the control can be changed from the follow up control with the handle to a control which rotates the shaft as long as the relevant button is pressed.
- Emergency control of the rate of revolutions – this is not in function at the moment
- Pitch control– this is also not in function at the moment

Due to the fact, that the bridges 1 and 6 are located at different locations, it is recommendable to use transport boxes for the change of handles on and between the different sites. These cases are shown in Fig 9. The boxes are not only used for the transport, but also for the storage of the handles, when not installed. For that reason three of them are identical, the fourth is used for the exchangeable instrument modules.

Fig 9 – Transport boxes

Fig 10 – Harting plug

For the electrical installation of the modular handles in the bridges a common plug system has been used both for the handle plates and the instrument plates. These plugs have multiple pins which can be used both for the transmission of the signals but also for the identification of the module in the bus system of the console processor. Depending on the application, only those pins of the plug, which are needed, are used while the socket is equipped with all contacts for all modules. Fig 10 shows a medium sized plug / socket of this type.

4 POSSIBILITIES FOR HELM RESPONSE VARIATION DEPENDING ON THE CONFIGURATION OF THE SELECTED CONTROL SYSTEMS

4.1 Angular feedback

When operating a control device that gives an angular command as it is the case for a conventional rudder or an ACD handle, the helmsman has always the problem that he has to know the actual angle of the device. This is important because when thinking that a certain force is needed for a certain action the helmsman must know, whether this commanded angle is already available or not. Giving full thrust before the shaft has reached the desired angle might result in a wrong reaction of the ship and may cause an accident. The worst case of all is that the device does not react to the instruction due to a failure with the steering gear machine.

The common way to solve this problem is a feedback instrument (see Fig 4, right instrument), which gives the information about the actual angle by visual inspection. In most situations this seems to be sufficient, but in some applications with a great demand on manoeuvrability a better response on the commanded angle is needed.

In situations like "manoeuvring in a harbour", "turning", "going alongside a pier" or "towing" the helmsman is constantly observing the situation around him and he operates the handles "blind". He has no time to switch his eyes to the instruments and he needs a feedback in his hands. Several options are possible to give information about the actual angle in comparison to the commanded one. Some ideas are listed below and discussed thereafter.

1. A mechanical pointer
2. Response signal by variable angular momentum
3. Response signal by variable vibration

The mechanical pointer (1) give a feedback to the helmsman like the angular indicator on the instrument. It might be positioned directly below the rotator if the ACD-handle so that the helmsman can feel it with his fingertips. This enables him to inform himself whether the shaft has reached the commanded angle or not.

Another technique to give the feedback might an angular momentum (2) on the rotation axis of the handle. When the helmsman rotates the device he has to use the more power the bigger the angular difference is. By that he feels in his hands, how far he is off from the actual angle with his command. This has an advantage against the mechanical pointer because the helmsman doesn't need to position his hand close to the mechanical pointer. But also two disadvantages can be pointed out. If the helmsman put his hand off the handle after he has set it to a desired angle it might move back until it meets the actual angle of the shaft of the ACD. Another disadvantage is the permanent angular momentum in the wrist when manoeuvring which may affect the health of the helmsman (in worst) or which will tire him earlier.

A third option seems to be a vibration signal (3). An oscillator in the handle produces a variable vibration which is the stronger the farther the actual angle is off the commanded one. When the desired angle is reached the vibration stops. This might be the best option out of the three listed here because the disadvantages of the other two are not applicable here.

4.2 Multiple control stations

On large bridges like on cruise ships there are multiple control stations available for the operation of the ACD's of the ship. Normally there are three: one in the centre and two on the bridge wings for the pier operations. On some vessels like offshore supply vessels a fourth control station is installed looking aft for the loading and unloading on the aft deck of these ships. Already with two control stations the problem with the settings of the handles is occurring.

When a certain station is in command the handles will be moved to control the ACD's. For the other station(s) two opportunities are possible.

A) The handles stand still.

B) The handles move and follow the position of that station, which has the control.

Case A) is the simplest version because no additional components have to be installed. But there is a problem when transferring control from the active command station to a station with the handles in different positions. Two things can happen:

- The system reads the position of the new station with "wrong" settings of the handles. This is a really dangerous situation because the ship may be affected from extreme control forces if the handle positions (angle and thrust) differ very much.
- The system reads the position of the handles of the new station only when the handles are moved. This can also be dangerous, because when the handles are moved back to the position of the other station which left control they still send command signals which are apart from the actual setting of the ACD

To avoid this, a safe strategy is, to set all devices to zero before switching command to another station. But there is still a risk because the handles of the new station may have been operated without control and be brought off the safe zero setting. In that case the two risky situations listed above can happen.

Resulting from this an improvement in the safety of operation is, that a station must have a "lock" status with all handles in zero position. A transfer of control can only be done, when all stations are in this zero status.

That seems to be a safe strategy, but in emergency situations it can cause real trouble when it is not possible to take immediate control from another station if it (or another) is not set to zero. To find out, which station is not zero, moving to it, setting it back to zero, moving back and finally taking control will take too much time for the proper reaction in an emergency situation.

Case B), which incorporates a follow up system for the handles, is a better variant when considering the quick change of control from one station to another. Follow up system means that the handles on all stations are equipped with servo motors which copy the settings of the handles of the active control station to the handles of those, which are not used at the moment.

When a change in control is performed, the servo motors of the now active stations have to be disconnected to give the handles free for new action and the servo motors of the now deactivated stations have to be clutched in to change into the follow up mode. By this it is guaranteed, that the handles of the new active station have the same settings that that which was deactivated and now sudden change of the instruction of the controls can damage the propulsion system as it may be in case A).

A problem could occur when the free motion of a handle in the follow up mode is blocked by an item placed on that console. In this case an overload sensor must be installed at the servo motors that initiate an alarm to indicate this problem until the blockage will be eliminated. If someone would try to use such a deactivated handle, then this system would also become active and indicate that the station is not active and should not be touched. A simple press on the button for transfer of control would render these handles free and make them usable for manoeuvring the ship from the newly activated station.

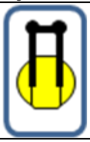
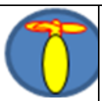
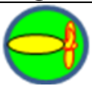
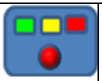
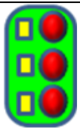
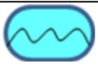
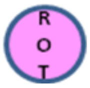
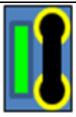
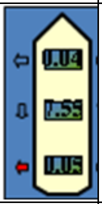
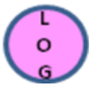
5 OPTIONS FOR BRIDGE SYSTEMS AND USE

Based on the detailed information presented in the other packages of this project, an overview of the required equipment related to the ACD control and information is given below.
Separate information is presented for the following group of ship types as they require more or less the same equipment and lay out related to ACD propulsion.

1. Merchant marine , pipe/cable layers, ice breakers and sea going tugs
2. Off shore supply vessels, anchor handlers and short track ferry
3. Harbour tugs

The navy is not taken into account since very specific lay out and equipment is required by military aspects unless they perform task similar to the ship types mentioned above.

Symbols used in the lay out diagrams

										
ACD HD	ACD status indicat or	Bow thruster	Bow thruster indicat or	Joy stick/ turn knob	ACD take over	ACD mode	Wind meter	Depth indicat or	R.O.T indicat or	Auto pilot
										
VHF	Gyro comp.	Doppler log	Speed indicat or	Tiller steer.						

5.1 Merchant marine vessels, pipe/cable layers, ice breakers.

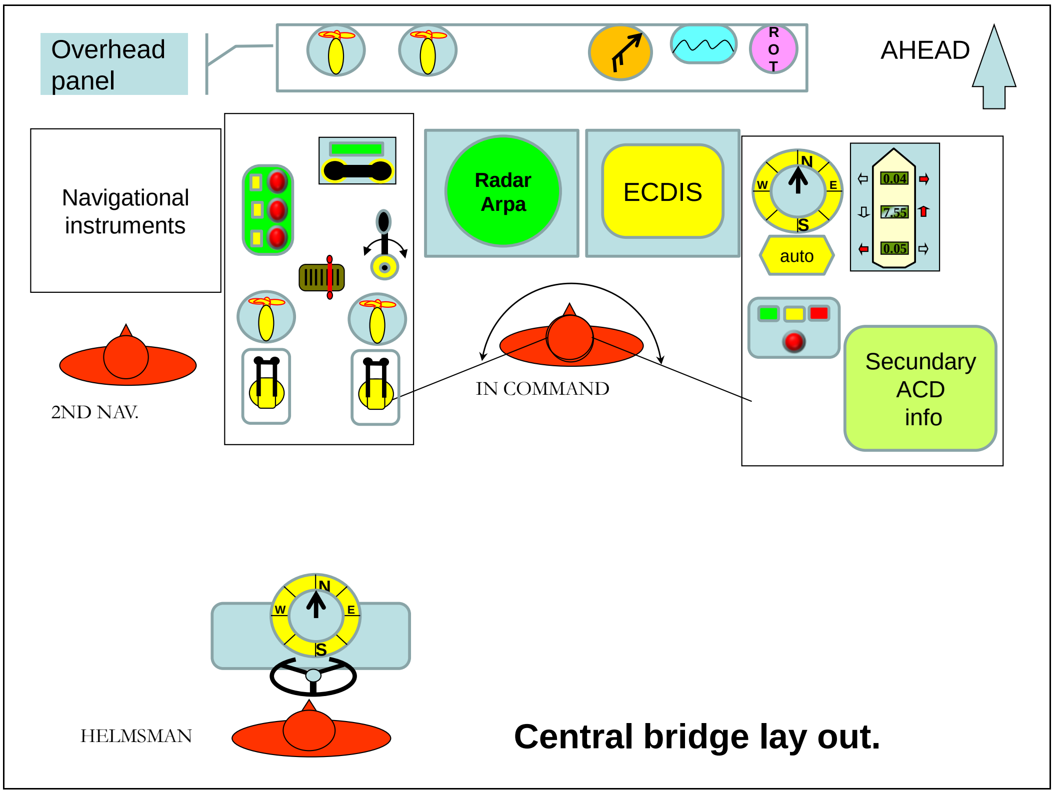
The table below indicates the required equipment in the various ship handling situations.

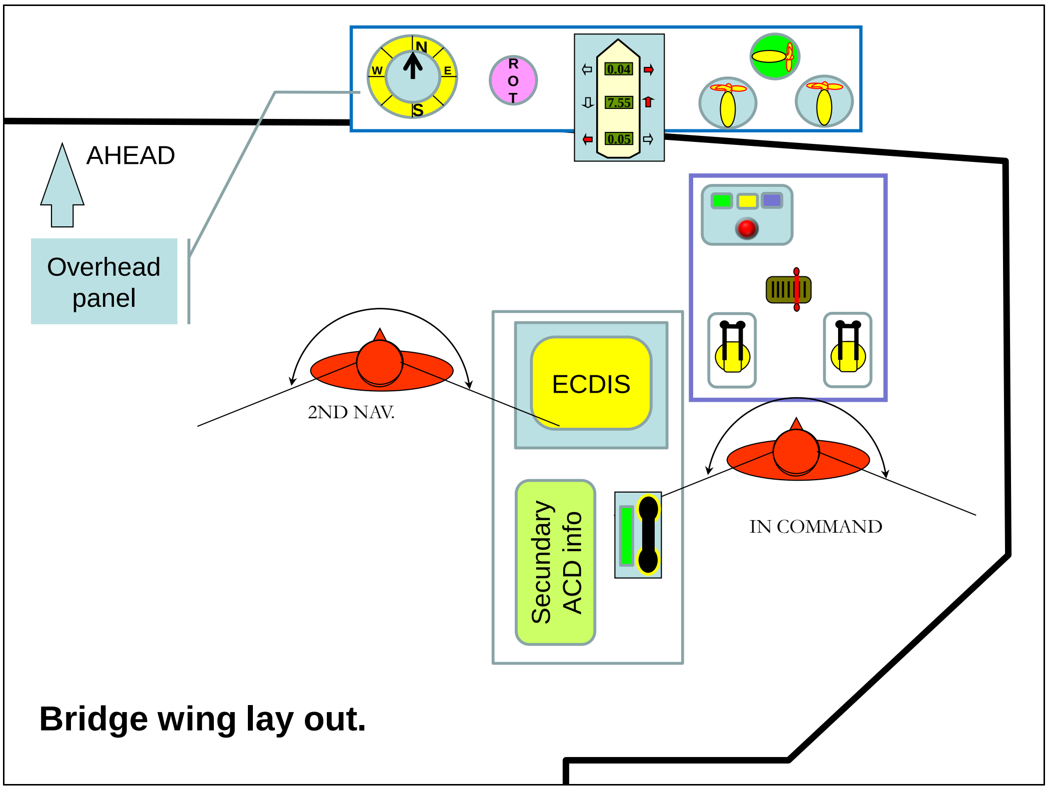
			Open water	Open sea off shore	Confined waters *Congested*	Anchor areas *Port approach*	Narrow channel / rivers	Port basins	Bridge locks	Terminal area	Terminal approach	Short track ferry	Tug operation
Nr. Of ACD pod's		1 or 2											
ACD Control by		Wheel	■		■								
		Auto pilot	■		■								
		Tiller					■						
		ACD Handles					■	■	■	■	■		
		Joystick + turning knob							■	■			
		DP system											
Primary info & commands	ACD status	Pod thrust				■	■	■	■	■	■		
		Pod azimuth				■	■	■	■	■	■		
	Ship position	Outside view	■		■	■	■	■	■	■			
		Radar/Arpa	■		■	■	■	■		■			
		ECDIS	■		■	■	■	■		■			
	Ship movement	Longitudinal speed	■		■	■	■	■	■	■	■		
		Lateral speed				■	■	■	■	■	■		
		ROT				■	■	■	■	■	■		
	Commands	ACD Take over					■	■	■	■			
		ACD shut down					■	■	■	■	■		
		ACD mode			■	■	■						
	Communication	VHF handsfree											
Secondary info	Pod status	Pod rpm /pitch	■		■	■	■	■	■	■	■		
		Pod alarms	■		■	■	■	■	■	■	■		
		Pod shut down	■		■	■	■	■	■	■	■		
	Ship position	Radar/Arpa							■		■		
		ECDIS							■		■		
	Communication	VHF	■		■	■	■	■	■	■	■		
		Intercom	■		■	■	■	■	■	■	■		
	Environment	Wind indicator	■		■	■	■	■	■	■	■		
		Depth indicator	■		■	■	■	■	■	■			
ACD Console location		Navigation bridge centre	■		■	■	■		■				
		Navigation bridge wing						■	■	■	■		
		Navigation bridge rear											

Remarks:

The main ACD controls and ship handling information sources are situated in the bridge centre location. However, the ship handling with high frequency to ACD settings take place in the bridge wing location and are carried out in all kind of weather conditions in day and night time. Therefore most of the ACD handles and information as well as the other ship handling information sources are also placed in this location. The intensity of ship handling for pipe/ cable layers and ice breakers will at open sea be more intensive than for other merchant marine vessels.

Bridge lay out in relation to ACD controls





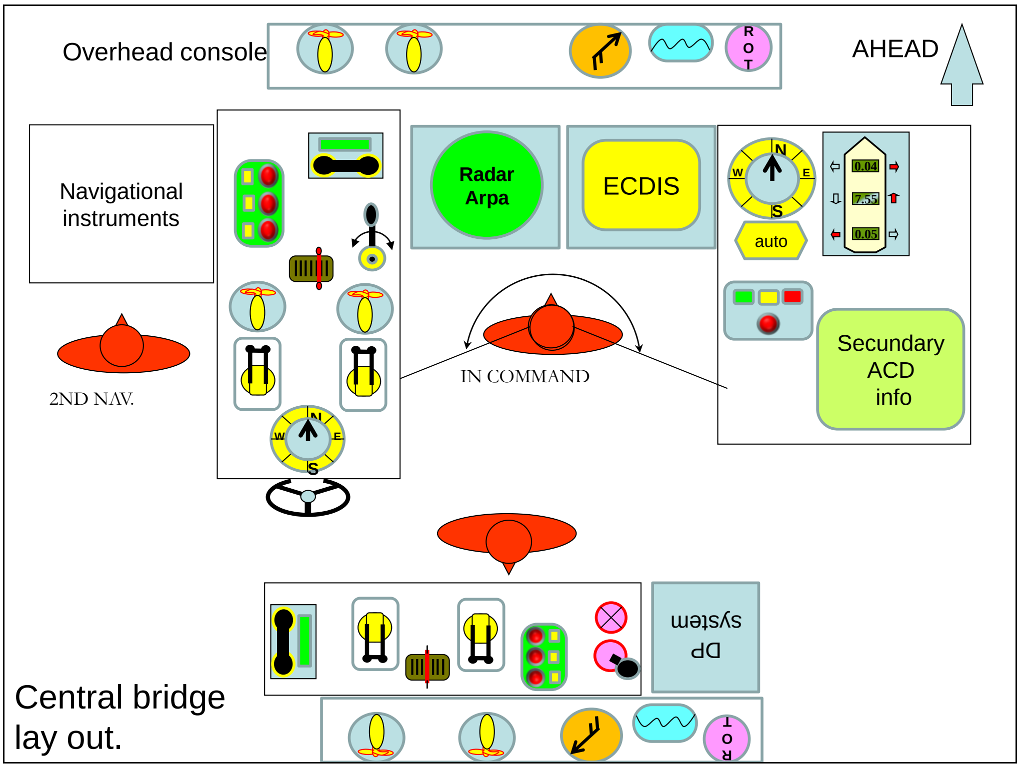
5.2 Off shore supply vessels, anchor handlers and short track ferries.

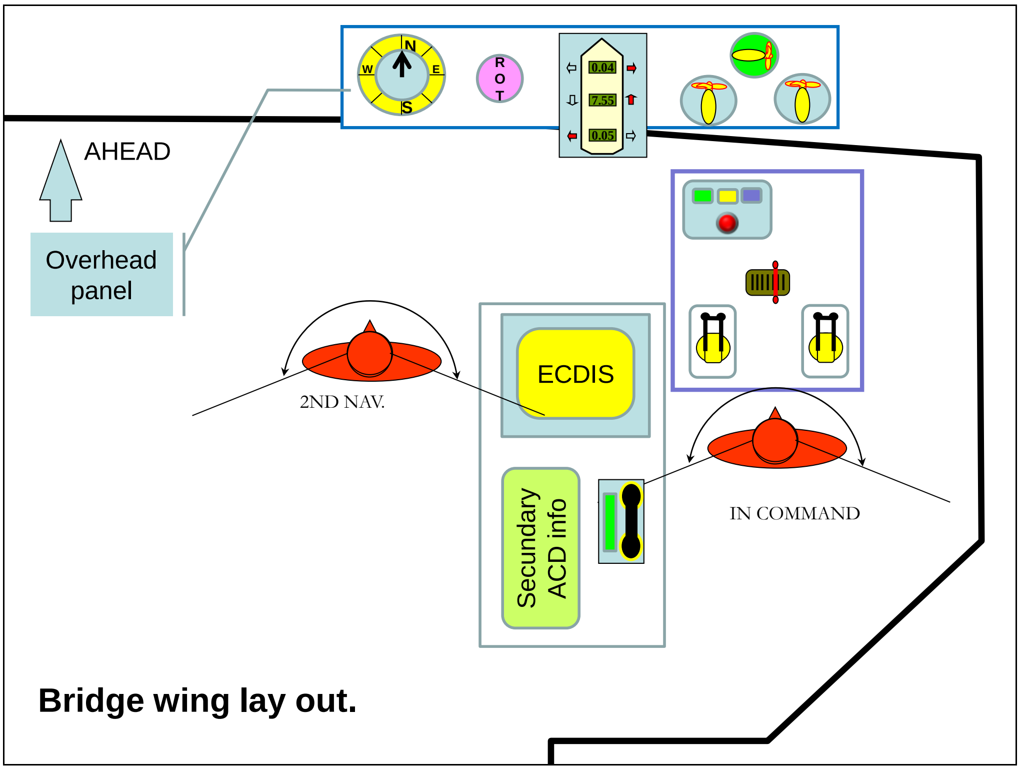
The table below indicates the required equipment in the various ship handling situations.

			Open water	Open sea off shore	Confined waters *Congested*	Anchor areas *Port approach*	Narrow channel / rivers	Port basins	Bridge locks	Terminal area	Terminal approach	Short track ferry	Tug operation
Nr. Of ACD pod's		1 or 2											
ACD Control by		Wheel	X		X								
		Auto pilot	X		X								
		Tiller					X						
		ACD Handles		X			X	X	X	X	X	X	
		Joystick + turning knob		X					X	X		X	
		DP system		X									
Primary info & commands	ACD status	Pod thrust		X		X	X	X	X	X	X	X	
		Pod azimuth		X		X	X	X	X	X	X	X	
	Ship position	Outside view	X	X	X	X	X	X	X	X		X	
		Radar/Arpa	X	X	X	X	X	X		X		X	
		ECDIS	X	X	X	X	X	X		X			
	Ship movement	Longitudinal. speed	X	X	X	X	X	X	X	X	X	X	
		Lateral speed		X		X	X	X	X	X	X	X	
		ROT		X		X	X	X	X	X	X	X	
	Commands	ACD Take over		X			X	X	X	X		X	
		ACD shut down		X			X	X	X	X	X	X	
		ACD mode		X	X	X	X					X	
	Communication	VHF handsfree		X									
Secondary info	Pod status	Pod rpm /pitch	X	X	X	X	X	X	X	X	X	X	
		Pod alarms	X	X	X	X	X	X	X	X	X	X	
		Pod shut down	X	X	X	X	X	X	X	X	X	X	
	Ship position	Radar/Arpa		X					X		X	X	
		ECDIS		X					X		X	X	
	Communication	VHF	X	X	X	X	X	X	X	X	X	X	
		Intercom	X	X	X	X	X	X	X	X	X		
	Environment	Wind indicator	X	X	X	X	X	X	X	X	X	X	
		Depth indicator	X	X	X	X	X	X	X	X			
ACD Console location		Navigation bridge centre	X	X	X	X	X		X			X	
		Navigation bridge wing		X				X	X	X	X		
		Navigation bridge rear		X								X	

Remarks.
This group of vessels are situated in the same ship handling situations as the first group but on top of that need a centre bridge rear ACD console facing the whole stern of the vessel. For a short track ferry sailing in both directions this will be a total copy of the ACD front equipment and information sources.

Bridge lay out in relation to ACD controls





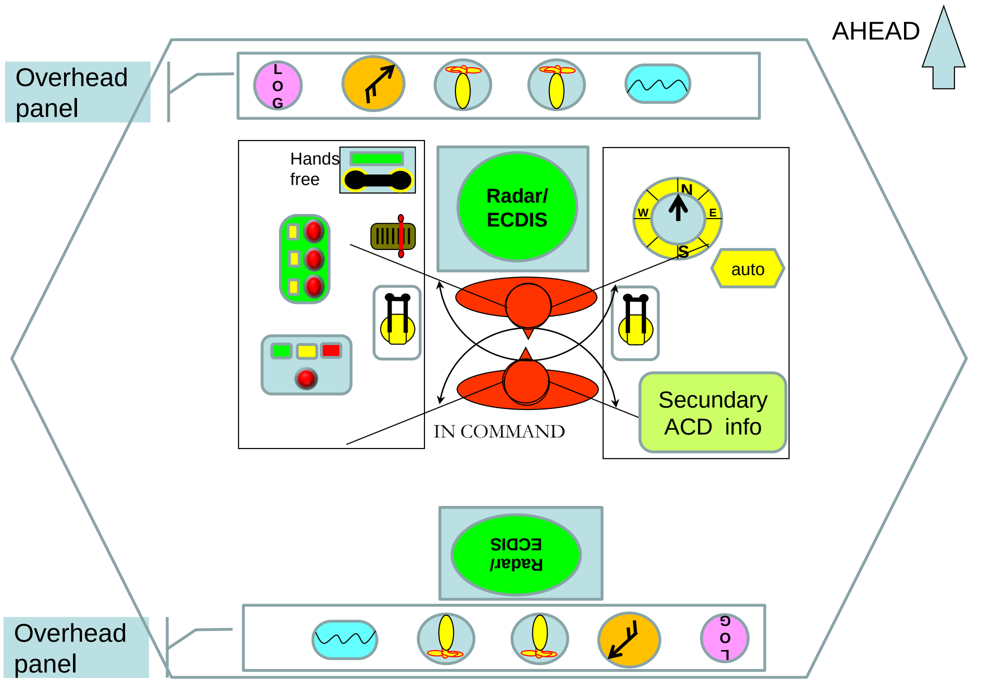
5.3 Harbour tugs

The table below indicates the required equipment in the various ship handling situations.

			Open water	Open sea off shore	Confined waters *Congested*	Anchor areas *Port approach*	Narrow channel / rivers	Port basins	Bridge locks	Terminal area	Terminal approach	Short track ferry	Tug operation
Nr. Of ACD pod's		1 or 2											
ACD Control by		Wheel											
		Auto pilot			X								
		Tiller											
		ACD Handles			X	X	X	X	X	X	X		X
		Joystick + turning knob											
		DP system											
Primary info & commands	ACD status	Pod thrust				X	X	X	X	X	X		X
		Pod azimuth				X	X	X	X	X	X		X
	Ship position	Outside view			X	X	X	X	X	X	X		X
		Radar/Arpa			X	X	X	X	X	X	X		X
		ECDIS			X	X	X	X	X	X	X		X
	Ship movement	Longitudal. speed			X	X	X	X	X	X	X		X
		Lateral. speed											
		ROT											
	Commands	ACD Take over											
		ACD shut down											
		ACD mode											
	Communication	VHF handsfree			X	X	X	X	X	X	X		X
Secondary info	Pod status	Pod rpm /pitch			X	X	X	X	X	X	X		X
		Pod alarms			X	X	X	X	X	X	X		X
		Pod shut down			X	X	X	X	X	X	X		X
	Ship position	Radar/Arpa											
		ECDIS											
	Communication	VHF											
		Intercom											X
	Environment	Wind indicator			X	X	X	X	X	X	X		X
		Depth indicator											X
ACD Console location		Navigation bridge centre			X	X	X	X	X	X	X		X
		Navigation bridge wing											
		Navigation bridge rear											

Remarks
The lay out will be focussing on a high frequent handling of the ACD controls in more stressful ship handling situations.
Although observation of the tug stern is an important element a separate rear ACD console is not relevant. Tug masters prefer to turn around but still handle the ACD controls of the front console.

Bridge lay out in relation to ACD controls



Bridge lay out.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This deliverable, D 2.5, contains encapsulated knowledge gained in Task 2 using "Task Analysis" feedback and has culminated in the provision of clear recommendations and guidelines for ACD user's regarding the use of the given ACD. Along with this, current shortcomings of each ACD system has given and furthermore linked with possible ways forward. Thereby the following results have been obtained:

1. The findings of the task analysis specific to different types of ACD have been condensed and discussed in Chapter 2 giving thereby a valuable overview of ships types, ACD types and bridge/control layouts.
2. The Options for control layout and use (Simulators) has been given and discussed in Chapter 3 whereby two new control layouts for double ended ferries have been identified that had not been identified in D2.4.
3. The possibilities regarding helm response variation depending on configuration of the selected ACD control systems has been given and discussed in Chapter 4
4. The options for bridge systems and use have been given and discussed in Chapter 5.

The condensed finding of the task analysis specific to different types of ACD has led to the following conclusions:

- There are quite a large number (6) of different Azimuthing propulsion devices and these often differ in great extend from each other and are rather representing the individual view of the manufacturer than based on a general philosophy regarding such mechanical devices.
- There are quite a large number (around 14) of different ACD control devices and these often differ in great extend from each other and are rather representing the individual view of the manufacturer than based on a general philosophy regarding implementation of relevant ergonomic rules.
- Each observed system has, in one way or another, a less optimal element in the design or layout of the ACD control components.
- At least a maximum 9 different types of manoeuvres have been identified which may be frequently carried out on board of at least 6 different ship types. Some of these manoeuvres can be very stressful for the bridge team (i.e. harbour tug boat operations while undertaking towing/pushing work).
- The various bridge layouts have been identified for the different ship types whereby number and position of ACD console stations have been discussed and stated. The number of consoles range from 1 to 4 and the position thereof from the centre of the wheelhouse, the bridge wings and the rear of the wheel house. Two new layouts have been identified for the double ended ferry and the inland waterway vessel.
- In the old discussion of flow versus force representation of the working of an ACD, the best solution is thought to be a force indicator which combines the thrust direction (forward or backwards) and the angle of the direction of the ACD (0° to 360°) in one instrument. As this is problematic for mechanical instruments, an electronic solution with a display may be the best variant of an intuitive instrument which hopefully then lacks the potential of misinterpretations.
- For the future more work has to be done to produce more harmonized and optimal designed ACD control systems fully fit for the use by ship handlers in various manoeuvring circumstances.

The Options for control layout and use (Simulators) has led to the following conclusions:

- Simulation applications of ACD's differ mostly in the type of propulsion system and the additional control instruments as bow thrusters etc. The problem for the simulation facility is the fact, that the different propulsion systems such as conventional rudder – propeller arrangement, single or multiple propellers, ACD's of the various types, waterjet propulsion, etc. use special handles for their proper operation.
- In principle, all control handles can be used in a simulator as long as the signals form from each handle can be transformed and inter phased with the propulsion system concerned.
- A number of such modularised simulator console setups for ACD's have been shown as presently in use at the inland navigation simulator SANDRA (DST) along with planned future extensions thereof.

The possibilities regarding helm response variation depending on configuration of the selected ACD control systems has led to the following conclusions:

- A response signal in the form of a vibration signal seems to be the best for angular feedback on ACD for the helmsman.
- When multiple ACD control consoles are installed on a vessel, the non active console(s) are best fitted out with handles that move and follow the position of the handles of the active console (even though this means that overload sensors should be installed at these consoles to protect unwanted blockage of any of these handles due to any items placed on such consoles).

The options for bridge systems and use has led to the following conclusions:

- Based on overviews of required equipment, bridge systems and bridge layout related to the ACD control and systems information has been produced for the following ship types: Merchant marine, pipe/cable layers, ice breakers and sea going tugs.
- Naval vessel have not been catered for since very specific lay out and equipment is required by military aspects unless they perform task similar to the aforementioned ship types.

Previous work carried out in the Azipilot project, has shown that:

1. Specific ACD control lay out is required for the different type of manoeuvres and positions on the navigation bridge.
2. There is a clear need for optimal ergonomic lay-out and design of the bridge equipment
3. Particular attention be given to the lay out of the ACD handling controls, display of ACD status information and take-over command features.
4. Intuitive control, degree of automation and stress aspects play a role in the optimizing of the ACD control systems.
5. The ergonomic requirements of the IMO guidelines on bridge lay out affects the ACD systems.

The options for bridge systems and use reported in D 2.5 has also recognised these five points and endeavoured to include all these points and more in the presented options for bridge systems and use.

6.2 Recommendations

For the future more work has to be done to produce more harmonized and optimal designed ACD control systems fully fit for use by the ship handlers in various manoeuvring circumstances.

Official standardization for operating systems should be consulted further as well as further consultation of experienced users in order to come to a standardized bridge layout for ACD's.

Use of ACD's and standardized bridge layout should be supported by educating and training at the very least by simulator training and, if possible, supplemented by on site training.